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THÈSE

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DÉDICACÉ

À ceux qui vivent, passionnément
À Jo
À Séb
Que la vie vous soit douce

À Ganj'
À Pj
À ceux qui sont partis trop tôt

"Je voudrais être un arbre, boire l'eau des orages
Me nourrir de la terre, être ami des oiseaux
Et puis avoir la tête si haut dans les nuages
Qu'aucun homme ne puisse y planter un drapeau
Je voudrais être un arbre et plonger mes racines
Au coeur de cette Terre que j'aime tellement
Et que ce putain d'homme chaque jour assassine
Je voudrais le silence, enfin, et puis le vent"
Renaud

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ABSTRACT

This PhD thesis focuses on the findings from Arbon-Bleiche 3, a Neolithic lacustrine village on the Southern shore of Lake Constance (Bodensee, Switzerland). From 1993 to 1995, 1100 m^2 were excavated by the archaeological service of Thurgau (Leuzinger, 2000). The settlement was occupied during a very short period, fifteen years (3384-3370 BC) in the transitional period between Pfyn (3900-3600 BC) and Horgen (3200-2800 BC) cultures.

Dr. A. De Capitani studied the ceramics from Arbon-Bleiche 3. She observed in the ceramics several characteristics of Pfyn culture and of Horgen tradition.

She made a typological classification of the ceramics separating Pfyn / Horgen pots from diverse kinds of special forms divided into four sub-groups: special forms Pfyn, special forms Bayern, special forms Boleráz and undetermined special forms. Special forms Pfyn have characteristics from the Pfyn culture, special forms Bayern have specificities in relation with Altheim and Cham cultures in Bavaria, and special forms Boleráz were related to the Boleráz stage of the Baden culture (western Carpathian Basin). For De Capitani (2002), Pfyn / Horgen pots and special forms Pfyn were probably local. A research to detect a possible travel of the other special forms across Europe had to be made. This is the principal goal of this study.

First, petrographical analyses permitted to separate non-ceramic material (cob fragments and loom weight) from the ceramics and spindle whorls. The first group was made of an inclusion-rich and carbonate-rich clay, without temper for the cobs and with organic temper for the loom weight. Inversely, the ceramics were manufactured with an inclusion-poor and silicate-rich clay and tempered in various ways. The ceramics were then separated into ten petrographical group according to the clay used and the main temper added (i.e. granite, gabbro, chert, rhyolite, grog and bone). These groups were not in direct relation with the typological groups of de Capitani (2002).

Second, chemical analyses let three main groups separate: non-ceramic material (CaO-rich) vs. bone tempered ceramics (P_2O_5-rich) vs. the great majority of the ceramics from Arbon Bleiche 3. From an archaeological point of view, the Pfyn / Horgen pots are thought to be local. Moreover, because the ceramics cannot be chemically split into groups, the same provenance for the other ceramics is also proposed. Only 13 samples are outliers and were surely foreign. However, a study of 14 ceramics from the western Carpathian Basin (probable import area defined by the archaeologists) did not match the chemistry of the outliers (except maybe one). Their provenance was, hence, not elucidated. Only their typological features are bound to Bavaria or to the western Carpathian Basin.

RÉSUMÉ

Le but de ce travail de doctorat a été d'étudier en détail les objets archéologiques mis à jour sur le site lacustre de Arbon Bleiche 3, village néolithique situé sur la rive Sud du lac de Constance (Suisse). Entre 1993 et 1995, le service archéologique du canton de Thurgovie a fouillé un périmètre de 1100 m^2 (LEUZINGER, 2000). La particularité de ce village est d'avoir été occupé pendant une très courte période (15 ans, entre 3384 et 3370 av. J.-C.), durant la période chronologique qui sépare la culture de Pfyn (3900-3600 av. J.-C.) de celle de Horgen (3200-2800 av. J.-C.), période assez mal documentée en Suisse.

La Dr. A. De Capitani a étudié le matériel céramique du site. Elle y observe des caractères des traditions Pfyn et Horgen.

Les céramiques sont classées d'après leur affinités typologiques: les pots à caractéristiques Pfyn / Horgen sont séparés des formes spéciales, divisées en quatre sous-groupes: formes spéciales Pfyn (caractéristiques de la culture de Pfyn), formes spéciales Bayern (en relation avec les cultures de Altheim et Cham de Bavière), formes spéciales Boleráz (liées à l'étage Boleráz de la culture de Baden dans la partie ouest du Bassin des Carpates) et les formes spéciales indéterminées. DE CAPITANI (2002) propose une origine locale pour les pots Pfyn / Horgen et pour les formes spéciales Pfyn. Un import de céramiques depuis l'Allemagne ou le Bassin des Carpathes étant probable, le but de ce doctorat est d'affirmer ou d'infirmer cette hypothèse.

Les analyses pétrographiques ont tout d'abord permis de séparer le matériel non céramique (torchis et poids de tisserand) des céramiques et des fusaïoles. Le premier groupe est fait d'une argile riche en inclusions et carbonatée ; le torchis n'étant pas dégraissé, contrairement au poids de tisserand (dégraissé par de la matière organique). Les céramiques, en revanche, sont formées d'une argile siliceuse contenant peu d'inclusions et sont dégraissées.

Les céramiques ont ensuite été séparées en 10 groupes pétrographiques différents, en fonction de leur argile et de leur plus important dégraissant (granite, gabbro, rhyolite, chert, chamotte ou os). Ces groupes n'ont pas de relation directe avec les groupes typologiques.

Les analyses chimiques, quant à elles, ont permis de séparer trois groupes principaux : le matériel non céramique (riche en CaO), les céramiques dégraissées à l'os (riches en P_2O_5) de la grande majorité des céramiques d'Arbon Bleiche 3. Du point de vue archéologique, les pots Pfyn / Horgen sont locaux. La majorité des céramiques ne pouvant pas être séparées chimiquement, nous pensons qu'elles ont aussi été produites localement. Seuls 13 échantillons sont des exceptions ; ils ne sont donc pas locaux. Malheureusement, leur chimisme ne correspond pas à celui des céramiques du bassin ouest des Carpathes, lieu de production supposé (exception peut-être de un échantillon). Leur provenance n'a donc pas pu être élucidée. Seules les caractéristiques typologiques des céramiques de Arbon Bleiche 3 ont un lien avec la Bavière ou le bassin des Carpathes.

1 - GENERAL INTRODUCTION

1.1 FOREWORD

The Arbon Bleiche 3 project is the result of three distinct phases. First, excavations were made between 1993 and 1995 under the direction of the archaeological service of Canton Thurgau, J. Bürgi and U. Leuzinger. A first synthesis was published, describing the excavated area (geography, stratigraphy and map of the site). Every Neolithic house is presented, together with the archaeological findings (LEUZINGER, 2000).

Second, an interdisciplinary team of archaeologists and biologists was created to study the material brought to light, i.e. stones, woods, textiles, ceramics and bones (DE CAPITANI ET AL., 2002).

This PhD, focusing on the archaeometrical study of the ceramic products of Arbon Bleiche 3 is part of specialised studies of natural sciences and was financially supported by the Swiss National Science Foundation (Project 12-52498.97), and done from 1999 to 2005 at the University of Fribourg, Department of Geosciences, under the direction of Prof. M. Maggetti.

Three articles in direct relation with this work are in press (BONZON, 2003, 2004A, 2004B) and one will be proposed soon (BONZON-FREUDIGER, 2005). The first one deals with the petrographical and mineralogical study, the second one summarises this work, the third one presents the bone tempered ceramics and the last one will discuss the representativeness of archaeometrical analyses (Appendix 12).

1.2 THE STUDY OF CERAMIC IN ARCHAEOMETRY

A ceramic is a marker that helps archaeologists to identify cultural groups. The study of the ceramic materials, the nature of its compounds and the way it was manufactured by the potter will lead to a better understanding of the ceramic production of the Past. These kinds of studies are part of archaeometrical researches. In this study, petrographical, mineralogical and chemical analyses will be used to describe archaeological material.

A great abundance of broken ceramic sherds may cause problems to archaeologists: a satisfactory identification by stylistic criteria like colour and shape is not always possible because sherds are too similar or because not enough of these correspond to reconstruct the ceramics. Hence, some very interesting questions, such as “What technique was used to produce this ceramic?”, “Where was it made?” and “How did it get here?” can only be partially answered by archaeologists. A precise study of the material composing the ceramics often may answer such questions. The aim of researches in archaeometry is, for example, to determine the origin of each component of one ceramic; the reason why the potter chose this kind of material, possibly according to its physical properties; if the material was fired, and the way it was done (BENGHEZAL, 1994A; NUNGÄSSER AND MAGGETTI, 1978; MARTINEAU AND PÉTREQUIN, 2000).

1.3 AIM OF THE STUDY

A major contribution of LEUZINGER's work (2000) was to precisely map the different houses of the village of Arbon Bleiche 3 and date their erection. A well described stratigraphy of the excavation permitted DE CAPITANI (2002) to correlate ceramics with stratigraphic beds and houses.

In Arbon Bleiche 3 as in other sites, archaeologists assume that certain kinds of forms or different thicknesses of the ceramics could reflect different provenances of the potteries.

De Capitani also provided typological grouping of ceramics, with possible relation to other countries. Summarising her results, Pfyn / Horgen pots and the special forms Pfyn were locally made in the village of Arbon Bleiche 3, whereas the special forms Bayern could be typologically related to the Bavarian area, and the special forms Boleráz to the western Carpathian Basin. The undetermined special forms did not show any parallels with known forms and could not be attributed.

This study shall answer the following questions:

1. Which kind of clay was used to manufacture the archaeological material?
2. How were the ceramics tempered?
3. How were they shaped (coil-build technique or in a different way)?
4. How were they fired?
5. Was the clay used to build the walls of the houses (= cob) also employed for ceramic production?
6. Is it possible to detect imported ceramics in Arbon Bleiche 3? Is there a possible connection between the ceramics from Arbon Bleiche 3 and those of the western Carpathian Basin?
7. Were the ceramics from Arbon Bleiche 3 produced in a domestic way (as defined by Pétrequin et al., 1994)?

2 - A Neolithic village in Switzerland: description and history of Arbon Bleiche 3

2.1 Generalities on the Neolithic period

From the end of the Palaeolithic, a general and rapid sea transgression, induced by the climate amelioration and the glacial melting made sea water levels rise. In the Neolithic, the sea levels were very similar as those of today (Mohen and Taborin, 1998). In Europe, between 5500 BC and 2200 BC, hence during the Neolithic period, the temperate oceanic climate is very similar to the today situation. At the end of this period, the climatic optimum induced an annual average temperatures of about 2°C higher than today.

The man was a hunter and a gatherer in the Mesolithic, before becoming a producer in the Neolithic, creating for the first time his own food by the domestication of plants and animals. Domestication means that man totally controls the biological cycle of animals: the latter are protected, which involves a forced development of the species and modifies the

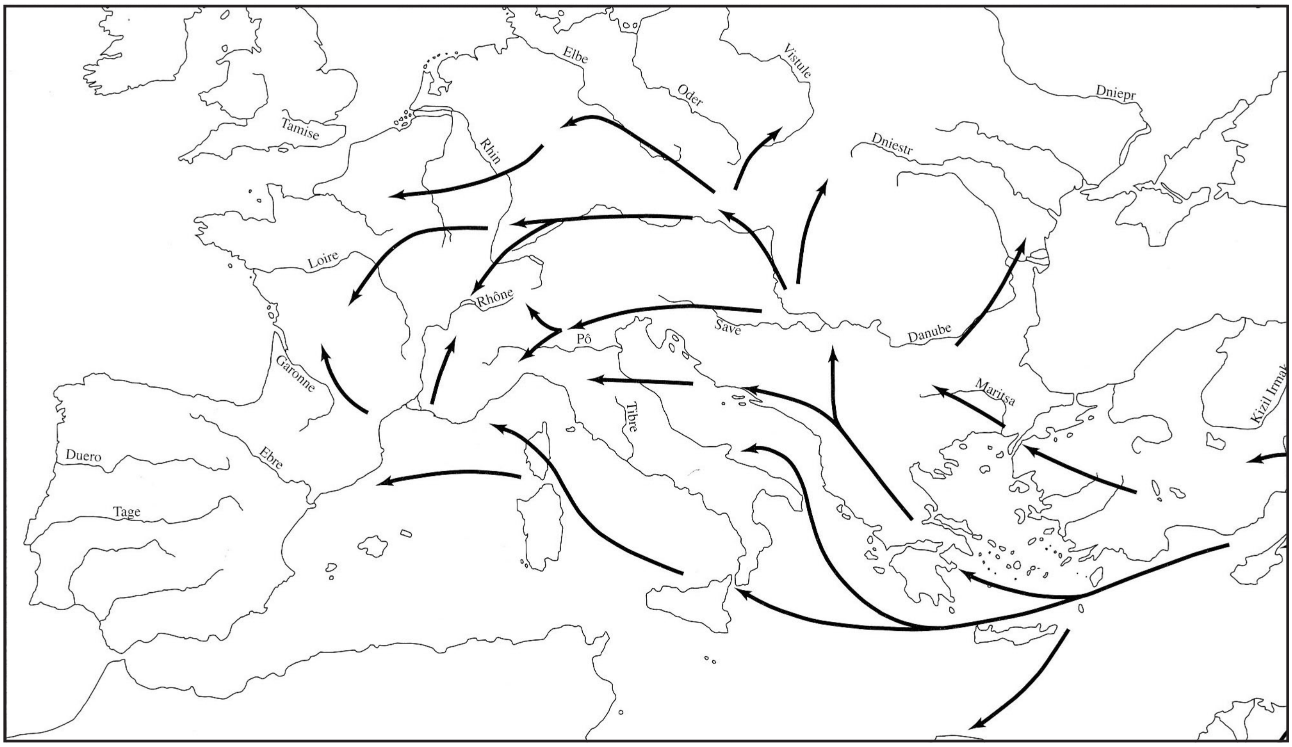
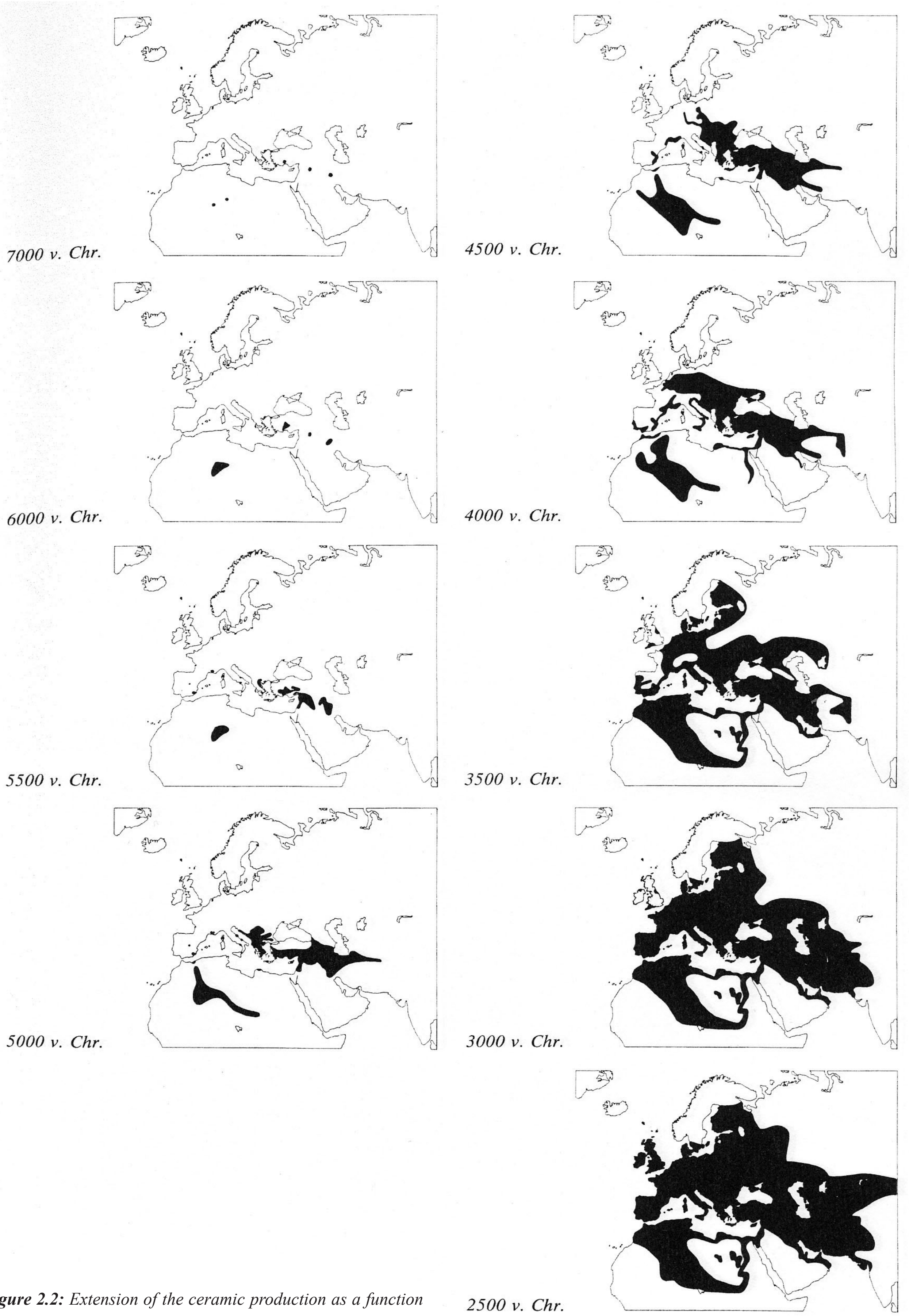


*Figure 2.1: Neolithic and ceramic diffusion paths in Western Europe. Contacts between the main paths are probable (*D'Anna et al., 2003*).*



7000 v. Chr.

6000 v. Chr.

5500 v. Chr.

5000 v. Chr.

4500 v. Chr.

4000 v. Chr.

3500 v. Chr.

3000 v. Chr.

2500 v. Chr.

***Figure 2.2:** Extension of the ceramic production as a function of time (*LITZOW, 1984*).*

natural evolution. Men adapted their environment by the clearing of trees and exploiting the forest to implant new cultures, pastures and villages. Agriculture and breeding were widely practiced and accompanied by sedentary life. However, the exploitation of arable ground, interrupted with fallow, can only be made for several years. New fields have to be then searched, which involves cyclical moving of villages or migrations. The transition to a production economy corresponds to big changes that are underlined by new techniques like stone polishing and ceramics modelling (Philibert, 2000; Guilaine, 2003). The proper characteristics of the Neolithic are the domestication of animals (except dog) and the production of ceramics.

Figure 2.1 shows the diffusion of these two cultural features from Near-East to Central Europe (D'Anna et al., 2003). The new way of life diffused to the Mediterranean south-east, to the Balkans and the Danube Basin. From there, the progression separated into two directions: the Mediterranean current followed the Adriatic shores to Italy and southern France, whereas the continental current crossed the Danube plains to the Rhine and Elbe valleys to finally reach the Paris Basin. The propagation is presented as a progressive acculturation between neighbours by adopting better ways of living and knowledge. In the Danube valley and in southern Moravia, the Neolithic began around 4750 BC (Fig. 2.2). Five centuries later, a massive production of ceramics with linear or curved ornaments propagated to the Paris basin. Figure 2.3 shows this East to West movement. Note that the Danube River is a preferential path. The motives on the ceramics are relatively uniform from the Danube to the Paris region, which implies a rapid transmission of the know-how. The principal motives are undulated lines, lying S, horse-shoe or angular lines. Little motives are grouped points, lines, crosses, V- and U-forms. A few centuries later, a new Danube way of life conquered the whole Europe developing farming and big trapezoidal houses for several families (Mohen and Taborin, 1998).

Camps (1990), Philibert (2000) and Guilaine (2003) propose that the ceramic process was invented at different places; imagining one single place in which the ceramic production was developed and this technique afterwards widely distributed is very improbable.

The period between the fifth and the third millenary before Christ is characterised by the growing importance of favouring a minority. Localities of more importance, defensive architecture and spectacular funeral monuments were signs of social distinction. The extraction of blocks of stone for megaliths, the weight of which was up to 300 tons, their transport on several kilometres and their erection surely necessitated the presence of an authority to decide and coordinate labour. Some beautiful special tools, found in Neolithic tombs, are indicators for a hierarchical society (axes of alpine jadeite in Carnac, gold and metal treasuries in Varna, Black Sea; Guilaine, 2003). This hierarchy gets along with the emergence of an economical system based on the development of handicraft, exchanges of prestige goods, and intensification of production abilities (Philibert, 2000).

Silex extraction sites appeared in the early Neolithic as open mines or galleries, the main ones situated in Grand-Pressigny (Indre-et-Loire, France). Several hundreds of kilometres often separated these mines from the production area of the tools. Such an increase of distances and of travelling material that could exceed 800 km differentiates Neolithic from former periods.

During Neolithic specialised competences emerge: people that produce tools become specialised and depend on exchanges. Know-how is not any more bound to one individual in a group, but to one distinct group. A new techno-economical organisation emerges: one group furnishing tools depends on another furnishing food involving a new equilibrium due to exchanges and trade (Philibert, 2000).

The Neolithic period in Switzerland is delimited between 5500 BC and 2200 BC (Stöckli et al., 1995). The second phase of the Neolithic (around 4600 BC to 3200 BC) is characterised by the expansion of the Neolithic economy, by the human impact on landscape and by the apparition of the first grouped vil-

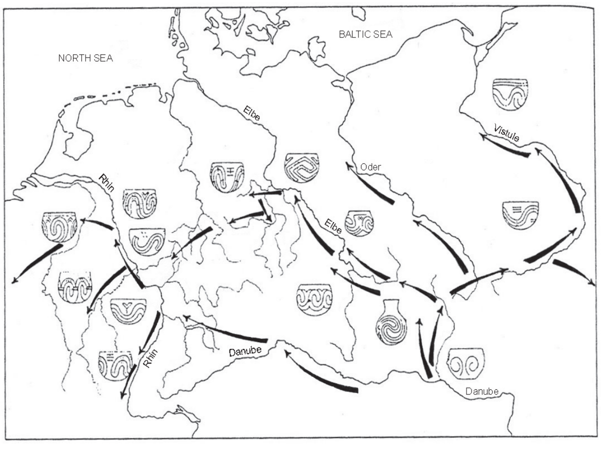


Figure 2.3: *Propagation to the Paris Basin of the linear ceramics (Mohen and Taborin, 1998).*

lages, such as lacustrine sites. Important homogeneous cultural human groups formed, keeping preferential material and spiritual relations with their region of origin, and using more and more complex funeral rituals (Voruz, 1991).

For various reasons – inhumations as funeral ritual, ornaments of the ceramics evolving from deep perforations to linear incisions, first copper metallurgy between 3600 and 3500 BC – it seems that the north-eastern part of Switzerland had preferential relations with southern Germany (Altheim culture), and kept a cultural heritage from their Danube ancestors (Voruz, 1991).

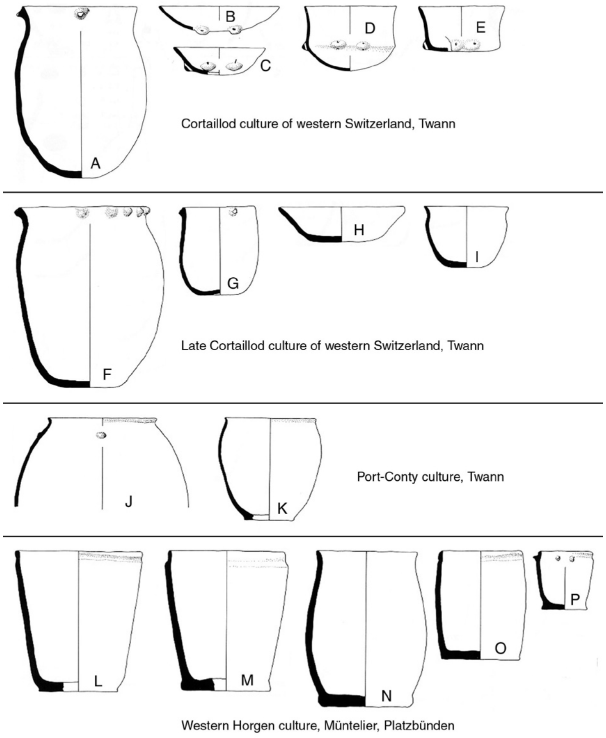


Figure 2.4: *Representative pottery forms from the Neolithic cultures of western Switzerland. Cortaillod culture: A: Jar with globular body, S-shaped profile, with knobs under the lip; B, C: Deep plates with perforated knobs placed side by side; D: Carenated bowl; E: Bowl with concave walls; Late Cortaillod culture: F, G: Jars with flat bottom; H: Deep plate; I: Deep S-shaped bowl; Port-Conty culture: J: Cooking pot with a rim and knobs at the shoulder; K: Cooking pot with flat bottom; Western Horgen culture: L, M: Conical to cylindrical jars with round or vertical lips reduced to a ridge; N: Jar with slight everted lips; O, P: Lips underlined by a ridge and sometimes knobs (drawings from* Stöckli et al., 1995*).*

2.2 The Neolithic cultures in Switzerland

The duration of the cultures proposed here are coming from Voruz (1991); the descriptions of the ceramics and the pictures are taken from Stöckli et al. (1995).

2.2.1 Western Switzerland

In western Switzerland, the Cortaillod culture began in 4500 BC and ended in 3800 BC. In the early period, it produced black fine smoothed ceramics. 90% of the vessels are jars with a globular body and an S-shaped profile decorated with knobs under the lip (Fig. 2.4A), together with deep plates with perforated knobs placed side by side (Fig. 2.4: B, C). Bowls are seldom (Fig. 2.4: D, E).

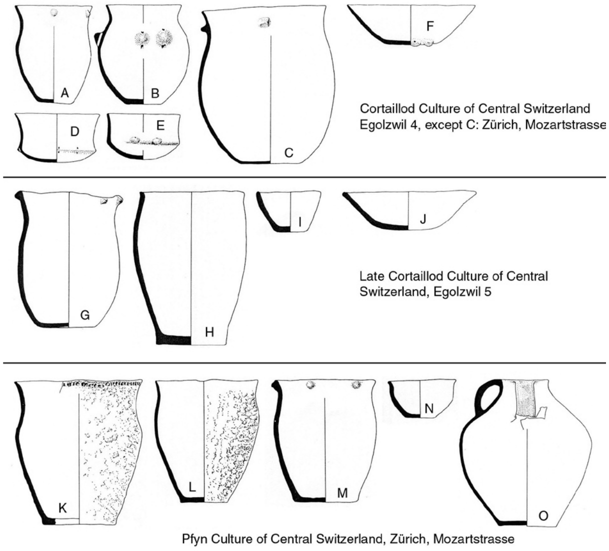


Figure 2.5: *Representative pottery forms from the Neolithic cultures of Central Switzerland. Cortaillod culture: A, B, C: Jars with flat bottom, S-shaped profile, A and C with knobs under the lip, B with perforated knobs on the body; D, E: Carenated bowls, D with perforations, E with perforated knobs on the carene; F: Plate with juxtaposed perforated knobs on the bottom; Late Cortaillod culture: G, H: Jars with flat bottom and S-shaped profile, G with knobs on the lip; I: Bowl with convex body, simple rim and flat bottom; J: Deep plate; Pfyn culture: K, L, M: Jars with S-shaped profile, flat bottom and elongated lower body, K and L are coated with barbotine, K with finger prints on the lip, M with knobs on the lip; N: carenated bowl with flat bottom; O: Jug with handles (drawings from* Stöckli et al., 1995*).*

Between 3750 BC and 3500 BC, late Cortaillod developed and the ceramics had coarser walls with a simplified repertory. Almost 80% of the vessels are jars with a flat bottom (Fig. 2.4: F, G); deep plates represent less than 10% (Fig. 2.4H) and bowls are seldom (Fig. 2.4I). Perforated knobs become rare.

Between 3500 BC and 3200 BC, a cultural impoverishment in the ceramics happened during the Port-Conty Culture, which made the transition between Cortaillod and Horgen civilisations. The cooking pots have then usually flat bottoms, their walls are slightly widening out with a rim and knobs at the shoulder (Fig. 2.4: J, K).

Between 3200 BC and 2800 BC, during the Horgen culture, this impoverishment is clear: the walls are coarser, the jars conical to cylindrical and the lips reduced to a simple ridge. The knobs appear very seldom (Fig. 2.4: L-P).

2.2.2 Central and eastern Switzerland

The Cortaillod culture of central Switzerland began in 4250 BC and finished in 3500 BC. The ceramics are typologically similar to those of the Cortaillod culture of Western Switzerland. Jars and cooking pots with flat bottom, together with deep plates with perforated knobs are predominant whereas bowls are seldom (Fig. 2.5: A-F).

Between 3900 BC and 3600 BC, the Cortaillod civilisation neighboured the Pfyn Culture. The ceramics of Late Cortaillod are simplified, often with a flat bottom and rare knobs (Fig. 15: G-J). The vessels of the Pfyn culture are jars often covered with barbotine, with S-shaped profile, flat bottom, elongated lower body and rare knobs (Fig. 2.5: K-M), carenated bowls with flat bottom (Fig. 2.5N) and jug with handles (Fig. 2.5O). Thin walls, ornaments composed of finger impressions on or under the lip, simple decorations of lines, points and finger pinches are also characteristic, together with copper crucibles (Billamboz and Schlichtherle, 1985).

In eastern Switzerland, the Pfyn culture began in 3950 BC and is characterised by vessels with a flat bottom, jars with S-shaped profile and elongated lower body, with rimmed lip and often coated with brushed barbotine (Fig. 2.6: A-D).

Between 3700 BC and 3500 BC, late Pfyn induced a higher percentage of cooking pots and a depreciation of the esthetical quality of the whole ceramic,

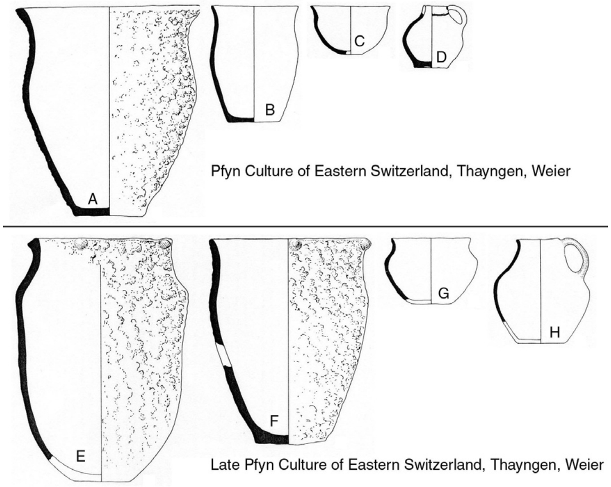


Figure 2.6: *Representative pottery forms from the Neolithic cultures of Eastern Switzerland. Pfyn culture: A, B: Jars with S-shaped profile, flat bottom and elongated lower body, B with rimmed lip and coated with brushed barbotine; C: Carenated bowl with flat bottom; D: Jug with handle; Late Pfyn culture: E, F: Jars with S-shaped profile, flat bottom and elongated lower body, coated with barbotine and with knobs on the lip; G: Carenated bowl with flat bottom; H: Jug with handle (drawings from* Stöckli et al., 1995*).*

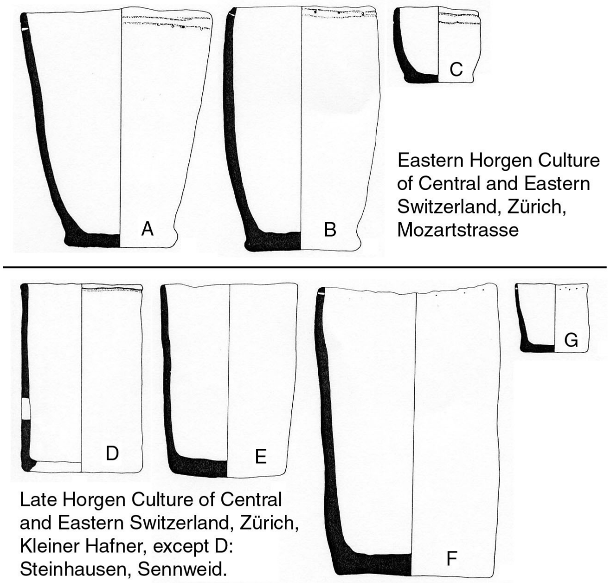


Figure 2.7: *Representative pottery forms from the Late Neolithic cultures of Eastern and Central Switzerland. Eastern Horgen culture: A, B, C: Cooking pots with sub-cylindrical profile; Late Horgen culture: D: Cooking pot with cylindrical profile; E, F, G: Cooking pots with cylindrical profile and sometimes perforations on the lip (drawings from* Stöckli et al., 1995*).*

which has then thicker walls (Fig. 2.6: E-H).

From 3250 BC to 2750 BC, the Horgen culture is to be found in central and eastern Switzerland with the emergence of cooking pots with a quite cylindrical profile, and with thick and rough walls (Fig. 2.7: A-C). In the late Horgen times, the repertory of the vessels is very simplified: the most frequent ceramics are coarse walled cylindrical jars with rare perforated lip (Fig. 2.7: D-G). Figured stamped or incised drawings are new. They are made of abstract sketches or characters, solar motives and even houses and landscape (HÖNEISEN, 1985).

Note that Arbon Bleiche 3 (3384-3370 BC) developed during the transitional period between Pfyn and Horgen cultures.

2.2.3 Life during the mid-Neolithic period

The mid-Neolithic period is defined in the literature between 4600 and 3200 BC (VORUZ, 1991). We will focus on this period, because it includes the dendrochronological data obtained in Arbon Bleiche 3 (3384-3370 BC). Many innovations modified the life conditions of the mid-Neolithic societies: first villages, first agricultural systems, inhumations with numerous ornaments, imports of metallic objects followed by first copper metallurgy, pirogues and fishing material, cooking pots, etc. This period is characterised in Switzerland by the beginning of the lacustrine communities. Hunting concentrated on deer, whose horns were intensively exploited (DE CAPITANI ET AL., 2002). Culinary practices changed also, because the ceramic material permitted to cook. The modification of the ceramic material between Pfyn and Horgen cultures shows a restriction of the vessels repertory and a coarsening of the walls. These facts shall not be interpreted as a lowering of quality, but as a transfer; the idea of beauty is not any more to be found in ceramic, but in wood vessels, axes, knives, horn tools, etc. (VORUZ, 1991).

*Figure 2.8: During several winters of the 19th century, the water level of the lakes lowered and wooden piles were observed in several lakes, here in Cortaillod (*LOUBOUTIN, 1998*).*

The concentration of typologically similar vessels in every domestic unit let BLEUER (1993), GERBER ET AL. (1994) and MARTINEAU AND PÉTREQUIN (2000) think that every household made its own ceramic according to its needs. Ethnology associates the production of ceramics to women work, together with the cooking of goods.

During the winters of 1853-1854 and 1890-1891, the water level of the lakes lowered and wooden piles were observed in several Swiss and French lakes (Fig. 2.8, SCHIFFERDECKER, 1985). Ethnological comparisons led to the hypothesis of a wooden platform on which houses were erected, the platform being connected to the land with a foot-bridge (Fig. 2.9, KAESER, 2004). The well-preserved material excavated in the Neolithic sites permits to reconstruct the house structures and to draw their evolution. Recent excavations showed several variations in their construction: in Yverdon (VD), the houses were built on piles in the border of the lake; in Chalain (F) and Tayngen-Weier (SH), they were built on wooden floors, whereas they were laid directly on the ground in Portalban (FR), Egolzwil (LU) and Charavines (F). In all these cases, the villages were erected on the lake shore (Fig. 2.10) and not in shallow water. The proximity of the Alps induced, with the melting of snow in spring, a seasonal variation in the water of the lakes. Hence, some villages may have been erected on areas inundated during a part of the year (CORBOUD, 2001).

The abandon of villages were frequently provoked by a rise of the water level and the inundation of the houses. Moreover, the archaeological objects are often covered with sterile lacustrine sediments that deposed in high water and that protect the remains (CORBOUD, 2001).

The place of burial corresponding to a Neolithic village is only rarely evidenced. In the case of the lacustrine villages of Switzerland, the graves are frequently unknown (HÖNEISEN, 1985).

2.3 PRESENTATION OF ARBON BLEICHE 3

2.3.1 Geography

Arbon is today a little city in the north-east of Switzerland, on the southern shore of Lake Constance (Fig. 2.11). The southern fields of the city, where the excavations took place, are named Bleiche (Fig. 2.11). The land, very flat, lies about 400 meters over sea level. Small straight streams cross the land to the lake. The excavation lies at 670 m from the actual shore.

The first location of a lacustrine village on the Bleiche was discovered in 1885 when a draining network was excavated. Other villages neighbouring the first one were put into light in 1944. Since then archaeological excavations were done in three large areas of the Bleiche. The third one, named Arbon Bleiche 3 will be discussed in this work. All these areas are distributed on an east-west line in a 500 m perimeter. They were undoubtedly situated on the very shore of the lake in the Neolithic, as often described in other places in Switzerland.

The sedimentary beds containing the archaeological material are situated between 393.90 meters over sea and 397.00 meters over sea (mos). The higher, northern part of the Neolithic village culminates at 396.20 mos and the area extends in gentle slope to the south to 394.00 mos. The 400 m curve, which can be observed on figure 2.11, can be regarded as the maximum water level in the Neolithic period.

About three kilometres south and west from the excavation, small hills rise to 650 m.

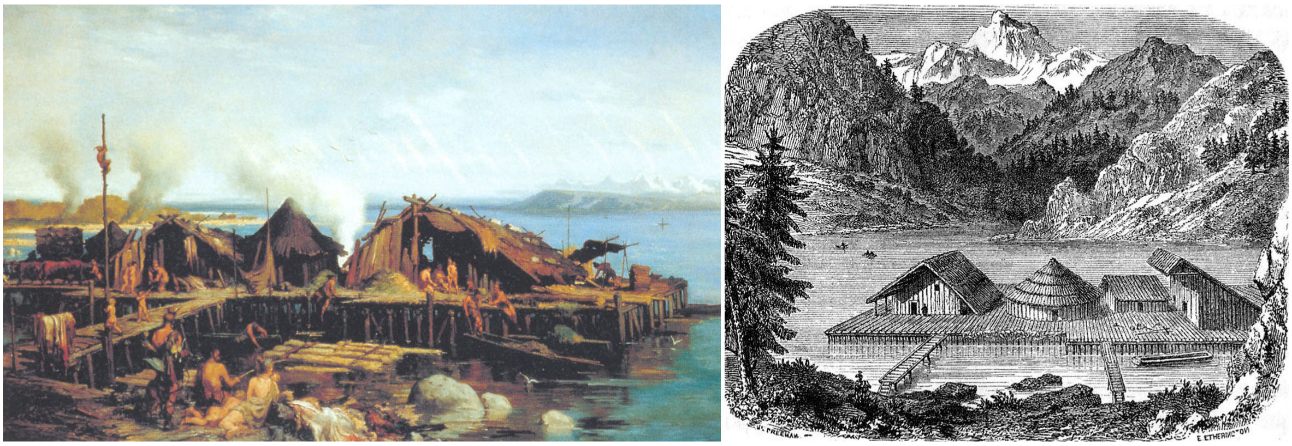


***Figure 2.9:** Lacustrine villages constructed on a wooden platform connected to the land with a foot-bridge (left: painting of* BACHELIN, 1867, *Swiss National Museum, Zürich; right, drawing of* TROYON, 1857, *in* KAESER, 2004*).*

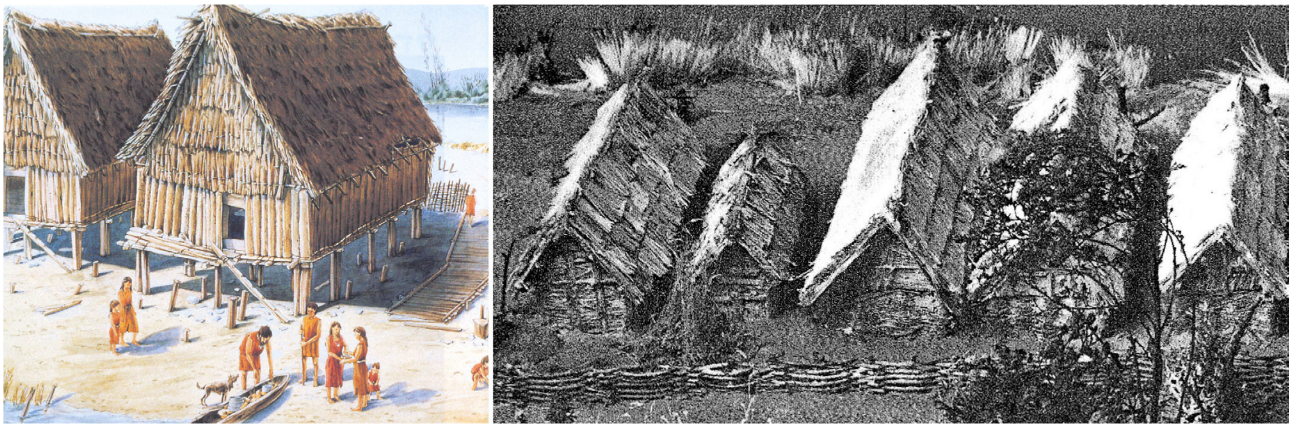


***Figure 2.10:** Neolithic villages erected on the lake shore (left, picture of* GUBLER, 1996, *Swiss National Museum, Zürich; right: model of Egolzwil 5 LU, from* HÖNEISEN, 1985*).*

2.3.2 Geology

The hills are composed of Tertiary sediments, the Molasse, the beds of which appear when the Quaternary cover (Würm moraines from the Rhine glacier) is eroded by streams, rivers and in artificial excavations (Fig. 2.11).

Three main geological deposits have to be described to understand the environment in which the Neolithic village stood. First, the eldest beds are Tertiary sediments (Molasse), which dominantly consists of carbonate-rich deposits (yellow on Fig. 2.11); second, the Quaternary Rhine Glacier Moraine, deposited during the Riss (blue on Fig. 2.11) or during the Würm (greenish on Fig. 2.11), that is either carbonate- or silicate-rich; and third, the late Quaternary lacustrine sediments, which are the foundation of the Neolithic village and its subsequent covering strata (white on Fig. 2.11).

The Molasse present as basement in the region of Arbon is the Upper Freshwater Molasse formed during the Middle Miocene, between ten and fifteen million years. It is composed of various sedimentary beds of silts, marls and shales, often yellow to beige. These

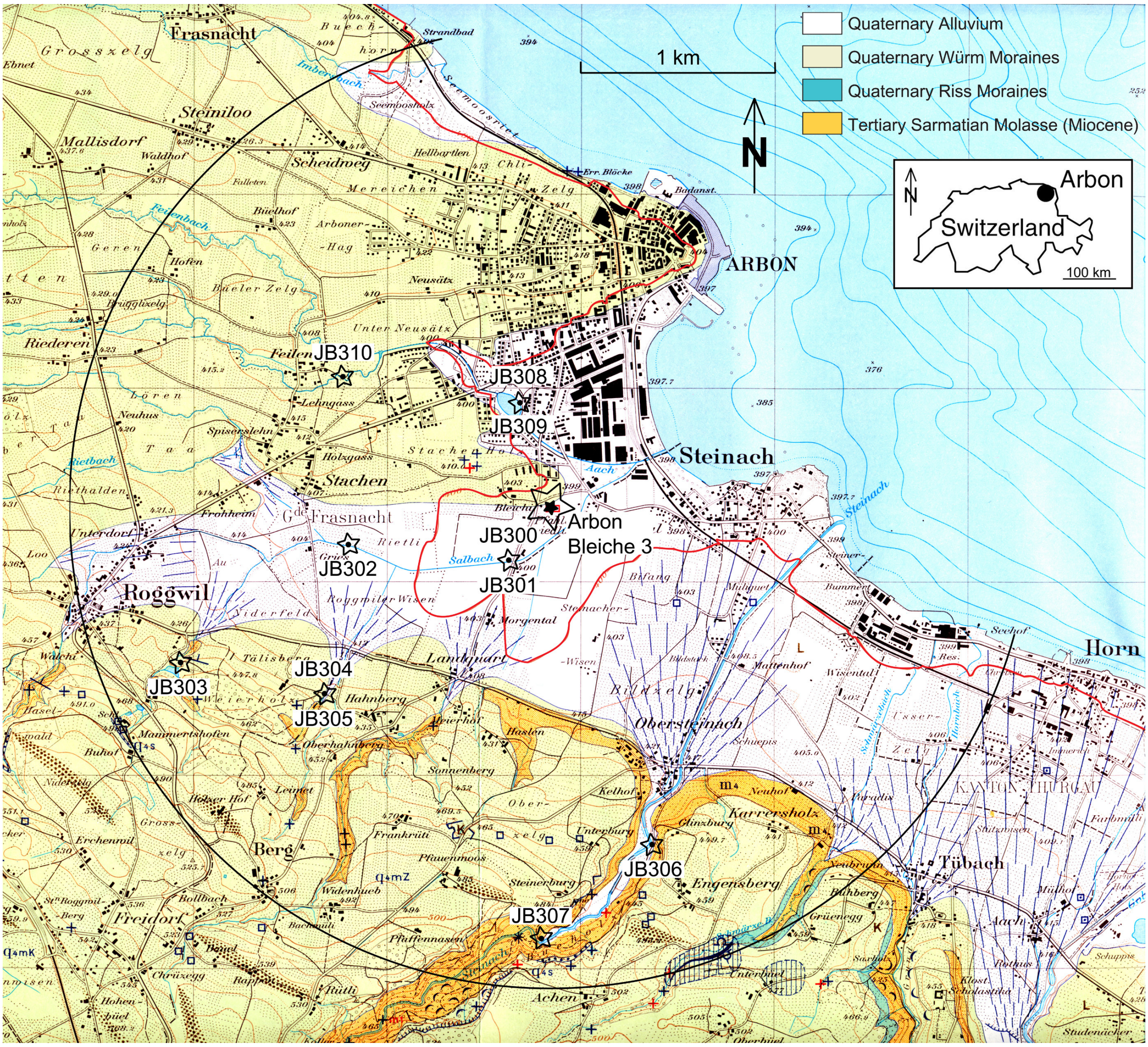


Figure 2.11: *Geological map of the surroundings of Arbon with the emplacement of the excavations of Arbon Bleiche 3. The red line in the centre of the picture is the 400 m curve, which represents the maximum water level in the Neolithic. JB300-JB310 are the finding places of the local clays. The black circle is the perimeter of 2.5 km around the archaeological site in which the clays were searched (Map from the geological atlas of Switzerland, sheet 45, 1:25.000, 1075 Rorschach, Schweizerische geologischen Kommission, Bern, 1964)*

beds are the result of the erosion of the Alps Mountains and were deposited in an ancient lake.

During Quaternary (before 1.5 million years), at least four phases of glaciations modified the Swiss landscape. Riss and Würm were the two most important (respectively from 300’000 to 120’000 and from 80’000 to 12’000 years before present). In these times, the Rhine glacier was covering North-East Switzerland to the Lake Constance (Hantke, 1993). When it retired, important sedimentary deposits, the moraines, were deposited in the surroundings of this lake, often in little lakes formed in front of the dropping glacier (fluvio-glacial or fluvio-lacustrine deposits). These deposits are still present on the shores of Lake Constance; they are composed of non-compacted sediments of any size: the huge blocks are named erratic blocks; middle-sized deposits contain pebbles with sand and clay, whereas the fine-sized are shales often mixed with sand particles. The erratic blocks as well as the pebbles consist of a great variety of lithologies, including granites, gabbros, rhyolites, cherts, etc. They were all transported from the Rhine catchments in the Eastern Swiss Alps (Wegelin, 1936).

During late Quaternary (postglacial ages: < 10’000 years), the erosion of the Alps continued and new beds deposited in the Swiss lakes. Those of Lake Constance were fine (often clays) because the source of the Rhine River was far. These beds were observed in the basement of the excavations. They are silts and fine sands, quite similar to lacustrine chalk (calcareous lake deposits). They can be differentiated from this latter by their lower content of carbonates (less than 56%) and too abundant fragments of algae and molluscs shells (Characea, Fig. 2.12: A, B, C; Ostracods, Fig. 2.12: D, E, F) (Hochuli, 1994).

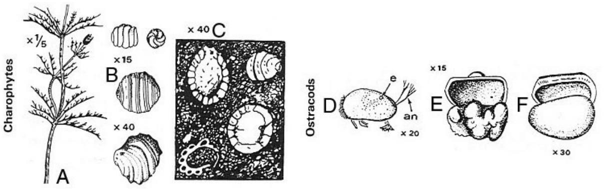


Figure 2.12: *A: Algae Chara vulgaris; B: seeds of charophytes that are found in thin sections (C). D: living ostracoda, an: antennae, e: eye; E: both separated valve of an ornated ostracoda (Devonian), F: and of a smoothed one (Jurassic) (*Foucault and Raoult, 1992)

2.3.3 Dendrochronology

The chronological frame is well established with the help of dendrochronological dating (Leuzinger, 2000). The first house was built in 3384 BC. During the following years, 26 new houses were erected forming rows separated by narrow lanes (Fig. 2.13). Around 3370 BC a fire destroyed the village. Since then the village was abandoned. The settlement was occupied for a very short period: only 15 years.

As said before, in eastern Switzerland, the Pfyn culture is dated between 3950 and 3500 BC, followed by the Horgen culture (3250-2750 BC) (Voruz, 1991; Stöckli et al., 1995). The village of Arbon-Bleiche 3 was therefore occupied during the poorly known transitional period between Pfyn and Horgen cultures. Several characteristics of the material are of Pfyn tradition, but others are already bound to the coming Horgen culture. This cultural change is not abrupt, but is a continuous development from Pfyn to Horgen forms (de Capitani, 2002).

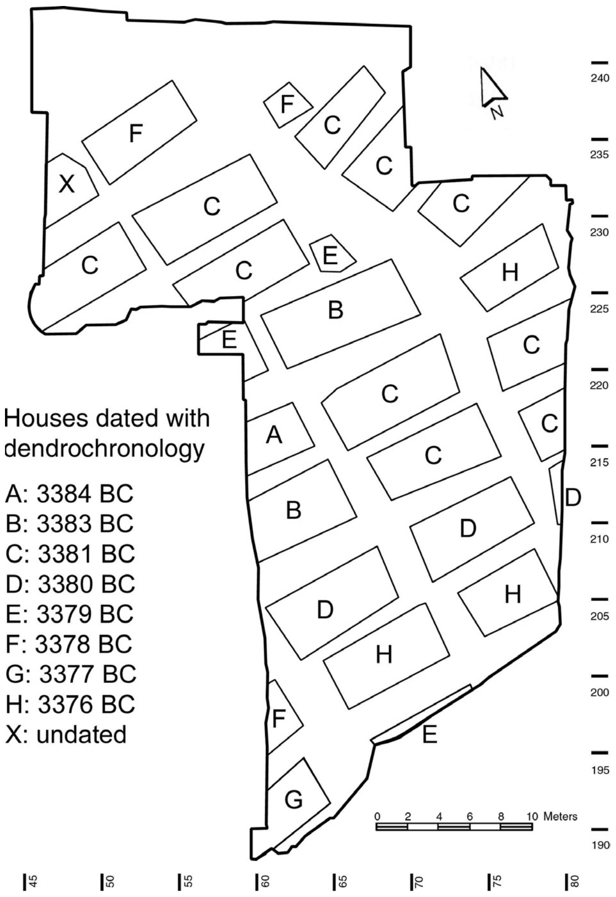


Figure 2.13: *Schematic map of the excavations 1983 and 1993-1995 of Arbon-Bleiche 3 with the location of the different houses, their dating by dendrochronology, and the trace of square meters (modified from* de Capitani, 2002*).*

3 - THE NEOLITHIC CERAMICS IN ARCHAEOMETRY: STATE OF THE ART AND DEFINITIONS

3.1 INTRODUCTION

As described in MAGGETTI (2001, 924), “the lifespan of a piece of pottery can be divided into five steps: (1) extraction of the clay from the pit; (2) manufacture of the object (processing of the clay, firing); (3) use, with subsequent breakdown; (4) burial; (5) excavation, cleaning, treatment and analysis”. Hence, the chemical analysis of a sherd will reflect “the composition of the original clay, its processing (the extraction of coarse, a-plastic particles or the addition of temper fragments can change the chemistry), the use of the object (e.g. the chemical composition of a cooking pot can be affected by reaction processes between the pot itself and the food), the burial stage (infiltration of foreign matter into the ceramic body or extraction of sherd matter caused by solvents from invading solutions) and the post-excavation treatment (e.g. cleaning with acids can lead to dissolution of carbonates)”. These different transformations of the clay will be discussed here.

3.2 COMPOSITION OF THE CLAY

3.2.1 Clay

According to CORRENS (1968), quoted in Heimann and FRANKLIN (1980, 24), “the mechanical mixture [called clay] consists of four main components: (1) The fine-grained weathering relics: quartz, feldspar, micas; (2) Neo-formations i.e. the clay minerals, as such, that are formed during weathering: kaolinites, halloysites, montmorillonites and illites; (3) Remainders of organisms: calcium carbonate (shells), silica (chert), carbon; (4) Neo-formations that occur after deposition: pyrite, dolomite, glauconite”.

The first group of components is often defined as natural inclusions or non-plastic elements, whose sizes are often less than 20 µm in diameter (NUNGÄSSER AND MAGGETTI, 1978). The second one (the argillaceous minerals) is made of weathering residues such as: feldspars partially leached in a humid climate transform to smectites, keeping their Mg2+ and Fe^{2+} ions; when totally leached, they turn to kaolinites. Micas, partially leached, form illites, main components of most Swiss clays. Clay minerals have grain sizes smaller than 2 µm in diameter and therefore are too fine-grained to be studied by the methods of optical mineralogy. They require to be studied by X-ray analysis because X-rays have much shorter wavelengths than visible light.

Often the first thing a potter does is to prepare the clay that will be fired to make a ceramic: it is rare to find a local clay in which the clay minerals and the non-plastic elements are mixed in a right proportion. The clays, very frequent in nature, have a very variable composition, which is linked to the kind of impurities present with or inside the argillaceous minerals. Quartz is always present in clays (clays containing much quartz are called shales), often with carbonates (the carbonate-rich clays are described as marls); other detrital minerals are also to be found in a natural clay (epidotes, zircons etc.). The prehistoric potter probably used preferentially naturally heterogeneous clays containing much silicatic natural inclusions. He also surely mixed clays of different origins (DE CAPITANI, oral communication).

Choosing good clay can reduce the risk of spalling. For example, clay containing montmorillonite has “extreme plasticity and high shrink / swell ratio that are difficult to overcome by the mechanical expedient of adding temper. Even a small amount of montmorillonite will significantly alter the workability of a clay body” (GRIM 1968 in STIMMELL ET AL., 1982, 220).

3.2.2 Temper

The temper is all the non-plastic materials that the potter voluntary adds to the clay when it is too fat and too plastic. The higher the proportion of fine-grained particles, the longer the drying time, the shrinkage and the deformations. During drying and firing, the water is expelled and can cause profound shrinkage and frequent spalling of the ceramic object. Adding temper reduces this inconvenient. Moreover, potters used the adding of temper to increase the workability of clays, so that they could be easily formed into vessels. The voluntary introduction of temper has been present since early Neolithic. The most common temper is of mineral origin, and mostly local: crushed crystalline rocks, calcite or alluvial sands. The temper crushed from previously heated pebble stones of, for instance, granite and serpentinite is described as splintered and sharp-edged fragments by MAGGETTI (1994). Crushed calcite is easily recognisable in thin sections, because it disintegrates into cleavage rhombohedra. Limestones and calcite turn to lime in a firing process at 750°C, which inconveniently often implies the breaking of the ceramics. Grog, small fragments of fired broken ceramics, is also frequently used to temper vessels. Other materials of biological origin were also used as temper, such as shells, straw and other vegetable elements or fragments of bone (CAMPS, 1990; HARDMEYER ET AL., 1995).

Increasing the proportion of temper or using shell temper instead of rock pieces can also reduce the risk of spalling: "Shell temper is more effective than either limestone, quartz or grog temper in minimising the crack propagation and, thus, in reducing the risk of ultimate failure due to the stresses resulting from a rapid change in temperature" (TITE AND KILIKOGLOU, 2002, 2).

The addition of organic material, such as chopped straw, produces an artificial porosity when fired and increased the sherd's resistance to changes in temperature (MAGGETTI 1994, 29).

LIVINGSTONE SMITH (2000, 24) studied the way the clay was processed in northern Cameroon: "treating the raw clays consists of "tempering" and kneading them. The materials selected for temper are (1) a dried and ground raw material (the temper is the same as the raw clay), (2) another clay, (3) sand, (4) crushed rock, (5) grog, (6) ashes and/or (7) dung. Most of these materials, available everywhere in the area, may be used alone or combined. When asked about the reasons for altering the clay in these ways, potters invariably answer that they are a necessity. Non-tempered clay would not stand drying or firing. Pressed further, they often admit that, in fact, tempering is primarily the best way to adjust the plasticity of soaked clay. The material chosen for tempering depends on how one was taught. As put by an old potter, "using one technique or the other is essentially a question of habit". While it appears that potters do modify the compositional and textural characteristics of the raw material, it is clear that these modifications and the tempers selected for this purpose are the result of choices made by the artisans between equally viable options" (LIVINGSTONE SMITH 2000, 31).

3.2.3 Discussion

The important separation between clay and natural inclusions on the one hand and tempers in the other hand will permit to deduce the manufacturing of the ancient potters. The petrographical study permits to distinguish between these components and will permit to split diverse tempers (rocks vs. grog vs. organic material, for example).

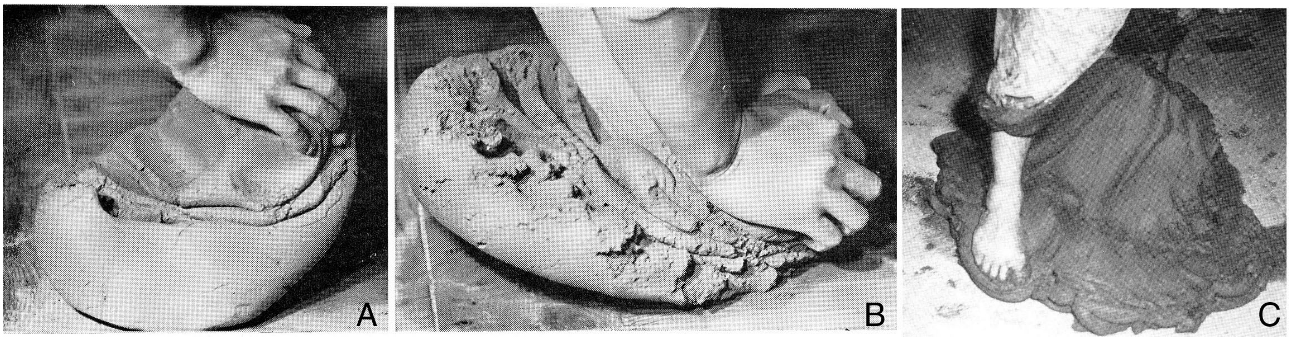


Figure 3.1: *A, B: kneading with the hands (*SANDERS, 1976*) and C: with the feet (*RADA, 1991*).*

3.3 PROCESSING THE CLAY

3.3.1 Forming techniques

Once the clay and temper were prepared, mixed with water and kneaded with the hands or the feet (Fig. 3.1) to obtain a well homogenised paste, several forming techniques can be used to manufacture a ceramic. These techniques are presented in HUYSECOM (1992), GOSSELAIN (1999, 2001) and VELDE AND DRUC (1999) for example, and the main ones are described here.

Casting (Fig. 3.2A) is a technique in which the clay is pounded into a mould. In the coiling technique (Fig. 3.2: B, C; Fig. 3.3) a lump of paste is rolled between the hands or on a flat surface to make a long rope. Then, these coils are placed one on top of the other, in rows, to build the walls of the pottery. Coil thickness and length vary as a function of the size of the pot, the wall thickness, the ability of the potter, etc. The coils can be long and assembled following a spiral (Fig. 3.2B; Fig. 3.3) or as short as the diameter of the pottery and superimposed in circles (Fig. 3.2C). The coils are sealed together with water and hand pressure and the walls thinned by vertical movements of fingers. Pots break preferentially along these junction lines, which stay fragile. A very big ring can also be simply drawn (Fig. 3.2D). The moulding technique is shown

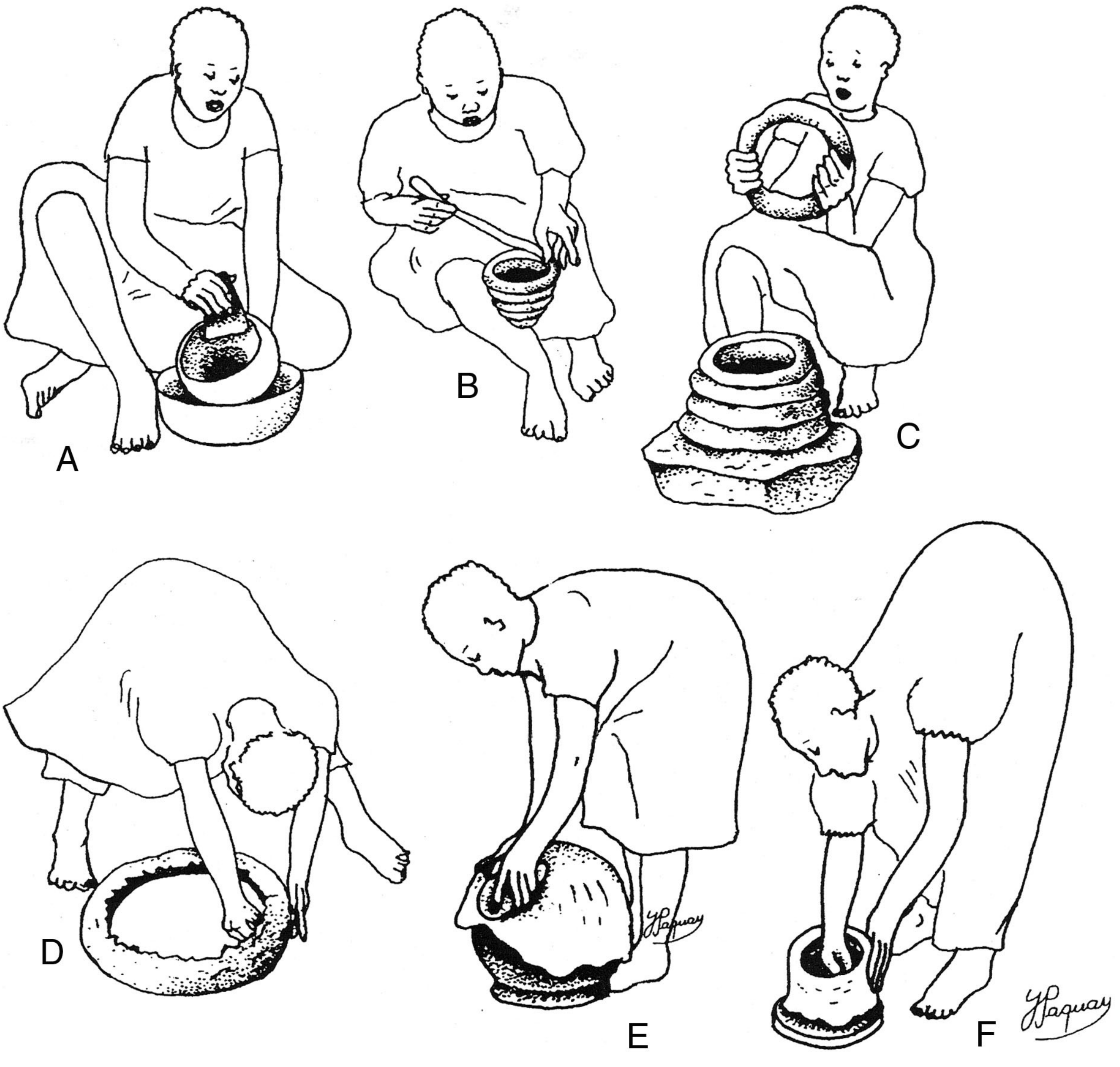


Figure 3.2: *Different forming techniques: A: casting, B, C: coiling: the coils can be long and assembled following a spiral (B) or as short as the diameter of the pottery and superimposed in circles (C). D: drawing of a ring, E: moulding, F: drawing (*GOSSELAIN, 1999*).*

on figure 3.2E; the clay lump is applied over a mould and pressed down with the hands and eventually hammered. With the drawing technique (Fig. 3.2F), the ceramic is formed by drawing up a clay lump after opening it with the fingers or the fist. In the flat plate technique, also called slab building technique, clay slabs are flattened to a desired size, usually rectangular, then wetted and joined. Finally, the wheel-thrown technique, known as "tournette" (manually or with the feet rotated, without continuing rotation) is often described as a large piece of broken pottery set over a wooden support. The lump of clay is set over the rotating wheel and modelled (Fig. 3.4).

The most common forming techniques to finish the building process are the beating and the paddle-and-anvil techniques. In the first case, the paddle (often a wooden flat piece) is beaten on the external surface of the piece, the hand of the potter inside the ceramic to retain the beating. Second, the paddle beats the external surface as the anvil (a round rock, a clay tool or a wooden "mushroom", Fig. 3.5) is used to counteract the paddle. These latter are used as secondary techniques to strengthen the walls and lift them up.

When observing an ancient ceramic, fractures between sherds are frequently visible. Horizontal fractures sometimes underline coils, but in the case of a good beating, these separations can disappear. Multidirectional fractures between sherds often do not permit to favour a forming technique more than another.

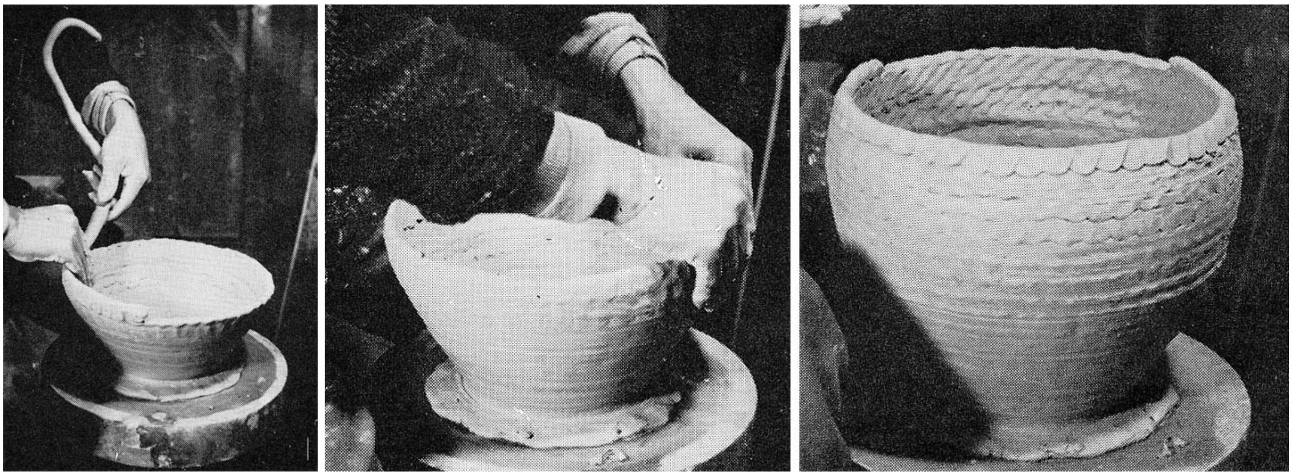


Figure 3.3: *Coiling technique: the long coils are placed one on top of the other and assembled following a spiral to build the walls of the pottery. Then, they are sealed together with water and hand pressure and the walls thinned by vertical movements of fingers (*Sanders, 1976*).*

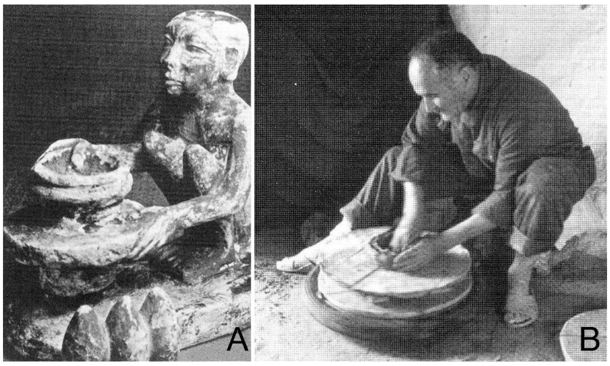


Figure 3.4: *A: Wooden statue of a Egyptian potter with a hand turntable; B: pottery hand turning in Morocco (picture* A. Desbat, D'Anna et al., 2003*)*

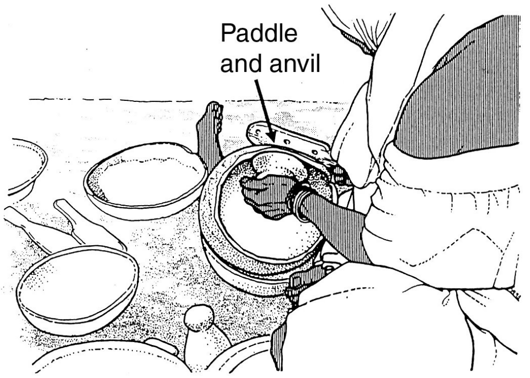


Figure 3.5: *The paddle-and-anvil technique: the paddle beats the external surface as the anvil (a wooden "mushroom" in this case) is used to counteract the paddle (*Huysecom, 1992*).*

3.3.2 Surface treatment

Frequent post-firing treatments are organic coatings, smoking or soaking deposited on the vessel just after the firing. The more frequent is putting the red-hot ceramics into grass or leaves until they become black. For GOSSELAIN AND LIVINGSTONE SMITH (1995) they constitute one of the most unrecognised stages of the manufacturing process. In Cameroon, for example, "an organic mixture prepared by boiling, soaking or infusing parts of at least 26 plants or trees is either sprinkled on the pots when they come red-hot from the fire or rubbed on after cooling". Coating practices allow an increase of thermal effectiveness by waterproofing the vessels.

3.4 FIRING

3.4.1 Firing techniques

Archaeologists and ethnologists have proposed two major techniques of firing used during Neolithic times. First, open or bonfire firing (Fig. 3.6A); second, pit firing (Fig. 3.6B).

In a bonfire firing, the ceramics are piled on the ground and covered with fuel like wood, dung or grass. The fuel burns rapidly (about half an hour), but still gives high temperatures (up to 940°C, VELDE AND DRUC, 1999). Often, the firing temperatures vary from around 300°C and 900°C (Fig. 3.7; GOSSELAIN, 1992). This structure of fire does not permit a plateau of high temperature, and irregularities in the firing process, such as high temperatures reached in a very short time are frequent. Due to their proximity to the fuel, some parts of pots can be over-fired whereas others are under-fired. The firing temperatures obtained with this technique produce combustion smokes made of water vapour, acids of firing woods and firing wood tars. These smokes can penetrate some millimetres of the surfaces of the ceramics and induce their black coloration. The ceramics also often contain organic matter (straw, grass, hair, etc.) in the matrix and/or as temper that induce the same phenomena. Around 750°C (as a function of the firing time and of the oxygen fugacity), in an oxidising firing, the carbonates turn into lime, the tars are oxidised, and the sherds turn red.

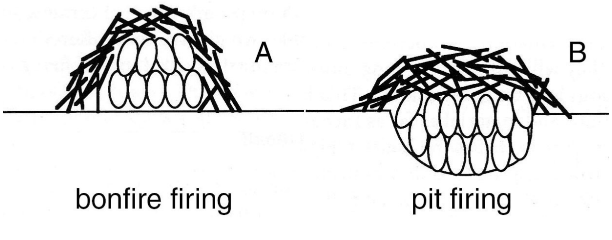


Figure 3.6: *Sketches of bonfire (A) and pit firing (B): in A the ceramics are heaped up on the ground, whereas in B they are mostly placed in a hole in the ground (*VELDE AND DRUC, 1999*).*

The pitfiring differs from the bonfire by a shallow hole in the ground. The ceramics are piled in the hole and covered with fuel. The ground maintains the heat around the ceramics during a longer time and permits a more constant firing. Even if the temperature rises as rapidly as in a bonfire, the primary inflammation is less violent; the temperature rises more regularly and is maintained during a longer time, as is the cooling time. The air entering the fire at the end of the process permits the combustion of the tars, which will give

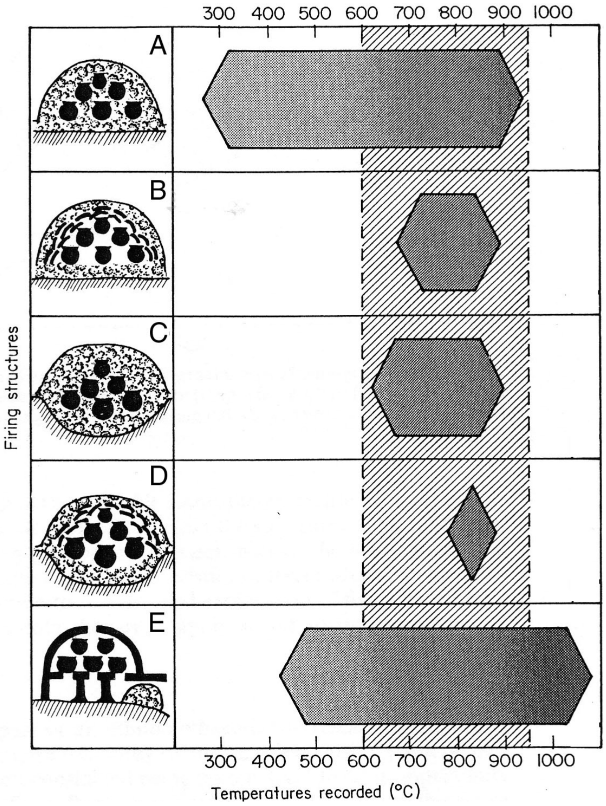


Figure 3.7: *Temperature ranges for the five kinds of firing described in* GOSSELAIN *(1992): A: Open firing, B: open firing with sherds covering the pots, C: pit firing, D: pit firing with sherds covering the pots, E: updraft kiln firing. The shaded area comprises more than two thirds of the ethno-thermometric data, and is in every case situated between 600 and 900°C (from* GOSSELAIN, *1992).*

ceramics grey to red coloration and a black core in the sections. Pit firing in regard to bonfire induce many technical improvements (Arnal and Andrieux, 1991; Gosselain, 1992, 1995; Licka, 1991).

Gosselain (1992, 244, 246) discuss five different types of firing structures (Fig. 3.7): open firing, open firing with sherds covering the pots, pit firing, pit firing with sherds covering the pots and updraft kiln firing. If a firing temperature is proposed for a group of ceramics and if this temperature is between 600°C and 900°C (dashed area on Fig. 3.7), the firing structure used cannot be deduced. Only in some rare cases, i.e. when the firing is less than 450°C or more than 950°C, the structure can be determined, respectively open and kiln firings.

Fuels used do not seem to influence the temperature. Considering the data on the time needed to reach maximum temperature, it is clear that the heating rate is the most specific parameter for each firing technique. "On average, 22 min are needed to reach the maximum temperature in open firing, 60 min when a layer of sherds separates the vessels from the fuel, 41 min for pit firing, 114 min for pit firing with sherds and 259 min (4-5 h) for updraft kiln firing".

Livingstone Smith (2001) made a study on the different methods used to fire ceramics. He studied 80 firing procedures recorded around the world. He wrote that a thermal profile shall be defined in terms of maximum temperature, heating rate (the average temperature increase per minute until maximum temperature is reached) and soaking time (the number of minutes the vessels remain above a certain temperature threshold, above 700°C in this paper). The technological study is made on four different parameters: the structure of the firing, the fuel used, the schedule based on the way the firing process finishes and the scale based on the number of vessels fired at the same time.

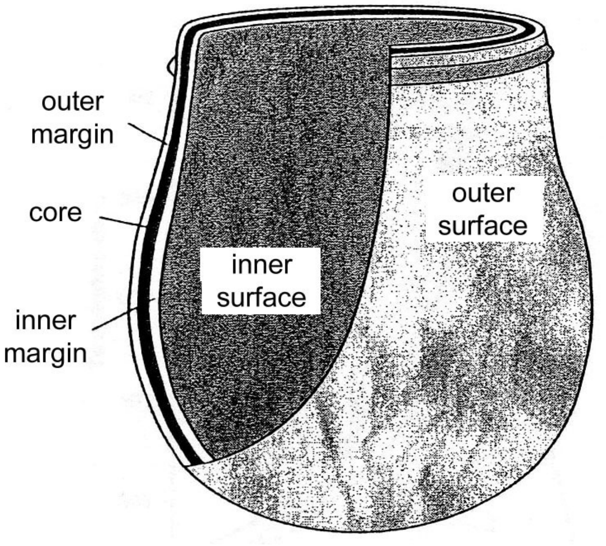


Figure 3.8: Division of the section of a sherd into five distinct parts (modified from Martineau and Pétrequin, 2000)

The firing structures studied are: bonfires, bonfires with light insulation, bonfires with heavy insulation (complete sherd covering), depressions, depressions with heavy insulation, pits, pits with heavy insulation, simple kilns (updraught kilns without firebox) and kilns (updraught kilns with firebox). The fuels are sorted into three categories: light fuel (dominant material is grass, straw, millets husks or stems, palm fronds etc.), heavy fuel (dominant material is wood or bark) and dung as dominant material. Two types of schedules are taken into account: interrupted processes (the vessels are drawn out of the fire while red hot) and slow cooling processes (the vessels are left to cool down in the structure). The scale ranges from one to over 600 pots fired at the same time, while the dimension of the structure varies from 0.5 to 7.5 m in diameter. It was divided into small scale firing (< 5 vessels), medium (6 – 60 vessels) and large scale firings (> 60 vessels).

This study leads to the following conclusions: different firing procedures may induce similar thermal profiles, as discussed in Gosselain (1992). The simplistic opposition between the thermal characteristics of "open" and "kiln" firing does not take into account much technical and cultural information. The duration of both types of procedures is extremely variable. The upper range of maximum temperature is higher for kilns than for open firings. The heating rate of open firing ranges from a few degree per minutes to over 120°C/min, while heating rates for kiln firings are below 20°C/min. However, kiln firings are not the only one to allow for very low heating rates, the lower range of heating rates for open firings being inferior to

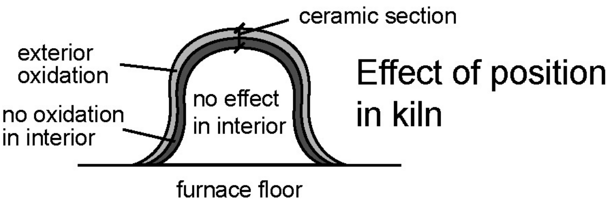


Figure 3.9: Schematic cross-section of a ceramic showing the un-oxidation of the inside due to its mouth down position on the ground (modified from Velde and Druc, 1999*).*

that of kiln firings. The soaking time above 700°C is about 20 minutes for both categories, the upper range of open firings being around 2 h, against 1 h for kilns, while both categories may also produce no soaking time above 700°C. Hence, be it from the point of view of "open" and "kiln" firings, or from the point of view of the various structures, fuels, schedules and scales, none of the technical categories induce specific thermal characteristics. In other words, it is impossible to relate a particular set of thermal characteristics (duration, maximum temperature, heating rate and soaking time) to a specific firing procedure, because very different characteristics may be achieved within the same structure and similar fuel.

Even if often not described and taken into account, the type of fuel "is an extremely important variable in the thermal cycle, due to its effect on the parameters of time (rapidity of lighting, duration) and temperature (effectiveness and economy), and on the nature of the solid volatile residue (coals and smoke)" (Fabbri et al., 2002, 192).

Whatever the firing technique used, a gentle firing reduces the risk of spalling: "The primary driving force for thermal shock is the stresses associated with the differential expansion or contraction of the inner and outer surfaces of a pottery vessel that are caused by a rapid change in temperature at one surface and the resulting temperature gradients through the vessel wall" (Tite and Kilikoglou, 2002, 1).

3.4.2 Firing Atmosphere

In 2000, Martineau and Pétrequin conducted experimental firing of reproductions of Neolithic ceramics from Chalain (France). They observed that bonfire and pit firing techniques necessitate the description of five parts in the section of a sherd to understand the firing process: the section divides into the core, two margins and two surfaces (Fig. 3.8).

When ceramics are fired in a bonfire, during the rising of temperature, the fuel uses all the available oxygen. This induces always a reducing atmosphere for the ceramics. After reaching the maximal temperature, when the wood is consumed, the oxygen of the air begins to be in contact with the ceramics and the atmosphere turns to oxidising. In this situation, the ceramics are orange, sometimes with a grey core. Black marks stay on the external surfaces where the air is not in contact. If a very fine fuel is used so that the oxygen cannot penetrate inside the firing after combustion, the atmosphere stay reducing and carbon completely blackens the ceramics. Another way to obtain a reducing cooling consists of interrupting the firing, taking away the incandescent ceramics and putting them into organic matter (i.e. grass, leaves) until they become black.

Velde and Druc (1999) show that putting the ceramics mouth down onto the ground, the inside remains un-oxidised during firing because air cannot reach the inside (Fig. 3.9).

Martineau and Pétrequin (2000) defined five firing phases in a bonfire firing:
- Phase I: Between 20°C and 400°C, the ceramic does not change its colour, remaining the same as the paste.
- Phase II: during the second part of the rise of temperature, the whole section of the piece becomes black.
- Phase III: on the peak of temperature, the section becomes clearer from the outer margin to the core.
- Phase IV: when the temperature decreases, two different possibilities were observed:
- Phase IVa: after its action on the outer margin (Phase III), the oxygen, which circulates less easily inside the ceramics than outside, makes the inner margin clearer before the core. If the duration of the cooling is long enough, the latter becomes also clear.
- Phase IVb: when the ceramics are close forms or if they are piled, the internal oxidation is more difficult, and the core becomes clear before the inner margin.
- Phase V: with the end of the decrease of temperature, the whole sherd becomes clear.

The black ceramics result from a confined atmosphere during the whole firing or only during the cooling. No sherds with inner oxidised margin and outer black margin were observed in the material of Chalain.

3.4.3 Experimental firing of clays

Several authors frequently made experimental firings on clays, in order to detect mineralogical changes as a function of temperature, time and fugacity of oxygen. The clays are normally fired in an electric oven in oxidising atmosphere, between 500°C and 1000 to 1200°C. In the laboratory of Fribourg, the temperatures are held constant for one hour at peak temperature to let the new minerals crystallise. The mineralogy of the fired clays are determined by X-ray diffraction. That way, the mineralogical changes of one clay during a firing process are precisely described. Hence, most temperature estimations of ancient ceramics are indirect, as explained by TITE (1995). He quoted NORTON AND HODGDON (1931), who proved that "to a first approximation, increasing the time at maximum temperature by a factor of five is more or less equivalent to increasing the maximum temperature by approximately 30°C. Therefore, instead of trying to determine the actual maximum temperature reached during a firing, it is more appropriate to define an equivalent firing temperature which is the temperature maintained for one hour which would produce the observed mineralogy or microstructure". The firing temperatures resulting from these experiments are only rough approximations of the firing temperatures attained in the Neolithic, because the firing conditions used by prehistoric potters were obviously different (rise of temperature not constant, temperature varying in the firing area, fugacity of oxygen, etc.).

3.4.4 Generalities on colour changes in the ceramic during open firings

For ANDRIEUX (1991), the best way to understand the coloration of the ceramics is by analysing the chemistry of the wood firing. The combustion of the wood into gaseous phases, varying with the rise of temperature, generates different firing atmospheres impregnating the ceramics in contact: until 750°C, the water vapour is the impregnation vector for the tars and soot, generating the black coloration of ceramics. Over 750°C, these tars and soot decompose, and the carbons (C, CO, CO_2), the oxygens (O^-, O^{2-}) and the hydrogens (H^+) are liberated from the tars. Only at about 900°C ceramics tend to get oxidised (reddish, orange or white colours) or reduced (grey colour, not black). Traces of the previous stages in the firing process remain visible in a thin section of the sherd, often appearing with a black core, even in this range of temperature.

The red colour of the sherds fired in an oxidising atmosphere is given by hematite (Fe_2O_3), which contains iron in its oxidised form (Fe^{3+}). Apart of carbon, the grey to black colouration can be given by magnetite (Fe_3O_4) or hercynite that contains iron in its reduced form Fe^{2+}; it can also be bound to the presence of manganese oxides, such as Mn-spinels ($MnFe_2O_4$), bixbyite (Mn_2O_3) and hausmannite (Mn_3O_4). These latter appear around 1000°C as a function of the percentage of Mn_2O_3 present in the clay: if Mn_2O_3 is between 20-40 wt.%, spinel and hematite form; if it is around 65 wt.%, bixbyite crystallises and if it is between 75-85 wt.%, hausmannite is present (MAGGETTI, 1974; MAGGETTI AND GALETTI, 1986; LETSCH AND NOLL, 1983).

According to MAGGETTI (1979) and to HEIMANN AND FRANKLIN (1980), the change of the firing colour from red to brown at temperatures above 1100°C is strongly related to the presence of fayalite (Fe_2SiO_4). The brown colour is a mixture between the red of the hematite and the green of the fayalite.

WOLF (1999, 57) explained the colouration of fired clays as follows: "The progressive change from orange (500°C-900°C) to red (900°C-1100°C) then to brown-red (>1100°C) can be related to grain coarsening of hematite with increasing temperature (PETERS, 1969) and to small amounts of spinel which forms at high temperature".

SIGG (1991) explained the difference of red and yellow colouration of the sherds: in CaO-rich clays, "if the ratio Al_2O_3 / Fe_2O_3 is more than 3 and less than 5, the fired sherds turn from red to pink. If it becomes higher than 5, the pink colour turns to yellow. If the ratio Fe_2O_3 / CaO is less than 0.5, the pink colouration turns also to yellow. Generally, the products stay yellow if CaO / Al_2O_3 is higher than 1, even if iron oxides increase". A red burning clay can change its colour to yellow if $CaCO_3$ is added to the raw material.

3.4.5 Mineralogical transformations during experimental firings

3.4.5.1 Introduction

As a summary, HERZ AND GARRISON (1998, 257) explained that during firing "the principal changes that take place are by (1) oxidation or reduction; (2) loss of volatiles and dehydration, principally loss of hydroxyl ions (OH) from the clay structure; and (3) formation of higher-temperature phases and finally, at very high temperatures of firing, (4) vitrification" (formation of a liquid). The presence of melt in the samples is evidenced by a rise of the background noise in the XRD pattern at T > 900°C in the CaO-poor samples and at T > 800°C in the CaO-rich samples due to the presence of an amorphous phase.

The crystalline and amorphous phases present in a sherd are of three types: (1) primary minerals (relic minerals inherited from the initial clay: i.e. quartz, clay minerals, calcite); (2) firing minerals (formed during firing: i.e. gehlenite, diopside, mullite) and (3) secondary minerals (formed after firing: i.e. portlandite, calcite, gypsum) (Maggetti, 1982, 123; 1986, 94)

The mineralogy and chemistry of the clay imply the formation of new minerals during firing process: Tite et al. (1982, 63), summarising several authors, such as Maggetti (1979), explained that in CaO-rich clays (> 5% CaO), fired sherds are characterised "by the presence of a high concentration of calcium (and/or magnesium) silicates (anorthite, wollastonite, diopside, gehlenite). These silicates had been formed through the reaction between the calcium (and/or magnesium) oxide and the dehydroxylised clay minerals". In contrast, in CaO-poor clays (< 5% CaO) "the formation of high-temperature crystalline phases was very much less pronounced. Only weak lines associated with spinel and mullite were detected". Nöller and Knoll (1988) fired a montmorillonitic and illitic clay mixed with varying quantities of $CaCO_3$. "The more Ca that is added the greater the extent of and the faster the formation of silicates. The Ca-rich material even shows a decrease in the amount of relatively stable quartz with the formation of extensive amounts of the calcium silicates gehlenite and wollastonite".

For oxidising atmosphere of firing, the work of the following authors was taken into account: Béarat (1992); Béarat and Bauer (1994); Benghezal (1990, 1994a, 1999); Courtois (1973); Cultrone et al. (2001); Echallier and Méry (1992); Grim (1968); Heimann (1989); Heimann and Franklin (1980); Heimann and Maggetti (1981); Hertli et al. (1999); Herz and Garrison (1998); Jornet (1980, 1982); Jornet and Maggetti (1983); Jornet et al. (1985); Kilka (1987); Küpfer and Maggetti (1978); Letsch and Noll (1983); Maggetti (1974, 1979, 1981, 1982, 1986, 1993, 1995b); Maggetti and Heimann (1979); Maggetti et al. (1984); Maggetti et al. (1988); Michel (1985); Murad and Wagner (1989); Nöller (1983); Peters and Iberg (1978); Peters and Jenni (1973); Picouet (1997); Stimmell et al. (1982); Tite (1995) and Tite et al. (1982).

For reducing atmosphere of firing, the literature is less abundant and the works used are the following: Heimann et al. (1980); Herz and Garrison (1998); Letsch and Noll (1983); Maggetti (1993); Maniatis et al. (1983) and Murad and Wagner (1989).

3.4.5.2 Problem of pressure and of thermodynamically incompatible minerals

As exposed in Maggetti (2001, 924), "in contrast to natural rock-forming processes, pressure is insignificant in the genesis of [ceramics], because the kiln can be considered as a technical system. In such open systems, neither pore solutions, present before firing, nor gaseous reaction products, which may have been produced during the high temperature process, have an influence on the transformation, because they can leave the system at any time." Hence, the new mineralogical associations produced during firing are high temperature minerals, but no high pressure minerals are observed.

Maggetti (1986) and Heimann (1989) explained the presence of thermodynamically non-compatible minerals side by side in ceramics. For Maggetti (1986), only small regions confined to the reactive interfaces between mineral grains are in equilibrium. Heimann (1989, 132) added that "the inherent inhomogeneity of the clay, together with low temperatures and short firing times, generate a thermodynamic non-equilibrium with respect to the global system."

3.4.5.3 Lime popping

When fired over 600°C (oxidising atmosphere) or over 750°C-900°C (reducing atmosphere), calcite ($CaCO_3$) decomposes to lime (CaO) with production of CO2. When exposed to the air, the lime reacts with moisture to form portlandite ($Ca(OH)_2$). Since the latter crystals have a larger volume than the original calcite crystals, this expansion forms cracks that can destroy the vessel (Maggetti et al., 1984; Tite and Kilikoglou, 2002).

Methods to avoid this lime popping are well known by potters firing CaO-rich clays and listed in Tite and Kilikoglou, 2002: (1) "Avoid the temperature reaching much above about 650°C in an oxidising atmosphere or much above about 750°C in a reducing atmosphere"; (2) "Wetting the clay with sea water (Rye, 1976) or adding a few percent of sodium chloride to the clay" (even 0.5% NaCl promotes a reaction between CaCO3 and iron, which forms stable compounds at temperatures below 900°C-1000°C; Laird and Worcester, 1956; Butterworth, 1956, quoted in Stimmell et al., 1982, 222); (3) "Quenching the vessel, immediately after firing and whilst still red-hot, in cold water"; (4) Firing at temperatures exceeding 900°C let the free CaO combine with alumina and silica released by the thermal decomposition of clay minerals to form high temperature minerals such as diopside, gehlenite and anorthite (Heimann, 1989 141).

Firing method (open firing vs. kiln firing) and granulometry of the clay are important, resulting in varying the temperature of lime formation. Hence, the temperatures proposed here are only approximate.

3.4.5.4 Oxidising firing of carbonate-rich clays

Appendix 7A shows the mineralogical associations published in the literature for oxidising firing of carbonate-rich clays.

BENGHEZAL (1994A) expressed that (002) and (003)-peaks of chlorite disappear at 550°C, whereas (001)-peak is lost at 700°C. These facts are in concordance with the observations of the other authors for who chlorite disappears between 650° and 700°C (TITE, 1995; BÉARAT, 1992 and JORNET ET AL., 1985).

For every author, kaolinite disappears below 500°C or around 550°C, except for HERZ AND GARRISON (1998, 263, 264): "750°C-850°C: (…) kaolinite and smectite begin to lose their characteristic crystalline structure. (…) 950-1100°C: The structure of most kaolinite and smectite is irreversibly lost."

Montmorillonite seems to have a very varied temperature of disappearance: 500°C (BENGHEZAL, 1994A) or 750°C in marls (MAGGETTI, 1986; MAGGETTI ET AL. 1984). PETERS AND IBERG (1978) studied a marl from the Molasse Basin of Switzerland and observed that montmorillonite starts to disappear at 650-700°C, with a rapid decrease of the mineral around 800-850°C and its loss at 950°C. HERZ AND GARRISON (1998) showed that smectites disappear around 950°-1100°C.

Illite disappears between 900°C (LETSCH AND NOLL, 1983) and over 1100°C (HERZ AND GARRISON, 1998). The detailed disappearance of (001), (002) and (110)-peaks is varying between 800°C and 1000°C as a function of the authors' experiments. In HERTLI ET AL. (1999), (001) peak of illite is well visible below 850°C; between 850°C and 950°C (001) peak of illite "has disappeared or is only present as small shoulder. The maximum temperature of 950°C can be determined through the presence of the illite (020) reflex. Missing illite is a sign that the temperature is above 950°C". CULTRONE ET AL. (2001, 631) wrote that over 1000°C, phyllosilicates have already disappeared in all clays, being transformed into sanidine and mullite plus a melt".

In HERZ AND GARRISON (1998, 263), "quartz inverts at 573°C from the alpha (low temperature) to the beta (high temperature) form, accompanied by a volume expansion of 2%". For many authors, quartz is lost at 1150°C and plagioclase is always present until over 1100°C.

K-feldspar disappears at 900°C (MAGGETTI, 1982), 1000°C (BÉARAT, 1992) or over 1100°C (JORNET ET AL., 1985; HERZ AND GARRISON, 1998). CULTRONE ET AL. (2001, 631) observed that "K-feldspar progressively disappears as temperature increase. It seems that low-temperature K-feldspar (microcline) is not stable at high temperature, therefore, it transforms into a high-temperature K-feldspar (i.e. sanidine) or reacts with lime to form anorthite". Moreover, TITE ET AL. (1982) show that the content in anorthite is maximum in CaO-rich clays if Ca is equal to 10% in clay containing fine-grained calcite, and if Ca is around 15-25% when calcite is present as inclusions.

Aragonite is lost below 500°C (ECHALLIER AND MÉRY, 1992), whereas dolomite disappears from 550°C (HEIMANN, 1989) to 800°C (CULTRONE ET AL., 2001).

Calcite turns to lime from 650°C (BÉARAT, 1992; BENGHEZAL, 1994A) to below 800°C (JORNET ET AL., 1985), and this latter is lost from 800°C (LETSCH AND NOLL, 1983) to 1100°C (JORNET ET AL., 1985). Several authors did not mention the disappearance of lime at high temperature (BÉARAT, 1992; BENGHEZAL, 1994A; ECHALLIER AND MÉRY, 1992; MAGGETTI, 1986; MAGGETTI ET AL. 1984). ECHALLIER AND MÉRY (1992) AND MAGGETTI ET AL. (1984, 173) resume the phenomenon well: "the transformation of calcite into lime begins slowly around 750°C, brutally accelerates between 800 and 850°C and achieves at 900°C. But when the ceramics are made of marls in which calcite is present as very small particles, the temperatures are often inferior". For CULTRONE ET AL. (2001, 628), calcite and dolomite "are fully transformed either into burnt lime (CaO) or into a mixture of burnt lime and periclase (MgO)" at 800°C. Finally, HEIMANN AND MAGGETTI (1981, 166) specify that the temperature of decarbonisation of calcite is strongly dependant on the particle size; quoting MACKENZIE (1957), some of the larger grains cause markedly delayed dissociation and will be preserved therefore at considerably higher temperature (up to 1050°C!).

BÉARAT (1992) described a presence of hematite below 800°C, with its loss at this temperature. For other authors, hematite appears at 750°C (or 820°C, TITE, 1995) and can disappear at 900°C (MURAD AND WAGNER, 1989) or not (BENGHEZAL, 1994A, for example). CULTRONE ET AL. (2001) observed an increase of hematite peaks over 1000°C.

Periclase appears at 700°C (Béarat, 1992). Gehlenite forms from 750°C (Letsch and Noll, 1983) to 900°C (Jornet et al., 1985) and disappears respectively from 950°C to over 1100°C, or is still present over 1100°C (Béarat, 1992). Cultrone et al. (2001), following the work of Maggetti, specify that "gehlenite starts to form at 800°C by grain-boundary reaction between CaO, Al_2O_3 and SiO_2, the first deriving from former carbonates and the later two from already dehydroxylised phyllosilicates". Moreover, a direct correlation between amounts of CaCO3 and gehlenite was observed by Stimmell et al. (1982, 222): "the relative peak heights of the gehlenite (211) interference at 2.85 Å against the calcite (102) interference at 3.86 Å" show a correlation coefficient of 0.79. Tite et al. (1982) specify that if Ca >25% in clay (hence, CaO > 35 %), gehlenite is present at 1100°C; if there is less Ca, gehlenite disappears around 1000°C. Gehlenite is often not described in ancient pottery sherds. Heimann (1989), Heimann and Maggetti (1981), Küpfer and Maggetti (1978), Maggetti (1982) and Maggetti and Heimann (1979), propose three different possibilities for that absence: (1) Because gehlenite is metastable, it tends to disappear at firing temperatures exceeding 950°C and forms anorthite by reaction with silica: very high firing temperatures or very long holding at maximum temperatures prevent its crystallisation ; (2) Gehlenite is often absent of well-processed clays with a small grain size, and is present when the same clay is used to manufacture coarse products; (3) Gehlenite is decomposed to calcite and zeolites by soil solution during burial in a humid climate, whereas it stays if the soil is dry.

Maggetti (1979) observed that the transformation from goethite present in pisoliths to hematite is done at 370°C.

Anorthite appears from 750°C (Murad and Wagner, 1989) to around 900°C (Peters and Iberg, 1978; Cultrone et al., 2001); it starts to form at the expenses of calcite and illite, plus quartz. Diopside and wollastonite respectively form at the dolomite-quartz interfaces and at the carbonate-quartz interfaces from 800°C (Letsch and Noll, 1983; Cultrone et al., 2001, 631). Tite et al. (1982) add that diopside or wollastonite crystallise whereas Ca is equal to 15-25% (CaO: 21-35%) in clay as fine-grained calcite and whereas Ca >25% (CaO >35%) in clay as calcite inclusions.

Sanidine and mullite respectively appear over 950°C and around 1000°C.

As shown on Appendix 7A, these differences of temperatures cannot be put into relation with the mineralogy of the fired clay.

To resume the table A of Appendix 7, it is obvious that the apparition and disappearance temperatures of each mineral are strongly dependant on the clay composition: carbonate-rich clays differ a lot from one place to another, depending on the geology, even in one country. For example, a carbonate-rich clay containing lots of illite will react differently than a kaolinitic one. Hence, the stability of minerals should not be taken from the literature between geological regions. Authors have to make their own firing experiments in order to appreciate the behaviour of the minerals present in the clay used in the studied potteries.

3.4.5.5 Oxidising firing of silicate-rich clays

Appendix 7B shows the mineralogical associations published in the literature for oxidising firing of silicate-rich clays.

Benghezal (1994a, 1999) shows that (002) and (003)-peaks of chlorite disappear at 500°C, whereas (001)-peak stays until 600°-700°C. Other authors observed a lack of chlorite over 670° to 750°C. Maggetti (1979) quoted Grim (1968) who measured at 550°C that chlorite had disappeared. Murad and Wagner (1989) explained the wide variation of the minerals formed from fired chlorites: "Upon heating chlorites, the brucite sheet becomes dehydroxylised at 500-600°C whereas the silicate sheet becomes dehydroxylised at about 700-800°C. Heating low-iron chlorites to over 600°C leads to complete oxidation of iron (II), whereas iron (II) in iron-rich chlorites is only insignificantly oxidised. Depending upon the original chlorite composition and the firing atmosphere, a wide variety of heating products (olivine, spinel, hematite, cristobalite) can ensue when chlorites are fired."

Kaolinite transforms, loosing their hydroxyl groups, to an amorphous constituent called meta-kaolinite between 350° and 500°C (Murad and Wagner, 1989; Heimann and Franklin, 1980) and disappears before 500°C (Murad and Wagner, 1989) or around 550°C.

Vermiculite is lost before 500°C (Murad and Wagner, 1989; Picouet, 1997).

Montmorillonite disappears before 550°C for several authors (Picouet, 1997; Maggetti, 1993; Benghezal, 1994a), but is still present to 800° or

950°C for others (only (110)-peak?; MAGGETTI, 1982, 1986; MAGGETTI ET AL. 1984).

At 500° to 550°C, illite looses its hydroxyl groups, and retains a distorted structure for another several hundred degrees (HEIMANN AND FRANKLIN, 1980, 27). Illite, then, is lost from 850°C to 1050°C (MAGGETTI, 1982). When each peak – (001), (002), (110) – disappears is not clear in the literature. For example, BENGHEZAL (1990) observed (001) and (002)-peaks of illite disappear at 850°C and no illite left between 900° and 950°C. The explanation of CULTRONE ET AL. (2001), "only the diffraction peak at 10 Å, corresponding to a dehydroxylised illite-like phase, remains at 700°C. This peak intensity is reduced upon firing at higher temperature, till it disappears at ~900°C" is prevailing.

Muscovite undergoes a solid-state phase change into a mixture of mullite and K-feldspars at temperature ranging from 800 to 1000°C (CULTRONE ET AL., 2001, 630).

Quartz is still present at 1050°C (MAGGETTI, 1986; MAGGETTI ET AL. 1984) and even at 1150°C.

K-feldspar disappears at 1050°C; is transformed from microcline to sanidine over 1000°C (CULTRONE ET AL., 2001) or from low-microcline to intermediate microcline at 900°C (PICOUET, 1997). For BÉARAT (1992), it is always present. CULTRONE ET AL. (2001), quoting the work of various authors, show that the plagioclase increases its Ca-content (becomes more anorthite-rich) together with its main peak intensity as the temperature increases. As observed in PICOUET (1997), a phase appear by two peaks (2θ= 21.16° and 27.16°) between 900 and 1050°C. These peaks could be attributed to intermediate microcline. These two peaks are not new, but result of a displacement of peaks 20.98°2θ and 27.02°2θ, due to a change in its structure. The "low-microcline" is triclinic and becomes monoclinic with the elevation of temperature.

Plagioclase disappears from 850°C (BENGHEZAL, 1999) to 1050°C (MAGGETTI, 1993, 1995B) or is always present (MAGGETTI, 1986; MAGGETTI ET AL. 1984).

As observed under the microscope, amphibole disappears at 950°C (MAGGETTI, 1986; MAGGETTI ET AL. 1984) or not, only changing its colour (ECHALLIER AND MÉRY, 1992).

LETSCH AND NOLL (1983) show an increase of hematite between 500°C and 900°C, followed by a decrease over 900°C. Other authors observed the formation of hematite from 600°C (BENGHEZAL, 1999) to 850°C (BÉARAT, 1992; MURAD AND WAGNER, 1989).

Dolomite is lost at 500°C (BENGHEZAL, 1994A) or 670°C (BÉARAT, 1992), whereas calcite disappears at 950°C (BENGHEZAL, 1994A).

Bixbyite disappears at 850°C (LETSCH AND NOLL, 1983) It is replaced by spinel if Mn*100/(Mn+Fe) = 2.3-57% and by spinel and braunite if the ratio is equal to 73-91% (LETSCH AND NOLL, 1983). Pyroxene is still present at 1150°C (MAGGETTI, 1986; MAGGETTI ET AL. 1984). Mayenite and braunite respectively appear at 774°C, (ECHALLIER AND MÉRY, 1992) and 850°C (LETSCH AND NOLL, 1983). This latter decreases over 900°C. The first forms from the breakdown of clay minerals and calcite and the second from the decomposition of bixbyite and illite in presence of manganese.

For every author, spinel forms between 850°C and 1000°C (PICOUET, 1997). Only MAGGETTI (1982) describes spinel between 500° and 700°C. Spinel crystallises if illite is predominant to kaolinite in the clay (TITE ET AL., 1982). These temperatures shall be taken with care, fact which was well explained in LETSCH AND NOLL (1983, 269): "A drop in the oxygen content of the kiln atmosphere to, say, 1% would result in the formation of spinel beginning at 722°C instead of at 873°C. […] Moreover, since the manganese-oxide phase transformations proceed quite rapidly, this would explain why spinel can be found in antique sherds fired at relatively low temperatures. Once formed, spinel is essentially resistant to the reactive siliceous matrix developed through the decomposition of illite". As explained in HEIMANN AND FRANKLIN (1980, 27), above 900°C, the meta-kaolinite and illite begin to crystallise into an Al-spinel.

Mullite forms from 800°C (MURAD AND WAGNER, 1989) to 1100°C (MAGGETTI, 1982). Mullite crystallises if kaolinite is predominant to illite in the clay (TITE ET AL., 1982). CULTRONE ET AL. (2001) specify that the intensity of the main diffraction peak of mullite (3.39 Å) increases over 900°C. Mullite and cristobalite are formed from the break down of the structure of meta-kaolinite. Some iron can substitute for aluminium in mullite and the rest will form hematite (MURAD AND WAGNER, 1989). HEIMANN AND FRANKLIN (1980) say that above 1000°C, spinel breaks down to form mullite.

Cristobalite appears from 800°C (MURAD AND WAGNER, 1989) to 1050°C (MAGGETTI, 1982), and ackermanite at 1058°C (ECHALLIER AND MÉRY, 1992).

In the table B of Appendix 7, the stability of the minerals is also strongly dependant on the clay composition: an illitic or illitic-montmorillonitic clay is quite different from a kaolinitic clay. Hence, the results presented in the literature shall be taken with care; they have to be used only if the geology of the studied area is similar to that of the literature.

3.4.5.6 Reducing firing of carbonate-rich clays

Appendix 7C shows the temperature of formation of the different minerals mentioned in the literature.

Quartz disappears at 1150°C. Plagioclase increases between 800°C and 1000°C (Letsch and Noll, 1983). Chlorite and illite disappear at 700°C. Calcite disappears around 900°C. No lime is formed. Hematite is lost below 600°C, turning to magnetite, which appears at low temperatures in reducing conditions (around 700°C) and remains un-dissociated up to higher temperatures (Maniatis et al., 1983). Magnetite is a typical mineral to show a firing in a reducing atmosphere (Maggetti, 1993); moreover, according to Heimann et al. (1980) the absence of magnetite in a CaO-rich ceramic points to strongly reducing conditions (f_{O2} less than 10^{-4} atm). Gehlenite forms at 850°C after the reaction of CaO with the Al_2O_3 and SiO_2 of the clay minerals and disappears at 950°C, replaced by diopside (Maniatis et al., 1983; Letsch and Noll, 1983). The results produce evidence that gehlenite accommodates ferric iron in its structure, probably in Al sites, and that the formation of this Fe-gehlenite phase is not inhibited by the reducing conditions (Maniatis et al., 1983).

Wollastonite crystallises around 900°C, at the expense of SiO_2, which decreases in quantity, together with diopside. Hercynite is present around 1000°C, whereas hedenbergite appears at 1000°C. The lack of formation of fayalite and hercynite is probably due to the low iron content of the clay, whereas its presence indicates that strongly reducing conditions were obtained (Maniatis et al., 1983).

Table C of Appendix 7 proves the few experiments proposed in the literature concerning reducing firings. As for oxidising firings, the forming and disappearing temperatures of minerals is strongly bound to the composition of the clay used. In this case however, the oxygen fugacity is a second very important parameter to care about. The results in the literature concerning reducing firings have to be used with very much care in other geological areas.

3.4.5.7 Reducing firing of silicate-rich clays

Appendix 7D, quartz, plagioclase, chlorite and illite behave as described for reducing firing in CaO-rich clays. Kaolinite and manganosite respectively disappear below 500°C and 750°C.

In Fe_2O_3-rich clay, hematite disappears below 600°C forming magnetite (Letsch and Noll, 1983), whereas it appears at 800°C in Murad and Wagner (1989).

Magnetite is lost at 900°C; its absence is explained by its poor crystallisation and small particle size in Maniatis et al. (1983). Tephroite (formed from thin clay particles and manganosite), hercynite (crystallising from illite and magnetite), spessartine (replacing quartz grains), fayalite and iron (which presence indicates extremely strong reducing conditions) are respectively formed at 750°C, 850°C, 900°C and around 950°C for both last. Fayalite appears if Fe/Si <50%, whereas iron is formed if the ratio is higher than 50% (Letsch and Noll, 1983).

Around 1100°C, “the quartz grains are surrounded by glass and the small ones appear rounded, indicating their gradual fusion into the glass. No iron oxides are visible. Fayalite and cordierite have not been formed; the failure of this formation may be attributed to the high amount of Al_2O_3 present in this clay, which does not favour the formation of fayalite” (Maniatis et al., 1983).

Table D of Appendix 7 is similar to table C, but moreover, kaolinitic clays have very different belongings from illitic and illitic-montmorillonitic clays. Hence, the results concerning kaolinitic clays should not be used for illitic clays. The results of table D shall also be used with very much care.

3.4.6 Firing temperatures: main results of previous studies on Swiss Neolithic ceramics

Nungässer and Maggetti (1978) studied the ceramics of Burgäschisee (10 km SE of Solothurn) and observed illite and chlorite. Due to the presence of the latter, they suggest a firing temperature between 450°C and 500°C.

Nungässer et al. (1985) studied the ceramics of Twann: 80 ceramics are of the Cortaillod period (3840-

3530 BC) and 20 of the Horgen (3410-3070 BC). The firing temperature is around 400°C to 600°C in a reducing atmosphere.

KILKA (1999 193, 194) described 61 Neolithic to Iron-Age ceramics from Borscht (FL). 8% are fired under 700°C, 76% fired between 700 and 850°C, 13% around 850°C and 3% over 850°C.

SCHUBERT (1984A, 1984B, 1987) studied Neolithic ceramics (late Cortaillod and Horgen cultures) from Zürich Kleiner Hafner and suggests a firing temperature around 700°C to 800°C.

BENGHEZAL (1993, 1994A, 1994B) studied 194 samples from five Swiss late Neolithic sites (Auvernier, Portalban, St. Blaise, Vinelz and Sutz). These ceramics were fired in reducing atmosphere with an oxidising cooling or post-firing. 50% of the ceramics were fired between 500 and 650°C, 44% between 650 and 750°C and 6% around 800°C. The petrographical, mineralogical and chemical analyses demonstrate that thin and coarse ceramics cannot be distinguished and had the same firing temperatures (500°C-650°/750°C). She also studied French sites: in Chalain and Clairvaux the firing temperatures were not higher than 650°C, and around 750-800°C in Barrou and Charavines. DI PIERRO (2002) studied 128 samples from Portalban and St. Blaise (late Neolithic sites); he agrees with the results of BENGHEZAL (1993, 1994A, 1994B) concerning the firing temperatures.

In conclusion, there is three groups of firing temperatures: 450°C-600°C as defined by NUNGÄSSER AND MAGGETTI (1978) and NUNGÄSSER ET AL. (1985); 500°C-750°C defined by BENGHEZAL (1993, 1994A, 1994B) and DI PIERRO (2002) and 700°C-850°C defined by KILKA (1999) and SCHUBERT (1984A, 1984B,1987). These differences are less important than it can be thought: all are low temperatures in regard to Roman firings for example. Moreover, open firings induce a wide variation of temperatures during firing (see figure 3.7).

3.4.7 Discussion

Based on the literature and on experimental firings in oxidising atmosphere, mainly, the firing temperatures of ancient ceramics can only be approached indirectly. As presented here, minerals appear and disappear at known temperatures, governed by thermodynamic rules. Moreover, the results of the firing experiments proposed in the literature should be used with caution because the clays of other sites are normally mineralogically and granulometrically different.

The firing atmosphere of ancient ceramics can be deduced by observing the colour of the sherds (if not contaminated) and assured by the reduction factor FeO / FeOtot (for details, see 6.5.2).

The mineralogical associations analysed by X-ray diffraction, the firing atmosphere and the literature permit to deduce a range of temperature in which the ceramics were fired. Unfortunately, this range is often broad (i.e. 300-500°C of variation) and often does not permit to determine neither the firing structure, nor the firing duration, nor the fuel used.

3.5 CONTAMINATION BY USE AND BURIAL

3.5.1 Introduction

Contamination group various phenomenons that modify archaeological remains during their deposition and/or use. It may strongly affect the composition of these objects. Large variation in the concentration of a component in a group of similar samples (with similar proportions of temper) is a strong indicator for contamination. Mobile elements (such as K and Na) can be leached and carried away, or transported and precipitated into the ceramic. The filling of cavities with Ca- and/or Mg-carbonates is frequent. CaO and P_2O_5 are the more susceptible to change with contamination and should be used with care.

The more stable and reliable chemical elements are SiO_2, Al_2O_3, Fe_2O_3 and TiO_2. At this list, MgO, Na_2O, K_2O, Li, Rb and Cs can be added in the case of CaO-poor clays (BÉARAT AND DUFOURNIER, 1994A).

3.5.2 Secondary montmorillonitisation

The presence of expandable phyllosilicates (smectites) such as montmorillonite or mixed-layer minerals in low-fired ancient sherds is explained as a rehydration during burial of primary smectites, which were partially destroyed during firing (MAGGETTI AND SCHWAB, 1982). Montmorillonite is obviously a secondary mineral, because a mineral containing a smectitic phase looses its water layer below 300°, and all the ceramics were fired higher than 400°C-500°C (more than the lower temperature proposed in the literature for Neolithic firings, Nungässer and Maggetti, 1978; Maggetti, 1979; Nungässer et al., 1985). However, X-Ray diffractograms of Neolithic ceramics frequently show a broad peak between 5 and 10°2θ. Detection by glycolation techniques show a mixed-layer phase containing montmorillonite. This broad peak, which is reduced to a single peak of illite or split into an illite and chlorite basal peak if fired to 200-300°C, is caused by very fine grained clay particles of a mixed layer type (probably chlorite-illite). The disappearance of this peak at 300° shows that these mixed layers were formed during burial (Maggetti, 1982).

Even if montmorillonites are fired to 600°C, they can regain their water interlayers during burial (Nungässer and Maggetti, 1978).

3.5.3 Phosphorus

Phosphorus is the most common element affected by contamination. The bulk P_2O_5 concentration of most of the clays varies between 0.1 and 0.5 wt.% (Koritnig, 1978). Higher phosphorous contents than these values in ceramics have been frequently detected and described (see for example Béarat 1990, 1992; Benghezal, 1990; Dufournier, 1976; Duma, 1972; Freestone et al., 1985; Heimann and Maggetti, 1981; Lemoine and Picon, 1982; Maggetti, 1980, 1982; Morzadec, 1991; Picon, 1976; Walter and Besnus, 1989). Such high values may have different origins.

First, high contents of P_2O_5 can be related to a treatment of the clay before firing; substances rich in phosphorus such as urine or faecal material can increase the plastic behaviour of the clay (Rottländer, 1981-1983; Maggetti, 2001).

Second, the presence of bone fragments as temper may be a cause for high phosphorus contents (Bonzon, 2004b).

These two first cases are not considered as contamination in opposite to the next points.

Third, the daily use of the ceramics was only rarely studied (Béarat, 1990; Béarat and Dufournier, 1994a, 1994b; Duma, 1972; Fabbri et al., 1994). In Béarat and Dufournier (1994a, 1994b), the ceramics are put in contact with milk, wine and urine and their belonging is studied. They show an increase of P_2O_5-content after holding and cooking of phosphorous-rich products such as milk and wine. The phosphorous is adsorbed on pore walls or substituted into clay minerals. At the end of the experiments, the proportions of P_2O_5, CaO, MgO, K_2O, MnO, Na_2O and loss on ignition (LOI) showed significant variations. They conclude that the fixation of P_2O_5 is better if the clay is CaO-rich, if the temperature of the environment is high, if the time of contact is long, if the ceramic is used during a long time, and if the ceramics are fired around 600°C to 800°C (Duma, 1972; Béarat and Dufournier, 1994b).

Fourth, Duma (1972) put into relation the high content of phosphorus with the use of the vessel as a funeral urn, implying after a time the dissolution of bone and the precipitation of the phosphorus into the ceramic.

Fifth, the enrichment in phosphorus is frequently related to the burial environment (Béarat, 1990; Freestone et al., 1985; Lemoine and Picon, 1982; Morzadec, 1991). The leaching of certain elements is another mechanism to increase the concentration of the remaining elements. Heimann and Maggetti (1981) studied calcareous ceramics after firing and burial. They evidenced possible modifications in the concentrations of the elements Ca, Fe, Mn, Na and K during burial. Lemoine and Picon (1982) experimentally showed that high phosphorous values in their sherds are directly correlated with the leaching of mobile elements such as K, Na, Si and Mg. Hence, a negative correlation between mobile elements and P may indicate chemical modifications due to leaching. Maggetti (1994) and Collomb and Maggetti (1996) explained the post-depositional phenomena as follows: “Lightly fired pottery consists of a large proportion of decomposed clay minerals, of which the amorphous breakdown products are highly reactive. In the ground they react relatively quickly to outside influences and following reaction processes may be listed: extraction of sherd material (dissolution phenomena); deposition of minerals in pores and voids (cementation phenomena); decomposition of existing primary or firing minerals to secondary minerals” (Maggetti, 1994, 31).

3.5.4 Others

Diagenetic changes during burial are an especially serious problem for low-temperature ceramics. Potteries fired below 700°C are generally very porous, allowing easy access for outside solutions. The porosity is due to the manufacturing and firing process, the chemistry and mineralogy of the starting material, and the loss of outburning substances. Dissolution and neocristallisation will take place: deposition in pore spaces and replacement of primary minerals by secondary carbonates (calcite; MAGGETTI AND KAHR, 1981), hydrates (hydration of hematite to goethite; ENRIQUEZ ET AL., 1979), oxides, hydrosilicates (zeolites, clay minerals), and sulphates (gypsum; COURTOIS, 1976) (MAGGETTI, 1982; HERZ AND GARRISON, 1998).

Secondary calcite results either from a migration of carbonatic solutions from the ground during burial and deposits into porosity or, if the firing process is too rapid or the maximum temperature too low, the new formed lime has no time to react with the silicates and re-carbonates during the cooling or the burial (MAGGETTI, 1982; ECHALLIER, 1984). This can induce the lime-popping phenomenon described before.

Contamination with barium is less frequent (PICON, 1985; PICON AND LE MIÈRE, 1987; BENGHEZAL, 1990).

Chlorides sometimes alter deeply the ceramics that become very light and non-resistant. Variations of temperature, such as frost, also modify the sherds. Hence, sometimes, only the microscopic analysis permits to distinguish between altered and fresh sherds (CAMPS, 1990).

3.5.5 Discussion

Contamination implies severe problems when analysing ceramics. A chemical analysis can be totally modified because a sample was contaminated. In such cases, mixing “clean” and contaminated sherds leads to wrong grouping, and, hence, wrong geological attributions. Hence, the sherds have to be well described before being analysed. A piece of sherd is always kept until the end of the study to assure the observations if necessary.

4 - GENERALITIES CONCERNING THIS ARCHAEOMETRICAL STUDY

4.1 SAMPLING STRATEGY

4.1.1 Non-ceramic material from Arbon Bleiche 3

1 loom weight (of 23 discovered) and 11 cob fragments were studied. The cobs were analysed in order to identify the raw material used to build the house walls and to compare it with the clay used for pottery.

4.1.2 Clays and rocks

12 clays and around 60 rocks were collected in the region of Arbon to determine the quality and the mineralogy and chemistry of the resources (clay and temper) that were available in the Neolithic.

The local clays were collected within a 2.5 kilometres wide perimeter around the site (Fig. 2.11). This 2.5 km perimeter was chosen because it included the Rhine morainic deposits of the vicinity of Arbon and the molassic deposits present in the hills of the neighbourhood, which are the main geological resources of the surroundings of Arbon Bleiche 3.

As visible on Fig. 2.11, JB303, JB304 and JB305 were collected in the Würm moraines whereas JB306 and JB307 were collected in the Molasse. JB300, JB301, JB302, JB308 and JB309 seem to have been collected in the Quaternary alluviums. However, JB300, JB301 and JB302 were sampled at the level of the water of the small stream, i.e. under about 3 meters alluviums, in the Würm moraines. JB308 and JB309 were sampled when a little dam reservoir was being digged and the deep sediments deposited on its borders; geologically, these sediments correspond to molassic deposits. Even if JB310 seems to come from the Würm moraines on Fig. 2.11, a little molassic deposit was observed in this place and the sample came from it. Hence, even if Fig. 2.11 does not show precisely what the sampled clays are, JB300 – JB305 were collected in the Würm moraines whereas JB306 – JB310 were sampled in the Molasse beds.

4.1.3 Ceramics from Arbon Bleiche 3

At least one sherd, and frequently three sherds were taken from every studied pottery. Among the about 3000 vessels (DE CAPITANI 2002, 139) 153 potteries were analysed (Appendix 1), at different dates, in collaboration with A. de Capitani:

60 sherds of Pfyn / Horgen pots of 352 (17%). This sampling of pots was sufficient, because the results were repetitive. Hence, 15 Pfyn / Horgen pots first selected were not analysed (JB156, JB161, JB168, JB170, JB176, JB184, JB191 to JB199).

93 special forms (of 135, thus 69%). This sampling was maximised because the results were not repetitive; the other special forms could not be analysed, since it was not possible to destroy these unique potteries by sampling. Two undetermined special forms were only partially analysed because the sherds were too small (JB172, JB188).

10 spindle whorls (of more than 400 found in the excavation).

4.1.4 Ceramics from the western Carpathian Basin

14 ceramic sherds from the western Carpathian Basin were investigated; they came from Austria (site Mödling "Jennyberg", 5 samples); Slovakia (Zlkovce, 5 samples) and the Czech Republic (Náměšt na Hané, 4 samples). The sherds were chosen by de Capitani and are typical Boleráz forms. The archaeological description of these samples is found in DE CAPITANI (2002, 214). These samples come from the region where Boleráz' typology was first defined by the archaeologists. Hence, they have to be correlated with the special forms of Boleráz-pottery from Arbon Bleiche 3.

4.2 METHODOLOGY

4.2.1 Ceramics and non-ceramic material

4.2.1.1 Thin sections

First, a picture of every sherd was taken, before the latter being sawed, permitting to prepare a thin section. All the sherds were cut perpendicular to the lip and parallel to the vertical axis of the pottery. In the case of body fragments without clear orientation, the section was cut perpendicular to the long axis of the sherd. The majority of the thin sections were then comparable. One thin section was made from every archaeological object by J.-P. Bourqui.

4.2.1.2 Qualitative study of the thin sections

Thin sections were qualitatively studied under a Leitz Laborlux polarising light microscope to define petrographical groups by observing the nature of the matrix, of the non plastic inclusions and their structure. The study of the thin sections was carried out without knowing to which typological group the studied sample belongs.

BISHOP ET AL. (1982), quoted in BARNETT (1990) expresses that a "successful petrographical analysis of pottery to determine production location requires that ceramic assemblage be made from clays that are found in an area with diverse geologic resources, and contain a significant amount of coarse inclusions in the paste". The ceramics from Arbon Bleiche 3 fulfils both of these criteria: the ceramics have typically coarse pastes, and contain detrital and added particles up to 1 cm Ø that are geographically unique, derived from granite, gabbro, chert and rhyolite of the eastern Alps and deposited in the Rhine Basin.

In this work, the qualitative observation of one thin section pro sample is assumed to be representative of individual ceramics. Petrographical analysis is used because it can classify individual non-plastic grains of clay and pottery samples, even though the categories are descriptive. These classifications include mineralogical and petrographical compositions, size and angularity of the grains and are not significantly affected by chemical and mineralogical changes that can occur during firing and burial. Petrographical analysis can also identify the effects of modification of the clay by ancient potters such as tempering (MAGGETTI, 1982, 1994; HOWARD, 1982; RYE, 1981; BARNETT, 1991).

The mineralogical taxonomy established for angularity by PETTIJOHN (1957) was used to describe the grains (angular, sub-angular, sub-rounded, rounded). As proposed in BARNETT (1991), angularity and size ranges for each mineralogical group are first established for the clay samples. These are then compared on an individual basis to vessel samples. Once added components are identified, they are distributed in various petrographical groups.

The problem of provenance of the sherds bound to their temper content observed in thin section was studied as described in MAGGETTI (1994, 26).

The forming technique of all the ceramics was studied on the thin sections and on the cut sections of the sherds.

4.2.1.3 Quantitative study of the thin sections

The quantitative measurements of the temper (vol.%) were done on all the samples with the help of the "Spots before the eyes" method of MATTHEW (1991). Another quantitative analysis on 20 thin sections was made with a Swift Automatic Point Counter (Swift and Son, London). This latter is fixed on the microscope, permitting a 0.33 mm movement of the thin section for each impulse. The mineral on the intersection of the reticules was taken into account. The number of counted points varied around 1000 points. The integrated surface was about 108.5 mm2. We followed the principles given in FREESTONE (1991, 403, 405) to decide how to point-count the thin sections:

"The accuracy and precision of a point count measurement depends on a number of factors, in particular the number of points counted (the more the better), the spacing between the points of the grid (ideally greater than the mean diameter of the particles being measured) and the proportion of the pace being measured (measurements of an abundant component will be relatively more precise than those of a minor component). These considerations indicate that if a component is actually present as 5% of the inclusions, then to state with 95% confidence that its concentration lies in the range 2.5% - 7.5% requires a total of 300 grains to be counted (GALEHOUSE, 1971). Thus, for a ceramic with 20% sand inclusions, 1500 point would have to be recorded to obtain such a level of precision. For components present in lower proportions, the requirements of the measurement are even more demanding. A point of contention is that of deciding which tapes of grains are to be measured; some authors advocate measurement of all non-plastic grains in a section whereas others exclude certain categories. The significance of measurements on very fine grains is unclear and many analysts do not measure below 20 – 30 µm".

SCHUBERT (1986, 194) expresses some problems related on thin sections measurements: The point-counting results do not mean, however, "that the sherd (and the slice thereof) is really representative of the whole vessel of coarse ware pottery".

THUESEN ET AL. (1989, 277) made a blind test to evaluate visual sorting of thin sections (such as the "Spots before the eyes" method of MATTHEW, 1991) by three persons. "The test showed a successful score between 78 and 94% for three persons, the actual fail sorting less than 5% in each case. Hence, the method is suitable for a general fabric classification".

This first approximation was then correlated with point-counting measurements (Point-counter Swift, London) permitting to assess the percentage of temper, of matrix and of porosity in the thin sections (MIDDLETON ET AL., 1985). As the differences between these two methods were less than 10 vol.%, the "Spots before the eyes" method was validated and used for the rest of the thin sections (validation method as defined in NUNGÄSSER ET AL.,1985).

20 thin sections were analysed on a coarse tempered pot (BONZON-FREUDIGER, 2005) in order to test the representativity of the sampling and we have to admit that the size of the sections is too small to get representative results from a single sample. In such coarse ceramics, 4 thin sections are necessary to have a good estimation of the percentage of temper used. Hence, the results of the quantitative measurements of the temper described before have to be taken as useful information, but not at all as a precise quantity.

4.2.1.4 *X-ray diffraction*

X-ray diffraction (XRD) was carried out on every sample, except those of the western Carpathian Basin, to identify mineralogical groups. After the removal of the possibly contaminated external and internal surfaces with a diamond saw, the samples were powered in a tungsten carbide mill. About 10 to 50 g of the coarse ceramics were ground. About 10 g of the fine ceramics were used when possible; if not, the minimum sample weight was 3 g. X-ray diffraction was carried out using a Philips PW 1800 diffractometer (CuKα, 2-65 °2θ, PC-APD and X-Pert software).

4.2.1.5 *X-ray fluorescence*

On every sample geochemical analyses (XRF) were also made. The same powder was used as for XRD. Analyses were performed by Prof. G. Galetti on glassy tablets for major and trace elements. Those tablets were prepared by O. Marbacher with about 3 g powder dried for minimum 6 hours at 110°C and charred for one hour at 1000°C. The loss of ignition (LOI) was calculated from the weight of each sample after each step. 0.700 g of charred powder was mixed with 0.350 g of lithium fluoride and 6.650 g of lithium tetraborate. This mixture was put into a platinum crucible and melt at 1150°C for 10 min (Philips Perl X-2). Major elements (Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P) and trace elements (Ba, Cr, Cu, Nb, Ni, Pb, Rb, Sr, V, Y, Zn, Zr) were analysed using X-ray fluorescence (Philips PW 2400). Calibration of major and trace elements were made on 59 standards. For analytical reproducibility and detection limits, see GALETTI (1994) and GIACOMINI (2001).

23 major elements (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, FeO, MnO, MgO, CaO, Na_2O, K_2O and P_2O_5 expressed in weight percents) and traces (Ba, Cr, Cu, Nb, Ni, Pb, Rb, Sr, V, Y, Zn and Zr expressed in parts per million) were analysed for each sample in the laboratory of mineralogy. All these elements except FeO were used for the statistical treatment, for each analysed sample. FeO was not used, because it was not measured for every sample and because it depends on the firing atmosphere.

4.2.1.6 Statistics

The high number of X-ray fluorescence data made a statistical treatment of the results possible. Only for the ceramics, 163 samples were analysed and the results for each sample are presented as 23 chemical elements (major elements and traces). These elements are considered as statistical variables. The statistical analyses of the chemical data were made with the program SPSS, version 11.0. The statistical methodology used is proposed by BAXTER (1992; 1994A; 1994B; 1995; 1999; 2001A; 2001B; 2003); BOCQUET (1995); LE MAITRE (1982) and PICON (1984; 1992).

The presence of bone temper lowers the SiO_2 and Na_2O bulk concentrations relative to the other ceramics. In order to eliminate the influence of the bone temper and to compare the silicate part of the bone-tempered pottery with the other samples, the analyses were recalculated. The phosphate content was reduced to the average concentration of all other ceramics (mean: 0.23 wt.%) using a ratio for CaO / P_2O_5 of 1.33, a value determined by microprobe analyses of the apatite, the main constituent of the bone (BONZON, 2004B).

Before performing the analysis, all the chemical elements are standardized in order to put the major elements (in wt.%) and the trace elements (in ppm) at the same scale. The standardisation transforms the variables (chemical elements) to centred reduced variables. No log transformation was used. The standardised values were used for all the methods described further.

The similarity coefficient is then calculated: “Groups of neighbouring points in space are called clusters and are thought to represent the composition of a certain place. A similarity coefficient, e.g. the simple mean interpoint Euclidian distance between two points in this hyperspace is chosen. The nearer the points in space, the more similar they are in composition” (MOMMSEN ET AL., 1988, 48). The similarity coefficient is calculated for each pair of samples using average linkage between groups. When all the samples are clustered, the results are presented on a dendrogram that shows at which level the samples clustered together. The later two groups of samples are fused, the more dissimilar they are.

Principal component analysis (PCA) is a mathematical transformation from a matrix of n data and m variables to a new matrix of m new variables obtained by linear combination of the first variables. This method permits to reveal the existing structure between the variables and shows the proximity of the samples, hence, it is possible to discern groups in the multivariate dimensions. PCA permits to reduce the number of variables keeping the maximum of variance. PCA was used in this work to visualise the distribution of the samples as a function of the 22 chemical variables, in order to recognise if different chemical groups can be separated.

Discriminant analysis (DA) is a statistical treatment in which discriminant factors are calculated in order to maximise the chemical differences of pre-established groups in the data set. If the DA finds a significant distinction between groups, these are used as reference to classify the archaeological samples of uncertain source. DA is frequently used to correlate ceramics from one site with groups of defined workshops, which permit to attribute an origin for a ceramic.

The Mahalanobis distance is often used in archaeometry to observe the appertaining of ceramics to a predefined group. This distance is a measure of how much the value of a variable of one sample differs from the average of all samples for a specific reference group. The greater the distance, the lower the probability for one sample to belong to a group defined by other samples. This method is one of the most sensitive, and permits to detect very small compositional differences between groups (PICON AND LE MIÈRE, 1987). SCHMID ET AL. (1999) observed that the chemical homogeneity of samples is demonstrated by the normal distribution of the samples in the histogram of Mahalanobis distances. WOLF (1999) confirms the results of SCHMITT (1998) that the Mahalanobis distance of a given sample seems to depend only little on the proportion of non-plastic inclusions.

4.2.1.7 FeO

FeO content was determined on samples JB001 to JB154 with the dipiridil method (LANGE AND VEJDELEK, 1980; BENGHEZAL, 1994A): 0.05 g of dry powder was put into a 2 ml acid solution (HF: H_2SO_4 1:1). The solution was evaporated in a boiling water bath for 45 min. The residue was added to 50 ml buffer solution, then distilled water was added up to 500 ml. FeO was analysed with a Philips Pye Unicam PU 8650 (528 nm spectrophotometer). For standard preparation, see ZANCO (1999, 12). (Relative error for FeO: 0.04%, detection limit: 0.3 wt.%).

4.2.1.8 CO_2 and H_2O

CO_2 and H_2O were analysed respectively between

600°-1000°C and 20°-1000°C with a multiphase carbon determinator (Leco RC 412). The detection time was of 300 sec. (relative error for C: 3.5%, detection limit: 0.08 wt.%; relative error for H_2O: 12%, detection limit: 0.1 wt.%). CO_2 and H_2O were only measured on JB001 to JB154. These determinations were not performed on the other samples because the results were repeating themselves and the range of variation for quite all the ceramics was determined.

4.2.1.9 Scanning electron microscope

Scanning electron microscope was used to take secondary electron images of bone fragments used as temper in some ceramics. The investigations were made on polished sections covered with carbon. A JEOL JSM-840A LGS microscope was used, operated at 15 kV.

4.2.1.10 Electron microprobe

Electron microprobe was used to determine the bone temper. Analyses were performed at the Institute of Geology of the University of Bern with a Cameca SX50 instrument (15 kV, 20 nA, about 1µm electron beam diameter). Ca, P, F and Cl were measured on about 100 points on JB020 and JB069 bone fragments. To convert percent counts into oxides, the PAP program of Cameca was used.

4.2.1.11 Nota Bene

All these methods were used as defined in Di Pierro (2002), Giacomini (2001), Picouet (1997) and Zanco (1999). The preparations and measurements were all made at the Mineralogy and Petrography Laboratory of the University of Fribourg, except those of the microprobe.

4.2.2 Clays

4.2.2.1 Briquettes and thin sections

In Fribourg, 8.1 x 4.1 x 1.2 cm briquettes of local clays were made and fired in an electric oven in oxidising atmosphere between 500°C and 1000°C. The elevation of temperature was of 100°C per hour. Temperatures were held constant for one hour at peak temperature to let new minerals form; then the oven cooled naturally down. Thin sections of every briquette were studied with a petrographical microscope. The evolution of the mineralogy during the experiments was identified by X-ray diffraction.

4.2.2.2 Granulometry

Laser granulometry was made on a Fritsch Particle Sizer Analysette 22 at the Institute of Mineralogy and Petrography of the University of Lausanne, under the direction of Dr. P. Thélin.

4.2.2.3 X-ray diffraction

X-ray diffraction was made on each clay as described higher. Then, the argillaceous minerals were studied in two different granulometric fractions: < 2 µm and 2-16 µm. The clays collected in the neighbourhood of Arbon were mixed with demineralised water and were decarbonated. The needed fraction was separated by decantation and centrifugation. Each fraction was put on three different sections: one was not treated; one was glycolated during one night, which makes the clays swell, and the last one was heated at 550°C for one hour. The sections were analysed on a Philips Rigaku diffractometer (CuKα, 40 kV, 30 mA, 1-35 °2θ, NEWMOD software). This latter measurement was done at the Institute of Mineralogy and Petrography of the University of Lausanne, under the direction of Dr. P. Thélin.

4.2.2.4 X-ray fluorescence

X-ray fluorescence was made on each clay as described higher.

4.3 TERMINOLOGY

The archaeological description of all samples (even the sherds from the western Carpathian Basin), their attribution to the typological groups together with the geographical coordinates at which the sherds were found in the excavation are described in de Capitani (2002) and in Appendix 1.

4.3.1 Non-ceramic material

In Arbon Bleiche 3, 11 samples of cob fragments and one loom weight were not voluntarily fired before being used, and were therefore considered as non-ceramic material.

4.3.2 Ceramics and potteries

In contrast, the ceramics are all the samples fired. Only the ceramic containers or vessels are named potteries. In Arbon Bleiche 3, the group is composed of 163 sherds of potteries and spindle whorls. From a macroscopic point of view, some Pfyn / Horgen pots are covered with barbotine. This latter is defined as a mixture of clay, temper and water put together on the outer surface of the pots (Fig. 4.1).

4.3.3 Matrix, non-plastic or natural inclusions and temper

The thin sections of Arbon-Bleiche 3 and those of the western Carpathian Basin were studied as shown on Fig. 4.2 with the following terminology: the samples are composed of a matrix (fired fine natural clay material) and non-plastic inclusions. These latter can come from the natural clay, they are then natural inclusions, or can be added by the potter and are named temper.

4.3.3.1 Matrix typology

Two types of matrix are observed: Silicate-rich matrix: no optically visible grains of carbonate in the matrix, which is constituted mostly of silicates (argillaceous minerals, quartz, feldspars).

Carbonate-rich matrix: presence of micro-grains of carbonate in the matrix.

The proportion of matrix and natural inclusions defines two categories (modified from Nungässer et al., 1985; Maggetti, 1982 and Benghezal, 1994a):
Natural inclusions: < 5 vol.%: inclusion-poor matrix
Natural inclusions: > 5 vol.%: inclusion-rich matrix

The matrix can contain natural inclusions as clay pellets and ARF (argillaceous rock fragments) (Whitbread, 1986). The differentiation between grog and argillaceous rock fragment (ARFs) followed the work of Whitbread (1986) and Cuomo di Caprio and Vaughan (1993). Iron oxide nodules are also natural inclusions.

Figure 4.1: *Barbotine covering a Pfyn/Horgen pot. (*de Capitani, 2002, *fig. 217; picture AATG, D. Steiner).*

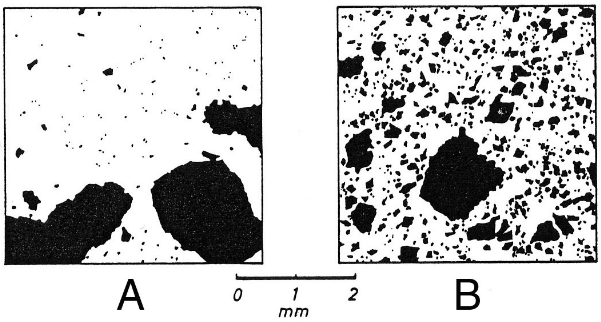


Figure 4.3: *A: Hiatal distribution of inclusions in a thin section: large grains are temper; B: serial distribution of the inclusions, which are possibly all natural (*Nungässer and Maggetti, 1978*).*

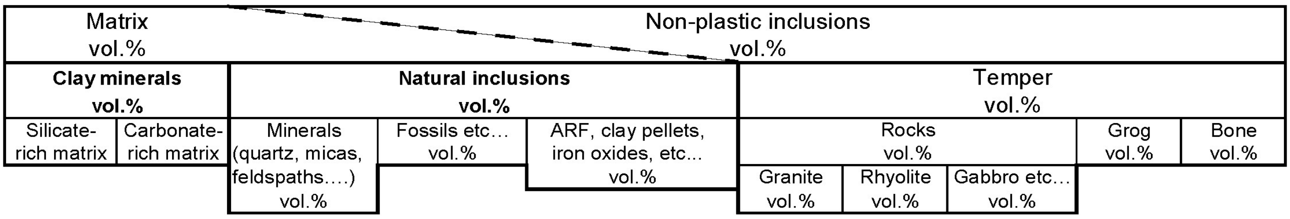


Figure 4.2: *What has to be described in a petrographical thin section*

4.3.3.2 *Temper typology*

The temper is sometimes hard to separate from the natural inclusions. MAGGETTI (1982, 130-131) noticed five principal criteria to identify temper:
"(1) Calcite fragments. The presence of fresh rhomboedric calcite crush fragments with angular, sharp outlines is possible only if the ancient potters used crushed calcite; naturally present calcite would be very fine grained owing to the splitting behaviour of calcite and would also have rounded edges because of transport by water during the deposition of the clay.
(2) Fired clay. Fired clay, too, is an indication of artificially added temper and can be recognized – with respect to the embedding sherd – by differing colour, mineralogical composition, or texture (MAGGETTI, 1979)
(3) Organic material. Addition of straw, etc., was also frequently used by ancient potters and can be identified by the presence of abnormally high and coarse porosity and/or relicts of organic matter, often as black carbonaceous substance.
(4) Shape of the fragments. Angular fragments with sharp edges are often an indication that crushed material has been used (MARRO, 1978)". However, some alpine clay can also have angular quartz grains as natural inclusions, due to the short distance of transport that does not allow a rounding of the grains.
(5) "Granulometry. The presence of two populations of grain sizes (hiatal structure) is also an indication that coarser particles were added artificially (NUNGÄSSER AND MAGGETTI, 1978)". If the distribution is hiatal (Fig. 4.3A), the coarse grains are added temper and if it is serial (Fig. 4.3B), all grains are natural inclusions (NUNGÄSSER AND MAGGETTI, 1978). KILKA (1987, 1992) and KILKA AND GALETTI (1994) measure the size of grains and show the result in a histogram.

The local clays from Arbon Bleiche 3 have natural inclusions with a diameter normally below 0.5 mm, and rarely bigger than 1 mm. For that reason, we have defined the temper being all the grains above 0.5 mm of diameter in assumed locally made ceramics.

The temper is separated into three groups: fine temper is particles from 0.5 to 1 mm of diameter; medium temper, between 1 and 3 mm; and coarse temper, bigger than 3 mm. These classes are also used in DE CAPITANI (2002).

4.3.4 Reference groups

Several reference groups for Neolithic ceramics were defined in the Institute of Mineralogy and Petrography of Fribourg. MAGGETTI & GALETTI (1981) wrote: "A reference group is defined by a number of physical and chemical analyses statistically sufficient from an archaeological material obviously local. It can be a well defined ceramic typology (terra sigillata), a particular workshop (its own production), many workshops of a same region, or a group of sherds coming from one archaeological excavation, without a known production workshop." BÉARAT (1992) precised that "A reference group establishes when a ceramic whole is mineralogically and chemically homogeneous and refers to a distinct clay or to a place of production."

4.4 REPRESENTATIVENESS OF THE DATA

BONZON-FREUDIGER (2005) studied 20 sherds of a large Neolithic Pfyn / Horgen pot (see Appendix 12). She proves that the quantitative results extracted from X-ray diffraction and X-ray fluorescence analyses are representative for the whole ceramic, instead of the observation of one thin section per pottery.

After SCHNEIDER (1978), FREESTONE (1999, 114) says that "where groups are established on the basis of statistical analysis of quantitative [chemical] data, then the minimum size of a group to ensure that it is valid may well be 10 or more". In this work, the main groups contain enough ceramics to be representative. The samples of small petrographical groups (AII, AIII, AVI, BI, BII, BIII, CI, CII) are considered as exceptions. The use of statistics on archaeometrical studies is frequent, because the element concentration values of each sherd gives indications on the raw materials used to manufacture the ceramics. "Sherds with similar composition are thought to be produced by the same "recipe" in a specific pottery workshop using a clay bed in its neighbourhood. The composition data of pottery therefore allow provenance studies." (MOMMSEN ET AL., 1988, 47). Hence, sherds produced in different geological regions should show distinct chemistry. Only some of the elements can partly overlap. As specified in PICON (1992, 11), chemical resemblances in clay exploitation sites from different geological context only constitute a minor risk.

5 - ARCHAEOMETRICAL RESULTS CONCERNING THE NON-CERAMIC MATERIAL: THE 12 SAMPLES OF LOOM WEIGHT AND COB FRAGMENTS FROM ARBON BLEICHE 3

5.1 MACROSCOPIC DESCRIPTION

The analysed one loom weight and 11 cob fragments consist of inclusion-rich clay made of a homogeneous carbonate-rich matrix, as revealed by the HCl reaction. All the samples are beige. Only on their external surfaces black marks are present, probably remains of the burning of the village at the end of the settlement phase.

5.2 PETROGRAPHICAL STUDY

All samples (loom weight, tempered and cob fragments, not tempered) entirely form the petrographical group CIII. This group is composed of an inclusion-rich and carbonate-rich matrix (Table 5.1, Appendix 3).

The non-plastic inclusions in the samples are of various sizes (<0.01–0.5 mm), various proportions (10-50 vol.%) and of various shapes (small ones: sub-rounded, big ones: sub-angular to angular). They are pieces of amphibolite, calcite, granite, or amphiboles. The loom weight (JB121) is tempered with organic material (straw, grass, hair, etc.) in opposition with the cob fragments, which are not tempered with such material (Fig. 5.1A). The vegetal fragments appear as carbonised black cells network. Textile and vegetal elements, such as straw, grass, hairs or ropes let long and thin open traces resulting from their charring (COURTOIS, 1976).

JB122 and JB123 show banded homogenous areas containing more (40 vol.%, 0.02 – 0.5 mm, angular) or less (2 vol.%, 0.02 – 0.1 mm, rounded) quartz grains as natural inclusions. JB122 contains a few broken shells (~2 vol.%). JB124, JB130 and JB132 show one fragment of sub-angular to angular bone (respectively 0.5 mm, 0.1 mm and 0.25 mm long).

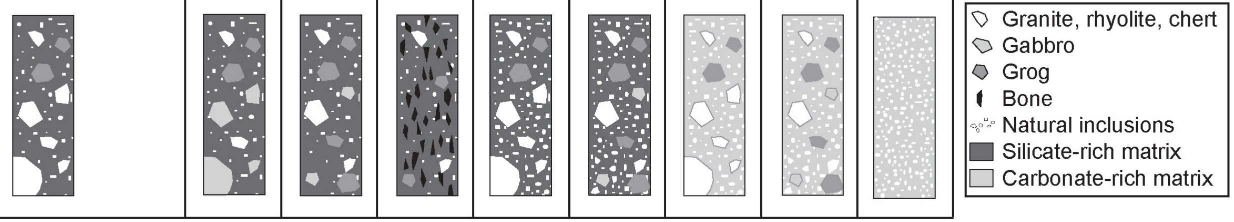
5.3 MINERALOGICAL STUDY

The organic matter, present as temper in the loom weight, is still visible on thin section (Fig. 5.1A) and not replaced by a hole, as it would be after firing. The mineralogy of the cobs cannot be distinguished from that of the analysed actual calcareous clays of the surroundings of Arbon. Apart from the minerals often present in clays (montmorillonite, kaolinite…), chlorite and calcite are still present, which tend to prove an absence of firing before the use of the cobs and the loom weight.

5.4 FIRING?

All 12 samples contain illite, quartz, plagioclases and potassic feldspars, but the proportion of calcite is higher or equal to the proportion of quartz (Appendix 2). They form one mineralogical group because of this high content of calcite. All these minerals can be present in a non-fired sample, hence this fact, together with the presence of non-fired organic matter described before, leads to an absence of firing during the manufacturing of this group of non-ceramic material.

Typological groups (de Capitani, 2002)	Inclusion-poor silicate-rich matrix						Inclusion-rich silicate-rich matrix		Inclusion-rich carbonate-rich matrix				
	AI	**AII**	**AIII**	**AIV**	**AV**	**AVI**	**BI**	**BII**	**CI**	**CII**	**CIII**	**Sum**	**Sum**
Pots Pfyn / Horgen	39	4		6	6		1		4			60	37%
SF Pfyn	2		1									3	2%
SF Bayern	6				6					1		13	8%
SF Boleráz	4			2	17	3		3				29	18%
USF	25			3	17	1	1		1			48	29%
Spindle whorls	7				3							10	6%
Cob fragments and Loom weight											12	-----	-----
Sum	83	4	1	11	49	4	2	3	5	1	-----	163	100%
Sum	51%	2%	1%	7%	30%	2%	1%	2%	3%	1%	-----	100%	



Petrographical groups (thin section sketches)

SF: Special Forms, USF: Undetermined Special Forms; AI: mostly tempered with granite, AII: mostly tempered with rhyolite, AIII: mostly tempered with chert, AIV: mostly tempered with gabbro, AV: mostly tempered with grog, AVI: mostly tempered with bone; BI: mostly tempered with granite, BII: mostly tempered with grog; CI: mostly tempered with granite, CII: mostly tempered with grog, CIII: tempered with organic material (loom weight), without temper (cob fragments).

Table 5.1: *Relations between typological and petrographical groups for every studied sherd.*

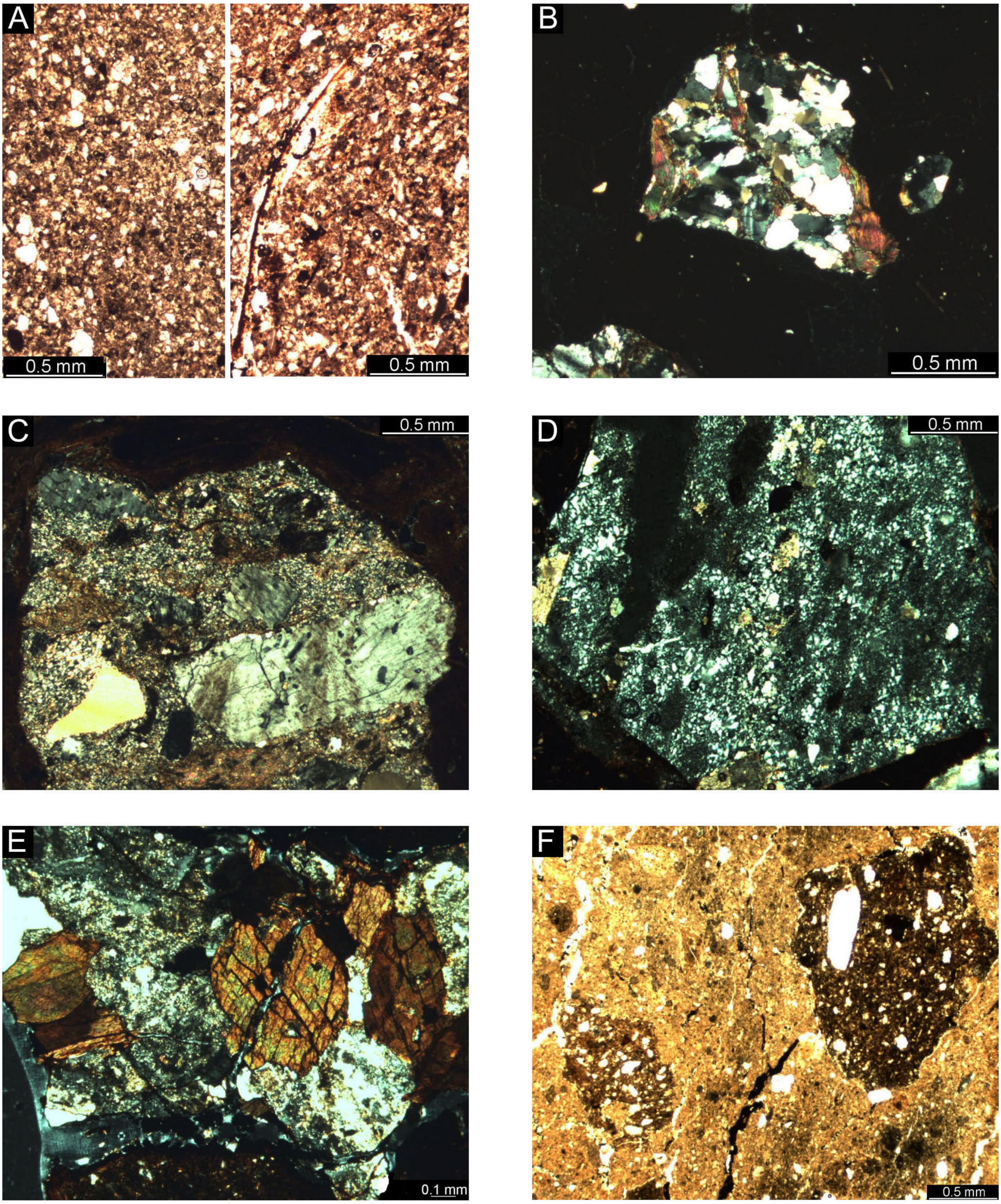


Figure 5.1 (part 1): *Pictures of thin sections. A: Petrographical group CIII: Inclusion-rich and carbonate-rich matrix, not tempered; (left): JB124, cob fragment, PL; (right): JB121, loom weight, tempered with organic material still present, PL. B: Petrographical group AI: Inclusion-poor and silicate-rich matrix mainly tempered with granite, JB003, CP (Crossed Polars). C: Petrographical group AII: Inclusion-poor and silicate-rich matrix mainly tempered with rhyolite, JB085C, CP. D: Petrographical group AIII: Inclusion-poor and silicate-rich matrix mainly tempered with chert, JB007, CP. E: Petrographical group AIV: Inclusion-poor and silicate-rich matrix mainly tempered with gabbro, JB049, CP. F: Petrographical group AV: Inclusion-poor and silicate-rich matrix mainly tempered with grog, JB004, PL (Plain Light).*

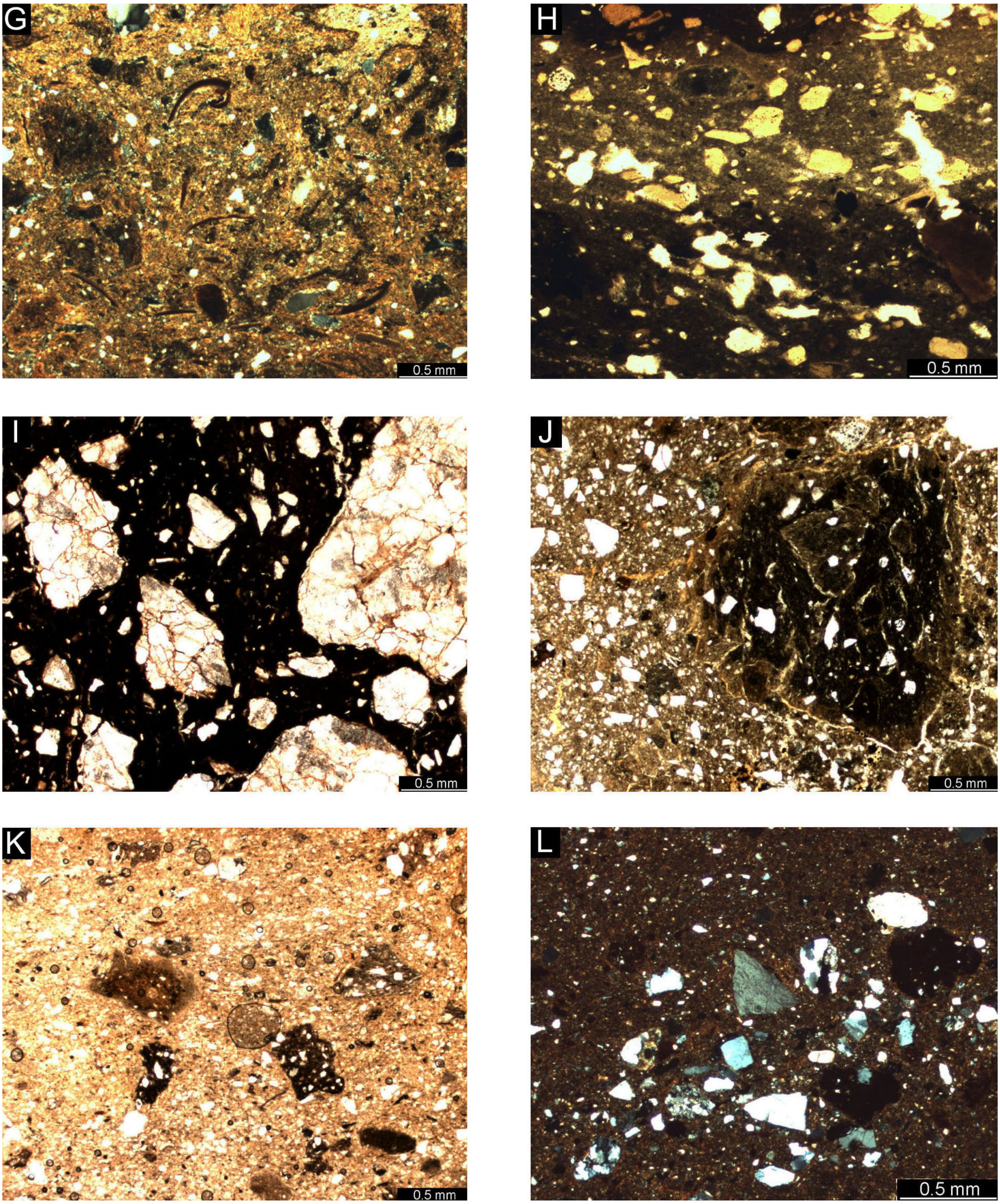


Figure 5.1 (part 2): *Pictures of thin sections. G: Petrographical group AV: Inclusion-poor and silicate-rich matrix mainly tempered with grog, JB037: contains shell fragments (curved), PL.H: Petrographical group AVI: Inclusion-poor and silicate-rich matrix mainly tempered with bone, JB069, PL. I: Petrographical group BI: Inclusion-rich and silicate-rich matrix mainly tempered with granite, JB064, PL. J: Petrographical group BII: Inclusion-rich and silicate-rich matrix mainly tempered with grog, JB175, PL. K: Petrographical groups CI and CII: Inclusion-rich and carbonate-rich matrix mainly tempered with granite (CI) or grog (CII); here, CII is shown, JB073, PL. L: Inclusion-poor silicate-rich matrix of a clay from the surroundings of Arbon (JB301, CP).*

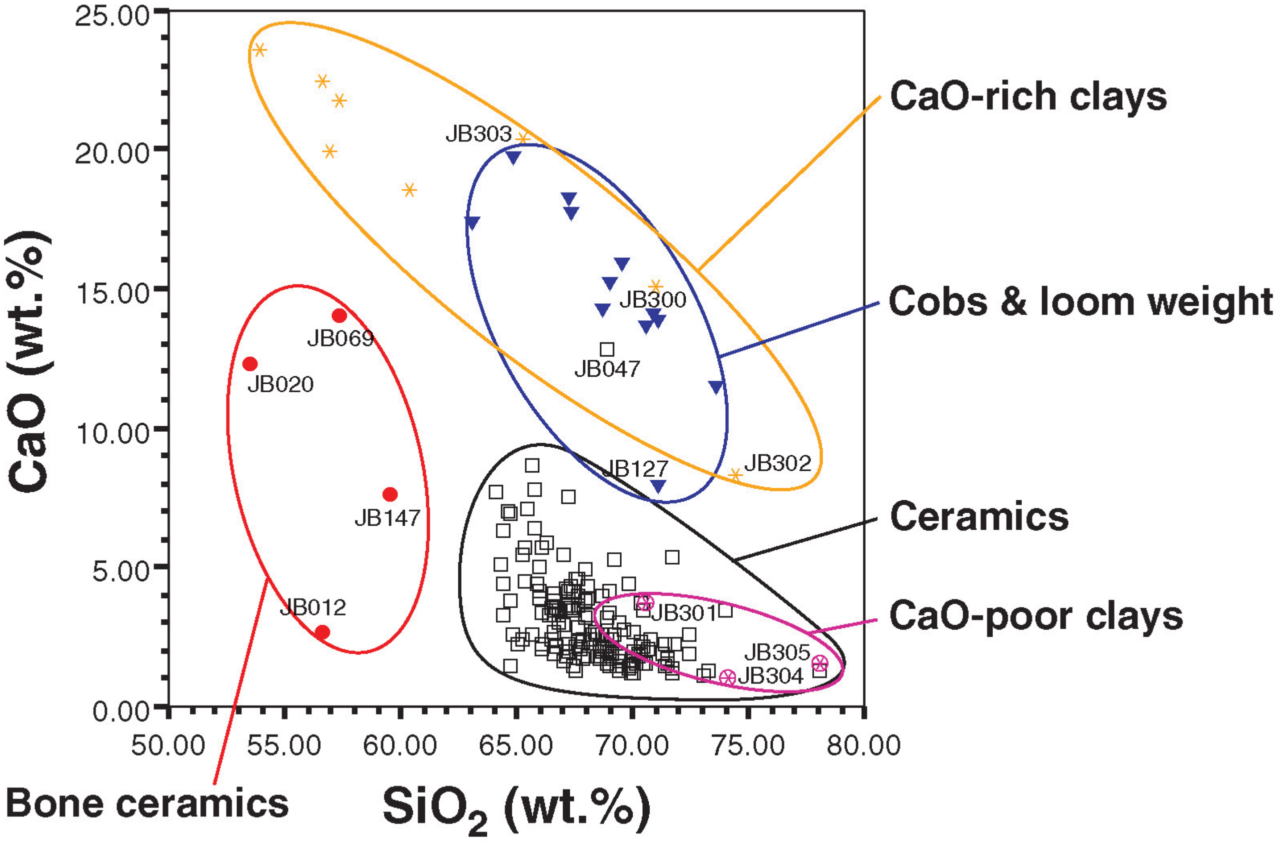


Figure 5.2: *The major chemical groups of Arbon Bleiche 3 (AB3): ceramics, bone tempered ceramics, cob fragments and loom weight, local clays.*

5.5 CHEMICAL DESCRIPTION

On Fig. 5.2, the major groups of Arbon Bleiche 3 (ceramics without bone temper, cob fragments and loom weight, ceramics tempered with bone, local clays) are presented in a CaO vs. SiO_2 (wt.%) concentration graph. This figure shows a good separation between the cob fragments and the loom weight on the one hand and the ceramics from Arbon Bleiche 3 on the other hand. Only one cob sample, JB127, consisted of a less carbonate-rich clay and plots near the ceramics. For all cob fragments, the SiO_2-content is in the range of the ceramics.

Appendix 9A shows the chemical variations of the cob fragments and the loom weight. Compared to the ceramics from Arbon Bleiche 3 (Appendix 9B), almost all the chemical elements have lower minimum and lower maximum values (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, FeO, K_2O, Ba, Cu, Ni, Pb, Rb, V and Zn). Only CaO, Sr and Zr have higher minimum and maximum values. The rest of the elements are in the range of the ceramics. It implies that the clays used to make the loom weight and the house walls contained more calcium than those used to manufacture the ceramics.

6 - ARCHAEOMETRICAL RESULTS CONCERNING THE CERAMIC MATERIAL: THE 163 SAMPLES OF POTTERIES AND SPINDLE WHORLS FROM ARBON BLEICHE 3

6.1 TYPOLOGICAL CLASSIFICATION OF THE POTTERY AND ITS RELATION WITH THE NEOLITHIC CULTURES FROM THE LAKE CONSTANCE TO THE WESTERN CARPATHIAN BASIN

The typological study of the pottery found in Arbon Bleiche 3 was made by Dr. A. de Capitani, archaeologist, in her PhD work (DE CAPITANI, 2002).

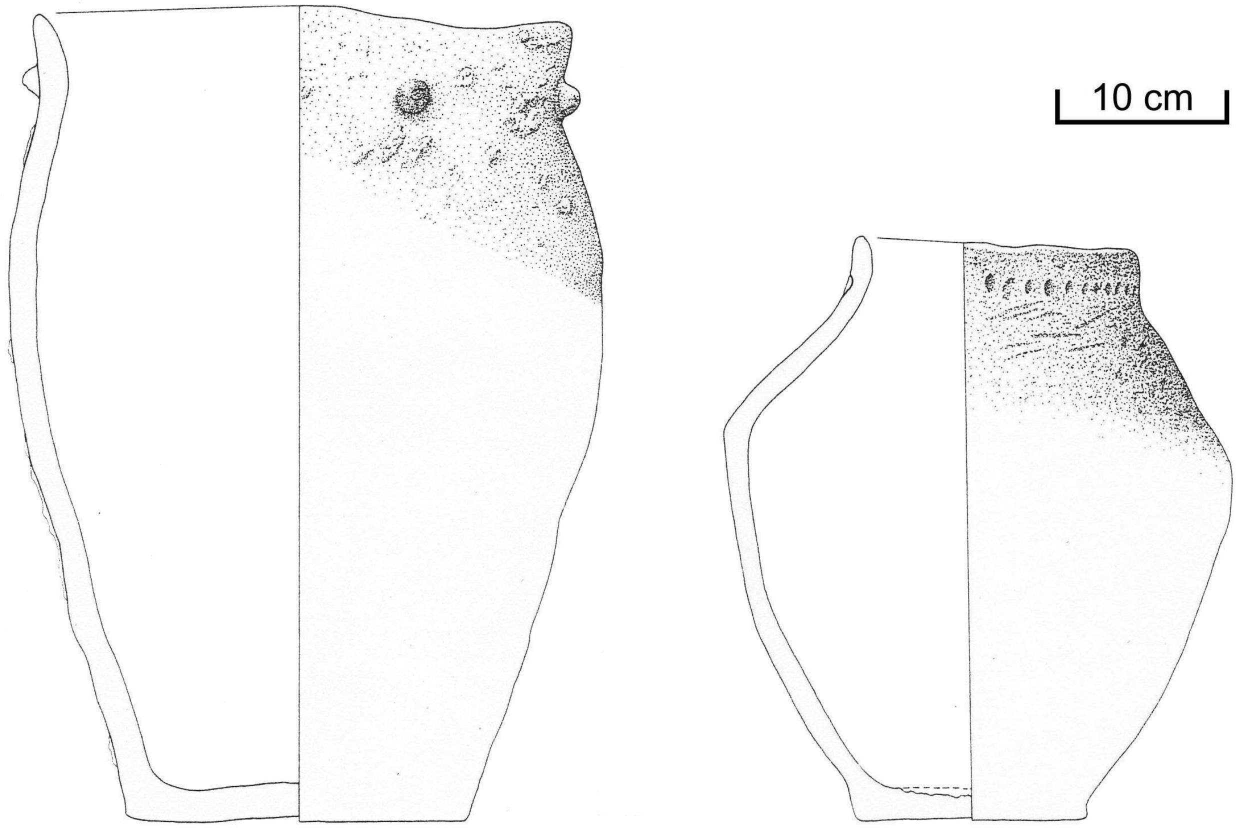
She defined two material groups, A and B by observing the sections of the sherds with a magnifying glass as follows: the sections showing only white grains as temper (i.e. rocks as temper) were distributed into group A, whereas the samples showing beige to brown grains (i.e. grog temper) were put into group B (DE CAPITANI, 2002, 143 and oral communication). Because all the ceramics were observed with a petrographic microscope in the present study, the previous distinction made by de Capitani was not used further on.

Then, de Capitani subdivided A and B into five different typological groups that will be described and used in this study (Table 6.1). Examples of ceramics from each typological group are shown in Fig. 6.1.

The first typological group described is the Pfyn / Horgen pots (subsection 6.1.1); the special forms (SF) are distributed into four groups (subsections 6.1.2 to 6.1.5). “In this group (special forms) you can find all kinds of vessels, which mostly cannot be derived from the Pfyn tradition. Comparisons cannot be made for all the special shapes, but some examples have parallels in the early period of the Baden culture (stage Boleráz), which mainly is prevalent in the Western Carpathian Basin, and within the Bavarian Altheim culture. “ (DE CAPITANI, 2002, 374). The Bavarian Altheim culture (3800-3600 BC), followed by the Cham culture (3000-2800 BC) are also used to describe some parallels. However, these cultures are not strictly contemporaneous to Arbon Bleiche 3; their duration and repartition area are shown on Fig. 6.2.

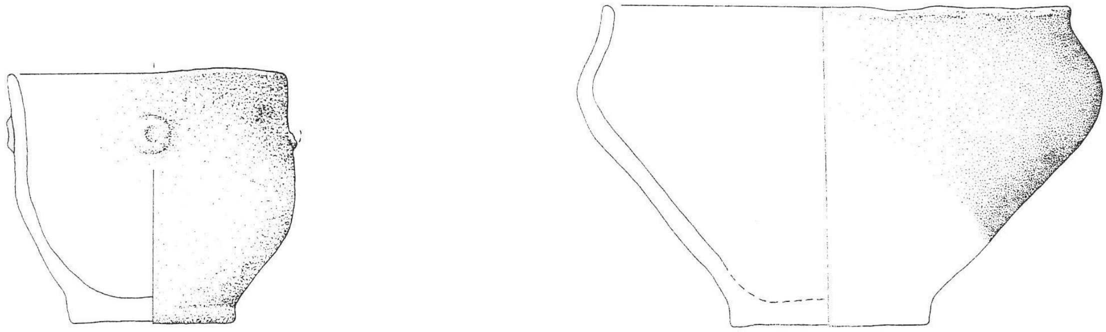
Typological groups (De Capitani, 2002)		Materialgruppe		Bonzon	Typological groups
		A (n=)	B (n=)	(n=)	(Bonzon, 2004, 2005)
Töpfe	Pfyn / Horgen	178	33	60	Pfyn / Horgen pots
Sonstige Formen	Pfyn	9	0	3	SF Pfyn
	Bayern	4	10	13	SF Bayern
	Frühen Badener Kultur (Stufe Boleráz)	3	33	29	SF Boleráz
	Ohne Parallelen	46	38	48	USF
	Sum	240	114	153	

Table 6.1: *Relation between* DE CAPITANI (2002*) typological groups (n= reconstructed pottery) and* BONZON (2004, 2005*) petrographical groups (n= analysed reconstructed pottery).*



A Pfyn / Horgen Pot, H = 49 cm
Inv. No. 18948, JB104

B SF Pfyn, H = 35 cm
Inv. No. 16746, JB009



C SF Bayern , H = 15 cm
Inv. No. 20893, JB150

E USF, H = 19 cm
Inv. No. 19777, JB095

D SF Boleráz, H = 8 cm
Inv. No. 17576, JB139

E USF, H = 11 cm
Inv. No. 19624, JB165

Figure 6.1: *Typical ceramics of every typological group: A: Pfyn / Horgen pot, B: special form Pfyn C: special form Bayern D: special form Boleráz E: undetermined special form. H: height, SF: special form, USF: undetermined special form, Inv. No.: Inventory Number, refers to Appendix 1 and* de Capitani (2002)*, JB…: refers to the sample number (drawings Archaeological service, Thurgau, M. Lier and E. Schön; from* de Capitani, 2002*).*

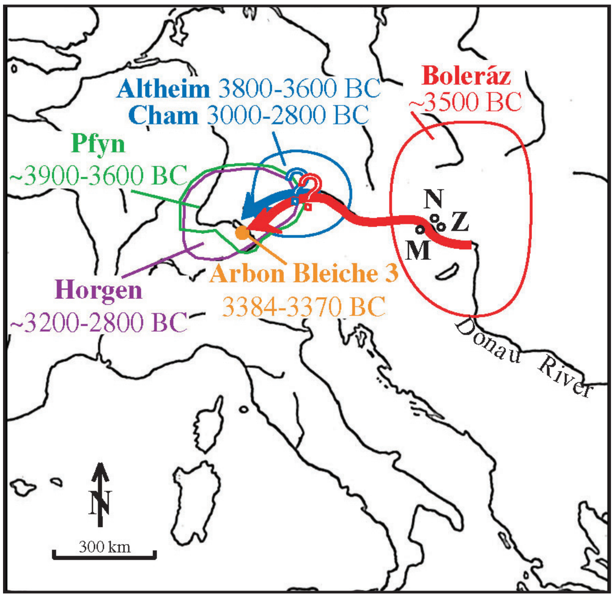


Figure 6.2: *Repartition and duration of the archaeological cultures discussed in this work. The arrows represent the possible travel of people in the Neolithic. M: Mödling-Jennyberg (Austria); Z: Žlkovce (Slovakia); N: Náměšt na Hané (Czech Republic)*

6.1.1 Pfyn / Horgen pots related to the Pfyn and Horgen cultures

The Pfyn / Horgen pots are the most abundant in the excavation: 70% of the ceramics studied by DE CAPITANI (2002, 161) are of that type. The pots (Fig. 6.1A) are grey to beige, "thick-walled, roughly slenderised and they have mostly a weak S-shape profile. The vessels are almost always unadorned: only now and then the neck is decorated with an encircling finger tapping, or fingernail incision band. There are some examples with a circular row of holes. Almost all the pots have knobs. On vessels with S-shaped profiles they are situated in the neck or just underneath. For the bottom shapes, flat standing and throated standing are almost equally represented" (DE CAPITANI, 2002, 374).

In the region around Arbon, the Pfyn culture (~3900-3600 BC) is followed by the Horgen culture (~3200-2800 BC) (STÖCKLI ET AL., 1995), as shown on Fig. 6.2. The village of Arbon Bleiche 3 was occupied during the transitional period between these two cultures. These vessels show at the same time characteristics of the Late Pfyn culture (around 3600 BC) – i.e. S-shaped profile, flat bottom, elongated lower body, barbotine covering, fingerprints, knobs – as well as those of the Eastern Horgen culture (around 3100 BC) – i.e conical to cylindrical profile, circular row of holes in the neck –. The pots from Arbon Bleiche 3 prove that the eastern Swiss Horgen culture has to be understood as resulting from a continuing development from the Pfyn culture.

6.1.2 Special forms Pfyn related to the Pfyn Culture

Only very few ceramics (9 samples) studied by the archaeologist (DE CAPITANI 2002, 155) are defined as special forms Pfyn. The pieces are of different shapes: 1 bottle, 3 miniature pots, 1 dish, 1 pot and 1 jar; the bottle is decorated with an encircling finger tapping and the outer surfaces of the pot and jar are both smoothed (Fig. 6.1B).

Special forms Pfyn are linked to the Pfyn tradition without any characteristics of the Horgen culture. Parallels with other Pfyn forms can be found in Steckborn Schanz (TG, CH) and the Thayngen Weier III (SH, CH).

6.1.3 Special forms Bayern related to the Altheim and Cham cultures from Bavaria

Another small group of ceramics (13 samples) studied by the archaeologist are defined as special forms Bayern (DE CAPITANI 2002, 156, 159).

This group includes small, large or double-conical dishes with knobs with finger impressions and cups with handles. The outer surface can be smoothed and an encircling finger tapping or fingernail incisions are sometime present. The sherds are also grey on both surfaces with thick walls (Fig. 6.1C).

Details of these ceramics are correlated with those of the Bavarian Altheim (3800–3600 BC) and Cham (3000–2800 BC) cultures (Fig. 6.2). These cultures are not contemporaneous to Arbon Bleiche 3, but the intermediate time between these two cultures is archaeologically very poorly described. Special forms Bayern from Arbon Bleiche 3 have parallels in Ergolding Fischergasse (D), Altheim (D), Alkofen (D), Galgenberg (D) und Koislhof (D) for the Altheim culture and Dobl (D) for the Cham culture (DE CAPITANI, 2002).

6.1.4 Special forms Boleráz related to the Boleráz stage of the Baden culture

Another group of the ceramics is special forms Boleráz (36 samples, de Capitani 2002, 156, 158). They are cups or other bigger forms such as jars or amphorae with handles or handles with a hole to pass a string, and conical dishes. The ornaments are incised streaks that can form a fluted surface or that are arranged like fish-bone; very little buttons are also described with encircling fingernail incisions, or with a clay ring (Fig. 6.1D). These forms are thin (walls ≤ 8 mm), mostly black, polished and adorned.

Two particular samples (JB140 and JB149, de Capitani 2002, Fig. 353, chapter 6.7) show the Boleráz' style, but are grey with thick walls. They are maybe local imitations of Boleráz pottery (de Capitani, oral communication).

These ceramics are related to the early period of the Baden culture (Stage Boleráz, around 3500 BC), which is present in the western Carpathian Basin (Fig. 6.2). Special forms Boleráz have parallels with forms from Donnerskirchen (A), Mödling Jennyberg (A), Zlkovce (SK), Stúrovo (SK), Bratislava (SK), Nitrianshy Hrádok (SK), Blatné (SK), Jevisovice C1 (CZ), Brno-Lisen (CZ) and Staré Zámky (CZ).

6.1.5 Undetermined special forms

The remaining of the special forms (84 samples, almost 25% of the corpus studied by de Capitani 2002 156, 160) contains all kinds of forms, with no resemblance to known ceramics: they are classified as undetermined special forms (USF). They are of diverse colours (mostly grey and black), their walls are thin or thick, their surfaces are smooth or rough, or covered with barbotine, they are decorated or not, and come with or without handles (Fig. 6.1E).

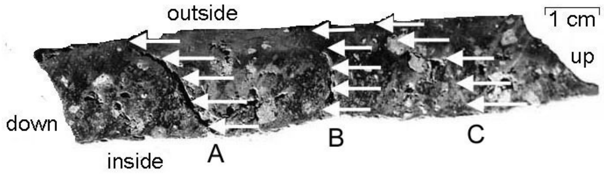


Figure 6.3: Sewed section of sherd JB083 (Pfyn / Horgen pot studied in Bonzon, 2005): four coils were detected after sewing, separated by holding surfaces AB, BC & CD.

6.2 MACROSCOPIC DESCRIPTION

6.2.1 Pfyn / Horgen pots

The Pfyn / Horgen pots (Fig. 6.1A) are coarse ceramics, grey to beige coloured on both outer and inner surfaces and on the sections. The latter contains sometimes black areas in the core or on the inner or outer margin. Barbotine covered some pots. The walls are around 1 cm thick (± 2 mm) and coil-built (see Fig. 6.3, Appendix 12 and Bonzon 2005). The temper is composed of medium to large angular white grains (2-10 mm Ø, rock fragments) and/or of beige to brown grains (grog). The outer surface is often black due to the use of these ceramics on open fire. A black crust, remain of organic cooked matter, sometimes covers the inner surface from the bottom up to the middle of the pots.

The thick-walled ceramics of Arbon Bleiche 3 are characterised by a quasi systematic presence of dark-brown carbonised organic residues adhering to the internal surface. They are to be found in the first third of the ceramics from the basis. The function of these pots was essentially culinary (Regert et al., 1999) and the study of such residues (on Horgen pots of Chalain) proved the use of animal fats (ruminants principally), of beeswax and milk products. The organic crusts of Arbon Bleiche 3 are made of the same material (except beeswax) (Spangenberg, oral communication).

6.2.2 Special forms Pfyn and special forms Bayern

Special forms Pfyn and special forms Bayern (Fig. 6.1: B, C) have a similar macroscopic aspect to the pots. Rare pieces have thinner walls (8-10 mm) and medium temper. Coils are normally thinner, when visible (lost during fabrication?; Martineau 2000, 2002).

6.2.3 Special forms Boleráz

Special forms Boleráz (Fig. 6.1D) have thinner walls (5-8 mm) and are normally black, or grey with a black core. The temper grains are mostly beige to brown (grog), small (≤ 4 mm Ø), and small white grains or fragments (rocks) can be present. Three samples of this group contain black long thin fragments (bone). No coils are detected in this group; these ceramics were probably built with a different technique (slab building technique?), which could explain their delicacy.

Without the use of advanced analytical tools, it is difficult to ascertain the presences of coloured bone material in a ceramic matrix. It is for example not possible to distinguish with certainty bone fragments from grog temper only by visual inspection, even when aided by a magnifying glass. Dark colours are characteristic for bone material and the shape helps to distinguish them from organic remains (also black but with proper shapes). Nevertheless, attention has to be paid to their similarity with black rocks.

6.2.4 Undetermined special forms

Undetermined special forms (USF; Fig. 6.1E) do not form a homogeneous group. All the features described above were observed, even fragments of bone in one sample (JB012).

6.2.5 Spindle whorls

The spindle whorls have a diameter between 45 and 57 mm, and a thickness between 8 and 15 mm. All are flat, except JB112 and JB116, which are conical and double conical respectively. Seven spindle whorls are thick (11-15 mm), beige to grey and resemble in its macroscopic appearance sherds of Pfyn / Horgen pots. Three are thin (6-9 mm), black and similar to the sherds of the special forms Boleráz.

6.3 PETROGRAPHICAL STUDY

6.3.1 Introduction

The petrographical description of each sample is presented in Appendix 3.

The petrographical study, based on the nature and relative quantity of the matrix and temper(s), permitted to separate the samples into 11 petrographical groups shown on Table 5.1. The samples are split into the different petrographical groups based on the nature of their matrix (inclusion-poor or inclusion-rich, silicate-rich or carbonate-rich), and then, based on the nature and proportion of the temper (mainly rock, nature of the rock; mainly grog; mainly bone). Fig. 5.1 illustrates every single group with a picture of a portion of one representative thin section.

Mineralogical changes due to firing are often observed in the thin sections of Arbon Bleiche 3 and were previously described by COURTOIS (1976) and MAGGETTI ET AL. (1984): Quartz are often broken into several fragments. Feldspars show twins, microperthites between orthoclase and albite and micropegmatites in association with quartz. Amphiboles show rubefaction, the initial homogeneously green specimens develop red borders at 700°C, a process which is terminated at 800°C when the amphiboles become homogeneously red. Biotites are altered: they either only keep their pleochroism in parts or are made opaque; they rarely show half-opened flakes due to vermiculitisation. In Arbon Bleiche 3 as in MAGGETTI AND SCHWAB (1982), the sherds reflect the alpine source of their temper and natural inclusions by their content of biotite from granites and strongly saussuritised plagioclases, typical for the alpine metamorphic rocks.

6.3.2 Inclusion-poor and silicate-rich matrix: petrographical groups AI-AVI

6.3.2.1 Petrographical group AI: granite temper

Petrographical group AI (Fig. 5.1B) is tempered either with granite only, or is dominated by granite, with minor proportions of gabbro, rhyolite, chert or grog. The temper is normally coarse (0.5 to 10 mm Ø), angular to sub-angular, and its proportion varies between 2 and 25 vol.%. Accessory minerals are present in various proportions, such as biotite (often altered), epidote and zircon.

About 80% samples present little iron oxide nodules in the matrix (< 0.5 mm Ø). ARF are also visible, but small (< 3 mm Ø).

83 of the 163 ceramics (51%) belong to this group. It is the main petrographical group of Arbon Bleiche 3 (Table 5.1). In this principal group, all the different typological groups are found: Pfyn / Horgen pots (47%), undetermined special forms (30%), spindle whorls (9%), special forms Bayern (7%), special forms Boleráz (5%) and special forms Pfyn (2%).

6.3.2.2 Petrographical group AII: rhyolite temper

Petrographical group AII (Fig. 5.1C) is mostly tempered with rhyolite, plus granite, gabbro or grog in minor proportions. The description of the temper is similar to the one of group AI, except its amount (10-20 vol.%). The same accessory minerals as described in group AI are present.

The samples present little iron oxide nodules in the matrix (< 0.5 mm Ø). ARF are also visible, but small (< 3 mm Ø).

Four of the 163 ceramics (2%) belong to this group (Table 5.1), which only contains the typological group of the Pfyn / Horgen pots.

6.3.2.3 Petrographical group AIII: chert temper

Petrographical group AIII (Fig. 5.1D) is mostly tempered with chert, plus granite, gabbro and grog in minor proportions. The description of the temper is similar to the one of group AI. Iron oxide nodules and ARF are also present. Only one sample of special form Pfyn belongs to this group (Table 5.1).

6.3.2.4 Petrographical group AIV: gabbro temper

Petrographical group AIV (Fig. 5.1E) is mostly tempered with gabbro, plus granite, rhyolite, chert or grog in minor proportions. The description of the temper is similar to the one of group AI, except its amount, varying between 7 and 25 vol.%. The same accessory minerals as described in group AI are present. About 50% of the samples present little iron oxide nodules in the matrix (< 0.5 mm Ø). ARF are also visible, but small (< 3 mm Ø).

Eleven ceramics (7% of the samples) belong to this group (Table 5.1). AIV is constituted of the following typological groups: 55% Pfyn / Horgen pots, 27% undetermined special forms and 18% special forms Boleráz.

6.3.2.5 Petrographical group AV: grog temper

Petrographical group AV (Fig. 5.1F) is either tempered with grog only, or mainly with grog together with granite, gabbro, rhyolite or chert in minor proportions. The temper, usually rounded, is thinner than the rock fragments described before (0.5-8 mm Ø), and its proportion varies between 2 and 15 vol.%, with one exception of 25 vol.%. Grog looks like the silicate-rich clay and if often tempered with granite similar to that of AI. Only biotite is often present as accessory minerals; epidotes and zircons are rare. ARF (particles size: 0.5-3 mm Ø) are rarely present as inclusions, and no iron oxide nodule was observed. In one sample (JB037), many shell fragments are present (gastropods and lamellibranches, Fig. 5.1G). MAGGETTI AND NUNGÄSSER (1981) described 2-5 % of the vessels from the Cortaillod culture from Twann containing shell fragments as temper. These fragments were described as brachiopods shells (Rhynchonels); gastropods shells were also present, but rare. However, this kind of temper is not frequently described in the literature, as far as we know.

This petrographical group contains 49 samples (30% of the samples) and is the second most important group of Arbon Bleiche 3 (Table 5.1). AV is constituted of the following typological groups: 35% special forms Boleráz, 35% undetermined special forms, 12% Pfyn / Horgen pots, 12% special forms Bayern and 6% spindle whorls.

6.3.2.6 Petrographical group AVI: bone temper

Petrographical group AVI (Fig. 5.1H) is tempered either principally or exclusively of bone fragments (1-2 mm long). They are yellow, beige, dark brown, black or grey in plain light (Fig. 6.4A); the colours are randomly distributed in the sections, except in JB012 composed only of black fragments. For example, JB069 has a black core due to the firing process, but the coloration of the bone fragments do not correspond to the colour of the surrounding matrix. The fragments also can be two-coloured yellow and dark-brown to black (Fig. 6.4B); they are neither distributed in relation to the surface of the pottery. The firing of the ceramics is, therefore, not the origin of the coloration. In figure 6.4B, the two fragments next to the outer surface are yellow towards the outside and black towards the inside of the thin section, whereas in the upper part of the picture, one grain has a reversed colour scheme, outside black, inside yellow.

In sample JB069, 20 vol.% bone temper is present (Fig. 5.1H). JB012 contains 10 vol.% of black bone fragments and 10 vol.% of grog (1-3 mm Ø). JB020 and JB147 are tempered respectively with 20 and 10 vol.% bone, 10 and 7 vol.% grog and 5 and 2 vol.% granite.

The accessory minerals are the same as those described in the petrographical group AV and no iron nodule is present.

AVI petrographical group is composed of four ceramics (2% of the samples): three special forms Boleráz and one undetermined special form (Table 5.1); it is the particular petrographical group of Arbon Bleiche 3.

6.3.3 Inclusion-rich and silicate-rich matrix: petrographical groups BI and BII

6.3.3.1 Petrographical group BI: granite temper

Petrographical group BI (Fig. 5.1I) is the matching piece to group AI: its temper is mostly granite, together with chert or grog in minor proportions. The rock temper is coarse and its proportion is of 7 vol.% in one case and 15 vol.% in the other one. The description of the temper, the accessory minerals, the ARF and the iron oxide nodules are similar to the one of group AI.

Two ceramics belong to this group (Table 5.1). One sample is a Pfyn / Horgen pot, and the other one an undetermined special form.

6.3.3.2 Petrographical group BII: grog temper

Petrographical group BII (Fig. 5.1J) is matching to group AV. One sherd is only tempered with grog and two are mostly tempered with grog, together with granite or gabbro in minor proportions. The temper, the accessory minerals and the ARF are similar to the one of group AV. The grog proportion is 5 vol.%. Three ceramics (~2% of the samples) are part of this group and typologically belong to special forms Boleráz (Table 5.1).

6.3.4 Inclusion-rich and carbonate-rich matrix: petrographical groups CI and CII

6.3.4.1 Petrographical group CI: granite temper

Petrographical group CI (Fig. 5.1K) is the matching piece to groups AI and BI: 3 samples are only tempered with granite, and 2 are mostly tempered with granite, together with gabbro or grog in minor proportions. The temper, the accessory minerals, the ARF and the iron oxide nodules are the same as those described in group AI. The proportion of temper varies from 10 to 20 vol.%.

Five ceramics (3% of the samples) belong to this group. 4 samples are Pfyn / Horgen pots, and one is an undetermined special form (Table 5.1).

6.3.4.2 Petrographical group CII: grog temper

Petrographical group CII (Fig. 5.1K) is matching to groups AV and BII. Only one ceramic belongs to this group and is tempered with 10 vol.% grog and 2

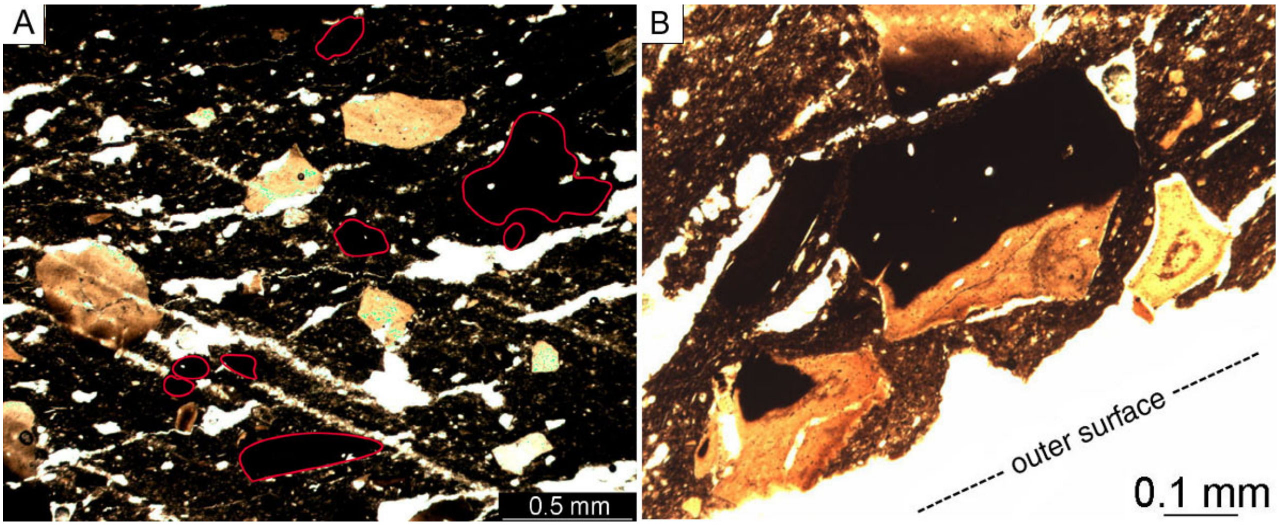


Figure 6.4: *A: Yellowish and black bone fragments as temper in thin section JB020. Black fragments are underlined with red colour. B: Two-coloured bone fragments visible in thin section JB069.*

vol.% granite (Table 5.1). The temper, the accessory minerals and the ARF are as described in group AV.

The sample of this petrographical group is typologically bound to special forms Bayern.

6.4 SPECIFIC STUDIES ON BONE TEMPERED CERAMICS

6.4.1 Introduction

Four samples of petrographical group AVI contain more than 10 vol.% bone fragments. Such fragments were never observed for the Neolithic period in Switzerland. MORZADEC (1992) described bone temper in some rare Mid-Neolithic ceramics from the Paris Basin, the North of France, Bretagne, Alsace and from La Hoguette site. This type of temper disappears in France during final Neolithic (MORZADEC, 1993). CONSTANTIN AND COURTOIS (1976) dated the ceramics containing bone temper in France roughly between 4000 and 3500 BC. The decoration of the bone temper ceramics from the Paris Basin are typologically alike the Limbourg ceramics, observed in the Neolithic of Holland. Bone fragments were also observed in the latter group (CONSTANTIN AND COURTOIS, 1985).

6.4.2 Firing

The firing of the ceramics is not the origin of the coloration of the fragments of bone. Their colours are rather linked to a primary heating of the bone. A heat treatment of the bone fragments is necessary to break them into pieces, because raw bones are too elastic to be crushed into very little fragments (CONSTANTIN & COURTOIS, 1985). Reddish brown, very dark grey-brown, neutral dark grey, or reddish-yellow colours are typical of heating Stage II (temperature 285-<525°C) in bone tissues defined by SHIPMAN ET AL. (1984). Most of these colours are also observed in our samples. The annealing temperature of the bone fragments has, therefore, been probably less than 525°C. Following SHIPMAN ET AL. (1984), the absolute smooth surface of the bone fragments visible in SEM pictures (Fig. 6.5) is typical in heating Stage III in bone tissues (temperature 285-<440°C): “the pores and asperities typical of Stage II disappear, the bone surface becomes glassy and smoother than it was in Stage I. Areas of bone may take a vitrified appearance.” (314, table 5). Therefore, the bone fragments must not have reached more than 440°C.

The broad peaks between 32 and 35° 2q in the XRD patterns (Appendix 5) are typical for nanocrystalline bone apatite. X-ray patterns of bone that has not experienced temperatures above 400°-450°C is characterized by a single broad peak centred at 33°C (SHIPMAN ET AL., 1984), such as seen in the pattern of JB147. The firing temperature of this ceramic could have been higher than 400°C, provided the temperature treatment did not last to long (MAGGETTI, oral communication).The ceramics were fired mostly under reducing conditions, as shown by their black heart. JB020 has been fired at lower temperature than the other samples, because chlorite is still present (< 550-600°C, NUNGÄSSER ET AL., 1985). The firing temperatures are higher for JB147, JB069 and JB012, because the peaks of illite are less and less visible. JB012 has probably been fired at temperatures about 800°C, which would explain the absence of illite (NUNGÄSSER ET AL., 1985; LETSCH & NOLL, 1983). JB147 & JB069 were probably fired between 600 and 800°C. The presence of pyrite can be secondary and resulting from the deposition of the sherds in a reducing environment (NUNGÄSSER ET AL., 1985).

6.4.3 Scanning electron microscope (SEM)

The coloured fragments have always a smooth appearance in SEM pictures and are easy differentiable from the surrounding ceramic matrix (Fig. 6.5A). At high magnification, Havers canals (pores originally containing blood vessels, lymphatic vessels and nerves) are observed (Fig. 6.5B) and prove the bone nature of the fragments.

The kind of bone used and its provenance is very difficult to determine. Only some fish bone are excluded, because they present special characters (i.e. special shaped little elements or fragments of some other looking like circles) visible under a microscope (communication HÜSTER-PLOGMANN). The microtextures, such as the almost total absence of holes and spongy parts, are typical for long bones (tibia, fibula etc.; MORZADEC, 1993). The heat treatment that the bone fragments suffered excludes a DNA analyses that could tell the origin of bone (WATSON ET AL., 1994). The use of human bone cannot be excluded, because the histology of bone cannot give any negative or positive evidence on that question.

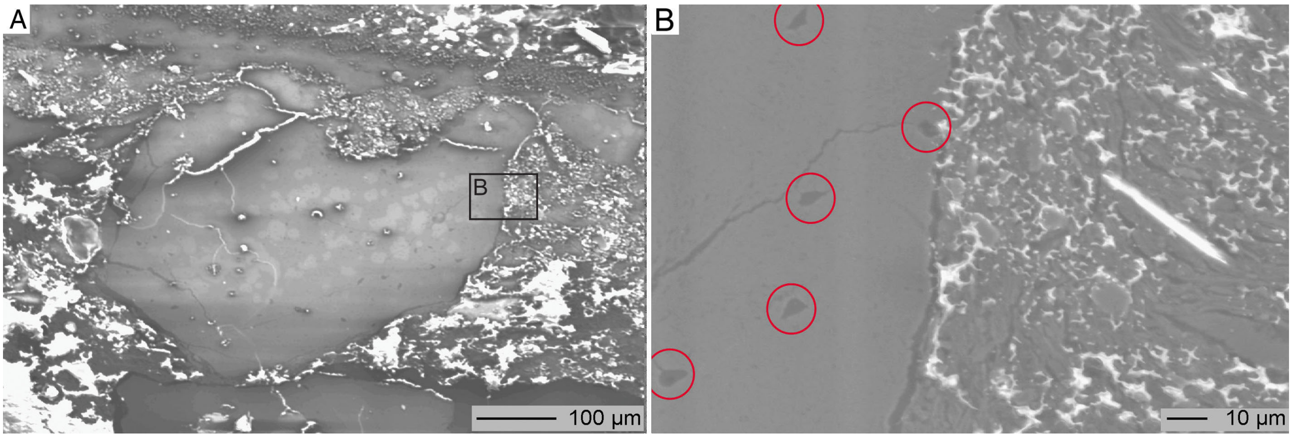


Figure 6.5: A: Bone temper (smooth surface) observed with SEM, with position of picture B. Note that the surrounding fired clay has an irregular surface. On picture B, Havers canals are circled.

Oxides		**Bone tempered ceramics**									**Other ceramics**	
Elements	**Unit**	JB012		JB020		JB069		JB147			mean	s
SiO2	**wt.%**	56.18	-	53.11	-	56.92	-	59.10	-	**Mean and s on 158 ceramics from Arbon Bleiche 3**	67.84	2.18
TiO2	**wt.%**	1.60	+	0.64	√	0.62	-	0.75	√		0.73	0.09
Al2O3	**wt.%**	28.48	+	16.31	-	15.31	-	18.01	√		17.87	1.39
Fe2O3*	**wt.%**	6.30	+	4.38	√	3.42	-	4.31	√		4.61	0.70
MnO	**wt.%**	0.03	√	0.04	√	0.06	√	0.04	√		0.05	0.02
MgO	**wt.%**	0.86	-	2.07	√	1.56	√	2.25	+		1.76	0.42
CaO	**wt.%**	2.67	√	12.30	+	14.00	+	7.60	+		3.10	1.74
Na2O	**wt.%**	0.31	-	0.54	√	0.30	-	0.72	√		0.91	0.47
K2O	**wt.%**	1.83	-	2.32	-	2.09	-	2.84	√		2.88	0.42
P2O5	**wt.%**	1.12	+	8.00	+	5.53	+	4.29	+		0.23	0.09
Ba	**ppm**	799	+	663	√	651	√	848	+		663	133
Cr	**ppm**	214	+	104	√	104	√	117	√		113	18
Cu	**ppm**	42	√	36	√	35	√	52	+		39	8
Nb	**ppm**	34	+	13	√	15	√	19	+		16	3
Ni	**ppm**	124	+	68	√	57	√	61	√		63	13
Pb	**ppm**	66	+	29	√	24	√	14	-		27	5
Rb	**ppm**	103	-	135	-	119	-	143	√		159	23
Sr	**ppm**	212	√	305	+	282	+	226	√		191	55
V	**ppm**	194	+	114	√	112	√	128	√		122	20
Y	**ppm**	444	+	30	+	26	√	31	+		25	4
Zn	**ppm**	184	+	137	+	109	√	123	√		109	19
Zr	**ppm**	388	+	123	-	125	√	139	√		152	27
SUM	**wt.%**	99.66		99.89		99.98		100.10				
FeO	**wt.%**	1.90		2.43		1.54		2.88				
L O I	**wt.%**	15.48		10.84		9.24		12.92				

Table 6.2: *Chemical data of the four bone tempered ceramics in regard to mean and standard deviation (s) of all the other ceramics from Arbon Bleiche 3 (n= 158, see Appendix 9B). √, + and – respectively refer to "equal to", "more" or "less" than the range of "mean plus or minus s" for 158 ceramics from Arbon Bleiche 3.*

6.4.4 Chemical study

Fig. 5.2 shows the clear separation between all the ceramics from Arbon Bleiche 3 on the one hand and the four samples containing bone temper on the other hand: CaO is present respectively between 1 wt.% and 9 wt.%, and between 2 wt.% and 14 wt.%; SiO_2 values vary between 65 wt.% and 75 wt.% and between 53 wt.% and 60 wt.% respectively. Moreover, this distinction is evident, chemically speaking. Table 6.2 and Appendix 9C show the chemistry of these samples and their descriptive statistics. Compared to all the other ceramics from Arbon Bleiche 3 (Table 6.2 and Appendix 9B), these exceptional potteries are quite different. JB012 has only four oxides and chemical elements that are situated in the mean range of all other ceramics from Arbon Bleiche 3; SiO_2, MgO, Na_2O, K_2O and Rb are below the mean range whereas TiO_2, Al_2O_3, Fe_2O_{3tot}, P_2O_5, Ba, Cr, Nb, Ni, Pb, V, Y, Zn and Zr values are above this range. As for JB020, JB069 and JB147, they share the same trend, deficient in SiO_2 and with high values of CaO and P_2O_5. This has to be put in relation with the presence of bone as temper, which is principally composed of Ca and P. Other chemical differences (excess of Sr, Y and Zn in JB020, of Sr in JB069 and of MgO, Ba, Cu, Nb and Y in JB147; lack of Al_2O_3, K_2O, Rb and Zr in JB020, of TiO_2, Al_2O_3, Fe_2O_{3tot}, Na_2O, K_2O, Rb in JB069 and of Pb in JB147) are to be noticed but cannot be explained yet. However, it shall be pointed out that even if JB012 is chemically very different from all the "normal" ceramics from Arbon Bleiche 3, the three other ceramics tempered with bone are not chemically similar with one another. These four are petrographical and chemical exceptions and will not be used in further statistical analyses.

6.4.5 Microprobe

The combined XRD, XRF and the microprobe remove the last doubts on the bone nature of the fragments. The main inorganic constituent of bone is apatite, a phase with composition $Ca_5(PO_4)_3(X)$ (NESSE, 2000). Three end members with X = F, OH, and Cl are known. The crystal chemistry of bone apatite is still disputed. Despite being called hydroxylapatite or carbonated hydroxylapatite in the medical literature, recent IR, Raman and NMR spectroscopy revealed no sign of OH^--groups in mouse bones and moderate quantities in enamel (PASTERIS ET AL, 2001). Bone apatite is characterized by its nanocrystalline texture and the presence of CO_3^{2-} groups, which replace PO_4^{3-} groups, anions on the X-site or both. HANDSCHIN AND STERN (1994) calculated weight percents of fluorapatite: 55.60 wt.% CaO, 42.22 wt.% P_2O_5 and 3.77 wt.% F, which gives a CaO/P_2O_5 ratio of 1.32 and a P_2O_5/F ratio of 11.14. The closest microprobe analyse of apatite gives a CaO/P_2O_5 ratio of 1.33 and a P_2O_5/F ratio of 11.20 (37.11 wt.% CaO, 27.94 wt.% P_2O_5 and 2.51 wt.% F). The mean on 98 microprobe analyses gives a ratio Ca/P of 2.03 (Fig. 6.6). The same ratio in HANDSCHIN & STERN (1994) is of 2.18. The variation between these two results is surely due to the presence of an apatite with OH partially replacing fluorine, $Ca_5(PO_4)_3(OH,F)$. During burial, the fluorine is leached and hydration from the surrounding wet ground permits OH to replace partially the F component (RYCHNER-FARAGGI AND WOLF, 2001).

6.5 FIRING OF THE POTTERIES AND SPINDLE WHORLS FROM ARBON BLEICHE 3

6.5.1 Firing process

See also chapter 3.4.

Surface treatment after the firing was not observed in the ceramics from Arbon Bleiche 3: no sample has a black surface resulting from a pre- or post-firing treatment. Hence, we will only describe the three first parts (core, outer and inner margins, Fig. 3.8). They will permit to describe all the phenomena that happened during the firing process.

The archaeologists found no trace of bonfire or pit-firing in Arbon Bleiche 3, and were therefore not able

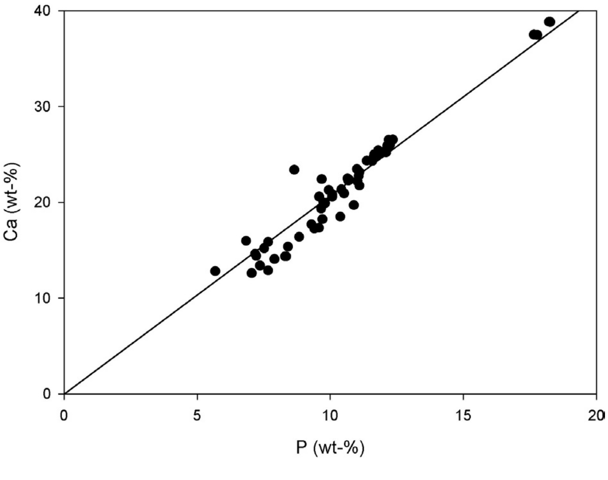


Figure 6.6: *Microprobe measurements in bone temper, Ca/P ratio is equal to 2.03.*

to determine the type of firing, like in other Neolithic villages of Switzerland (DE CAPITANI, oral communication). Hence, the Neolithic people could have used either bonfire or pit firing methods. Even the coloration of the sherds does not permit to detect which firing method was used.

With the help of the thin sections, the ceramics from Arbon Bleiche 3 could be separated into five colour groups (Appendix 4):

- Colour group 1: the section of the sherds has a plain colour (grey, yellowish-beige or orange; no black)
- Colour group 2: the section is completely black
- Colour group 3: the inner margin is black and the outer margin coloured
- Colour group 4: the core of the section is black and both inner and outer margins are coloured
- Colour group 5: the outer margin is black and the inner margin coloured.

Colour group 1 corresponds to a simple bonfire (or pit fire) firing: the rise of temperature without available oxygen followed by a cooling with available oxygen; the potter lets the ceramics in the firing area until they are cold. (Phases I, II, III, IVa or IVb and V: MARTINEAU AND PÉTREQUIN, 2000).

Colour group 2 corresponds to a heating and a cooling without available oxygen: the best way to attain this is to use a pitfiring process and to cover the pit after the plateau to induce a confined atmosphere (Phases I, II and III, followed by a confined atmosphere; MARTINEAU AND PÉTREQUIN, 2000).

Colour group 4 corresponds to a heating without available oxygen followed by a cooling with available oxygen; the oxygen reacted with both margins during the cooling. This can be attributed to a bonfire (or a pit firing) where the ceramics are not piled up (Phases I, II, III and IVa; MARTINEAU AND PÉTREQUIN, 2000). The difference between colour group 4 and 1 (plain colour) is related to the firing time: colour group 1 implies a long cooling, so that the oxygen has enough time to enter the section of the ceramic entirely. In contrast, colour group 4 experienced only a short and rapid cooling, so that the oxygen interacted only with the margins. It had no time to penetrate the core. The potter takes the ceramics out of the fire, to cool in fresh air or even in water.

Colour group 3 looks like group 4, but the ceramics were probably piled up, obstructing the oxygen entering the inner margins (Phases I, II, III and IVb; MARTINEAU AND PÉTREQUIN, 2000). Note that a thin coloured margin results from a rapid cooling (i.e. the potter takes the ceramics out of the fire when they are warm); whereas a large one implies a long cooling (i.e. the potter let the ceramics in the firing area during the cooling).

Colour group 5 is a real problem. Following MARTINEAU AND PÉTREQUIN (2000) these sherds should not exist. A simple firing cannot explain their colouration. The only explanation that can be proposed is that the ceramics got burnt a second time by the fire which destroyed the village of Arbon Bleiche 3. Therefore, some coloured sherds, covered by falling wood debris could fire once again in a confined atmosphere. This can lead to a sherd with an outer black part and an inner coloured part. Sometimes, the outer part can correspond to the outer margin of a ceramic. This group had to be fired twice to explain the presence of an outer black margin. (Phases I, II, III, IVa or IVb and V,

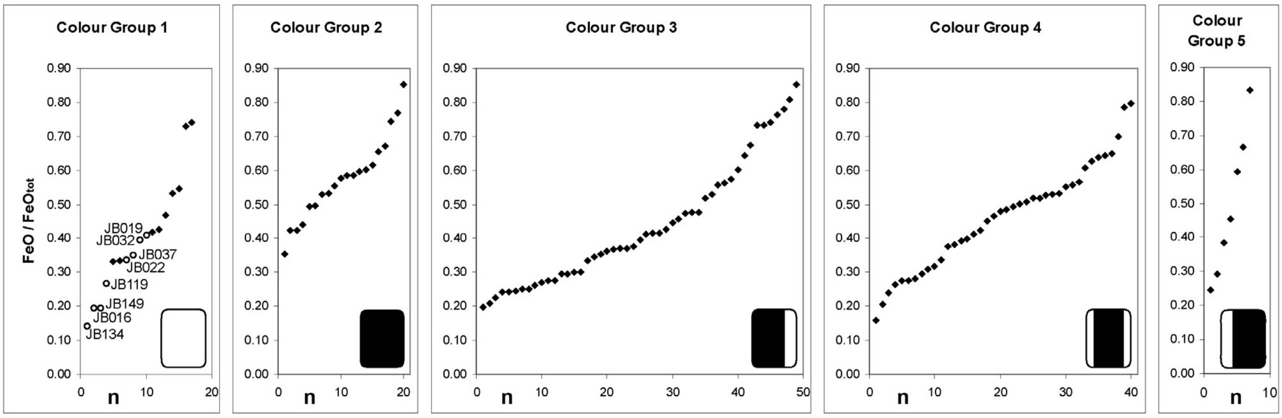


Figure 6.7: *Reduction index (calculation of the ratio FeO/FeOtot) for JB001-JB154: about 80% of the samples were fired in a reducing atmosphere (reduction index > 0.30) (n: number of samples, black-and-white rectangles show the sections of the sherds, outside on the right-hand side; in colour group 1, dots are the yellowish-beige samples and black diamonds are the grey ones).*

followed by a fire, which burnt down the entire village; Martineau and Pétrequin, 2000).

To resume, colour group 2 was fired under confined conditions followed by a confined cooling atmosphere, whereas the other colour groups (1, 3, 4) were fired under confined conditions, followed by a cooling with available oxygen. A second firing in confined conditions, the burning down of the village, possibly modified colour group 5.

6.5.2 Firing atmosphere

The stability of the firing atmosphere is described using the FeO/FeOtot ratio (Maggetti and Schwab, 1982). This reduction index shows the intensity of the iron reduction during the firing. When a firing is surveyed, the ratio is quite similar for two sherds of the same firing process. When the variation is very important (0.1 to 1 in Kilka and Galetti, 1994), it indicates a non-followed firing.

FeO was measured only for JB001 to JB154. The diagram of Fig. 6.7 shows the intensity of the reduction during the firing for these ceramics. Because those samples represent the majority of the studied samples and all the typological groups, the range of variation determined here is thought to be representative of all the ceramics from Arbon Bleiche 3.

The rare sherds that are homogeneously coloured are shown in Appendix 4, as colour group 1. They are yellowish-beige or grey. The yellowish-beige ones had time to completely re-oxidise during the cooling, contrary to the grey ones. These latter have to be put into relation to those of colour group 2 that are totally black. On figure 6.7, the yellowish-beige ones are symbolised by a dot and four among them are below 0.3 (ratio FeO/FeOtot; JB016, JB119, JB134, JB149). Moreover, all the reduced black samples (colour group 2) have a ratio higher than 0.3. We suggest 0.3 as the limit between the oxidising and the reducing atmosphere. However, the other yellowish-beige ones (JB019, JB022, JB032, JB037) situate between 0.3 and 0.4, hence in the reducing atmosphere area! Probably some parts of the sherds were still greyish (still reduced) but not visible to the naked eye.

Note that in the literature (Maggetti and Schwab, 1982; Kilka and Galetti, 1994), the limit between the oxidising and the reducing atmospheres is frequently around 0.2. This difference may be put in relation to the fact that in a Neolithic open firing, the atmosphere is not always stable and can vary rapidly. The large variation of the reduction index (0.1 to 0.9) proves a non-followed firing. In such a case, “jumps” during the firing and the cooling between oxidising and reducing atmospheres are probable.

For colour groups 3 to 5, FeO was measured on the whole sherd. Due to its banded aspect (black and various colourations) the reduction index changes from one part to another. Hence, the reduction index represents the average of these differently coloured areas. It shows, for the major part of the ceramics, a reducing atmosphere of firing (reduction index > 0.3).

Hence, almost 80% of the samples from Arbon Bleiche 3 were fired in a dominantly reducing atmosphere (> 0.3); only 30 on 154 samples (19%) cooled and were maybe partially fired in an oxidising atmosphere (colour group 1: JB016, JB019, JB022, JB032, JB037, JB119, JB134, JB149; colour group 3: JB004, JB007, JB010, JB026, JB038, JB061, JB076, JB089, JB090, JB092, JB094, JB097, JB135; colour group 4: JB024, JB031, JB033, JB073, JB095, JB107, JB144; colour group 5: JB034 and JB088).

6.5.3 Mineralogical transformations during firing

6.5.3.1 Nota Bene

The chemical study presented further will show that JB302 (carbonate-rich clay) and JB301 (silicate-rich clay) seem to fit quite well with the clays used to manufacture respectively the non-ceramic material and the ceramics from Arbon Bleiche 3. However, the experimental firings discussed underneath were made on JB304 (carbonate-rich clay) and JB306 (silicate-rich clay). Indeed, at that time, the chemical study was not achieved and these results not yet known.

6.5.3.2 Experimental oxidising firing of a carbonate-rich clay from the surroundings of Arbon

An experimental firing in a furnace was performed on an inclusion-rich and carbonate-rich clay collected in the surroundings of Arbon (Fig. 2.11, JB306). Figure 6.8 shows the mineral associations present in this clay between 20°C and 1000°C. The clay in its natural state (at 20°C) is composed of smectite, chlorite, illite, quartz, K-feldspar, plagioclase, calcite and dolomite.

At 1000°C, the mineralogical association of the transformed clay is composed of residues of illite, of quartz, K-feldspar, plagioclase, lime, hematite, gehlenite and diopside. The mineralogical transformations of this "JB306-experiment" as a function of temperature are put into relation with the results of the literature in Appendix 7A and discussed here.

In the "JB306-experiment", the disappearance of the different peaks of chlorite was not distinguishable (in opposition with Benghezal, 1994a) and the mineral disappeared below 600°C, lower than what is proposed in the literature in which chlorite disappears between 650° and 700°C (Tite, 1995; Béarat, 1992 and Jornet et al., 1985). The smectite disappeared below 500°C, in accordance with the results of Benghezal (1994a). At 1000°C, the two major peaks of illite (002: 10Å and 110: 4.48Å) are still visible, implying its disappearance above this temperature. Quartz, plagioclase and K-feldspar are also always present. Dolomite disappears at the same temperature as calcite, i.e. near 750°C, around the temperature proposed in Cultrone et al. (2001). Hematite is present from 700°C to over 1000°C, which does not exactly correspond to the literature. Gehlenite and diopside form around 800°C and are still present at 1000°C, in accordance with the results of Benghezal (1994a) and Cultrone et al. (2001).

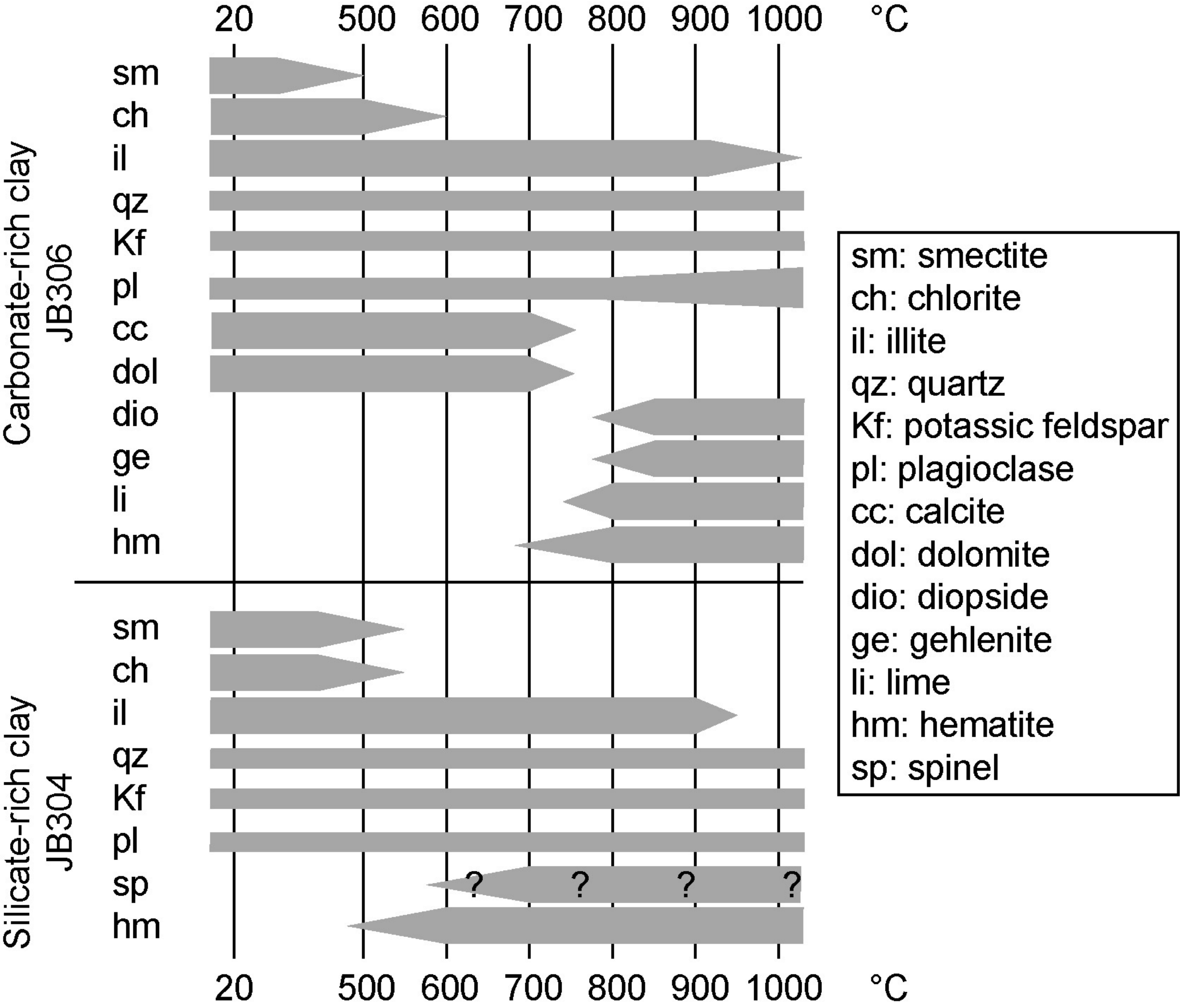


Figure 6.8: *Mineralogical changes between 20° and 1000°C (oxidising atmosphere) for two local clays from the surroundings of Arbon. JB306 (upper part) is a carbonate-rich clay; JB304 (lower part) is a silicate-rich clay. Note: smectite is probably a mixed layer illite/smectite as observed in Table 8.3.*

6.5.3.3 Experimental oxidising firing of a silicate-rich clay from the surroundings of Arbon

The same kind of firing was performed on an inclusion-poor and silicate-rich clay collected in the surroundings of Arbon (Fig. 2.11, JB304). The clay in its natural state (at 20°C) is composed of smectite, chlorite, illite, quartz, K-feldspars and plagioclases (Fig. 6.8). At 1000°C, the new mineralogical association is composed of quartz, K-feldspar, plagioclase, hematite and spinel. The mineralogical transformations of this "JB304-experiment" as a function of temperature are put into relation with the results of the literature in Appendix 7B and discussed below.

Maggetti (1979) quoted Grim (1968) who measured at 550°C that chlorite had disappeared, which is in accordance to the observation of the "JB304-experiment". The same temperature is observed for smectite, as proposed in Picouet (1997), Maggetti (1993) and Benghezal (1994a). All the peaks of illite reduced to 900°C and had disappeared around 950°C, which is not exactly what is proposed in the literature. Quartz always stays, whereas K-feldspar and plagioclase are much reduced at 1000°C.

The "JB304-experiment" show hematite increase between 500°C and 1000°C, which is quite similar to Letsch and Noll (1983) showing an increase of hematite between 500°C and 900°C, followed by a decrease over 900°C. It also seems to show spinel from 600°C up, but the superposition of its main peak (313-peak) with the (110) peak of hematite implies to take this temperature of formation with precautions, because only Maggetti (1982) describes spinel between 500° and 700°C, this latter being the "normal" forming temperature in the literature.

6.5.4 Mineralogy and estimation of the firing temperatures

The X-ray diffractograms of every studied sample are presented in Appendix 5; Appendix 6 lists the mineralogy observed in each diffractograms.

In order to simplify, we will now consider that all the yellowish-beige samples had time to completely re-oxidise, whereas all the plain black and plain grey sherds were fired in a completely reducing atmosphere. Even if we know that this fact is an approximation (the reduction indexes of these samples do not correspond exactly, see 6.5.2), it will permit to suggest an approximate firing temperature for these ceramics.

Therefore, the appendix 7B and the "306 experiment", both resulting of oxidising firings, will be used to determine a firing temperature for the yellowish-beige sherds of colour group 1 (JB016, JB019, JB022, JB032, JB037, JB119, JB134, JB149, JB174, JB175, JB190).

In these eleven samples, two mineralogical associations (MA) were determined, with quartz, K-feldspar, plagioclase and illite always present (Table 6.3):

RE-OXIDISED SAMPLES

Min. Assoc. / Yellow.-beige	MA1	MA2
Quartz	■	■
K-feldspar	■	■
Plagioclase	■	■
Illite	■	■
Chlorite	■	
Hm, Sm, Cc, Dol, Amph	■ ■ ■	■ ■ ■
Firing temp.	< 550°C	550°C - 950°C
n	2	9

REDUCED SAMPLES

Min. Assoc. / Grey and black	MA3	MA4	JB105
Quartz	■	■	■
K-feldspar	■	■	■
Plagioclase	■	■	■
Illite	■	■	
Chlorite	■	■ ■ ■	
Hm, Sm, Cc, Dol, Amph	■		
Firing temp.	< 600°C	600°C - 700°C	> 700°C
n	16	30	1

Table 6.3: *The observed mineralogical associations of colour groups 1and 2 and their inferred firing temperatures and predominant atmosphere of firing. Min. Assoc.: Mineralogical association, Colour gr.: Colour group; Firing temp.: Firing temperature (for details see text); n: number of samples; Hm: hematite, Sm: Smectite; Cc: Calcite; Dol: Dolomite; Amph: Amphibole.*

MA1: Mineralogical association with chlorite, i.e. fired below 550°C, with or without hematite, smectite, calcite, dolomite and amphibole, containing two samples (JB119, JB134).

MA2: Mineralogical association without chlorite, i.e. fired between 550°C and 950°C (temperature of illite vanishing), with or without hematite, smectite, calcite, dolomite and amphibole, containing nine samples (JB016, JB019, JB022, JB032, JB037, JB149, JB174, JB175, JB190).

In the mixed group composed of the black sherds (colour group 2) and the grey sherds of colour group 1, appendix 7C (reducing atmosphere) was used to propose a firing temperature. Except for JB105 that was fired above 700°C (illite vanished), all the samples contain quartz, K-feldspar, plagioclase and illite and distribute into two mineralogical associations (MA, Table 6.3):

MA3: Mineralogical association with hematite, with or without smectite, chlorite, calcite, dolomite and amphibole. As presented in LETSCH AND NOLL (1983), hematite disappears in reducing atmosphere at 600°C. Hence, the samples containing hematite were fired below 600°C. This group contains 16 samples (JB012, JB017, JB018, JB020, JB086, JB143, JB145, JB150, JB158, JB159, JB162, JB164, JB166, JB167, JB178, JB180). JB012 and JB020 contain extra apatite.

MA4: Mineralogical association without hematite, i.e. fired above 600°C and 700°C (temperature of illite vanishing), with or without smectite, chlorite, calcite, dolomite and amphibole, containing 30 samples (JB001, JB003, JB006, JB011, JB029, JB046, JB047, JB065, JB072, JB074, JB100, JB112, JB113, JB115, JB116, JB118, JB120, JB147, JB148, JB153, JB169, JB171, JB173, JB177, JB181, JB183, JB185, JB186, JB187, JB189). JB065 contains extra magnetite and JB147 contains extra apatite.

JB105 contains quartz, K-feldspars, plagioclase, calcite and dolomite, but no illite. This sample was fired over 700°C.

Because the mineralogical associations depend on the temperatures reached, on the firing atmosphere, on the mineralogy of the clay, but also on the duration of the peak temperature as well as on the granulometry of the matrix and temper, these associations are strongly dependent on the clay used. The papers presenting reducing atmosphere firings (LETSCH AND NOLL, 1983; MANIATIS ET AL., 1983; HERZ AND GARRISON, 1989; MURAD AND WAGNER, 1989) do not completely correspond to the mineralogy of the clays used in Arbon Bleiche 3, and the results of the firing temperatures shall therefore be considered with precautions.

On 58 ceramics (colour groups 1 and 2), 3% were fired below 550°C and 28% below 600°C. 52% were fired between 600°C and 700°C and 16% between 550°C and 950°C. One other sample (2%, JB105) was fired above 700°C.

These firing temperatures are in accordance with the common ceramic firing activities in the Neolithic and correspond well to an open fire; they also conform to the literature.

The material of colour groups 3, 4 and 5 (banded sherds) were fired in a reducing atmosphere, followed with complicated cooling processes wavering between oxidising and reducing atmospheres.Therefore, it is not possible to properly estimate the firing temperature reached by these sherds, due to a complete absence of experiments in such complex cases. The only thing we can prove is the presence of illite in each sample, except for JB002. Hence, whatever the cooling was, these samples were not fired at much higher than 700°C, the temperature of disappearance of illite in a reducing atmosphere. Diopside and gehlenite were detected in only one sample, JB002, which was fired over 800°C (small bubbles are present in the matrix and show an over-firing of the sample).

The clays used to manufacture the ceramics from Arbon Bleiche 3 surely contained, as JB304 (Fig. 6.8), some smectites (illite/smectite or montmorillonite for example), chlorite, illite, quartz, K-feldspar, plagioclase but no calcite.

The ceramics can contain secondary minerals such as smectite and calcite. As described in the literature (see e.g. MAGGETTI, 1979; HEIMANN AND MAGGETTI, 1981; VELDE, 1995) smectite often reform by rehydration during burial. Small grains of calcite or dolomite (undifferentiated in the thin sections) are often observed in the fractures of the sherds as neo-crystallised grains. Both also reform during burial. Hence, these both minerals were not used to determine the firing temperatures.

Conversly, chlorite is not a secondary mineral because it does not appear during burial under normal conditions of pressure and temperature. As specified in MAGGETTI ET AL. (1990, 102), chlorite is often a primary mineral, because it is found in the superficial

Swiss sediments according to Peters (1969), Mumenthaler (1979) and Schubert (1987). Therefore, chlorite was used to establish firing temperatures.

***Figure 6.9:** Reconstructed special form Boleráz: samples JB013 and JB014 are respectively coming from the grey and orange parts (from* Leuzinger*, 2000).*

6.6 CHEMICAL STUDY

6.6.1 Contaminated ceramics

One reconstructed special form Boleráz is composed of grey and orange sherds (Fig. 6.9; Leuzinger, 2000, Fig. 25; de Capitani, 2002, chapter 5.5). One sample of each coloured part was studied: JB013 is grey on both surfaces and black inside, and JB014 is orange and black, respectively. The orange sherds of the vessel were collected in the northern part of the excavation, whereas the grey ones came from its southern area (de Capitani, 2002). The northern area was dry and the sherds deposited above the ground water level. In the opposite, the grey sherds were found in a humid environment. However, JB014 has a very high loss of ignition (14.03, Table 6.4) and contained much more water than JB013 (loss of ignition: 4.71). This fact cannot be explained, but could maybe be put in relation with a problem during its sampling in the excavations.

On table 6.4, the possibly contaminated ceramics are put into relation with the mean and the standard

Oxides		**Possibly contaminated potteries from Arbon-Bleiche 3**															**Other ceramics**	
Elements	**Unit**	JB013		JB014		JB002		JB025		JB028		JB031		JB061			mean	s
colour		grey borders		orange borders		orange borders		orange borders		orange borders		orange borders		orange borders		**Mean and s on 158 ceramics from Arbon Bleiche 3**		
SiO2	**wt.%**	66.23	√	64.70	-	64.85	-	64.39	-	67.67	√	70.31	+	68.55	√		67.84	2.18
TiO2	**wt.%**	0.76	√	0.93	+	0.71	√	0.72	√	0.75	√	0.75	√	0.63	√		0.73	0.09
Al2O3	**wt.%**	18.94	√	23.03	+	17.58	√	17.94	√	17.79	√	17.60	√	17.94	√		17.87	1.39
Fe2O3	**wt.%**	5.38	+	4.47	√	5.72	+	4.59	√	5.35	+	4.24	√	4.46	√		4.61	0.70
MnO	**wt.%**	0.06	√	0.02	-	0.06	√	0.07	+	0.06	√	0.04	√	0.04	√		0.05	0.02
MgO	**wt.%**	1.85	√	1.20	-	1.76	√	1.61	√	1.69	√	1.30	-	1.43	√		1.76	0.42
CaO	**wt.%**	3.42	√	2.25	√	5.45	+	6.93	+	3.24	√	2.02	√	1.58	√		3.10	1.74
Na2O	**wt.%**	0.36	-	0.38	-	0.70	√	0.72	√	0.76	√	1.44	+	1.60	+		0.91	0.47
K2O	**wt.%**	3.02	√	2.59	√	3.27	√	2.72	√	2.66	√	2.33	-	3.47	+		2.88	0.42
P2O5	**wt.%**	0.19	√	0.42	+	0.21	√	0.29	√	0.22	√	0.21	√	0.23	√		0.23	0.09
Ba	**ppm**	676	√	603	√	392	-	850	+	623	√	734	√	838	+		663	133
Cr	**ppm**	128	√	152	+	112	√	111	√	116	√	89	-	98	√		113	18
Cu	**ppm**	40	√	53	+	33	√	34	√	38	√	26	-	31	√		39	8
Nb	**ppm**	17	√	20	+	17	√	18	√	14	√	17	√	16	√		16	3
Ni	**ppm**	65	√	91	+	56	√	57	√	63	√	48	-	48	-		63	13
Pb	**ppm**	30	√	38	+	28	√	27	√	29	√	25	√	30	√		27	5
Rb	**ppm**	169	√	146	√	183	+	148	√	155	√	135	-	182	√		159	23
Sr	**ppm**	218	√	124	-	214	√	270	+	202	√	212	√	279	+		191	55
V	**ppm**	143	+	160	+	134	√	132	√	139	√	109	√	112	√		122	20
Y	**ppm**	25	√	26	√	30	+	24	√	29	√	21	√	19	-		25	4
Zn	**ppm**	114	√	163	+	110	√	103	√	107	√	95	√	100	√		109	19
Zr	**ppm**	135	√	148	√	142	√	136	√	153	√	175	√	126	√		152	27
SUM	**wt.%**	100.39		100.16		100.46		100.17		100.36		100.41		100.12				
FeO	**wt.%**	2.57		2.22		3.23		1.92		2.68		0.79		1.01				
L O I	**wt.%**	4.71		14.03		3.21		9.71		3.89		4.22		2.94				

***Table 6.4:** Chemical data of the possibly contaminated ceramics (plus JB013, non-contaminated sample) in regard to mean and standard deviation (s) of all the ceramics from Arbon Bleiche 3 except those tempered with bone (n= 158, see Appendix 9B). √, + and – respectively refer to "equal to", "more" or "less" than the range of "mean plus or minus s" for 158 ceramics from Arbon Bleiche 3.*

deviation -for each chemical element- of every ceramic from Arbon Bleiche 3, ceramics tempered with bone excepted. In JB014, SiO_2, MnO, MgO, Na_2O and Sr decreased whereas TiO_2, Al_2O_3, P_2O_5, Cr, Cu, Nb, Ni, Pb, V and Zn increased. The other chemical elements stayed stable. This is the opposite process of the well described leaching, which decreases chemical elements such as P and Na. The orange sherd (JB014) chemically differs from almost all the other analysed ceramics: on Fig. 6.14 it is represented in the exceptions (Fig. 6.14E) whereas the grey one not (JB013, Fig. 6.14A). Hence, these chemical changes due to the deposition of the sherd in the sediment are high enough to be perceived by the analyses.

Other partially orange samples were analysed, but often, the colouration was only visible on one surface, in opposition with JB014. It can be observed that JB013 (grey borders) and JB028 (one orange surface) are in the range of the mean, except for three and one elements respectively (Fe_2O_{3tot}, Na_2O, V). JB025, JB002, JB061, JB031 and JB014 have respectively 5, 6, 6, 8 and 15 elements out of the range of the mean. JB025 is depleted in SiO_2 and enriched in MnO, CaO, Ba and Sr. JB002 has too high SiO_2 and Ba whereas Fe_2O_{3tot}, CaO, Rb and Y are too high compared to the mean. JB061 is depleted in Ni, Y whereas Na_2O, K_2O, Ba and Sr are too high. JB031 has too low MgO, K_2O, Cr, Cu, Ni, Rb, and too high SiO_2 and Na_2O. Apart from Na_2O, the contamination is different for these two letter samples, because the elements do not follow the same trend. The way all these samples (JB002, JB014, JB025, JB028, JB031, JB061) were contaminated cannot be understood in detail.

However (except for JB014), these samples were not contaminated enough to be chemically separated from the other samples, but their results shall be used with precautions.

The little standard deviation and variation coefficient for Na_2O and the very low concentration of P_2O_5 (max. for 158 ceramics equal 0.7 wt.%) imply an absence of contamination during the deposition of the other sherds in the ground (Wedepohl, 1969-1978). All the samples contain between 12 ppm and 66 ppm Pb, except one, JB030, which contains 1863 ppm Pb. This latter value is correlated with an analytical problem and is therefore not included in the statistical analyses.

Even if some exceptions were evidenced at the time, all the samples will be used further on for statistical analyses. If these exceptions can be evidenced according to various statistical methods, they will be finally defined as real outliers.

6.6.2 Statistical treatment of the data

6.6.2.1 *Introduction*

The raw chemical data can be found in Appendix 8.

The statistical methods used are as follows:

1. The high number of data were first simplified and reduced to several numbers (mean, standard deviation…) that describe them. These latter summarise the different aspects contained in the data (Descriptive Statistics).
2. Classify the samples by their resemblances (Cluster Analysis)
3. Identify the characteristic elements of each chemical group by reducing the number of variables (Principal Component Analysis, PCA)
4. Assign samples of indeterminate origin to the chemical groups resulting from PCA (Discriminant Analysis and Mahalanobis Distance)

As explained in Rapp and Hill (1988), “cluster analysis is useful for identifying completely separate groups but less helpful for identifying groups that overlap, whereas discriminant analysis seeks to discover and use those attributes which discriminate between known groups in order to assign unknowns to one of the groups.”

6.6.2.2 *Descriptive statistics*

The chemical characteristics of the ceramics of every group are printed on Appendix 9. For each chemical element the minimum and maximum values, the range containing the values and their means and standard deviations are given. The standard deviation (σ, s) is a measurement of the dispersion of the data in one group (for one chemical element), which has the same unit as the data (weight percents for the major elements and parts per million for the traces). Inversely, the variation coefficient, equal to the standard deviation divided by the mean, has no unit and permits to compare the dispersion of data measured in different units.

The examination of the dispersion of one chemical element is important: Picon (1984) proposed to neglect the elements with a high standard deviation and a high variation coefficient for the statistical analyses. As it can be observed on Appendix 9B, no chemical element presents a high standard deviation and a high variation coefficient. Hence, all the measured elements are considered for the statistical analyses. In Appendix 9C, JB012 contains 444 ppm Y whereas all the other samples contain between 16 ppm and 52 ppm Y. This sample is a particular one, containing bone temper. Hence, this particularity is not assigned to an analytical error and will be taken into account.

Picon (1991) showed that the chemical components measured by XRF have a variable aptitude to separate the samples into different groups. Ca is the best, followed by K, Mg, Al, Ti, Mn, Si and Fe. Normally, Al_2O_3, TiO_2, MgO, Fe_2O_3, K_2O, Cr, Ni, Rb, V and Zn are positively correlated with the clay content (Sigg et al., 1986; Béarat and Bauer, 1994; Wolf, 1999). Using several correlation diagrams (SiO_2/Al_2O_3, MgO/CaO, TiO_2/Fe_2O_3, Na_2O/K_2O, Ba/Zr, Cu/Zn, Ni/Cr and Rb/Sr), distinct groups resulting from different chemistry of clays and of tempering were searched; abnormal samples are evidenced that way (Maggetti and Galetti, 1993). All these correlations were studied, and some are presented in Fig. 6.10.

The petrographical group AIV is tempered with gabbro. This kind of rock normally contains a high proportion of MgO, Fe_2O_3, Cr, Ni and V (Kilka and Galetti, 1994, 1108; Maggetti et al., 1998, 26; Nungässer et al., 1992; Duruz and Maggetti, 1997; Hertli et al., 1999; Giacomini, 2001). Unfortunately, AIV does not show a good chemical separation from the other petrographical groups for those elements. This fact shall be put into relation with the small amount of gabbro tempering the clay. On figure 6.10: A and B, the samples tempered exclusively with granite (AI*), mostly with gabbro (AIV) and exclusively with grog (AV*) are plotted together. These three groups are the most different of Arbon Bleiche 3, petrographically speaking. In the graphs showing the major elements (Fig. 6.10A), only Na_2O permits to separate AV* from the other groups. AIV and AV* overlap the higher range of values of AI* for TiO_2, MgO and its lower values for K_2O. AV* overlaps the higher values of AI* and AIV for Cr, Cu, Ni and Zn. Hence, for these chemical elements and for the other element not illustrated, AIV cannot be separated from AI*. Moreover, there is no way to chemically split AIV from AI*. Hence, all the ceramics from Arbon Bleiche 3 are chemically very similar; even the most different petrographical groups (AI* vs. AIV vs. AV*) cannot be separated chemically. The outliers visible on these figures will be discussed further.

As said before, one could have thought that so many different petrographical groups would also divide into several chemical groups. Unfortunately, this is not the case. All the samples form, indeed, a single large homogeneous chemical group. Fig. 6.11 shows that there is, however, a tendency for the ceramics from Arbon Bleiche 3 (ceramics tempered with bone excepted) to chemically differ: on the left hand, the petrographical group AI (mainly tempered with granite) tends to split up from the petrographical group AV (mainly tempered with grog) visible on the right-hand side of the graph. These two petrographical groups were the most dissimilar of this study (except AVI, petrographical group with bone temper), and tend to split up only for Na_2O and Ni.

Hence, because such a partition is very difficult to evidence, we propose that a single type of clay was used to produce almost all the ceramics from Arbon Bleiche 3. Accordingly, only small chemical differences due to the main temper present in the samples can be put into light, such as in Fig. 6.11.

6.6.2.3 Cluster analysis

The multivariate statistics permit us to study the correlation between the chemical variables. The cluster analysis groups the samples of similar chemical compositions (Fig. 6.12). Fig. 6.13: A-E illustrates the dendrogram with each sketch of the ceramics and the petrographical group they belong to. On Fig. 6.12, the separation between the pages of Fig. 6.13 is represented by a horizontal line. These separations do not imply any chemical grouping or any separation.

> In a dendrogram, "each ceramic is represented by a vertical line at the basis of the diagram. The similarities that exist between two or more ceramics are more and more important as the horizontal line that unites them together is next to the basis of the diagram." (Picon, 1992, 6).

No clear grouping either of typological or petrographical groups was evidenced by such a dendrogram (Fig. 6.12). Only some typologically and petrographically similar ceramics can be put into evidence as very close chemically. The first group is indicated on Fig. 6.12 and 6.13: B, C by one asterisk; these are six Pfyn / Horgen pots (JB023, JB032, JB054, JB093, JB100, JB104) and one spindle whorl (JB114), mostly tempered with granite (petrographical group AI). The second group is indicated on Fig. 6.12 and 6.13D with two asterisks. These are six Pfyn / Horgen pots (JB038, JB044, JB056, JB061, JB062, JB135) and one special form

Bayern (JB153); all seven samples belong to group AI. However, when discussing these chemical and petrographical resemblances with A. de Capitani, she explained that, from the archaeological point of view, the vessels of these two groups do not have any similar details (form, decoration…) and would not be considered as made by the same potter by an archaeologist.

The opposite has to be considered too: de Capitani (2002, 177) noticed that the spatial repartition of some ceramics in the excavation showed several concentrations of vessels with similar details. If these groups could have been defined also archaeometrically, one could have imagined a single potter, using one single clay and one kind of temper for manufacturing vessels in his own personal style. This is obviously not the case: the groups with similar details as presented in de Capitani (2002) are shown with small letters (a to j) on Fig. 6.13. There is no chemical proximity between the samples of these groups. Hence, it is not possible to describe groups of ceramics from Arbon Bleiche 3 surely made by one single potter.

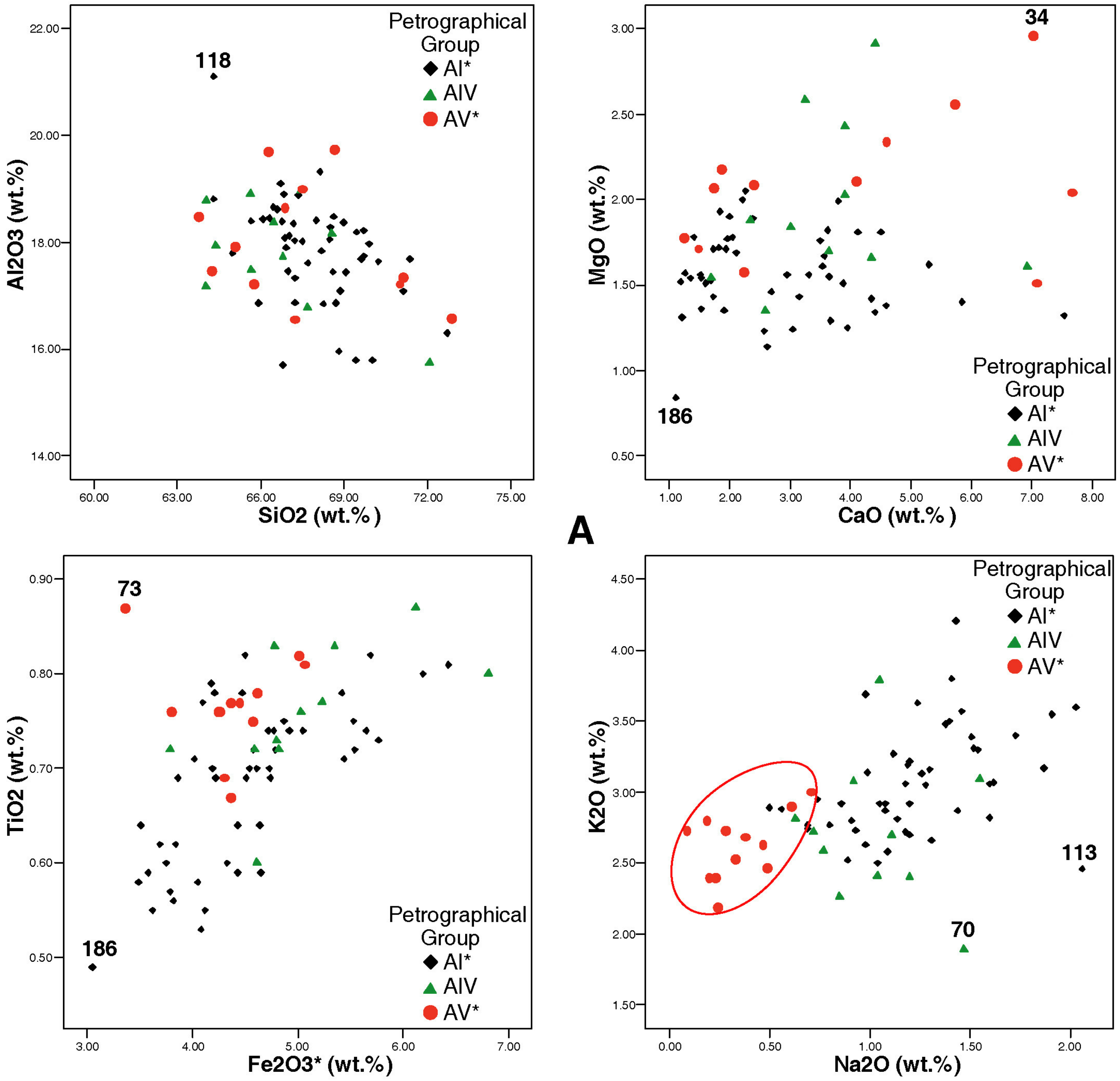
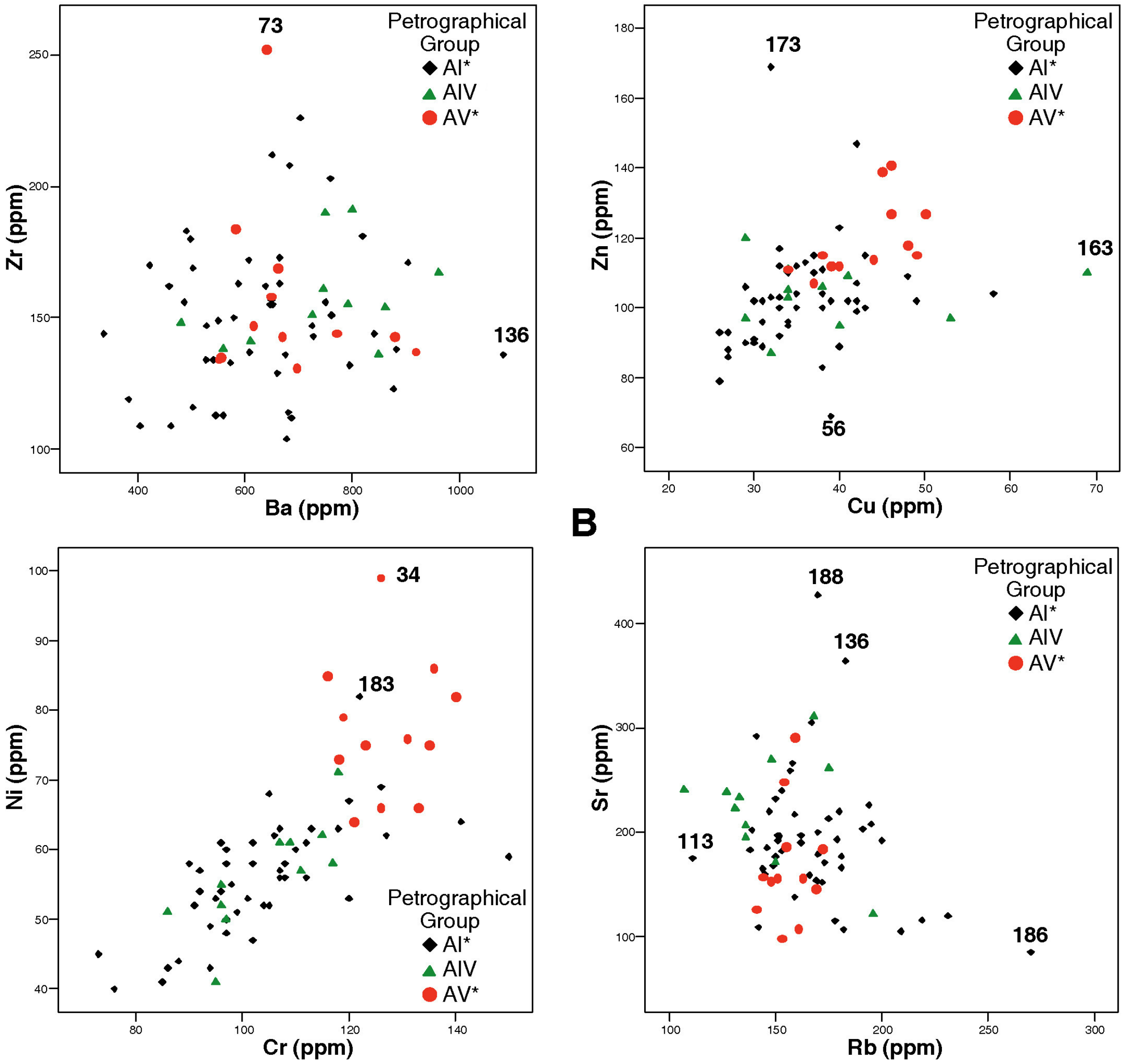


Figure 6.10A: Petrographical groups AIV in relation with AI and AV*; major elements (Fe_2O_3* as Fe_2O_{3tot}; numbers = sample numbers: JB...).*



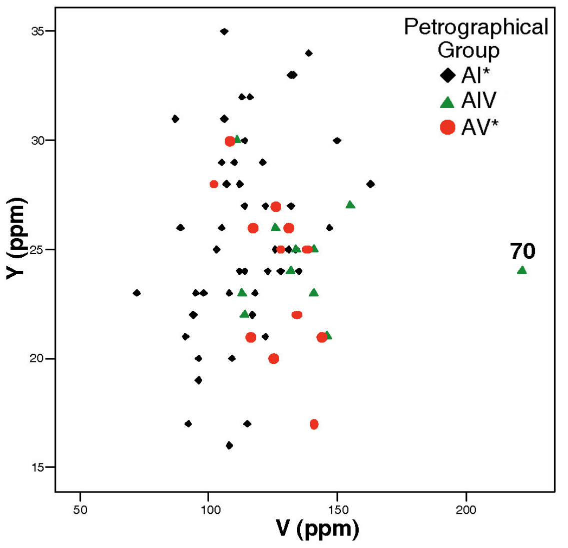


__Figure 6.10B:__ Petrographical groups AIV in relation with AI and AV*; minor elements (numbers = sample numbers: JB…)*

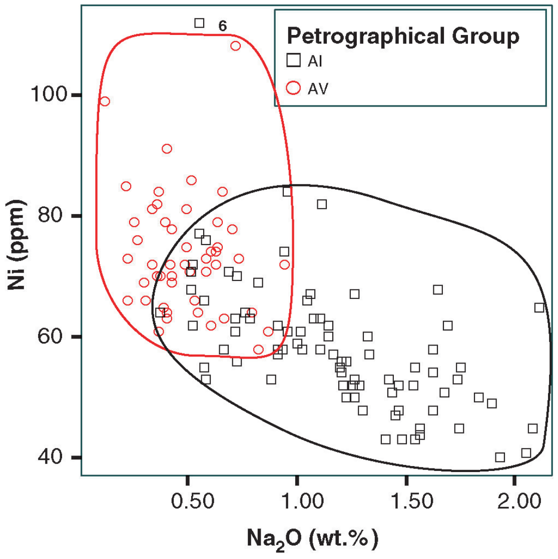


__Figure 6.11:__ Na$_2$O versus Ni: petrographical groups AI and AV tend to split. For petrographical groups definitions see Table 5.1 and text (number = sample number: JB006)..

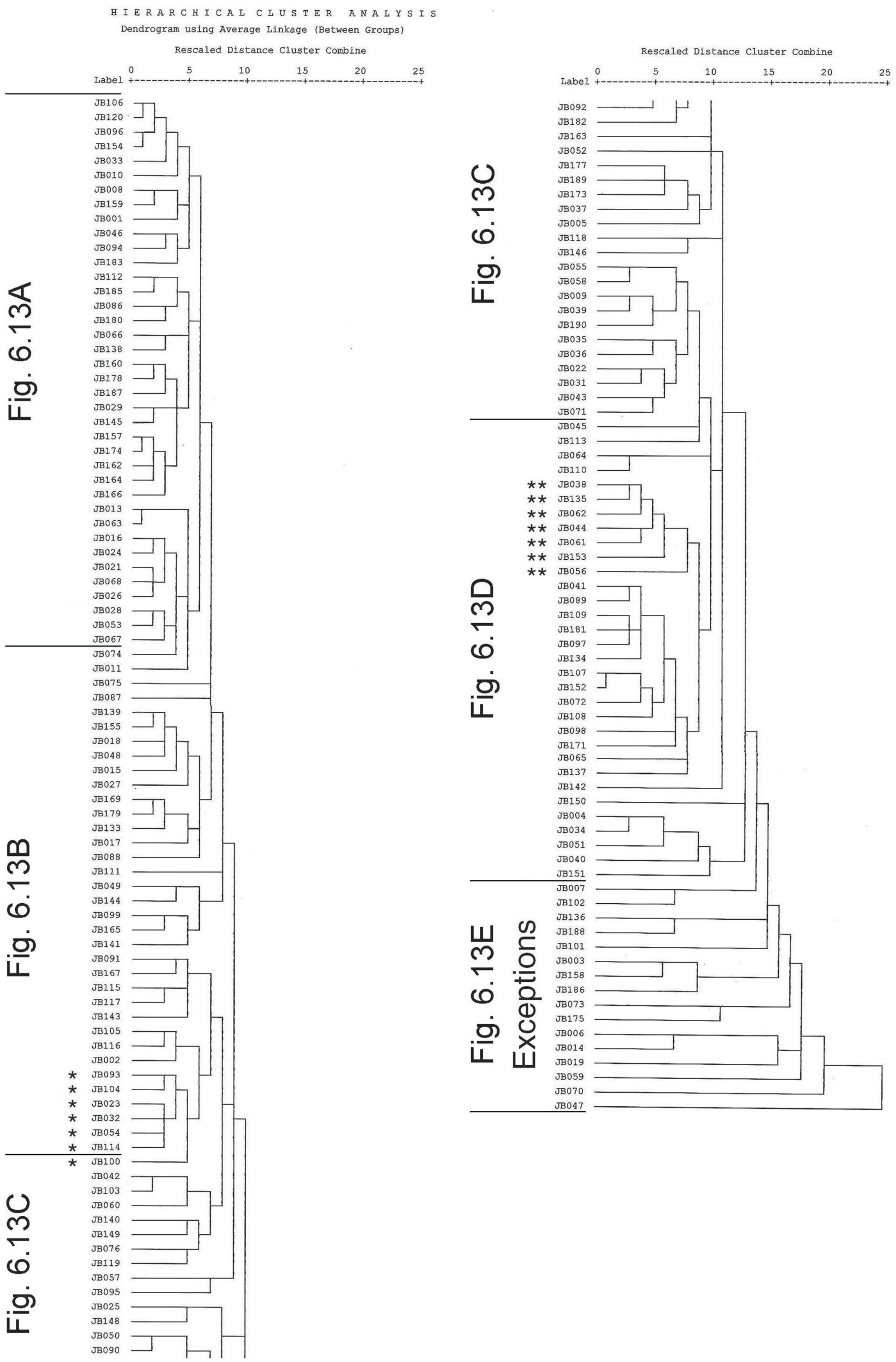


Figure 6.12: *Dendrogram showing the results of the cluster analysis. * shows seven ceramics of the petrographical group AI chemically alike, six Pfyn/Horgen pots and one spindle whorl. ** show seven ceramics of the petrographical group AI chemically alike, six Pfyn/Horgen pots and one special form Bayern. Fig. 6.13A–E will show this dendrogram with the ceramics grouped as proposed here. Horizontal lines show the splitting of this dendrogram into several pages in Fig. 6.13 A-E.*

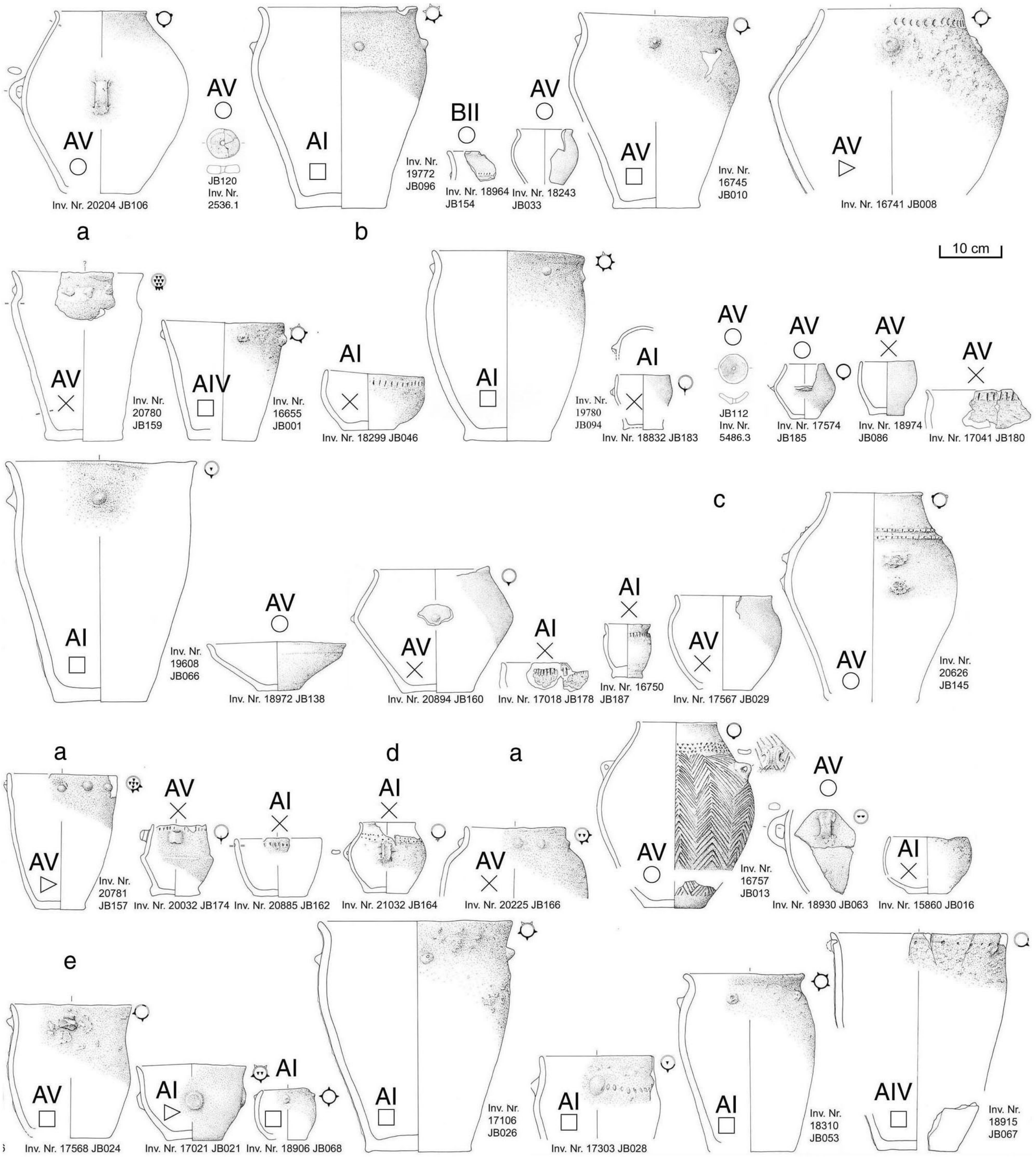


Figure 6.13A: *Illustration of the dendrogram (Fig. 6.12): each ceramic is presented (drawing de Capitani, AATG, M. Lier and E. Schön) and the typological and petrographical group (see Table 5.1) it belongs to is mentioned. Small letters (a, b, c, etc.) represent the ceramics with similar details (after* DE CAPITANI 2002*).*

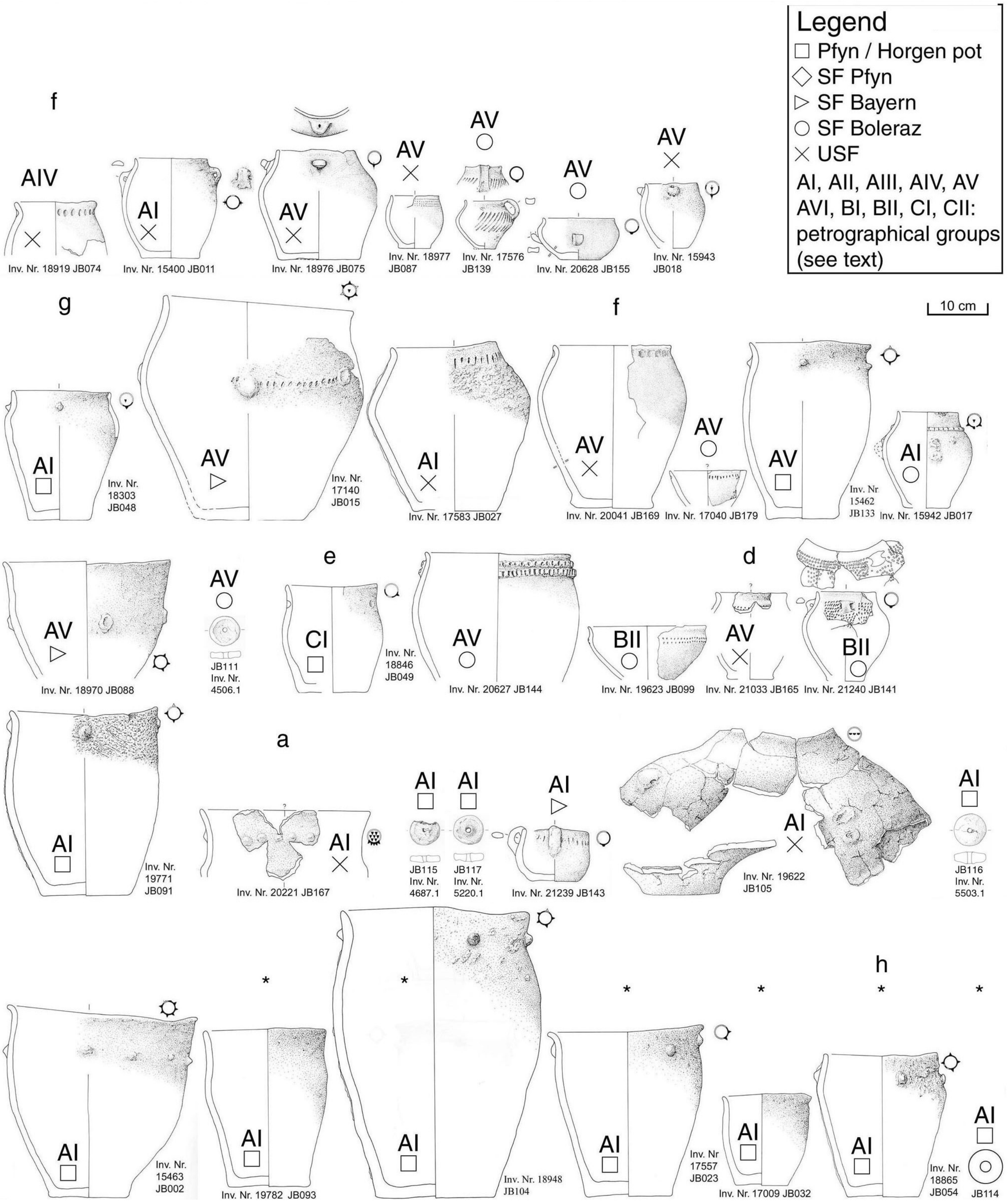


Figure 6.13B: *Illustration of the dendrogram (Fig. 6.12): each ceramic is presented (drawing AATG, M. Lier and E. Schön) and the typological and petrographical group (see Table 5.1) it belongs to is mentioned. Small letters (a, b, c, etc.) represent the ceramics with similar details (after* de Capitani 2002). ** shows seven ceramics of the petrographical group AI chemically alike, six Pfyn/Horgen pots and one spindle whorl.*

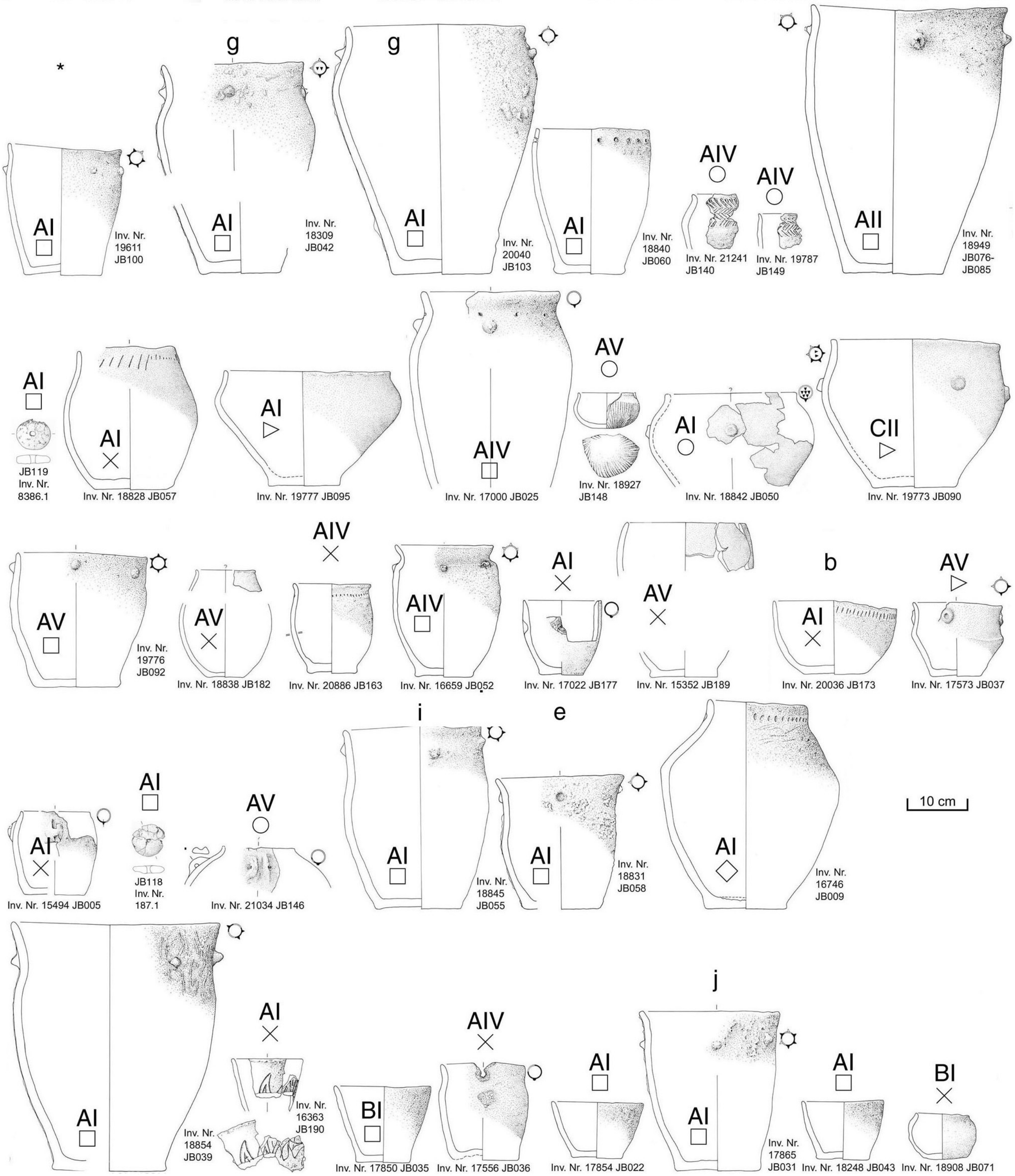


***Figure 6.13C:** Illustration of the dendrogram (Fig. 6.12): each ceramic is presented (drawing AATG, M. Lier and E. Schön) and the typological and petrographical group (see Table 5.1) it belongs to is mentioned. Small letters (a, b, c, etc.) represent the ceramics with similar details (after* DE CAPITANI 2002*). * shows seven ceramics of the petrographical group AI chemically alike, six Pfyn/Horgen pots and one spindle whorl.*

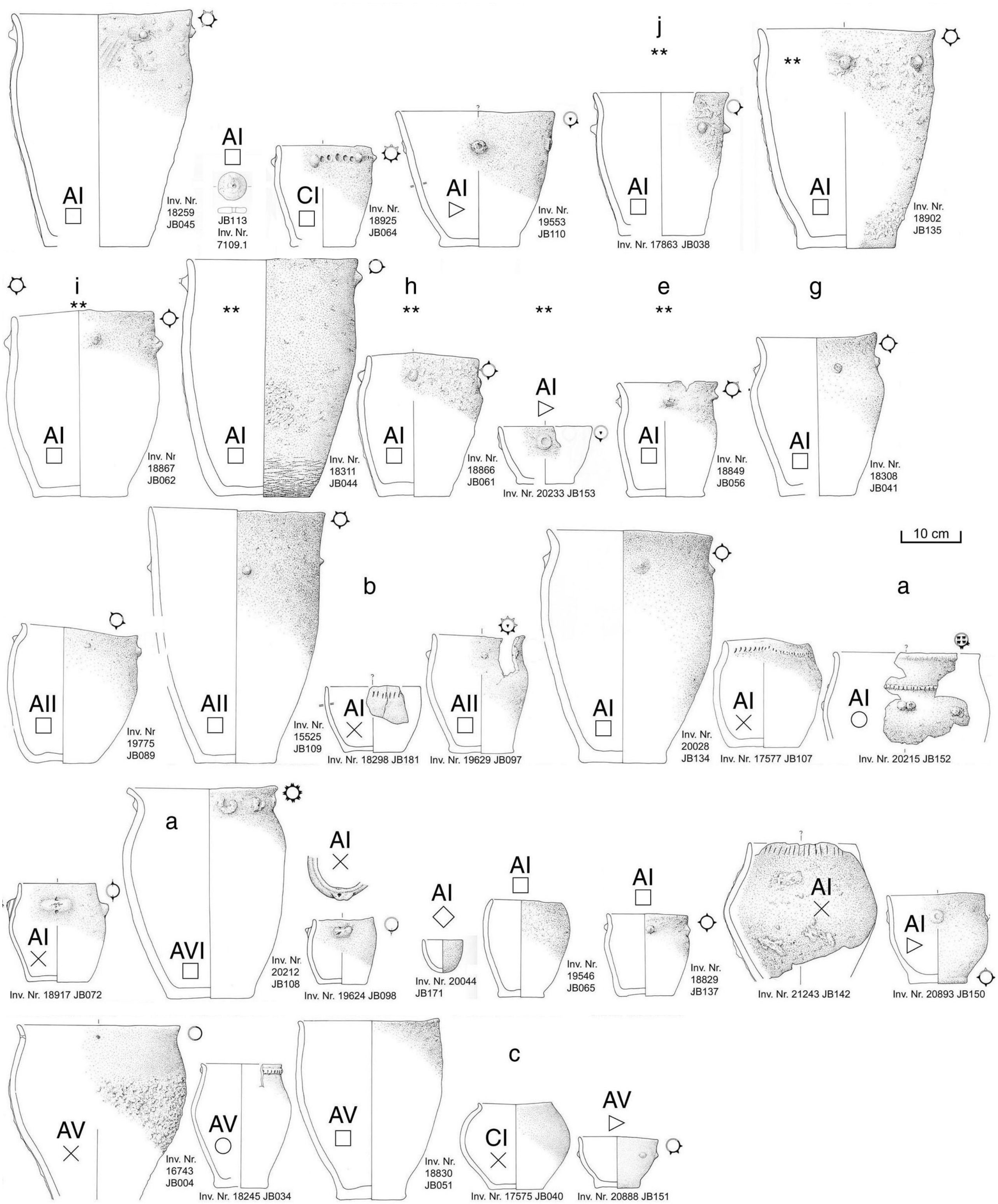


Figure 6.13D: *Illustration of the dendrogram (Fig. 6.12): each ceramic is presented (drawing AATG, M. Lier and E. Schön) and the typological and petrographical group (see Table 5.1) it belongs to is mentioned. Small letters (a, b, c, etc.) represent the ceramics with similar details (after* de Capitani 2002*). ** show seven ceramics of the petrographical group AI chemically alike, six Pfyn/Horgen pots and one special form Bayern.*

As previously shown with the bivariate plots, all the ceramic samples presented here do not chemically match the typological or petrographical groups, being chemically similar (except some rare outliers discussed after). Therefore different provenance of the samples seems not plausible. Only small chemical differences (same clay, but several beds for example, or same clay, but various temper types or amounts) can lead to such a dendrogram. The exceptions presented at the end of Fig. 6.13E are put as outliers because of their position, separated from the other groups, in the dendrogram; they will be discussed below.

6.6.2.4 Principal component analysis (PCA)

As shown on Fig. 6.14A, no petrographical group can be separated in the ceramic from Arbon Bleiche 3 (except those tempered with bone that are not represented). Only some samples can be considered as exceptions, such as JB012 and JB070. Hence, we took the three major petrographical groups of Arbon Bleiche 3 (AI, 83 samples; AIV, 11 samples and AV, 49 samples, see Table 5.1) and repeated the PCA only with these samples (Fig. 6.14B). The result is somewhat better, but the groups are still not well separated. If we only include the groups AI and AV (Fig. 6.14C), and finally only the Pfyn / Horgen pots belonging to the group AI and the special form Boleráz belonging to group AV (Fig. 6.14D), the results become clearer, but even these latter two groups are not easy to differentiate. As mentioned in the last subsection, only small chemical differences can induce such a difficulty in separating the samples into groups.

PCA using the recalculated compositions of the samples containing bone as temper (see subsection 4.2.1.6.) shows that three potteries now figure in the

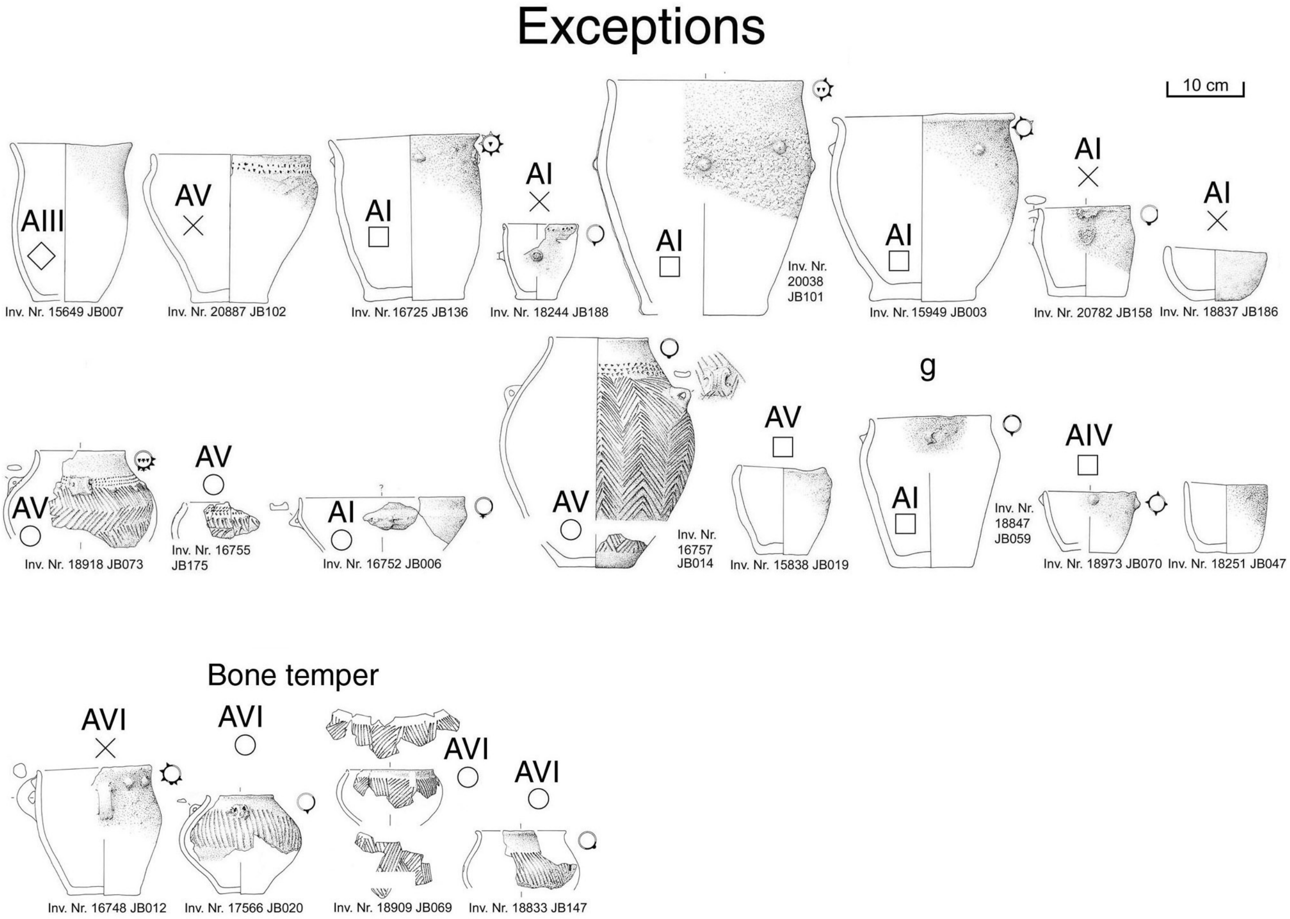


Figure 6.13E: *Illustration of the dendrogram (Fig. 6.12): each ceramic is presented (drawing AATG, M. Lier and E. Schön) and the typological and petrographical group (see Table 5.1) it belongs to is mentioned. Small letters (a, b, c, etc.) represent the ceramics with similar details (after* de Capitani 2002*). The drawings of the four ceramics containing bone temper are added, even if they are chemically very different from all the ceramics of Arbon Bleiche 3.*

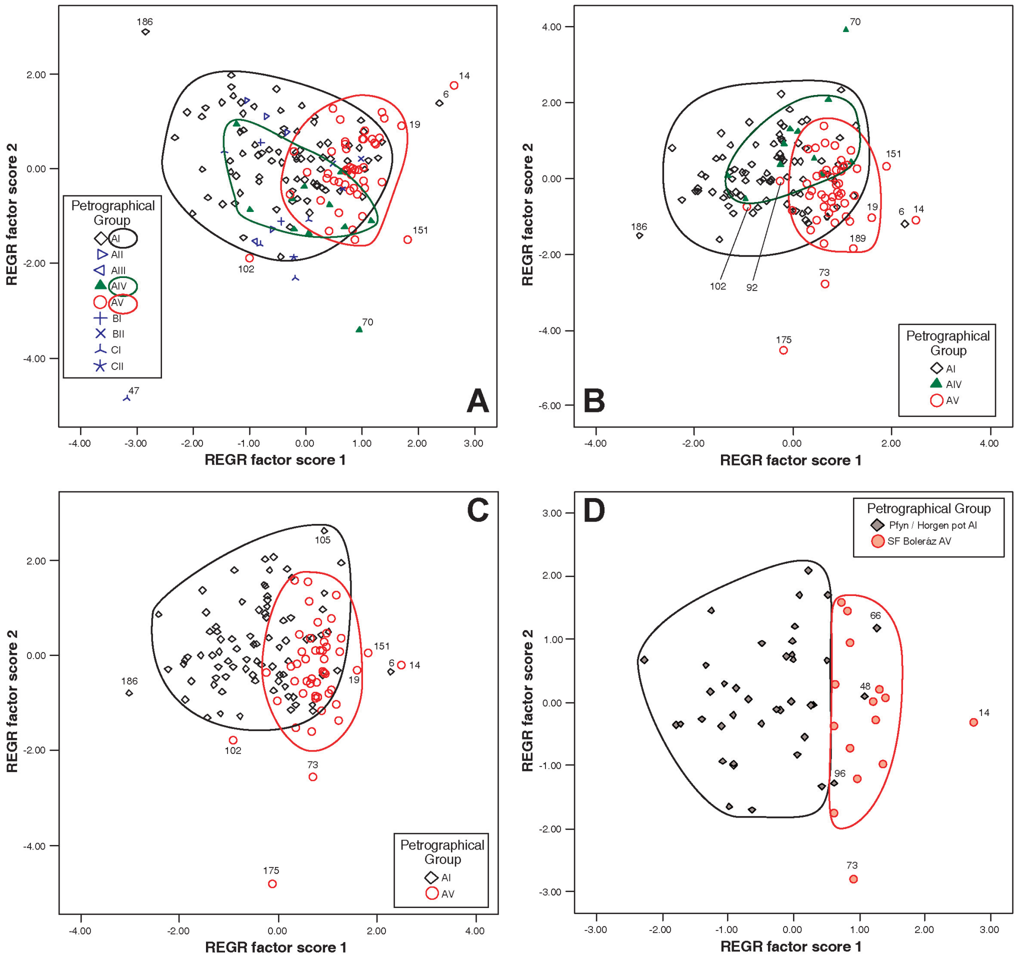


Figure 6.14: *PCA results for : A: all the petrographical groups (see Table 6.3), B: the petrographical groups AI, AIV, AV; C: the petrographical groups AI and AV, D: Pfyn / Horgen pots AI and SF Boleráz AV. Note that the groups gradually separate better, but there is no way to split them totally (numbers = sample numbers: JB…)..*

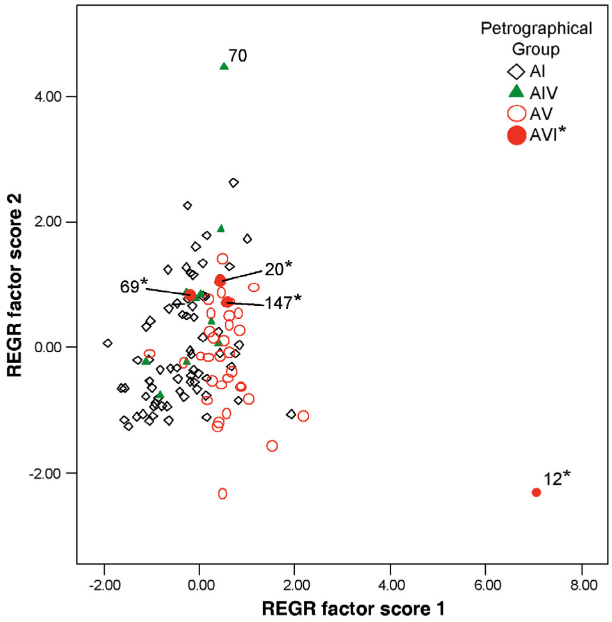


Figure 6.15: *PCA of recalculated ceramics tempered with bone versus the main petrographical groups from Arbon Bleiche 3 (* for recalculated composition, numbers = sample numbers: JB…).*

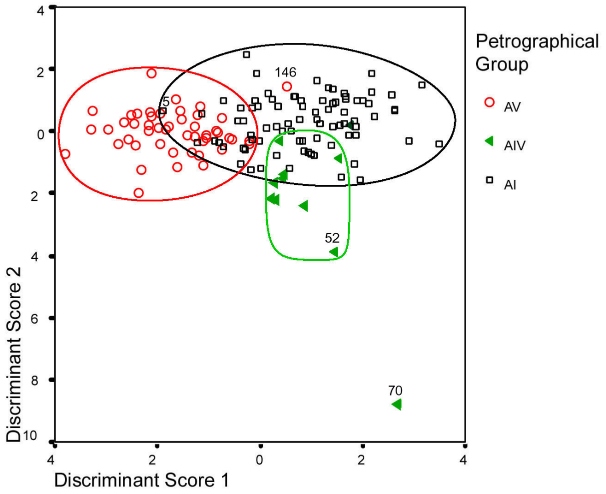


Figure 6.16: *DA on the petrographical groups AI, AIV and AV (see Table 5.1). A fairly good separation between groups is almost achieved.*

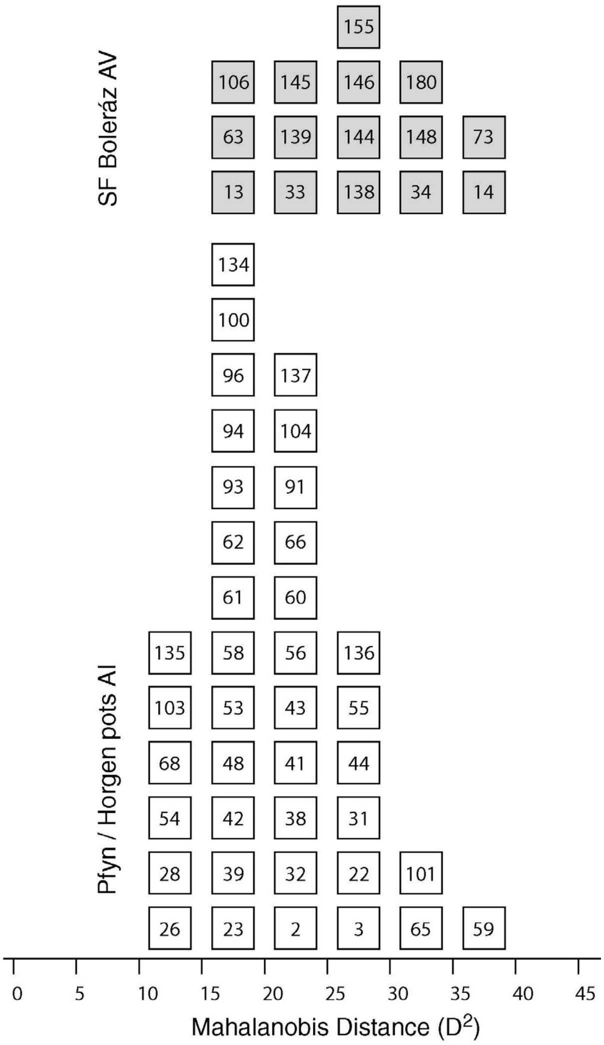
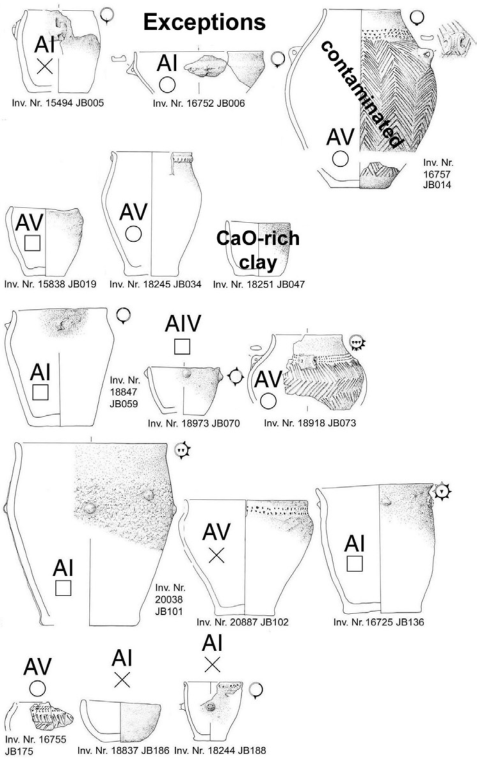


Figure 6.17: *Histogram of the Mahalanobis distance (MD) for the special forms Boleráz (petrographical group AV) calculated in relation to the petrographical group Pfyn / Horgen pots (petrographical group AI). Both histograms overlap (one square = one sample; number in squares: sample number).*

Fig. 6.18: *Possible exceptions in the samples from Arbon Bleiche 3 as a function of different chemical methods (descr. stat.: descriptive statistics; cluster: cluster analysis; PCA: principal component analysis; DA: discriminant analysis; JB…: sample numbers). On the right-hand side, drawing of the ceramics present two or more times in the table (drawings AATG, M. Lier and E. Schön), the typological and petrographical groups it belongs to (see Table 5.1).*

Possible exceptions

Contamination	Descr. stat.	Cluster	PCA	DA	Mahalanobis
JB002 ?					
		JB003			
	JB005			JB005	
	JB006	JB006	JB006		
		JB007			
JB014		JB014	JB014		JB014
		JB019	JB019		
JB025 ?					
JB028 ?					
JB031 ?					
	JB034				JB034
	JB047	JB047	JB047		
				JB052	
	JB056				
		JB059			JB059
JB061 ?					
					JB065
	JB070	JB070	JB070	JB070	
	JB073	JB073	JB073		JB073
			JB092		
		JB101			JB101
		JB102	JB102		
	JB113				
	JB118				
	JB136	JB136			
				JB146	
			JB151		
		JB158			
	JB163				
	JB173				
		JB175	JB175		JB175
	JB183				
	JB186	JB186	JB186		
	JB188	JB188			



range of the ceramic samples that do not contain bone (Fig. 6.15). This means that the clay used for these bone tempered samples is probably similar to the clays used for the other potteries. Only JB012, which also contains high proportions of TiO_2, Al_2O_3, Fe_2O_3, Ba, Cr, Nb, Ni, Pb, Sr, V, Y, Zn and Zr, whereas MgO, CaO, Na_2O and K_2O are lower, still stays apart from the other ceramics. A different clay must have been used to make this ceramic.

6.6.2.5 Discriminant analysis (DA)

DA calculates factors that maximise the differences between the pre-established groups (in this case, the petrographical groups). That statistical method did not permit to separate the ceramics into several well-distinguished groups (Fig. 6.16); only the distinction due to the kind of temper used is perceptible and leads to this partial grouping of the samples.

6.6.2.6 Mahalanobis distance (MD)

The comparison between the two most different typological and petrographical groups of Arbon Bleiche 3, Pfyn / Horgen pots AI vs. the special form Boleráz AV is shown on Fig. 6.17. We can only observe a small difference between the two histograms of the MD. The histogram of the Pfyn / Horgen pots AI has the majority of its samples between 15 and 25, whereas those of the special form Boleráz AV are mainly between 20 and 35.

The grouping of the samples is very good: each histogram on Fig. 6.17 can be represented by a Gaussian curve. Moreover, even if one single histogram is made by the grouping of the two presented, a single Gaussian curve still includes all the samples.

The matching of both histograms is clear evidence that both groups are chemically similar and therefore of a same origin, i.e. there is no way to detect two different origins of the samples.

6.6.2.7 Exceptions

Fig. 6.18 shows the outliers put into light by the diverse methods presented higher. It was said before that one sample was surely contaminated, JB014. This one was an exception in three different methods, i.e. cluster, PCA and DA. Other samples were possibly contaminated (2, 25, 28, 31, 61); they were never present in the outliers, whatever was the method used. These five samples were not contaminated enough to be considered as chemical exceptions.

Other ceramics, present as exceptions in only one method, were not chemically different enough form the other samples to be considered as outliers. It is the case for JB003, JB007, JB052, JB056, JB065, JB092, JB113, JB118, JB146, JB151, JB158, JB163, JB173 and JB183. Some samples are exceptions in two different methods (JB005, JB019, JB034, JB059, JB101, JB102, JB136 and JB188) or in three (JB006, JB014, JB047, JB070, JB073, JB175 and JB186). Note that in these latter samples, JB014 is contaminated and JB047 (petrographical group CI) is a sherd of a ceramic made of a carbonate-rich clay (CaO = 12.84 wt.%), which could be made with a similar clay than the one used to manufacture the non-ceramic material (mean CaO: 14.92 wt.%).

Hence, on 159 ceramics from Arbon Bleiche 3 (bone tempered ones excepted), only five (JB006, JB070, JB073, JB175 and JB186) are chemically quite different. These are surely made of a different clay. The other eight outliers present twice in Fig. 6.18 are also probably made of a dissimilar clay, but this affirmation shall be taken with care.

The 15 ceramics drawned on Fig. 6.18 are now considered as outliers and will not be part of the reference group of Arbon Bleiche 3.

6.7 REFERENCE GROUPS

6.7.1 Arbon Bleiche 3 – a new reference group

The potteries from Arbon Bleiche 3 are chemically similar and form one single group (in this case, the 13 outliers, plus JB014 – contaminated – and JB047 – made of a CaO-rich clay – are not part of this group). It is not possible to distinguish chemically the different petrographical groups. The question whereas the ceramics are local or imported can be answered with comparing this group to others reference groups.

6.7.2 Swiss Neolithic chemical reference groups versus Arbon Bleiche 3 ceramics

In this study, 163 pottery samples have been analysed, a number that is sufficient to delimit different chemical reference groups, if they are present, and to evaluate their homogeneity. Eight Neolithic reference groups of different Swiss sites (Appendix 10) were used for comparison.

First, the samples studied in Zürich (Kleiner Hafner) by SCHUBERT (1987). Second, the two reference groups defined in BENGHEZAL (1994A) as Vinelz-Sutz-Auvernier-Portalban-St. Blaise. Those groups, separated one from the other by their content in CaO, were not considered as homogeneous; as DI PIERRO (2002) discussed, both groups contain potteries, cob fragments, and loom weights together. We only used the raw chemical analyses of potteries of all these sites, as if they were five separated reference groups (Vinelz, Sutz, Auvernier, Portalban and St. Blaise). Third, the ceramics studied by DI PIERRO (2002): he defined two reference groups, Portalban and St. Blaise.

The Mahalanobis distances were calculated for all these samples in relation with those of Arbon Bleiche 3. The calculation was done with 18 available elements for Zürich (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5, Ba, Cr, Cu, Ni, Rb, Sr, Zn and Zr) and 22 elements for the other reference groups (the same ones plus Nb, Pb, V and Y). Figure 6.19 show the Mahalanobis distances of the ceramics from Zürich versus those of Arbon Bleiche 3. Figure 6.20 shows the distances measured for all the other reference groups versus Arbon Bleiche 3. In both figures, the possible belonging of each ceramic to one or another reference group can be observed. Higher is the distance, lower is the probability for the sample to belong to the reference group.

The majority of the ceramics from Arbon Bleiche 3 (D2 < 25) can be distinguished from those of Zürich (D2 > 25, Fig. 6.19). However, the samples from Arbon Bleiche 3 with a Mahalanobis distance higher than 25 (23 samples) cannot be chemically distinguished. This overlap is attributed to the geographical proximity of these two sites and moreover, their similar geology (mollasic beds of the eastern Swiss).

All the samples from Arbon Bleiche 3 (D2 < 60, Fig. 6.20) are easily separated from those of Auvernier and St. Blaise. Only one sample (D2 < 55) from Portalban (BENGHEZAL, 1994A), Sutz and respectively Vinelz superposes the higher distances of Arbon Bleiche 3 ceramics. However, the samples of DI PIERRO (2002) from Portalban do not separated well. This fact is difficult to explain, because those of BENGHEZAL (1994A) from Portalban separate much better.

All the mentioned reference sites lie in the Molasse basin (Fig. 6.21). Arbon Bleiche 3 and Zürich are between the Alps and the Jura, and were covered by the Rhine glacier, which carried moraine deposits from the Eastern Alps to the Constance Lake. Below the glacial deposits Upper Marine Molasse beds are present in Arbon Bleiche 3 and Zürich. In Zürich Upper Freshwater Molasse outcrops can also be found. These geological similarities explain the superposition of the samples observed on Fig. 6.19.

Vinelz, Sutz and Portalban are closer to the Jura Mountains, from which they are separated by the lakes of Biel and Neuchâtel. St. Blaise and Auvernier are lying on the Western side of the lake Neuchâtel, directly on the foot of the Jura chain. These last five sites were covered by the Rhône and partially the Aar glaciers during the glaciations, which carried material from the Western Alps. In Vinelz, Sutz and Portalban, the moraine deposits are underlain by Upper Marine Molasse and of Lower Freshwater Molasse beds. In St. Blaise and Auvernier, Mesozoic rocks related to the Jura Mountains are also close to the surface. These geological differences can explain the separations between the samples of the sites presented on Fig. 6.20, except for Portalban (DI PIERRO, 2002).

As a conclusion, the samples of Arbon Bleiche 3 cannot be attributed to an existing reference group, and, hence, are defined as a new Swiss Neolithic reference group. The chemical differences within the Pfyn / Horgen pots, the special forms and the spindle whorls are small enough to form one single reference group, despite the petrographical differences described in the samples.

As specified in MAGGETTI (1995A, 236), "the results concerning the reference groups should be taken with care, because a sample today resembling a reference group can be tomorrow better correlated with a new defined reference group. A reference group is established with only a few samples (n= 30-100), which is not a guaranty of the representativeness of all the production site."

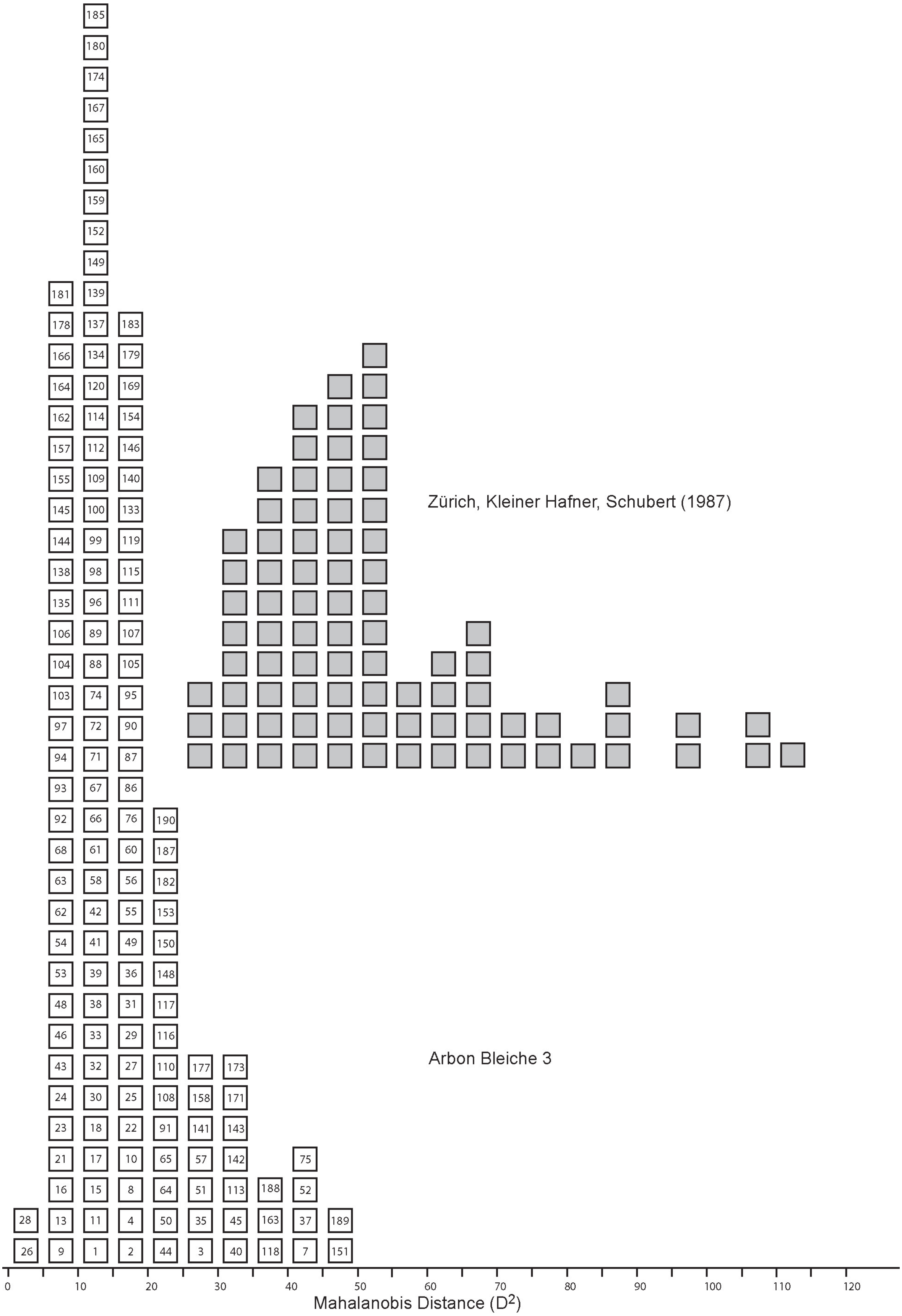


Figure 6.19: *Histogram of the Mahalanobis distance (MD) for the reference group Zürich Kleiner Hafner calculated in relation to the ceramics from Arbon Bleiche 3. The histograms are separated (one square = one sample; number in white squares: sample number).*

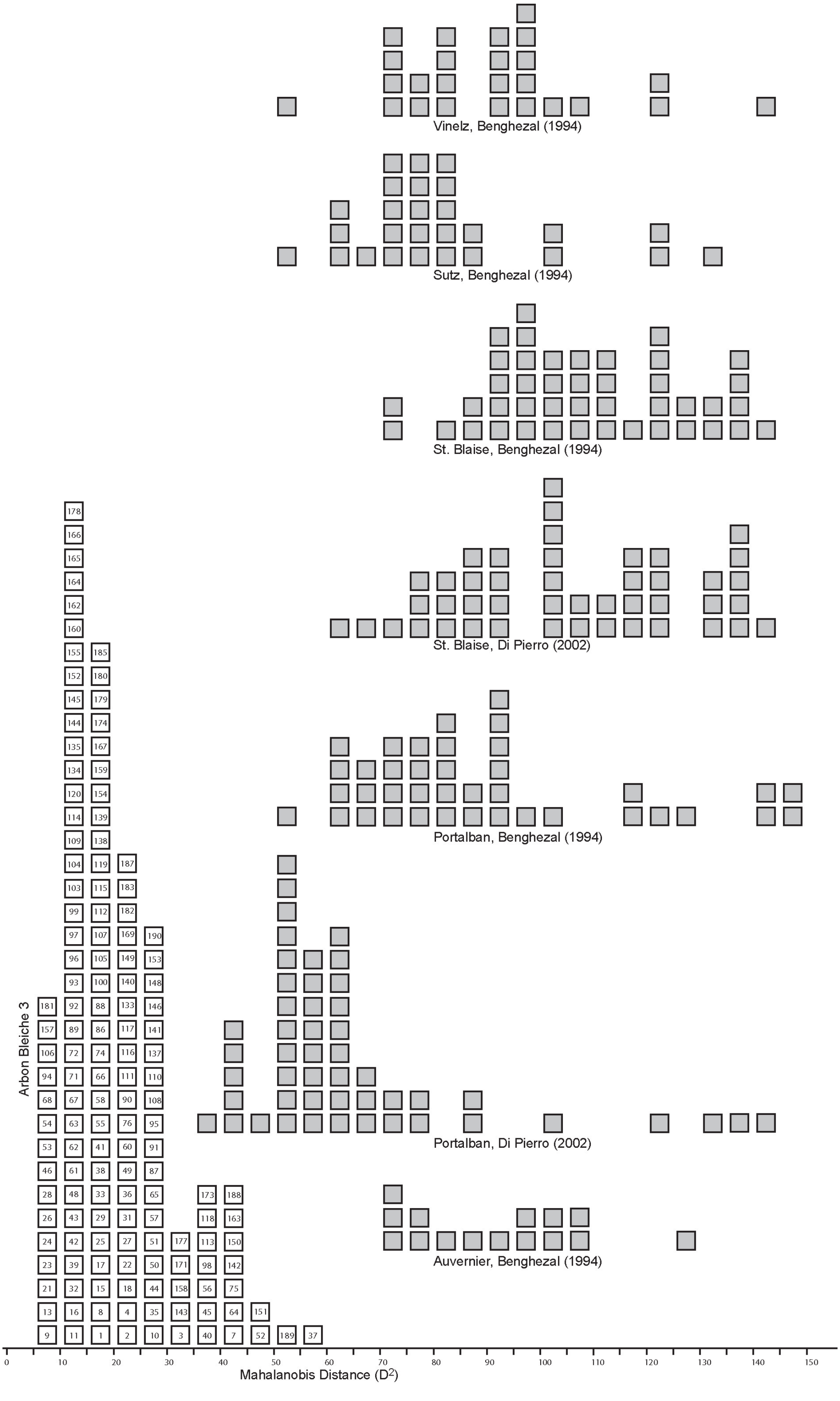


Figure 6.20: *Histogram of the Mahalanobis distance (MD) for seven Swiss Neolithic reference groups calculated in relation to the ceramics from Arbon Bleiche 3. Each histogram is separated from that of Arbon Bleiche 3 (one square = one sample; number in white squares: sample number).*

6.8 SPATIAL REPARTITION

PÉTREQUIN ET AL. (1994, 1996) describe the domestic production of pottery in Chalain during final Neolithic as follows: each household exploits its own raw material to manufacture the ceramics it needs. In this case, temper and matrix used in one house should be differentiable from those used in other houses if the potters used different clays and/or tempers.

DE CAPITANI (2002) observed no correlation between the archaeological typology and no spatial distribution in the houses.

The petrographical and chemical groups defined in this work did neither show any particular relation with houses. Even the smallest groups of ceramics (AII: n=4; AVI: n=4; BI: n=2; B2: n=3 and CI: n=5) were not found in a single house (Fig. 6.22).

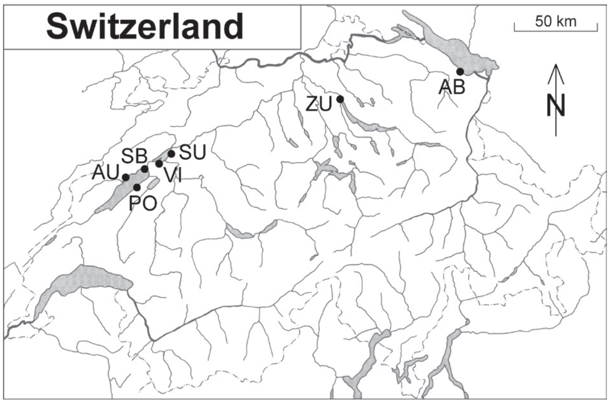


Figure 6.21: Map of Switzerland with the emplacement of the Swiss Neolithic reference groups; AB: Arbon Bleiche 3, AU: Auvernier La Saunerie, PO: Portalban, SB: St. Blaise, SU: Sutz, ZU: Zürich Kleiner Hafner.

As defined in the beginning, the Pfyn / Horgen pots are though by the archaeologists to be local ceramics, due to their typology, number abundance and manufacturing process. As shown by the chemistry, the local clays could correspond with the clays used to manufacture these Pfyn / Horgen pots. Moreover, all the ceramics from Arbon Bleiche 3 (except 15 outliers, plus JB012, tempered with bone) show only small chemical variations, but cannot be split into several groups. Hence, we propose that all the ceramics from Arbon Bleiche 3 (except these 16 outliers) were made of local clays.

The presence of one kind of clay used to manufacture ~90% of the studied ceramics induces the idea of one or several potter(s) producing ceramics for the whole village. The source of clay was certainly a precise pit, local, and bound to a single geological bed. In such a case, it is no surprise that so many ceramics show so few chemical variations (see chapter 8).

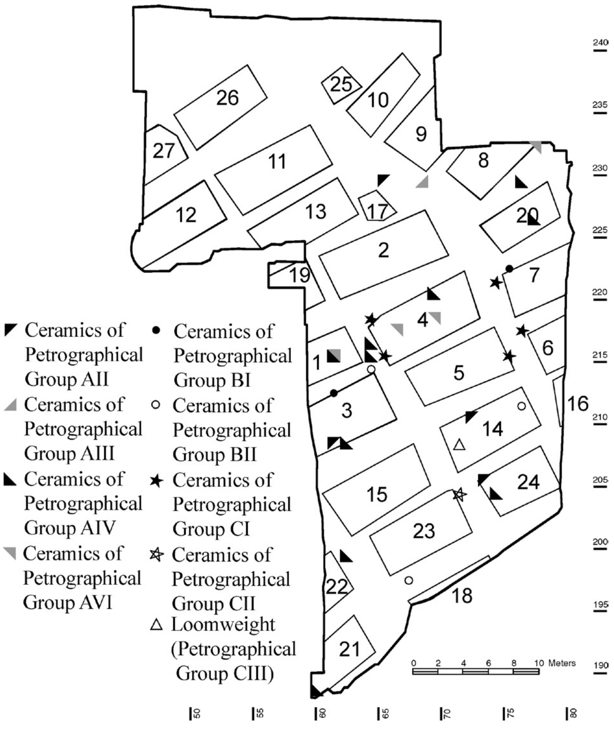


Figure 6.22: Map of the excavations of Arbon Bleiche 3 with the precise location of the studied sherds for several small petrographical groups (AII, AIII, AIV, AVI, BI, BII, CI, CII, CIII).

7 - ARCHAEOMETRICAL RESULTS CONCERNING THE CERAMIC MATERIAL: THE 14 SAMPLES OF POTTERIES FROM THE WESTERN CARPATHIAN BASIN

7.1 INTRODUCTION

The archaeological typology and the presence of bone temper in four ceramic pieces from Arbon Bleiche 3 have induced a necessary comparison with 14 sherds coming from the western Carpathian Basin (Baden culture). The 14 samples studied come from three different regions: five ceramics from Mödling "Jennyberg" (A), five from Žlkovce (SK) and four from Náměšt na Hané (CZ) (DE CAPITANI, 2002, 214).

7.2 MACROSCOPIC DESCRIPTION

All the sherds resemble strongly to those of the special form Boleráz from Arbon Bleiche 3: the sherds are thin (< 8 mm), black or grey with a black core and tempered with small beige to brown grains (grog). One sample also contains white grains or fragments (rock) as temper.

7.3 PETROGRAPHICAL STUDY

The petrographical study showed that all the samples from the western Carpathian Basin have an inclusion-poor and silicate-rich matrix. 93% of the ceramics were mostly tempered with grog (13 samples have a similar aspect to those of petrographical group AV of Arbon Bleiche 3). Granite mostly tempered only one sample (this sample from Mödling, JB201, is alike petrographical group AI of Arbon Bleiche 3).

None of these fourteen samples was tempered with bone, but six thin sections contained a few small fragments of bone (JB202, JB203, JB208, JB212: one fragment; JB200: two fragments; JB213: three). A direct correlation between these ceramics and the petrographical group AVI of Arbon Bleiche 3 (ceramics tempered with bone) is not possible, but this can go back to the insufficient number of samples studied.

7.4 CHEMICAL DESCRIPTION

First goal of the chemical investigation of the 14 samples from the western Carpathian Basin was to detect chemical differences to those from Arbon Bleiche 3. We also wanted to know if some potteries from Arbon Bleiche 3 could be chemically alike these samples and therefore show a far provenance.

A comparison between the ceramics from the three sites of the western Carpathian Basin (Mödling, Appendix 9D; Žlkovce, Appendix 9E and Náměšt na Hané, Appendix 9F) and those from Arbon Bleiche 3 mainly tempered with grog and with less or no granite (petrographical group AV, Appendix 9G) was done with descriptive statistics. The ceramics made in Mödling contained less SiO_2, Cu and Zn, and more TiO_2, Al_2O_3, Fe_2O_3, MnO, Cr, Pb, V, Y and Zr than those from Arbon Bleiche 3. Those from Žlkovce contained less Cu and more Fe_2O_3, MnO, Na_2O, K_2O, Sr, Y and Zr whereas those of Náměšt na Hané were poorer in CaO, Ba, Cu, Ni, Sr and Zn and richer in TiO_2, Fe_2O_3, P_2O_5, Y and Zr. As shown on Fig. 7.1, PCA permit to distinguish the petrographical group AV from Arbon Bleiche 3 from the ceramics from the three western Carpathian Basin sites, respectively Mödling (Fig. 7.1A), Žlkovce (Fig. 7.1B) and Náměšt na Hané (Fig. 7.1C). Only one sample, JB175, a chemical outlier in the ceramics from Arbon Bleiche 3 can maybe be put into relation with the ceramics from Žlkovce, due to their proximity on Fig. 7.1B.

All three western Carpathian Basin groups are too different from the ceramics of the petrographical group AV of Arbon Bleiche 3 to think of an importation of ceramics from the western Carpathian Basin to Arbon.

All the ceramics from the western Carpathian Basin have a higher content of Y (up to 51 ppm) than the potteries from Arbon Bleiche 3. We mentioned before, that sample JB012 from Arbon Bleiche 3, the possible exogenous ceramic, has a high proportion of Y (444 ppm). Hence, the content of Y in the samples from the western Carpathian Basin is too low to show a relation with JB012. The value of 444 ppm Y is very uncommon, and it will be a challenge for the future to find the provenance of this clay.

Fig. 7.2 presents the Mahalanobis distances (MD) of the Pfyn / Horgen pots of the petrographical group AI and the special form Boleráz of the petrographical group AV from Arbon Bleiche 3 versus the ceramics from the western Carpathian Basin. The relation between these histograms is very different from that of Fig. 6.17. The MD of the majority of the samples from the western Carpathian Basin is high, between 45 and 55, whereas the one of the ceramics from Arbon Bleiche 3 (Pfyn / Horgen pots AI and special form Boleráz AV) is between 10 and 35. Hence, we can deduce by the chemistry that the samples from Arbon Bleiche 3 have a different provenance than those of the western Carpathian Basin.

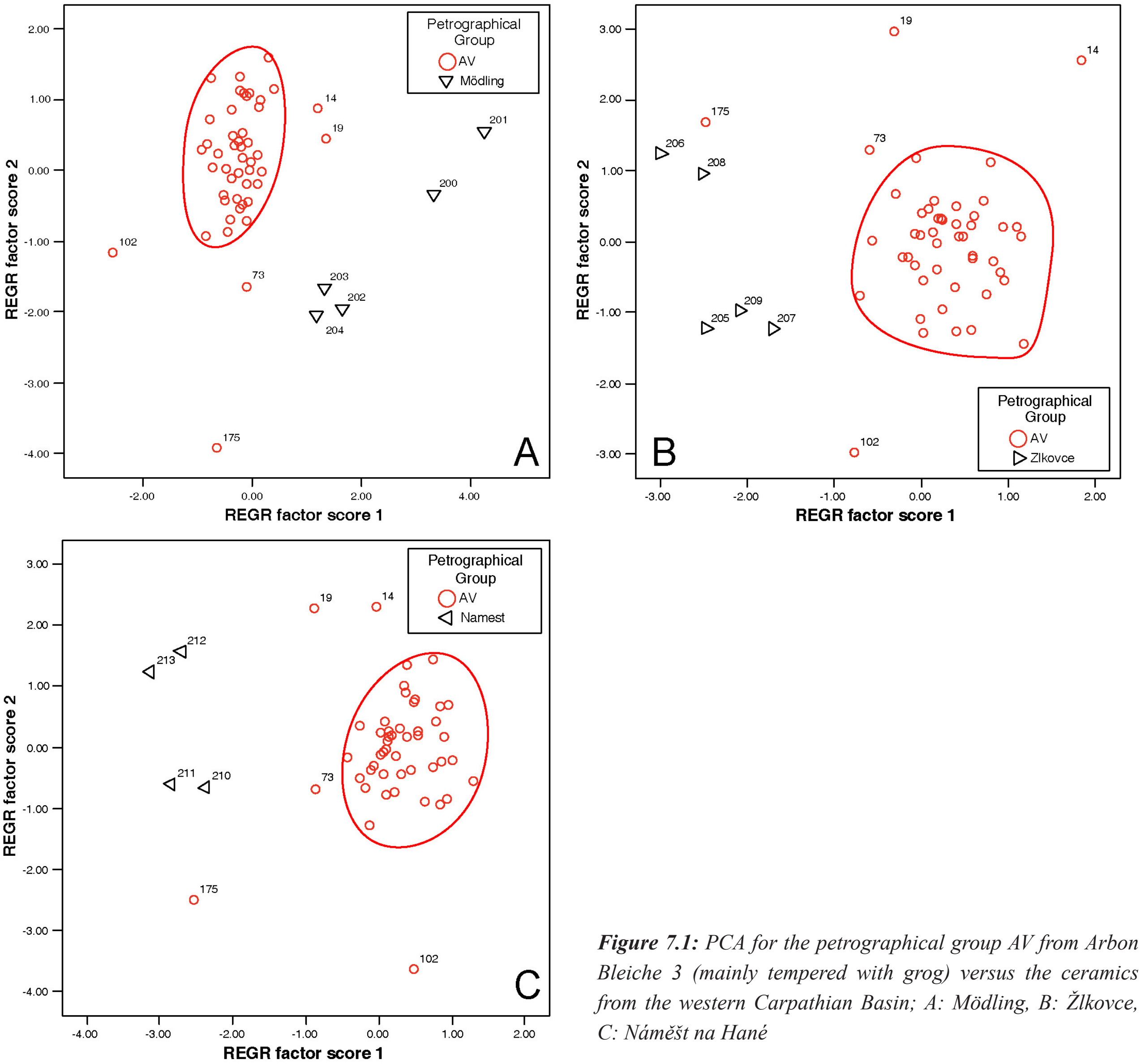


Figure 7.1: PCA for the petrographical group AV from Arbon Bleiche 3 (mainly tempered with grog) versus the ceramics from the western Carpathian Basin; A: Mödling, B: Žlkovce, C: Náměšt na Hané

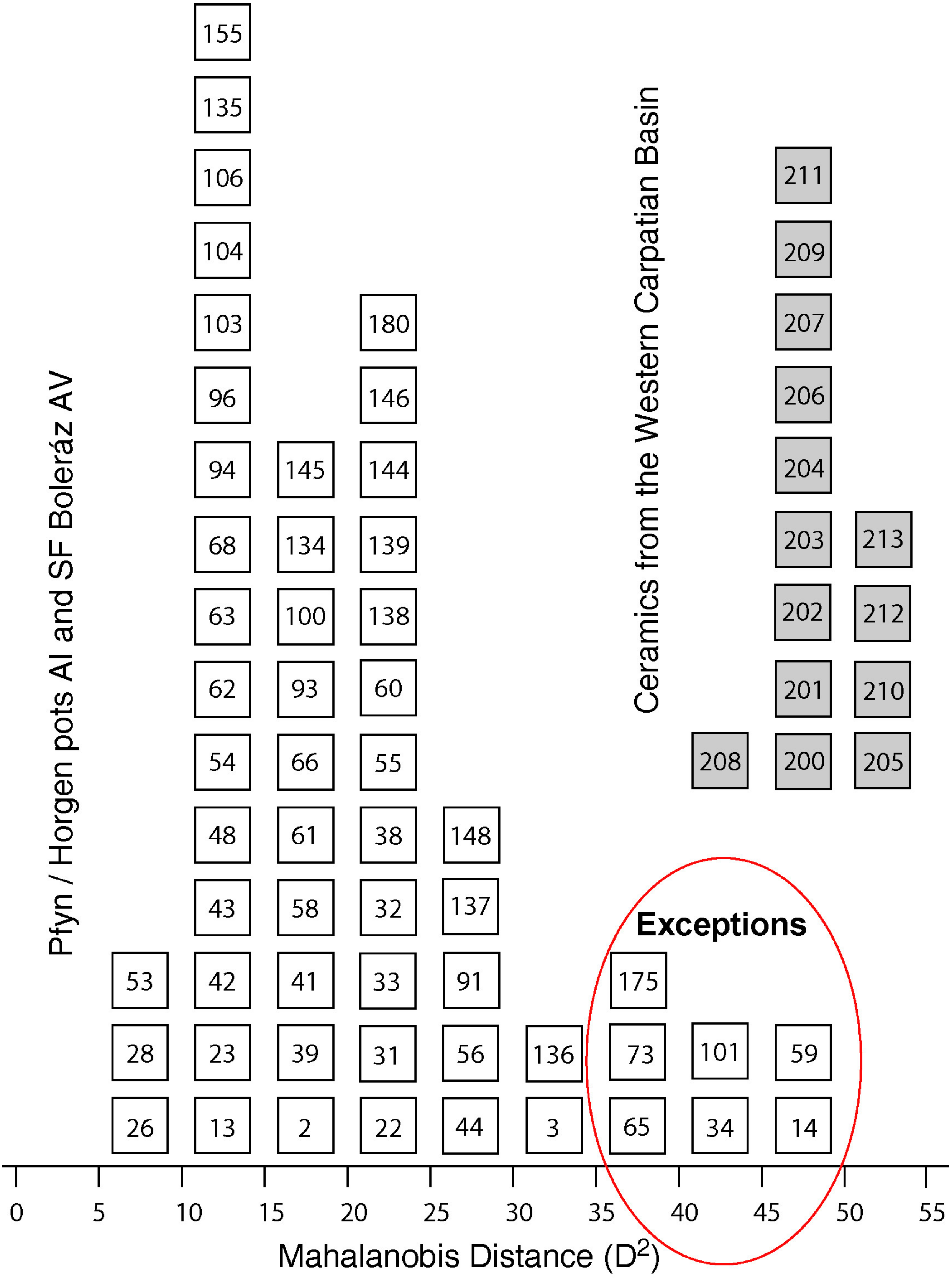


Figure 7.2: *Histogram of the Mahalanobis distance for the ceramics from the Western Carpathian Basin calculated in relation to the reference groups Pfyn / Horgen pots (petrographical group AI) and SF Boleráz (petrographical group AV). The histograms are quite dissimilar (one square = one sample; number in squares: sample number).*

The samples circled on Fig. 7.2 are considered as exceptions and were previously discussed (subsection 6.6.2.7). Even if these potteries show a Mahalanobis distance just below or in the range of that of the ceramics from the western Carpathian Basin, a relationship cannot be deduced. Indeed, the PCA presented before have shown a clear division between these exceptions and the samples from the western Carpathian Basin (Fig. 7.1).

8 - ARCHAEOMETRICAL RESULTS CONCERNING THE POTENTIAL TEMPER AND CLAY RESSOURCES OF THE NEOLITHIC VILLAGE

8.1 THE ROCKS

On the lake shore near Arbon, a "museum of erratic blocks" was created in the 1930s. These rocks were all discovered in-situ and were brought there by the Rhine glacier. According to WEGELIN (1936), they are composed of (Fig. 8.1): (1). Suretta-Rofna-Porphyroid. (Quartz-porphyroid, rich in orthoclase, provenience: Via Mala, travel distance: 135 km along the Rhine valley); (2). Syenite (Taspin Alps, coarse-grained, crystalline rock with big, white feldspars, small grey quartz and pale green to grey micas; (3). Epidote-Chlorite-Hornblende Schist (from the Valsertal region); (4). Granite from the Julier region; (5). Light coloured granites (uncertain provenance); (6) Banded gneiss (from Val Somvix, Greina or Val Gonda or Gotthardmassiv, West Val Medels); (7). Paragneiss (from Silvretta or Adula or Gotthardmassiv); (8). Granite (from Julier or Albula, Amphibole-biotite granite with apple-green plagioclases); (9). Pegmatite (from Tavetsch and Somvitg); (10). Red Verrucano (from the region of Davos, conglomerate with pebbles of quartzite, rhyolite and ophiolite); (11). Amphibolite (maybe from Val Puntaiglas or Medelser Gipfeln or Piz Valdrans); (12). Granite (from Val Puntaiglas, with big orthoclase twinning and titanite); (13) Many kinds of limestones, including one shelly sandstone.

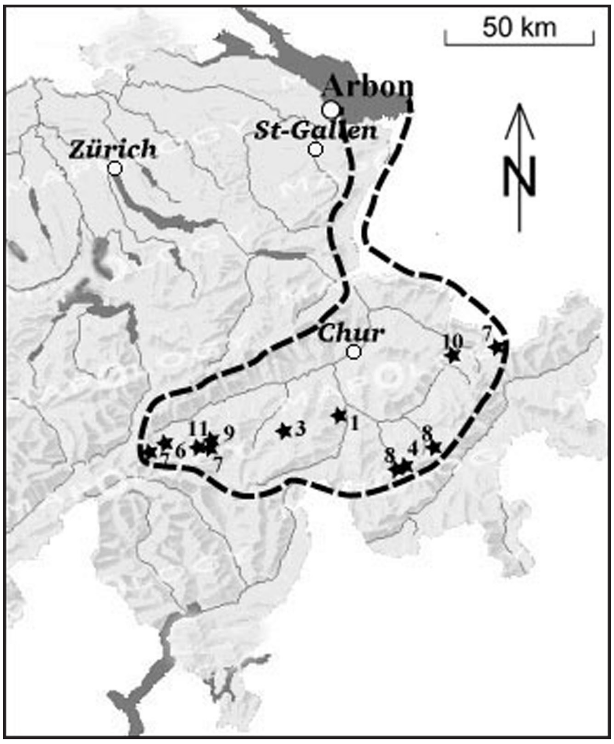


Figure 8.1: *The Rhine River Basin and the provenance of the rocks described in the "museum of erratic blocks"; the number refer to text.*

Bonzon			
Granite **large grains of:** quartz alcaline feldspars plagioclases micas **no matrix**	**Rhyolite** **large grains of:** quartz alcaline feldspars plagioclases micas **glassy matrix**	**Chert** **very small grains of:** quartz **no matrix**	**Gabbro** **large grains of:** plagioclases pyroxenes sometimes with hornblendes, olivines, micas **no matrix**
Wegelin (1936)			
Granite **Pegmatite** **numbers:** 4, 5, 8 & 12 9	**Porphyroïde** **number:** 1 **Present as pebbles in Verrucano** number 10	**Present as pebbles in Verrucano** number 10	**Present as pebbles in Verrucano** number 10

Table 8.1: *Relation between the nomenclature used for the names of rocks in this work and in* WEGELIN (1936)*; the numbers refer to text and to figure 8.1.*

The relation between the rocks described as temper in this thesis and those used by WEGELIN (1936) are shown on Table 8.1.

The Neolithic people used mainly granites and smaller amounts of gabbros, rhyolites and cherts to temper their potteries. All those rocks are still present on the shore of Lake Constance, near Arbon. Various kinds of coarse granitic rocks are available in the morainic deposits (numbers 4, 5, 8, 9 and 12 in the above description). Gabbros, rhyolites and cherts are also present: the gabbros could have been carried from the ophiolite zones described near Arosa and Platta sheet or from calc-schists in the southern part of the Rhine River, between Chur and the Splügen pass. The rhyolites can come from the upper part of the Rhine River basin, in the dykes and effusive rocks of the Permian, in the south-west region of Davos. The cherts are frequent as nodules in the limestones of the Cretaceous Period, between Buchs and the Lake of Walenstadt area or in the neighbourhood of Landquart (SPICHER, 1980). It is also possible to find those kinds of rocks as pebbles in the Verrucano conglomerate (number 10).

Our microscopic observations, made on small fragments of rock in ceramic sherds, do not allow a more precise identification of a rock from a specific region of the Alps.

8.2 THE LOCAL CLAYS

8.2.1 Description of the CaO-rich clays

The eight CaO-rich samples were collected in the surroundings of Arbon, three in the moraines, JB300, JB302, JB303 and five in the Molasse, JB306–JB310 (precise provenance see Fig. 2.11). These yellow to beige samples have an inclusion-rich matrix and are petrographically very similar. Their matrix is homogeneous, containing 10 to 30 vol.% quartz grains (<0.01–0.5 mm) as natural inclusions. The smaller inclusions are rounded to sub-rounded; larger grains are sub-angular to angular.

As special features, JB308 contains one sub-angular grain of sandstone (10 mm Ø), and JB310 one grain of rounded amphibolite (0.5 mm Ø).

Table 8.2: Chemical data of the local clays collected in the surroundings of Arbon.

Arbon: Local clays:	Carbonate-rich clays									Silicate-rich clays				
Oxide, Element	JB300	JB302	JB303	JB306	JB307	JB308	JB309	JB310	Std. Deviation	Variation Coefficient	JB301	JB304	JB305	Std. Deviation	Variation Coefficient
SiO2 (wt.%)	√ 70.64	+ 74.07	√ 64.91	- 59.94	- 56.56	- 56.97	- 56.22	- 53.51	7.48	0.140	√ 70.22	√ 73.71	+ 77.70	3.74	0.048
TiO2 (wt.%)	- 0.39	√ 0.49	- 0.40	√ 0.57	√ 0.62	√ 0.46	√ 0.46	√ 0.47	0.08	0.167	√ 0.78	√ 0.79	√ 0.74	0.03	0.036
Al2O3 (wt.%)	- 6.81	√ 9.28	- 7.23	√ 11.41	+ 12.84	+ 10.26	√ 10.23	√ 10.61	2.02	0.191	√ 13.94	√ 14.49	√ 11.93	1.35	0.113
Fe2O3 (wt.%)	√ 2.38	+ 3.52	√ 2.66	+ 4.37	+ 4.76	+ 3.66	+ 3.73	+ 3.88	0.79	0.205	√ 5.51	√ 5.70	√ 4.48	0.66	0.147
FeO (wt.%)	+ 1.50	√ 0.94	+ 1.57	√ 0.57	√ 0.66	√ 1.33	√ 1.28	+ 1.54	0.40	0.259	√ 1.23	√ 0.58	- 0.54	0.39	0.717
MnO (wt.%)	+ 0.09	√ 0.06	+ 0.09	√ 0.07	+ 0.09	+ 0.08	+ 0.08	+ 0.08	0.01	0.134	+ 0.13	√ 0.09	√ 0.08	0.03	0.331
MgO (wt.%)	√ 2.04	√ 1.68	√ 1.74	+ 2.65	+ 2.59	+ 3.63	+ 3.83	+ 5.14	1.20	0.234	√ 1.95	√ 1.61	√ 1.28	0.34	0.262
CaO (wt.%)	√ 15.09	√ 8.34	+ 20.35	√ 18.51	+ 19.90	+ 21.74	+ 22.43	+ 23.59	4.95	0.210	√ 3.74	- 0.99	√ 1.57	1.45	0.923
Na2O (wt.%)	+ 0.97	+ 0.86	√ 0.78	- 0.22	- 0.20	+ 0.97	+ 0.98	√ 0.73	0.32	0.444	√ 0.83	√ 0.29	√ 0.38	0.29	0.761
K2O (wt.%)	- 1.43	√ 1.67	- 1.42	√ 2.17	√ 2.34	√ 2.04	√ 1.97	√ 2.05	0.34	0.167	√ 2.38	√ 2.44	√ 2.06	0.20	0.099
P2O5 (wt.%)	√ 0.18	√ 0.11	√ 0.27	√ 0.12	- 0.09	√ 0.12	√ 0.13	√ 0.12	0.06	0.479	√ 0.13	- 0.07	- 0.06	0.04	0.631
Ba (ppm)	- 240	√ 273	√ 291	- 249	√ 278	√ 258	√ 261	√ 270	16.4	0.061	√ 382	- 325	- 294	44.6	0.152
Cr (ppm)	√ 61	√ 71	√ 60	√ 87	√ 90	√ 78	√ 70	√ 73	10.9	0.149	√ 106	√ 109	√ 98	5.7	0.058
Cu (ppm)	√ 32	√ 62	√ 37	√ 39	√ 32	√ 26	√ 28	√ 25	11.9	0.477	√ 29	√ 32	√ 30	1.5	0.051
Nb (ppm)	- 8	√ 10	- 8	√ 14	√ 14	√ 10	√ 10	√ 11	2.3	0.211	√ 16	√ 16	√ 14	1.2	0.083
Ni (ppm)	- 24	√ 32	- 28	√ 43	√ 47	√ 39	√ 40	√ 40	7.9	0.196	√ 57	√ 54	√ 43	7.4	0.171
Pb (ppm)	+ 46	√ 17	+ 40	√ 15	√ 16	√ 18	√ 15	√ 13	12.8	0.988	√ 32	√ 24	√ 21	5.7	0.271
Rb (ppm)	- 65	√ 86	√ 73	+ 120	+ 132	√ 98	√ 98	√ 100	22.3	0.223	√ 145	√ 145	√ 124	12.1	0.098
Sr (ppm)	√ 332	- 201	√ 335	√ 492	+ 596	+ 574	+ 580	√ 531	146.8	0.276	√ 145	√ 83	√ 90	34.0	0.377
V (ppm)	- 41	√ 71	√ 52	+ 105	+ 109	√ 82	√ 78	√ 82	23.3	0.285	√ 109	√ 122	√ 94	14.0	0.149
Y (ppm)	√ 25	√ 28	√ 25	√ 28	√ 25	√ 25	√ 26	√ 24	1.5	0.062	√ 34	+ 40	√ 33	3.8	0.115
Zn (ppm)	+ 151	√ 56	+ 121	√ 78	√ 84	√ 62	√ 64	√ 69	33.3	0.483	√ 92	√ 97	√ 75	11.5	0.154
Zr (ppm)	√ 258	- 201	√ 257	√ 227	- 149	- 174	- 172	√ 154	43.9	0.285	√ 223	+ 264	+ 303	40.0	0.132

+, √, -: value respectively under, in, and over the range shown in appendix 9A (see text)

All these clays are composed of illite, quartz, K-feldspars, plagioclases, calcite and dolomite (Fig. 8.2). Chlorite is present in JB302, JB308, JB309 and JB310 and hematite in JB300, JB308, JB309 and JB310. Note that the presence of dolomite is typical in clays from the North-East Switzerland, as shown in Mumenthaler (1979).

The CaO-rich local clays (Table 8.2) were chemically compared to the samples of the loom weight and the cobs (Fig. 5.1; Appendix 9A), in order to demonstrate if some clay could correspond to those used to manufacture this kind of material. JB302 (see Table 8.2) is the one that fits best: 18 elements are in the same ranges as those on Appendix 9A. SiO_2 is a little bit low, but it can vary a lot from one bed to another and also in the same geological bed (Sigg et al. 1986). This value is near enough to the range to be acceptable.

8.2.2 Description of the CaO-poor clays

Three clays with a silicate-rich matrix (JB301, JB304, JB305) were collected. They are grey, greyish-white or bluish-grey.

JB301 (Fig. 5.1L) contains natural, non-plastic inclusions similar to those described in the thin sections of the ceramics from Arbon Bleiche 3, such as granite and chert, quartz, amphiboles and rare calcite grains, ARF and little iron oxide nodules.

JB304 matrix can be divided into different zones, each containing more or less important percentage of natural inclusions, which was also visible in some ceramics. Only particles of granite and quartz are visible as natural inclusions.

JB305 contains a very high percentage of natural inclusions, and could only be used to manufacture the ceramics with an inclusion-rich and silicate-rich matrix (petrographical groups B, hence 5 on 163 samples, see Table 5.1).

The granulometric study of these three clays shows that JB301 has a unimodal grain size distribution in contrast to JB304 and JB305, which have respectively a bi- and tri-modal grain size distribution (Fig. 8.3). These two last clays contain one class of bigger particles (15-50 µm), which is not present in JB301. This method, however, did not permit to define a proper signature for each clay that could have assured their distinction.

JB301, JB304 and JB305 contain similar clay minerals: a mixed layer illite / smectite, chlorite and illite in both argillaceous fractions (<2 µm, 2-16 µm; Table 8.3), plus quartz, K-feldspar and plagioclase. The three silicate-rich matrix clays are very similar; only the quantity of natural inclusions varies.

A chemical comparison was made between the CaO-poor clays (Table 8.2) and the ceramics from Arbon Bleiche 3 of Appendix 9B. JB301 fits the best with all the 23 chemical elements of the ceramics from Arbon Bleiche 3 (even if MnO = 0.13 wt.% and the minimum value of the range is 0.14 wt.% MnO).

As demonstrated by Di Pierro (2002), a calculated ideal solution (Fig. 8.4A) shows that the mixing of a

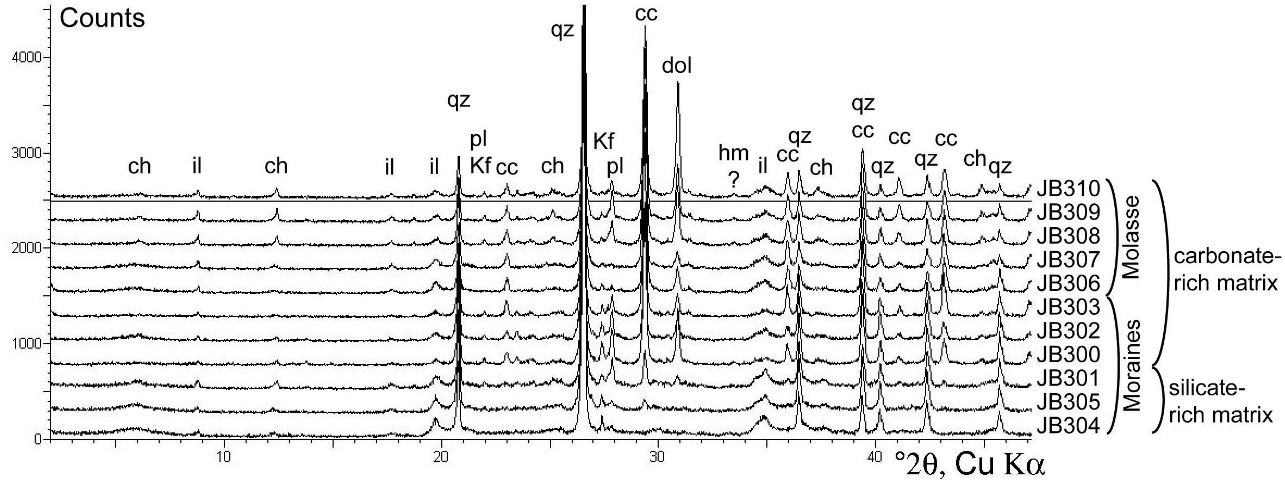


Figure 8.2: *X-ray diffractograms of eleven local clays permitting to separate carbonate-rich and silicate-rich matrixes (cc: calcite, ch: chlorite, dol: dolomite, hm: hematite, il: illite, Kf: K-feldspars, pl: plagioclase, qz: quartz).*

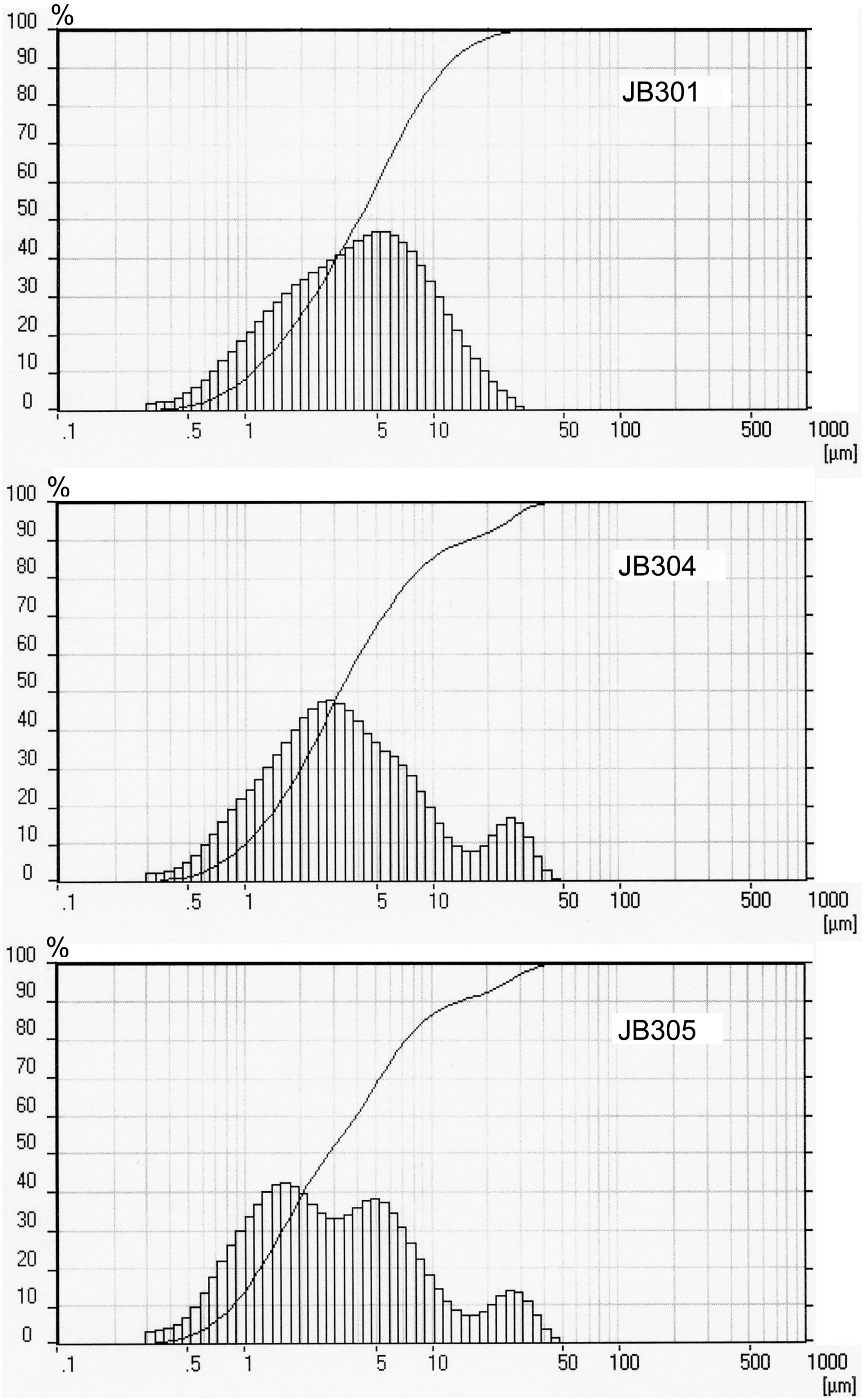


Figure 8.3: *Granulometric study of the matrix of the three silicate-rich local clays; horizontal axis: grain size diameter, vertical axis: volume percent of the grains (histogram and cumulative curve).*

	2-16 µm			< 2 µm		
Local clays	**Mix. I/S**	**Chlorite**	**Illite**	**Mix. I/S**	**Chlorite**	**Illite**
JB301	2	3	3	2	3	3
JB304	2	2	2	3	3	3
JB305	2	2	2	3	2	2

Mix. I/S = Mixed layer Illite / Smectite
1: a few, **2**: middle, **3**: much

Table 8.3: *The mineral present in two fractions (2-16 µm, < 2 µm) of the three silicate-rich local clays.*

clay (right hand side) and 23 vol.% of granite (temper, left hand side) giving potteries (centre) are in linear correlation. The latter are situated somewhere on the line between clay and granite as a function of their volume. The same graph is presented for the ceramics from Arbon Bleiche 3 and three silicate-rich clays (Fig. 8.4B). The silicate-rich clays sampled in the surroundings of Arbon do not correspond to the ones used to manufacture the potteries. If the clay used was represented, it would lie on the right hand side of the ceramics. The potteries being the result of the mixing of granite temper (grey area on Fig. 8.4B) and clay must lie somewhere on the correlation line between the two raw materials.

As mentioned before, the proportion of quartz in a geological bed varies a lot, linked with its depositional environment. Maybe the clay used in the Neolithic times is not far away from the JB301 clay, which was collected less than 500 m far from the village.

8.2.3 Interpretation

As discussed before, these observations confirm the possibility for the potters of Arbon Bleiche 3 to have found local clay in the surroundings to manufacture the ceramics. Because the local clays petrographically and mineralogically correspond to the ceramics, and as no chemical diversity was put into light within the chemical analyses, the majority of the ceramics from Arbon Bleiche 3 are surely local, as defined by archaeologists, with a well defined and proximal source.

However, as demonstrated higher, the clays sampled in the surroundings of the site do not fit perfectly well –in a chemical point of view– with the ceramics of Arbon Bleiche 3.

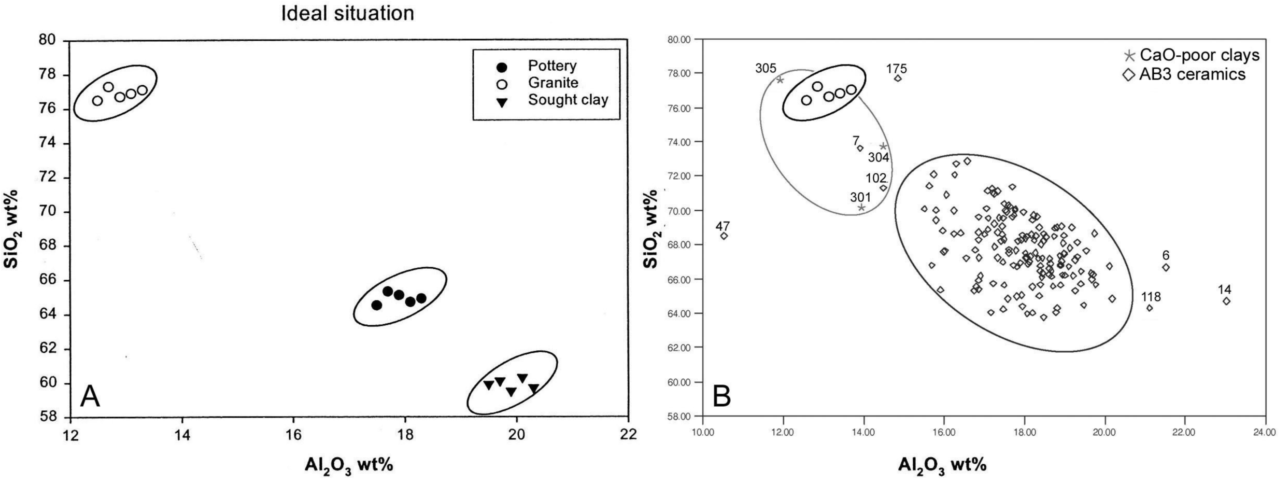


Figure 8.4: *Chemical correlation for SiO_2 and Al_2O_3: A: Ideal situation: the potteries lie on the correlation line between clays and temper (*Di Pierro, 2002*); B: Arbon Bleiche 3 situation: clays and tempers are both on the left hand side of the potteries.*

9 - FINAL CONCLUSIONS

Arbon Bleiche 3 is a typical Swiss Neolithic lacustrine village; occupied between 3384 and 3370 BC, its remains were well preserved in wet ground.

The study of the archaeological material of this site was carried over by de Capitani (2002).

In this work, 153 potteries, 10 spindle whorls, 11 cob fragments and one loom weight from Arbon Bleiche 3 were analysed petrographically, mineralogically and chemically. 12 ceramics from the western Carpathian Basin were also studied.

Several very interesting main points result from this work:

9.1 COMPOSITIONAL DISCREPANCY BETWEEN THE NON-CERAMIC AND THE CERAMIC MATERIAL

The non-ceramic material (cob fragments and loom weight) were made of an inclusion-rich and carbonate-rich clay, whereas 93% of the ceramics are made of an inclusion-poor and silicate-rich clay.

The cobs and loom weights are respectively non-tempered and tempered with organic material (straw, grass, hair…); on the contrary, the ceramics are tempered with rock fragments (granite, gabbro, rhyolite, chert), with grog and/or with bone.

Because the organic temper is still present in the thin section and did not disappear during a firing process, the loom weight was therefore not fired. No trace of firing is either observed in the thin sections of the cob fragments. Only the fire that destroyed the village modified this material (black marks on external surfaces).

Only six ceramic pieces were built with that type of carbonate-rich clay (only 4% of the ceramics; Table 6.3). Even if this clay probably needed less temper to be fired – because it was containing many natural inclusions – the same proportion of rocks tempered these samples. Maybe the clay was also harder to mould. Hence, these samples must be considered as exceptions and even as manufacturing errors. The Neolithic people probably knew that this kind of clay did not suit for ceramics.

These important differences between non-ceramic and ceramic material is also constant in the western Swiss Plateau (Benghezal, 1994a; Di Pierro, 2002) and has also been observed in the French Jura (Martineau, oral communication). The Neolithic people used obviously one kind of sediment for non-fired material (cob fragments and loom weights), and a different silicate-rich clay for the fired material (potteries and spindle whorls). They knew well how to differentiate sediments and made a conscious choice to collect them.

The carbonate-rich clay used to waterproof the houses (cob) and to manufacture the loom weights is probably local (as defined in Médard, 2000) and even to be found just inside the village or at least less than 500 m from it (Leuzinger, 2000). Moreover, the high amount of clay needed to build a house is so important (Ramseyer, 1985) that a distant provenance is quite improbable.

9.2 CERAMICS: PETROGRAPHICAL DIVERSITY VS. CHEMICAL HOMOGENEITY

Constantin and Courtois (1985) wrote: "The sherds that have followed the same production process can be named "material group"; there is mainly a correlation between the "material groups" and the types of forms, as there is often a correlation between the types of forms and the types of adornments". Hence, it seemed reasonable to think that the typological groups defined by de Capitani (2002) would also be differentiated according to the petrographical and mineralogical observations. Nevertheless, no direct relationship between the petrographical and typological groups was noticed for the ceramics. However, this absence of relation is frequent and not linked to a preferential period or any specific area (Echallier and Courtin, 1994a, 1994b and Echallier and Thiercelin, 1991).

93% of the ceramics are made of an inclusion-poor and silicate-rich clay. These samples divide into six petrographical groups, according to their main temper (54% are mainly tempered with granite, 32% with grog, 7% with gabbro, 3% with rhyolite, 3% with bone and 1% with chert; table 5.1). This important variety of temper used is quite unusual in the Neolithic and reinforces the impression of a not well-established ceramic tradition due to the cultural mixing of the site. A conscious choice is proven, because no limestone and no dark rocks such as amphibolites are used, even if they are frequent in the surroundings of the site.

Even with such a petrographical variation and so many stylistic separations, all these ceramics form a chemically largely homogeneous group. Within it, multivariate analysis have permitted to cluster several quite identical samples (see * and ** on Fig. 6.12). Besides, 13 chemical outliers have been pointed out, together with JB014 (contaminated) and JB047 (made of a carbonate-rich clay).

Only for a few elements, like Na_2O and Ni for example, a quite good separation can be made between the two main different petrographical groups AI vs. AV, i.e. granite vs. grog temper. This is due to the differences in tempering. In this case, Na_2O is bound to the granite pieces that preferentially temper group AI, whereas Ni is typical for the clay and the grog mostly present in group AV (Fig. 6.11). Hence, the chemical variations observed in the samples are mainly linked with the kind of temper used in the ceramics.

The homogeneity of the raw chemical compositions of most pottery samples over different stylistic categories is an interesting result. De Capitani (2002) showed typological parallelism between ceramics from Arbon Bleiche 3 and ceramics from Bavaria and the Western Carpathian Basin. The question was whether these ceramics were imported or not. Considering the chemical resemblance, a foreign origin of the pottery is quite unlikely. We propose a local provenance for almost all the potteries studied, forming one single chemical group. Only nine samples are surely chemically different, but an exact provenance cannot be suggested.

Three samples of silicate-rich clays were collected in the surroundings of Arbon. These are petrographically and mineralogically compatible with the material used to make the ceramics. JB301, collected in the near vicinity of the archaeological excavation (Fig. 2.11), fits well with the chemistry of the ceramics. Its SiO_2-content is too high, but it can be correlated with the high percentage of natural temper it contains. Moreover, SiO_2 variations in one single geological bed are typical of such sediments with a glacio-lacustrine origin (Sigg et al., 1986).

All the rocks used as temper can also be found in the surroundings of Arbon, in the Rhine moraines. These facts also incline to a local manufacturing of the ceramics.

9.3 OBSERVATION OF THE FIRST BONE TEMPERED SWISS NEOLITHIC CERAMICS

For the first time, bone temper was identified in Swiss Neolithic ceramics, after being described in France and Holland during Mid-Neolithic. Four samples of potteries tempered with bone were described in this work. Only 2% of the ceramics from Arbon Bleiche 3 are of this kind. The presence of bone was assured by XRD, XRF, SEM and microprobe (Bonzon, 2004b). If the assumption that bone temper was not an established temper neither in the Western Carpathian Basin nor in Switzerland is correct, the only explanation for the combination of Northern European technology with Eastern European shapes found in a Central European site, is multiple exchange of material, culture and/or technology over long distances. But a larger study in the Western Carpathian Basin should be done to prove the absence of bone temper in this region.

Based on typological analogies, De Capitani (2002) proposed a foreign origin for these peculiar ceramics: the Boleráz Stage from the Western Carpathian Basin.

Apart from one (JB012), they are chemically similar to the other potteries from Arbon Bleiche 3, which implies their local manufacturing.

Only JB012 can have been imported, since its chemistry does not correspond to any other sample (even those from the western Carpathian Basin). No geographical origin could be proposed.

Another general question that remains unanswered is the reasons behind the use of bone material as temper. As Morzadec (1993) writes "Bone has no particular technological property in the fabrication process of the ceramic". In only one case (JB069), the bone tempering was necessary for technical reasons, i.e. because no other temper was present in this pottery. In the three other samples, the bone temper was added to a sufficient proportion of other temper, granite and/or grog. Hence, is this peculiar temper resulting of a cultural know-how? If human bone was used, would it be linked to a heritage pertaining to worship, some kind of cult of the Ancient?

9.4 DEFINITION OF THE TWO TRADITIONS PRESENT IN ARBON BLEICHE 3

If we follow the idea of Constantin and Courtois (1985) that a choice of material (clay, temper) corresponds to a cultural behaviour, two different cultural traditions can be put into evidence in the potteries from Arbon Bleiche 3.

The first one is bound to the AI petrographical group (ceramics mainly tempered with granite) and to the Pfyn / Horgen pots typological group. This coil-built tradition (Bonzon, 2005) is linked to Pfyn and Horgen local cultures (de Capitani 2002, 220). These forms are surely local (as defined in Arnold, 1985, 2001 and Médard, 2000), as their high percentage in the village witnesses (~70% of the ceramics studied by de Capitani 2002).

The second tradition is quite different: the potteries are thinner, darker and often polished, without coil traces (slab-building technique?). They are mainly represented in the petrographical group AV (preferentially tempered with grog) and form three on four samples of petrographical AVI (bone temper). They correspond to the Boleráz typology of the western Carpathian Basin (de Capitani 2002, 158–159). Some sherds of this region were studied. They are petrographically and mineralogically close to the samples of Arbon Bleiche 3, but chemically different. Hence, no exchange of pottery was put into light between these two regions.

No noticeable chemical differences (apart from those put into relation with the kind of temper used) are evidenced in the ceramics from Arbon Bleiche 3.

We propose an interpenetration of both different traditions on the site. Some traces of this fact can be observed: 10% of Pfyn / Horgen pots are part of the petrographical groups AV, and 21% of the special forms Boleráz belong to AI and AIV groups (Table 5.1). Many samples also present both tempers mixed in various proportions, which can be considered as a mix of both traditions. In the opposite, spindle whorls are bound to one or the other tradition, without any feature of the second one. The Arbon Bleiche 3 village is changing: Pfyn culture comes to the end and Horgen culture appears. These changes are probably visible in the ceramics and may induce this mix of different technologies and typologies.

These two traditions do not chemically separate, even if they are very different from the samples of the western Carpathian Basin. Hence, the ceramics of both traditions are thought to be local. Nine samples of ceramics, plus one of bone tempered pottery are chemically different and could be imported. Unfortunately, their chemistry does not correspond with the samples from the western Carpathian Basin, and no precise provenance is proposed.

9.5 FIRING TECHNIQUE, ATMOSPHERE AND TEMPERATURE

All the ceramics from Arbon Bleiche 3 were certainly fired in open fire; no other technique has been described for the Neolithic, and the petrographical, mineralogical and chemical variation inside a single pot (Bonzon, 2005) let think of a fire with variable temperature.

The atmosphere of firing was mainly reducing and the temperatures reached by the potteries were less than 950°C and maybe less than 700°C.

Two samples are considered as resulting from a firing error (JB002, JB151): they are overfired (>800°C?). This high temperature can also be related to the fire that destroyed the village; there is no way to attribute this over-firing to one or to the other fact.

9.6 NO EVIDENCE OF A DOMESTIC CERAMIC PRODUCTION IN ARBON BLEICHE 3

The typologies of the ceramics show no evidence of a spatial distribution in the village (de Capitani 2002, chapters 5.10.3 and 5.11.1). Moreover, the petrography, mineralogy and chemistry of the samples cannot have been differentiated according to the sherd location in the settlement.

In the case of a domestic production, Pétrequin et al. (1994) defined a relation between spatial repartition of the ceramics and their characteristics.

Because nothing similar was observed in Arbon Bleiche 3, a single potter or several potters are thought to have manufactured the ceramics for the whole village. The clay came probably from a well-defined single pit or several pits in the same morainic deposit. This is only in this case that we can explain so few chemical variations in such a big village.

We have to note that in the case in which several potters used the same pit and the same clay, no chemical differences would either be observed.

10 - PERSPECTIVES & ACKNOWLEDGEMENT

Coming to the end of this work, three main directions of further researches can be proposed:

10.1 MINERALOGICAL TRANSFORMATIONS DURING FIRING

Almost every author tests one or several clay(s) to determine the firing temperature reached by the ceramics. The results are varying much from one to another paper.

An important study on several types of clay, under oxidising, but especially under reducing atmospheres should be done to fix the subject.

10.2 STUDY OF THE MANUFACTURING TECHNIQUES

Martineau (2000, 2002) developed a study on the manufacturing traces observed on the surfaces of the ceramics. This study leads to very precise information concerning the potters' know-how and personal techniques, which cannot be determined in other ways. Such a study should be regularly done with prehistoric ceramics.

10.3 PROVENANCE OF BONE TEMPERED CERAMICS

Even if three on four ceramics tempered with bone are surely local, this technological innovation was probably imported. From where? It will be a challenge to discover the origin of this peculiar technique, because the inhabitants of Arbon Bleiche 3 were once in relation with this population.

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APPENDIXES

1 - APPENDIX 1

List of the studied samples from Arbon Bleiche 3.
*(In "Sherd Nr.": Rs: Randscherbe, sherd from the lip, Ws: Wandscherbe, sherd from the body, Bs: Bodenscherbe, sherd from the bottom. In "Bed": BRA: Brandschttschicht, bed of fired sediments, Ks: Kulturschicht, bed of cultural sediments). The sample numbers with * were finally not analysed and with ** were only partially analysed (reasons, see text). (Modified from* de Capitani, 2002*);*
List of the studied samples from the western Carpathian Basin and list of the studied samples of local clays from the surroundings of Arbon.

SPINDLE WHORLS AND LOOM WEIGHT

Inventary Nr.	*Bed*	*Coordinates*	*Type*	*Sample Nr.*
1994.01.4506.1	KS	75.08/217.08/394.45	flat	JB111
1994.01.5486.3	KS	70.00/220.00/394.62	conical	JB112
1995.01.7109.1	BRA	63.05/193.30/394.08	flat	JB113
1995.01.8756.1	BRA	65.78/217.00/394.73	bi-conical	JB114
1994.01.4687.1	BRA	70.00/217.00/394.63	flat	JB115
1994.01.5503.1	BRA	74.21/223.32/394.66	flat	JB116
1994.01.5220.1	KS	71.53/219.15/394.66	flat	JB117
1993.01.187.1	KS	65.43/238.38/395.86	flat	JB118
1995.01.8386.1	KS	62.14/210.68/394.65	flat	JB119
1993.01.2536.1	KS	73.30/229.87/394.80	flat	JB120
1994.01.4136.1	BRA	71.77/208.46/394.32	Loom weight	JB121

COB FRAGMENTS

Inventary Nr.	*Bed*	*Coordinates*	*Type*	*Sample Nr.*
1994.01.5708.0	BRA	69.00/222.00/394.83	Cob	JB122
1995.01.9735.0	KS	66.00/221.00/394.69	Cob	JB123
1995.01.7032.0	KS	60.00/192.00394.18	Cob	JB124
1994.01.3639.0	KS	78.00/209.00/394.20	Cob	JB125
1994.01.5474.1	BRA	77.00/220.00/394.52	Cob	JB126
1994.01.3999.0	BRA	71.00/206.00/394.20	Cob	JB127
1994.01.4071.0	BRA	78.00/203.00/393.92	Cob	JB128
1995.01.8243.0	KS	61.00/209.00/ ?	Cob	JB129
1994.01.4074.0	BRA	73.00/210.00/394.33	Cob	JB130
1995.01.10250	KS	62.00/211.00/394.47	Cob	JB131
1995.01.7831.0	BRA	61.00/210.00/394.70	Cob	JB132

POTTERIES

Pottery Nr.	*Sherd Nr.*	*Coordinates*	*Bed*	*Typological Gp.*	*Sample Nr.*
16655	Rs 93.01.1757	76/229	KS	Pfyn / Horgen pot	JB001
	Ws 93.01.1757	76/229	KS		
15463	Rs 93.01.363	63/229	BRA	Pfyn / Horgen pot	JB002
	Ws 93.01.363	63/229	BRA		
15949	Rs 93.01.1225	72/230	KS	Pfyn / Horgen pot	JB003
	Ws 93.01.1225	72/230	KS		
	Ws 93.01.954.1	72/230	BRA		
16743	Ws 94.01.5633	75/224	KS	USF	JB004
	Ws 94.01.5368	76/224	KS		
15494	Ws 94.01.1686	62/228	KS	USF	JB005
	Ws 94.01.1686	62/228	KS		
	Ws 94.01.1686	62/228	KS		
16752	Ws 93.01.98	54/227	BRA	SF Boleráz	JB006
	Ws 93.01.98	54/227	BRA		
	Ws 93.01.98	54/227	BRA		
15649	Ws 83.01.156.SII	68/229	KS	SF Pfyn	JB007
	Ws 83.01.156.SII	68/229	KS		
16741	Rs 93.01.1233	80/231	?	SF Bayern	JB008
	Rs 93.01.1233	80/231	?		

Ceramic Nr.	*Sherd Nr.*	*Coordinates*	*Bed*	*Typological Gp.*	*Sample Nr.*
16746	Rs 93.01.968.1	78/229	BRA	SF Pfyn	JB009
16745	Ws 93.01.1675	76/226	BRA	Pfyn / Horgen pot	JB010
	Ws 93.01.1767	77/227	KS		
	Ws 93.01.1767	77/227	KS		
15400	Rs 93.01.1571	59/225	KS	USF	JB011
16748	Ws 93.01.1735	77/232	KS	USF	JB012
16757	Ws 94.01.4152.1	73/210	KS	SF Boleráz	JB013
16757	Ws ?	?	?	SF Boleráz	JB014
17140	Ws 95.01.10356.1	60/219	KS	SF Bayern	JB015
	Ws 95.01.10356.1	60/219	KS		
15860	Rs 93.01.1905	71/226	BRA	USF	JB016
	Ws 93.01.2173	71/226	BRA		
	Ws 93.01.2173	71/226	BRA		
	Ws 93.01.2173	71/226	BRA		
15942	Ws 93.01.1261	69/231	KS	SF Boleráz	JB017
15943	Rs 93.01.1678	71/231	KS	USF	JB018
	Ws 93.01.1542	70/230	KS		
15838	Rs 93.01.2226	70/226	KS	Pfyn / Horgen pot	JB019
17566	Ws 95.01.5798	69/218	KS	SF Boleráz	JB020
	Ws 95.01.10026.1	68/218	KS		
	Ws 95.01.10026.1	68/218	KS		
	Ws 95.01.10026.1	68/218	KS		
17021	Rs 95.01.10674	60/219	KS	SF Bayern	JB021
	Rs 95.01.10657	60/219	KS		
	Ws 95.01.9239	59/219	KS		
	Ws 95.01.9239	59/219	KS		
17854	Rs 94.01.3158	80/221	?	Pfyn / Horgen pot	JB022
17557	Ws 95.01.10729	63/224	KS	Pfyn / Horgen pot	JB023
17568	Ws 95.01.5678	69/218	KS	Pfyn / Horgen pot	JB024
17000	Ws ?	?	?	Pfyn / Horgen pot	JB025
17106	Ws 93.01.9934.1	61/220	BRA	Pfyn / Horgen pot	JB026
17583	Ws 94.01.5540.1	71/221	KS	USF	JB027
17303	Rs 93.01.1673	70/229	KS	Pfyn / Horgen pot	JB028
	Ws 95.01.10765	63/219	KS		
	Ws 95.01.10765	63/219	KS		
17567	Ws 95.01.10522	68/218	KS	USF	JB029
17139	Ws 95.01.10515.1	61/218	KS	USF	JB030
17865	Ws 94.01.5574	76/218	KS	Pfyn / Horgen pot	JB031
17009	Rs ?	?	?	Pfyn / Horgen pot	JB032
18234	Rs 94.01.4865	78/215	KS	SF Boleráz	JB033
	Ws 94.01.4865	78/215	KS		
	Ws 94.01.4772	78/215	KS		
	Ws 94.01.4772	78/215	KS		
	Ws 94.01.4772	78/215	KS		
18245	Ws 94.01.5294	70/214	KS	SF Boleráz	JB034
	Ws 94.01.4688	74/214	KS		
17850	Ws 94.01.5451.1	78/222	BRA	Pfyn / Horgen pot	JB035
	Ws 94.01.5451.1	78/222	BRA		
	Ws 94.01.5451.1	78/222	BRA		
17556	Rs ?	?	?	USF	JB036
	Ws 94.01.5649	69/220	KS		
17573	Ws ?	?	?	SF Bayern	JB037
	Ws 94.01.5480.1	71/218	KS		

Ceramic Nr.	*Sherd Nr.*	*Coordinates*	*Bed*	*Typological Gp.*	*Sample Nr.*
17863	Ws ?	?	?	Pfyn / Horgen pot	JB038
	Ws 94.01.5753	77/218	KS		
18854	Ws 95.01.9092	66/213	KS	Pfyn / Horgen pot	JB039
17575	Ws 94.01.5745	74/221	BRA	USF	JB040
	Ws 94.01.5926	73/221	KS		
	Ws 94.01.5360	73/221	KS		
	Ws 94.01.5360	73/221	KS		
	Ws 94.01.5360	73/221	KS		
18308	Rs 94.01.4946	73/215	KS	Pfyn / Horgen pot	JB041
	Ws 94.01.4946	73/215	KS		
18309	Rs ?	?	?	Pfyn / Horgen pot	JB042
	Rs 94.01.5118	73/215	KS		
18248	Ws 94.01.5084	77/211	KS	Pfyn / Horgen pot	JB043
	Ws 94.01.5084	77/211	KS		
18311	Ws 94.01.4969	70/213	KS	Pfyn / Horgen pot	JB044
	Ws 94.01.5000	71/214	BRA		
18259	Ws 94.01.4454	76/217	BRA	Pfyn / Horgen pot	JB045
18299	Rs 94.01.4688	70/214	KS	USF	JB046
	Rs 94.01.4688	70/214	KS		
	Rs 94.01.4755	70/214	KS		
	Rs 94.01.4630	70/214	KS		
	Rs 94.01.4455	71/206	KS		
	Rs 94.01.5104	71/215	KS		
18251	Rs 94.01.4395	75/215	BRA	Pfyn / Horgen pot	JB047
18303	Ws 94.01.5253	69/213	KS	Pfyn / Horgen pot	JB048
	Ws 94.01.5080	75/217	KS		
18846	Ws 95.01.8996.1	65/215	KS	Pfyn / Horgen pot	JB049
	Ws 95.01.8996.1	65/215	KS		
	Ws 95.01.8996.1	65/215	KS		
	Ws 95.01.8996.1	65/215	KS		
	Ws 95.01.8996.1	65/215	KS		
	Ws 95.01.8996.1	65/215	KS		
18842	Ws 94.01.5263	69/213	KS	SF Boleráz	JB050
18830	Ws 94.01.4565	70/214	BRA	Pfyn / Horgen pot	JB051
16659	Ws 93.01.2359	77/226	KS	Pfyn / Horgen pot	JB052
	Ws 93.01.2424	78/227	KS		
18310	Ws ?	?	?	Pfyn / Horgen pot	JB053
	Ws 94.01.4667	70/214	BRA		
18865	Ws 95.01.8018	?	?	Pfyn / Horgen pot	JB054
	Ws 95.01.8018	?	?		
18845	Rs 94.01.3116	68/213	KS	Pfyn / Horgen pot	JB055
	Ws 94.01.3116	68/213	KS		
18849	Ws 95.01.9404	67/216	BRA	Pfyn / Horgen pot	JB056
18828	Rs 94.01.4877	71/214	KS	USF	JB057
	Ws 94.01.5331	69/212	KS		
18831	Rs 94.01.5547	70/219	KS	Pfyn / Horgen pot	JB058
	Ws 94.01.5896	69/220	KS		
	Ws 94.01.5896	69/220	KS		
18847	Ws 95.01.9543	68/217	KS	Pfyn / Horgen pot	JB059
	Ws 94.01.3150	68/217	BRA		
18840	Rs 94.01.5710.1	78/218	KS	Pfyn / Horgen pot	JB060
	Ws 94.01.5587	69/215	BRA		
	Ws 94.01.5350	69/215	BRA		

Ceramic Nr.	*Sherd Nr.*	*Coordinates*	*Bed*	*Typological Gp.*	*Sample Nr.*
18866	Ws 94.01.3191	68/219	KS	Pfyn / Horgen pot	JB061
	Ws ?	?	?		
	Ws 94.01.3191	68/219	KS		
18867	Ws 95.01.8891	66/212	KS	Pfyn / Horgen pot	JB062
	Ws 95.01.8891	66/212	KS		
	Ws 95.01.9096.1	66/212	KS		
18930	Ws 95.01.9264	61/215	KS	SF Boleráz	JB063
	Ws 95.01.8988	61/215	BRA		
	Ws 95.01.8988	61/215	BRA		
18925	Ws 95.01.10707	64/218	KS	Pfyn / Horgen pot	JB064
	Ws 95.01.10707	64/218	KS		
19546	Rs 95.01.10028	62/211	KS	Pfyn / Horgen pot	JB065
	Ws 95.01.10028	62/211	KS		
	Ws 95.01.10028	62/211	KS		
	Rs 95.01.10028	62/211	KS		
	Ws 95.01.10028	62/211	KS		
	Ws 95.01.8335	61/209	KS		
19608	Ws 95.01.8917	66/216	KS	Pfyn / Horgen pot	JB066
18915	Ws 95.01.9138	61/215	BRA	Pfyn / Horgen pot	JB067
	Ws 95.01.8970	61/215	BRA		
18906	Rs 95.01.9974	63/211	KS	Pfyn / Horgen pot	JB068
	Ws 95.01.9974	63/211	KS		
	Rs 95.01.7879	63/208	BRA		
	Ws 95.01.7879	63/208	BRA		
18909	Ws 95.01.9356.1	61/215	BRA	SF Boleráz	JB069
	Ws 95.01.8829.1	60/212	BRA		
	Ws 95.01.8959.1	61/214	BRA		
	Ws ?	?	?		
	Ws 95.01.9354.1	61/215	BRA		
	Ws 95.01.8959.1	61/214	BRA		
	Ws 95.01.8959.1	61/214	BRA		
18973	Rs 95.01.9922	64/216	KS	Pfyn / Horgen pot	JB070
18908	Ws 95.01.8863.1	61/212	BRA	USF	JB071
	Ws 95.01.9245	62/212	BRA		
18917	Bs 95.01.9894.1	63/214	KS	USF	JB072
	Bs 95.01.9894.1	63/214	KS		
	Bs 95.01.9894.1	63/214	KS		
	Bs 95.01.9894.1	63/214	KS		
	Rs 94.01.5742	78/222	KS		
	Ws 94.01.5742	78/222	KS		
	Ws 94.01.5742	78/222	KS		
	Ws 94.01.5612	78/222	BRA		
	Ws 94.01.5612	78/222	BRA		
	Ws 94.01.5257	79/223	KS		
18918	Ws 95.01.7634.1	59/213	KS	SF Boleráz	JB073
	Ws 95.01.7658.1	59/213	KS		
	Ws 95.01.7658.1	59/213	KS		
	Ws 95.01.7658.1	59/213	KS		
	Ws 95.01.7658.1	59/213	KS		
	Ws 95.01.7658.1	59/213	KS		
18919	Rs 95.01.10331.1	64/215	KS	USF	JB074

Ceramic Nr.	*Sherd Nr.*	*Coordinates*	*Bed*	*Typological Gp.*	*Sample Nr.*
18976	Ws 94.01.5184	69/217	KS	USF	JB075
	Ws 94.01.5804	69/220	KS		
	Ws 94.01.5804	69/220	KS		
18949	Rs 95.01.7917	61/208	BRA	Pfyn / Horgen pot	JB076
	Ws 95.01.7917	61/208	BRA		
	Ws 95.01.7917	61/208	BRA		
	Ws 95.01.7917	61/208	BRA		
	Ws unleserlich	?	?		
18949	Ws 95.01.7917	61/208	BRA	Pfyn / Horgen pot	JB077
18949	Ws 95.01.7917	61/208	BRA	Pfyn / Horgen pot	JB078
18949	Ws 95.01.7917	61/208	BRA	Pfyn / Horgen pot	JB079
18949	Ws 95.01.7917	61/208	BRA	Pfyn / Horgen pot	JB080
	Ws 95.01.7917	61/208	BRA		
18949	Ws 95.01.9113	61/212	KS	Pfyn / Horgen pot	JB081
18949	Ws 95.01.9113	61/212	KS	Pfyn / Horgen pot	JB082
18949	Ws 95.01.7657	59/212	KS	Pfyn / Horgen pot	JB083
18949	Ws 95.01.10725	61/211	BRA	Pfyn / Horgen pot	JB084
18949	Bs 95.01.9245	62/212	BRA	Pfyn / Horgen pot	JB085
18974	Ws 95.01.8842	63/217	BRA	USF	JB086
	Ws 95.01.8842	63/217	BRA		
	Ws 95.01.8842	63/217	BRA		
	Ws 95.01.8842	63/217	BRA		
	Ws 95.01.8842	63/217	BRA		
	Ws 95.01.8842	63/217	BRA		
18977	Ws 95.01.9000.1	63/217	BRA	USF	JB087
	Ws 95.01.9000.1	63/217	BRA		
	Ws 95.01.9000.1	63/217	BRA		
18970	Ws 95.01.7656	59/217	KS	SF Bayern	JB088
	Ws ?	?	?		
19775	Ws 94.01.3852	73/205	BRA	Pfyn / Horgen pot	JB089
	Ws 94.01.3852	73/205	BRA		
	Rs 94.01.3173	79/207	?		
	Rs 94.01.3931	78/ ?	KS		
19773	Ws 94.01.4743.1	71/204	KS	SF Bayern	JB090
	Ws 94.01.4743.1	71/204	KS		
	Ws 94.01.4743.1	71/204	KS		
19771	Ws 94.01.4137	73/206	KS	Pfyn / Horgen pot	JB091
19776	Ws 94.01.3974	71/206	KS	Pfyn / Horgen pot	JB092
	Ws ?	?	?		
	Ws ?	?	?		
19782	Ws 94.01.4300	74/204	BRA	Pfyn / Horgen pot	JB093
	Ws 94.01.4300	74/204	BRA		
	Ws 94.01.4300	74/204	BRA		
19780	Rs 94.01.4207	71/207	KS	Pfyn / Horgen pot	JB094
	Ws 94.01.4207	71/207	KS		
19777	Rs 94.01.4297	70/207	KS	SF Bayern	JB095
	Rs 94.01.4297	70/207	KS		
	Ws 94.01.4297	70/207	KS		
	Ws 94.01.4297	70/207	KS		
	Ws 94.01.4297	70/207	KS		
	Ws 94.01.4297	70/207	KS		
	Ws 94.01.4297	70/207	KS		
	Ws 94.01.4297	70/207	KS		

Ceramic Nr.	***Sherd Nr.***	***Coordinates***	***Bed***	***Typological Gp.***	***Sample Nr.***
19777 (follow)	Ws 94.01.4297	70/207	KS	SF Bayern	JB095
	Ws 94.01.4297	70/207	KS		
	Ws 94.01.4297	70/207	KS		
19777	Ws 94.01.4297	70/207	KS	SF Bayern	JB095
19772	Rs 94.01.4161	73/205	BRA	Pfyn / Horgen pot	JB096
	Ws 94.01.4161	73/205	BRA		
	Ws 94.01.4161	73/205	BRA		
	Ws 94.01.3797	73/205	BRA		
19629	Ws 94.01.4233	72/210	KS	Pfyn / Horgen pot	JB097
	Ws 94.01.4202	71/209	KS		
	Ws 94.01.4329	70/209	KS		
	Ws 94.01.4410	70/208	KS		
19624	Ws 94.01.3246	76/208	BRA	USF	JB098
	Ws 94.01.3246	76/208	BRA		
19623	Rs 94.01.4709.1	76/211	KS	SF Boleráz	JB099
	Ws 94.01.4709.1	76/211	KS		
19611	Rs 94.01.3656	75/205	KS	Pfyn / Horgen pot	JB100
	Ws 94.01.3656	75/205	KS		
	Bs 94.01.3972	78/207	KS		
20038	Ws 94.01.7965	66/207	BRA	Pfyn / Horgen pot	JB101
	Ws 94.01.7965	66/207	BRA		
	Ws 94.01.7965	66/207	BRA		
	Ws 94.01.7965	66/207	BRA		
	Ws 95.01.8072	68/207	KS		
20887	Ws 95.01.7647	64/200	KS	USF	JB102
	Ws 95.01.8574.1	66/204	KS		
	Ws 95.01.7669	64/200	KS		
	Ws 95.01.7669	64/200	KS		
	Ws 95.01.7669	64/200	KS		
20040	Ws 94.01.5580	68/211	KS	Pfyn / Horgen pot	JB103
18948	Ws 95.01.9410	63/212	BRA	Pfyn / Horgen pot	JB104
	Ws ?	?	?		
19622	Rs 94.01.4031	74/208	BRA	USF	JB105
20204	Ws 94.01.5580	68/211	KS	SF Boleráz	JB106
	Ws 94.01.5580	68/211	KS		
	Ws 94.01.5580	68/211	KS		
17577	Ws 94.01.5782	73/218	BRA	USF	JB107
	Ws 94.01.5782	73/218	BRA		
20212	Ws 95.01.8603	62/208	KS	Pfyn / Horgen pot	JB108
	Ws 95.01.8339	61/210	KS		
	Ws 95.01.8660	61/210	KS		
15525	Ws 93.01.2352.1	65/229	?	Pfyn / Horgen pot	JB109
	Ws 93.01.2352.1	65/229	?		
	Ws 93.01.2352.1	65/229	?		
	Ws 93.01.2352.1	65/229	?		
	Ws 93.01.2352.1	65/229	?		
19553	Rs 95.01.10629	64/216	KS	SF Bayern	JB110
	Rs 95.01.9964	68/220	KS		
	Rs 95.01.10099	64/216	KS		
15462	Ws 93.01.569	63/231	KS	Pfyn / Horgen pot	JB133
	Ws 93.01.385.2	62/231	KS		
	Ws 93.01.385.2	62/231	KS		

Ceramic Nr.	*Sherd Nr.*	*Coordinates*	*Bed*	*Typological Gp.*	*Sample Nr.*
20028	Ws 94.01.4170.1	69/206	BRA	Pfyn / Horgen pot	JB134
	Ws 94.01.4170.1	69/206	BRA		
	Ws 94.01.4170.1	69/206	BRA		
18902	Ws 95.01.9506	60/217	BRA	Pfyn / Horgen pot	JB135
	Ws 95.01.9506	60/217	BRA		
	Ws 95.01.9829	60/217	BRA		
16725	Ws 93.01.2623	77/225	KS	Pfyn / Horgen pot	JB136
	Ws 93.01.2265	79/226	KS		
	Ws 93.01.2432	78/226	KS		
	Ws 93.01.2232	78/226	KS		
18829	Ws 95.01.9826	63/214	KS	Pfyn / Horgen pot	JB137
	Ws 95.01.9826	63/214	KS		
	Ws 95.01.9826	63/214	KS		
18972	Ws 95.01.9555.1	63/217	BRA	SF Boleráz	JB138
17576	Rs 94.01.5300.1	72/222	KS	SF Boleráz	JB139
	Ws 94.01.5300.1	72/222	KS		
	Ws 94.01.5300.1	72/222	KS		
	Ws 94.01.5300.1	72/222	KS		
	Ws 94.01.5300.1	72/222	KS		
	Ws 94.01.5300.1	72/222	KS		
	Ws 94.01.5300.1	72/222	KS		
21241	Ws 95.01.8042	59/188	KS	SF Boleráz	JB140
21240	Ws 94.01.3216	67/197	BRA	SF Boleráz	JB141
	Ws 95.01.7652	61/202	KS		
	Ws 95.01.7123.1	62/193	BRA		
21243	Ws 95.01.8569.1	60/189	BRA	USF	JB142
21239	Ws 95.01.7010.1	62/189	-	SF Bayern	JB143
	Ws 95.01.7010.1	62/189	-		
	Ws 95.01.7010.1	62/189	-		
	Ws 95.01.7010.1	62/189	-		
20627	Ws 94.01.3587	71/203	KS	SF Boleráz	JB144
	Ws ?	?	?		
20626	Ws 94.01.3402	72/199	KS	SF Boleráz	JB145
	Ws 94.01.3437	71/198	KS		
21034	Ws 95.01.7022	60/195	BRA	SF Boleráz	JB146
	Ws 95.01.7022	60/195	BRA		
18833	Ws 95.01.8905.1	66/217	BRA	SF Boleráz	JB147
	Ws 95.01.8851.1	66/217	KS		
	Ws 95.01.8851	66/217	KS		
18927	Ws 95.01.8954.1	60/213	BRA	SF Boleráz	JB148
19787	Ws 94.01.4585	74/204	KS	SF Boleráz	JB149
	Ws 94.01.4585	74/204	KS		
	Ws 94.01.4585	74/204	KS		
	Ws 94.01.4585	74/204	KS		
20893	Rs 95.01.7642	63/202	KS	SF Bayern	JB150
	Rs 95.01.7642	63/202	KS		
20888	Ws 94.01.3725	69/202	BRA	SF Bayern	JB151
20215	Ws 95.01.8022	61/209	BRA	SF Boleráz	JB152
	Ws 95.01.8022	61/209	BRA		
	Ws 95.01.7957	63/210	BRA		
20233	Rs 95.01.10739	61/211	KS	SF Bayern	JB153
	Rs 95.01.8236	60/207	KS		
	Rs 95.01.8209	61/207	KS		

Ceramic Nr.	***Sherd Nr.***	***Coordinates***	***Bed***	***Typological Gp.***	***Sample Nr.***
18964	Ws 95.01.8967	64/214	BRA	SF Boleráz	JB154
	Ws 95.01.7660	59/213	KS		
	Ws 95.01.7660	59/213	KS		
20628	Bs 94.01.3473	71/202	KS	SF Boleráz	JB155
20632	Ws 94.01.3230	74/201	BRA	Pfyn / Horgen pot	JB156*
	Ws 94.01.3457	72/200	KS		
	Ws 94.01.3457	72/200	KS		
20781	Ws 94.01.3759	67/199	KS	SF Bayern	JB157
	Ws 94.01.3759	67/199	KS		
	Ws 94.01.3752	67/198	BRA		
20782	Bs 95.01.7603	65/198	BRA	USF	JB158
20780	Ws 94.01.3384	69/200	BRA	USF	JB159
	Ws 94.01.3717	68/199	BRA		
20894	Ws 95.01.7607	61/199	KS	USF	JB160
	Ws 95.01.7147	60/201	BRA		
	Ws 95.01.7147	60/201	BRA		
20897	Ws 95.01.7386	63/199	BRA	Pfyn / Horgen pot	JB161*
	Ws 95.01.7444	62/199	BRA		
	Ws 95.01.7525	62/199	KS		
	Ws 95.01.7532	62/199	BRA		
20885	Ws 95.01.7495	62/200	BRA	USF	JB162
	Ws 95.01.7576	61/199	KS		
	Ws 95.01.7118	60/199	BRA		
	Ws 95.01.7118	60/199	BRA		
	Ws 95.01.7495	62/200	BRA		
20886	Ws 95.01.7747.1	62/199	KS	USF	JB163
	Ws 95.01.7817	69/198	KS		
	Ws 94.01.3228	66/197	BRA		
21032	Ws 95.01.7198	62/194	BRA	USF	JB164
	Ws 95.01.7198	62/194	BRA		
	Ws 95.01.7198	62/194	BRA		
	Ws 95.01.7202.1	61/195	BRA		
21033	Ws 95.01.7448	61/195	KS	USF	JB165
	Ws 95.01.7448	61/195	KS		
20225	Rs 95.01.8720	64/201	BRA	USF	JB166
	Rs 95.01.7577	64/200	BRA		
	Ws 95.01.7474	64/206	KS		
	Ws 95.01.7574	63/200	BRA		
20221	Ws 94.01.3440	68/201	BRA	USF	JB167
	Ws 94.01.3440	68/201	BRA		
	Ws 94.01.3440	68/201	BRA		
	Ws 94.01.3440	68/201	BRA		
20218	Bs 95.01.8457	62/209	KS	Pfyn / Horgen pot	JB168*
	Bs 95.01.8036	62/209	KS		
20041	Ws 95.01.8238	67/209	KS	USF	JB169
20043	Ws 95.01.8080	67/206	KS	Pfyn / Horgen pot	JB170*
	Ws 95.01.8080	67/206	KS		
20044	Rs 95.01.8362	66/210	KS	SF Pfyn	JB171
	Rs 95.01.8658	66/210	KS		
	Ws 95.01.8362	66/210	KS		
	Ws 95.01.8658	66/210	KS		
	Ws 95.01.8658	66/210	KS		

Ceramic Nr.	*Sherd Nr.*	*Coordinates*	*Bed*	*Typological Gp.*	*Sample Nr.*
20045	Ws 95.01.7968	67/209	BRA	USF	JB172**
	Ws 95.01.7915	67/209	BRA		
	Ws 95.01.7915	67/209	BRA		
	Ws 95.01.4324	69/207	KS		
20036	Ws 94.01.4676	70/215	BRA	USF	JB173
20032	Rs 94.01.4146	74/208	KS	USF	JB174
	Ws 94.01.3073.1	68/207	?		
	Ws 94.01.3072	68/207	?		
	Ws ?	?	?		
16755	Ws 93.01.1472	59/230	BRA	SF Boleráz	JB175
	Ws 93.01.1472	59/230	BRA		
17848	Ws 95.01.8888	67/215	KS	Pfyn / Horgen pot	JB176*
	Ws 95.01.8888	67/215	KS		
	Ws 95.01.8888	67/215	KS		
	Ws 95.01.8888	67/215	KS		
	Ws ?	?	?		
17022	Ws 95.01.10513.1	62/219	KS	USF	JB177
17018	Ws 95.01.9944	61/219	BRA	USF	JB178
	Ws 95.01.9944	61/219	BRA		
17040	Ws 95.01.8936	59/219	KS	SF Boleráz	JB179
	Ws 95.01.8936	59/219	KS		
	Ws 95.01.10550	62/218	KS		
17041	Ws 95.01.8706	59/220	BRA	USF	JB180
	Ws 95.01.8706	59/220	BRA		
18298	Rs 94.01.5235	?	KS	USF	JB181
	Ws 94.01.4871	70/215	KS		
18838	Ws 95.01.8769	66/216	KS	USF	JB182
	Ws 95.01.8769	66/216	KS		
	Ws 95.01.8769	66/216	KS		
	Ws 95.01.8769	66/216	KS		
	Ws 95.01.8769	66/216	KS		
18832	Bs 95.01.9344	65/212	KS	USF	JB183
	Bs 95.01.9344	65/212	KS		
	Ws 95.01.9344	65/212	KS		
	Ws 95.01.8998.1	65/213	KS		
	Ws 95.01.8998.1	65/213	KS		
17571	Rs 94.01.3217.1	76/206	BRA	Pfyn / Horgen pot	JB184*
17574	Ws 94.01.5346.1	72/223	BRA	SF Boleráz	JB185
18837	Rs 95.01.8861.1	65/215	KS	USF	JB186
16750	Ws 93.01.2303.1	63/233	?	USF	JB187
18244	Ws 94.01.4730.1	75/214	KS	USF	JB188**
15352	Rs 93.01.1746	62/233	KS	USF	JB189
16363	Ws 93.01.2454	77/226	KS	USF	JB190
17868	Rs 94.01.5255	78/223	BRA	Pfyn / Horgen pot	JB191*
	Ws 94.01.5351	79/220	BRA		
17869	Ws 94.01.3032	80/220	?	Pfyn / Horgen pot	JB192*
	Ws 94.01.3158	80/221	?		
15763	Ws 93.01.391	66/234	KS	Pfyn / Horgen pot	JB193*
	Ws 93.01.391	66/234	KS		
15524	Rs 93.01.2368	65/233	KS	Pfyn / Horgen pot	JB194*
	Rs 93.01.2368	65/233	KS		

Ceramic Nr.	*Sherd Nr.*	*Coordinates*	*Bed*	*Typological Gp.*	*Sample Nr.*
18250	Rs 94.01.4846.1	77/211	KS	Pfyn / Horgen pot	JB195*
	Bs 94.01.4846.1	77/211	KS		
	Bs 94.01.4846.1	77/211	KS		
	Ws 94.01.4846.1	77/211	KS		
	Ws 94.01.4846.1	77/211	KS		
	Ws 94.01.4846.1	77/211	KS		
18250 (follow)	Ws 94.01.4846.1	77/211	KS	Pfyn / Horgen pot	JB195*
20027	Rs 94.01.3797	73/205	BRA	Pfyn / Horgen pot	JB196*
15948	Ws 93.01.956.1	71/229	BRA	Pfyn / Horgen pot	JB197*
	Ws 93.01.956.1	71/229	BRA		
	Ws 93.01.956.1	71/229	BRA		
16543	Ws 93.01.1549	77/225	BRA	Pfyn / Horgen pot	JB198*
	Ws 93.01.1829	78/226	KS		
18306	Ws 94.01.4603	76/216	KS	Pfyn / Horgen pot	JB199*
	Ws 94.01.4603	76/216	KS		

CERAMICS FROM THE WESTERN CARPATHIAN BASIN

Exact provenance	*Land*	*Typological Gp.*	*Sample Nr.*
Mödling “Jennyberg”	Austria	SF Boleráz	JB200
Mödling “Jennyberg”	Austria	SF Boleráz	JB201
Mödling “Jennyberg”	Austria	SF Boleráz	JB202
Mödling “Jennyberg”	Austria	SF Boleráz	JB203
Mödling “Jennyberg”	Austria	SF Boleráz	JB204
Žlkovce	Slovakia	SF Boleráz	JB205
Žlkovce	Slovakia	SF Boleráz	JB206
Žlkovce	Slovakia	SF Boleráz	JB207
Žlkovce	Slovakia	SF Boleráz	JB208
Žlkovce	Slovakia	SF Boleráz	JB209
Naměšt na Hané	Czech Republic	SF Boleráz	JB210
Naměšt na Hané	Czech Republic	SF Boleráz	JB211
Naměšt na Hané	Czech Republic	SF Boleráz	JB212
Naměšt na Hané	Czech Republic	SF Boleráz	JB213

CLAYS

Geographical Coordinates	*Altitude*	*Geological bed*	*Sample Nr.*	*Note*
263.110 / 749.610	399	Moraines	JB300	CaO-rich
263.110 / 749.610	399	Moraines	JB301	CaO-poor
263.175 / 748.720	404	Moraines	JB302	CaO-rich
262.550 / 747.910	440	Moraines	JB303	CaO-rich
262.400 / 748.700	425	Moraines	JB304	CaO-poor
262.400 / 748.700	425	Moraines	JB305	CaO-poor
261.600 / 750.350	425	Molasse	JB306	CaO-rich
261.175 / 749.775	440	Molasse	JB307	CaO-rich
263.910 / 749.690	398	Molasse	JB308	CaO-rich
263.910 / 749.690	398	Molasse	JB309	CaO-rich
264.030 / 748.725	405	Molasse	JB310	CaO-rich

2 - APPENDIX 2

Summary table of typological and archaeometrical groups discussed in the PhD for each studied sample and estimated ancient firing temperature.
(SF: Special form; USF: Undetermined special form; G: Grey; Y: Yellow; B: Black; O: Orange).

Sample Number	Typological Group	Petrographical Group	Section Colour	Colour Group	Firing Temperature
JB001	Pfyn / Horgen pot	AIV	G	1	600-700°C
JB002	Pfyn / Horgen pot	AI	G-B-O	4	> 950°C
JB003	Pfyn / Horgen pot	AI	G	1	600-700°C
JB004	USF	AV	B-G	3	< 950°C
JB005	USF	AI	Y-B	5	< 950°C
JB006	SF Boleráz	AI	B	2	600-700°C
JB007	SF Pfyn	AIII	B-G	3	< 950°C
JB008	SF Bayern	AV	Y-B-Y	4	< 950°C
JB009	SF Pfyn	AI	G-B-Y	4	< 950°C
JB010	Pfyn / Horgen pot	AV	B-G	3	< 950°C
JB011	USF	AI	G	1	600-700°C
JB012	USF	AVI	G	1	600-700°C
JB013	SF Boleráz	AV	G-B-G	4	< 950°C
JB014	SF Boleráz	AV	O-B-O	4	< 950°C
JB015	SF Bayern	AV	Y-B-Y	4	< 950°C
JB016	USF	AI	Y	1	550-950°C
JB017	SF Boleráz	AI	B	2	< 600°C
JB018	USF	AV	G	1	< 600°C
JB019	Pfyn / Horgen pot	AV	Y	1	550-950°C
JB020	SF Boleráz	AVI	B	2	< 600°C
JB021	SF Bayern	AI	G-B-Y	4	< 950°C
JB022	Pfyn / Horgen pot	AI	Y	1	550-950°C
JB023	Pfyn / Horgen pot	AI	G-B-G	4	< 950°C
JB024	Pfyn / Horgen pot	AV	Y-B-Y	4	< 950°C
JB025	Pfyn / Horgen pot	AIV	O-B-G	4	< 950°C
JB026	Pfyn / Horgen pot	AI	B-Y	3	< 950°C
JB027	USF	AI	B-G	3	< 950°C
JB028	Pfyn / Horgen pot	AI	O-B-G	4	< 950°C
JB029	USF	AV	B	2	600-700°C
JB030	USF	AI	G-B-G	4	< 950°C
JB031	Pfyn / Horgen pot	AI	O-B-O	4	< 950°C
JB032	Pfyn / Horgen pot	AI	Y	1	550-950°C
JB033	SF Boleráz	AV	Y-B-Y	4	< 950°C
JB034	SF Boleráz	AV	G-B	5	< 950°C
JB035	Pfyn / Horgen pot	BI	B-G	3	< 950°C
JB036	USF	AIV	Y-B-Y	4	< 950°C
JB037	SF Bayern	AV	Y	1	550-950°C
JB038	Pfyn / Horgen pot	AI	B-Y	3	< 950°C
JB039	Pfyn / Horgen pot	AI	G-B	5	< 950°C
JB040	USF	CI	Y-B-Y	4	< 950°C
JB041	Pfyn / Horgen pot	AI	B-Y	3	< 950°C
JB042	Pfyn / Horgen pot	AI	B-Y	3	< 950°C
JB043	Pfyn / Horgen pot	AI	Y-B-Y	4	< 950°C
JB044	Pfyn / Horgen pot	AI	G-B	5	< 950°C
JB045	Pfyn / Horgen pot	CI	Y-B-Y	4	< 950°C
JB046	USF	AI	B	2	600-700°C
JB047	Pfyn / Horgen pot	CI	B	2	600-700°C
JB048	Pfyn / Horgen pot	AI	B-Y	3	< 950°C
JB049	Pfyn / Horgen pot	CI	B-G	3	< 950°C
JB050	SF Boleráz	AI	B-G	3	< 950°C
JB051	Pfyn / Horgen pot	AV	B-Y	3	< 950°C
JB052	Pfyn / Horgen pot	AIV	B-Y	3	< 950°C
JB053	Pfyn / Horgen pot	AI	B-Y	3	< 950°C
JB054	Pfyn / Horgen pot	AI	Y-B-G	4	< 950°C
JB055	Pfyn / Horgen pot	AI	B-Y	3	< 950°C
JB056	Pfyn / Horgen pot	AI	B-G	3	< 950°C
JB057	USF	AI	Y-B-Y	4	< 950°C
JB058	Pfyn / Horgen pot	AI	B-G	3	< 950°C
JB059	Pfyn / Horgen pot	AI	B-Y	3	< 950°C
JB060	Pfyn / Horgen pot	AI	B-G	3	< 950°C
JB061	Pfyn / Horgen pot	AI	B-O	3	< 950°C
JB062	Pfyn / Horgen pot	AI	B-Y	3	< 950°C
JB063	SF Boleráz	AV	B-Y	3	< 950°C
JB064	Pfyn / Horgen pot	CI	B-Y	3	< 950°C
JB065	Pfyn / Horgen pot	AI	B	2	600-700°C
JB066	Pfyn / Horgen pot	AI	B-Y	3	< 950°C
JB067	Pfyn / Horgen pot	AIV	B-Y	3	< 950°C
JB068	Pfyn / Horgen pot	AI	G-B-Y	4	< 950°C
JB069	SF Boleráz	AVI	G-B-G	4	< 950°C
JB070	Pfyn / Horgen pot	AIV	Y-B-Y	4	< 950°C
JB071	USF	BI	Y-B-Y	4	< 950°C
JB072	USF	AI	B	2	600-700°C
JB073	SF Boleráz	AV	Y-B-Y	4	< 950°C
JB074	USF	AIV	B	2	600-700°C
JB075	USF	AV	Y-B-Y	4	< 950°C
JB076	Pfyn / Horgen pot	AII	B-Y	3	< 950°C
JB086	USF	AV	B	2	< 600°C
JB087	USF	AV	Y-B-Y	4	< 950°C
JB088	SF Bayern	AV	Y-B	5	< 950°C
JB089	Pfyn / Horgen pot	AII	B-G	3	< 950°C
JB090	SF Bayern	CII	B-G	3	< 950°C
JB091	Pfyn / Horgen pot	AI	B-Y	3	< 950°C
JB092	Pfyn / Horgen pot	AV	B-Y	3	< 950°C
JB093	Pfyn / Horgen pot	AI	B-G	3	< 950°C
JB094	Pfyn / Horgen pot	AI	B-Y	3	< 950°C
JB095	SF Bayern	AI	Y-B-Y	4	< 950°C
JB096	Pfyn / Horgen pot	AI	B-Y	3	< 950°C
JB097	Pfyn / Horgen pot	AII	B-Y	3	< 950°C
JB098	USF	AI	G-B-G	4	< 950°C
JB099	SF Boleráz	BII	Y-B-Y	4	< 950°C
JB100	Pfyn / Horgen pot	AI	G	1	600-700°C
JB101	Pfyn / Horgen pot	AI	B-Y	3	< 950°C
JB102	USF	AV	Y-B-Y	4	< 950°C
JB103	Pfyn / Horgen pot	AI	Y-B-Y	4	< 950°C
JB104	Pfyn / Horgen pot	AI	B-G	3	< 950°C
JB105	USF	AI	B	2	> 700°C
JB106	SF Boleráz	AV	Y-B-Y	4	< 950°C
JB107	USF	AI	Y-B-Y	4	< 950°C
JB108	Pfyn / Horgen pot	AIV	B-Y	3	< 950°C
JB109	Pfyn / Horgen pot	AII	Y-B	5	< 950°C
JB110	SF Bayern	AI	B-Y	3	< 950°C
JB111	Spindlewhorl	AV	Y-B-Y	4	< 950°C
JB112	Spindlewhorl	AV	B	2	600-700°C
JB113	Spindlewhorl	AI	B	2	< 600°C
JB114	Spindlewhorl	AI	B-G	3	< 950°C
JB115	Spindlewhorl	AI	B	2	< 600°C
JB116	Spindlewhorl	AI	G	1	600-700°C
JB117	Spindlewhorl	AI	B-G	3	< 950°C
JB118	Spindlewhorl	AI	G	1	600-700°C
JB119	Spindlewhorl	AI	Y	1	< 500°C
JB120	Spindlewhorl	AV	B	2	600-700°C
JB121	Loomweight	CIII			non fired
JB122	Cob	CIII			non fired
JB123	Cob	CIII			non fired
JB124	Cob	CIII			non fired
JB125	Cob	CIII			non fired
JB126	Cob	CIII			non fired
JB127	Cob	CIII			non fired
JB128	Cob	CIII			non fired
JB129	Cob	CIII			non fired
JB130	Cob	CIII			non fired
JB131	Cob	CIII			non fired
JB132	Cob	CIII			non fired

Sample Number	Typological Group	Petrographical Group	Section Colour	Colour Group	Firing Temperature
JB133	Pfyn / Horgen pot	AV	B-Y	3	< 950°C
JB134	Pfyn / Horgen pot	AI	Y	1	< 500°C
JB135	Pfyn / Horgen pot	AI	B-Y	3	< 950°C
JB136	Pfyn / Horgen pot	AI	B-G	3	< 950°C
JB137	Pfyn / Horgen pot	AI	Y-B-Y	4	< 950°C
JB138	SF Boleráz	AV	Y-B-Y	4	< 950°C
JB139	SF Boleráz	AV	G-B-G	4	< 950°C
JB140	SF Boleráz	AIV	B-G	3	< 950°C
JB141	SF Boleráz	BII	B-G	3	< 950°C
JB142	USF	AI	G-B	5	< 950°C
JB143	SF Bayern	AI	B	2	< 600°C
JB144	SF Boleráz	AV	Y-B-Y	4	< 950°C
JB145	SF Boleráz	AV	G	1	< 600°C
JB146	SF Boleráz	AV	G-B-G	4	< 950°C
JB147	SF Boleráz	AVI	B	2	600-700°C
JB148	SF Boleráz	AV	B	2	600-700°C
JB149	SF Boleráz	AIV	Y	1	550-950°C
JB150	SF Bayern	AI	B	2	< 600°C
JB151	SF Bayern	AV	B-Y	3	< 950°C
JB152	SF Boleráz	AI	B-Y	3	< 950°C
JB153	SF Bayern	AI	B	2	600-700°C
JB154	SF Boleráz	BII	B-Y	3	< 950°C
JB155	SF Boleráz	AV	B-Y	3	< 950°C
JB157	SF Bayern	AV	G-B-G	4	< 950°C
JB158	USF	AI	B	2	< 600°C
JB159	USF	AV	G	1	< 600°C
JB160	USF	AV	Y-B-Y	4	< 950°C
JB162	USF	AI	G	1	< 600°C
JB163	USF	AIV	Y-B-Y	4	< 950°C
JB164	USF	AI	G	1	< 600°C
JB165	USF	AV	B-G	3	< 950°C
JB166	USF	AV	B	2	< 600°C
JB167	USF	AI	B	2	< 600°C
JB169	USF	AV	G	1	600-700°C
JB171	SF Pfyn	AI	G	1	600-700°C
JB173	USF	AI	G	1	600-700°C
JB174	USF	AV	Y	1	550-950°C
JB175	SF Boleráz	AV	Y	1	550-950°C
JB177	USF	AI	B	2	600-700°C
JB178	USF	AI	G	1	< 600°C
JB179	SF Boleráz	AV	Y-B-Y	4	< 950°C
JB180	USF	AV	G	1	< 600°C
JB181	USF	AI	G	1	600-700°C
JB182	USF	AV	Y-B-Y	4	< 950°C
JB183	USF	AI	G	1	< 600°C
JB185	SF Boleráz	AV	B	2	600-700°C
JB186	USF	AI	B	2	600-700°C
JB187	USF	AI	B	2	600-700°C
JB188	USF	AI	G	1	600-700°C
JB189	USF	AV	G	1	600-700°C
JB190	USF	AI	Y	1	550-950°C

3 - APPENDIX 3

Petrographical description of the thin sections.
(SF: special form, USF: undetermined special form; Si: silicate-rich matrix, Ca: carbonate-rich matrix, incl.: inclusion; in "Temper": 1: few; 2: present; 3: frequent; 4: much; GR: Granite, GA: Gabbro, GG: grog; RH: Rhyolite; CH: Chert; BO: Bone; definition of the petrographical groups, see text).

Sample Number	Typological Group	Matrix	Temper							Temper Type				Petrographical Group
			Rock (vol.%)	Granite	Rhyolite	Chert	Gabbro	Grog (vol.%)	Bone (vol.%)	Main	Second	Third	Fourth	
JB001	Pfyn / Horgen pot	Si, incl. poor	20	1			3	2		GA	GR	GG		AIV
JB002	Pfyn / Horgen pot	Si, incl. poor	10	2	1			2		GR	RH	GG		AI
JB003	Pfyn / Horgen pot	Si, incl. poor	20	3				0		GR				AI
JB004	USF	Si, incl. poor	0					5		GG				AV
JB005	USF	Si, incl. poor	5	2				0		GR				AI
JB006	SF Boleráz	Si, incl. poor	10	2				5		GR	GG			AI
JB007	SF Pfyn	Si, incl. poor	15	1		3	1	3		CH	GR	GA	GG	AIII
JB008	SF Bayern	Si, incl. poor	5	2	1		1	10		GG	GR	RH	GA	AV
JB009	SF Pfyn	Si, incl. poor	25	3		1		0		GR	CH			AI
JB010	Pfyn / Horgen pot	Si, incl. poor	0					7		GG				AV
JB011	USF	Si, incl. poor	20	3				0		GR				AI
JB012	USF	Si, incl. poor	0					10	10, black	BO	GG			AVI
JB013	SF Boleráz	Si, incl. poor	5	2				10		GG	GR			AV
JB014	SF Boleráz	Si, incl. poor	3	2		1		7		GG	GR	CH		AV
JB015	SF Bayern	Si, incl. poor	5	2				10		GG	GR			AV
JB016	USF	Si, incl. poor	5	2				0		GR				AI
JB017	SF Boleráz	Si, incl. poor	5	2	2			2		GR	RH	GG		AI
JB018	USF	Si, incl. poor	2	2				5		GG	GR			AV
JB019	Pfyn / Horgen pot	Si, incl. poor	2	2				5		GG	GR			AV
JB020	SF Boleráz	Si, incl. poor	5	2				10	20	BO	GG	GR		AVI
JB021	SF Bayern	Si, incl. poor	10	2				5		GR	GG			AI
JB022	Pfyn / Horgen pot	Si, incl. poor	25	3				0		GR				AI
JB023	Pfyn / Horgen pot	Si, incl. poor	20	3		2		0		GR	CH			AI
JB024	Pfyn / Horgen pot	Si, incl. poor	5	2				10		GG	GR			AV
JB025	Pfyn / Horgen pot	Si, incl. poor	10	1			2	0		GA	GR			AIV
JB026	Pfyn / Horgen pot	Si, incl. poor	20	3				0		GR				AI
JB027	USF	Si, incl. poor	10	2	1			2		GR	RH	GG		AI
JB028	Pfyn / Horgen pot	Si, incl. poor	5	2		1		2		GR	CH	GG		AI
JB029	USF	Si, incl. poor	2	2				5		GG	GR			AV
JB030	USF	Si, incl. poor	15	3				2		GR	GG			AI
JB031	Pfyn / Horgen pot	Si, incl. poor	25	3	1			0		GR	RH			AI
JB032	Pfyn / Horgen pot	Si, incl. poor	10	2		1		0		GR	CH			AI
JB033	SF Boleráz	Si, incl. poor	0					2		GG				AV
JB034	SF Boleráz	Si, incl. poor	0					2		GG				AV
JB035	Pfyn / Horgen pot	Si, incl. rich	15	3		1		2		GR	CH	GG		BI
JB036	USF	Si, incl. poor	15	2			2	0		GA	GR			AIV
JB037	SF Bayern	Si, incl. poor	3	2				10		GG	GR			AV
JB038	Pfyn / Horgen pot	Si, incl. poor	20	3				0		GR				AI
JB039	Pfyn / Horgen pot	Si, incl. poor	20	3				0		GR				AI
JB040	USF	Ca, incl. rich	10	2				0		GR				CI
JB041	Pfyn / Horgen pot	Si, incl. poor	20	3	1			0		GR	RH			AI
JB042	Pfyn / Horgen pot	Si, incl. poor	25	3				0		GR				AI
JB043	Pfyn / Horgen pot	Si, incl. poor	7	2				2		GR	GG			AI
JB044	Pfyn / Horgen pot	Si, incl. poor	25	3			1	2		GR	GA	GG		AI
JB045	Pfyn / Horgen pot	Ca, incl. rich	20	3				0		GR				CI
JB046	USF	Si, incl. poor	10	2				0		GR				AI
JB047	Pfyn / Horgen pot	Ca, incl. rich	10	2				0		GR				CI
JB048	Pfyn / Horgen pot	Si, incl. poor	5	2				2		GR	GG			AI
JB049	Pfyn / Horgen pot	Ca, incl. rich	10	2			1	2		GR	GA	GG		CI
JB050	SF Boleráz	Si, incl. poor	5	2				2		GR	GG			AI
JB051	Pfyn / Horgen pot	Si, incl. poor	3	2				15		GG	GR			AV
JB052	Pfyn / Horgen pot	Si, incl. poor	25			1	3	0		GA	CH			AIV
JB053	Pfyn / Horgen pot	Si, incl. poor	7	2				3		GR	GG			AI
JB054	Pfyn / Horgen pot	Si, incl. poor	15	3				0		GR				AI
JB055	Pfyn / Horgen pot	Si, incl. poor	15	3				0		GR				AI
JB056	Pfyn / Horgen pot	Si, incl. poor	15	3				0		GR				AI
JB057	USF	Si, incl. poor	15	3				3		GR	GG			AI
JB058	Pfyn / Horgen pot	Si, incl. poor	20	3				0		GR				AI
JB059	Pfyn / Horgen pot	Si, incl. poor	10	2	1		2	0		GR	GA	RH		AI
JB060	Pfyn / Horgen pot	Si, incl. poor	10	2				0		GR				AI

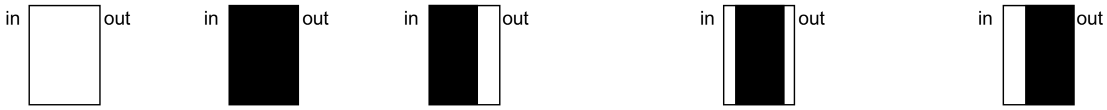
Sample Number	Typological Group	Matrix	Temper							Temper Type				Petrographical Group
			Rock (vol.%)	Granite	Rhyolite	Chert	Gabbro	Grog (vol.%)	Bone (vol.%)	Main	Second	Third	Fourth	
JB061	Pfyn / Horgen pot	Si, incl. poor	15	3				2		GR	GG			AI
JB062	Pfyn / Horgen pot	Si, incl. poor	20	3				0		GR				AI
JB063	SF Boleráz	Si, incl. poor	3				1	10		GG	GA			AV
JB064	Pfyn / Horgen pot	Ca, incl. rich	20	3			1	0		GR	GA			CI
JB065	Pfyn / Horgen pot	Si, incl. poor	15	3				0		GR				AI
JB066	Pfyn / Horgen pot	Si, incl. poor	7	2				2		GR	GG			AI
JB067	Pfyn / Horgen pot	Si, incl. poor	15		2		3	0		GA	RH			AIV
JB068	Pfyn / Horgen pot	Si, incl. poor	10	2				0		GR				AI
JB069	SF Boleráz	Si, incl. poor	0					0	20	BO				AVI
JB070	Pfyn / Horgen pot	Si, incl. poor	25			1	3	0		GA	CH			AIV
JB071	USF	Si, incl. rich	7	2				2		GR	GG			BI
JB072	USF	Si, incl. poor	15	3				0		GR				AI
JB073	SF Boleráz	Si, incl. poor	0					10		GG				AV
JB074	USF	Si, incl. poor	10	2	1		2	0		GA	GR	RH		AIV
JB075	USF	Si, incl. poor	5	2	1			10		GG	GR	RH		AV
JB076	Pfyn / Horgen pot	Si, incl. poor	15	2	3			0		RH	GR			AII
JB086	USF	Si, incl. poor	0					7		GG				AV
JB087	USF	Si, incl. poor	0					7		GG				AV
JB088	SF Bayern	Si, incl. poor	3	2				7		GG	GR			AV
JB089	Pfyn / Horgen pot	Si, incl. poor	10		2		1	0		RH	GA			AII
JB090	SF Bayern	Ca, incl. poor	2	2				10		GG	GR			CII
JB091	Pfyn / Horgen pot	Si, incl. poor	20	3				0		GR				AI
JB092	Pfyn / Horgen pot	Si, incl. poor	2	2				5		GG	GR			AV
JB093	Pfyn / Horgen pot	Si, incl. poor	15	3				0		GR				AI
JB094	Pfyn / Horgen pot	Si, incl. poor	10	3				2		GR	GG			AI
JB095	SF Bayern	Si, incl. poor	5	2				2		GR	GG			AI
JB096	Pfyn / Horgen pot	Si, incl. poor	3	2				10		GR	GG			AI
JB097	Pfyn / Horgen pot	Si, incl. poor	10	2	2		1	5		RH	GR	GA	GG	AII
JB098	USF	Si, incl. poor	25	3				0		GR				AI
JB099	SF Boleráz	Si, incl. rich	0					5		GG				BII
JB100	Pfyn / Horgen pot	Si, incl. poor	15	3				0		GR				AI
JB101	Pfyn / Horgen pot	Si, incl. poor	5	2				3		GR	GG			AI
JB102	USF	Si, incl. poor	15	3				10		GG	GR			AV
JB103	Pfyn / Horgen pot	Si, incl. poor	20	3				0		GR				AI
JB104	Pfyn / Horgen pot	Si, incl. poor	5	2				0		GR				AI
JB105	USF	Si, incl. poor	2	2				0		GR				AI
JB106	SF Boleráz	Si, incl. poor	2	2				7		GG	GR			AV
JB107	USF	Si, incl. poor	7	2				0		GR				AI
JB108	Pfyn / Horgen pot	Si, incl. poor	20	2			2	0		GA	GR			AIV
JB109	Pfyn / Horgen pot	Si, incl. poor	20	1	3			0		RH	GR			AII
JB110	SF Bayern	Si, incl. poor	25	3				2		GR	GG			AI
JB111	Spindlewhorl	Si, incl. poor	2	2				10		GG	GR			AV
JB112	Spindlewhorl	Si, incl. poor	2	2				7		GG	GR			AV
JB113	Spindlewhorl	Si, incl. poor	25	3				0		GR				AI
JB114	Spindlewhorl	Si, incl. poor	10	2				0		GR				AI
JB115	Spindlewhorl	Si, incl. poor	20	3				0		GR				AI
JB116	Spindlewhorl	Si, incl. poor	5	2				0		GR				AI
JB117	Spindlewhorl	Si, incl. poor	15	3				0		GR				AI
JB118	Spindlewhorl	Si, incl. poor	5	2				0		GR				AI
JB119	Spindlewhorl	Si, incl. poor	5	2				0		GR				AI
JB120	Spindlewhorl	Si, incl. poor	2	2				7		GG	GR			AV
JB121	Loomweight	Ca, incl. rich	0					0						CIII
JB122	Cob	Ca, incl. rich	0					0						CIII
JB123	Cob	Ca, incl. rich	0					0						CIII
JB124	Cob	Ca, incl. rich	0					0						CIII
JB125	Cob	Ca, incl. rich	0					0						CIII
JB126	Cob	Ca, incl. rich	0					0						CIII
JB127	Cob	Ca, incl. rich	0					0						CIII
JB128	Cob	Ca, incl. rich	0					0						CIII
JB129	Cob	Ca, incl. rich	0					0						CIII
JB130	Cob	Ca, incl. rich	0					0						CIII
JB131	Cob	Ca, incl. rich	0					0						CIII
JB132	Cob	Ca, incl. rich	0					0						CIII

Sample Number	Typological Group	Matrix	*Temper*							*Temper Type*				Petrographical Group
			Rock (vol.%)	Granite	Rhyolite	Chert	Gabbro	Grog (vol.%)	Bone (vol.%)	Main	Second	Third	Fourth	
JB133	Pfyn / Horgen pot	Si, incl. poor	2	2				7		GG	GR			AV
JB134	Pfyn / Horgen pot	Si, incl. poor	20	3				0		GR				AI
JB135	Pfyn / Horgen pot	Si, incl. poor	15	3		1		0		GR	CH			AI
JB136	Pfyn / Horgen pot	Si, incl. poor	15	3				0		GR				AI
JB137	Pfyn / Horgen pot	Si, incl. poor	20	3				0		GR				AI
JB138	SF Boleráz	Si, incl. poor	2	2				5		GG	GR			AV
JB139	SF Boleráz	Si, incl. poor	0					2		GG				AV
JB140	SF Boleráz	Si, incl. poor	15	2			3	0		GA	GR			AIV
JB141	SF Boleráz	Si, incl. rich	2	2				5		GG	RH			BII
JB142	USF	Si, incl. poor	20	2	2			0		GR	RH			AI
JB143	SF Bayern	Si, incl. poor	10	2				0		GR				AI
JB144	SF Boleráz	Si, incl. poor	0					10		GG				AV
JB145	SF Boleráz	Si, incl. poor	2		2			15		GG	RH			AV
JB146	SF Boleráz	Si, incl. poor	7	2				10		GG	GR			AV
JB147	SF Boleráz	Si, incl. poor	2	2				7	10	BO	GG	GR		AVI
JB148	SF Boleráz	Si, incl. poor	0					15	1 fragment	GG				AV
JB149	SF Boleráz	Si, incl. poor	7	1			2	0		GA	GR			AIV
JB150	SF Bayern	Si, incl. poor	15	3			1	0		GR	GA			AI
JB151	SF Bayern	Si, incl. poor	3	2				10		GG	GR			AV
JB152	SF Boleráz	Si, incl. poor	15	3				10	1 fragment	GR	GG			AI
JB153	SF Bayern	Si, incl. poor	20	3				0		GR				AI
JB154	SF Boleráz	Si, incl. rich	2				2	5		GG	GA			BII
JB155	SF Boleráz	Si, incl. poor	2	2	1			10		GG	GR	RH		AV
JB157	SF Bayern	Si, incl. poor	5	2			2	10		GG	GR	GA		AV
JB158	USF	Si, incl. poor	20	3				5		GR	GG			AI
JB159	USF	Si, incl. poor	3	2				15		GG	GR			AV
JB160	USF	Si, incl. poor	3	2				7		GG	GR			AV
JB162	USF	Si, incl. poor	7	2				2		GR	GG			AI
JB163	USF	Si, incl. poor	7				2	3		GA	GG			AIV
JB164	USF	Si, incl. poor	10	2				3		GR	GG			AI
JB165	USF	Si, incl. poor	3	2				7		GG	GR			AV
JB166	USF	Si, incl. poor	0					15		GG				AV
JB167	USF	Si, incl. poor	10	2				5		GR	GG			AI
JB169	USF	Si, incl. poor	2	2				7		GG	GR			AV
JB171	SF Pfyn	Si, incl. poor	15	3				0		GR				AI
JB172	USF	Si, incl. poor	3	2				10		GG	GR			AV
JB173	USF	Si, incl. poor	10	2				0		GR				AI
JB174	USF	Si, incl. poor	3				2	10		GG	GA			AV
JB175	SF Boleráz	Si, incl. poor	2	2				10		GG	GR			AV
JB177	USF	Si, incl. poor	7	2				5		GR	GG			AI
JB178	USF	Si, incl. poor	10	2				0		GR				AI
JB179	SF Boleráz	Si, incl. poor	3	2				7		GG	GR			AV
JB180	USF	Si, incl. poor	3	2				7		GG	GR			AV
JB181	USF	Si, incl. poor	15	3				0		GR				AI
JB182	USF	Si, incl. poor	0					25		GG				AV
JB183	USF	Si, incl. poor	10	2				0		GR				AI
JB185	SF Boleráz	Si, incl. poor	7	2				10		GG	GR			AV
JB186	USF	Si, incl. poor	25	3				0		GR				AI
JB187	USF	Si, incl. poor	15	3				0		GR				AI
JB188	USF	Si, incl. poor	25	3				0		GR				AI
JB189	USF	Si, incl. poor	7	2				15		GG	GR			AV
JB190	USF	Si, incl. poor	7	2				0		GR				AI

4 - APPENDIX 4

Description of the section of each ceramic sherd and their distribution into five colour groups (details see text). One third black, half black and two thirds black are the thickness of the black coloration on the section.

Description of the sections of the ceramic sherds.



Colour Group 1: Plain colour		
☐	JB001	G
☐	JB003	G
✕	JB011	G
✕	JB012	G
✕	JB016	Y
✕	JB018	G
☐	JB019	Y
☐	JB022	Y
☐	JB032	Y
▷	JB037	Y
☐	JB100	G
☐	JB116	G
☐	JB118	G
☐	JB119	Y
☐	JB134	Y
○	JB145	G
○	JB149	Y
✕	JB159	G
✕	JB162	G
✕	JB164	G
✕	JB169	G
◇	JB171	G
✕	JB173	G
✕	JB174	Y
✕	JB175	Y
✕	JB178	G
○	JB180	G
✕	JB181	G
✕	JB183	G
✕	JB189	G
✕	JB190	Y

Colour Group 2: Plain black		
○	JB006	B
○	JB017	B
○	JB020	B
✕	JB029	B
✕	JB046	B
☐	JB047	B
☐	JB065	B
✕	JB072	B
✕	JB074	B
✕	JB086	B
✕	JB105	B
○	JB112	B
☐	JB113	B
☐	JB115	B
○	JB120	B
▷	JB143	B
○	JB147	B
○	JB148	B
▷	JB150	B
▷	JB153	B
✕	JB158	B
✕	JB166	B
✕	JB167	B
○	JB177	B
✕	JB185	B
○	JB186	B
✕	JB187	B

Colour Group 3: Bi-coloured, inside black		
Group 3A: One third black		
✕	JB004	B-G
✕	JB027	B-G
☐	JB097	B-Y
☐	JB108	B-Y
○	JB140	B-G
Group 3B: Half black		
☐	JB010	B-G
☐	JB026	B-Y
☐	JB041	B-Y
☐	JB049	B-G
☐	JB052	B-Y
☐	JB053	B-Y
☐	JB055	B-Y
☐	JB056	B-G
☐	JB058	B-G
☐	JB060	B-G
☐	JB061	B-O
☐	JB062	B-Y
☐	JB089	B-G
☐	JB091	B-Y
▷	JB090	B-G
☐	JB092	B-Y
☐	JB093	B-G
☐	JB094	B-Y
☐	JB096	B-Y
☐	JB114	B-G
☐	JB117	B-G
☐	JB133	B-Y
☐	JB135	B-Y
○	JB155	B-Y
Group 3C: Two thirds black		
▷	JB007	B-G
☐	JB035	B-G
☐	JB038	B-Y
☐	JB042	B-Y
☐	JB048	B-Y
○	JB050	B-G
☐	JB051	B-Y
☐	JB059	B-Y
○	JB063	B-Y
☐	JB064	B-Y
☐	JB066	B-Y
☐	JB067	B-Y
☐	JB076-85	B-Y
☐	JB101	B-Y
☐	JB104	B-G
▷	JB110	B-Y
☐	JB136	B-G
○	JB141	B-G
▷	JB151	B-Y
○	JB152	B-Y
○	JB154	B-Y
✕	JB165	B-G

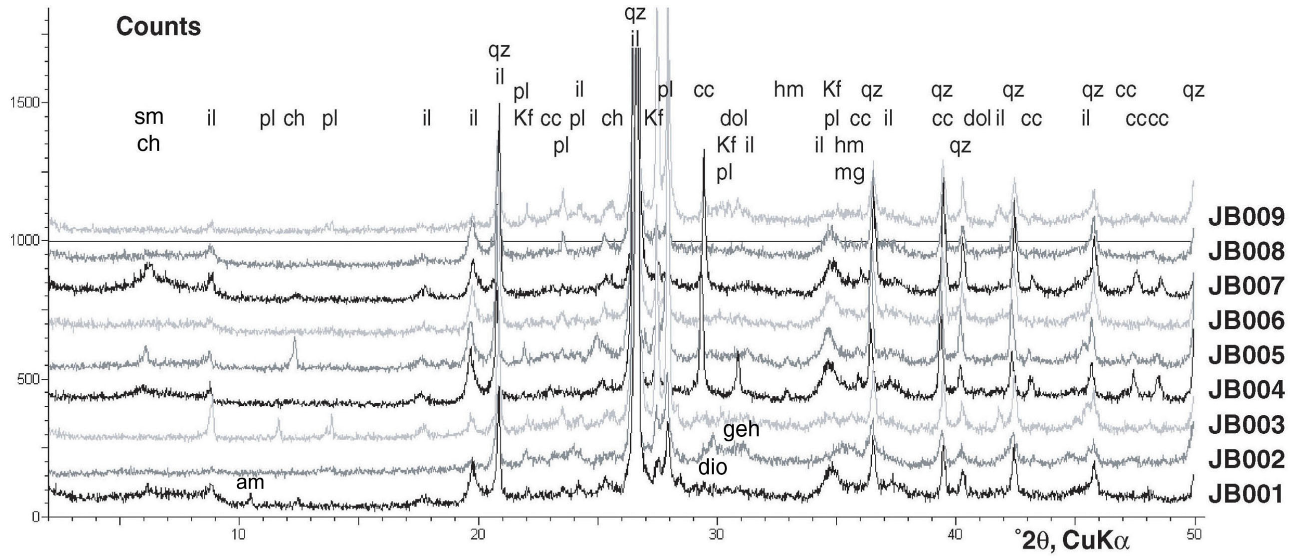
Colour Group 4: Bi-coloured, black core		
☐	JB002	G-B-O
▷	JB008	Y-B-Y
◇	JB009	G-B-Y
○	JB013	G-B-G
○	JB014	O-B-O
▷	JB015	Y-B-Y
▷	JB021	G-B-Y
☐	JB023	G-B-G
☐	JB024	Y-B-Y
☐	JB025	O-B-G
☐	JB028	O-B-G
✕	JB030	G-B-G
☐	JB031	O-B-O
○	JB033	Y-B-Y
✕	JB036	Y-B-Y
✕	JB040	Y-B-Y
☐	JB043	Y-B-Y
☐	JB045	Y-B-Y
☐	JB054	Y-B-G
✕	JB057	Y-B-Y
☐	JB068	G-B-Y
○	JB069	G-B-G
☐	JB070	Y-B-Y
✕	JB071	Y-B-Y
○	JB073	Y-B-Y
✕	JB075	Y-B-Y
✕	JB087	Y-B-Y
▷	JB095	Y-B-Y
✕	JB098	G-B-G
○	JB099	Y-B-Y
✕	JB102	Y-B-Y
☐	JB103	Y-B-Y
○	JB106	Y-B-Y
✕	JB107	Y-B-Y
○	JB111	Y-B-Y
☐	JB137	Y-B-Y
○	JB138	Y-B-Y
○	JB139	G-B-G
○	JB144	Y-B-Y
○	JB146	G-B-G
▷	JB157	G-B-G
✕	JB160	Y-B-Y
✕	JB163	Y-B-Y
✕	JB179	Y-B-Y
✕	JB182	Y-B-Y

Colour Group 5: Bi-coloured, outside black		
Group 5A : One third black		
✕	JB142	G-B
Group 5B : Half black		
○	JB034	G-B
☐	JB039	G-B
☐	JB044	G-B
▷	JB088	Y-B
Group 5C : Two thirds black		
✕	JB005	Y-B
☐	JB109	Y-B

B: Black
G: Grey
Y: Yellowish-beige
O: Orange
in: inner surface
out: outer surface
☐ Pfyn / Horgen pot
◇ SF Pfyn
▷ SF Bayern
○ SF Boleráz
✕ USF

5 - APPENDIX 5

X-ray diffractograms of each sample.
(am: amphibole; ank: ankerite; ap: apatite; cc: calcite; ch: chlorite; dol: dolomite; hm: hematite; il: illite; Kf: K-feldspars; mg: magnetite; pl: plagioclase; qz: quartz; sm: smectite).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pl Kf
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il
Kf pl
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qz cc
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dol il
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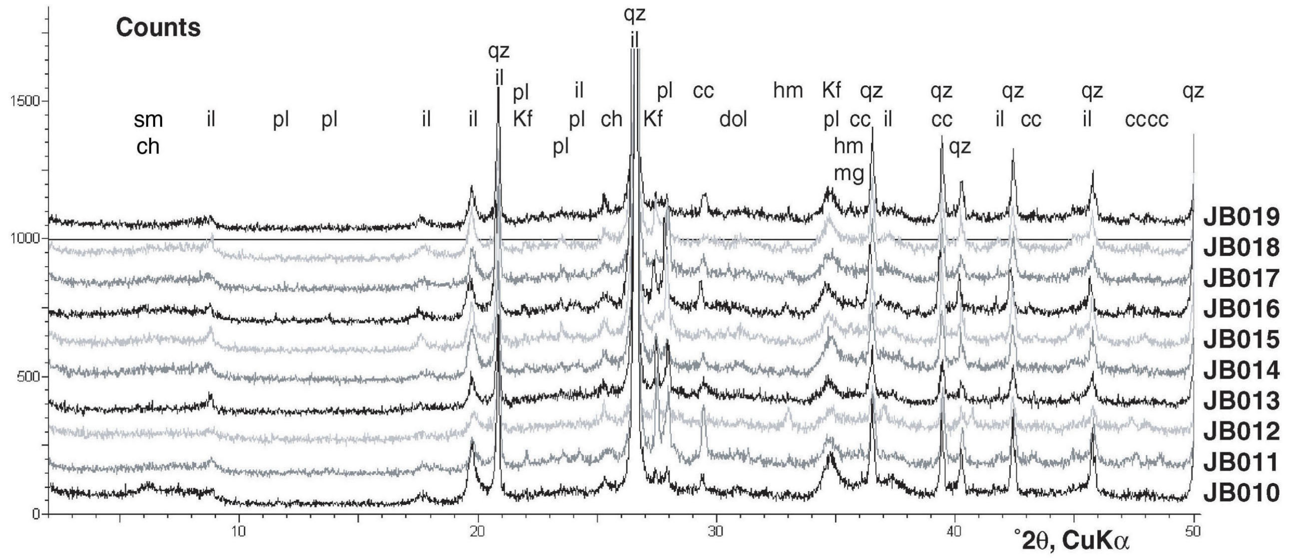
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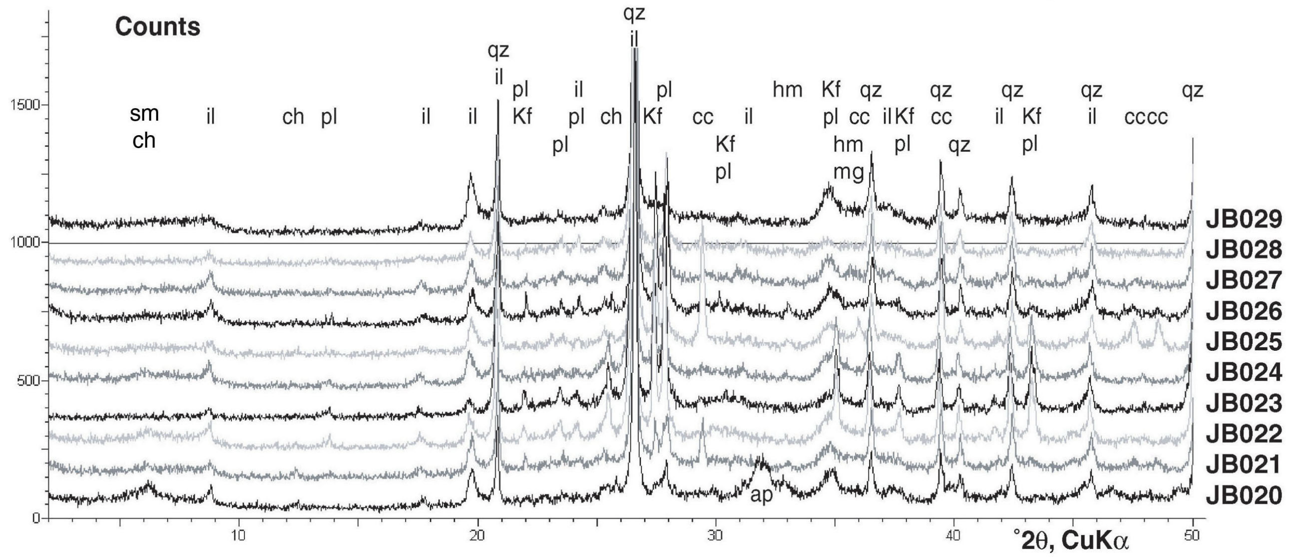
JB011
JB010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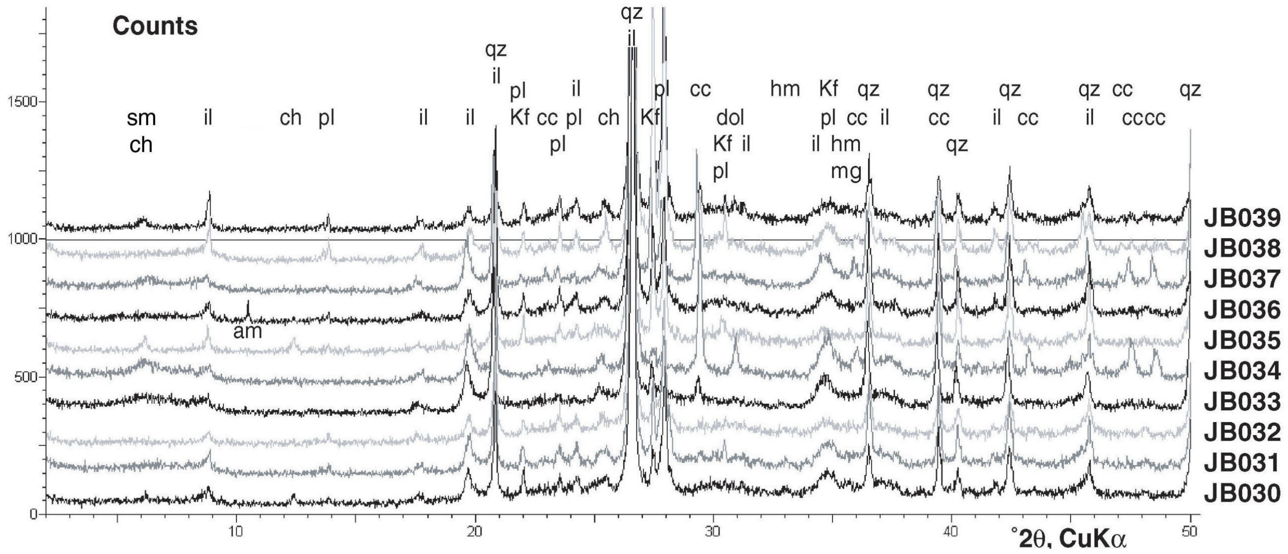
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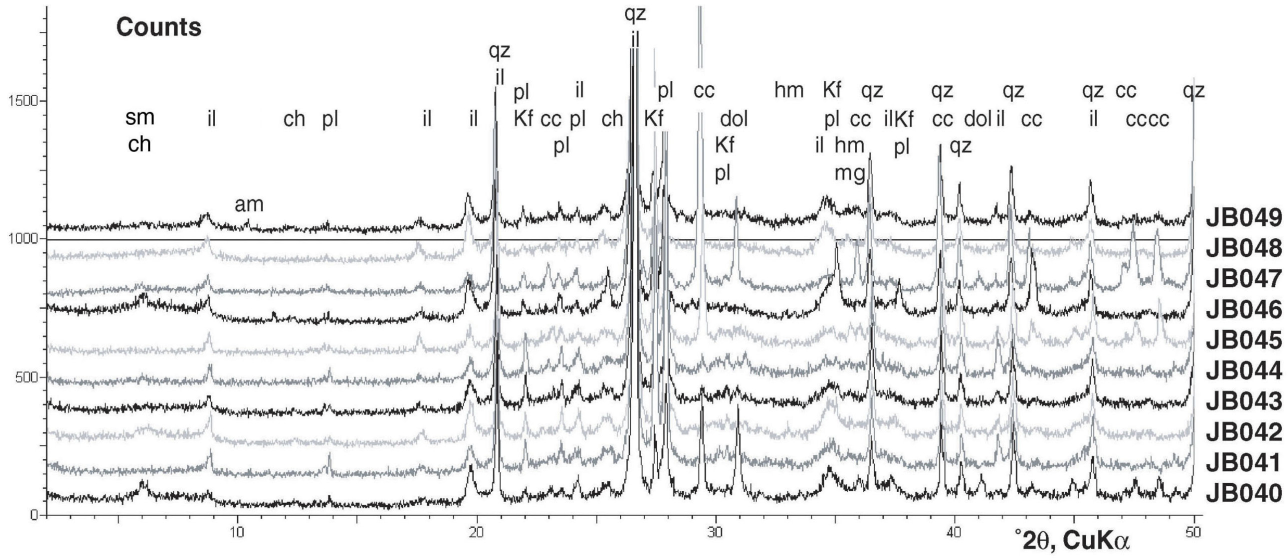
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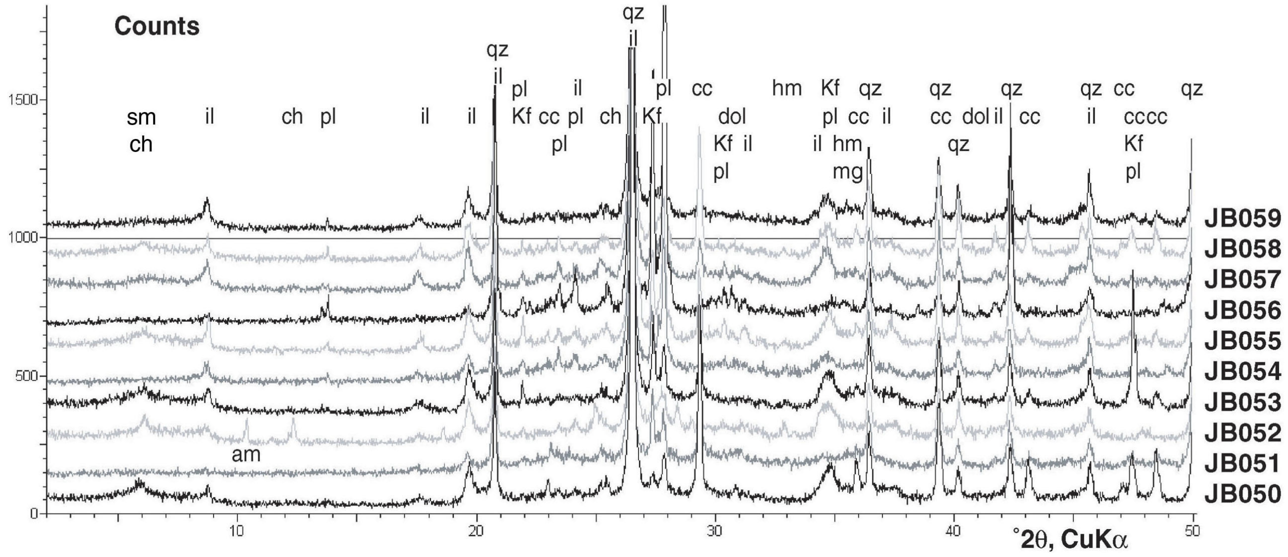
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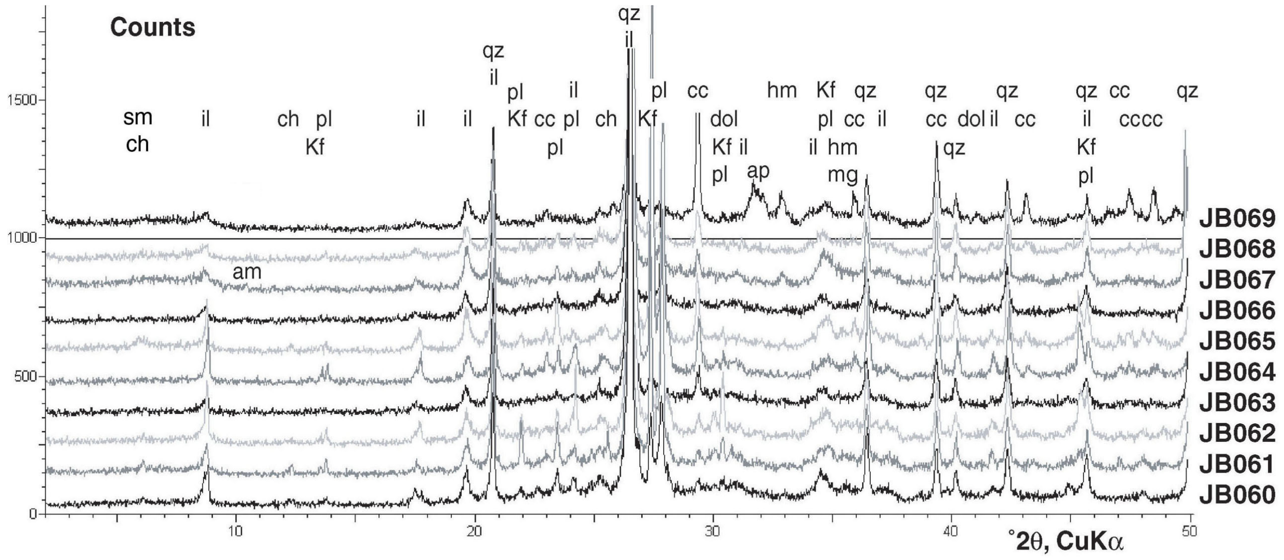
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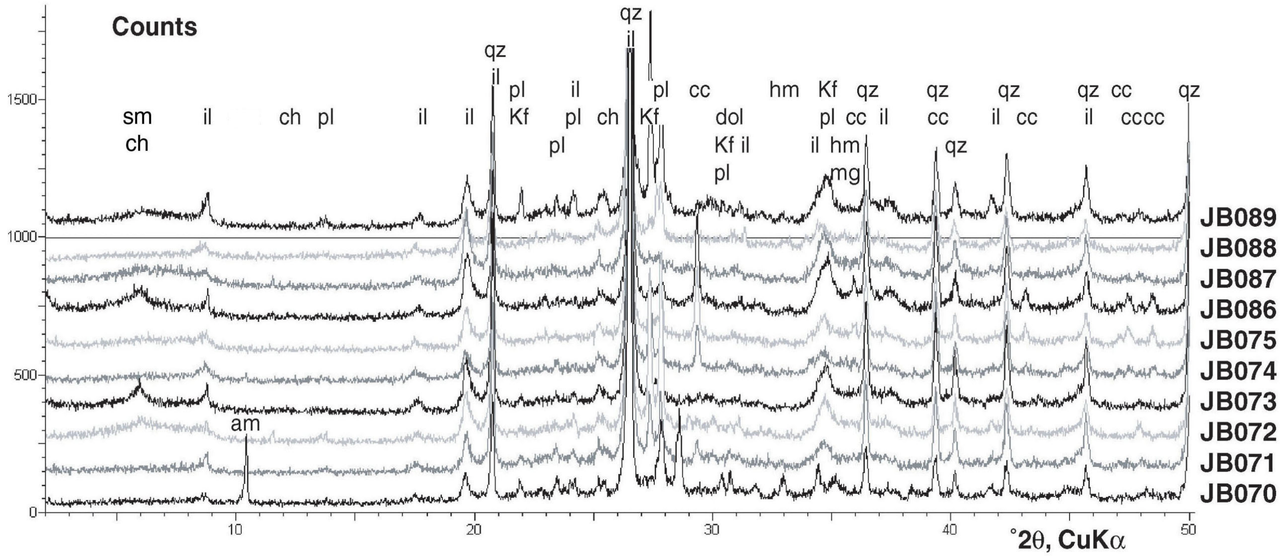
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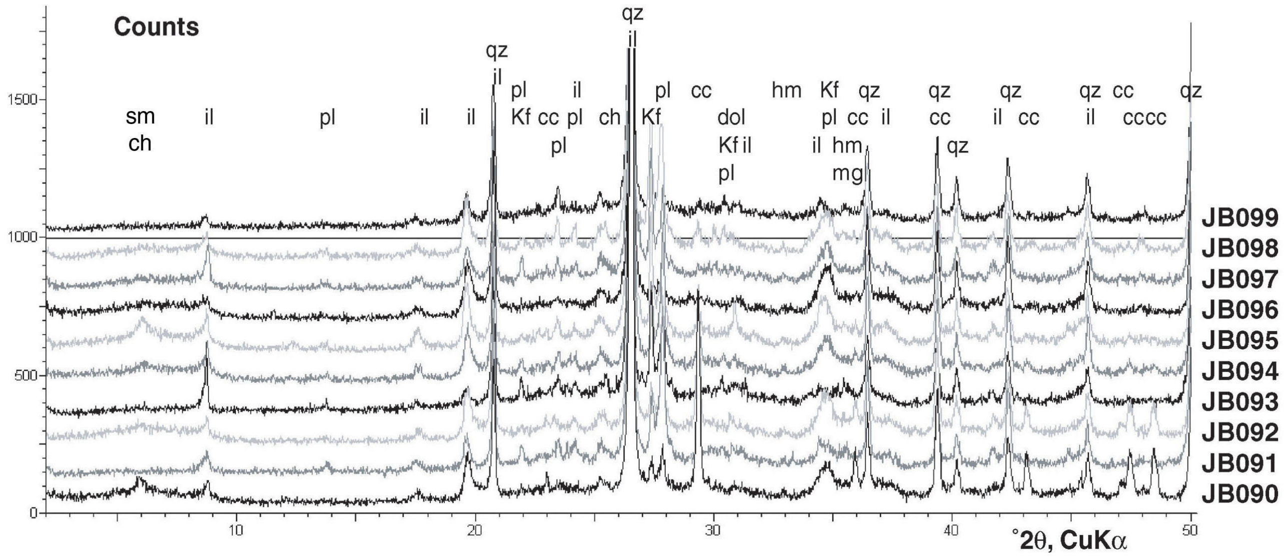
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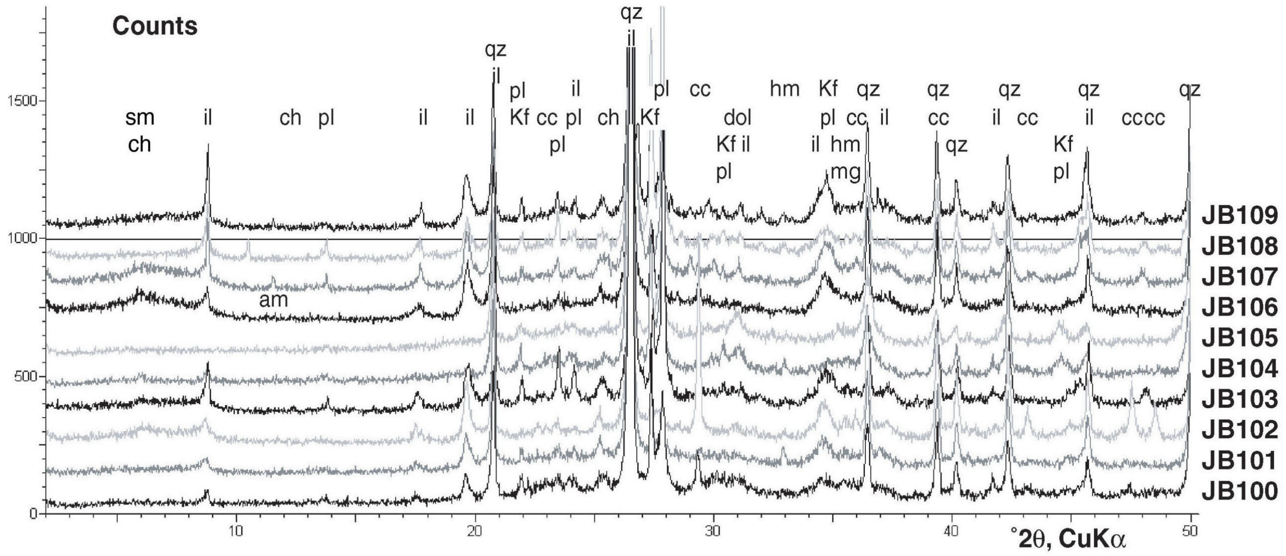
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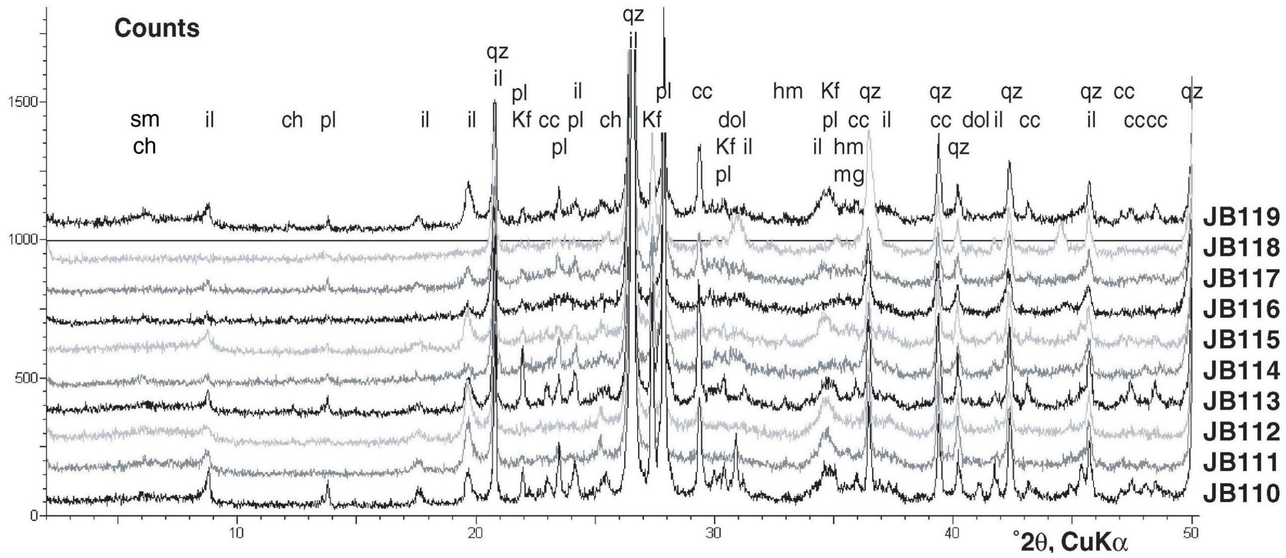
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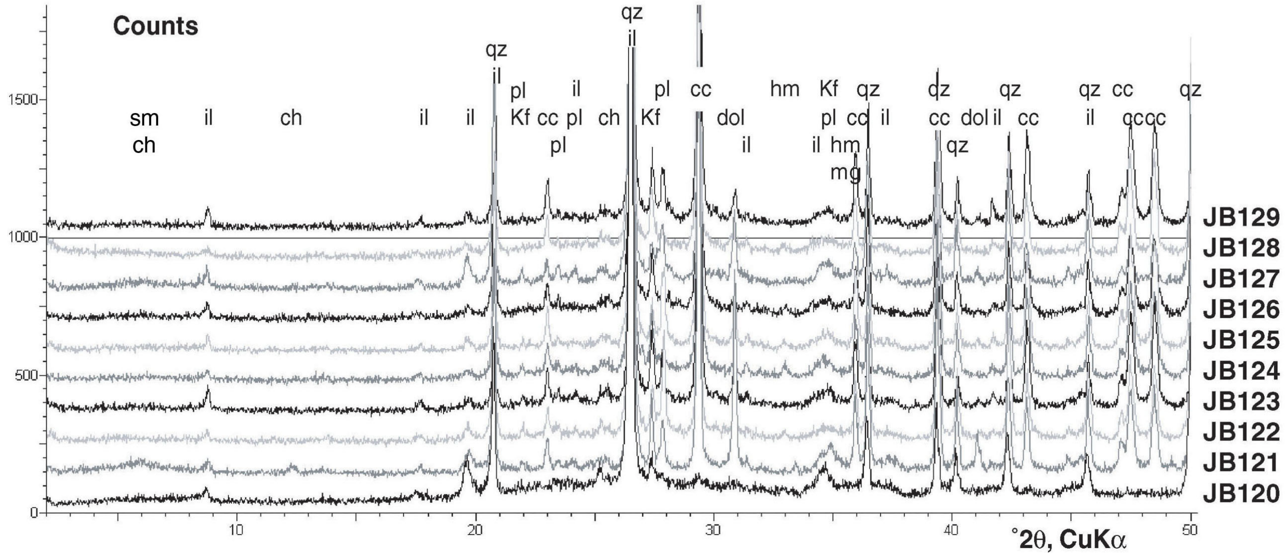
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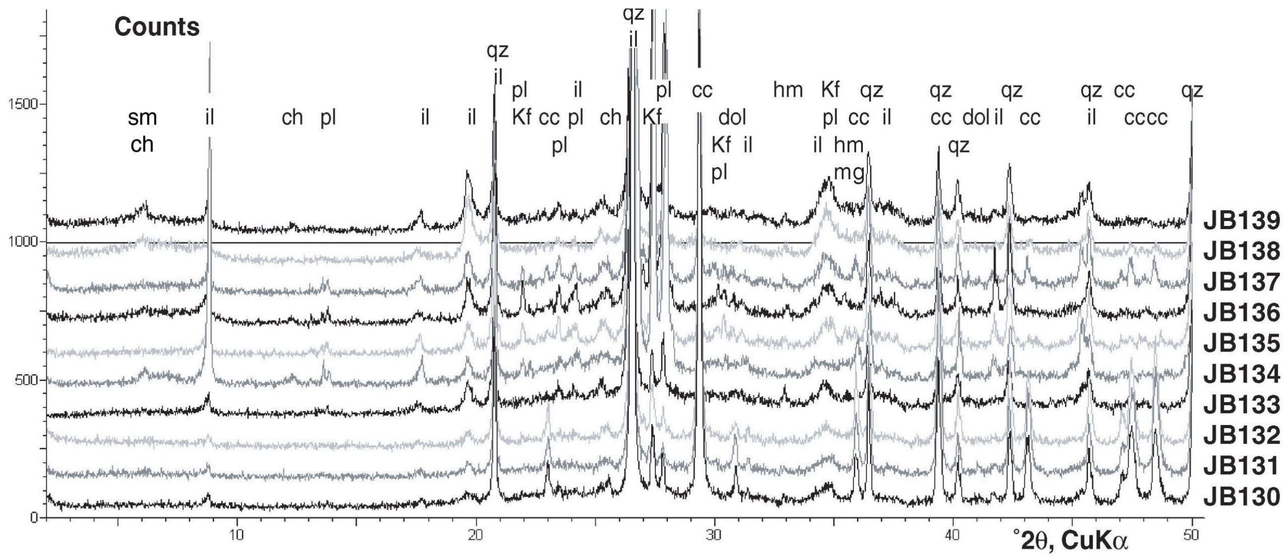
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qz il
pl Kf
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dol Kf il pl
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Kf pl il
qz cc hm mg
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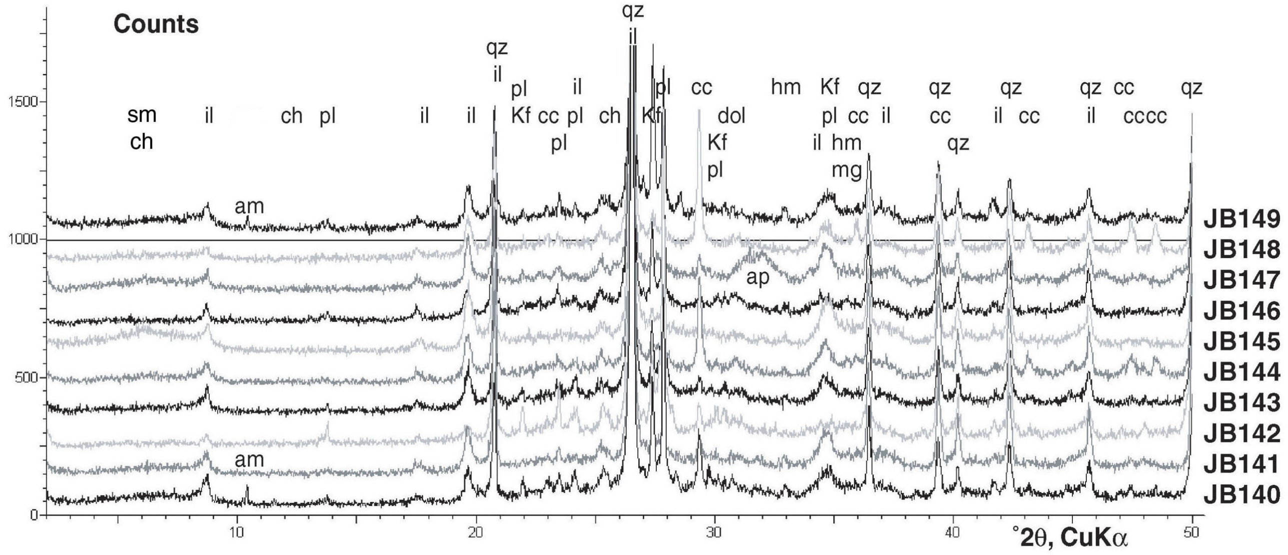
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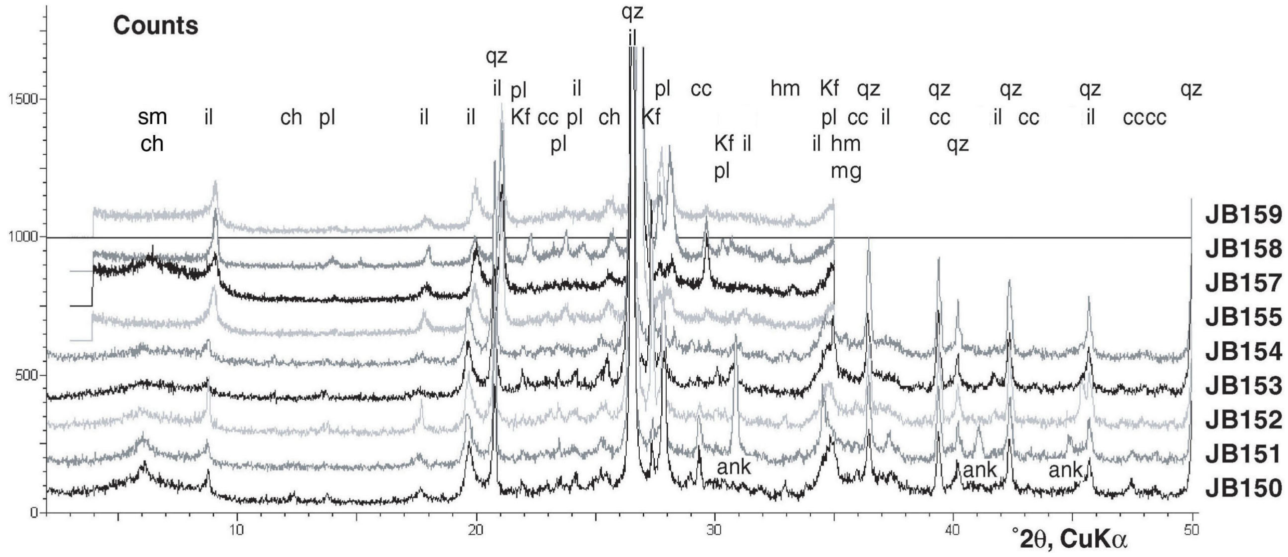
JB140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JB159
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JB155
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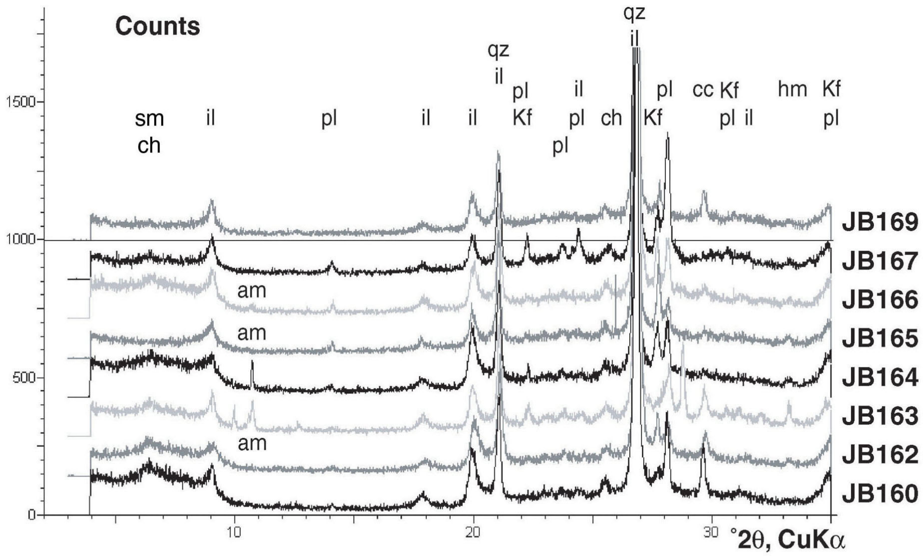
JB151
JB150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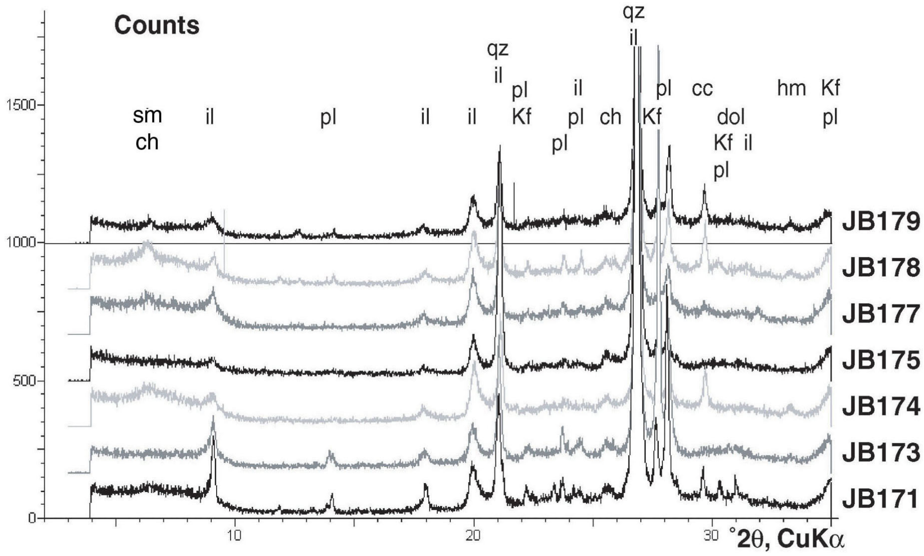
JB169
JB167
JB166
JB165
JB164
JB163
JB162
JB160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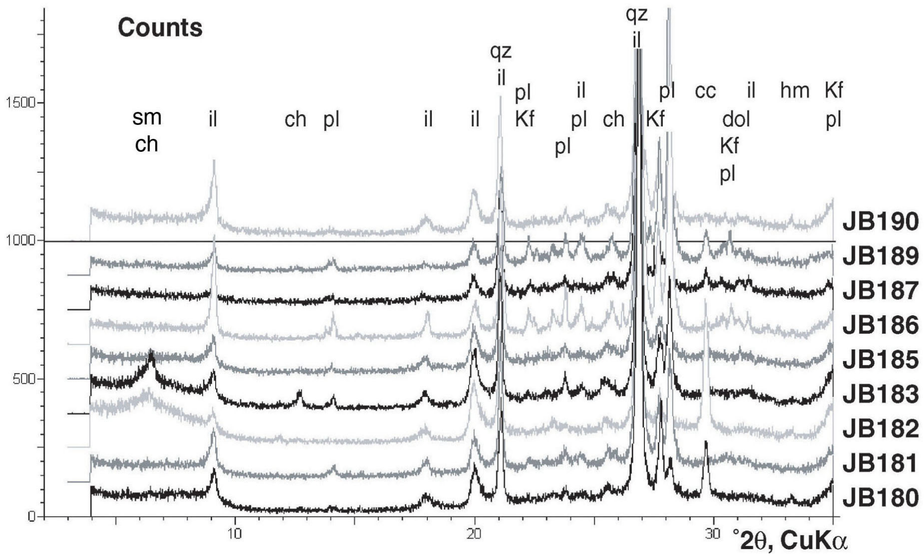
JB179
JB178
JB177
JB175
JB174
JB173
JB171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dol
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Kf
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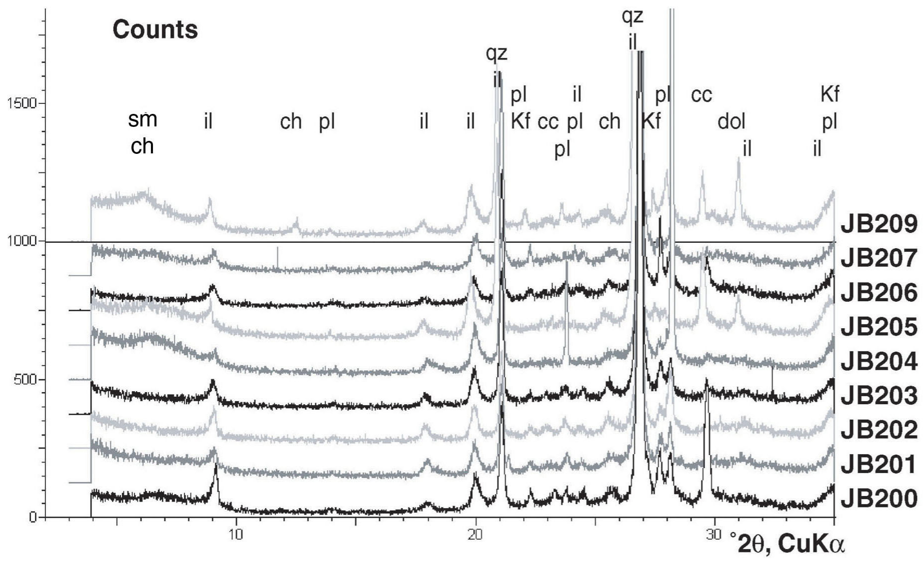
JB190
JB189
JB187
JB186
JB185
JB183
JB182
JB181
JB180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qz
il
pl
Kf
cc
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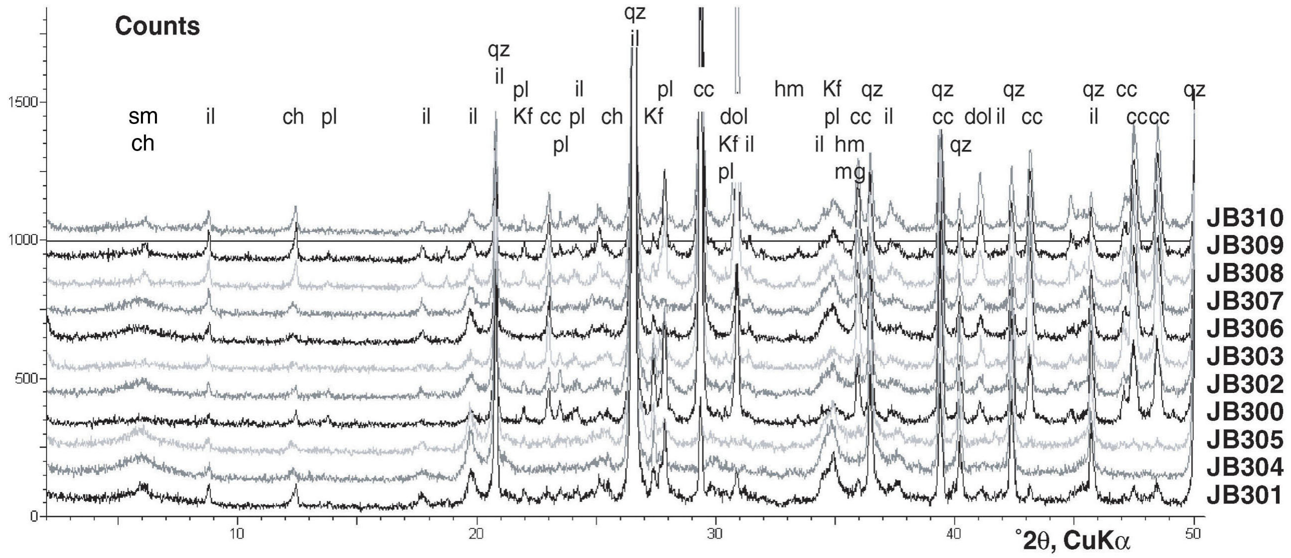
Kf
pl
il
JB209
JB207
JB206
JB205
JB204
JB203
JB202
JB201
JB200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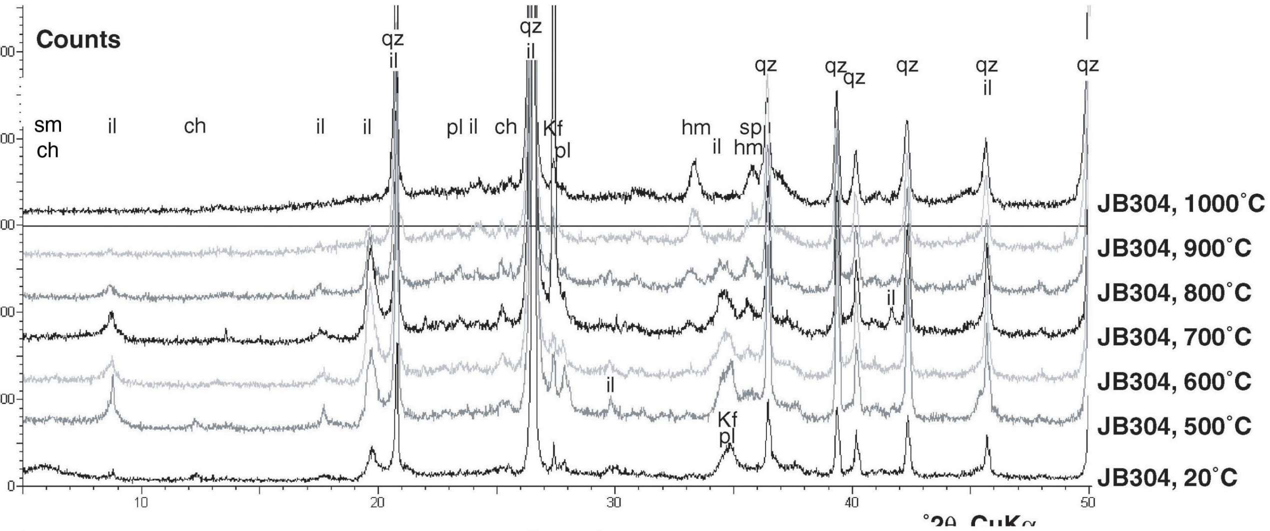
qz
cc
hm
mg
il
qz
cc
qz
dol
il
qz
cc
qz
il
cc
cc
cc
qz
JB310
JB309
JB308
JB307
JB306
JB303
JB302
JB300
JB305
JB304
JB301

X-ray diffractograms between 20° and 1000°C of two local clays from the surroundings of Arbon.
JB306 (upper part) is carbonate-rich; JB304 (lower part) is silicate-rich.
(cc: calcite; ch: chlorite; dio: diopside; dol: dolomite; geh: gehlenite; hm: hematite; il: illite; Kf: K-feldspars; pl: plagioclase; qz: quartz; sm: smectite; sp: spinel).


Counts
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1500
1000
500
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10
20
30
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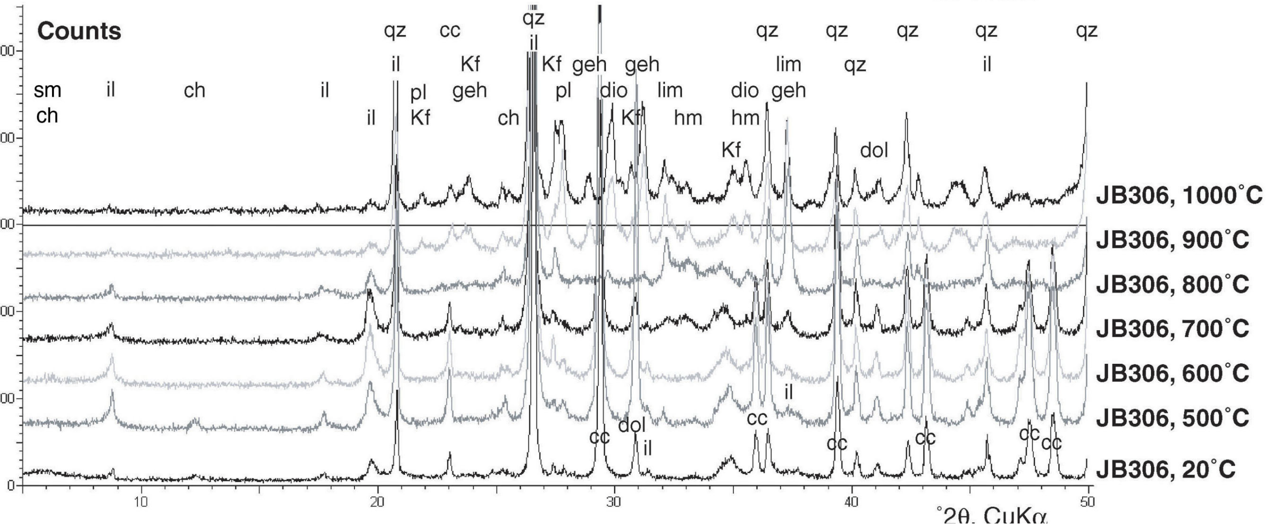
50
°2θ, CuKα
sm
ch
il
ch
il
il
qz
il
pl il
ch
qz
il
Kf
pl
il
hm
il
sp
hm
Kf
pl
qz
qz
qz
qz
qz
il
il
qz
JB304, 1000°C
JB304, 900°C
JB304, 800°C
JB304, 700°C
JB304, 600°C
JB304, 500°C
JB304, 20°C


Counts
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2000
1500
1000
500
0
10
20
30
40
50
°2θ, CuKα
sm
ch
il
ch
il
il
qz
il
pl
Kf
cc
Kf
geh
ch
qz
il
Kf
pl
geh
dio
cc
dol
Kf
geh
il
lim
hm
dio
hm
Kf
cc
qz
lim
geh
il
qz
qz
cc
dol
qz
cc
qz
il
cc
cc
qz
JB306, 1000°C
JB306, 900°C
JB306, 800°C
JB306, 700°C
JB306, 600°C
JB306, 500°C
JB306, 20°C

6 - APPENDIX 6

Mineralogical Data (X-Ray Diffraction) and estimated ancient firing temperatures.
(SF: Special form; USF: Undetermined special form; G: Grey; Y: Yellow; B: Black; O: Orange; in "Mineralogy": 1: few; 2: present; 3: frequent; 4: much).

Sample Number	Typological Group	Section Colour	Colour Group	Mineralogy															Firing Temperature
				Quartz	K-feldspars	Plagioclase	Amphibole	Smectite	Chlorite	Dolomite	Calcite	Illite	Hematite	Magnetite	Diopside	Gehlenite	Ankerite	Apatite	
JB001	Pfyn / Horgen pot	G	1	2	2	3	2	1	1		1	1							< 700°C
JB002	Pfyn / Horgen pot	G-B-O	4	1	2	3									2	2			> 700°C
JB003	Pfyn / Horgen pot	G	1	2	3	4					1	3							< 700°C
JB004	USF	B-G	3	2	2	1		2		3	3	1	2						< 700°C
JB005	USF	Y-B	5	2	2	3		1	3		2	1	2						< 700°C
JB006	SF Boleráz	B	2	3	2	2						1							< 700°C
JB007	SF Pfyn	B-G	3	3	1	1		2	1		3	2							< 700°C
JB008	SF Bayern	Y-B-Y	4	2	1	1		1			1	1		1					< 700°C
JB009	SF Pfyn	G-B-Y	4	2	3	3				1	2	1							< 700°C
JB010	Pfyn / Horgen pot	B-G	3	3	1	1		1			1	1							< 700°C
JB011	USF	G	1	2	3	2					2	1							< 700°C
JB012	USF	G	1	1	2	1					1	1	2					2	< 600°C
JB013	SF Boleráz	G-B-G	4	1	2	2					1	2							< 700°C
JB014	SF Boleráz	O-B-O	4	2	1	1				1	1	1							< 700°C
JB015	SF Bayern	Y-B-Y	4	2	1	3				1	1	2		2					< 700°C
JB016	USF	Y	1	2	2	3		2			2	1	2						550-950°C
JB017	SF Boleráz	B	2	2	1	2					1	1	2						< 600°C
JB018	USF	G	1	2	2	2						2	2						< 600°C
JB019	Pfyn / Horgen pot	Y	1	2	1	1					2	1	1						550-950°C
JB020	SF Boleráz	B	2	1	1	2		2	1			2	1					3	< 600°C
JB021	SF Bayern	G-B-Y	4	2	2	2		1	2		2	1	2						< 700°C
JB022	Pfyn / Horgen pot	Y	1	3	4	4		1				2							550-950°C
JB023	Pfyn / Horgen pot	G-B-G	4	2	3	4					1	1							< 700°C
JB024	Pfyn / Horgen pot	Y-B-Y	4	2	3	3		1				2							< 700°C
JB025	Pfyn / Horgen pot	O-B-G	4	2	3	2					3	1	2						< 700°C
JB026	Pfyn / Horgen pot	B-Y	3	2	3	3					2	2	2						< 700°C
JB027	USF	B-G	3	3	1	3				1	1	2		2					< 700°C
JB028	Pfyn / Horgen pot	O-B-G	4	2	1	3					1	1							< 700°C
JB029	USF	B	2	2	1	1		1				1							< 700°C
JB030	USF	G-B-G	4	2	2	4		1	2		1	1	2						< 700°C
JB031	Pfyn / Horgen pot	O-B-O	4	3	3	4					1	2							< 700°C
JB032	Pfyn / Horgen pot	Y	1	2	2	4						1							550-950°C
JB033	SF Boleráz	Y-B-Y	4	2	2	1		1			2	1							< 700°C
JB034	SF Boleráz	G-B	5	2	2	3		2		3	4	1							< 700°C
JB035	Pfyn / Horgen pot	B-G	3	3	3	3		2	3		2	2							< 700°C
JB036	USF	Y-B-Y	4	3	3	4	3				2	2							< 700°C
JB037	SF Bayern	Y	1	2	4	3		1			4	1							550-950°C
JB038	Pfyn / Horgen pot	B-Y	3	2	4	4					3	3							< 700°C
JB039	Pfyn / Horgen pot	G-B	5	2	4	4		2		1	2	3							< 700°C
JB040	USF	Y-B-Y	4	2	2	3		3	1	4	3	1							< 700°C
JB041	Pfyn / Horgen pot	B-Y	3	3	4	4					1	2							< 700°C
JB042	Pfyn / Horgen pot	B-Y	3	3	3	3		2				3							< 700°C
JB043	Pfyn / Horgen pot	Y-B-Y	4	2	3	3				1	1	2		2					< 700°C
JB044	Pfyn / Horgen pot	G-B	5	2	3	4		1			1	2							< 700°C
JB045	Pfyn / Horgen pot	Y-B-Y	4	2	4	3					4	2							< 700°C
JB046	USF	B	2	2	2	4		2			1	2							< 700°C
JB047	Pfyn / Horgen pot	B	2	3	3	4		1		4	4	2							< 700°C
JB048	Pfyn / Horgen pot	B-Y	3	2	1	2					1	2		2					< 700°C
JB049	Pfyn / Horgen pot	B-G	3	2	2	3	2				2	2							< 700°C
JB050	SF Boleráz	B-G	3	3	1	2		3		1	4	2							< 700°C
JB051	Pfyn / Horgen pot	B-Y	3	2	3	2					3	1							< 700°C
JB052	Pfyn / Horgen pot	B-Y	3	2	2	2	3	3	3			1	2						< 700°C
JB053	Pfyn / Horgen pot	B-Y	3	3	3	2		2			3	2							< 700°C
JB054	Pfyn / Horgen pot	Y-B-G	4	3	3	4					1	2							< 700°C
JB055	Pfyn / Horgen pot	B-Y	3	3	3	4		2			3	3							< 700°C
JB056	Pfyn / Horgen pot	B-G	3	2	4	4				1	1	1		1					< 700°C
JB057	USF	Y-B-Y	4	3	3	3		1			2	3							< 700°C
JB058	Pfyn / Horgen pot	B-G	3	3	3	4		2			4	2							< 700°C
JB059	Pfyn / Horgen pot	B-Y	3	3	3	4					3	3							< 700°C
JB060	Pfyn / Horgen pot	B-G	3	3	2	3		1	1		1	3		1					< 700°C

Sample Number	Typological Group	Section Colour	Colour Group	Mineralogy															Firing Temperature
				Quartz	K-feldspars	Plagioclase	Amphibole	Smectite	Chlorite	Dolomite	Calcite	Illite	Hematite	Magnetite	Diopside	Gehlenite	Ankerite	Apatite	
JB061	Pfyn / Horgen pot	B-O	3	2	4	4		2	2	1	1	3							< 700°C
JB062	Pfyn / Horgen pot	B-Y	3	3	3	4					2	3							< 700°C
JB063	SF Boleráz	B-Y	3	2	2	3					3	2							< 700°C
JB064	Pfyn / Horgen pot	B-Y	3	2	4	4					3	4							< 700°C
JB065	Pfyn / Horgen pot	B	2	3	4	4		2	1		3	3		2					< 700°C
JB066	Pfyn / Horgen pot	B-Y	3	2	2	4					1	2							< 700°C
JB067	Pfyn / Horgen pot	B-Y	3	2	3	3	1	1			2	2	2						< 700°C
JB068	Pfyn / Horgen pot	G-B-Y	4	2	3	3					2	2							< 700°C
JB069	SF Boleráz	G-B-G	4	2	3	2	4	1			4	2	1					3	< 700°C
JB070	Pfyn / Horgen pot	Y-B-Y	4	2	1	3				2		1	2						< 700°C
JB071	USF	Y-B-Y	4	3	3	3					2	2							< 700°C
JB072	USF	B	2	2	4	4		2				2							< 700°C
JB073	SF Boleráz	Y-B-Y	4	3	2	3		3			1	3							< 700°C
JB074	USF	B	2	3	4	3	1				3	2							< 700°C
JB075	USF	Y-B-Y	4	2	2	3					4	2							< 700°C
JB076	Pfyn / Horgen pot	B_Y	3	2	2	2						2							< 700°C
JB086	USF	B	2	3	1	2		3			4	3	2						< 600°C
JB087	USF	Y-B-Y	4	3	1	1		2				1							< 700°C
JB088	SF Bayern	Y-B	5	2	3	3					1	1	1						< 700°C
JB089	Pfyn / Horgen pot	B-G	3	3	4	4		2	1		1	3	1						< 700°C
JB090	SF Bayern	B-G	3	3	2	3		3		1	4	2							< 700°C
JB091	Pfyn / Horgen pot	B-Y	3	3	3	4				1	1	2		1					< 700°C
JB092	Pfyn / Horgen pot	B-Y	3	3	2	4		2		1	4	2							< 700°C
JB093	Pfyn / Horgen pot	B-G	3	2	4	3				1	1	4		2					< 700°C
JB094	Pfyn / Horgen pot	B-Y	3	3	3	4		2		1	3	3	2						< 700°C
JB095	SF Bayern	Y-B-Y	4	3	4	3		3	1	3	2	3							< 700°C
JB096	Pfyn / Horgen pot	B-Y	3	3	2	2		1				2							< 700°C
JB097	Pfyn / Horgen pot	B-Y	3	3	4	3		1			1	3							< 700°C
JB098	USF	G-B-G	4	3	4	4		1		1	2	2		1					< 700°C
JB099	SF Boleráz	Y-B-Y	4	3	2	2				1	1	1		2					< 700°C
JB100	Pfyn / Horgen pot	G	1	2	4	3					2	2							< 700°C
JB101	Pfyn / Horgen pot	B-Y	3	3	2	3					1	1	2						< 700°C
JB102	USF	Y-B-Y	4	3	2	2		2			4	2		2					< 700°C
JB103	Pfyn / Horgen pot	Y-B-Y	4	3	3	4		1	1		1	3		2					< 700°C
JB104	Pfyn / Horgen pot	B-G	3	2	4	4		1		2	2	2	2						< 700°C
JB105	USF	B	2	1	1	3				2	1								> 700°C
JB106	SF Boleráz	Y-B-Y	4	3	3	2		3			2	3							< 700°C
JB107	USF	Y-B-Y	4	3	2	4		3		2	1	4							< 700°C
JB108	Pfyn / Horgen pot	B-Y	3	3	4	4	3			1	1	4	1						< 700°C
JB109	Pfyn / Horgen pot	Y-B	5	3	4	3		1		1		4	1						< 700°C
JB110	SF Bayern	B-Y	3	3	4	4		1		3	4	3							< 700°C
JB111	Spindlewhorl	Y-B-Y	4	3	1	2		1			1	2		2					< 700°C
JB112	Spindlewhorl	B	2	2	3	4		1			2	1							< 700°C
JB113	Spindlewhorl	B	2	3	3	4			1		4	2	2						< 700°C
JB114	Spindlewhorl	B-G	3	2	4	4		1		1	1	1		2					< 700°C
JB115	Spindlewhorl	B	2	2	4	4					2	2	2						< 700°C
JB116	Spindlewhorl	G	1	2	2	3		1	1			1							< 700°C
JB117	Spindlewhorl	B-G	3	2	3	4					3	1							< 700°C
JB118	Spindlewhorl	G	1	3	4	3				2	1	1							< 700°C
JB119	Spindlewhorl	Y	1	3	2	4		2	1		3	2	2						< 550°C
JB120	Spindlewhorl	B	2	2	2	1					1	1							< 700°C
JB121	Loomweight			3	3	2		2	2	4	4	1							non fired
JB122	Cob			3	2	3					4	1	2						non fired
JB123	Cob			3	3	2					4	2							non fired
JB124	Cob			3	3	1					4	1	2						non fired
JB125	Cob			3	2	3					4	1	2						non fired
JB126	Cob			3	3	2					4	1	2						non fired
JB127	Cob			3	2	3		1		4	4	2							non fired
JB128	Cob			3	3	1					4	1							non fired
JB129	Cob			3	3	3				3	4	2							non fired
JB130	Cob			3	3	2				3	4	1							non fired
JB131	Cob			3	2	2				3	4	1							non fired
JB132	Cob			3	3	2				2	4	1							non fired

Sample Number	Typological Group	Section Colour	Colour Group	Mineralogy															Firing Temperature
				Quartz	K-feldspars	Plagioclase	Amphibole	Smectite	Chlorite	Dolomite	Calcite	Illite	Hematite	Magnetite	Diopside	Gehlenite	Ankerite	Apatite	
JB133	Pfyn / Horgen pot	B-Y	3	2	2	3						2	2						< 700°C
JB134	Pfyn / Horgen pot	Y	1	2	4	4		2	2		1	4							< 550°C
JB135	Pfyn / Horgen pot	B-Y	3	3	4	4				1	2	3	1	1					< 700°C
JB136	Pfyn / Horgen pot	B-G	3	2	4	4		1	1	1	1	3	2						< 700°C
JB137	Pfyn / Horgen pot	Y-B-Y	4	3	4	4				1	3	2	2						< 700°C
JB138	SF Boleráz	Y-B-Y	4	2	3	2		2			3	1	2						< 700°C
JB139	SF Boleráz	G-B-G	4	3	3	2		3	1			2	2						< 700°C
JB140	SF Boleráz	B-G	3	2	3	4	2	1			3	3	2						< 700°C
JB141	SF Boleráz	B-G	3	3	2	3					2	2	2						< 700°C
JB142	USF	G-B	5	2	3	4					2	1							< 700°C
JB143	SF Bayern	B	2	2	3	4					2	3	2						< 600°C
JB144	SF Boleráz	Y-B-Y	4	3	2	2				1	4	2	2						< 700°C
JB145	SF Boleráz	G	1	2	2	2		3			2	3	2						< 600°C
JB146	SF Boleráz	G-B-G	4	3	3	4					2	2	2						< 700°C
JB147	SF Boleráz	B	2	2	1	2		1			2	2						2	< 700°C
JB148	SF Boleráz	B	2	2	2	2					4	1							< 700°C
JB149	SF Boleráz	Y	1	2	4	4	2	1			3	2	2						550-950°C
JB150	SF Bayern	B	2	2	2	4		3	2		2	3	2						< 600°C
JB151	SF Bayern	B-Y	3	2	2	3		3		4	3	3		2			3		< 700°C
JB152	SF Boleráz	B-Y	3	3	4	4		2			1	4	2						< 700°C
JB153	SF Bayern	B	2	3	4	3		2		2	1	1							< 700°C
JB154	SF Boleráz	B-Y	3	3	3	2		2				2	2						< 700°C
JB155	SF Boleráz	B-Y	3	3	1	2					1	4		?					< 700°C
JB157	SF Bayern	G-B-G	4	3	2	2		3			3	4	2	?					< 700°C
JB158	USF	B	2	3	3	4					2	4	2	?					< 600°C
JB159	USF	G	1	3	3	2					1	4	2						< 600°C
JB160	USF	Y-B-Y	4	3	2	3		3			3	3		?					< 700°C
JB162	USF	G	1	3	2	2		3			2	2	2						< 600°C
JB163	USF	Y-B-Y	4	3	3	4	3	3	1		3	3	3	?					< 700°C
JB164	USF	G	1	3	3	3	3	3			3	3	2						< 600°C
JB165	USF	B-G	3	3	3	2					1	3	2	?					< 700°C
JB166	USF	B	2	3	3	3	1	3			1	3	1	?					< 600°C
JB167	USF	B	2	3	3	4		2				3	1	?					< 600°C
JB169	USF	G	1	3	2	1					2	3							< 700°C
JB171	SF Pfyn	G	1	3	3	4		1		3	2	4							< 700°C
JB173	USF	G	1	3	4	4						3							< 700°C
JB174	USF	Y	1	3	1	2		3			2	2	1						550-950°C
JB175	SF Boleráz	Y	1	3	2	2						1							550-950°C
JB177	USF	B	2	3	1	3		2			1	3		?					< 700°C
JB178	USF	G	1	3	2	3		3			3	2	1						< 600°C
JB179	SF Boleráz	Y-B-Y	4	3	1	3		2	1		3	2	1	?					< 700°C
JB180	USF	G	1	3	4	2					3	3	1						< 600°C
JB181	USF	G	1	3	3	4					1	3							< 700°C
JB182	USF	Y-B-Y	4	3	2	1		3			4	2		?					< 700°C
JB183	USF	G	1	3	3	4		3	3		1	3							< 700°C
JB185	SF Boleráz	B	2	3	2	3					2	3		?					< 700°C
JB186	USF	B	2	3	3	4				2	1	4		?					< 700°C
JB187	USF	B	2	3	3	3					2	1		?					< 700°C
JB189	USF	G	1	3	3	4				2	2	2							< 700°C
JB190	USF	Y	1	3	3	2					1	4	2						550-950°C
JB200	Mödling			3	3	3		2			4	4	1	?					
JB201	Mödling			3	2	3					1	2		?					
JB202	Mödling			3	2	3						3		?					
JB203	Mödling			3	3	3					1	2		?					
JB204	Mödling			3	1	4		2			1	1		?					
JB205	Zlkovce			3	2	1		2		3	3	2		?					
JB206	Zlkovce			3	3	2					2	2		?					
JB207	Zlkovce			3	1	2					1	1		?					
JB209	Zlkovce			3	2	3		3	3	4	3	2		?					

7 - APPENDIX 7

Stability of minerals as a function of the temperature in the literature (X-ray diffraction results)
A: carbonate -rich clays under oxidising atmosphere
B: silicate -rich clay under oxidisind atmosphere
C: carbonate-rich clay under reducing atmosphere
D: silicate-rich clay under reducing atmosphere
(app.: appearance, disp.: disappearance).

Oxidising Atmosphere, CaO-rich clay										
A	**<500°C**	**500°C**	**600°C**	**700°C**	**800°C**	**900°C**	**1000°C**	**1100°C**	**Clay Type**	**Reference**
Chlorite	▨	disp.: 550°C								Bonzon (2004)
	▨	▨	disp.: 650°C							Tite (1975)
	▨	▨	disp.: 670°C							Béarat (1992)
	▨	▨	disp.: <700°C						Illitic, chloritic and kaolinic	Grimes (1968), Maggetti (1979)
	▨	▨	disp.: <700°C						Illitic	Jornet et al. (1985)
(002) (003)	▨	disp.: 550°C								Benghezal (1994)
(001)	▨	▨	▨	disp.: 700°C						Benghezal (1994)
Fe-chlorite	▨	disp.: <550°C							Illitic, chloritic and kaolinic	Grimes (1968), Maggetti (1979)
Kaolinite	▨	disp.: <500°C							Kaolinic and illitic	Murad and Wagner (1989)
	▨	disp.: 530°C							Not mentionned	Courtois (1973)
	▨	disp.: 500-550°C							Marl from the Molasse Basin, Switzerland	Peters and Iberg (1978)
	▨	disp.: ~550°C							Illitic, chloritic and kaolinic	Maggetti (1979)
	~700°C: Kaolinite begins to lose its cristalline structure	▨	▨	▨	▨	▨	disp.: <1100°C			Herz and Garrison (1998)
Montmorillonite	▨	disp.: 500°C								Benghezal (1994)
	▨	▨	▨	disp.: 750°C					White-burning marl / Marl	Maggetti (1986), Maggetti et al. (1984)
	Decomposition starts 650°-700°C, rapid decrease 800°-850°C	▨	▨	▨	▨	disp.: 950°C			Marl from the Molasse Basin, Switzerland	Peters and Iberg (1978)
	~750°C: Smectites begin to lose their cristalline structure	▨	▨	▨	▨	▨	disp.: <1100°C			Herz and Garrison (1998)
Illite	▨	▨	▨	▨	▨	disp.: 900°C				Letsch and Noll (1983)
	Decomposition starts 650°-700°C, rapid decrease 800°-850°C	▨	▨	▨	▨	disp.: 950°C			Marl from the Molasse Basin, Switzerland	Peters and Iberg (1978)
	Only (110)-peak is present at 1000°C, at 19.89Å.	▨	▨	▨	▨	▨	disp.: >1000°C		Illitic	Jornet et al. (1985)
	▨	▨	▨	▨	▨	▨	disp.: >1000°C			Bonzon (2004)
	From 600°C, micas lose structural hydroxyls from their lattice	▨	▨	▨	▨	▨	▨	disp.: >1100°C		Herz and Garrison (1998)
(001)	▨	▨	▨	▨	disp.: 800°C					Tite (1975)
(001)	Only (001)-peak remains between 700°-900°C	▨	▨	▨	▨	disp.: 900°C				Cultrone et al. (2001)
(001)	▨	▨	▨	▨	▨	disp.: 940°C				Béarat (1992)
(001)	▨	▨	▨	▨	▨	disp.: 950°C			Illitic	Maggetti (1982)
(001) (002) (110)	▨	▨	▨	▨	disp.: 800°C					Benghezal (1994)
(110)	▨	▨	▨	▨	disp.: 850°C					Béarat (1992), Tite (1975)
Quartz	▨	▨	▨	▨	▨	▨	▨	disp.: 1150°C	Whatever	all authors
K-feldspar	▨	▨	▨	▨	▨	disp.: 900°C			Illitic	Maggetti (1982)
	▨	▨	▨	▨	▨	▨	disp.: 1000°C		Illitic	Béarat (1992)
	▨	▨	▨	▨	▨	▨	disp.: >1000°C			Bonzon (2004)
	▨	▨	▨	▨	▨	▨	▨	disp.:>1100°C		Jornet et al. (1985), Herz and Garrison (1998)
Plagioclase	?	?	▨	700°-1000°C: Plagioclases increase	▨	▨	▨	?		Letsch and Noll (1983)
	▨	▨	▨	▨	▨	▨	▨	▨		Béarat (1992), Maggetti et al. (1984)
	▨	▨	▨	▨	▨	▨	▨	▨	Illitic	Maggetti (1982), Jornet et al. (1985)
	▨	▨	▨	▨	▨	▨	▨	▨	White-burning marl / Marl	Maggetti (1986), Maggetti et al. (1984)
	▨	▨	▨	▨	▨	▨	disp.: >1000°C			Bonzon (2004)

Oxidising Atmosphere, CaO-rich clay										
A (follow)	**<500°C**	**500°C**	**600°C**	**700°C**	**800°C**	**900°C**	**1000°C**	**1100°C**	**Clay Type**	**Reference**
Anorthite				app.: 750°C	▨	▨	▨	▨	Illitic and kaolinic	Murad and Wagner (1989)
					app.: 860°C	▨	▨	▨	Marl from the Molasse Basin, Switzerland	Peters and Iberg (1978)
						app.: 900°C	▨	▨		Cultrone et al. (2001)
Aragonite	disp.: <500°C									Echallier and Méry (1992)
Dolomite	▨	disp.: 550°C								Heimann (1989)
	▨	▨	disp.: ~600°C						Illitic, chloritic and kaolinic	Maggetti (1979)
	▨	▨	disp.: 650°C							Benghezal (1994), Peters and Jenni (1973)
	▨	▨	disp.: 650°C						Marl from the Molasse Basin, Switzerland	Peters and Iberg (1978)
	▨	▨	▨	disp.: 704°C						Echallier and Méry (1992)
	▨	▨	▨	disp.: 750°C						Béarat (1992), Bonzon (2004)
	▨	▨	▨	▨	disp.: 800°C					Cultrone et al. (2001)
Calcite	▨	▨	disp.: 650°C							Peters and Jenni (1973)
	▨	▨	disp.: ~650°C						Illitic, chloritic and kaolinic	Maggetti (1979)
	▨	▨	▨	disp.: 700°C					Marl from the Molasse Basin, Switzerland	Peters and Iberg (1978)
	▨	▨	▨	disp.: 750°C						Letsch and Noll (1983), Bonzon (2004)
	▨	▨	▨	disp.: >750°C					Illitic and kaolinic	Murad and Wagner (1989)
	▨	▨	▨	▨	disp.: 800°C					Cultrone et al. (2001)
	▨	▨	▨	▨	disp.: 800°C					Benghezal (1994)
	▨	▨	▨	▨	disp.: 800°C				Illitic	Maggetti (1982)
	▨	▨	▨	▨	disp.: 850°C					Béarat (1992), Tite (1975)
	▨	▨	▨	▨	disp.: 850°C				White-burning marl / Marl	Maggetti (1986), Maggetti et al. (1984)
	▨	▨	▨	▨	disp.: >870°C					Herz and Garrison (1998)
	▨	▨	▨	▨	▨	disp.: 900°C			Illitic	Jornet et al. (1985)
	▨	▨	▨	▨	▨	disp.: <900°C				Echallier and Méry (1992)
Lime	?	Lime increases <700°C, then decreases	▨	▨	disp.: 800°C					Letsch and Noll (1983)
			app.: 650°C	▨	▨	▨	▨	▨		Béarat (1992), Benghezal (1994)
			app.: ?°C	▨	disp.: 850°C				Illitic	Maggetti (1982)
			app.: 725°C	▨	▨	disp.: 920°C			Marl from the Molasse Basin, Switzerland	Peters and Iberg (1978)
				app.: 750°C	Calcite turns to lime from 750° to 900°C	▨	▨	▨		Echallier and Méry (1992)
				app.: 750°C	▨	▨	disp.: 900°C		Illitic and kaolinic	Murad and Wagner (1989)
				app.: 750°C	▨	▨	▨	▨	White-burning marl / Marl	Maggetti (1986), Maggetti et al. (1984)
				app.: ~750°C	▨	▨	▨	▨	Illitic	Maggetti (1982), Bonzon (2004)
				app.:<800°C	▨	▨	▨	disp.:~1100°C	Illitic	Jornet et al. (1985)

Oxidising Atmosphere, CaO-rich clay

A (follow)	<500°C	500°C	600°C	700°C	800°C	900°C	1000°C	1100°C	Clay Type	Reference
Hematite	?	?	▨	▨	▨	▨	?	?	Fe2O3-rich clay	Letsch and Noll (1983)
	?	Hematite increases between 500°C and 900°C and decreases over 900°C	▨	▨	▨	▨	▨	?	MnO2-rich clay: Mn*100/(Mn+Fe) = 2.3-73%	Letsch and Noll (1983)
	▨	▨	disp.: 600°C							Bonzon (2004)
	▨	▨	▨	▨	disp.: ~800°C					Béarat (1992)
			▨	?	?	▨	▨	▨	Illitic	Maggetti (1982)
				app.: 750°C	▨	▨	▨	▨		Benghezal (1994)
				app.: 750°C	▨	▨	disp.: 900°C		Illitic and kaolinic	Murad and Wagner (1989)
					app.: 820°C	▨	present at 1050°C			Tite (1975)
Goethite	disp.: ~350°C								Illitic, chloritic and kaolinic	Maggetti (1979)
Periclase				app.: 700°C	▨	▨	▨	▨		Béarat (1992)
Gehlenite				app.: 750°C	max.: 850°C	disp.: 950°C				Letsch and Noll (1983)
				app.: 750°C	▨	▨	▨	▨	White-burning marl / Marl	Maggetti (1986), Maggetti et al. (1984)
					app.: 800°C	▨	disp.: 1000°C			Tite (1975)
					app.: 800°C	max.: 900°C	▨	▨		Benghezal (1994), Cultrone et al. (2001), Bonzon (2004)
					app.: 860°C	▨	max.: 1050°C	▨	Marl from the Molasse Basin, Switzerland	Peters and Iberg (1978)
					app.: 850°C	▨	▨	disp.: >1100°C	Illitic	Maggetti (1982), Hertli et al. (1999)
						app.:~900°C	▨	disp.: >1100°C	Illitic	Jornet et al. (1985)
						app.: 900°C	▨	▨		Béarat (1992)
						app.: 900°C	▨	▨	Illitic and kaolinic	Murad and Wagner (1989)
							present	▨		Tite et al. (1982)
Diopside					app.: 800°C	▨	?	?		Letsch and Noll (1983)
					app.: 800°C	▨	▨	▨		Benghezal (1994), Bonzon (2004)
					app.: 850°C	▨	▨	▨		Tite (1975), Hertli et al. (1999)
					app.: 850°C	▨	▨	▨	Illitic	Maggetti (1982)
					app.: 860°C	▨	▨	▨	Marl from the Molasse Basin, Switzerland	Peters and Iberg (1978)
						app.: 900°C	▨	▨		Cultrone et al. (2001)
						app.: ~900°C	▨	▨		Béarat (1992)
						app.: ~900°C	▨	▨	Illitic	Jornet et al. (1985)
						app.: 892°C	▨	▨		Echallier and Méry (1992)
							app.:1000°C	▨		Cultrone et al. (2001)
								present		Tite et al. (1982)
Wollastonite					app.: 800°C	▨	▨	▨		Cultrone et al. (2001)
					app.: 850°C	▨	▨	▨	White-burning marl / Marl	Maggetti (1986), Maggetti et al. (1984)
					app.: 860°C	▨	▨	▨	Marl from the Molasse Basin, Switzerland	Peters and Iberg (1978)
						app.: 900°C	▨	▨	Illitic and kaolinic	Murad and Wagner (1989)
							app.:1000°C	▨		Herz and Garrison (1998)
								present		Tite et al. (1982)
Sanidine						app.: 900°C	▨	▨		Bonzon (2004)
						app.: 950°C	▨	▨	Marl from the Molasse Basin, Switzerland	Peters and Iberg (1978)
							app.:1000°C	▨		Cultrone et al. (2001)
Mullite							app.:1000°C	▨		Cultrone et al. (2001)
							app.:~1000°C	▨	Illitic	Jornet et al. (1985), Herz and Garrison (1998)
Iron-rich spinel								app.: 1100°C	Illitic and kaolinic	Murad and Wagner (1989)

Oxidising Atmosphere, silicate-rich clay										
B	**<500°C**	**500°C**	**600°C**	**700°C**	**800°C**	**900°C**	**1000°C**	**1100°C**	**Clay Type**	**Reference**
Chlorite	▨	disp.: 550°C								Bonzon (2004)
	▨	▨	disp.: 670°C							Béarat (1992)
	▨	▨	▨	disp.: 750°C					Chloritic and illitic	Maggetti (1993), Maggetti (1995)
(002) (003)	▨	disp.: 500°C								Benghezal (1994)
(002) (003)	▨	disp.: 500°C							Illitic	Benghezal (1999)
(001)	▨	▨	disp.: 600°C						Illitic	Benghezal (1999)
(001)	▨	▨	▨	disp.: 700°C						Benghezal (1994)
Kaolinite	Transforms to metakaolinite between 300° and 400°C								Kaolinic and illitic	Murad and Wagner (1989)
	Transforms to metakaolinite at 400°C								Pure kaolinite	Murad and Wagner (1989)
	Transforms to metakaolinite at 500°C									Maggetti (1974), Heimann and Franklin (1980)
	▨	disp.: 530°C								Courtois (1973)
	disp.: <500°C								Kaolinic, illitic, vermiculitic	Murad and Wagner (1989)
	▨	disp.: ~550°C							Kaolinic	Maggetti (1982)
	▨	disp.: ~550°C								Picouet (1997)
(002) (003)	▨	disp.: <500°C							Illitic	Benghezal (1999)
Vermiculite	disp.: <400°C									Picouet (1997)
	▨	disp.: <500°C							Kaolinic, illitic, vermiculitic	Murad and Wagner (1989)
Montmorillonite	disp.: <400°C									Picouet (1997)
	▨	disp.: <500°C							Chloritic and illitic	Maggetti (1993)
	▨	disp.: 550°C								Benghezal (1994)
	▨	▨	▨	▨	disp.: >800°C					Maggetti et al. (1984)
	▨	▨	▨	▨	disp.: 850°C				Red-burning volcanic clay	Maggetti (1986)
(110)	▨	▨	▨	▨	▨	disp.:~950°C			Kaolinic	Maggetti (1982)
Illite	▨	▨	▨	▨	disp.: 850°C					Letsch and Noll (1983), Murad and Wagner (1989), Picouet (1997)
	▨	▨	▨	▨	disp.: 850°C				Illitic	Benghezal (1999)
	▨	▨	▨	▨	▨	disp.: 950°C				Hertli et al. (1999), Bonzon (2004)
	▨	▨	▨	▨	▨	disp.: 950°C			Chloritic and illitic	Maggetti (1993), Maggetti (1995)
(001) (002)	▨	▨	▨	▨	▨	disp.: 900°C				Benghezal (1994)
(001)	▨	▨	▨	▨	▨	disp.: 900°C			Illitic	Maggetti (1982), Hertli et al. (1999)
(001)	▨	▨	▨	▨	▨	disp.: 960°C				Béarat (1992)
(002)	▨	▨	▨	▨	▨	disp.:~950°C			Kaolinic	Maggetti (1982)
(110)	▨	▨	▨	▨	disp.: 860°C					Béarat (1992)
(110)	▨	▨	▨	▨	▨	disp.: 950°C				Benghezal (1994)
(020)	▨	▨	▨	▨	▨	disp.: 950°C			Illitic	Maggetti (1982), Hertli et al. (1999)
(010)	▨	▨	▨	▨	▨	▨	disp.:~1050°C		Kaolinic	Maggetti (1982)
Quartz	▨	▨	▨	▨	▨	▨	▨	disp.: 1150°C	Whatever	all authors
	▨	573°C: Quartz inverts from the α- to the β-form	▨	▨	▨	▨	▨	disp.: 1150°C		Herz and Garrison (1998)
	▨	▨	▨	▨	▨	▨	disp.: 1050°C		Red-burning volcanic clay	Maggetti (1986), Maggetti et al. (1984)
K-feldspars	▨	▨	▨	▨	▨	▨	disp.: 1050°C		Illitic	Maggetti (1982), Bonzon (2004)
	▨	▨	▨	▨	▨	▨	disp.: 1050°C		Chloritic and illitic	Maggetti (1993), Maggetti (1995)
	▨	▨	▨	▨	▨	▨	▨	▨		Béarat (1992)
Microcline	▨	▨	▨	▨	▨	▨	disp.: >1000°C			Cultrone et al. (2001)
Sanidine							app.: >1000°C	▨		Cultrone et al. (2001)
Low-microcline	▨	▨	▨	▨	▨	disp.: 900°C				Picouet (1997)
Intermediate micr.						app.: 900°C	▨	▨		Picouet (1997)

Oxidising Atmosphere, silicate-rich clay

B (follow)	<500°C	500°C	600°C	700°C	800°C	900°C	1000°C	1100°C	Clay Type	Reference
Plagioclases	▨	▨	▨	▨	disp.: 850°C				Illitic	Benghezal (1999)
	▨	▨	▨	▨	▨	disp.: 900°C				Picouet (1997)
	▨	▨	▨	▨	▨	disp.: 950°C			Illitic	Maggetti (1982)
	▨	▨	▨	▨	▨	▨	disp.: 1050°C		Chloritic and illitic	Maggetti (1993), Maggetti (1995), Bonzon (2004)
	▨	▨	▨	▨	▨	▨	▨	▨	Red-burning volcanic clay	Maggetti (1986), Maggetti et al. (1984)
								▨ present		Tite et al. (1982)
Amphibole	▨	▨	▨	▨	▨	disp.: 950°C			Red-burning volcanic clay	Maggetti (1986), Maggetti et al. (1984)
Hornblende	▨ From green, hornblende becomes brown-reddish when temperature increases	▨	▨	▨	▨	▨	▨	▨		Echallier and Méry (1992)
Hematite	?	?	▨	▨	▨	▨	?	?	Fe2O3-rich clay	Letsch and Noll (1983)
	?	▨ 500°-900°C: Hematite increases; >900°C: Hematite decreases	▨	▨	▨	▨	▨	?	MnO2-rich clay: Mn*100/(Mn+Fe) = 2.3-73%	Letsch and Noll (1983)
		▨ 500°-1000°C: Hematite increases	▨	▨	▨	▨	▨			Bonzon (2004)
			app.: 600°C	▨	▨	▨	▨	▨	Illitic	Benghezal (1999)
			▨	?	?	▨	▨	▨	Illitic	Maggetti (1982)
			app.: 650°C	▨	▨	▨	▨	▨	Chloritic and illitic	Maggetti (1993), Maggetti (1995)
				app.: 750°C	▨	▨	▨	▨		Benghezal (1994)
				app.: 750°C	▨	▨	▨	▨	Red-burning volcanic clay	Maggetti (1986), Maggetti et al. (1984)
					app.: <800°C	▨ 800°-1000°C: hematite cristallinity improves	▨	▨	Kaolinic, illitic and vermiculitic	Murad and Wagner (1989)
					app.: 800°C	▨	▨	▨		Picouet (1997)
					app.: 850°C	▨	▨	▨		Béarat (1992)
					app.: 850°C	▨	▨	▨	Kaolinic and illitic	Murad and Wagner (1989)
Dolomite	▨	disp.: 500°C								Benghezal (1994)
	▨	▨	disp.: 670°C							Béarat (1992)
Calcite	▨	▨	▨	▨	▨	disp.: 950°C				Benghezal (1994)
Bixbyite	▨	▨	▨	▨	disp.: 850°C				MnO2-rich clay: Mn*100/(Mn+Fe) = 2.3-57% or 73-91%	Letsch and Noll (1983)
Pyroxene		▨	▨	▨	▨	▨	▨ >1000°C: borders become oxidated	disp.: 1150°C	Red-burning volcanic clay	Maggetti (1986), Maggetti et al. (1984)
Mayenite				app.: 774°C	▨	▨	▨	▨		Echallier and Méry (1992)
Braunite					app.: 850°C	▨ increases to 900°C, decreases over 900°C	▨		MnO2-rich clay: Mn*100/(Mn+Fe) = 2.3-73%	Letsch and Noll (1983)
Spinel					app.: 850°C	▨	▨	▨		Béarat (1992), Murad and Wagner (1989)
					app.: 850°C	▨	▨	▨	Chloritic and illitic	Maggetti (1993), Maggetti (1995)
					app.: 873°C	▨	?	?	MnO2-rich clay: Mn*100/(Mn+Fe) = 2.3-57% or 73-91%	Letsch and Noll (1983)
						app.: 1000°C	▨	▨		Picouet (1997)
				?	?	?	?	?		Maggetti et al. (1984)
		▨	▨	?	?	▨	▨	▨	Illitic and kaolinic	Maggetti (1982)
								▨ present		Tite et al. (1982), Herz and Garrison (1998)
Mn-spinel					app.: 900°C	▨	▨	▨		Benghezal (1994)
Al-spinel					app.: 900°C	▨	▨	▨	Illitic	Heimann and Franklin (1980)
Mullite					app.: 800°C	▨	▨	▨	Kaolinic and illitic	Murad and Wagner (1989)
						app.: 900°C	▨	▨	Kaolinic and illitic	Murad and Wagner (1989)
						app.: 900°C	▨	▨		Cultrone et al. (2001)
						app.: ~950°C	▨	▨	Kaolinic	Maggetti (1982)
							app.: 1000°C	▨	Illitic	Heimann and Franklin (1980)
							app.: 1000°C	▨	Kaolinic, illitic and vermiculitic	Murad and Wagner (1989)
							app.: 1050°C	▨	Illitic and chloritic / Red-burning volcanic clay	Maggetti (1986), Maggetti (1995), Maggetti et al. (1984)
								app.: ~1100°C	Illitic	Maggetti (1982)
								▨ present		Tite et al. (1982)
Cristoballite					app.: 800°C	▨	▨	▨	Kaolinic and illitic	Murad and Wagner (1989)
						app.: 900°C	▨	▨	Kaolinic and illitic	Murad and Wagner (1989)
							app.:~1050°C	▨	Kaolinic	Maggetti (1982)
							app.:~1050°C	▨	Red-burning volcanic clay	Maggetti (1986), Maggetti et al. (1984)
Ackermanite							app.: 1058°C	▨		Echallier and Méry (1992)

Reducing Atmosphere, CaO-rich clay

C	<500°C	500°C	600°C	700°C	800°C	900°C	1000°C	1100°C	Clay Type	Reference
Quartz	▨	▨	▨	▨	▨	▨	▨	disp.: 1150°C	Whatever	all authors
Plagioclases	?	?	▨	▨	▨ 800°-1000°C:Plagioclases increase	▨	▨	?		Letsch and Noll (1983)
Chlorite	▨	▨	▨	disp.: 700°C					Chloritic and illitic	Maniatis et al. (1983)
Illite	▨	▨	▨	disp.: 700°C					Chloritic and illitic	Maniatis et al. (1983)
	▨	▨	▨	▨	▨	disp.: ~900°C			Illitic	Heimann et al. (1980)
Calcite	▨	▨	▨	▨	▨	disp.: ~900°C			Chloritic and illitic	Maniatis et al. (1983)
	?	?	▨	▨	▨	disp.: ~900°C				Letsch and Noll (1983)
	▨	▨	▨	▨	▨	disp.: ~950°C			Illitic	Heimann et al. (1980)
Hematite	▨	disp.:< 600°C							Fe2O3-rich clay	Letsch and Noll (1983)
Magnetite				app.: ~700°C	▨	▨	?		Chloritic and illitic	Maniatis et al. (1983)
						app.: ~900°C	▨	▨	Illitic	Heimann et al. (1980)
Gehlenite					app.: 850°C	disp.: 950°C				Letsch and Noll (1983)
						app.: ~900°C	▨	▨	Chloritic and illitic	Maniatis et al. (1983)
Wollastonite						app.: ~900°C	▨	▨	Chloritic and illitic	Maniatis et al. (1983)
Diopside						app.: ~930°C	▨	?		Letsch and Noll (1983)
Hercynite							▨ present?		Chloritic and illitic	Maniatis et al. (1983)
Ferrocordierit							app.:~1000°C	▨	Illitic	Heimann et al. (1980)
Hedenbergite							app.: 1000°C	▨		Herz and Garrison (1989)

Reducing Atmosphere, CaO-poor clay

D	<500°C	500°C	600°C	700°C	800°C	900°C	1000°C	1100°C	Clay Type	Reference
Quartz	▨	▨	▨	▨	▨	▨	▨	disp.: 1150°C	Whatever	all authors
Plagioclases	?	?	▨	▨	▨ 800°-1000°C:Plagioclases increase	▨	▨	?		Letsch and Noll (1983)
Kaolinite	disp.: <500°C								Kaolinitic, illitic, vermiculitic	Murad and Wagner (1989)
Chlorite	▨	▨	▨	disp.: 700°C					Chloritic and illitic	Maniatis et al. (1983)
Illite	▨	▨	▨	disp.: 700°C					Chloritic and illitic	Maniatis et al. (1983)
Manganosite	?	?	▨	disp.: 750°C					MnO2-rich clay: Mn*100/(Mn+Fe) = 2.3-57% or 73-91%	Letsch and Noll (1983)
Hematite	▨	disp.:< 600°C							Fe2O3-rich clay	Letsch and Noll (1983)
					app.: 800°C	▨	▨	▨	Kaolinitic, illitic, vermiculitic	Murad and Wagner (1989)
Magnetite	?	?	▨	▨	▨	disp.: 900°C			Fe2O3-rich clay	Letsch and Noll (1983)
Tephroite				app.: 750°C	▨	▨	?	?	MnO2-rich clay: Mn*100/(Mn+Fe) = 2.3-57% or 73-91%	Letsch and Noll (1983)
Hercynite					app.: 850°C	▨	?	?	Fe2O3-rich clay	Letsch and Noll (1983)
							▨ present		Chloritic and illitic	Maniatis et al. (1983)
Fayalite						app.: ~950°C	▨	?	Fe2O3-rich clay	Letsch and Noll (1983)
Spessartine						app.: 900°C	▨	?	MnO2-rich clay: Mn*100/(Mn+Fe) = 2.3-57% or 73-91%	Letsch and Noll (1983)
Iron						app.: ~950°C	▨	?	Fe2O3-rich clay	Letsch and Noll (1983)
							▨ present		Chloritic and illitic	Maniatis et al. (1983)

8 - APPENDIX 8

Raw chemical data of all studied samples (X-ray fluorescence)
(s: standard deviation; Fe_2O_3** as* Fe_{tot}*; Ceramics mean potteries and spindle whorls).*

Oxides		**Ceramics from Arbon-Bleiche 3**																
Elements	**Unit**	JB001	JB002	JB003	JB004	JB005	JB006	JB007	JB008	JB009	JB010	JB011	JB013	JB014	JB015	JB016	JB017	JB018
SiO2	**wt.%**	67.45	64.85	68.71	65.74	68.48	66.67	73.62	70.09	68.66	71.12	67.02	66.23	64.70	69.07	68.01	66.18	66.74
TiO2	**wt.%**	0.83	0.71	0.64	0.69	0.79	0.95	0.63	0.77	0.63	0.76	0.78	0.76	0.93	0.77	0.74	0.79	0.84
Al2O3	**wt.%**	18.97	17.58	16.86	17.22	18.05	21.51	13.91	17.77	16.41	17.34	18.12	18.94	23.03	18.93	18.41	19.21	20.11
Fe2O3*	**wt.%**	4.78	5.72	4.64	4.30	4.18	4.72	3.91	4.61	4.39	4.26	4.21	5.38	4.47	4.19	4.92	5.14	4.73
MnO	**wt.%**	0.06	0.06	0.06	0.05	0.04	0.03	0.04	0.07	0.07	0.02	0.05	0.06	0.02	0.02	0.04	0.05	0.03
MgO	**wt.%**	1.88	1.76	1.35	2.56	1.43	1.09	2.25	1.61	1.36	2.07	1.81	1.85	1.20	1.90	1.46	1.79	2.00
CaO	**wt.%**	2.34	5.45	1.91	5.73	3.15	1.64	3.47	2.16	4.12	1.73	4.12	3.42	2.25	1.65	2.69	3.24	1.81
Na2O	**wt.%**	0.77	0.70	1.43	0.19	0.98	0.53	0.25	0.38	1.24	0.33	0.91	0.36	0.38	0.77	0.69	0.50	0.60
K2O	**wt.%**	2.59	3.27	4.21	2.80	2.63	2.56	2.13	2.47	3.11	2.53	2.80	3.02	2.59	2.59	2.74	2.91	2.89
P2O5	**wt.%**	0.19	0.21	0.41	0.29	0.48	0.26	0.10	0.14	0.18	0.14	0.29	0.19	0.42	0.29	0.27	0.36	0.33
Ba	**ppm**	862	392	383	671	684	526	476	730	678	583	905	676	603	821	796	972	988
Cr	**ppm**	115	112	102	116	150	145	109	125	91	140	102	128	152	119	107	127	124
Cu	**ppm**	34	33	34	48	42	53	33	40	31	39	37	40	53	45	41	41	45
Nb	**ppm**	19	17	15	14	15	19	12	17	13	16	18	17	20	16	16	18	18
Ni	**ppm**	62	56	47	85	59	112	70	63	50	82	58	65	91	64	63	72	74
Pb	**ppm**	26	28	23	32	32	38	24	28	29	27	30	30	38	34	29	34	35
Rb	**ppm**	150	183	231	155	145	134	117	148	161	161	139	169	146	164	151	151	163
Sr	**ppm**	171	214	120	186	160	97	189	161	266	108	202	218	124	146	197	211	164
V	**ppm**	141	134	105	117	132	150	94	133	110	134	121	143	160	126	118	147	134
Y	**ppm**	23	30	29	26	33	36	20	22	27	22	29	25	26	26	23	23	29
Zn	**ppm**	111	110	96	118	147	136	85	106	90	112	115	114	163	124	102	119	138
Zr	**ppm**	154	142	119	143	208	183	158	160	161	184	171	135	148	140	132	135	146
SUM	**wt.%**	100.05	100.46	100.35	99.74	100.39	100.12	100.45	100.24	100.34	100.46	100.30	100.39	100.16	100.36	100.15	100.38	100.29
FeO	**wt.%**	1.83	3.23	1.95	0.95	2.50	2.25	0.97	1.32	2.57	1.04	1.58	2.57	2.22	1.81	0.86	2.30	2.26
L O I	**wt.%**	5.55	3.21	2.21	8.13	10.73	13.00	6.48	4.25	2.17	6.33	6.16	4.71	14.03	5.90	6.33	9.68	7.46

Oxides		Ceramics from Arbon-Bleiche 3																
Elements	**Unit**	JB019	JB021	JB022	JB023	JB024	JB025	JB026	JB027	JB028	JB029	JB030	JB031	JB032	JB033	JB034	JB035	JB036
SiO2	**wt.%**	68.34	66.24	71.14	68.29	68.43	64.39	66.45	65.32	67.67	68.95	67.16	70.31	68.28	71.02	64.24	71.41	72.09
TiO2	**wt.%**	0.97	0.76	0.70	0.65	0.76	0.72	0.72	0.83	0.75	0.72	0.72	0.75	0.68	0.77	0.67	0.73	0.72
Al2O3	**wt.%**	18.02	18.61	17.08	17.49	18.54	17.94	18.66	19.25	17.79	18.76	18.63	17.60	17.92	17.21	17.47	15.63	15.75
Fe2O3*	**wt.%**	4.48	5.25	4.19	5.12	5.08	4.59	4.79	5.35	5.35	5.29	5.07	4.24	5.38	4.45	4.36	4.57	3.79
MnO	**wt.%**	0.05	0.04	0.04	0.06	0.05	0.07	0.05	0.04	0.06	0.04	0.04	0.04	0.07	0.04	0.04	0.08	0.06
MgO	**wt.%**	1.51	1.88	1.36	1.64	1.63	1.61	1.56	2.24	1.69	2.03	1.63	1.30	1.70	1.58	2.96	1.74	1.35
CaO	**wt.%**	2.57	3.81	1.53	2.04	2.11	6.93	3.31	2.54	3.24	1.46	2.12	2.02	2.01	2.23	7.03	2.19	2.59
Na2O	**wt.%**	0.40	0.70	1.44	1.23	0.58	0.72	1.08	0.92	0.76	0.20	1.35	1.44	1.02	0.23	0.09	1.21	1.20
K2O	**wt.%**	2.91	2.61	2.87	3.42	2.83	2.72	2.92	3.32	2.66	2.64	3.06	2.33	2.93	2.40	2.73	2.38	2.40
P2O5	**wt.%**	0.70	0.26	0.10	0.19	0.30	0.29	0.22	0.40	0.22	0.18	0.27	0.21	0.16	0.18	0.21	0.24	0.26
Ba	**ppm**	888	844	651	523	800	850	842	718	623	662	857	734	528	649	556	561	801
Cr	**ppm**	143	117	91	107	120	111	108	121	116	132	112	89	121	119	126	124	86
Cu	**ppm**	29	38	27	38	35	34	33	38	38	45	39	26	35	44	50	33	32
Nb	**ppm**	23	16	13	14	17	18	15	19	14	16	13	17	16	15	15	14	14
Ni	**ppm**	70	70	52	52	62	57	58	74	63	73	58	48	66	79	99	57	51
Pb	**ppm**	40	29	24	28	28	27	30	30	29	29	1863	25	29	25	33	29	28
Rb	**ppm**	157	155	138	170	162	148	157	169	155	162	155	135	174	144	172	131	127
Sr	**ppm**	216	257	183	184	198	270	259	177	202	122	294	212	187	157	184	227	239
V	**ppm**	143	137	94	124	133	132	126	123	139	148	129	109	120	116	128	114	111
Y	**ppm**	35	24	22	27	23	24	25	31	29	20	25	21	28	21	25	30	30
Zn	**ppm**	143	111	88	95	118	103	103	132	107	123	98	95	98	114	127	89	87
Zr	**ppm**	237	142	212	142	152	136	144	164	153	124	150	175	135	158	135	211	191
SUM	**wt.%**	100.16	100.35	100.61	100.28	100.49	100.17	99.95	100.39	100.36	100.44	100.43	100.41	100.30	100.27	99.97	100.34	100.39
FeO	**wt.%**	1.65	1.85	1.27	2.80	0.72	1.92	1.27	2.14	2.68	3.19	2.25	0.79	1.91	1.11	0.96	3.01	1.80
L O I	**wt.%**	6.76	5.56	5.64	2.40	4.37	9.71	5.72	4.20	3.89	9.91	7.92	4.22	2.15	6.11	9.33	3.56	3.81

Oxides		Ceramics from Arbon-Bleiche 3																
Elements	**Unit**	JB054	JB055	JB056	JB057	JB058	JB059	JB060	JB061	JB062	JB063	JB064	JB065	JB066	JB067	JB068	JB070	JB071
SiO2	**wt.%**	66.77	67.70	68.87	64.47	68.82	69.62	65.66	68.55	68.19	65.54	68.62	70.02	66.21	66.47	67.23	64.03	72.07
TiO2	**wt.%**	0.72	0.57	0.53	0.68	0.60	0.75	0.74	0.63	0.59	0.77	0.52	0.55	0.79	0.77	0.74	0.80	0.71
Al2O3	**wt.%**	18.39	17.61	17.09	19.47	15.96	16.85	18.40	17.94	17.84	18.20	16.25	15.79	19.01	18.38	18.03	17.17	16.26
Fe2O3*	**wt.%**	5.54	3.79	4.08	4.62	3.75	4.64	4.72	4.46	4.65	5.57	3.87	4.12	6.08	5.23	4.77	6.81	3.69
MnO	**wt.%**	0.05	0.03	0.06	0.03	0.04	0.05	0.04	0.04	0.04	0.06	0.06	0.03	0.05	0.05	0.05	0.12	0.04
MgO	**wt.%**	1.71	1.51	1.23	2.08	1.62	1.49	2.00	1.43	1.53	1.77	1.92	1.29	1.91	1.84	1.55	2.91	1.28
CaO	**wt.%**	1.94	3.88	2.57	2.62	5.30	2.67	2.21	1.58	1.69	4.38	3.38	3.67	2.71	3.01	3.65	4.41	1.91
Na2O	**wt.%**	1.19	1.60	2.03	1.24	0.86	0.89	1.41	1.60	1.40	0.34	1.91	1.28	0.53	1.04	0.69	1.47	0.77
K2O	**wt.%**	3.19	2.82	3.60	4.21	2.92	2.83	3.80	3.47	3.50	2.90	3.16	3.05	2.82	2.41	2.77	1.89	2.91
P2O5	**wt.%**	0.21	0.18	0.11	0.32	0.19	0.18	0.36	0.23	0.26	0.26	0.16	0.35	0.16	0.28	0.24	0.18	0.19
Ba	**ppm**	665	528	462	817	574	655	760	838	687	662	665	580	609	726	883	560	626
Cr	**ppm**	104	90	85	119	95	115	99	98	101	124	102	97	132	117	112	96	97
Cu	**ppm**	33	38	39	29	40	41	36	31	30	41	31	33	44	38	43	53	39
Nb	**ppm**	15	14	9	16	14	36	17	16	13	16	22	14	15	15	17	11	15
Ni	**ppm**	52	58	41	67	53	57	51	48	53	61	65	48	77	58	61	52	52
Pb	**ppm**	31	27	39	30	29	28	29	30	35	32	29	31	23	25	29	20	28
Rb	**ppm**	159	152	194	189	146	154	170	182	191	174	178	181	178	131	158	107	154
Sr	**ppm**	217	196	226	193	185	168	179	279	203	232	192	177	207	223	266	241	141
V	**ppm**	132	95	91	126	98	114	113	112	112	146	86	106	148	141	135	222	108
Y	**ppm**	27	23	21	24	23	27	32	19	24	25	25	31	26	25	24	24	28
Zn	**ppm**	100	83	69	109	89	93	113	100	90	113	80	117	120	106	100	97	97
Zr	**ppm**	163	134	109	122	133	150	203	126	112	139	127	150	131	151	138	138	166
SUM	**wt.%**	99.88	99.83	100.31	99.92	100.21	100.13	99.52	100.12	99.86	99.97	100.01	100.31	100.44	99.66	99.92	99.95	99.99
FeO	**wt.%**	3.18	1.03	2.69	1.56	1.13	1.54	2.39	1.01	1.44	3.83	2.35	2.17	2.89	1.39	2.23	2.45	2.14
L O I	**wt.%**	5.33	5.73	1.76	4.56	7.37	5.01	3.12	2.94	4.54	3.82	6.81	12.18	3.27	5.17	5.96	3.50	3.86

Oxides		Ceramics from Arbon-Bleiche 3																
Elements	Unit	JB072	JB073	JB074	JB075	JB076	JB086	JB087	JB088	JB089	JB090	JB091	JB092	JB093	JB094	JB095	JB096	JB097
SiO2	wt.%	68.99	72.87	67.69	68.61	64.02	66.88	68.64	65.71	69.57	65.39	66.08	66.69	66.86	67.53	64.83	70.98	68.19
TiO2	wt.%	0.60	0.87	0.73	0.79	0.71	0.76	0.78	0.81	0.66	0.68	0.71	0.69	0.78	0.76	0.80	0.79	0.73
Al2O3	wt.%	18.37	16.58	16.78	17.01	18.20	18.65	19.74	19.39	17.37	16.85	18.43	17.82	18.08	17.61	20.17	17.24	17.42
Fe2O3*	wt.%	4.33	3.36	4.80	4.38	4.72	4.24	4.61	5.86	4.14	4.27	5.44	3.87	5.42	4.73	4.82	4.44	4.50
MnO	wt.%	0.04	0.03	0.07	0.05	0.05	0.04	0.03	0.05	0.03	0.05	0.08	0.04	0.07	0.05	0.03	0.03	0.04
MgO	wt.%	1.57	1.78	1.66	1.58	1.52	2.11	1.71	1.94	1.56	1.70	1.89	1.69	2.05	2.03	2.33	1.83	1.69
CaO	wt.%	1.26	1.24	4.35	4.12	6.30	4.10	1.49	2.06	1.41	7.78	2.39	5.47	2.26	3.15	2.44	1.49	2.12
Na2O	wt.%	1.30	0.49	0.63	0.37	1.10	0.28	0.20	0.49	1.33	0.40	1.62	0.80	1.12	1.12	0.93	0.35	0.95
K2O	wt.%	3.16	2.47	2.81	2.43	2.90	2.73	2.40	3.21	3.62	2.34	3.07	2.86	3.27	2.61	3.18	2.74	3.49
P2O5	wt.%	0.11	0.19	0.22	0.22	0.21	0.25	0.27	0.31	0.24	0.23	0.15	0.19	0.23	0.16	0.16	0.19	0.32
Ba	ppm	546	641	793	772	724	617	771	690	631	659	588	634	608	608	720	589	690
Cr	ppm	97	136	96	164	91	126	133	127	93	106	105	111	110	102	124	116	102
Cu	ppm	34	49	40	38	31	37	46	57	32	35	35	41	37	33	36	47	36
Nb	ppm	16	17	14	18	13	15	17	18	16	15	16	16	14	15	16	17	16
Ni	ppm	60	86	55	79	53	66	66	66	52	60	68	58	60	62	84	64	54
Pb	ppm	30	32	25	29	23	21	22	24	25	19	20	24	25	26	25	24	25
Rb	ppm	178	153	133	148	149	163	141	180	179	128	150	155	166	137	176	155	167
Sr	ppm	115	98	233	204	248	156	126	184	118	226	177	216	159	178	157	119	153
V	ppm	108	102	134	125	112	131	141	151	103	111	110	123	139	116	139	124	117
Y	ppm	23	28	25	23	26	26	17	30	24	23	29	22	34	26	20	24	26
Zn	ppm	95	115	95	111	96	107	141	126	99	112	100	106	110	104	106	114	108
Zr	ppm	113	252	155	152	168	147	144	144	142	127	163	137	172	172	143	175	157
SUM	wt.%	99.87	100.05	99.92	99.75	99.90	100.20	100.05	100.01	100.08	99.85	100.02	100.28	100.30	99.91	99.86	100.24	99.62
FeO	wt.%	1.38	0.80	2.39	1.50	1.06	2.30	1.76	1.55	0.78	1.06	3.15	0.84	3.80	0.96	1.20	1.90	0.98
L O I	wt.%	6.56	4.73	6.29	7.16	8.43	13.39	9.38	4.90	4.59	10.59	3.85	8.30	3.05	5.69	5.48	9.59	4.14

Oxides		Ceramics from Arbon-Bleiche 3																
Elements	**Unit**	JB098	JB099	JB100	JB101	JB102	JB0103	JB104	JB105	JB106	JB107	JB108	JB109	JB110	JB111	JB112	JB113	JB114
SiO2	**wt.%**	70.23	69.54	67.24	70.91	71.30	67.36	67.18	64.30	69.63	69.71	68.57	69.55	67.64	70.02	67.80	69.43	67.50
TiO2	**wt.%**	0.59	0.80	0.70	0.72	0.56	0.69	0.75	0.81	0.83	0.64	0.60	0.70	0.48	0.86	0.80	0.58	0.73
Al2O3	**wt.%**	17.64	17.10	17.33	16.06	14.48	18.88	18.35	18.81	18.32	18.22	18.17	17.48	16.03	17.76	19.13	15.79	18.02
Fe2O3*	**wt.%**	3.58	5.27	4.73	4.72	3.68	4.22	5.53	6.43	4.40	4.43	4.61	4.93	3.35	4.36	4.38	3.49	5.77
MnO	**wt.%**	0.03	0.05	0.06	0.04	0.04	0.04	0.06	0.07	0.04	0.03	0.04	0.05	0.05	0.03	0.06	0.04	0.05
MgO	**wt.%**	1.56	2.18	1.82	1.68	1.63	1.78	1.69	1.99	1.79	1.52	1.54	1.42	2.34	1.63	1.85	1.34	1.71
CaO	**wt.%**	1.52	1.61	3.62	1.89	5.34	2.05	2.11	3.80	1.99	1.19	1.69	1.19	4.31	1.99	2.42	4.41	1.73
Na2O	**wt.%**	1.51	0.42	1.20	0.49	0.34	1.60	1.26	0.50	0.33	0.99	1.55	1.08	2.09	0.39	0.35	2.06	1.18
K2O	**wt.%**	3.39	2.86	3.22	3.05	2.34	3.06	3.13	2.89	2.50	3.14	3.09	3.29	3.22	2.49	2.70	2.46	3.06
P2O5	**wt.%**	0.13	0.26	0.17	0.27	0.14	0.26	0.16	0.18	0.20	0.19	0.15	0.20	0.23	0.34	0.27	0.18	0.11
Ba	**ppm**	542	563	529	567	497	751	503	423	691	503	481	588	644	820	813	551	459
Cr	**ppm**	91	135	107	119	98	96	105	127	123	102	95	98	89	120	125	73	112
Cu	**ppm**	30	41	49	91	39	35	38	43	48	48	29	30	27	45	39	26	31
Nb	**ppm**	18	16	15	15	12	15	15	17	17	15	15	16	18	17	15	12	15
Ni	**ppm**	52	81	56	68	84	54	52	62	70	61	41	54	65	72	70	45	56
Pb	**ppm**	22	23	22	24	16	26	31	23	24	23	17	25	26	22	27	23	28
Rb	**ppm**	182	157	162	145	124	151	173	175	148	209	196	180	181	143	156	111	179
Sr	**ppm**	107	130	190	162	276	192	171	213	166	105	122	101	197	182	173	175	193
V	**ppm**	106	135	116	113	105	114	133	150	132	114	114	109	80	132	147	87	134
Y	**ppm**	35	31	32	24	17	30	33	30	25	24	22	26	25	29	24	31	25
Zn	**ppm**	91	121	102	105	94	104	100	115	110	109	97	96	83	110	117	79	102
Zr	**ppm**	134	161	147	133	107	156	169	170	170	116	148	162	121	207	137	149	162
SUM	**wt.%**	100.32	100.25	100.24	99.99	100.00	100.11	100.37	99.93	100.20	100.20	100.15	100.04	99.90	100.06	99.94	99.92	100.01
FeO	**wt.%**	2.25	3.72	2.33	1.28	0.98	1.93	4.24	4.94	1.34	0.95	1.64	1.70	1.12	1.62	2.10	1.55	4.19
L O I	**wt.%**	7.98	2.45	2.73	5.14	7.21	5.63	2.33	2.00	5.34	5.53	2.60	8.02	5.14	4.68	7.00	4.70	1.12

Oxides		**Ceramics from Arbon-Bleiche 3**																
Elements	**Unit**	JB115	JB116	JB117	JB118	JB119	JB120	JB133	JB134	JB135	JB136	JB137	JB138	JB139	JB140	JB141	JB142	JB143
SiO2	**wt.%**	66.31	66.99	64.98	64.30	66.92	70.02	66.32	68.60	69.22	68.51	67.24	65.97	66.26	65.65	69.99	67.86	66.60
TiO2	**wt.%**	0.75	0.82	0.74	0.80	0.71	0.84	0.80	0.70	0.56	0.58	0.62	0.78	0.81	0.76	0.81	0.61	0.74
Al2O3	**wt.%**	18.45	17.46	17.80	21.11	17.90	17.53	19.66	17.45	17.25	18.28	16.87	19.67	19.71	17.49	16.25	17.26	18.62
Fe2O3*	**wt.%**	4.87	5.69	5.65	6.19	4.02	4.81	5.59	4.54	3.78	4.05	3.69	4.87	5.06	5.03	4.67	4.97	5.05
MnO	**wt.%**	0.08	0.07	0.09	0.05	0.04	0.04	0.05	0.06	0.04	0.03	0.04	0.04	0.03	0.06	0.07	0.09	0.07
MgO	**wt.%**	1.67	1.76	1.81	1.78	1.42	1.69	1.59	1.77	1.26	1.43	1.38	1.94	2.18	2.03	2.15	1.55	1.56
CaO	**wt.%**	3.57	3.50	4.51	1.41	4.35	2.15	2.14	1.96	2.75	1.73	4.59	3.27	1.86	3.91	2.29	2.54	2.95
Na2O	**wt.%**	1.18	0.56	1.20	0.74	1.31	0.27	0.46	1.38	1.54	1.73	1.24	0.40	0.71	1.05	0.49	1.69	1.14
K2O	**wt.%**	2.72	2.88	2.70	2.95	2.66	2.60	2.89	3.48	3.44	3.40	3.63	2.75	3.00	3.79	3.12	3.37	2.81
P2O5	**wt.%**	0.21	0.18	0.18	0.12	0.33	0.20	0.42	0.20	0.22	0.25	0.41	0.17	0.35	0.26	0.23	0.19	0.22
Ba	**ppm**	665	487	491	337	820	751	692	499	597	1083	762	710	879	750	629	353	704
Cr	**ppm**	92	120	97	141	92	123	132	94	85	98	95	133	118	107	133	96	107
Cu	**ppm**	38	35	30	40	42	44	41	32	28	58	29	48	46	41	39	51	42
Nb	**ppm**	17	16	16	16	15	17	17	16	13	14	14	14	16	16	16	17	15
Ni	**ppm**	54	53	50	64	57	69	72	43	45	55	53	69	73	61	86	53	57
Pb	**ppm**	21	23	18	25	25	24	24	24	32	25	15	21	27	25	24	34	20
Rb	**ppm**	162	180	170	142	141	156	167	170	187	183	195	156	169	175	146	170	150
Sr	**ppm**	197	220	200	109	292	185	191	153	166	364	208	193	146	261	142	183	232
V	**ppm**	123	147	131	163	105	135	145	112	96	115	110	151	126	126	122	118	131
Y	**ppm**	24	26	26	28	26	24	27	28	24	17	29	23	27	26	29	28	25
Zn	**ppm**	104	112	102	123	99	107	128	103	85	104	106	120	127	109	112	104	102
Zr	**ppm**	173	156	183	144	181	180	142	180	113	136	151	130	143	190	214	137	226
SUM	**wt.%**	99.98	100.07	99.81	99.58	99.85	100.33	100.10	100.29	100.21	100.22	99.89	100.04	100.16	100.22	100.24	100.26	99.94
FeO	**wt.%**	1.85	3.79	3.77	4.07	0.97	2.83	2.09	0.58	0.89	1.32	1.76	2.48	2.06	2.60	2.53	3.72	2.66
L O I	**wt.%**	3.68	1.33	2.18	6.31	5.40	4.04	5.87	1.59	3.40	5.01	7.93	12.22	8.39	5.49	7.81	0.96	8.39

Oxides		Ceramics from Arbon-Bleiche 3																
Elements	Unit	JB144	JB145	JB146	JB148	JB149	JB150	JB151	JB152	JB153	JB154	JB155	JB157	JB158	JB159	JB160	JB162	JB163
SiO2	**wt.%**	67.21	67.64	67.21	65.06	66.80	65.67	63.98	68.23	69.45	71.28	68.08	67.53	70.08	70.38	66.44	68.49	65.63
TiO2	**wt.%**	0.77	0.81	0.77	0.76	0.72	0.68	0.84	0.64	0.62	0.81	0.84	0.80	0.53	0.82	0.83	0.82	0.83
Al2O3	**wt.%**	16.55	19.53	18.44	17.93	17.72	19.77	18.07	18.47	18.19	17.20	18.96	18.27	15.51	17.49	19.41	18.74	18.90
Fe2O3*	**wt.%**	4.36	5.11	5.82	3.80	4.82	4.61	4.38	4.64	3.84	4.63	4.67	4.77	3.21	4.35	4.52	4.81	5.35
MnO	**wt.%**	0.05	0.03	0.03	0.06	0.05	0.03	0.04	0.04	0.02	0.04	0.03	0.04	0.06	0.06	0.04	0.03	0.05
MgO	**wt.%**	2.34	2.04	2.10	1.51	1.70	1.77	4.11	1.64	1.54	1.70	2.12	1.92	1.44	1.47	1.89	1.82	2.43
CaO	**wt.%**	4.60	1.79	1.32	7.08	3.64	3.40	5.08	1.95	1.35	1.36	1.84	3.76	3.49	2.38	3.44	2.44	3.91
Na2O	**wt.%**	0.61	0.31	0.84	0.38	0.92	1.67	0.69	0.89	0.98	0.36	0.61	0.40	1.65	0.64	0.56	0.49	0.85
K2O	**wt.%**	2.90	2.66	3.40	2.68	3.08	2.45	2.50	3.24	3.69	2.43	2.73	2.44	3.68	2.54	2.66	2.30	2.26
P2O5	**wt.%**	0.29	0.14	0.19	0.49	0.22	0.15	0.19	0.21	0.14	0.18	0.32	0.18	0.41	0.18	0.16	0.13	0.16
Ba	**ppm**	661	565	442	920	962	633	581	586	682	677	846	619	466	661	721	603	611
Cr	**ppm**	123	130	120	121	109	96	152	103	97	115	134	126	92	121	129	128	118
Cu	**ppm**	34	41	46	38	34	35	57	41	31	49	47	45	31	34	42	44	69
Nb	**ppm**	15	16	15	15	16	14	16	15	12	16	15	16	15	17	16	16	15
Ni	**ppm**	75	72	61	64	61	62	108	58	58	60	79	78	51	63	73	71	71
Pb	**ppm**	24	28	27	22	24	47	23	22	34	26	29	25	25	26	28	26	26
Rb	**ppm**	151	167	186	159	168	145	151	204	181	136	162	145	220	158	141	138	136
Sr	**ppm**	156	138	103	291	311	214	145	130	166	121	151	191	151	204	178	146	195
V	**ppm**	108	146	126	138	113	106	122	119	108	123	128	125	81	121	128	131	146
Y	**ppm**	30	22	35	25	23	19	24	26	16	22	30	21	24	23	24	20	21
Zn	**ppm**	111	117	112	115	105	98	118	107	89	116	125	122	92	104	114	106	110
Zr	**ppm**	169	134	145	137	167	141	169	117	114	182	156	137	118	156	137	138	141
SUM	**wt.%**	99.85	100.22	100.26	99.95	99.88	100.36	100.05	100.10	99.98	100.15	100.39	100.28	100.20	100.48	100.12	100.23	100.54
FeO	**wt.%**	1.10	1.53	4.18	2.63	0.85	1.76	1.62	1.48	1.99	1.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L O I	**wt.%**	5.56	6.44	1.77	8.60	5.22	7.15	8.68	8.48	7.08	6.65	6.72	7.22	8.09	4.77	7.40	7.64	5.65

Oxides		Ceramics from Arbon-Bleiche 3																
Elements	Unit	JB164	JB165	JB166	JB167	JB169	JB171	JB173	JB174	JB175	JB177	JB178	JB179	JB180	JB181	JB182	JB183	JB185
SiO2	**wt.%**	68.99	68.24	67.50	67.30	65.58	71.38	69.72	67.03	77.69	67.28	66.72	66.13	66.77	69.62	63.75	68.63	68.53
TiO2	**wt.%**	0.83	0.78	0.82	0.70	0.80	0.64	0.70	0.83	0.88	0.82	0.78	0.79	0.74	0.69	0.75	0.82	0.80
Al2O3	**wt.%**	18.80	18.24	18.99	18.15	18.71	17.69	17.74	18.93	14.85	19.31	19.10	18.67	18.89	17.69	18.48	18.48	18.98
Fe2O3*	**wt.%**	4.85	5.67	5.01	4.81	5.47	3.51	4.61	5.21	2.29	4.98	4.47	5.51	4.46	4.74	4.57	4.50	4.31
MnO	**wt.%**	0.04	0.07	0.05	0.06	0.05	0.03	0.05	0.04	0.02	0.05	0.04	0.05	0.04	0.05	0.04	0.04	0.05
MgO	**wt.%**	1.80	1.88	2.09	1.68	1.83	1.31	1.54	1.78	0.66	1.94	1.61	1.86	1.60	1.51	2.04	1.93	1.68
CaO	**wt.%**	1.83	1.71	2.39	2.80	4.17	1.21	1.53	3.45	1.25	2.32	3.54	3.51	4.24	1.60	7.66	1.84	2.10
Na2O	**wt.%**	0.56	0.60	0.47	1.81	0.31	1.20	1.05	0.45	0.52	0.66	1.04	0.68	0.48	1.08	0.24	1.09	0.56
K2O	**wt.%**	2.58	2.87	2.63	2.97	2.81	2.92	2.92	2.23	1.71	2.76	2.50	2.53	2.46	2.87	2.19	2.58	2.61
P2O5	**wt.%**	0.13	0.20	0.18	0.16	0.46	0.23	0.23	0.19	0.37	0.19	0.16	0.36	0.31	0.23	0.15	0.12	0.35
Ba	**ppm**	687	551	698	682	828	560	676	632	442	791	728	868	734	661	552	639	805
Cr	**ppm**	138	139	135	100	143	108	118	129	123	129	120	133	137	113	131	122	132
Cu	**ppm**	41	40	40	30	41	26	32	42	32	39	38	38	38	31	45	38	36
Nb	**ppm**	16	15	18	16	16	14	14	18	16	17	16	15	14	16	16	15	17
Ni	**ppm**	76	72	75	50	81	56	63	81	64	71	67	78	71	63	76	82	71
Pb	**ppm**	27	23	25	21	27	23	28	25	29	24	27	25	23	26	24	26	24
Rb	**ppm**	152	155	148	151	160	219	172	142	96	156	147	159	154	169	154	159	163
Sr	**ppm**	180	162	153	209	242	116	152	188	80	193	220	250	197	154	248	138	178
V	**ppm**	125	140	144	110	149	96	122	127	90	142	117	136	130	114	125	109	137
Y	**ppm**	19	28	21	24	28	19	27	21	26	23	22	26	26	27	20	20	27
Zn	**ppm**	113	111	112	96	121	93	169	119	120	178	100	110	114	96	139	111	113
Zr	**ppm**	153	148	131	149	136	113	136	155	251	158	143	144	125	129	134	162	136
SUM	**wt.%**	100.58	100.42	100.30	100.60	100.39	100.26	100.26	100.31	100.38	100.50	100.13	100.29	100.17	100.24	100.04	100.19	100.15
FeO	**wt.%**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L O I	**wt.%**	7.41	5.55	7.37	6.85	5.10	4.90	6.15	7.26	9.37	11.42	6.37	4.26	6.77	5.96	10.40	6.10	6.25

Oxides		**Ceramics from Arbon-Bleiche 3**						
Elements	**Unit**	JB186	JB187	JB188	JB189	JB190	mean	s
SiO2	**wt.%**	72.72	68.14	68.26	69.00	66.80	67.92	2.21
TiO2	**wt.%**	0.49	0.77	0.56	0.84	0.69	0.73	0.09
Al2O3	**wt.%**	16.30	19.32	16.85	19.17	15.70	17.97	1.28
Fe2O3*	**wt.%**	3.05	4.10	3.82	4.00	3.86	4.64	0.69
MnO	**wt.%**	0.04	0.04	0.04	0.03	0.07	0.05	0.02
MgO	**wt.%**	0.84	1.14	1.25	1.29	1.32	1.74	0.39
CaO	**wt.%**	1.11	2.62	3.95	1.81	7.54	2.94	1.47
Na2O	**wt.%**	1.91	0.80	1.87	0.58	0.93	0.89	0.48
K2O	**wt.%**	3.55	2.77	3.17	2.69	2.73	2.87	0.42
P2O5	**wt.%**	0.19	0.22	0.19	0.24	0.30	0.23	0.09
Ba	**ppm**	405	609	878	650	650	663	138.59
Cr	**ppm**	76	126	94	138	96	114	17.29
Cu	**ppm**	27	42	39	42	27	39	8.53
Nb	**ppm**	17	15	11	16	14	16	2.54
Ni	**ppm**	40	69	49	74	61	64	12.45
Pb	**ppm**	23	27	34	27	28	40	154.72
Rb	**ppm**	270	149	170	152	153	160	22.71
Sr	**ppm**	85	168	427	134	240	186	53.70
V	**ppm**	72	128	92	132	89	123	19.41
Y	**ppm**	23	24	17	29	26	25	3.98
Zn	**ppm**	86	107	102	197	93	109	17.79
Zr	**ppm**	109	137	123	162	157	152	27.07
SUM	**wt.%**	100.32	100.08	100.16	99.83	100.10	100.15	0.22
FeO	**wt.%**	0.00	0.00	0.00	0.00	0.00	1.58	1.16
L O I	**wt.%**	13.27	6.87	4.93	8.96	7.74	6.06	2.66

Oxides		**Bone tempered ceramics**					
Elements	**Unit**	JB012	JB020	JB069	JB147	mean	s
SiO2	**wt.%**	56.18	53.11	56.92	59.10	56.33	2.48
TiO2	**wt.%**	1.60	0.64	0.62	0.75	0.90	0.47
Al2O3	**wt.%**	28.48	16.31	15.31	18.01	19.53	6.07
Fe2O3*	**wt.%**	6.30	4.38	3.42	4.31	4.60	1.21
MnO	**wt.%**	0.03	0.04	0.06	0.04	0.04	0.01
MgO	**wt.%**	0.86	2.07	1.56	2.25	1.69	0.62
CaO	**wt.%**	2.67	12.30	14.00	7.60	9.14	5.09
Na2O	**wt.%**	0.31	0.54	0.30	0.72	0.47	0.20
K2O	**wt.%**	1.83	2.32	2.09	2.84	2.27	0.43
P2O5	**wt.%**	1.12	8.00	5.53	4.29	4.74	2.86
Ba	**ppm**	799	663	651	848	740	98
Cr	**ppm**	214	104	104	117	135	53
Cu	**ppm**	42	36	35	52	41	8
Nb	**ppm**	34	13	15	19	20	10
Ni	**ppm**	124	68	57	61	78	31
Pb	**ppm**	66	29	24	14	33	23
Rb	**ppm**	103	135	119	143	125	18
Sr	**ppm**	212	305	282	226	256	44
V	**ppm**	194	114	112	128	137	39
Y	**ppm**	444	30	26	31	133	208
Zn	**ppm**	184	137	109	123	138	33
Zr	**ppm**	388	123	125	139	194	130
SUM	**wt.%**	99.66	99.89	99.98	100.10	99.91	0.19
FeO	**wt.%**	1.90	2.43	1.54	2.88	2.19	0.59
L O I	**wt.%**	15.48	10.84	9.24	12.92	12.12	2.70

Oxides		Loomweight and cob fragments													
Elements	**Unit**	JB121	JB122	JB123	JB124	JB125	JB126	JB127	JB128	JB129	JB130	JB131	JB132	mean	s
SiO2	**wt.%**	70.67	73.20	62.72	68.65	64.49	68.34	70.71	70.23	66.88	70.53	66.94	69.09	68.54	2.92
TiO2	**wt.%**	0.47	0.49	0.42	0.48	0.43	0.50	0.74	0.49	0.45	0.47	0.46	0.47	0.49	0.08
Al2O3	**wt.%**	8.19	8.55	9.81	8.18	7.89	8.78	12.47	8.29	7.83	8.23	8.00	8.05	8.69	1.30
Fe2O3*	**wt.%**	2.02	2.40	2.45	2.18	2.18	2.40	3.01	2.24	1.93	2.08	2.05	2.12	2.26	0.29
MnO	**wt.%**	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.07	0.06	0.01
MgO	**wt.%**	2.31	1.35	2.28	1.41	1.88	1.77	2.07	1.89	1.47	1.23	1.71	1.97	1.78	0.36
CaO	**wt.%**	13.97	11.45	17.30	15.20	19.69	14.25	7.87	13.58	18.22	14.01	17.67	15.86	14.92	3.21
Na2O	**wt.%**	0.52	0.51	0.65	0.47	0.52	0.34	0.82	0.29	0.45	0.43	0.37	0.35	0.48	0.15
K2O	**wt.%**	1.79	1.54	3.55	2.60	2.46	3.04	1.80	2.47	2.38	2.55	2.46	2.08	2.39	0.55
P2O5	**wt.%**	0.11	0.21	0.26	0.23	0.24	0.24	0.28	0.15	0.24	0.21	0.25	0.18	0.22	0.05
Ba	**ppm**	258	505	570	535	438	660	525	527	536	563	574	483	515	97
Cr	**ppm**	70	75	70	62	52	72	101	66	62	68	64	60	69	12
Cu	**ppm**	72	22	41	24	33	37	35	23	36	27	20	19	32	15
Nb	**ppm**	11	13	9	10	9	11	16	11	10	11	10	10	11	2
Ni	**ppm**	30	39	38	32	33	37	53	31	36	39	31	32	36	6
Pb	**ppm**	14	17	19	16	13	16	18	22	14	15	12	20	16	3
Rb	**ppm**	94	72	104	70	79	96	92	70	87	94	80	71	84	12
Sr	**ppm**	309	307	368	426	497	379	233	340	534	406	491	353	387	89
V	**ppm**	57	63	45	51	50	49	87	42	46	50	46	43	52	12
Y	**ppm**	26	23	26	25	23	30	35	24	26	26	27	27	27	3
Zn	**ppm**	59	57	74	53	62	74	97	58	50	60	52	50	62	14
Zr	**ppm**	262	245	210	252	214	274	255	304	268	277	271	267	258	26
SUM	**wt.%**	100.23	99.90	99.66	99.62	99.99	99.89	99.97	99.84	100.08	99.95	100.14	100.38	99.97	0.22
FeO	**wt.%**	1.20	1.06	0.49	0.41	0.45	0.40	1.43	0.34	0.41	0.42	0.26	0.29	0.60	0.40
L O I	**wt.%**	14.53	10.11	13.73	11.79	14.65	11.46	8.92	11.55	14.20	11.92	14.10	12.74	12.48	1.84

Oxides		Ceramic samples from the Western Carpathian Basin															
Elements	**Unit**	JB200	JB201	JB202	JB203	JB204	JB205	JB206	JB207	JB208	JB209	JB210	JB211	JB212	JB213	mean	s
SiO2	**wt.%**	59.52	56.72	65.42	66.72	64.16	66.05	71.50	66.15	70.09	66.16	72.80	74.30	68.82	70.02	67.03	4.83
TiO2	**wt.%**	1.02	1.15	1.02	0.86	0.93	0.77	0.85	0.79	0.87	0.80	0.87	1.03	1.06	1.02	0.93	0.12
Al2O3	**wt.%**	22.48	23.25	19.39	19.74	17.88	15.14	14.71	15.30	16.14	16.91	15.59	14.93	17.50	17.60	17.61	2.73
Fe2O3*	**wt.%**	9.24	10.80	7.19	6.93	7.49	5.64	5.66	7.46	6.28	6.62	6.49	5.71	7.33	6.95	7.13	1.42
MnO	**wt.%**	0.10	0.11	0.06	0.07	0.06	0.14	0.07	0.11	0.11	0.14	0.02	0.03	0.03	0.02	0.08	0.04
MgO	**wt.%**	2.14	1.89	1.65	1.97	3.11	2.66	1.47	2.98	1.68	2.22	1.02	1.03	1.22	0.77	1.84	0.73
CaO	**wt.%**	2.22	2.36	2.12	1.70	3.76	4.09	2.62	4.04	1.63	3.11	0.22	0.20	0.25	0.44	2.05	1.40
Na2O	**wt.%**	0.64	0.82	0.69	0.51	0.29	1.02	0.70	0.84	0.64	1.00	0.50	0.55	0.71	0.37	0.66	0.21
K2O	**wt.%**	2.34	2.71	2.40	1.82	2.18	4.25	2.08	2.25	2.24	2.40	2.10	2.04	2.46	2.14	2.39	0.58
P2O5	**wt.%**	0.20	0.26	0.19	0.13	0.12	0.25	0.52	0.17	0.24	0.60	0.56	0.41	0.67	0.87	0.37	0.23
Ba	**ppm**	654	752	613	728	640	844	831	618	548	857	442	445	482	405	633	155
Cr	**ppm**	153	165	157	140	145	129	129	127	136	136	118	118	147	131	138	14
Cu	**ppm**	56	41	24	45	24	26	27	32	25	35	31	28	31	28	32	9
Nb	**ppm**	22	22	18	16	18	13	14	15	16	12	16	19	19	19	17	3
Ni	**ppm**	78	63	71	64	87	63	65	62	86	62	72	90	83	51	71	12
Pb	**ppm**	42	37	29	37	25	21	25	22	27	21	25	25	26	24	28	6
Rb	**ppm**	127	136	129	116	127	131	125	145	133	141	133	128	134	121	130	8
Sr	**ppm**	71	91	75	71	61	213	176	177	99	347	40	44	51	46	112	88
V	**ppm**	155	193	123	147	133	104	114	121	118	128	129	109	136	148	133	23
Y	**ppm**	44	51	37	31	33	35	39	29	52	37	26	29	42	45	38	8
Zn	**ppm**	128	126	88	93	93	174	213	92	98	107	78	178	87	63	116	44
Zr	**ppm**	238	222	236	211	248	237	320	221	273	198	296	361	338	290	264	50
SUM	**wt.%**	100.08	100.26	100.29	100.62	100.14	100.21	100.39	100.26	100.08	100.17	100.31	100.39	100.21	100.34	100.27	0.14
FeO	**wt.%**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L O I	**wt.%**	11.37	11.99	8.21	8.24	9.53	4.24	5.60	7.75	1.54	4.40	6.08	4.79	7.39	7.49	7.04	2.86

Oxides												Clays from the region of Arbon						
Elements	**Unit**	JB301	JB304	JB305	mean	s	JB300	JB302	JB303	mean	s	JB306	JB307	JB308	JB309	JB310	mean	s
SiO2	**wt.%**	70.22	73.71	77.70	73.88	3.74	70.64	74.07	64.91	69.87	4.63	59.94	56.56	56.97	56.22	53.51	56.64	2.29
TiO2	**wt.%**	0.78	0.79	0.74	0.77	0.03	0.39	0.49	0.40	0.43	0.06	0.57	0.62	0.46	0.46	0.47	0.52	0.07
Al2O3	**wt.%**	13.94	14.49	11.93	13.45	1.35	6.81	9.28	7.23	7.77	1.32	11.41	12.84	10.26	10.23	10.61	11.07	1.10
Fe2O3*	**wt.%**	5.51	5.70	4.48	5.23	0.66	2.38	3.52	2.66	2.85	0.59	4.37	4.76	3.66	3.73	3.88	4.08	0.47
MnO	**wt.%**	0.13	0.09	0.08	0.10	0.03	0.09	0.06	0.09	0.08	0.02	0.07	0.09	0.08	0.08	0.08	0.08	0.01
MgO	**wt.%**	1.95	1.61	1.28	1.61	0.34	2.04	1.68	1.74	1.82	0.19	2.65	2.59	3.63	3.83	5.14	3.57	1.04
CaO	**wt.%**	3.74	0.99	1.57	2.10	1.45	15.09	8.34	20.35	14.59	6.02	18.51	19.90	21.74	22.43	23.59	21.23	2.03
Na2O	**wt.%**	0.83	0.29	0.38	0.50	0.29	0.97	0.86	0.78	0.87	0.10	0.22	0.20	0.97	0.98	0.73	0.62	0.39
K2O	**wt.%**	2.38	2.44	2.06	2.29	0.20	1.43	1.67	1.42	1.51	0.14	2.17	2.34	2.04	1.97	2.05	2.11	0.15
P2O5	**wt.%**	0.13	0.07	0.06	0.09	0.04	0.18	0.11	0.27	0.19	0.08	0.12	0.09	0.12	0.13	0.12	0.12	0.02
Ba	**ppm**	382	325	294	334	45	240	273	291	268	26	249	278	258	261	270	263	11
Cr	**ppm**	106	109	98	104	6	61	71	60	64	6	87	90	78	70	73	80	9
Cu	**ppm**	29	32	30	30	2	32	62	37	44	16	39	32	26	28	25	30	6
Nb	**ppm**	16	16	14	15	1	8	10	8	9	1	14	14	10	10	11	12	2
Ni	**ppm**	57	54	43	51	7	24	32	28	28	4	43	47	39	40	40	42	3
Pb	**ppm**	32	24	21	26	6	46	17	40	34	15	15	16	18	15	13	15	2
Rb	**ppm**	145	145	124	138	12	65	86	73	75	11	120	132	98	98	100	110	16
Sr	**ppm**	145	83	90	106	34	332	201	335	289	77	492	596	574	580	531	555	42
V	**ppm**	109	122	94	108	14	41	71	52	55	15	105	109	82	78	82	91	15
Y	**ppm**	34	40	33	36	4	25	28	25	26	2	28	25	25	26	24	26	2
Zn	**ppm**	92	97	75	88	12	151	56	121	109	49	78	84	62	64	69	71	9
Zr	**ppm**	223	264	303	263	40	258	201	257	239	33	227	149	174	172	154	175	31
SUM	**wt.%**	99.75	100.31	100.40	100.15	0.35	100.15	100.19	99.98	100.11	0.11	100.18	100.15	100.07	100.20	100.32	100.18	0.09
FeO	**wt.%**	1.23	0.58	0.54	0.78	0.39	1.50	0.94	1.57	1.34	0.35	0.57	0.66	1.33	1.28	1.54	1.08	0.43
L O I	**wt.%**	7.62	5.15	4.79	5.85	1.54	15.59	9.77	18.51	14.62	4.45	16.02	16.96	17.68	18.11	19.76	17.71	1.39

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Descriptive statistics of the different studied groups
A: cob fragments and loom weight;
B: ceramics from Arbon Bleiche 3 without those tempered with bone
Note: n=158 for all ceramics because JB172 was not measured.
C: ceramics from Arbon Bleiche 3 tempered with bone
D: ceramics from Mödling, western Carpathian Basin
E: ceramics from Žlkovce, western Carpathian Basin;
F: ceramics from Náměšt na Hané, western Carpathian
G: ceramics from Arbon Bleiche 3 mainly tempered with grog
(Fe_2O_3**=*Fe_{tot}*; AB3: Arbon Bleiche 3; WCB: western Carpathian basin; n: number of samples).*

Descriptive statistics of the cob fragments and the loom weight

A	N	Minimum	Maximum	Range	Mean	Standard Deviation	Variation Coefficient
SiO2 (wt.%)	12	62.72	73.20	10.48	68.54	2.92	0.043
TiO2 (wt.%)	12	0.42	0.74	0.32	0.49	0.08	0.169
Al2O3 (wt.%)	12	7.83	12.47	4.64	8.69	1.30	0.150
Fe2O3 (wt.%)	12	1.93	3.01	1.08	2.26	0.29	0.128
FeO (wt.%)	12	0.26	1.43	1.17	0.60	0.40	0.662
MnO (wt.%)	12	0.05	0.07	0.02	0.06	0.01	0.099
MgO (wt.%)	12	1.23	2.31	1.08	1.78	0.36	0.201
CaO (wt.%)	12	7.87	19.69	11.82	14.92	3.21	0.215
Na2O (wt.%)	12	0.29	0.82	0.53	0.48	0.15	0.308
K2O (wt.%)	12	1.54	3.55	2.01	2.39	0.55	0.232
P2O5 (wt.%)	12	0.11	0.28	0.17	0.22	0.05	0.225
Ba (ppm)	12	258	660	402	514.5	97.2	0.189
Cr (ppm)	12	52	101	49	68.5	12.0	0.174
Cu (ppm)	12	19	72	53	32.4	14.5	0.447
Nb (ppm)	12	9	16	7	10.9	1.9	0.177
Ni (ppm)	12	30	53	23	35.9	6.3	0.176
Pb (ppm)	12	12	22	10	16.3	3.0	0.183
Rb (ppm)	12	70	104	34	84.1	11.9	0.142
Sr (ppm)	12	233	534	301	386.9	88.6	0.229
V (ppm)	12	42	87	45	52.4	12.4	0.236
Y (ppm)	12	23	35	12	26.5	3.3	0.124
Zn (ppm)	12	50	97	47	62.2	13.6	0.219
Zr (ppm)	12	210	304	94	258.3	26.2	0.101

Descriptive statistics of all the ceramics of AB3 (except those tempered with bone)

B	N	Minimum	Maximum	Range	Mean	Standard Deviation	Variation Coefficient
SiO2 (wt.%)	158	63.75	77.69	13.94	67.84	2.18	0.032
TiO2 (wt.%)	158	0.48	0.97	0.49	0.73	0.09	0.129
Al2O3 (wt.%)	158	10.53	23.03	12.50	17.87	1.39	0.078
Fe2O3 (wt.%)	158	2.29	6.81	4.52	4.61	0.70	0.152
FeO (wt.%)	129	0.58	4.94	4.36	1.96	0.89	0.455
MnO (wt.%)	158	0.02	0.12	0.10	0.05	0.02	0.328
MgO (wt.%)	158	0.66	4.11	3.45	1.76	0.42	0.239
CaO (wt.%)	158	1.11	12.84	11.73	3.10	1.74	0.561
Na2O (wt.%)	158	0.09	2.09	2.00	0.91	0.47	0.516
K2O (wt.%)	158	1.71	4.21	2.50	2.88	0.42	0.146
P2O5 (wt.%)	158	0.10	0.70	0.60	0.23	0.09	0.384
Ba (ppm)	158	337	1083	746	662.5	133.1	0.201
Cr (ppm)	158	51	164	113	113.0	17.9	0.159
Cu (ppm)	158	25	91	66	38.5	8.5	0.220
Nb (ppm)	158	9	36	27	15.7	2.5	0.160
Ni (ppm)	158	34	112	78	63.4	12.8	0.202
Pb (ppm)	157	15	47	32	26.9	4.7	0.176
Rb (ppm)	158	96	270	174	159.5	22.8	0.143
Sr (ppm)	158	80	427	347	190.5	55.2	0.289
V (ppm)	158	56	222	166	122.1	20.0	0.164
Y (ppm)	158	16	36	20	25.4	3.9	0.155
Zn (ppm)	158	55	197	142	108.5	18.5	0.171
Zr (ppm)	158	104	252	148	152.5	27.5	0.180

Descriptive statistics of the ceramics of AB3 tempered with bone

C	N	Minimum	Maximum	Range	Mean	Standard Deviation	Variation Coefficient
SiO2 (wt.%)	4	53.11	59.10	5.99	56.33	2.48	0.044
TiO2 (wt.%)	4	0.62	1.60	0.98	0.90	0.47	0.519
Al2O3 (wt.%)	4	15.31	28.48	13.17	19.53	6.07	0.311
Fe2O3 (wt.%)	4	3.42	6.30	2.88	4.60	1.21	0.264
FeO (wt.%)	4	1.54	2.88	1.34	2.19	0.59	0.269
MnO (wt.%)	4	0.03	0.06	0.03	0.04	0.01	0.296
MgO (wt.%)	4	0.86	2.25	1.39	1.69	0.62	0.370
CaO (wt.%)	4	2.67	14.00	11.33	9.14	5.09	0.557
Na2O (wt.%)	4	0.30	0.72	0.42	0.47	0.20	0.431
K2O (wt.%)	4	1.83	2.84	1.01	2.27	0.43	0.189
P2O5 (wt.%)	4	1.12	8.00	6.88	4.74	2.86	0.604
Ba (ppm)	4	651	848	197	740.3	98.3	0.133
Cr (ppm)	4	104	214	110	134.8	53.2	0.395
Cu (ppm)	4	35	52	17	41.3	7.8	0.189
Nb (ppm)	4	13	34	21	20.3	9.5	0.469
Ni (ppm)	4	57	124	67	77.5	31.3	0.404
Pb (ppm)	4	14	66	52	33.3	22.7	0.683
Rb (ppm)	4	103	143	40	125.0	17.7	0.142
Sr (ppm)	4	212	305	93	256.3	44.4	0.173
V (ppm)	4	112	194	82	137.0	38.7	0.282
Y (ppm)	4	26	444	418	132.8	207.5	1.563
Zn (ppm)	4	109	184	75	138.3	32.6	0.236
Zr (ppm)	4	123	388	265	193.8	129.7	0.669

Descriptive statistics of the ceramics of the WCB (Mödling)

D	N	Minimum	Maximum	Range	Mean	Standard Deviation	Variation Coefficient
SiO2 (wt.%)	5	56.72	66.72	10.00	62.51	4.22	0.068
TiO2 (wt.%)	5	0.86	1.15	0.29	1.00	0.11	0.110
Al2O3 (wt.%)	5	17.88	23.25	5.37	20.55	2.24	0.109
Fe2O3 (wt.%)	5	6.93	10.80	3.87	8.33	1.65	0.198
FeO (wt.%)	0						
MnO (wt.%)	5	0.06	0.11	0.05	0.08	0.02	0.293
MgO (wt.%)	5	1.65	3.11	1.46	2.15	0.56	0.262
CaO (wt.%)	5	1.70	3.76	2.06	2.43	0.78	0.322
Na2O (wt.%)	5	0.29	0.82	0.53	0.59	0.20	0.341
K2O (wt.%)	5	1.82	2.71	0.89	2.29	0.33	0.142
P2O5 (wt.%)	5	0.12	0.26	0.14	0.18	0.06	0.317
Ba (ppm)	5	613	752	139	677.4	59.6	0.088
Cr (ppm)	5	140	165	25	152.0	9.8	0.065
Cu (ppm)	5	24	56	32	38.0	13.9	0.366
Nb (ppm)	5	16	22	6	19.2	2.7	0.140
Ni (ppm)	5	63	87	24	72.6	10.1	0.139
Pb (ppm)	5	25	42	17	34.0	6.9	0.202
Rb (ppm)	5	116	136	20	127.0	7.2	0.057
Sr (ppm)	5	61	91	30	73.8	10.9	0.148
V (ppm)	5	123	193	70	150.2	26.9	0.179
Y (ppm)	5	31	51	20	39.2	8.3	0.211
Zn (ppm)	5	88	128	40	105.6	19.7	0.186
Zr (ppm)	5	211	248	37	231.0	14.5	0.063

Descriptive statistics of the ceramics of the WCB (Žlkovce)

E	N	Minimum	Maximum	Range	Mean	Standard Deviation	Variation Coefficient
SiO2 (wt.%)	5	66.05	71.50	5.45	67.99	2.61	0.038
TiO2 (wt.%)	5	0.77	0.87	0.10	0.82	0.04	0.052
Al2O3 (wt.%)	5	14.71	16.91	2.20	15.64	0.88	0.056
Fe2O3 (wt.%)	5	5.64	7.46	1.82	6.33	0.76	0.119
FeO (wt.%)	0						
MnO (wt.%)	5	0.07	0.14	0.07	0.11	0.03	0.253
MgO (wt.%)	5	1.47	2.98	1.51	2.20	0.64	0.289
CaO (wt.%)	5	1.63	4.09	2.46	3.10	1.03	0.333
Na2O (wt.%)	5	0.64	1.02	0.38	0.84	0.17	0.204
K2O (wt.%)	5	2.08	4.25	2.17	2.64	0.90	0.342
P2O5 (wt.%)	5	0.17	0.60	0.43	0.36	0.19	0.536
Ba (ppm)	5	548	857	309	739.6	145.4	0.197
Cr (ppm)	5	127	136	9	131.4	4.3	0.033
Cu (ppm)	5	25	35	10	29.0	4.3	0.148
Nb (ppm)	5	12	16	4	14.0	1.6	0.113
Ni (ppm)	5	62	86	24	67.6	10.4	0.153
Pb (ppm)	5	21	27	6	23.2	2.7	0.116
Rb (ppm)	5	125	145	20	135.0	8.0	0.059
Sr (ppm)	5	99	347	248	202.4	90.9	0.449
V (ppm)	5	104	128	24	117.0	8.9	0.076
Y (ppm)	5	29	52	23	38.4	8.5	0.221
Zn (ppm)	5	92	213	121	136.8	53.8	0.393
Zr (ppm)	5	198	320	122	249.8	47.8	0.191

Descriptive statistics of the ceramics of the WCB (Náměšt na Hané)

F	N	Minimum	Maximum	Range	Mean	Standard Deviation	Variation Coefficient
SiO2 (wt.%)	4	68.82	74.30	5.48	71.49	2.51	0.035
TiO2 (wt.%)	4	0.87	1.06	0.19	1.00	0.09	0.085
Al2O3 (wt.%)	4	14.93	17.60	2.67	16.41	1.35	0.082
Fe2O3 (wt.%)	4	5.71	7.33	1.62	6.62	0.70	0.105
FeO (wt.%)	0						
MnO (wt.%)	4	0.02	0.03	0.01	0.03	0.01	0.231
MgO (wt.%)	4	0.77	1.22	0.45	1.01	0.18	0.183
CaO (wt.%)	4	0.20	0.44	0.24	0.28	0.11	0.397
Na2O (wt.%)	4	0.37	0.71	0.34	0.53	0.14	0.264
K2O (wt.%)	4	2.04	2.46	0.42	2.19	0.19	0.086
P2O5 (wt.%)	4	0.41	0.87	0.46	0.63	0.19	0.309
Ba (ppm)	4	405	482	77	443.5	31.5	0.071
Cr (ppm)	4	118	147	29	128.5	13.8	0.107
Cu (ppm)	4	28	31	3	29.5	1.7	0.059
Nb (ppm)	4	16	19	3	18.3	1.5	0.082
Ni (ppm)	4	51	90	39	74.0	17.0	0.230
Pb (ppm)	4	24	26	2	25.0	0.8	0.033
Rb (ppm)	4	121	134	13	129.0	5.9	0.046
Sr (ppm)	4	40	51	11	45.3	4.6	0.101
V (ppm)	4	109	148	39	130.5	16.3	0.125
Y (ppm)	4	26	45	19	35.5	9.4	0.265
Zn (ppm)	4	63	178	115	101.5	52.0	0.512
Zr (ppm)	4	290	361	71	321.3	34.0	0.106

Descriptive statistics of the samples of AB3 mainly tempered with grog							
G	**N**	**Minimum**	**Maximum**	**Range**	**Mean**	**Standard Deviation**	**Variation Coefficient**
SiO2 (wt.%)	42	63.75	77.69	13.94	67.78	2.66	0.039
TiO2 (wt.%)	42	0.56	0.97	0.41	0.78	0.07	0.087
Al2O3 (wt.%)	42	14.48	20.11	5.63	18.17	1.22	0.067
Fe2O3 (wt.%)	42	2.29	5.86	3.57	4.58	0.69	0.151
FeO (wt.%)	31	0.72	4.18	3.46	1.84	0.87	0.476
MnO (wt.%)	42	0.02	0.07	0.05	0.04	0.01	0.289
MgO (wt.%)	42	0.66	4.11	3.45	1.92	0.54	0.280
CaO (wt.%)	42	1.24	7.78	6.54	3.29	1.91	0.579
Na2O (wt.%)	42	0.09	0.92	0.83	0.47	0.19	0.411
K2O (wt.%)	42	1.71	3.40	1.69	2.67	0.28	0.106
P2O5 (wt.%)	42	0.14	0.70	0.56	0.27	0.11	0.410
Ba (ppm)	42	442	988	546	693.1	124.8	0.180
Cr (ppm)	42	98	152	54	127.6	10.3	0.081
Cu (ppm)	42	29	57	28	42.2	6.0	0.142
Nb (ppm)	42	12	23	11	16.0	1.7	0.104
Ni (ppm)	42	58	108	50	73.3	9.9	0.135
Pb (ppm)	42	16	40	24	26.2	4.7	0.178
Rb (ppm)	42	96	186	90	154.9	15.0	0.097
Sr (ppm)	42	80	291	211	178.3	47.1	0.264
V (ppm)	42	90	151	61	130.5	13.8	0.106
Y (ppm)	42	17	35	18	25.5	4.0	0.155
Zn (ppm)	42	94	197	103	120.5	18.0	0.149
Zr (ppm)	42	107	252	145	155.0	32.0	0.207

10 - APPENDIX 10

Swiss Neolithic reference groups defined in the University of Fribourg by several authors (n: number of samples).

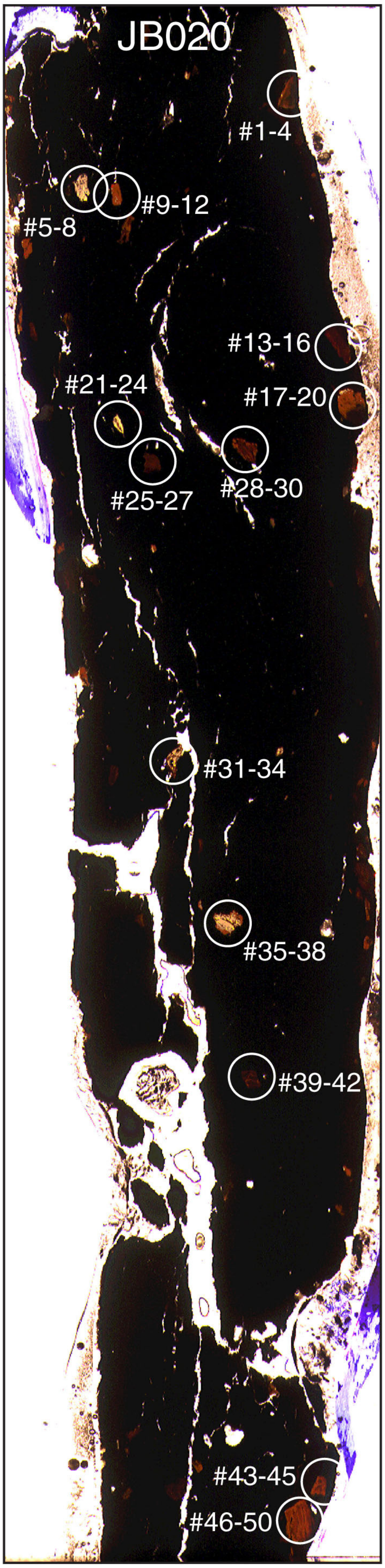
Station	Author	n	Description
Zürich, "Kleiner Hafner"	Schubert, 1987	85	12 ceramics of late Neolithic and 73 of early Neolithic
Vinelz, "alte Station NW"	Benghezal, 1994a	25	coarse and thin ceramics together with coarse and thin "Corded" ceramics of late Neolithic (2700 – 2400 BC)
Sutz, Rütte	Benghezal, 1994a	27	late Neolithic coarse and thin ceramics together with coarse and thin "Corded" ceramics
Auvernier – La Saunerie	Benghezal, 1994a	15	late Neolithic coarse and thin ceramics
Portalban	Benghezal, 1994a	39	late Neolithic coarse and thin ceramics together with coarse and thin "Corded" ceramics
	Di Pierro, 2002	50	Lüscherz Tradition (2950 – 2700 BC), "Corded Imitation" and "Corded true" ceramics (2700 – 2400 BC).
St. Blaise	Benghezal, 1994a	43	Neolithic coarse and thin ceramics (Horgen, 3250 – 2950 BC), Lüscherz, transitional period, Auvernier "Corded"
	Di Pierro, 2002	46	late Neolithic ceramics ("Corded", "Auvernier" and "Transition" ceramics)

11 - APPENDIX 11

Microprobe results for JB020, resp. for JB069 and emplacements of the microprobe measurements on the picture of the thin sections JB020 and JB069. The bone fragments are yellowish-brown (# for sampling numbers).

Atomic %	Na	F	Cl	Ca	Al	Si	P	S	Sr	Mg	Mn	Fe	O	Total
JB020#1	0.223	4.684	0.068	23.144	0.130	0.027	14.243	0.205	0.000	0.007	0.003	0.054	57.211	99.999
JB020#2	0.285	4.502	0.045	22.947	0.097	0.030	14.481	0.111	0.000	0.000	0.000	0.027	57.474	99.999
JB020#3	0.326	4.842	0.061	23.065	0.040	0.005	14.383	0.086	0.035	0.036	0.000	0.036	57.084	99.999
JB020#4	0.574	5.630	0.092	23.508	0.038	0.037	13.861	0.113	0.025	0.038	0.038	0.000	56.045	99.999
JB020#5	0.621	4.699	0.104	22.104	0.778	0.082	13.655	0.335	0.000	0.544	0.021	0.171	56.886	100.000
JB020#6	0.493	4.474	0.047	21.329	0.670	0.046	14.368	0.261	0.066	0.518	0.007	0.137	57.584	100.000
JB020#7	0.473	4.526	0.054	21.504	0.574	0.036	14.367	0.215	0.023	0.510	0.029	0.198	57.491	100.000
JB020#8	0.487	4.528	0.083	21.630	0.585	0.051	14.293	0.205	0.025	0.515	0.040	0.145	57.414	100.001
JB020#9	0.317	4.503	0.076	21.252	1.227	0.113	13.790	0.687	0.027	0.099	0.039	0.334	57.535	99.999
JB020#10	0.313	4.236	0.064	21.571	1.025	0.090	13.818	0.674	0.031	0.079	0.056	0.343	57.699	99.999
JB020#11	0.390	4.457	0.070	21.616	0.915	0.070	13.894	0.600	0.072	0.093	0.036	0.295	57.492	100.000
JB020#12	0.360	4.371	0.064	21.769	0.868	0.082	13.861	0.540	0.018	0.102	0.054	0.404	57.507	100.000
JB020#13	0.528	4.328	0.141	21.409	0.362	0.046	14.624	0.387	0.004	0.164	0.037	0.180	57.791	100.001
JB020#14	0.611	4.802	0.135	23.173	0.308	0.040	13.513	0.341	0.009	0.283	0.052	0.186	56.547	100.000
JB020#15	0.739	4.565	0.110	18.347	0.376	0.045	16.182	0.413	0.029	0.307	0.005	0.114	58.769	100.001
JB020#16	0.508	4.753	0.122	23.409	0.472	0.043	13.268	0.432	0.032	0.213	0.034	0.191	56.523	100.000
JB020#17	0.368	4.382	0.122	22.737	0.536	0.053	13.788	0.377	0.000	0.151	0.016	0.250	57.220	100.000
JB020#18	0.520	3.978	0.046	16.784	0.700	0.090	17.118	0.352	0.011	0.184	0.017	0.113	60.086	99.999
JB020#19	0.609	5.764	0.149	17.866	0.680	0.075	16.256	0.210	0.033	0.351	0.020	0.068	57.917	99.998
JB020#20	0.442	7.637	0.096	32.294	0.861	0.400	7.447	0.330	0.012	0.177	0.000	0.047	50.255	99.998
JB020#21	0.305	4.414	0.027	21.509	0.250	2.842	12.674	0.137	0.036	0.052	0.000	0.103	57.651	100.000
JB020#22	0.450	4.571	0.039	20.238	0.251	0.794	15.094	0.136	0.014	0.062	0.000	0.073	58.279	100.001
JB020#23	0.460	5.158	0.074	22.464	0.231	0.119	14.326	0.112	0.042	0.067	0.014	0.053	56.879	99.999
JB020#24	0.655	4.848	0.077	20.792	0.273	0.118	15.116	0.163	0.000	0.208	0.000	0.062	57.688	100.000
JB020#25	0.283	4.444	0.090	21.400	0.988	0.239	14.029	0.317	0.012	0.380	0.018	0.223	57.575	99.998
JB020#26	0.567	4.675	0.035	20.727	0.886	0.082	14.487	0.306	0.050	0.361	0.027	0.190	57.605	99.998
JB020#27	0.469	4.245	0.074	21.273	0.969	0.095	14.206	0.290	0.056	0.342	0.033	0.215	57.732	99.999
JB020#28	0.545	4.952	0.082	19.867	1.290	0.139	14.767	0.427	0.060	0.011	0.002	0.089	57.769	100.000
JB020#29	0.632	4.966	0.036	19.336	0.998	0.127	15.365	0.291	0.064	0.049	0.012	0.051	58.073	100.000
JB020#30	0.474	5.130	0.037	19.568	0.840	0.064	15.424	0.292	0.077	0.078	0.010	0.044	57.962	100.000
JB020#31	0.513	4.582	0.090	21.656	1.068	0.115	13.869	0.371	0.012	0.132	0.045	0.268	57.280	100.001
JB020#32	0.407	4.463	0.049	21.214	0.855	0.078	14.417	0.322	0.033	0.169	0.041	0.211	57.740	99.999
JB020#33	0.388	4.783	0.039	21.094	0.720	0.073	14.538	0.285	0.022	0.237	0.034	0.240	57.548	100.001
JB020#34	0.000	0.000	0.000	6.095	4.780	9.639	2.019	5.492	0.000	0.000	1.851	9.850	60.274	100.000
JB020#35	0.442	0.000	0.006	0.213	10.609	22.521	0.168	0.174	0.000	1.820	0.000	0.035	64.012	100.000
JB020#36	0.612	5.280	0.059	17.154	1.749	0.141	15.836	0.523	0.000	0.120	0.012	0.027	58.489	100.002
JB020#37	0.720	5.174	0.189	18.093	0.917	0.172	15.682	0.697	0.000	0.106	0.013	0.014	58.223	100.000
JB020#38	0.684	5.037	0.044	16.455	0.939	0.222	16.887	0.323	0.135	0.083	0.000	0.000	59.191	100.000
JB020#39	1.250	0.363	0.338	0.943	19.253	2.355	9.578	0.665	0.089	2.107	0.375	0.015	62.668	99.999
JB020#40	0.484	4.626	0.013	19.069	0.915	0.406	15.106	0.379	0.046	0.442	0.004	0.159	58.350	99.999
JB020#41	0.510	4.994	0.160	19.532	0.960	0.856	14.396	0.373	0.010	0.397	0.019	0.135	57.658	100.000
JB020#42	0.539	4.756	0.059	20.649	0.885	0.111	14.634	0.283	0.020	0.265	0.004	0.149	57.647	100.001
JB020#43	0.598	4.562	0.137	19.323	0.626	0.076	15.698	0.294	0.046	0.061	0.024	0.114	58.441	100.000
JB020#44	0.647	5.177	0.123	22.286	0.647	0.057	13.954	0.220	0.015	0.085	0.020	0.140	56.629	100.000
JB020#45	0.664	4.999	0.149	20.164	0.586	0.074	15.171	0.304	0.000	0.102	0.038	0.063	57.687	100.001
JB020#46	0.320	4.605	0.097	22.713	0.465	0.049	14.102	0.199	0.019	0.060	0.014	0.147	57.210	100.000
JB020#47	0.351	5.136	0.080	25.604	0.409	0.058	12.255	0.256	0.057	0.132	0.026	0.186	55.451	100.001
JB020#48	0.387	5.025	0.080	21.090	0.426	0.056	14.870	0.311	0.000	0.107	0.016	0.115	57.517	100.000
JB020#49	0.499	4.897	0.072	19.943	0.502	0.069	15.376	0.380	0.032	0.112	0.018	0.068	58.030	99.998
JB020#50	0.334	4.690	0.112	22.696	0.488	0.051	13.986	0.258	0.018	0.076	0.043	0.168	57.081	100.001
JB069#51	0.415	4.736	0.093	22.942	0.399	0.040	13.987	0.227	0.000	0.092	0.013	0.059	56.998	100.001
JB069#52	0.422	4.641	0.050	23.058	0.319	0.038	14.101	0.143	0.024	0.050	0.001	0.029	57.123	99.999
JB069#53	0.437	4.580	0.055	23.134	0.312	0.038	14.073	0.120	0.009	0.078	0.019	0.020	57.126	100.001
JB069#54	0.279	4.638	0.091	23.244	0.466	0.109	13.829	0.167	0.002	0.084	0.027	0.054	57.010	100.000
JB069#55	0.338	4.529	0.074	23.016	0.440	0.058	13.968	0.164	0.024	0.185	0.013	0.029	57.161	99.999
JB069#56	0.333	4.604	0.087	23.041	0.407	0.045	14.028	0.154	0.002	0.122	0.027	0.032	57.120	100.002
JB069#57	0.344	4.733	0.100	22.869	0.397	0.045	14.092	0.166	0.023	0.116	0.017	0.034	57.063	99.999
JB069#58	0.299	5.119	0.069	21.140	0.496	0.166	14.766	0.111	0.000	0.396	0.018	0.050	57.372	100.002
JB069#59	0.501	4.675	0.067	20.687	0.506	0.111	14.974	0.198	0.044	0.331	0.025	0.051	57.830	100.000
JB069#60	0.714	4.692	0.023	17.904	0.671	0.414	15.961	0.465	0.045	0.246	0.000	0.000	58.864	99.999
JB069#61	0.721	5.566	0.045	23.515	0.756	0.443	12.450	0.491	0.000	0.285	0.019	0.104	55.605	100.000
JB069#62	0.402	0.835	0.086	4.677	7.458	14.857	6.177	0.287	0.000	1.578	0.005	0.362	63.277	100.001
JB069#63	0.655	4.611	0.067	20.746	0.376	0.131	15.073	0.221	0.012	0.174	0.002	0.030	57.902	100.000
JB069#64	0.685	5.863	0.099	23.193	0.354	0.120	13.319	0.297	0.015	0.372	0.000	0.036	55.644	99.997
JB069#65	0.708	7.130	0.066	22.806	0.328	0.184	13.375	0.158	0.051	0.436	0.008	0.038	54.711	99.999
JB069#66	0.121	0.993	0.037	7.567	4.928	17.893	4.084	0.099	0.000	1.037	0.000	0.751	62.489	99.999
JB069#67	0.511	4.895	0.114	24.024	0.313	0.035	13.425	0.168	0.042	0.072	0.000	0.036	56.364	99.999
JB069#68	0.431	4.734	0.119	22.428	0.407	0.079	14.208	0.198	0.020	0.152	0.014	0.062	57.148	100.000
JB069#69	0.299	4.926	0.091	22.569	0.295	0.101	14.272	0.095	0.000	0.257	0.023	0.033	57.039	100.000
JB069#70	0.380	4.681	0.100	22.629	0.296	0.102	14.240	0.156	0.000	0.166	0.021	0.026	57.203	100.000
JB069#71	0.252	4.392	0.104	21.385	0.485	1.211	13.830	0.105	0.042	0.344	0.031	0.102	57.717	100.000
JB069#72	0.478	4.822	0.134	22.780	0.420	0.133	13.963	0.195	0.015	0.080	0.011	0.066	56.905	100.002
JB069#73	0.514	4.633	0.076	21.947	0.346	0.101	14.510	0.248	0.000	0.087	0.001	0.054	57.484	100.001
JB069#74	0.426	4.817	0.152	22.920	0.446	0.190	13.813	0.188	0.000	0.134	0.008	0.078	56.827	99.999
JB069#75	0.503	4.693	0.076	22.265	0.381	0.080	14.298	0.172	0.040	0.177	0.029	0.042	57.242	99.998
JB069#76	0.307	3.291	0.627	16.463	0.998	4.898	13.298	0.191	0.000	0.097	0.000	0.078	59.752	100.000
JB069#77	0.234	0.568	1.008	3.864	7.531	19.837	2.275	0.297	0.031	1.105	0.000	0.834	62.416	100.000
JB069#78	0.660	5.148	0.030	21.990	0.449	0.137	14.256	0.149	0.051	0.218	0.000	0.013	56.899	100.000
JB069#79	0.740	5.037	0.052	20.905	0.447	0.146	14.877	0.149	0.026	0.167	0.000	0.040	57.415	100.001
JB069#80	0.491	4.719	0.067	22.389	0.411	0.110	14.279	0.133	0.007	0.134	0.010	0.028	57.222	100.000
JB069#81	0.525	4.785	0.054	22.764	0.364	0.107	14.108	0.160	0.000	0.043	0.000	0.043	57.045	99.998
JB069#82	0.818	5.698	0.031	23.832	0.367	0.127	13.209	0.121	0.000	0.112	0.014	0.049	55.621	99.999
JB069#83	0.595	4.783	0.048	20.912	0.289	0.079	15.194	0.149	0.014	0.107	0.000	0.019	57.810	99.999
JB069#84	1.302	4.046	0.016	16.555	1.270	0.591	15.875	0.406	0.026	0.491	0.020	0.052	59.351	100.001
JB069#85	0.459	2.826	0.739	5.798	5.358	18.375	3.440	1.123	0.000	0.719	0.043	0.240	60.880	100.000
JB069#86	0.464	4.725	0.138	22.782	0.440	0.038	14.100	0.154	0.025	0.061	0.000	0.056	57.017	100.000
JB069#87	0.455	4.764	0.083	22.799	0.359	0.044	14.167	0.152	0.015	0.056	0.022	0.020	57.064	100.000
JB069#88	0.499	4.574	0.067	21.159	0.380	0.037	15.120	0.124	0.010	0.094	0.000	0.023	57.910	99.997
JB069#89	0.509	4.607	0.096	23.057	0.358	0.040	13.992	0.127	0.023	0.083	0.024	0.072	57.012	100.000
JB069#90	0.389	4.538	0.078	23.100	0.383	0.033	14.021	0.159	0.019	0.090	0.010	0.030	57.148	99.998
JB069#91	0.429	4.505	0.071	23.171	0.382	0.021	13.983	0.144	0.000	0.094	0.038	0.034	57.126	99.998
JB069#92	0.356	4.655	0.095	22.945	0.360	0.026	14.081	0.159	0.031	0.158	0.002	0.041	57.091	100.000
JB069#93	0.291	4.487	0.064	22.159	0.494	0.096	14.418	0.179	0.015	0.123	0.013	0.074	57.588	100.001
JB069#94	0.387	4.684	0.067	20.980	0.436	0.088	14.992	0.272	0.000	0.163	0.010	0.048	57.873	100.000
JB069#95	0.414	4.816	0.101	23.083	0.288	0.100	13.969	0.095	0.029	0.200	0.000	0.051	56.855	100.001
JB069#96	0.592	4.448	0.088	22.452	0.454	0.107	14.195	0.158	0.014	0.093	0.018	0.040	57.342	100.001
JB069#97	0.713	4.566	0.112	20.320	0.464	0.262	15.228	0.162	0.000	0.073	0.000	0.038	58.062	100.000
JB069#98	0.431	3.669	0.119	19.384	1.444	3.279	12.319	0.161	0.006	0.322	0.023	0.472	58.371	100.000
JB069#99	0.744	4.480	0.097	18.672	0.484	0.129	16.236	0.237	0.000	0.056	0.004	0.000	58.862	100.001
JB069#100	0.561	4.689	0.074	22.543	0.455	0.080	14.124	0.185	0.002	0.102	0.004	0.054	57.126	99.999
JB069#101	0.386	4.553	0.076	23.123	0.429	0.057	13.926	0.168	0.016	0.071	0.027	0.071	57.096	99.999
JB069#102	0.478	4.424	0.095	23.104	0.398	0.052	13.984	0.170	0.004	0.035	0.023	0.043	57.190	100.000
JB069#103	0.379	4.713	0.074	23.133	0.442	0.065	13.898	0.168	0.017	0.082	0.002	0.062	56.965	100.000

Weight %	Na	F	Cl	Ca	Al	Si	P	S	Sr	Mg	Mn	Fe	O	Total
JB020#1	0.135	2.343	0.063	24.425	0.093	0.02	11.616	0.173	0	0.005	0.004	0.08	24.101	63.058
JB020#2	0.169	2.206	0.041	23.725	0.067	0.022	11.57	0.092	0	0	0	0.039	23.72	61.651
JB020#3	0.199	2.443	0.058	24.546	0.029	0.003	11.829	0.073	0.082	0.023	0	0.053	24.249	63.587
JB020#4	0.218	1.764	0.054	15.534	0.017	0.017	7.079	0.06	0.036	0.015	0.034	0	14.784	39.612
JB020#5	0.219	1.367	0.057	13.569	0.322	0.035	6.478	0.164	0	0.202	0.018	0.146	13.939	36.516
JB020#6	0.252	1.889	0.037	19.002	0.402	0.029	9.892	0.186	0.128	0.28	0.009	0.17	20.478	52.754
JB020#7	0.244	1.928	0.043	19.325	0.347	0.023	9.978	0.155	0.046	0.278	0.035	0.248	20.624	53.274
JB020#8	0.258	1.985	0.068	20.006	0.364	0.033	10.217	0.152	0.05	0.289	0.05	0.187	21.198	54.857
JB020#9	0.169	1.979	0.063	19.706	0.766	0.073	9.881	0.51	0.055	0.056	0.05	0.431	21.296	55.035
JB020#10	0.171	1.914	0.054	20.566	0.658	0.06	10.181	0.514	0.064	0.046	0.074	0.455	21.959	56.716
JB020#11	0.201	1.899	0.056	19.432	0.554	0.044	9.653	0.432	0.142	0.051	0.044	0.37	20.631	53.509
JB020#12	0.191	1.91	0.052	20.072	0.539	0.053	9.876	0.398	0.037	0.057	0.068	0.519	21.166	54.938
JB020#13	0.3	2.035	0.124	21.235	0.241	0.032	11.21	0.307	0.009	0.099	0.05	0.248	22.882	58.772
JB020#14	0.318	2.064	0.108	21.008	0.188	0.025	9.467	0.248	0.018	0.155	0.065	0.235	20.464	54.363
JB020#15	0.303	1.547	0.07	13.119	0.181	0.023	8.943	0.236	0.045	0.133	0.004	0.113	16.775	41.492
JB020#16	0.268	2.075	0.099	21.561	0.293	0.028	9.444	0.319	0.064	0.119	0.043	0.245	20.782	55.34
JB020#17	0.152	1.502	0.078	16.441	0.261	0.027	7.705	0.218	0	0.066	0.016	0.252	16.517	43.235
JB020#18	0.114	0.718	0.016	6.391	0.18	0.024	5.038	0.107	0.009	0.043	0.009	0.06	9.133	21.842
JB020#19	0.112	0.876	0.042	5.725	0.147	0.017	4.026	0.054	0.023	0.068	0.009	0.031	7.408	18.538
JB020#20	0.087	1.249	0.029	11.14	0.2	0.097	1.985	0.091	0.009	0.037	0	0.023	6.92	21.867
JB020#21	0.173	2.067	0.023	21.254	0.167	1.968	9.678	0.108	0.077	0.031	0	0.141	22.739	58.426
JB020#22	0.195	1.632	0.026	15.25	0.127	0.419	8.79	0.082	0.023	0.028	0	0.076	17.529	44.177
JB020#23	0.196	1.819	0.049	16.713	0.116	0.062	8.237	0.067	0.068	0.03	0.015	0.055	16.892	44.319
JB020#24	0.247	1.512	0.045	13.683	0.121	0.054	7.688	0.086	0	0.083	0	0.057	15.155	38.731
JB020#25	0.137	1.774	0.067	18.021	0.56	0.141	9.13	0.214	0.023	0.194	0.021	0.262	19.354	49.898
JB020#26	0.258	1.754	0.025	16.408	0.472	0.045	8.863	0.194	0.087	0.174	0.03	0.21	18.203	46.723
JB020#27	0.242	1.812	0.059	19.158	0.588	0.06	9.887	0.209	0.11	0.187	0.041	0.27	20.754	53.377
JB020#28	0.195	1.465	0.046	12.404	0.542	0.061	7.125	0.213	0.082	0.004	0.001	0.078	14.397	36.613
JB020#29	0.201	1.304	0.018	10.71	0.372	0.049	6.577	0.129	0.078	0.016	0.009	0.039	12.839	32.341
JB020#30	0.177	1.583	0.021	12.741	0.368	0.029	7.761	0.152	0.109	0.031	0.009	0.039	15.064	38.084
JB020#31	0.206	1.524	0.056	15.193	0.504	0.057	7.519	0.208	0.018	0.056	0.043	0.262	16.041	41.687
JB020#32	0.195	1.765	0.036	17.699	0.48	0.045	9.296	0.215	0.059	0.086	0.047	0.246	19.23	49.399
JB020#33	0.193	1.96	0.03	18.237	0.419	0.044	9.713	0.197	0.041	0.124	0.04	0.289	19.86	51.147
JB020#34	0	0	0	0.014	0.007	0.015	0.003	0.01	0	0	0.006	0.031	0.054	0.14
JB020#35	0.068	0	0.001	0.057	1.907	4.213	0.035	0.037	0	0.295	0	0.013	6.821	13.447
JB020#36	0.097	0.688	0.014	4.716	0.324	0.027	3.364	0.115	0	0.02	0.004	0.01	6.418	15.797
JB020#37	0.134	0.796	0.054	5.874	0.2	0.039	3.934	0.181	0	0.021	0.006	0.006	7.545	18.79
JB020#38	0.133	0.808	0.013	5.572	0.214	0.053	4.419	0.088	0.1	0.017	0	0	8.001	19.418
JB020#39	0.18	0.043	0.075	0.236	3.246	0.413	1.854	0.133	0.049	0.32	0.129	0.005	6.265	12.948
JB020#40	0.166	1.309	0.007	11.386	0.368	0.17	6.97	0.181	0.059	0.16	0.003	0.133	13.907	34.819
JB020#41	0.119	0.961	0.057	7.932	0.263	0.244	4.518	0.121	0.009	0.098	0.01	0.076	9.347	23.755
JB020#42	0.23	1.677	0.039	15.358	0.443	0.058	8.412	0.168	0.032	0.119	0.004	0.154	17.116	43.81
JB020#43	0.234	1.476	0.083	13.189	0.288	0.036	8.281	0.161	0.068	0.025	0.022	0.108	15.923	39.894
JB020#44	0.264	1.746	0.078	15.852	0.31	0.028	7.671	0.125	0.023	0.037	0.019	0.139	16.079	42.371
JB020#45	0.271	1.687	0.094	14.359	0.281	0.037	8.349	0.173	0	0.044	0.037	0.062	16.398	41.792
JB020#46	0.203	2.422	0.095	25.2	0.348	0.038	12.092	0.176	0.046	0.041	0.021	0.228	25.338	66.248
JB020#47	0.184	2.224	0.064	23.393	0.252	0.037	8.653	0.187	0.114	0.073	0.032	0.236	20.223	55.672
JB020#48	0.181	1.949	0.058	17.253	0.235	0.032	9.401	0.204	0	0.053	0.018	0.131	18.783	48.298
JB020#49	0.185	1.499	0.041	12.876	0.218	0.031	7.672	0.196	0.045	0.044	0.016	0.061	14.955	37.839
JB020#50	0.205	2.381	0.106	24.308	0.352	0.038	11.576	0.221	0.041	0.049	0.064	0.251	24.404	63.996
JB069#51	0.257	2.426	0.088	24.793	0.29	0.03	11.681	0.196	0	0.061	0.019	0.089	24.588	64.518
JB069#52	0.27	2.455	0.049	25.738	0.24	0.03	12.163	0.128	0.059	0.034	0.001	0.045	25.451	66.663
JB069#53	0.28	2.427	0.054	25.86	0.235	0.03	12.157	0.107	0.023	0.053	0.03	0.031	25.491	66.778
JB069#54	0.183	2.508	0.092	26.522	0.358	0.087	12.194	0.152	0.005	0.058	0.043	0.087	25.966	68.255
JB069#55	0.218	2.414	0.073	25.889	0.333	0.046	12.142	0.147	0.059	0.127	0.021	0.046	25.666	67.181
JB069#56	0.216	2.465	0.087	26.029	0.309	0.035	12.246	0.139	0.005	0.083	0.041	0.05	25.757	67.462
JB069#57	0.219	2.492	0.098	25.406	0.297	0.035	12.098	0.147	0.055	0.078	0.027	0.052	25.305	66.309
JB069#58	0.133	1.879	0.047	16.372	0.259	0.09	8.837	0.069	0	0.186	0.019	0.054	17.736	45.681
JB069#59	0.175	1.351	0.036	12.609	0.208	0.048	7.054	0.097	0.059	0.122	0.021	0.043	14.071	35.894
JB069#60	0.225	1.222	0.011	9.841	0.248	0.159	6.78	0.205	0.055	0.082	0	0	12.915	31.743
JB069#61	0.207	1.319	0.02	11.754	0.254	0.155	4.809	0.196	0	0.086	0.013	0.073	11.095	29.981
JB069#62	0.106	0.182	0.035	2.152	2.31	4.79	2.196	0.106	0	0.441	0.003	0.232	11.623	24.176
JB069#63	0.255	1.483	0.04	14.073	0.172	0.062	7.902	0.12	0.018	0.071	0.001	0.028	15.679	39.904
JB069#64	0.217	1.535	0.048	12.81	0.132	0.047	5.685	0.131	0.018	0.125	0	0.028	12.268	33.044
JB069#65	0.166	1.38	0.024	9.309	0.09	0.053	4.219	0.052	0.046	0.108	0.004	0.022	8.915	24.388
JB069#66	0.072	0.489	0.034	7.859	3.446	13.022	3.278	0.082	0	0.653	0	1.087	25.905	55.927
JB069#67	0.274	2.165	0.094	22.42	0.197	0.023	9.682	0.125	0.087	0.041	0	0.047	20.997	56.152
JB069#68	0.227	2.06	0.096	20.588	0.251	0.051	10.079	0.145	0.041	0.085	0.018	0.079	20.941	54.661
JB069#69	0.162	2.207	0.076	21.329	0.187	0.067	10.424	0.072	0	0.147	0.03	0.043	21.518	56.262
JB069#70	0.219	2.231	0.089	22.758	0.201	0.072	11.067	0.125	0	0.101	0.03	0.037	22.964	59.894
JB069#71	0.13	1.882	0.083	19.334	0.295	0.767	9.663	0.076	0.082	0.189	0.038	0.129	20.83	53.498
JB069#72	0.27	2.256	0.117	22.483	0.279	0.092	10.65	0.154	0.032	0.048	0.015	0.09	22.419	58.905
JB069#73	0.292	2.174	0.067	21.728	0.231	0.07	11.102	0.196	0	0.052	0.001	0.074	22.717	58.704
JB069#74	0.219	2.051	0.121	20.583	0.27	0.12	9.586	0.135	0	0.073	0.01	0.098	20.371	53.637
JB069#75	0.288	2.22	0.067	22.216	0.256	0.056	11.025	0.137	0.087	0.107	0.04	0.059	22.799	59.357
JB069#76	0.054	0.477	0.17	5.037	0.205	1.05	3.144	0.047	0	0.018	0	0.033	7.298	17.533
JB069#77	0.029	0.057	0.19	0.823	1.08	2.962	0.375	0.051	0.015	0.143	0	0.248	5.309	11.282
JB069#78	0.248	1.599	0.018	14.413	0.198	0.063	7.221	0.078	0.073	0.087	0	0.011	14.887	38.896
JB069#79	0.272	1.529	0.029	13.387	0.193	0.065	7.362	0.076	0.036	0.065	0	0.036	14.676	37.726
JB069#80	0.25	1.989	0.053	19.905	0.246	0.069	9.81	0.094	0.014	0.072	0.012	0.034	20.307	52.855
JB069#81	0.306	2.309	0.049	23.178	0.25	0.076	11.101	0.13	0	0.027	0	0.061	23.184	60.671
JB069#82	0.315	1.81	0.019	15.974	0.165	0.06	6.842	0.065	0	0.045	0.013	0.046	14.882	40.236
JB069#83	0.302	2.004	0.038	18.485	0.172	0.049	10.379	0.106	0.027	0.057	0	0.023	20.397	52.039
JB069#84	0.357	0.917	0.007	7.917	0.409	0.198	5.867	0.155	0.028	0.142	0.013	0.034	11.33	27.374
JB069#85	0.093	0.476	0.232	2.059	1.281	4.572	0.944	0.319	0	0.155	0.021	0.119	8.628	18.899
JB069#86	0.262	2.2	0.12	22.38	0.291	0.026	10.704	0.121	0.055	0.036	0	0.076	22.358	58.629
JB069#87	0.255	2.204	0.072	22.253	0.236	0.03	10.686	0.119	0.032	0.033	0.03	0.027	22.233	58.21
JB069#88	0.235	1.776	0.049	17.333	0.21	0.021	9.572	0.082	0.018	0.047	0	0.027	18.936	48.306
JB069#89	0.297	2.222	0.087	23.467	0.245	0.028	11.005	0.104	0.05	0.052	0.034	0.102	23.162	60.855
JB069#90	0.24	2.311	0.075	24.816	0.277	0.025	11.64	0.137	0.046	0.059	0.015	0.045	24.507	64.193
JB069#91	0.265	2.304	0.067	25.001	0.278	0.016	11.66	0.124	0	0.062	0.056	0.051	24.604	64.488
JB069#92	0.223	2.407	0.091	25.032	0.264	0.02	11.871	0.138	0.073	0.105	0.003	0.062	24.862	65.151
JB069#93	0.158	2.009	0.053	20.928	0.314	0.064	10.523	0.135	0.032	0.07	0.016	0.097	21.711	56.11
JB069#94	0.209	2.086	0.055	19.711	0.276	0.058	10.886	0.204	0	0.093	0.013	0.062	21.705	55.358
JB069#95	0.219	2.104	0.083	21.274	0.179	0.064	9.949	0.07	0.059	0.112	0	0.065	20.916	55.094
JB069#96	0.302	1.874	0.069	19.96	0.271	0.067	9.753	0.112	0.027	0.05	0.022	0.05	20.349	52.906
JB069#97	0.289	1.528	0.07	14.344	0.22	0.13	8.307	0.092	0	0.031	0	0.037	16.36	41.408
JB069#98	0.187	1.311	0.079	14.615	0.733	1.732	7.178	0.097	0.009	0.147	0.024	0.496	17.568	44.176
JB069#99	0.258	1.284	0.052	11.287	0.197	0.055	7.585	0.114	0	0.02	0.003	0	14.204	35.059
JB069#100	0.297	2.051	0.061	20.803	0.283	0.052	10.073	0.136	0.005	0.057	0.004	0.07	21.044	54.936
JB069#101	0.254	2.477	0.077	26.542	0.332	0.046	12.353	0.155	0.041	0.049	0.043	0.113	26.16	68.642
JB069#102	0.289	2.208	0.089	24.329	0.282	0.038	11.379	0.144	0.009	0.022	0.033	0.064	24.039	62.925
JB069#103	0.239	2.455	0.072	25.423	0.327	0.05	11.804	0.148	0.041	0.055	0.003	0.096	24.991	65.704


JB020
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JB069
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CURRICULUM VITAE

Birthdate: August 28th, 1974
Citizenship: Swiss

EDUCATION

1993: High school diploma (Modern Languages) in Yverdon-les Bains (Switzerland).

1993-1999: Diploma studies in Earth Sciences at the University of Lausanne, Switzerland.

Diploma thesis under the direction of Prof. A. Parriaux, EPFL and "Privat-Docent" (Equivalent to Senior Lecturer) P. Thélin, UNIL: Étude géologique du tunnel Rail 2000 de la Raisse (près Concise, VD, CH) et étude minéralogique de ses remplissages karstiques. (Grade double 5.5 on 6)

1999-2003: PhD in archaeometry under the direction of Prof. M. Maggetti at the University of Fribourg (Switzerland). "Archaeometrical study (petrography, mineralogy and chemistry) of the Neolithic Ceramic of Arbon-Bleiche 3, (Canton of Thurgau, Switzerland)".

PROFESSIONAL EXPERIENCE

1996-1999:Part-time collaborator in the Laboratory of Geology at the EPFL in Lausanne.

1999-2001: Teaching assistant of Igneous Petrology at the Institute of Mineralogy and Petrography, University of Fribourg.

1999-2001: Teaching assistant of General Mineralogy and Macroscopy of Igneous and Metamorphic rocks at the Institute of Mineralogy and Petrography, University of Fribourg.

1999-2002: Assistant of Archaeometrical courses at the Institute of Mineralogy and Petrography, University of Fribourg.

2001: Preparation of EMAC'01 (European Meeting of Ancient Ceramics) held in Fribourg, Switzerland.

2000-2003: Responsibility on PC computers at the Institute of Mineralogy and Petrography, University of Fribourg.

1999-2002: Responsibility on X-ray diffractometer Philips PW 1800 at the Institute of Mineralogy and Petrography, University of Fribourg.

2003: Assistant on X-ray tomography at the Institute of Mineralogy and Petrography, University of Lausanne.

2003-2004: Assistant on ionic chromatography at the Institute of Mineralogy and Petrography, University of Lausanne.

PUBLICATIONS

BONZON, J. (1999): Étude géologique du tunnel Rail 2000 de la Raisse (près Concise, VD, CH) et étude minéralogique de ses remplissages karstiques. (unpublished)

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