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ABSTRACT

Ancient Concretes and Mortars of Selinous

Preliminary Results of the Project CaF »Concretes as Floors«

Frédéric Mège

The project CaF »Concretes as Floors« is an archaeological study of concrete floors carried out in Selinous and Megara Hyblaia in 2019–2020. Petrographic analyses and C-14 dating were at the heart of the investigations, meant to accurately determine the physicochemical properties of the floors and their prospective dates. One type of floor, the ›broken terracotta concrete/mortar‹ (BTC/BTM), most appreciated in the Antiquity, has been particularly investigated during the project because the technique's developments are still unclear. This paper focuses on the results in Selinous. There, the analyses' results have highlighted peculiar construction methods for the BTC/BTM floors, which could be explained by local technical traditions. They have also allowed refining their chronological framing, which turns out to be definitely wider than the sole Punic period of Selinous. Finally, their modes of utilisation in different living spaces, according to their physical properties, have been further evaluated.

KEYWORDS

Selinous, concrete floors, petrography, C-14 dating

FRÉDÉRIC MÈGE

Ancient Concretes and Mortars of Selinous

Preliminary Results of the Project CaF »Concretes as Floors«

Introduction

1 The project CaF is an archaeological study of concrete floors in Ancient Sicily[1], based on petrographic analyses and radiocarbon dating of representative samples coming from two archaeological sites: Selinous and Megara Hyblaia[2]. The present communication intends to present preliminary results on Selinous' floors[3].

2 As a whole, concretes can be defined as mixes of aggregates bounded with lime and water, also named ›mortars‹ when the mix is finer. The project CaF is particularly focused on a technique, named hereafter ›broken terracotta concrete/mortar‹ (BTC/BTM) floors[4], which main aggregate is made of broken pieces of terracotta. This declination is known under many different names in the archaeological literature, from the Latin ›opus signinum‹ to modern terms such as ›cocciopesto‹ or ›cement‹[5]. Most of the BTC/BTM have several layers that are traditionally named after Vitruvius (de arch. 7, 1, 1–3), whose words happen to be particularly suited to describe these floors[6]: the ›nucleus‹ is the upper layer, the visible one; the ›rudus‹ is the lower layer, also named preparation layer; the third one, named ›statumen‹, is the foundation layer and is not presented here, for it is not a concrete but a layer of packed earth and rubbles. This tech-

1 Funded by the *Deutsche Forschungsgemeinschaft* (DFG) and hosted by the *Institut für Klassische Archäologie* (IKA) of the *Freie Universität Berlin* (FUB), it started on 1 April 2019 and lasted until 31 December 2020.

2 Morgantina was initially supposed to be part of the investigated sites but was eventually not taken into account, due to unexpected administrative issues.

3 Only these have been thoroughly investigated so far. Analyses were still running at the time this article was written. A joint article about Selinous and Megara, co-written by all the project's stakeholders, will be submitted in 2022, with a full account on petrographic and dating analyses.

4 Terms already proposed in Mège 2019 so as to define as accurately as possible the nature of these floors and to avoid terminological confusions.

5 ›opus signinum‹ is a term interpreted from Vitruvius' accounts (de arch. 8, 7, 14). The Italian word ›cocciopesto‹ is actually quite close to our BTC/BTM, while ›cement‹ is an improper word that should be discarded (see also Mezzolani 2000, 216 note 13). This floating terminology reflects the complexity of the topic as it has been highlighted by several scholars (Mège 2021, 58–60; Mège 2019, 75 f.; Grandi – Guidobaldi 2006; Vassal 2006, 24–27; Tang 2005, 181–191; Mezzolani 2000, 211 note 1).

6 As already assessed, for instance in Mège 2021, 58–60; Mège 2019, 75 f.

nique, because of its above described physical specificities, was praised for its efficiency in terms of resistance and impermeability. While the origins of concretes and mortars can be safely located in the Near East[7], the invention of the BTC/BTM by the Carthaginians remains questionable[8]. However, it would make sense to suppose that the technique of concrete making initially came with the Phoenicians as they settled down in the western Mediterranean during the 8th cent. B.C.[9]: there, among the Punic populations of North Africa, it could have evolved later into BTC/BTM[10]. The Punic origin of BTC/BTM also appears to be confirmed by the Latin expression ›pauimenta poenica‹, attributed to Cato the Elder[11]. What is more, the archaeological data point out to the same direction. As a matter of fact, the earliest documented instances of BTC/BTM floors have been discovered in Punic northern Africa, particularly in 4th cent. B.C. contexts of Carthage and Kerkouane[12] and in western Sicily, at Selinous, during the Punic occupation of the city, ca. 340–250 B.C.[13]. At present, the available data suggest that the origin of the BTC/BTM floors took place in a wider Punic eparchia, which extended over North Africa and western Sicily. From there, this technique most likely spread to the rest of Sicily and to the western Mediterranean[14]. Actually, in the central and eastern regions of Sicily, at Morgantina, Megara Hyblaia or Syracuse, the chronology of BTC floors points out to the second half of the 3rd cent. B.C., may it be in bathing complexes[15] or somewhat later in domestic contexts[16]. Looking outside Sicily, in southern Italy, it turns out that the BTC floors appeared from the early 3rd cent. B.C., with a greatest period of diffusion in the 2nd cent. B.C. particularly at Pompeii[17]. Looking further afield, the situation is quite the same in Sardinia and Spain, where all the BTC floors should be linked to the Roman domination that started in both regions during the last quarter of the 3rd cent. B.C.[18]. Therefore, whereas the BTC/BTM can be confidently seen as a technical phenomenon

7 According in particular to investigations in Anatolia, a basic technique involving a pozzolanic reaction (see definition here in note 33) was used from the Neolithic (Hauptmann – Yalcin 2001). In the late Bronze Age, in Cyprus, an intentional and more sophisticated use of pozzolanic materials has been documented (Theodoridou et al. 2013). The earliest documented concretes are the coatings of cisterns in Phoenicia and Palestine, dating back to the 10th cent. B.C. (Vassal 2006, 34). Afterwards, concretes and mortars have been utilized, particularly in Greece, as floors and wall plasters, from the mid-5th cent. B.C. onwards in public buildings (Olympia, Greek Baths: Mallwitz 1972, 270. – Dipylon/Kerameikos, Baths: Greco 2014a, 1315 f.) and slightly later in domestic contexts (Olynthus: Robinson – Mylonas 1946, 289). – See also the use of mortars in cisterns that appeared during the 5th – 3rd cent. B.C. in different Punic settlements of the central Mediterranean: Schön 2020; Schön 2019.

8 For the different alleged origins, see Mezzolani 2000, 217 note 17. 218 notes 18 and 19 (with references). – See also: Joly 1997, 33 f.; Dunbabin 1994, 30.

9 For instance: Fumadó Ortega 2019, 170 f.; Vassal 2006, 105 – Nevertheless, it has also been argued that the concrete/mortar know-how was passed on by the Greeks to the Punics, rather than considering a Phoenician/Punic filiation: see for instance Prados Martínez 2007, 18. – See also note 19 here.

10 Wall plasters made of broken/crushed terracotta could be well considered as having preceded the development of BTC/BTM floors (Prados Martínez 2007, 28).

11 This alleged quotation is only known in a much later transcription, ›The Lexicon of Festus‹ (Bruneau 1982, 639 f.). According to Ph. Bruneau, this expression attributed to Cato could simply mean that »de son temps, l'usage des pavements était récent à Rome et pouvait passer pour un apport punique«. He also specifies that by ›Punic‹, the rhetorician could just as well mean North Africa and Sicily as a whole (Bruneau 1982, 653 f.) – On ›pauimenta poenica‹, see also Mezzolani 2000, 218 note 21. 218 f. note 22. – For a discussion on various Latin terms, see Mezzolani 2000, 217 note 15.

12 Tang 2005, 89–96 (with references); Dunbabin 1994, 38 (with references); Morel 1969, 515 f.

13 Helas 2011, 64–69.

14 Mège 2021, 243–250; Mège 2019, 82–84; Tang 2015, 42; Mezzolani 2000, 218 note 20.

15 Morgantina: Lucore 2018, 340; Lucore 2013, 154. 160. – Megara Hyblaia: Tréziny 2018, 224–233. – Syracuse: Broise 1994; Cultrera 1938, 300.

16 Mège 2019, 84 f.; Tsakirgis 1990, 441; Gentili 1956, 99–103; Gentili 1951, 281 f. 292 f.; Orsi 1915, 191.

17 Vassal 2006, 43; Coarelli – Pesando 2006, 104. 150. 221; Mezzolani 2000, 220 note 25; Baldassarre 1997, 523–530; De Cazanove 1996, 901–941; Dunbabin 1994, 31 note 15.

18 Tréziny 2006, 172–174. 172 note 52; Tang 2015, 35–37; Mezzolani 2000, 221–222. 221 note 21– same observation for the BTC/BTM *with* tesserae: Tang 2018, 14.

that first appeared in the western Mediterranean[19], the available archaeological data show that Sicily represents an interesting case-study as regards the early developments and the subsequent diffusion of the technique. For this reason, the project CaF has focused investigations on Sicilian BTC/BTM floors.

The Investigations: Methods and Goals

3 In Sicily, works dedicated to the BTC/BTM floors have been particularly pursued in Selinous, Megara Hyblaia and Morgantina[20]. Yet, these studies, like many others[21], lack application of scientific techniques such as petrographic observations on thin sections and physicochemical analyses – a crucial factor for understanding of the BTC/BTM as a technological product[22]. Now these methods of investigation are the only way to get an accurate idea of the compounds involved in the mix design and to identify a particular know-how or technical tradition[23]. The chronology, particularly for the earliest developments of the technique, is also a complex issue: as concerns the BTC/BTM floors, we lack more often than not of the dates usually provided by the ceramic's typologies or numismatics, because reliable artefacts are rarely found inside these floors. In this respect, specific methods of concretes/mortars dating have been successfully tested in many different archaeological contexts, allowing sometimes solving very controversial issues[24].

4 The project CaF was thus created with a view to shedding new light on this innovative technique through the application of scientific methods of investigation. The main goal is to determine which characteristics of the mix design are specifically responsible for its resistance and impermeability: in other words, to understand how binders and aggregates were selected on the basis of these particular properties. Once accurately determined, the physical properties of the BTC/BTM floors are to be interpreted in terms of purpose: this reflexion should help understanding the use of BTC/BTM floors in certain rooms. This part of the work has been entrusted to Arnaud Coutelas, an expert in the field of ancient concretes and mortars[25]. All the samples have been screened with petrographic analyses: optical observations of the raw samples with the naked eye and a magnifying glass, possibly completed by thin sections' observations

19 About the specific technique of the BTC/BTM *with* tesserae, which she calls ›tesserae-in-mortar‹, B. Tang considers that the theory of a Punic invention and its subsequent diffusion in other regions of the western Mediterranean is too simplistic. For her, the first developments took place at a time when Punics and Greeks had close relationships, both in Sicily and in North Africa; moreover, the technique of inserting small stone elements into mortars existed in the late 5th cent. B.C. both in Greece and Tunisia (Tang 2018, 185). She is therefore inclined to favour a joint invention of the Greeks and the Punics, while reminding that the earliest examples could actually be in Carthage (Tang 2018, 195).

20 Selinous: Helas 2011, 65–72. – Megara Hyblaia: Mège 2021, 243–250, Mège 2019. – Morgantina: Tsakirgis 1990 and Tsakirgis 1984, 425–439.

21 On the whole, concretes and mortars have been generally considered as decorative items (Greco 2014b; Greco 1997; Panvini 1997; Portale 1997; Portale 1995; Guimier-Sorbets 1994), the BTC/BTM floors with inlaid tesserae being generally considered as supposed ancestors of the mosaic floors (Mezzolani 2000, 219 note 23; Dunbabin 1994, 30–36) or for their decoration (Tang 2018; Tang 2015; Mezzolani 2000; Joly 1997).

22 Before the beginning of the project CaF, these pioneering methods had only been carried out in the ›Hellenistic-Roman‹ city of Solunto (Schön et al. 2019) and in the 3rd cent. B.C. Punic-Roman Palermo (Montana et al. 2016) – the same types of analyses have been carried-out on cisterns' mortar coatings: see for instance Codina et al. 2015; Lichtenberger et al. 2015; Schön et al. 2012.

23 As highlighted for instance in Roman Gaul (Coutelas 2011; Coutelas 2008; Coutelas et al. 2004).

24 Lichtenberger et al. 2015; Hale et al. 2003, 133–137; Heinemeier et al. 1997, 492–494. These methods, which principles are now well known, are being constantly improved and strengthened by new results (Ringbom et al. 2014; Lindroos et al. 2011).

25 Archaeologist at Arkemine SARL and research associate at AOROC (*École Normale Supérieure de Paris*, France).

under a microscope[26]. Additional physicochemical analyses in SEM (Scanning Electron Microscopy) have been performed on a limited number of samples after this first phase: they are meant to refine the optical observations and yield more specific information on the nature of the components. The second main point is to date the BTC/BTM floors. Mortar dating is a sophisticated method based on the measurement of the C-14 contained in the atmospheric CO_2 and trapped by carbonation in the concrete/mortar during the hardening process. Thus, if successful, such analyses can help to pinpoint the period when a BTC/BTM has been made: this would not only provide the generally missing chronological information, but it could bring new data on the technique's evolution (see note 24 here). The radiocarbon analyses of BTC/BTM floors have been processed by an already-structured team of geologist and physicist: Alf Lindroos and Jesper Olsen[27].

The Concrete Floors of Selinous

The Archaeological Contexts and the Samplings

5 Selinous is an ancient Greek city located on the south-western coast of Sicily. According to the tradition, it was founded in the second half of the 7th cent. B.C. by colonists coming mainly from Megara Hyblaia. The tremendous urban development of the 6th cent. B.C. was dramatically stopped in 409 B.C. with the Carthaginian invasion of the city. After this destructive event, the city was progressively abandoned until a Punic population decided to settle down around the mid-4th cent. B.C., mainly on the ancient Acropolis. Around the mid-3rd cent. B.C., during the first Punic War, the people of Selinous are said to have surrendered to the Roman armies and to have been deported to Lilybaion[28].

6 Numerous concrete floors, around 40 different units at least, can be found in different structures while BTC/BTM floors are only present in buildings pertaining to the Punic period of the city that is, to the time-span ca. mid-4th – mid-3rd cent. B.C. Nonetheless, BTC/BTM floors are too many to be extensively studied: consequently, the sampling had to be narrowed to an educated list of floors, including other types of concretes and mortars for contextualisation matters. This list was based on S. Helas' research, who has catalogued all the concrete floors of the Punic Selinous by collecting samples from 17 different rooms and studying them in an optical mode[29]. She could highlight four types of floors defined by two criterions: the number of layers and the presence of a decoration in the upper layer[30]. This typology is summed-up in Fig. 1.

Type 1	Type 3 (3a and 3b)	Type 2	Type 4; Type 5
Single layer concrete No decoration 5 to 6 examples	Single layer concrete With decoration 8 to 11 examples	Double layer concrete No decoration 13 examples	Double layer concrete With decoration 5 examples

1

Fig. 1: Selinous. Typology of the concretes

7 Each of these four types has therefore been investigated in the project, at least once. Eventually, for composition's study, we have made 17 samples coming from

26 This first step allows noting texture and internal structure of the mortars and highlighting the succession of layers. The aggregates are also better identified than by any other approach. In addition, one can also recognize the undercooked fragments of limestone, the terracotta, the clay nodules, the straw, the coals, lumps from old mortars, etc.

27 Respectively researcher at the Department of Geology and Mineralogy at *Åbo Akademi* University (Finland) and director of the Aarhus AMS Center at Aarhus University (Denmark).

28 According to Diodorus Siculus' account (Diod. 24, 1, 1).

29 Helas 2011, 65–72. 253–258.

30 Type 5 might be a stand-alone type, with the sole floor 3/36. Built like Type 4, it can be differentiated from the latter by its upper layer, where the limestone tesserae are placed one against the other.

14 floors (of which one tiled floor pointing) and one wall plaster: all the samples went under a macroscopic observation; 9 of these were then analysed in petrography; finally, 3 of the latter had physicochemical analyses. For the investigations on chronology (dating), 10 samples have been collected: 9 floors (of which one tiled floor pointing), one wall plaster (Fig. 2). Only a part of these samples, meant to be representative of the whole study (types of floors and types of analyses), is presented in this article (Fig. 3). All these preliminary results will be completed and further explained in the forthcoming publication. The houses and the rooms, which these floors belong to, are briefly described in Fig. 4.

The Analysis: Petrography and Dating

8 The petrographic analysis and the dating of the selected samples are presented in the form of a synoptic and simplified report (Fig. 5). For the dating, only the 95.4 % intervals are given. In order to get conclusive results from one floor, the dating process requires at least three measurements from each sample and preferably more than one sample should be dated for each floor[31]. Besides, the floor 3/20 is presented here, although not being a BTC/BTM, because of its striking characteristics: this is indeed a ›unicum‹ so far, may it be in Selinous, Roman Gaul or even Italy. The wall plaster associated to the floor 3/10 has also been included because it can yield additional information on the floor itself[32] (Fig. 6).

9 Some interesting observations can already be noted (Fig. 7 and Fig. 8). The petrographic analyses have shown that, in a surprising manner, the nucleus (a concrete) is systematically coarser than the rudus (a mortar): one would expect the opposite, as it is normally the case for that type of floor. Other important information: the terracotta used as aggregate mainly comes from tiles (although with some minor exceptions). Then, SEM analyses have confirmed the preliminary optical observations. All materials have been prepared with pure aerial lime, which was a rule for ancient concretes/mortars, with some variations though: the lime of the floor 3/34, slightly magnesian, is different from that of the floors 3/20 and 3/29 and comes consequently from another type of limestone. As expected, some floors such as 3/34 have hydraulic compounds due to pozzolanic reactions rims around terracotta grains[33]. It is less clear for the floor 3/29, probably because of dissolution, remobilization and recrystallization phases of the chemical elements. The latter contains a significant amount of silica that may come whether from earth mixed with the lime beforehand or from a terracotta powder added during the making of the concrete. Be as it may, both were in amounts high enough to produce a partial decarbonation of the binder, hence endowing the floor with waterproof properties.

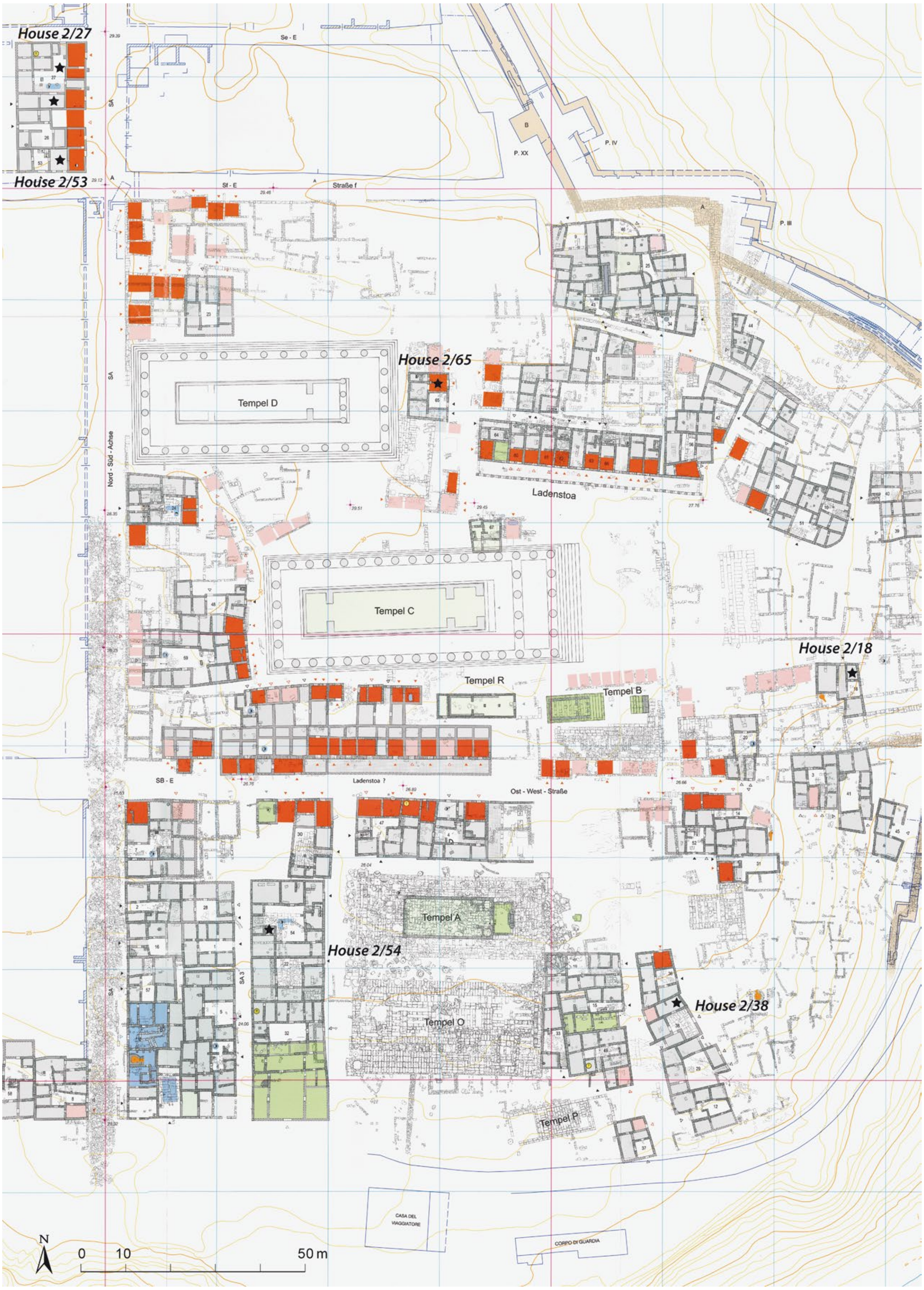
10 As concerns the dating, the usual contamination biases have been noted (Fig. 5 and Fig. 9). These biases, which hinder the interpretation of the results, are well known and come from the nature of the aggregates or from the building process of the concretes/mortars: that's why three or four measurements are needed for each sample[34].

31 Ringbom et al. 2014. See also note 24 here.

32 It has a total thickness of 7 cm, with two different layers clearly pertaining to two different construction phases; both have been investigated.

33 This chemical reaction is now well known. See for instance a definition in Siddall 2011, 153: »The slaked lime was mixed with a reactive aggregate which produced a stronger and waterproof set, by producing insoluble products with binding properties. Such an aggregate is known as a pozzolana, and referred primarily to volcanic-derived rocks and sediments which portray this property. […] For structures that required waterproofing or damp proofing, crushed ceramics in the form of potsherds, brick or tile were used to create a hydraulic set«. See also Siddall 2006.

34 Three or four vials are collected at different moments during the preparation of the floor sample and each one is analysed for C-14. It has been swhown by previous research that the first vial is generally the most reliable, without being a hard and fast rule. Usually the first measurement gives the right age and the subsequent measurements indicate how much limestone contamination there is in the sample. If there is



2

Fig. 2: Selinous. Plan of the Acropolis. Investigated houses and localisation of the samplings (black stars) (scale 1 : 1250)

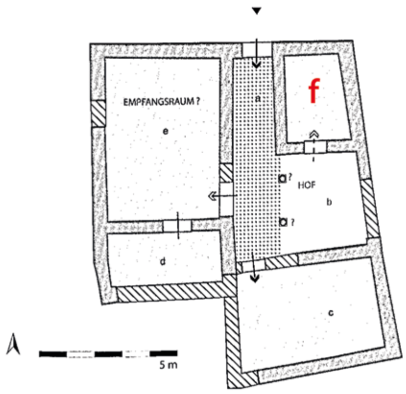
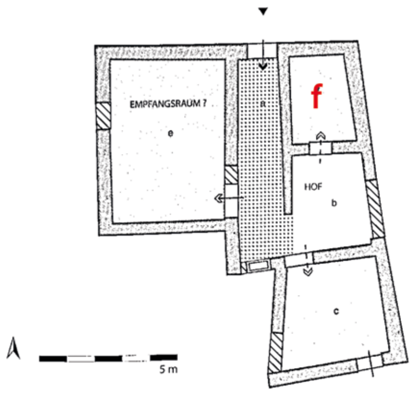
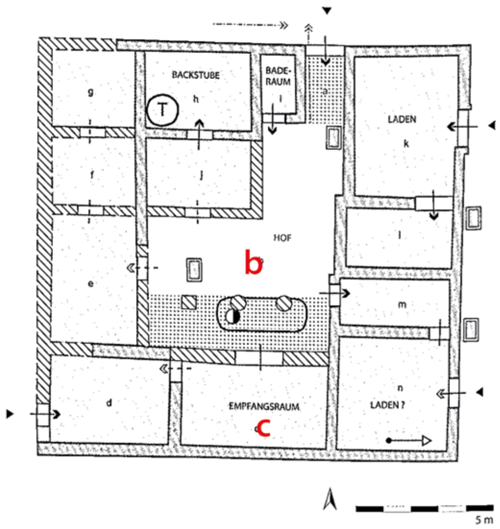
delayed hardening, the first measurement yields a too young age and the age must be deduced from the following measurements if not too much affected by limestone. A large proportion of limestone in the mix leads to much older ages than the real ones because of the CO_2 contained in the limestone, which age goes back to the geological period when the limestone was formed. On the contrary, because a concrete/mortar can take years to harden, the ›last‹ CO_2 molecules could be trapped in the mix long after it was actually made and, consequently, the AMS measurement could yield too young ages. See also references in note 24.

Number	Type	Analyses M: macroscopic P: petrographic PC: physicochemical D: dating	Localisation
3/3	Type 1	P	House 2/65, room e
3/10	Type 2	P, D	House 2/38, room e
3/19	Type 2	M, D	House 2/27, room b
3/20	Type 3	PC, D	House 2/18, room f
3/25	Type 3	P, D	House 2/53, room e
3/29	Type 3	PC	House 2/54, room j
3/34	Type 4	PC, D	House 2/27, room c

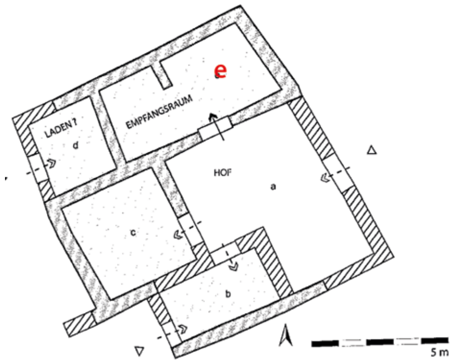
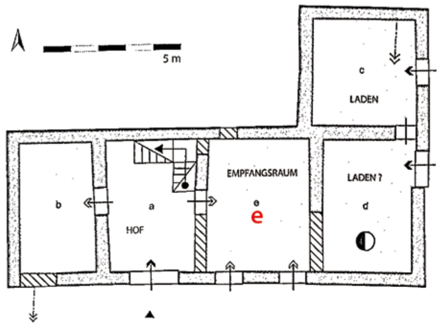
3

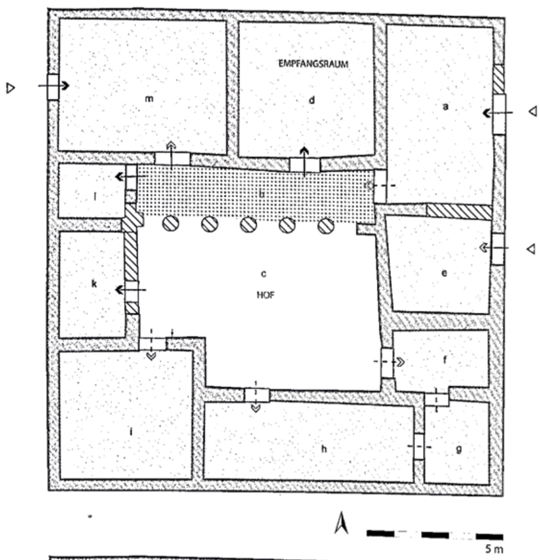
Fig. 3: Selinous. Types of analyses on the concretes

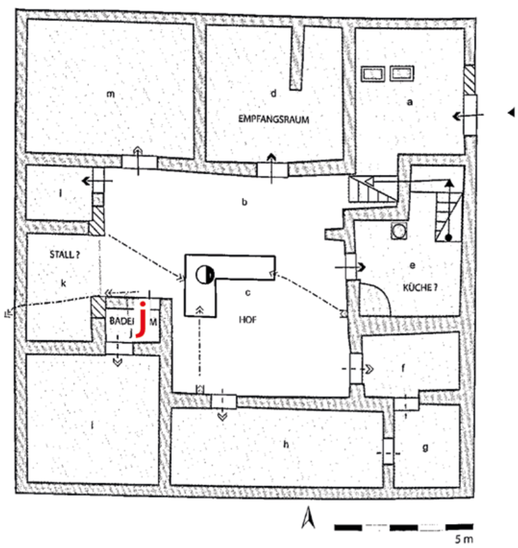
Fig. 4: Selinous. Description of the investigated houses

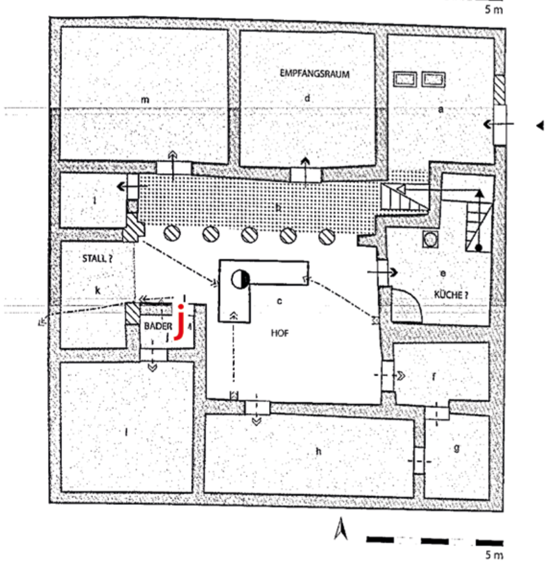
House	Description	Plan
2/18	House with a central courtyard and a long entrance corridor. In the 2nd phase, the south part of the house was replaced by a pottery kiln. Room f (floor 3/20) was probably a living, multifunctional room.	 
2/27	House with a central courtyard and short entrance corridor. Room b (floor 3/19) was a courtyard, equipped with a cistern. Room c (floor 3/34) was presumably a reception room.	

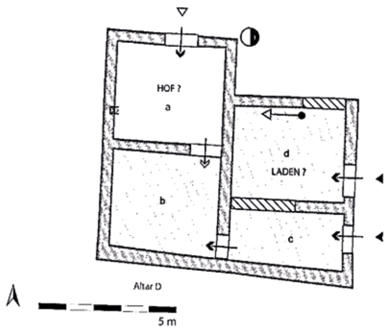
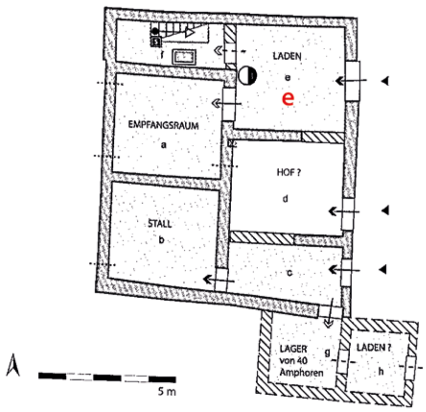
4

House	Description	Plan
2/38	Poorly preserved house, with many restorations. Room e (floor 3/10) was located on the north-eastern corner of the house and was probably a reception room.	
2/53	House with a central courtyard, without entrance corridor. Room e (floor 3/25) was a probable reception room.	
2/54	House with a central courtyard and a ›pastas‹ located on its northern end. In the 2nd phase, a cistern and a bathroom (room j, floor 3/29) were constructed in the courtyard.	







House	Description	Plan
2/65	House with an on-side courtyard. Room e (floor 3/3) was added in the 2nd phase, on the north-eastern corner of the house, and was a probable shop.	 

4

Complementary chronological indications, such as the archaeological context, can help to zero in on the most relevant dates (highlighted in bold characters in Fig. 5). In the case of the floors 3/10 and 3/25, only the first measurement seems correct, the others being far too old (long before the foundation date of Selinous). For the floor 3/34, the second measurement can be kept while the first one is too recent (more than 500 years after the alleged abandonment of the city) and the third, too ancient. The most relevant dates are also yielded by the first measurements of both layers of the wall plaster associated to the floor 3/10. The dating of the floor 3/19 is more complicated: all three measurements could be theoretically correct from an archaeological point of view. However, a stratigraphical excavation in the room b of the house 2/27 has shown that the floor 3/19 was most probably constructed before 300 B.C. and possibly after 350 B.C: therefore, only the second measurement should be considered. Finally, the case of the floor 3/20 is the most arduous, for only the first of the four measurements can be safely discarded.

Archaeological Interpretations

11 The goal of these investigations was to bring physical sciences-based data so as to complement the traditional archaeological methods[35]. The most striking information yielded by the petrographic investigations is the unexpected ›reverse order‹ of the upper and lower layers in the two-layer floors (types 2 and 4): in Selinous' floors, the upper layer (nucleus) is a concrete instead of a mortar. This is also the case for the only three-layer floor presented here: the nucleus of 3/25 is a concrete and the rudus was presumably a mortar, while the intermediate layer is a mortar. The reason for this is probably that there was no coating on the nucleus, such as slabs or mosaics, as it is

35 These include observation with the naked eye only, indirect dating through artefacts (pottery, coins), rarely found in concrete floors or hardly useful, or large chronological framing provided by architectural and urban studies.

Floor	Petrography	Date (calibrated 95.4 %)
3/3	Two layers. Only the *nucleus* (a BTC, 2.4 cm thick) is visible in the thin section. It is a very peculiar concrete, with a very homogeneous aerial matrix, a fairly low amount of terracotta and a high porosity, especially in the cracks around the grains. The *rudus* is at least 1.7 cm and is made of a slightly chalky caramel beige mortar, very rich in fine siliceous caramel sand, with some lime lumps and rare chippings.	
3/10	Two layers. The *nucleus* is a BTC, 0.5 cm thick, with few signs of reactions between the lime and the terracotta on the periphery of the grains. The *rudus* (1.1 cm thick) has a quite heterogeneous aggregate made of limestone and flint, certainly found in this state in a local deposit (the mixture seems to be natural).	**193 B.C. – 2 A.D. (95.4 %)** 826 B.C. – 776 B.C. (95.4 %) 2864 B.C. – 2802 B.C. (26.0 %) 2771 B.C. – 2769 B.C. (0.3 %) 2762 B.C. – 2578 B.C. (69.1 %)
3/19	Two layers (visible). The *nucleus* is a BTC, 1 cm thick, and is made of an off-white concrete, slightly pinkish, with light to medium brown terracotta powder and numerous lime lumps. The *rudus* is a white mortar, clear and chalky, with a fair amount of silico-calcareous sand, blunt and coarse (non-measurable thickness). Some flat gravel, rare charcoal pieces.	38 B.C. – 131 A.D. (95.4 %) **410 B.C. – 349 B.C. (66.1 %)** **306 B.C. – 208 B.C. (29.3 %)** 753 B.C. – 680 B.C. (27.0 %) 669 B.C. – 608 B.C. (15.3 %) 594 B.C. – 410 B.C. (53.1 %)
3/20	Two-layer floor, without terracotta. The *nucleus* (C1) is a concrete, with large pieces of marble (0.6 cm thick), while the preparation layer (C2, *rudus*) is a mortar, made of lime and crushed marble (1.5 cm thick). The SEM analyses show first of all that the lime used for C1 was an aerial lime. The matrix is calcium-rich and does not contain hydraulic compounds. The magnesian limestone that is found in grain with the marble is not a dolomite in the strict sense, the Mg/Ca ratio not being high enough. The results are completely identical for C2. Conclusion: aerial lime concrete and mortar, with aggregates made of marble and magnesian limestone, without hydraulic compounds.	255 A.D. – 303 A.D. (18.5 %) 316 A.D. – 418 A.D. (76.9 %) **183 B.C. – 3 A.D. (95.4 %)** **480 B.C. – 438 B.C. (3.5 %)** **432 B.C. – 356 B.C. (88.8 %)** **280 B.C. – 255 B.C. (3.1 %)** **753 B.C. – 679 B.C. (28.0 %)** **669 B.C. – 607 B.C. (16.1 %)** **594 B.C. – 411 B.C. (51.3 %)**
3/25	Three layers. Quite peculiar technique. The surface of the floor was treated with lime milk before the application of pigments. The *nucleus*, a not very thick BTC (0.9 cm), is a mix of terracotta and limestone. Intermediate thin layer (0.4 cm) of BTM especially rich in calcareous sand, which certainly served as an interface before the laying of the *nucleus*. The lower layer (*rudus*) is only made of calcareous sand, but perhaps the whole coarse part of concrete with gravel is missing. There is therefore a fine grain size which certainly explains the number of layers (meant to increase the strength of the floor). The aggregate load is also here among the lowest of the whole corpus. There are few, if not any, hydraulic compounds.	**169 B.C. – 4 A.D. (95.4 %)** 1194 B.C. – 1140 B.C. (14.1 %) 1132 B.C. – 1005 B.C. (81.3 %) 3010 B.C. – 2887 B.C. (95.4 %) 6634 B.C. – 6462 B.C. (95.4 %)
3/29	BTC, one layer (visible), 2.2 cm thick. The terracotta aggregate is made of fairly fine elements. SEM analyses show a very heterogeneous microstructure. Some are very carbonated, nevertheless with a rather significant amount of silica. There is also little silica in an analysed lime lump. The matrix shows above all a decarbonation process that has produced lamellar particles. These are clays that would have been incorporated with lime, in a kind of lime-earth mixture. However, it is questionable whether these fine particles could rather be terracotta powder incorporated with the rest of the filler, rather than with the lime. To be noted: no reaction rims were found around the large terracotta grains. The analyses also confirm the presence of lime milk on the surface. Its chemical composition is the same as the well-carbonated areas of the BTC matrix. Conclusion: aerial lime BTC with decarbonation phenomena rather than formation of hydraulic compounds.	

5

Floor	Petrography	Date (calibrated 95.4 %)
3/34	Two layers. The *nucleus* (C1, 1 cm thick) is a BTC with large pieces of architectural terracotta elements and decorative tesserae, laid on a *rudus* without terracotta (C2, non-measurable thickness), which is a silico-calcareous sand mortar. The SEM analyses of C1 have revealed a dense matrix of calcium carbonates. This aerial lime is relatively rich in magnesium (± 5 %), which could give indications of the origin of the limestone. Darker areas of the matrix are alumino-silicate compounds. They are limited to the periphery of the terracotta fragments. The matrix of C2 is quite dense and comes from a slightly magnesic aerial lime. There are secondary crystallizations of calcite in the cracks, but no hydraulic compounds. Conclusion: aerial lime lightly magnesic concrete and mortar. C1 is the only one to have evolved, with hydraulic compounds appearing in reaction rims around the terracotta fragments.	237 A.D. – 391 A.D. (95.4 %) **726 B.C. – 715 B.C. (1.8 %) 706 B.C. – 692 B.C. (2.2 %) 541 B.C. – 397 B.C. (91.4 %)** 1428 B.C. – 1278 B.C. (95.4 %)

5

The surface layer is only 0.3 cm thick. It is an off-white mortar very rich in medium/coarse silicocalcareous sand.	**345 B.C. – 318 B.C. (6.0 %) 205 B.C. – 50 B.C. (89.4 %)**
	1118 B.C. – 971 B.C. (91.0 %) 958 B.C. – 936 B.C. (4.4 %)
	3633 B.C. – 3549 B.C. (53.9 %) 3540 B.C. – 3499 B.C. (20.4 %) 3429 B.C. – 3378 B.C. (21.1 %)
The lower layer has been laid in several steps, the last application being 1.9 cm thick; it is a beige mortar, fairly porous, with few lime lumps, fine siliceous sand and blunt limestone chippings.	**406 B.C. – 351 B.C. (69.2 %) 294 B.C. – 227 B.C. (25.2 %) 218 B.C. – 211 B.C. (1.0 %)**
	1002 B.C. – 841 B.C. (95.4 %)
	3077 B.C. – 3071 B.C. (1.2 %) 3023 B.C. – 2891 B.C. (94.2 %)

6

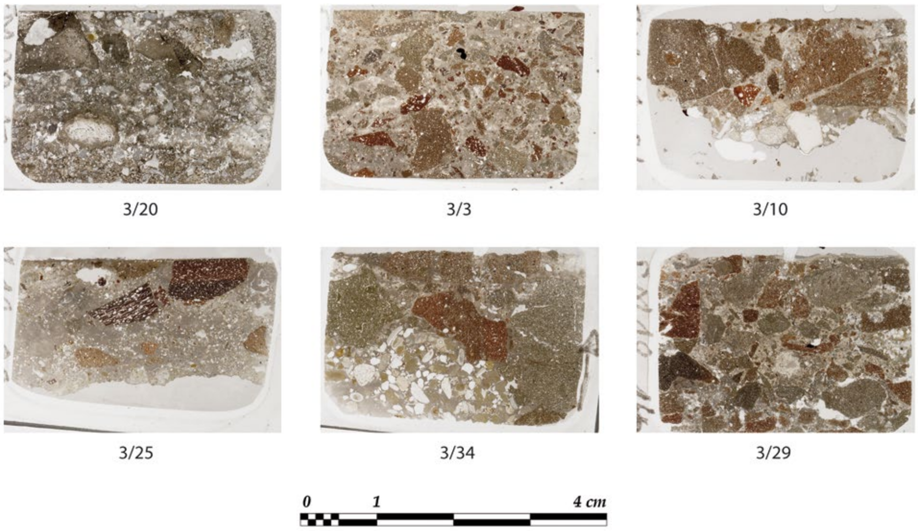
Fig. 5: Selinous. Petrographic analyses and dating results on the concretes

Fig. 6: Selinous. Petrographic analyses and dating results on the wall plaster associated to the floor 3/10

more often than not the case for Roman concretes. Consequently, the nucleus had to be tougher, with a coarser aggregate, so as to withstand people's traffic: hence the choice to build a concrete instead of a mortar. Besides, the one-layer floor 3/29 was also a concrete. Yet, this did not explain why, in multiple-layer floors, the rudus of the investigated floors is a mortar, whereas this preparation layer should be a more resistant concrete. This is all the more intriguing since provisional results of the on-going investigations on Megara Hyblaia's floors seem to *not* confirm this peculiarity[36]. Moreover, the petrographic analyses have helped to better define the number of layers of several floors, which was one of the criterions primarily used for the typology of concrete floors (see above and Fig. 1). Thus, it has been shown that the floor 3/3 has two layers instead of one (as previously assessed), 3/25 has three instead of one and 3/20 has two instead of one (Fig. 5). Another important issue tackled by petrography is the assessment of the hydraulicity for the investigated floors: most of the BTC/BTM are indeed supposed to have waterproof properties, which is one of the explanation of their wide spreading and maybe the reason why they were invented in the first place[37]. As previously said, all the present BTC/BTM used aerial lime as binder and no hydraulic lime is to be reported: therefore, hydraulicity can only be reached through the reactions between the lime and the terracotta aggregate (pozzolanic reaction, see note 33 here). However, only the floor 3/34 clearly shows such a reaction: it was found in a reception room (house 2/27, room c: Fig. 4) where that kind of waterproof property was surely useful (drinks and liquid

36 The composition and structure of the Megarian concretes are very close to their Roman counterparts. Same observations for Solunto's pavements (Schön et al. 2019, 117–120).

37 See notes 7 and 8 here.



7

Fig. 7: Selinous. Thin sections of the concretes

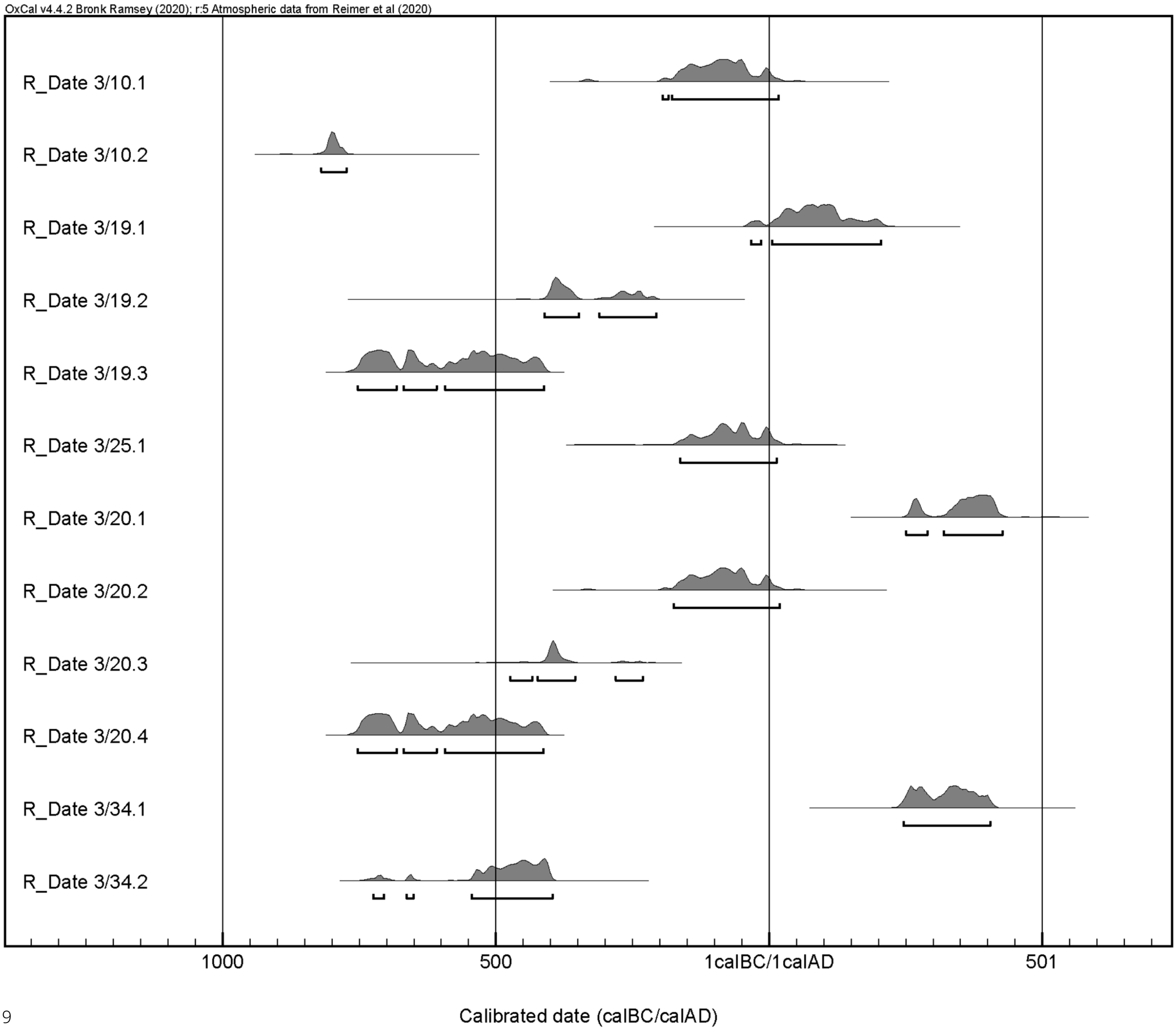
food were often spilled on the floor) but not mandatory. Furthermore, the floor 3/25 was also in a reception room (house 2/53, room e: Fig. 4) and it is barely waterproof. On the other hand, the floor 3/29 was used in a bathroom (house 2/54, room j: Fig. 4), a space where a waterproof floor would be certainly appreciated: the analyses demonstrated the hydraulicity of 3/29, as shown by the decarbonation of the matrix, which is the consequence of pozzolanic reactions (see above and Fig. 5). Solidity and resistance were other sought-after qualities of BTC/BTM floors. It is questionable whether the peculiar technique adopted by the builders in Selinous allowed them achieving this goal. This might be the reason why the floor 3/25 was constructed with three layers. On the contrary, the floor 3/29, with its single layer, was probably less resistant although it was not necessary in this case, for it was in a ›dead-end space‹ (a bathroom) where there was no traffic, by definition.

8

Fig. 8: Selinous. Sample of the floor 3/19 (SL 45417)

12 The chronology of the Selinous' BTC/BTM has been significantly improved by the AMS dating. For instance, the three layers of the floor 3/25, that we have just mentioned, could be seen as an evolution, given its relatively recent date (169 B.C. – 4 A.D., see Fig. 5). The floor 3/10 is equally recent (193 B.C. – 2 A.D., see Fig. 5), as confirmed by the upper layer of the associated plaster[38] (if we consider the most probable interval, see Fig. 6). In contrast to these rather recent floors, 3/19 and 3/34 are clearly older. Unfortunately, the dispersion of the time intervals' probability for these floors doesn't allow anymore precision on their ages (see Fig. 5). One can only notice that, for both floors, the time interval with the highest probability points out to periods older than ca. 350 B.C. Another contribution made to the chronology of Selinous' concrete floors is that the alleged anteriority of the types with one layer (1 and 3) compared to the types with two layers (2 and 4) has not been confirmed by the AMS dating (see above). In the limited

38 As regards this plaster, the dating of the lower layer shows that it was clearly older than the surface layer and therefore probably pertained to an earlier phase of the room. The presence of a concrete floor in this phase and the chronology of the phase itself cannot be securely determined. Nevertheless, the fact that the time intervals cover a long period (406–211 B.C., see Fig. 5) and that there were multiple ›sub-layers‹ could go in the same direction: this phase was seemingly long and the plaster had to be remade several times.



9

Fig. 9: Selinous. Radiocarbon dates of the concretes (only calibrated dates after 1000 B.C. are presented)

scope of the here presented corpus, this observation is backed up by the chronological diversity of the two-layer floors: as explained above, 3/10 is clearly more recent than 3/19, 3/20 and 3/34. The forthcoming publication of the whole corpus should confirm this renewed hypothesis.

Conclusion and Perspectives

13 Looking forward to the remaining analyses, we can already consider that the project CaF has brought promising results on Selinous' floors by solving some issues and by refining several previous hypotheses. Investigations on the chronology tend to show that the fact of going from one-layer floors to two-layer, as previously supposed, might not be seen as a chronological evolution but rather as a functional adaptation, regarding the built space where a concrete floor was generally laid. More importantly, the AMS dating indicates that several floors have been produced outside of the Punic period of Selinous, which was even so one of the main initial work hypotheses: the BTC/BTM floors 3/19 and 3/34 (Fig. 10) are probably older that the alleged beginning of the Punic

10

Fig. 10: Selinous. House 2/27. The floor 3/19 (foreground) and the floor 3/34 (background)

occupation of the city[39]. They could be even compared to the earliest attested BTC/BTM floors of the north-African sites Carthage and Kerkouane. If these floors are not to be directly attributed to the presence of Punic populations, their construction in the first half of the 4th cent. B.C. or before is further evidence that this whole region (North Africa and western Sicily) was involved in the early development of the BTC/BTM technique (see notes 8 and 9 here). Other floors, on the contrary, seem to have been built after the alleged abandonment of Selinous around the mid-3rd cent. B.C.: these are 3/10 and 3/25. The implication here is not on the BTC/BTM technique itself, but more widely on the occupation of the city. Although it would not be really surprising to find out that the place was still inhabited in the 3rd and 2nd cent. B.C., these outcomes suggest once again to what extent the traditional sources must be carefully handled regarding this kind of event[40].

14 One of the answers expected from the project CaF was to define the mix design of the investigated floors in a much more accurate manner: this goal was actually achieved, as presented here (see Fig. 5 and § 9–10). However, its purpose is not to simply have a better definition of these floors but above all to get insights on the ›recipes‹ followed by the craftsmen. In this respect, we have seen that the builders of Selinous had a peculiar way to construct multiple-layer floors: they used to invert the order of the layers, so-to-say, compared to Roman BTC/BTM floors. This might be the sign of a regional technical tradition, with apparently no relation to the chronology: for example, the floor 3/10 pertains to the late examples of the corpus, at a time period when Sicily was a Roman province. Although being a three-layer floor, 3/25 goes in the same direction, because its lower layer appears to be a mortar. The nature of the compounds used in the mix design could also reveal the existence of local know-how and way of doing. Deeper geological investigations will be necessary to determine the provenience of aggregates such as the silico-calcareous sand, widely used in Selinous concretes and mortars, or the more specific flint/limestone found in the floor 3/10[41]. The making of the lime is another point to clear up thanks to geology: which local limestone was preferably burned and why it was different in the case of the floor 3/34. Moreover, the preparation layer of the floor 3/29 denotes the use of a lime-earth mixture along with a fine aggregate and limestone gravel. It is even possible that terracotta powder has been added in the filler to produce pozzolanic reactions. This was one of the objectives of the project CaF:

39 Both belong to the same house 2/27 which, after its wall construction technique and the stratigraphical excavation of its room h, has been clearly constructed before 300 B.C. It is also one of the biggest and lavisher houses known so far in Selinous (see Fig. 10).

40 So far, Selinous is supposed to have been abandoned around the mid-3rd cent. B.C., mainly because of a single mention in ancient sources (Diod. 24, 1, 1). But one must be always cautious when relying on texts only, especially for that kind of event: Diodorus says that Selinus' people were deported but nothing would have prevented them to come back some time later. Actually, it is generally the case when the conditions are suitable again: now, that part of Sicily was at peace again after the Roman conquest on 241 B.C.

41 In ancient periods, craftsmen most generally looked to the local resources. In Selinous, the natural aggregate is visible mainly in the preparation levels: limestone pebbles are not much used but, on the other hand, natural sand is frequent. It is always made up of a part of limestone sand, usually the most important part, and a part of siliceous sand. The latter is made of quartz and sometimes also of flint. Limestone is either micritic or a biosparite.

to evaluate the utilisation of BTC/BTM floors in a living space according to their main sought-after properties, namely resistance and hydraulicity. For instance, the floor 3/29 was used in a bathroom, the floor 3/34 was in a reception room and 3/19 was in a courtyard. As concerns the latter, it tends to show that the builders in Selinous knew how to make a mix with hydraulic properties at a relatively early period. Finally, as demonstrated with the floor 3/10, the study of wall plasters, when in connection with a concrete floor, would also be a lead to explore for it can bring very useful information on the construction technique and its chronology.

15 The investigations in Megara Hyblaia will put Selinous' outcomes into a broader perspective, both geographical and chronological. Through this combination of point of views and scientific methods, we expect this whole study to clarify issues related to the concrete floors in Hellenistic Sicily and help fostering research in both fields, archaeological and physical. From an archaeological point of view, the results of the project CaF will contribute to the understanding of an essential technical innovation, the invention of which has clearly led to the appearance of new types of rooms and architectural structures. Taking a step back to look at the bigger picture, this study on concrete floors will provide important new data to research on building logistics. In fact, concrete floors were part of construction projects, such as sumptuous houses or public baths, which were probably supported by elites or wealthy benefactors.

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