STUDI MICENEI ED EGEO-ANATOLICI
NUOVA SERIE

1, 2015

Edizioni Quasar

STUDI MICENEI
ED EGEO-ANATOLICI
NUOVA SERIE

è una rivista dell'Istituto di Studi sul Mediterraneo Antico
del Consiglio Nazionale delle Ricerche, Roma

ISSN 1126-6651
e-ISBN 978-88-7140-761-6

Stampa e distribuzione / Printing and distribution
Edizioni Quasar di Severino Tognon s.r.l.
Via Ajaccio 41-43 – 00198 Roma
tel. +39 0685358444, fax + 39 0685833591
email: info@edizioniquasar.it
www.edizioniquasar.it

Area della Ricerca di Roma 1, Via Salaria Km 29,300, 00015 Monterotondo scalo (Roma)
Autorizzazione Tribunale di Roma nr. 288/2014 del 31.12.2014

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A ROYAL GIFT? BULK GRAIN STORAGE IN PROTOPALATIAL AND NEOPALATIAL CRETE

Torben P. Keßler

Summary

Recent years have witnessed a growing interest of Aegean archaeologists in methods of quantifying the subsistence economy in order to obtain a better idea of which parts of society were either economically dependent or in charge respectively. Quantification of subsistence levels has its difficulties since it involves a series of factors – such as diet composition or human daily caloric need – that have to be dealt with before the actual calculations. In this article, it is argued, firstly, that the Minoan palaces of both the Protopalatial and Neopalatial periods cannot be seen as centres for communal redistribution of staple goods since their storage capacities could not match this task by any means. In fact, they were storing goods only for themselves. Secondly, the interpretation of the Minoan *kouloures*, or underground pits in the west courts of Knossos and Phaistos, as granaries is reinforced, particularly on the basis of Hittite analogies. Since these long-term stores – when opened – had to be emptied *entirely*, their function within the Protopalatial economy could be considered either as reserves for the palace inhabitants in times of need, or as central elements of collective ritual activities taking place in the west courts, such as the distribution of grain rations to the community at large.

1. INTRODUCTION

The last years have witnessed an increasing interest within Minoan archaeology in matters of the palatial economy of Bronze Age Crete. None of the questions raised is completely without forerunners, indeed Arthur Evans had already made quite an effort towards producing a picture of the economic power of the palace of Knossos (*e.g.* Evans 1935, 647-648). The database of evidence, however, has greatly expanded since Evans's time and enables us to revisit some of these issues.

The main theoretical and terminological approach in describing the Aegean palatial economy is rooted in the study of Near Eastern and Mesopotamian palaces and their archives which give us insights into the functioning and characteristics of the economies of the closest neighbouring cultures of the Aegean. The term most constantly used to describe palatial economies is the Polanyian *redistribution*, i.e. the central administration and control of goods exchange.[1] Huge palatial storage capacities on the one hand and records of transactions between the periphery and the centre on the other have formed a convincing picture of oriental economies with the palace dominating all economic transactions by collecting and storing goods centrally and re-distributing them to (parts of) the population. The 'classical' type of redistribution might be understood in the biblical tale of Joseph giving advice to the pharaoh to save the grain from seven good years for the following seven bad years (*Genesis* 41, 25-36). The pharaoh as a good king has to take care of his people in the pure sense of securing their survival. On the other hand, control of food supply in times of need (bad years) meant that a considerable amount of wealth was spent, on which royal power might have been built.

1 Next to redistribution, Polanyi considered reciprocity and (market) exchange the existing forms of socioeconomic integration of pre-industrial societies: Polanyi 1957, 250-257. Whereas reciprocity works between two parties of equal status and power, i.e. on a symmetrical basis, redistributive exchange is organised between many minor actors and one major centre, i.e. on an asymmetrical basis. For criticism on the usage of Polanyian terminology in archaeology: Gledhill, Larsen 1982; Smith 2004, 75-76. For a recent discussion of the significance of the redistribution concept in the study of Aegean economies see: *Forum Redistribution in Aegean Palatial Societies*, *AJA*, 115, 2011, 175-244.

SMEA NS 1, 2015, 137-170

Above all, literary sources enable us to distinguish between distinct kinds and grades of redistribution at different Near Eastern sites: classical redistribution seems to be manifest in Old-Babylonian Larsa where massive grain capacities allow for the supplying of a large number – or even all – of the people (Breckwoldt 1995-96, 64-88).[2] A reduced central domination of transactions is to be drawn from two palatial archives in Arraphian Nuzi: much smaller capacities of grain were collected, and as such were directed to the palace and its employees, respectively (Klein 2012).[3] For the subsistence economy, this would constitue the spectrum we can expect when dealing with redistribution.

The aim of this article is to shed some light on some of the peculiarities of the Minoan palatial subsistence economy and to calculate to what degree redistribution might have been enacted as a form of socioeconomic integration. For reasons defined by the archaeological and bibliographical evidence the focus of this article lies on the three major palaces at Knossos, Phaistos, and Mallia, as well as on a selection of elite buildings. After a brief discussion of some basic considerations regarding the quantification of subsistence an attempt is made to calculate the storage capacities of these structures, while in the last section a small group of bulk storage facilities (the 'kouloures') will be analysed.

2. A METHOD TO QUANTIFY SUBSISTENCE – BASIC CONSIDERATIONS

The strength of the method pursued here is its relatively broad applicability combined with a certain degree of independence from single parameters – of which several had to be taken into account in the calculation. This independence derives from the proclaimed intention *not* to pinpoint the *exact* number of individuals living together in a defined economic unit but to determine an *order of magnitude* of the people that could at most have been subsidised with the storage capacities present. Even results with double, triple or half the size of the default calculation will not be outside the bounds of this order of magnitude and hence will give us an idea of the relative size of an economy.

2.1 *Minoan food and nutrition*

The first step is to clarify a series of elements concerning the nutrition and – deriving from that – the food storage of the Minoans. Therefore it is not sufficient to look solely at the archaeological evidence but anthropological and natural scientific findings need also to be taken into consideration.

2.1.1 *Food supply in the Aegean*

Modern excavation techniques and sensibilities have provided us with an increasingly representative (though qualitative) corpus of palaeobotanical data for the Aegean (Tzedakis, Martlew 1999; Kroll 2000, 31-68).[4] The most frequently detected foodstuffs are wheat, barley, lentils, peas, sweet peas, grape and fig, accompanied by the olive with its high-quality oil (Hansen 2000; Riley 2002). Furthermore some other cereals and pulses, fruits, nuts and different kinds of meat and fish are attested.

A listing of Late Bronze Age findspots of cereals on Crete as presented by Halstead (1992, 108, tab.1), Christakis (2005, 51), and Megaloudi (2006, 44-48, tab. 5.9-5.11b) produces the picture – albeit incomplete – in Table 1.

---

2 Different grain producing sites provided huge capacities within the control of the palace which obviously exceeded the needs of the mere inhabitants of Larsa. See also Kozyreva 1984. A similar situation has been suggested for Alalah VII (Zeeb 2001) and Assur (Llop 2011-12; Faist, Llop 2012).

3 Two palatial archives in the periphery of the city contain information about the economic system of production and distribution of grain in Nuzi. The produce delivered to the palatial stores in the recorded time span of one year did not exceed 4,800 litres of barley–an amount that would barely suffice to feed more than the inhabitants of the palace itself. For a discussion of a list of grain rations from the same kingdom see: Maul 1995.

4 For a reconstruction of the Aegean agricultural development based on archaeologically proven crops: see Renfrew 1982, 156-160.

Cultivar	*Find spot*	*Literature*
"grain"	Phaistos, magazines	Pernier, Banti 1951, 86. 115
	Mallia, east magazines	Chapouthier, Charbonneaux 1928, 38
	Knossos, mag. 3	Evans 1899-1900, 21 ("burnt")
wheat	Kamares cave	Dawkins, Laistner 1912-1913, 11
	Knossos, lapidary's workshop	Evans 1900-1901, 21 ("apparently")
	Myrtos Fournou Koryfi	Renfrew 1972, 317
	Palaikastro, room 23	Bosanquet 1901-1902, 316
Einkorn	Unexplored Mansion	Jones 1984
Emmer	Debla	Greig, Warren 1974, 130
	Chamalevri	Tzedakis, Martlew 1999, 41
	Aghia Triada, mag. 5	Follieri 1979-1980
	Unexplored Mansion	Jones 1984
durum wheat	Aghia Triada, mag. 5	Follieri 1979-1980
bread wheat	Knossos, Unexplored Mansion	Jones 1984
barley	Debla	Greig, Warren 1974, 130
	Aghia Triada	Follieri 1979-1980
	Knossos, Karavanserai	Evans 1928, 105 ("apparently")
	Knossos, mag. 3	Evans 1935, 621-22 ("eye witness")
six-rowed barley	Knossos, Unexplored Mansion	Jones 1984
	Fournou Koryfi	Renfrew 1972, 317

Table 1. Documented remains of grain at Bronze Age sites on Crete.

Based on these data it seems justified to propose a certain dominance of Einkorn (*Triticum monococcum* subsp. *monococcum*), Emmer (*Triticum turgidum* subsp. *dicoccum*) and barley (*Hordeum vulgare* subsp. *distichum*) in the Minoan cereal food supply.

2.1.2 *The Minoan 'menu'*

Much more difficult than detecting the components of the Cretan diet is to determine their actual percentages on the menu – especially for archaeology.[5] The so-called Mediterranean triad – grain, olives, and wine – is broadly accepted as the basis of Bronze-Age agriculture in the Aegean (Renfrew 1972, 280; Gamble 1979, 128).[6] The comparison of the documented modern traditional diet in Crete with the archaeological evidence has led various scholars to believe that the anthropological data – at least structurally – can be transferred to Minoan nutrition patterns. The only question remaining is that stated above: what percentage was occupied by the single aliment (Nowicki 1999, 153-154; Riley 1999, 22; Warren 2003, 281)?

The often-quoted anthropological study of Leland Allbaugh, which observed the diet of 128 Cretan households in 1948, concluded that 39 % of the daily energy demand[7] was covered by cereals – mainly wheat and barley (Allbaugh 1953). This percentage has been found inadequate by different other works which calculate up to 60 or even 75 % of cereals (energy value) [Riley 1999, 146 (30-60 %); Foxhall, Forbes 1982, 74 (70-75 % in classical times); Gallant 1991, 68 (60-65 %)].[8] Also, legal documents from pre-industrial (16th-17th century) Crete point to a necessarily higher emphasis on cereals as the main supplier of energy than that stated

5 For the problem of representativeness of seeds within archaeological assemblages: Wilson 1984, 205.

6 The addition of pulses as a fourth component has been postulated by Sarpaki 1990, 61-77.

7 It is important to make a clear distinction between the dietary energy ratio of an aliment and its percentage in weight since (due to respective caloric values) these differ substantially: see the next three sections.

8 The lack of the potato in prehistoric Crete has especially been used as an argument for a higher importance of cereals in these times: Riley 1999, 32.

by Allbaugh (Christakis 2008, 29).[9] In the following calculations, therefore, an energy supply ratio of 65 % by cereals will be hypothesized which would be consistent with about 38 % of the diet in weight.[10] The importance of olive-oil will be narrowed down to 17-29 % of the daily energy demand (maximum: Allbaugh 1953, 114; minimum: Christakis 2008, 30).

Because cereals and olive-oil seem to have covered in large part the nutritive needs of the Cretans we will leave aside the discussion of other aliments.[11]

2.1.3 *Nutrition value of Minoan food*

On the basis of carbohydrates, proteins, fats, and other components it is possible to calculate the energy value (unit kcal/g) of a particular aliment (Richter 2010, 315, pl. 12,1). It should suffice in our case to calculate this for the above mentioned Mediterranean triad.

Wine, however, is ruled out here because of its low nutritional value (about 70 kcal/100 g) and hence its minor role as a vital food.[12] Olive-oil in the Bronze Age might have had the same characteristics as today's cold-pressed products (Riley 2002, 72), which is approximately 880 kcal per 100 g (Chadfield 1954, 27; Souci, Fachmann, Kraut 1989, 159).

Given the dominance of Einkorn, Emmer, and barley in the Minoan diet (cf. preceding section) it would be desirable to know their specific nutrition values. Since the old grain breeds are, naturally, heavily underrepresented in modern agriculture, data acquisition is difficult.[13] Chemical analysis of Einkorn argues for its advantageous nutritional properties – which rival even those of bread wheat: hence the energy value of Einkorn would be 346.2 kcal per 100 g, compared to 343.2 kcal for bread wheat (Abdel-Aal, Hucl, Sosulski 1995). Concerning Emmer wheat and barley, differing data exist, but scientists from the Universität für Bodenkultur at Vienna have analysed these species and proposed 342.7 kcal for Emmer, and 306.2 kcal per 100 g for spelt barley (Grausgruber *et al.* 2004, 25, tab. 1: for naked barley the same study computes 333.1 kcal/100 g). Varying data might derive from the distinction between grain "in the glume" and the "dehusked" condition.[14] As the glumes are inedible, their staying attached to the grain decreases the particular energy value in reference to weight. In the case of Einkorn and Emmer the weight of the glumes reaches nearly 30 % while for barley a ratio of 20 % is to be adopted (Jantsch, Trautz 2003, 18).[15] A synopsis of the results is displayed in Table 2.

---

9 The overall diet reconstructed by Christakis ("adapting Allbaughs estimates") comprises 37.9 % cereals, 43.6 % legumes, wild greens, fruits and nuts, 3.7 % pulses, 3.8 % olive oil, 8.7 % wine and 2.3 % animal products relating to weight (!) ratio.

10 Since these numbers match quite well Allbaugh's percentage it might be assumed that he was in fact talking about the weight ratio and not the energy demand.

11 For the importance of wild greens: Zeghichi *et al.* 2003, 37. The (minor) role of fish for the Minoan diet is discussed by: Powell 1996, 2, 55-58, 167; Fischer 2007, 125-140.

12 Souci, Fachmann, Kraut 1989, 958-691, 963-964 with slightly varying values regarding red and white wine.

13 References in archaeological and palaeobotanical studies concerning energy values of grain vary accordingly: Foxhall, Forbes 1982, 46; Kroll 1983, 106 tab. 33; Jacomet, Kreuz 1999, 283; Christakis 2008, tab. 1.

14 Glumes: hypsophylls encasing the flower of sweet grass (*poaceae*), i.e. amongst others grain. If it is impossible to remove the glumes from the seed by threshing, the grain is referred to as "Spelzgetreide": Rösch 1998, 4-11; see also Cappers, Neef, Bekker 2009, 56-57, 72.

15 Similar reference values for the wheats are attested by Kroll 1989, 106, Tab. 33; lower calculations provided by Clark 1970, 57-58. The chosen glume ratio for barley is as suggested by Dr. Karl-Josef Müller, director of the Center for Cereal Breeding Research Darzau (www.darzau.de), although lower calculations exist: Grausgruber *et al.* 2004, 24.

Aliment	*Energy value (kcal/100 g)*	
Olive-oil		880
Wine		70
	in the glume	*dehusked*
Einkorn	242[i]	346
Emmer	240[ii]	343
Barley	245[iii]	306

[i] glumes weight 28,1 %
[ii] glumes weight 29,8 %
[iii] glumes weight 20 %

Table 2. Energy values of the 'Mediterranean triad'.

2.1.4 *Food requirements*

The significance of nutrition values does not become apparent until understood against human needs. This approach implies the basic striving of a community to meet the nutritive requirements of every single one of its members. Obviously this is not always the case due to biased access to food determined by age, sex, and social status (Palmer 1989, 116), but in the ideal model pursued here we will ignore these factors.

Human energy demand shall be defined as "energy intake that is considered adequate to meet the energy needs of the average healthy person in a specified category" (FAO/WHO 1973, 10). The daily basic metabolic rate (BMR) is highly affected by age and sex while the decisive factor is body weight. Modern physiological studies calculate a median of 24 kcal per kilo body weight (Lang, Lang 2007, 184 tab. 8.1), which corresponds approximately with the American recommended dietary allowances (RDA); the recommendations, though, differentiate between the energetic BMR of women (23.2 kcal/kg) and men (24 kcal/kg) (RDA 1989, 29 tab. 3.4).[16] The arithmetic means of body weight commonly used in studies of nutrition science is 70 kg (man) and 58 kg (woman) (Deutsche Gesellschaft für Ernährung 2008). Since these are values for modern Central Europe, the results of Allbaugh's study in 1948 on Crete, that is 64.8 kg (man) and 56.5 kg (woman), are certainly to be preferred (Allbaugh 1953, 481-483, pl. A17-A18).[17]

The daily energy needs of a person is fundamentally determined by the particular physical activity level (PAL) and may in case of hard work exceed the BMR by a factor of ten (Lang, Lang 2007, 184). According to the German Society of Nutrition, however, the activity level usually varies between 1.2 and 2.4 which – multiplied with the BMR – produces the overall demand (see Table 3 for minimum and maximum values).[18]

	BMR (kcal/day)	x	*PAL*	=	*Daily demand (kcal)*
Man (64 kg)	1,536	x	1.2-2.4	=	1,843-3,686
WomWoman (56 kg)	1,299	x	1.2-2.4	=	1,559-3,118

Table 3. Reference values for the daily energy demand.

Without doubt in pre-industrial societies we have to assume a higher percentage of 'middle-hard' and 'hard work' than today.[19] These categories are paralleled with an activity level of between 1.8-1.9 (housewife, craftsman)

16 The values reflect the demand of a 23-year-old adult.

17 Allbaugh's results are reconfirmed by those of a study conducted by Lawrence Angel at Lerna: Angel 1971, 85.

18 Deutsche Gesellschaft für Ernährung 2008, 32 tab. 5. Quite consistent are the results of the American recommendations (PAL: 1.375-2.25): RDA 1989, 28, tab. 3.3.

19 Angel attested arthritic symptoms at Lerna on 75 % of the male skeletons and on 50 % of the female skeletons (against 18 % on modern male Americans): Angel 1973, 86.

and 2.0-2.4 (farmer, lumberjack).[20] Taking the mean of this we arrive at a PAL value of 2.025 which results in an average daily energy demand of 2,631 kcal for a woman and 3,149 kcal for a man – an average then of 2,871 kcal.[21] This value is, however, to be understood as a working hypothesis, since without demographic data (*e.g.* regarding medium age) final certainty cannot be achieved.

2.1.5 *Mass density of food*

Throughout antiquity amounts of food – regardless of whether solids or fluids – were quantified by means of a system of measures of capacity.[22] The Linear B texts provide us both with a weight system and a capacity system, whereas grain was consistently recorded by volume (Ventris, Chadwick 1956, 55-60). A capacity system carries the obvious advantage of immediate comprehension when used. "One cup"[23] of a food is evidently much easier to understand than the abstract notion of a 29-kilogram-talent.[24]

While modern nutritional studies are based on measures of weight, archaeological evidence concerning storage capacities invariably delivers volume data. To cope with this problem it is necessary to introduce the parameter of the so-called mass density ρ which gives the ratio of mass (m) to volume (V) of a body via the formula $\rho = m/V$.

Again, the basis of our considerations will be the Mediterranean triad (see section 2.2). The mass densities of wine (ca. 1.09 kg/l) and olive-oil (0.91-0.92 kg/l) do not seem to be controversial, whereas the different grain species mentioned have to be discussed briefly (for olive oil, Krist, Buchbauer, Klausberger 2008, 325; for wine: Ribéreau-Gayon *et al.* 1960, 343). A small study of data regarding mass density of grain was kindly conducted at the Center for Cereal Breeding Research, Darzau. During the work, a clear distinction was drawn between 'free-threshing' grain species and those 'in the glume,' since the glumes are much lighter than the seed and hence they do affect the mass density.[25] Integrating the percentage of the glumes with regard to the total grain weight (cf. tab. 2) we end up with the numbers given in Table 4.

Aliment	*Mass density (kg/l)*	
olive-oil		0.91
wine		1.09
	in the glume	*dehusked*
Einkorn	0.51[i]	0.71
Emmer	0.46[ii]	0.66
barley	0.62[iii]	0.81[iv]

[i] winter Einkorn Tifi
[ii] black winter Emmer
[iii] summer barley Henkrike[26]
[iv] summer barley GS 2603

Table 4. Reference values for mass density of the Mediterranean triad.

20 Deutsche Gesellschaft für Ernährung 2008, 32 tab. 5.

21 Christakis' average value (2,393 kcal/day) in my opinion is too low since it builds on a PAL of 1.6: Christakis 2008, 33.

22 For literary source see Jardé 1925, 32. This contrasts with modern conventions which use a weight system for solids and capacity for fluids, except for Greek wine which is ordered by the kilo.

23 The equation of the 'cup' as the smallest volume unit in the Linear B texts might well be compared with the Greek *kotyle*: Ventris, Chadwick 1956, 58.

24 The Standard Palace Weight as inferred by Evans from a stone weight in magazine 15 at Knossos and a few copper ingots at Aghia Triada with about the same weight: Evans 1900-1901, 42-43; 1935, 650-652.

25 One example from the study: one litre of naked barley weighed 810 g, while one litre of barley with the glumes weighed only 640 g, i.e. the mass density is much lower.

26 The original result of the study at Darzau was 0.64 kg/l, but, in accordance with the advice of Dr. Müller and data from another archaeological study of the matter (van Wersch 1972, 185), the mass density for ancient barley was slightly diminished.

Daily ENERGY DEMAND *per person (PAL 2.025):*			2,871 kcal
Covered in the Minoan "menu" by:			
Grain	to 65 %[i]	=	1,866 kcal
Olive-oil	to 17-29 %[ii]	=	488-833 kcal

[i] Christakis 2008, 29 (adopted from Allbaugh 1953, 107). — *weight percentage*: 37.9 %.

[ii] minimum: Christakis 2008, 30; maximum: Allbaugh 1953, 132 tab. 16. — *weight percentage*: 3.8 %.

	ENERGY VALUE *(kcal/100 g)*		MASS DENSITY *(kg/l)*	
GRAIN	*in the glume*	*dehusked*	*in the glume*	*dehusked*
Einkorn	242	346	0.51	0.71
Emmer	240	343	0.46	0.66
Barley	245	306	0.62	0.82
OLIVE-OIL	880		0.91	

	DAILY RATION[iii]			
	Weight		*Volume*	
GRAIN	*in the glume*	*dehusked*	*in the glume*	*dehusked*
Einkorn	771 g	539 g	1.52 l	0.76 l
Emmer	778 g	544 g	1.69 l	0.82 l
Barley	762 g	610 g	1.23 l	0.74 l
OLIVE-OIL	55–95 g		0.06–0.1 l	

[iii] weight = $\frac{\textit{share in "menu" (kcal)}}{\textit{nutrition value (kcal / g)}}$ volume = $\frac{\textit{daily ration (g)}}{\textit{mass density (g / l)}}$

Table 5. Nutritional parameters for Bronze Age Crete.

For Bronze Age Crete it is difficult to deduce whether either the free-threshing or the husked grain went into storage. Basically applied, husked grain species if separated from their protective glumes become vulnerable to dehydration and thus lose their capability for long-term storage (Willerding 1998, 13). Judging from the documented remains of grain in Crete (cf. Table 1), cultivation and storage of husked species seem to have prevailed.[27] Capacity calculations conducted further below will, nonetheless, incorporate both the free-threshing and the husked forms.

2.1.6 *Summary*

This section has attempted to elucidate different problems that are related to the archaeological study of storage. It should be noted that the compiled data cannot provide more than an approximation to some Minoan reality. But they surely give us a quantification of the Cretan economy with regard to its order of magnitude. For a summary compilation of the data see Table 5.

If we therefore suggest that the energy demand of the Bronze Age population in Crete was 65 % cereals and 20 % olive-oil, we have to assume that on a daily level every person needed either 1.6 litres of husked wheat (1.52 l Einkorn/1.69 l Emmer) or 1.23 litres of husked barley. These could have been processed then to 540 g edible wheat and

27 An assured deposit of stored Einkorn and Emmer in the glume has been documented in the Unexplored Mansion at Knossos, Jones 1984, 303-306.

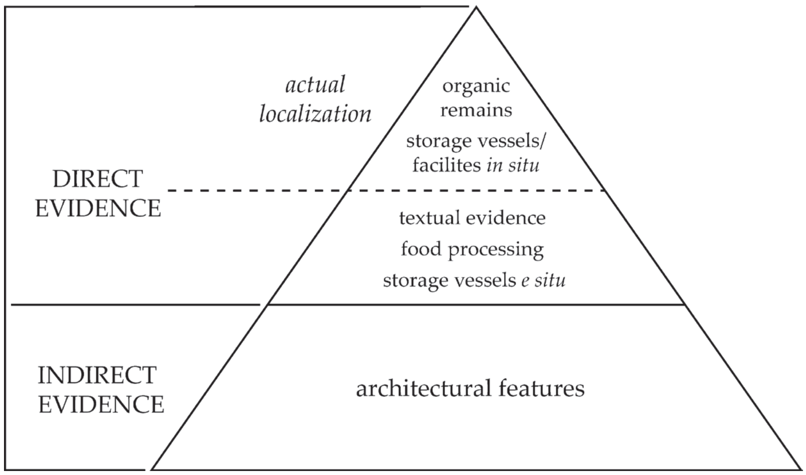

Fig. 1. Direct and indirect criteria for the identification of food storage in the archaeological evidence.

610 g barley.[28] On average 85 ml of olive-oil per day provided the second largest part of the energy demand. These values establish the basic dataset for the capacity calculations that follow.

2.2 *Identification of storage rooms*

A major difficulty for the quantification of subsistence levels on the basis of storage capacity is the identification of the storage rooms themselves. This identification is complicated not only by the scarcity of archaeological storing remains *per se* but also by the potentially multi-functional use of space.[29] This is why each case must be carefully considered as to whether a designated magazine can be securely identified.

The first systematic approach to define Late Minoan storage indicators was developed by Begg, who based his store room typology on two grounds: finds from within the rooms (stone, bronze, ceramic, and organic) and architectural features (scale, form, setting, location in the settlement) (Begg 1975). Sjöberg (1992, 21-26) proceeds in a similar way adding, though, as a third criterion the written evidence, obviously referring to the Linear B texts and the place they were found, respectively. Lastly, Christakis has treated the problem refuting architectural layout as a valid indication of storage if not accompanied by storage vessels or organic remains. As well as this he adds the presence of food processing facilities as a further clue for food storage (Christakis 2008, 14; likewise: Privitera 2010, 32). Bringing these criteria into a quantified picture we essentially arrive at what is displayed in Fig. 1.

Architectural features thus could be described as *indirect* evidence since they might – via analogies – be related to food storage but as a characteristic by themselves could also belong to spaces that fulfilled other purposes. In many cases, however, a designation of storage rooms, even without pithoi or other storage installations, is certainly correct on the basis of architectural parallels: *e.g.* those west magazines at Knossos which were found empty.[30] Also, in some specific cases we must accept the interpretation of a particular space as a storeroom solely on grounds of architectural analogy: *e.g.* the kouloures discussed below.

Amongst *direct* testimonies there are those that inform us of the mere existence of storage spaces within the excavated building (like storage vessels without the exact find spots, traces of food processing, and written records

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28 That is significantly lower than the *choinix* (839 g) of Classical Greece: Jardé 1925, 129; Foxhall, Forbes 1982, 73.

29 The possible difference between the intended use of a room or structure when built and its actual use afterwards is discussed by Allison 1999, 4. See also Zabrana 2008, 379.

30 The documentation of the West Magazines 1-3 and 14-18 at Knossos does not mention any remains of storage vessels or installations (Evans 1921, 172, 448; 1928, 356, 358, 664, no. 1; 1930, 280; 1935, 264, 650, 706). Nevertheless – based upon the adjacent magazines with a identical shape – an analogous functional designation seems inevitable.

of transactions of goods[31]) and those that provide us with an exact localization of the storage room (such as organic remains, and storage vessels *in situ*).

2.3 *Capacities*

Regardless of how intact the archaeological record has come down to us, any result deriving from the calculation of storage capacities of a room or building has to be understood as a minimum, with very few exceptions. The core of the method pursued here lies in furnishing the identified storage spaces with a maximum number of pithoi in order to gain an idea of the maximum that could be stored.[32]

Reconstructing storage capacities depends greatly on an ability to estimate the volume of the storage vessels – predominantly the pithoi.[33] Different methods have been applied but the simplest one seems to be – provided that a whole cross section of the vessel has survived – a geometrical method based on rotation symmetry.[34] From the technical point of view this procedure is uncomplicated since corresponding computer programs do exist (see Fig. 2 for an example).[35]

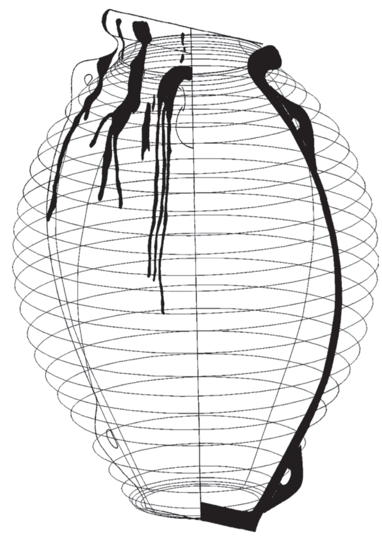

Fig. 2. Calculation of vessel capacity via CAD application.

As most of the Minoan pithoi are not published in detail, i.e. with a drawing of a cross section, the data provided by Christakis (2005) has to form the foundation for further considerations. Based on his information[36] it is possible to connect certain diameters of the vessels with a confined range of capacities in the following way:

small reference pithos:	dm 50 cm	=	vol 75 l (range 60-90 l)
middle reference pithos:	dm 70 cm	=	vol 225 l (range 200-250 l)
large reference pithos:	dm 80 cm	=	vol 450 l (range 400-500 l)

These calculations are meant to serve as a tool in cases where only basic information regarding size and capacity of Minoan pithoi are given in the excavation reports. In the study of archaeological evidence below, these three categories are used as reference figures.

31 *E.g.* the Linear B tablets from the so-called wine magazine at Pylos: Blegen, Rawson 1966, 344, 348-349.

32 The generated capacities are undoubtedly beyond archaeologically maintainable values; they form, however, the only useful platform of comparison between different buildings inasmuch as preservation conditions and formation processes are unique at every single site. On top of this, a certain degree of purpose and reason to build a storage room with certain characteristics – *e. g.* concerning maximum capacities – should be attributed to its constructors. On the formation of archaeological deposits: Schiffer *et al.* 2010.

33 Major efforts regarding Minoan pithoi have been made by Christakis leading to an extensive documentation and typology of the Cretan material. He defines 122 forms by their "functional performance characteristics": stability, capacity, accessibility, transportability: Christakis 1999, 1-20; 2005.

34 Hüttig 1999, 317-324. Geometrical methods have the great advantage – compared to physical ones – that they do not need the vessel to be completely intact.

35 All calculations conducted by the author of vessel capacities in this work have been made using a CAD application with the published cross sections of the pithoi.

36 For every form defined, Christakis (2005) gives the capacity and an example picture, from where the diameter can be measured. The total range of all the specimens recorded lies between 20 and 570 litres (with two exceptions reaching even 1,050 and 3,000 l respectively).

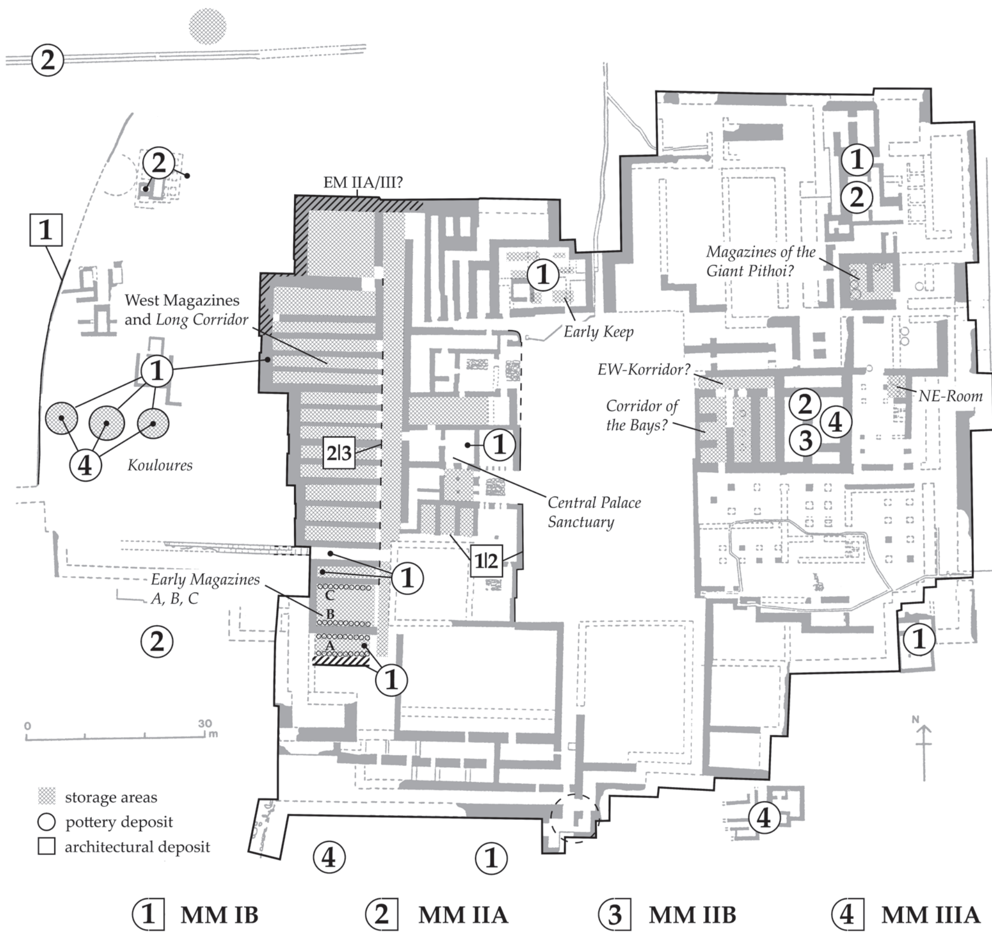

Fig. 3. Protopalatial evidence in the area of the palace at Knossos.

3. PALATIAL STORAGE CAPACITIES

3.1 *Knossos*

Following continuous use of the Kephala hill since early Neolithic times, a major milestone in the history of Knossos was reached after the beginning of the Middle Bronze Age (MM IB) with the construction of the so-called Old Palace. Its ground plan is difficult to determine since it has been affected massively by its successor, whose layout – dominated by a central courtyard – is, however, commonly assumed to resemble the older one (MacGillivray 1994). Fig. 3 depicts find spots in the area of the palace that have been ascribed to the Protopalatial period (MM IB-IIIA).[37]

It is not intended here to give a reconstruction of the complete layout of the complex with all its problems,[38] but rather to identify those spaces that can be connected with food storage. Unfortunately, the extensive lack of Protopalatial pithoi at Knossos[39] often forces us to assume the architectural setting of the room and its probable use

37 These data are based in large part on Evans 1921-1935 and MacGillivray 2007. Other works that have been used: Pendlebury 1929-1930; Overbeck, McDonald 1976; Mirié 1979; Driessen 1990; Momigliano 1992; Boskamp 1997; Panagiotaki 1998; Macdonald 2003; Schoep 2004; Macdonald, Knappett 2007.

38 The discussion concerning the south facade of the palace is of particular interest: Macdonald and Knappett (2007) postulate the wall south of the Early Magazine A as the Protopalatial facade. The abandonment of the Early Hypogaeum (Belli 1999) in MM IA, however, would point to extensive building activities already then in this area, perhaps in the course of the construction of the Old Palace.

39 Merely one pithos from the West Magazines (out of 162 specimens that were found *in situ* by the excavator: Evans 1935, 647-648)

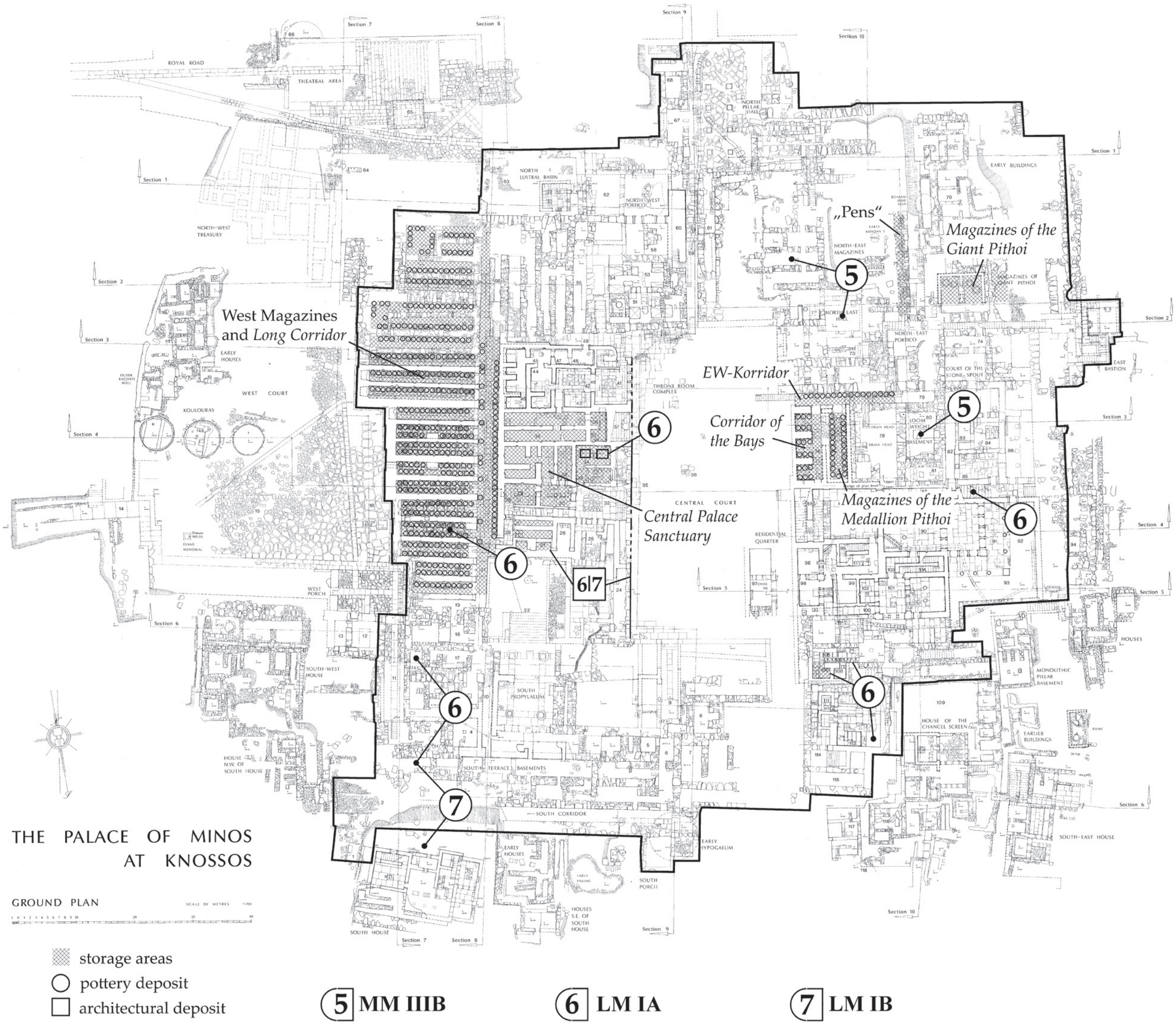

Fig. 4. Neopalatial evidence in the area of the palace at Knossos.

by analogy with the later phase. Using these assumptions, the conclusion is that the following spaces of the Old Palace have to be interpreted as storage rooms: the west magazines with the Long Corridor[40] and the northerly joining rooms, the three Early Magazines, the storage pits of the Early Keep (Evans 1921, 136-139), the East Pillar Crypt (Panagiotaki 1998, 49-51), the rooms north and south of the Central Palace Sanctuary (Driessen 1992, 104-105 fig. 9), possibly the rooms of the Magazines of the Giant Pithoi (MacGillivray 1994, 53), and the Royal Magazines (Evans 1921, 321; 1930, 270 fig. 183). Also, the kouloures had been constructed together with the palace when the west court was laid out; they will be discussed further below.

seems to be datable to MM III or earlier, Christakis 2008, 44.

40 The paved way running towards the west facade seems to be heading for a former entrance through the west magazine 2 (Evans 1935, 51, fig. 30; Schoep 2004, 255) which is why it is not included as a storage room here.

The total interior storage area of the Old Palace of Knossos therefore comprises about 1,300 square meters (without the kouloures) with overall dimensions of the complex of 12,380 square meters (ground floor), i.e. a ratio of 10.5 %. With what sizes of pithoi do we have to furnish these spaces to arrive at the above envisaged maximum storage capacities of the palace? A look at the Protopalatial forms of Christakis' categorization (2005) suggests surprisingly low pithos volumes – between 40 and 300 l – which is why the *middle size* reference vessel (cf. § 2.3) with 225 l volume and 70 cm diameter is used in the following calculation. Taking the Early Magazines into account, the area of the west wing could well have housed about 660 pithoi of the medium type, i.e. around 150,000 l capacity. Together with room for another 130 specimens in the area of the Royal Magazines and the Magazines of the Giant Pithoi, and about 20,000 l of storage room in the rectangular pits in the Early Keep (Branigan 1992), we derive a number of around 200,000 l internal capacity for the Old Palace at Knossos.

Regarding the Neopalatial period, we are faced with a somewhat superior set of archaeological evidence, although ceramic deposits datable to these phases remain scarce (Hatzaki 2007). Different studies give us insights into the architectural setting of the New Palace (Overbeck, McDonald 1976; Mirié 1979; Driessen 1992; Raison 1993; Niemeier 1994; Panagiotaki 1999; Macdonald 2002) (Fig. 4) which then reached its maximum extension of 13,650 m²– as did the settlement in the Kairatos valley.[41]

The pithoi of Neopalatial times – according to Christakis – comprised sizes between 30 and 575 l capacity, whereas the forms found in palatial contexts of northern central Crete range from 65 to 550 l (Christakis 2005). Only a few forms are assigned by him explicitly to particular west magazines, and in three cases their capacities range from 190 to 300 l, i.e. far below the biggest pithoi. Nevertheless, he suggests a mean volume of 550 l for the Knossian pithoi – a value that has been estimated much lower by Evans and Graham, while it has been slightly surpassed by Begg.[42] Taking into account the expertise concerning storage vessels of Christakis and Begg, the estimates of Evans and Graham seem too low; on the other hand, the evidence published by Christakis himself does not correspond to his high estimate. A calculation based on the *large* reference pithos (450 l/80 cm) mentioned above therefore will be applied here.

The number of pithoi that could have been placed in West Magazines 3-13 was first proposed by Evans and subsequently taken over by other scholars. The assumed 420 pithoi with a diameter of at least 80 cm – with a volume above 400 litres – would not fit into the magazines mentioned (cf. Fig. 4 with circles representing how the pithoi might fit in). Instead, just 300 specimens would fit the space provided by magazines 3-13 and the Long Corridor. Supplemented by another 135 vessels in the remaining West Magazines and the north-western rooms, there could have been 435 pithoi with a storage capacity of circa 200,000 litres. With a further 58 pithoi in the Royal Magazines, the four monumental pithoi in the Magazines of the Giant Pithoi, and about 20,000 l of capacity from the so-called pens in the north-east palace,[43] the calculation produces a total capacity of about 260,000 l for the interior storage areas of the New Palace at Knossos.[44] The total storage area therefore comprised 1,180 m², i.e. about 8.6 % of the palace ground surface.

It thus seems that the *interior* storage capacities of the palace at Knossos increased a little from Protopalatial to Neopalatial times, but – a crucial point to be taken away from this data – they remained within the same order of magnitude. It is important to mention the fact that, except for the pits in the Early Keep,[45] all the storage facilities *within* the palace walls were intended for short-term use, i.e. to serve the daily needs of the inhabitants. On the

41 Whitelaw (2004) assumes 14-18,000 inhabitants in this period.

42 Evans (1935, 647-648) assumed 185 l per pithos, Graham (1962, 130-133) just 132 l, and Begg (1975, 97) the highest volume of 586 l per vessel. All of them suggest space for 420 specimens in the West Magazines 3-13.

43 Boyd 1985; Hood 1985. For an alternative interpretation see Shaw 1985. The capacity of 20,000 l derives from a calculation assuming a filling height of one meter. If we suggest a whole number of 10 pens, as Hood (1985, 310) does, this would result in a volume of 34,000 l.

44 Some minor storage areas – like several rooms in the Central Palace Sanctuary, and two neighbouring niches (Driessen 1990, 106-107, fig. 10) – would increase this number slightly.

45 Judging from the architectural setting these pits were designed for long-term storage; cf. below: section 4.1.

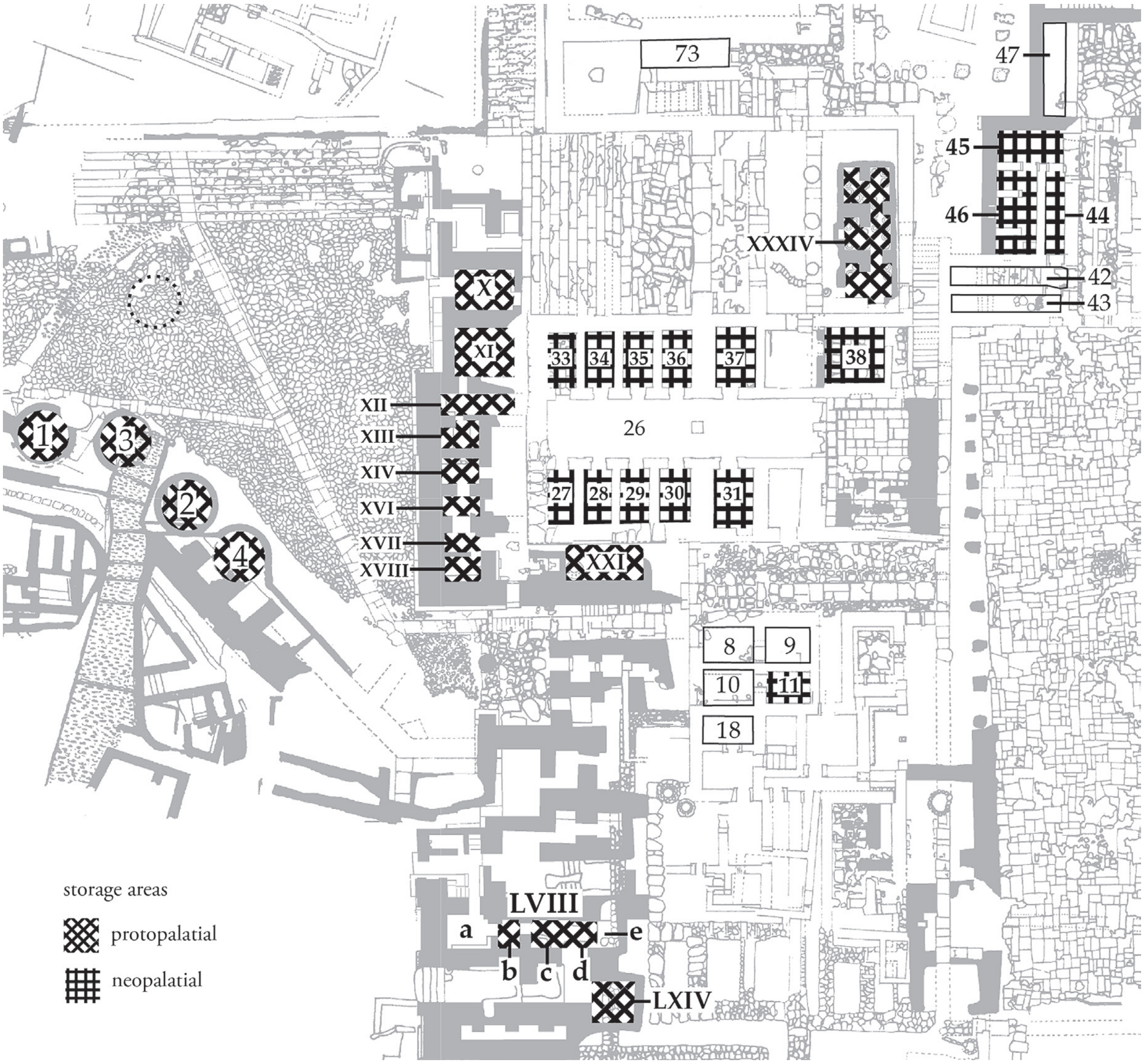

Fig. 5. Storage areas of the palace at Phaistos.

basis that 38 % of the storage capacities were used for cereals (cf. section 2.1.2), this would mean that between 130 and 170 people could have been supplied for one year in the Old Palace period, while this number increased to the range of 170-220 people in Neopalatial times.[46]

3.2 *Phaistos*

The first settlers on the hill of the later palace of Phaistos in the western Mesara can be traced back to the Final Neolithic (Vagnetti 1972-1973). The so-called First Palace was then erected in MM IB (Todaro 2009), followed by various phases of building modifications which seem to coincide with destruction events (Militello 2012). The caesura between the Protopalatial and Neopalatial palace is especially striking at Phaistos since here the destruction of the Old Palace in MM IIB necessitated a whole new construction of the building which was undertaken at the

46 Internal storage for cereals was calculated at 76,000 l in the Protopalatial period and 98,800 l in the Neopalatial period. The deviations derive from the different mass densities of wheat (1.6 l/kg) and barley (1.23 l/kg); cf. section 2.1.5.

beginning of LM IB (La Rosa 2002, 80). The destruction at the end of this phase finally ended the importance of Phaistos as a palatial centre even if settlement activity on the palace hill continued until Geometric times and beyond.[47]

Because of extensive levelling works carried out during the erection of the Second Palace it is difficult to get a picture of the dimensions of the First Palace, of which, apart from the well preserved west façade, only scattered remains have been documented.[48] Accordingly, identification of storage spaces and calculation of capacities is even more problematic.

Based on the finds of pithoi, the following areas can be identified as storage rooms of the First Palace: rooms X, XVI, XVII and XVIII (Fig. 5). Owing to their small size, and their proximity to these stores, rooms XI to XIV have also been classed as magazines (Pernier 1935, 239-269). All these were, however, used at the same time as stores for pottery as well as equipment, and it is, therefore, impossible to calculate their capacities for food storage. In contrast, the identification of room XXI as a food store is quite certain since it was the find spot for five monumental pithoi with a total capacity of 4,500-5,250 l (Pernier 1935, 277-279; Christakis 2005, 11, form 49). Another indisputable magazine for foodstuffs is room XXXIV, which housed 31 pithoi of *small* or *medium* size, i.e. with a total volume of between 2,500 and 6,000 l. Further pithoi were found in rooms LVIIIb-d and in room LXIV, adding up to a volume of about 1,000-1,600 l (Levi 1957-1958, 208-218; 1976, 114-116).[49] The minimum *internal* storage capacity of the First Palace at Phaistos is then envisaged as between 8,000 and 12,850 litres – i.e. a yearly supply for merely 8 to 11 people, with a 38 % ratio of storage room for cereals (Pernier, Banti 1951, 64, fig. 27; 87, 90-94; 115, fig. 63; 206).[50]

From Neopalatial times there are even fewer pithoi preserved to offer hints for the identification of storage rooms. Three pithoi were found in room 33, four in room 11, two in room 38, and the remains of single pithoi in rooms 27, 37, 43, and 88.[51] Regarding the west wing, it is, therefore, the architectural layout that forms the basis for identifying it as a storage complex (Hitchcock 2000, 132-145). Christakis calculates space for 100 examples of 300-350 l specimens, i.e. a total capacity of 30,000-35,000 litres (Christakis 2005, 9; 2008, 48).[52] Finally, about twelve pithoi of this form (3,600-4,200 l) would have fitted into room 38. Neglecting some other spaces that share certain formal features with storage rooms but do not allow for precise calculations (rooms 8-10, 18, 42, 44-47, and 73: cf. Christakis 2008, 48 and fig. 13), we end up at a total *internal* capacity of the Second Palace at Phaistos of between 34,500 and 40,100 litres – i.e. a yearly supply for about 22 to 34 inhabitants (Fig. 5).

At Phaistos, also, the end result seems to be a slight increase of *internal* storage capacities of the palace, though it must be emphasized that the poor preservation of the evidence does not allow for a high degree of accuracy. The order of magnitude for palatial self-sufficiency did, however, remain the same.

3.3 *Mallia*

Lying in the coastal plain north of the high plateau of Lasithi, the area of the palace at Mallia was first settled in the Early Bronze Age with the earliest architectural remains dating back to EM II (Hue, Pelon 1992, 36; Pelon 2006,

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47 For a survey of the post-Minoan settlement see Myers, Myers, Cadogan 1992, 235-241. The palace had presumably already lost a considerable part of its political and economic influence to the nearby settlement of Aghia Triada at the transition to the Neopalatial period: Carinci 1989, 80.

48 *I.e.* the west courts, the connecting stairs XXXI (6), the central court, rooms XLIV, XLV, XXXXII (80), and XXXI (48): Pernier, Banti 1951, 342-352.

49 Levi 1957-1958, 208-218; 1976, 114-116. Some single finds of storage vessels were made during the excavations, *e.g.* in rooms LI and XXVI; because of their minor importance to the total storage capacities of the palace they are here neglected.

50 For somewhat higher – though comparable – results for the number of people that could have been supported, see Militello 2012, 261.

51 The *medium* size pithoi found in room 11 even contained carbonized grain; rooms 43 and 88 seem, however, to have had functions other than food storage: Pernier, Banti 1951, 205, 244, 586.

52 The finding of carbonized grain in corridor 26 was interpreted as evidence for storage on the upper floor which is, unfortunately, difficult to verify: Pernier, Banti 1951, 85; Strasser 1997b.

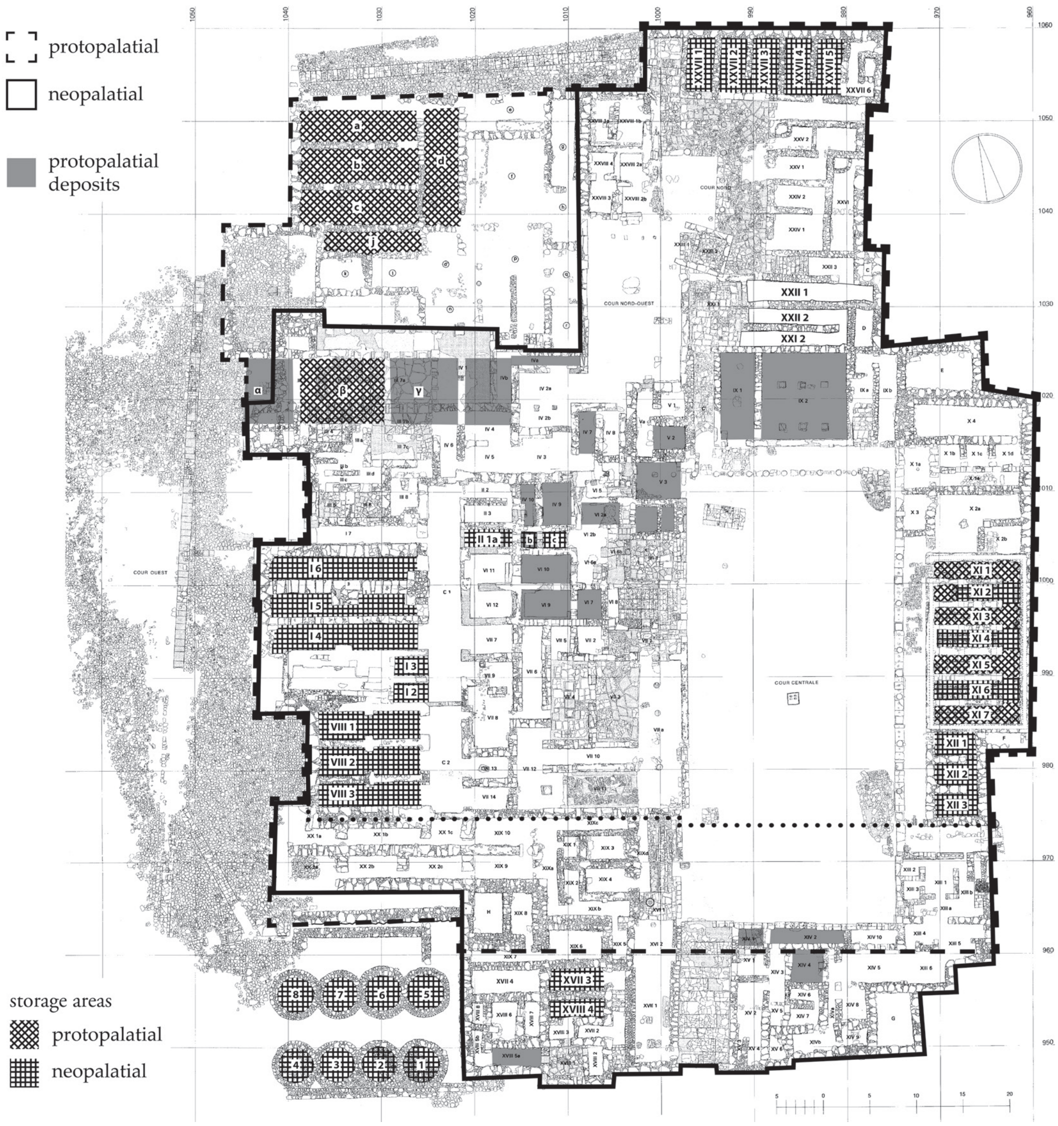

Fig. 6. Storage areas of the palace at Mallia.

143-145). Pottery places the erection of the First Palace into MM IA if not even to the end of the Early Bronze Age (Pelon 1983, 700; 1986; Spence 1990); its destruction occurred at the end of MM II (Pelon 2005, 190). In the Neopalatial period, three main building phases can be distinguished, of which the second (LM IA) is the one that saw construction of the Second Palace as it is visible today (Driessen, Macdonald 1997, 182). The striking lack of finds within the palace renders the date of its final destruction illusive. The pottery that has been found, however, points to a date in LM IA (Pelon 2005, 195).[53]

The remains of the First Palace are only sporadically preserved because of its complete destruction and later building activities.[54] Regarding the outer walls, a plan with dimensions resembling the successor building is usually

53 According to Pelon, a continuation of the pottery style into LM IB is quite possible: Pelon 2006, 150.

54 Against this, i.e. in favour of the west wing being of Protopalatial date: Chapouthier, Demargne 1962, 65-66. The utilization of rubble and mud bricks for the First Palace (instead of ashlar masonry) made an identification of Protopalatial deposits possible: Pelon 2006, 145-148; Schoep 2006.

suggested, with the exception of the southern façade which seems to have run somewhat further north of the silo complex (Fig. 6).[55]

The small number of Neopalatial pithoi found in the area of the palace[56] complicates the identification of storerooms; the layout, though, in some cases speaks for itself. With the analogy of the Knossian West Magazines, rooms VIII 1-3 and I 2-6 were undoubtedly used for storage. Their maximum capacity might have been 16,500-38,250 litres.[57] Furthermore Quartier XI was clearly a complex of magazines – without question intended for the storage of liquids, probably oil, as grooves on the benches and the floor leading to a receiver vessel indicate (Chapouthier, Demargne 1942, 1-5; Pelon 1980, 198-203). In a second phase, the floors were slightly elevated and now the space was used for the storage of solid food, evidenced by the finding of carbonized grain within some smaller pots.[58] Taking the grooves as indicators for the arrangement of the pithoi we arrive at a total number of 106 vessels equalling 12,700 l for the whole complex.[59] Finds of pithoi in the Northeast Magazines (XXVII 1-6) characterize them as storage rooms as well although the state of publication makes it difficult to conduct precise calculations (Chapouthier, Demargne 1942, 15-16; Pelon 1980, 91-94). Maximum utilization would allow for the accommodation of 42 pithoi of the *small* reference type – i.e. a capacity of about 3,150 l. Finally, eleven small and six middle-sized pithoi in rooms II 1*α-γ* suggest a storage area, which would have had a capacity of 2,175 l, with a maximum utilization of even 4,425 l. A great number of other spaces reveal features of storage rooms,[60] but the lack of pithoi throughout means they cannot be integrated into our calculations.

Given the poor preservation of the architectural remains of the First Palace most of the evidence surveyed above must be assigned to the Second Palace period. Only the eastern magazine complex (Quartier XI) seems surely to have been used for the same purpose in both periods. Accordingly, the *internal* storage capacities of the First Palace at Mallia would have totalled 12,700 litres – i.e. a yearly supply for eight to ten people – while in Neopalatial times an overall volume of between 34,525 and 58,525 litres – equalling 22 to 34 years of rations – has been computed.

As at Phaistos, a modest increase of capacities from Protopalatial to Neopalatial times seems to have taken place at the palace at Mallia. I have the strong feeling, though, that the values – especially regarding the First Palace – have to be augmented, although on the other hand that would not change the order of magnitude either.

4. BULK GRAIN STORAGE IN BRONZE AGE CRETE

4.1 *Technical principles of bulk grain storage*

A vital cause of the deterioration of foodstuffs is the activity of microorganisms–i.e. bacteria and fungi. All methods of preservation, thus, aim for the reduction or even termination of these activities in order to extend the shelf life of the aliment. Until not long ago, the lack of the refrigerator and freezer forced man to think of alternative solutions to achieve this objective, such as smoking, boiling down, drying, cooling, or salting.[61] In short, we can distinguish

55 Pelon 1980, 223 no. 4; Driessen, Macdonald 1997, 185; Schoep 2004, 254, fig. 5. A different approach following Chapouthier and Demargne (1962, 66) is presented by van Effenterre (1980, 316-317) and Moody (1987, 239 fig. 1): see Fig. 6.

56 According to Christakis only 40 middle-sized and 5 large pithoi were documented, while 546 middle-sized specimens would have fitted into the Neopalatial palace: Christakis 2008, 50.

57 This approximate value is based on the fact that at most either 220 *small* pithoi (at 75 l) or 170 *middle-sized* pithoi (at 225 l) would have fitted into the west magazines.

58 The 'liquid phase' seems to be dated to the First Palace, while in Neopalatial times solid food was stored: Pelon 2002, 118.

59 In that case a mean vessel volume of 120 l was adopted – in accordance with a diameter of 55 cm that could be measured from the distance between the grooves mentioned.

60 Rooms XII 1-3 (Chapouthier, Joly 1936, 9. 30; Chapouthier, Demargne 1942, 6; Pelon 1980, 203-205), room β (Chapouthier 1938, 13-15), rooms XVII 3 and XVIII 4 (Chapouthier, Demargne 1962, 8, 12; Pelon 1980, 213, 219-220), rooms XXII 1, 2 and XXI 2 (Chapouthier, Joly 1936, 21), rooms a-d (Pelon 1980, 236-237, 239).

61 For the biochemical functionality of different forms of food preservation, see Perco 2010, 1050-1059.

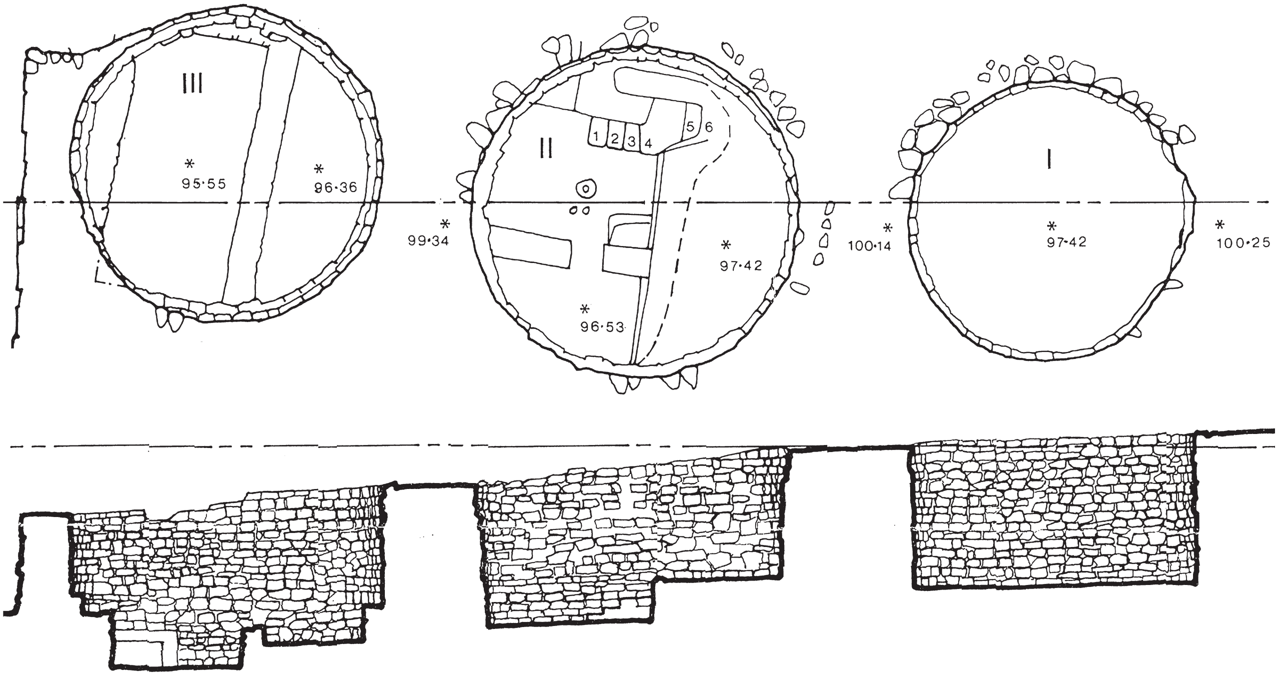

Fig. 7. Ground plan and section of the kouloures on the Knossian west court.

chemical and physical preservation, both of which try to destroy microorganisms. One powerful method is the reduction of humidity in the stock that can be achieved by heating, salting, sugaring, or smoking.[62] Fungi, the major threat for food stuffs, do not cease their activity before the humidity has fallen below a rate of 13.5 % (Abdalla *et al.* 2001, 76). Secondly, temperature has a substantial influence on microbiological activity, and, no less importantly, on insects which cease activity below 18-20 °C, although they can survive also at lower temperatures (Sigaut 1980, 12). A third preservation method is to create an artificial atmosphere, either through the external introduction of gas ('controlled atmosphere') or through the respiration process of the product ('modified atmosphere') (Adler 1998, 278; for the terminology, Calderon 1990, 4-5).

Since staple storage generally allows few ways to influence the temperature or humidity level, this last method perfectly suits bulk goods. A distinction between *hermetic* and *ventilated* facilities is particularly important with regard to storage under modified atmospheres (Sigaut 1988). Ventilated stores need to be kept cool and dry or the microbiological activity and growth of fungi increases, keeping in mind the additional danger of self-ignition (Mills 1989, 11-13). Accordingly, this technique is applied with greater success in a cool climate. Hermetic storage on the other hand operates by minimizing the oxygen content in the silo to such an extent that microorganisms cease their activity or even die; the accumulation of carbon dioxide can develop an additional toxic effect on pests.[63] A second result of this oxygen-poor atmosphere is the reduction of the metabolism of the stored products, stopping their deterioration (Adler 1998, 277). In this manner grain, for example, keeps its germination capacity and thus its potential application as seed (Storey 1980, 311; Pons i Brun 1998, 125). The general difference between hermetic and ventilated storage is that the latter can be used on a daily basis whereas the former needs to be kept sealed until the final emptying of the silo (Seeher 2006, 49). Opening the air-tight store destroys the artificial atmosphere and

62 The amount of water available in the stock determines the survival of microorganisms: Perco 2010, 1151. During smoking the acids contained in the smoke have an additional antibacterial effect: Glatz 2010, 576-577.

63 Bailey 1965; Navarro, Donahaye, Fishman 1994; Navarro 2006. The development of an oxygen-poor atmosphere is additionally accelerated by the respiration of the stored products, at least until the oxygen is consumed: Seeher 2000, 266.

allows for an abrupt rise in biological activity. Even if the silo is closed again heavy losses of the staples cannot be prevented so that a complete emptying is necessary (Seeher 2000, 268-269; Willerding 1989, 17). The suitability of underground pits for long-term storage has also been confirmed by several experimental archaeological studies (Reynolds 1974; 1979; Hill, Lacey, Reynolds 1983; Fenton 1983; Currid 1989).

The idea of air-tight (grain) storage has a long history. Various ancient authors dealt with the question of optimal food storage methods. Pliny states that storage in underground pits would be most suitable for grain (Plin., *Nat. Hist.* 18, 73). Likewise, the functionality of hermetic stores for the reduction or termination of pest activity was known,[64] as well as the positive effect it had on the duration of edibility and germination capacity.[65]

4.2 *The kouloures*

Excavations at the palace of Knossos in 1907 revealed the first of a group of stone-walled pits that would later be named kouloures (Karo 1908, 120).[66] The name was given to the four Knossian examples as well as to a further four (or five) at Phaistos and a final one in the so-called *petit palais* at Mallia. For the sake of brevity they will not be presented in detail here (Strasser 1994; 1997a). The three circular pits (Fig. 7) possess diameters between 5.4 and 6.2 m, while their depth lies around 3 m (Evans 1935, 62; for further reference, see: Evans 1921, 207-208, 318; 1928, 224, note 6; 609-610; 1930, 350, 365-366; 1935, 61-66, 100-104, 118, 128, 179). The walls were built of rubble stones without any traces of plastering, and no pavement or ground plaster was documented. MM IA buildings directly underneath kouloures 2 and 3 point to a construction date in MM IB (Pendlebury, Pendlebury 1930, 53-59; Strasser 1997a, 75), while their abandonment must have taken place before they were covered by the new pavement of the west court in MM IIIB.[67]

The fourth kouloura at Knossos is located on the north-western periphery in the so-called theatre court and seems to be slightly older: according to Evans it was built around MM IA and paved over already in MM IIA (Evans 1930, 247; 1935, 51 fig. 30; 247). It measured 6.45 m in diameter and also had no wall plaster.[68]

Similarly to the Knossian examples, the four kouloures at Phaistos were constructed on the west court of the palace. The diameters of the unplastered ring walls averaged 4 m, with a depth between 2.3 and 2.8 m. (Pernier 1935, 181; Levi 1976, 349-358, pl. W). The period of use of the pits covers Levi's Phases II and III, i.e. MM IIB to MM IIB-IIIA, followed by their abandonment when the Old Palace was destroyed (Levi 1976, 353-358). The recently postulated existence of a fifth kouloura a little further north of the others (Damiani Indelicato, Chighine 1984) is hard to confirm without further soundings under the court pavement. The fact, however, that the older pavement is flush with the wall section under discussion seems rather to suggest a retaining wall for the west court (Levi 1965-1966, 344-345; for an alternative interpretation as an above-ground structure see Yiannouli 2009).

Finally, in the so-called *petit palais* or House E south of the palace at Mallia, a circular pit was excavated (Deshayes, Dessenne 1959, 109-110) and subsequently termed a kouloura (Bradfer-Burdet 2005). The structure, however, exhibits some major differences to the aforementioned examples, *e.g.* its location *inside* a building and the detection of original plaster on the walls, and so has to be excluded from this group.[69]

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64 Varro (*Rust.* 1, 58) states that the opening of air-tight granaries is dangerous, undoubtedly referring to the high carbon dioxide level. See also Plin., *Nat. Hist*. 18, 73.

65 Theophrastus (*H. Plant.* 8, 11, 5) mentions a granary which kept grain still germinable after 40 years, and edible even after 70-80 years. See also Varro, *Rust.* 1, 57.

66 Karo 1908, 120. The name was given to them – according to the excavator (Evans 1935, 61) – by the Cretan workers who associated the circular walls of the pits with the baked sesame rings (*koulouria*) that are sold on Greek and Turkish streets still today.

67 A somewhat earlier termination of use – at least in view of their original purpose – is probable, given that the ceramic finds date mainly to the MM II phase (kouloures 2 and 3). Kouloura 1 might have been in use a little longer since MM III material prevails: Evans 1935, 63-64.

68 The measurements are based upon the ground plan by Hood and Taylor (1981). Today the kouloura is completely covered and its position can be judged only approximately.

69 Likewise "ένα είδος 'κουλούρας'" (Tsipopoulou 1988, 33) at the site of Aghia Photia – a ring wall with 2.5 m diameter directly outside the rectangular building – cannot be included since it was built entirely above ground.

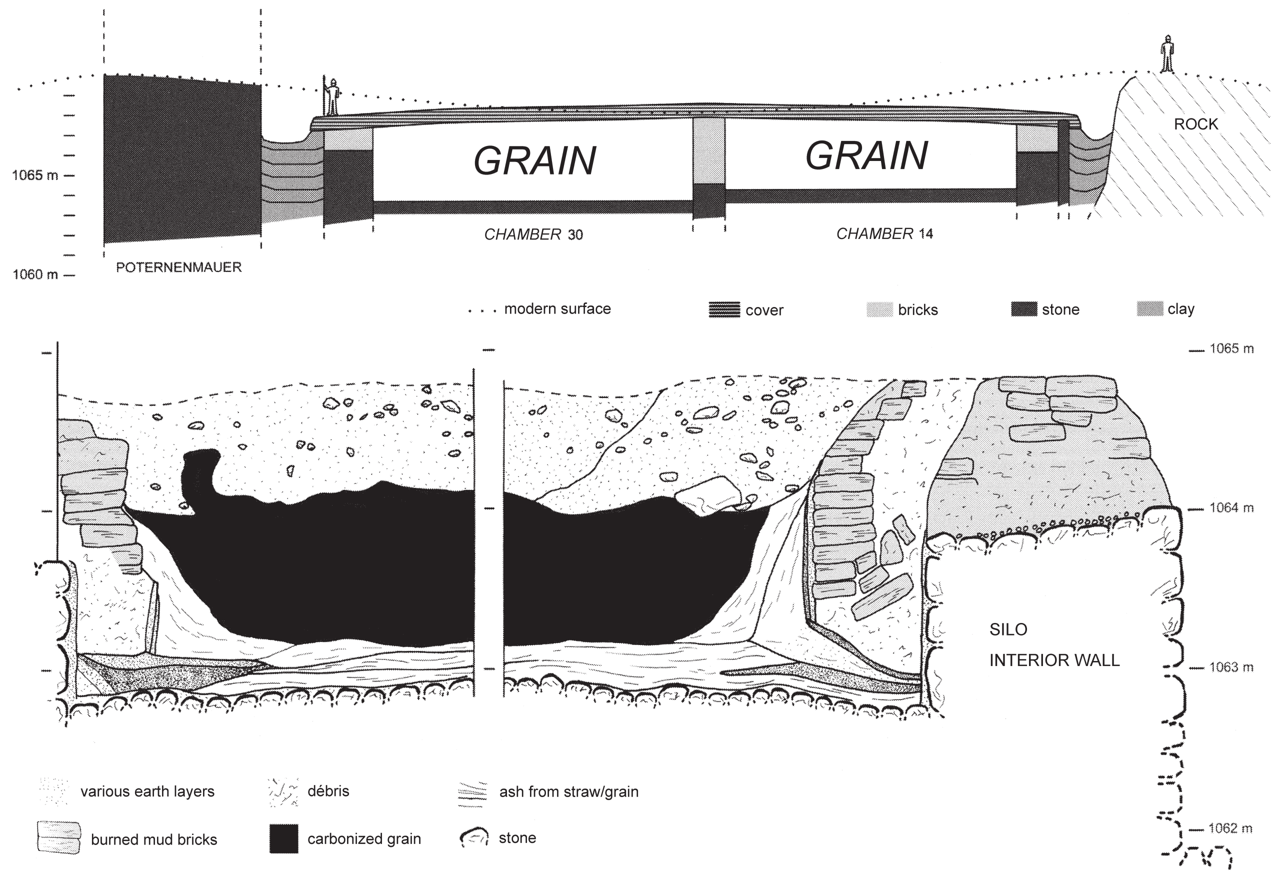

Fig. 8. Hattuša, silo complex at the *Poternenmauer*: a) reconstruction of transversal section, after Seeher 2006, 75 fig. 39; b) section through chamber 12 with black layer of carbonized grain, after Seeher 2006, 57, fig. 12.

4.2.1 *Interpretation as granaries*

Various functions have been proposed since the first example of the kouloures was unearthed, and no consensus has yet been reached.[70] Their interpretation as domestic rubbish pits (Evans 1921, 207-208; 1935, 61-65; Pendlebury 1939, 129) or receptacles for ritual offerings (Alexiou 1964, 140-141) is quite inconceivable because of the negative impact such structures would have on the aesthetics of the west courts and the main façades of the palaces. A strong argument against their identification as cisterns is the absence of hydraulic plaster along the walls.[71] The recently proposed interpretation as planting pits for trees connected to the Minoan tree cult is based mainly on iconographic evidence, especially the 'Sacred Grove and Dance Fresco' from Knossos (Carinci 2001). It depicts a celebrating crowd that gathered around two or three trees.[72] Paved ways crossing the scene have been connected to those in the west courts of Knossos and Phaistos. The fresco, however, has been dated to the Neopalatial period and is thus much later than the kouloures (Immerwahr 1990, 173 no. 16). One practical aspect that speaks against this interpretation is the fact that the surrounding walls continue to the ground level of the pits – a feature that would not have been necessary given their diameters of more than six meters.

70 See the discussion between Strasser (1997a) and Halstead (1997); Privitera 2014.

71 As had already been observed by Evans (1935, 65) followed by Alexiou (1964, 140) and Carinci (2001, 46). Differently for Phaistos: Pernier 1935, 181.

72 Evans (1930, 66 pl. 18) reconstructed two trees while the reconstruction of Marinatos (1987, 142, fig. 7) shows three specimens. For the Minoan tree cult, see: Nilsson 1950, 262; Marinatos 1989, 136.

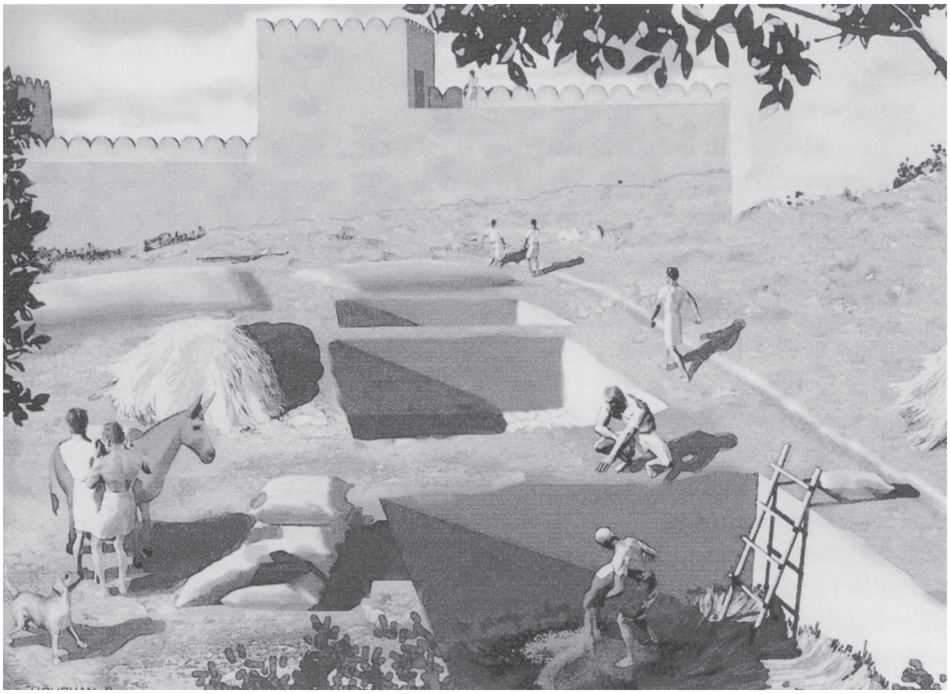

Fig. 9. Hattuša. Reconstruction of silos on lower plateau of Büyükkaya, after Seeher 2000, 277, fig. 5.

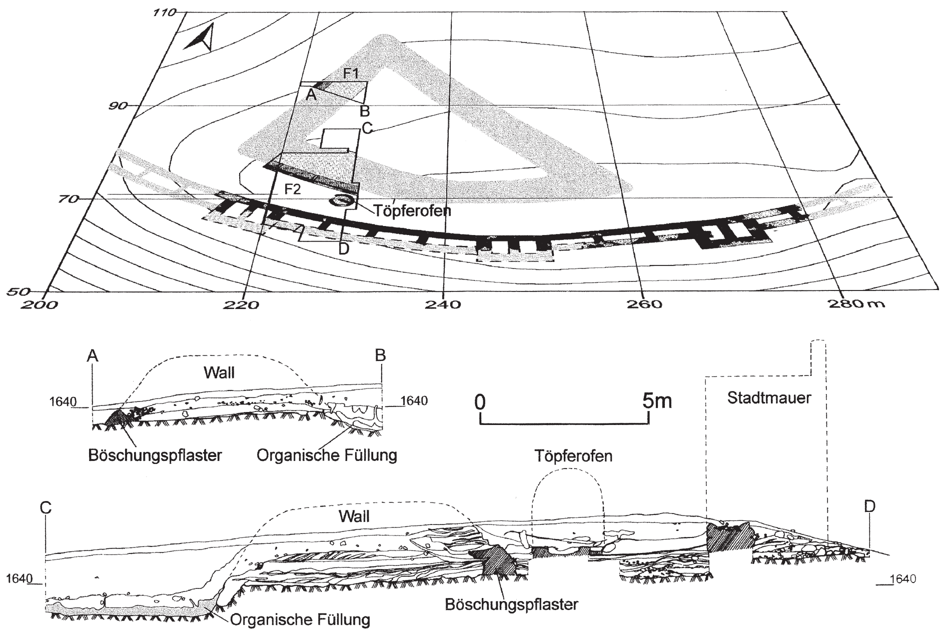

Fig. 10. Sarissa/Kuşaklı. D-shaped granary at the south corner of the settlement, after Mielke 2001, 238, fig. 5.

The interpretation favoured here is that the kouloures were granaries. The idea of bulk grain storage is not new to Minoan archaeology although the first building designated as a granary, the Early Hypogaeum, in fact does not seem to be one.[73] Since Levi turned towards the granary thesis for the Phaistian kouloures (Levi 1961-1962,

73 Various interpretations have been put forward (Belli 1999): entrance of an earlier building (Evans 1921, 103-106), tholos grave (Dawkins 1908, 325; Karo 1908, 120-126), granary (Lawrence 1957, 298, no. 3; Hutchinson 1962, 163), and cistern (Dawkins 1910, 362; Karo 1910, 148; MacGillivray 1994, 54). The spiral stair along the wall points to a quite highly frequented storeroom which would not be possible in the case of underground grain storage (cf. section 4.1); accordingly an interpretation as a cistern seems to be most probable.

669-670) the interpretation has remained more or less for some decades (Levi 1976, 352; Damiani Indelicato, Chighine 1984, 229-230; Branigan 1987, 248; Moody 1987, 236, tab. 1; Hitchcock 2000, 174) and was again extensively dealt with – rather critically – by Strasser.[74] His arguments against the granary hypothesis are: the technical shortcomings of the kouloures in subterranean grain storage; the lack of *secure* archaeological and iconographical analogies; the absence of organic remains; and the presence of a stone channel leading to the north-western kouloura at Knossos. While I agree that iconographic and organic evidence with regard to granaries is wanting, this is, however, an argument *e silentio* and could be used against their interpretation as cisterns or tree pits as well. The question of the single stone channel mentioned is difficult to resolve since the area where it ran has been substantially reconstructed.[75] Given the sloping down of this area to the west it might also be the case that the channel was in fact leading water *away* from the pit to prevent water from leaking into the granary. Without precise measurement of the levels, though, this must remain hypothetical. Halstead has attempted to qualify some of the points concerning the technical shortcomings of the kouloures as granaries as argued by Strasser, i.e. the lack of a cover or plaster on the walls, as well as the unnecessarily huge dimensions of the pits.[76] The following survey of several archaeological sites with storage deposits resembling the Cretan kouloures gives us more insight into the issue and will back up their interpretation as granaries. It is, however, not my intention to establish a direct cultural connection between Crete and other probable analogous sites.

Various storage facilities at the Hittite capital Hattuša were undoubtedly used for grain. The so-called silo complex at the *Poternenmauer* comprised 16 basement chambers of remarkable size that were reachable only from above (Seeher 2000) (Fig. 8 a-b).

Fig. 11. Kaman-Kalehöyük. Aerial view of round structure 1, after Fairbairn 2005, 132, fig. 3.

Inside of these the excavators found huge amounts of carbonized grain – Einkorn and hulled barley – that had been lying there *in situ* since the destruction of the building in the 16th century BC (Seeher 2002, 77-78; for the stored grain cultivars, Neef 2001). Although the walls were covered with clay plaster, the actual means by which the chambers were rendered air-tight was a straw layer surrounding the grain that in a decomposed condition formed an impenetrable wrapping. The floor was covered by several layers of this material, each separated by an earth layer that was filled in when the pits were emptied and prepared for the next use. Also, there was no wooden roof construction, just a similar layer of earth that was able to compensate for potential setting processes (Seeher 2002, 74-75). This functionality is crucial for understanding the kouloures since it fits perfectly with their architectural setting and could be the key to grasping their meaning. A second group of storage facilities was found on top of the Büyükkaya: eleven rectangular pits that were sunk into the ground and furnished with a rubble stone pavement (Seeher 2000, 270-278) (Fig. 9). Pottery finds indicate a date of advanced to late 13th century BC.

74 Strasser (1997a) argues, in accordance with Evans, for an interpretation of them as pits for rubbish or waste water; today, however, he is convinced of their interpretation as tree-pits (pers. comm.).

75 Today just above one meter of the channel is visible under the later pavement (cf. likewise Hood, Taylor 1981). In Evans' plan it is traced for a length of about 9.5 m: Evans 1935, 51, fig. 30.

76 Halstead (1997) states that neither an extra built cover nor wall plaster would be necessary for long term food storage. Regarding the size of the kouloures, he points out that each pit would not have had to be filled at the same time or for the same purpose.

Layers of organic material covering the floors – again Einkorn but also straw – point to a similar *modus operandi* to the silo complex. Additionally, traces of degradation on the surface of the ground stones are consistent with the formation of lactic acid during the fermentation of the organic hull.

At another Hittite settlement, Sarissa/Kuşaklı (late 16th century BC), a storage facility consisting of a D-shaped earth wall came to light that functioned like modern earth-covered bunkers (Mielke 2001) (Fig. 10).[77] Humified material in the inner area undoubtedly derives from the former organic filling whose capacity originally exceeded the Minoan kouloures by far.[78]

The last Hittite site to be mentioned in this survey is the settlement of Kaman-Kalehöyük. About 4,000 small-sized earth pits (diam. maximum 2 m) were documented in addition to five 'round structures' of much bigger dimensions (Fairbairn 2005; Fairbairn, Omura 2005).[79] The largest, round structure 1, had a diameter of 16 m and a capacity of about 400 m^3 (Fig. 11). In contrast to the other pits it had a rubble wall and stone pavement while simultaneously lacking any plastering, as is the case with the kouloures. Remains of barley and a straw layer in one of the small pits as well as wheat on the ground of round structure 2 clearly point to an interpretation of the large pits as grain silos (Fairbairn, Omura 2005, 19-20).[80] In the excavators' opinion they were intended for long term storage and not for daily use.

Several round pits from Bronze Age phase IVb (18th-17th centuries BC) at Aphrodisias in Caria also have an analogous appearance (Kadish 1969; 1971). Within these, thick ash layers with a 'fibrous consistency' were documented that seemingly were formed by the remains of a straw lining that protected the stored grain (Greaves 2008, 260). Rubble walls or plastering were obviously not considered necessary.

The list could be continued with various other examples of underground grain storage, ranging from Chalcolithic pits with unplastered stone walls at Gilat in Israel,[81] to the *bothroi* of the Early Helladic and Troian cultures (Hutchinson 1935; Strasser 1999) and to much later specimens at Megara Hyblaia on Sicily (Vallet, Villard, Auberson 1976, 270; De Angelis 2002, 301).

All these structures had the same function – to fulfil their builder's intent to secure the food supply in the long term. The Hittite examples in particular give clear evidence for the technical suitability of unplastered pits to preserve grain efficiently and over a long range. Even if absolute certainty cannot be reached – given the lack of organic remains *in situ* – there is a high probability that the Minoan kouloures were in fact granaries.

4.3 *The silo complex at Mallia*

A highly interesting group of eight round structures was unearthed in the south-west corner of the palace at Mallia and soon recognized as granaries (Pelon 1980, 45, 222; already earlier: Graham 1962, 135, no. 11, fig. 58; Renfrew 1972, 292) (Fig. 12).[82]

As the buildings are not constructed below ground – as the kouloures were – they must be discussed separately. The plastered[83] rubble stone walls probably formed the basis for a mud brick construction. Different reconstructions have been suggested, ranging from beehive-shaped (Graham 1962, fig. 58) to cylindrical (van Effenterre 1980, 335,

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77 For comparable modern facilities see: Champ, McCabe 1984, 500, fig. 1. A massive granary of this type with a length of over 13 m and a depth of about 2.7 m was also excavated at the south lakes at the site of Hattuša. A layer of organic material testifies again to the aforementioned method of surrounding the grain with an organic yet impermeable wrapping: Seeher 2006, 66-68.

78 Mielke (2001, 241) calculates a filling depth of 3.15 m.

79 A similar accumulation of several round and rectangular pits of small size has been recorded at the Hittite settlement of Alaca Höyük in central Anatolia. They possess diameters of about 2.5 m, rubble stone walls, and, in contrast to the kouloures, a plaster coating: Koşay, Akok 1973, 58, pl. 87-88.

80 It has to be admitted that the grain found in the small-sized pit no. 2548 seems to be an exception since the normal use of these small structures was for the deposition of rubbish.

81 Levy *et al*. 2006, 95-137, 175-176, pls. 5, 9-11. For an example from Israel dating back to the Iron Age: Currid 1989.

82 The first interpretation of the excavators had been as a *château d'eau*: Bequignon 1929, 524; Chapouthier, Demargne 1962, 17-19.

83 According to Bradfer-Burdet (2005, 42) the plaster was not watertight.

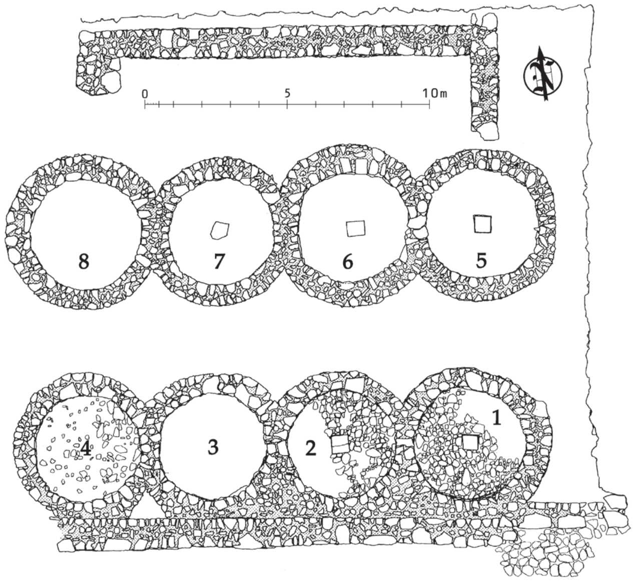

Fig. 12. Mallia. Silo complex at the southwest corner of the palace, after Pelon 1980, plan 28.

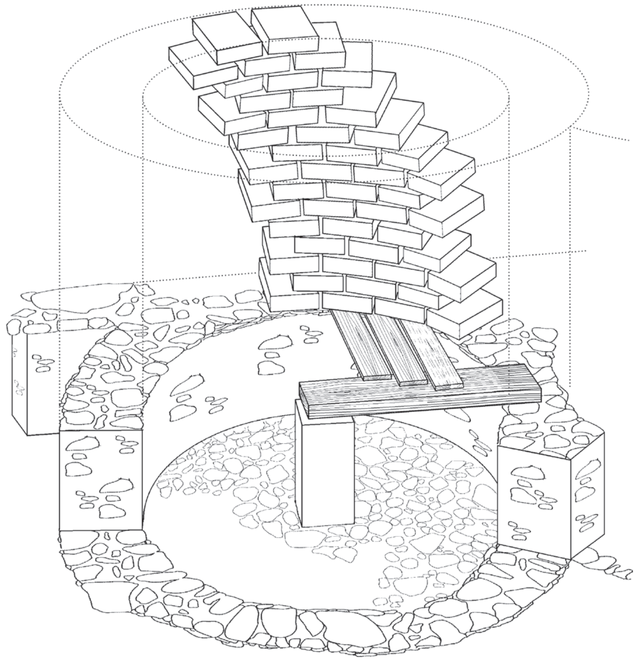

Fig. 13. Hypothetical reconstruction of one of the granaries at the palace at Mallia.

fig. 457) and even integration within a closed building was proposed.[84] In five cases a central pillar was preserved that presumably supported an inserted floor for aeration since, with the structures' diameter below 4 m, the roof construction would not need an extra support (Bradfer-Burdet 2005, 43. Differently: Pelon 1980, 225; Strasser 1997a, 79) (Fig. 13). A stone threshold implies that the complex was accessible from its north-western corner.[85] The ceramic finds point to Protopalatial use although MM III pottery in the destruction debris would allow for a continuation of use into the first phase of the Neopalatial period (Pelon 1980, 31; Driessen, Macdonald 1997, 182).

Given that the complex was built above-ground, it is clear that we are dealing with ventilated storage. This method of storing grain in bulk has many parallels in the Mediterranean world. An early example is the famous granary model from Phylakopi on Melos which shows a row of seven cylindrical buildings surrounding an open court. A similar model – this time with beehive-shaped granaries – from El Kab (Egypt) confirms the interpretation (Oelmann 1925). An archaeological counterpart was found at Beth Yerah (Khirbet el-Kerak, Israel) where nine silos border a central area. Evidently they also had inserted floors supported by walls protruding from the outer wall of each structure (Strasser 1997a, 88-89, fig. 12, after Mellaart 1966, 75, fig. 28; for the chronology of Beth Yerah, Negev, Gibson 2001, 88-89).

A group of silos that matches the layout of the complex at Mallia was excavated at Tell el-Dab^{c}a, part of a huge storage district. The capacity of the whole facility is estimated at more than 5,000 m^3 and it is interpreted as a military supply centre (Bietak, Dorner, Jánosi 2001, 60 fig. 19; Bietak, Forstner-Müller 2007, 38-41; Bietak, Marinatos, Palivou 2007, 17, fig. 7).[86] At Tell Edfu in Upper Epypt a series of round structures with diameters up to 6.5 m also has been interpreted as granaries (Möller 2005-2010), as were also 19 silos at Middle-Chalcolithic Tel Tsaf where the interpretation is confirmed by the finding of carbonized grain in one of them (Garfinkel, Ben-Shlo-

84 This last reconstruction can be viewed in a model exhibited at the museum on site.

85 Access from inside the palace, however, has been suggested on the basis of the π-shaped wall abutting at the north side of the silos: van Effenterre 1980, 335, fig. 457.

86 The complex has been dated to the middle 16th century BC.

mo, Kuperman 2009, 316). The list of parallels – archaeological (Marinatos 1946; Currid 1985; Llop 2005) and ethnographical (Giles 2009; Triantafyllidou-Baladie 1979; Miret i Mestre 2005) – could be expanded further, but for the time being it suffices to attest that above-ground circular granaries have a long history in being a preferred method for bulk storage throughout millennia. This 'popularity' is certainly connected with its suitability for daily use since the stores could be – and had to be – opened at any time.

4.4 *Capacities of the granaries and their operational framework*

The cylindrical shape of the kouloures makes calculating their volumes simple; Table 6 gives a synopsis.

Knossos[87]	
Kouloura 1: 58,880 l	Kouloura 2: 82,630 l
Kouloura 3: 72,000 l	NW-kouloura: 86,660 l
Total: 300,170 l[88]	
Phaistos	
Kouloura 1: 31,120 l	Kouloura 2: 25,310 l
Kouloura 3: 25,750 l	Kouloura 4: 22,030 l
Total: 104,210 l[89]	

Table 6. Capacities of the kouloures at Knossos and Phaistos.

Recalling the results of the considerations about the Minoan diet (§. 2), it is possible now to convert the capacities into the number of people that could have subsisted on these stocks.[90] In Table 7 different time scales have been computed to get a better idea of the dimensions we are dealing with.

RATIONS FOR			
1 DAY			
Knossos	197,480	176,570	244,040
Phaistos	68,560	61,300	84,720
1 WEEK			
Knossos	28,210	25,220	34,860
Phaistos	9,790	8,780	12,100
1 MONTH			
Knossos	6,580	5,890	8,130
Phaistos	2,290	2,040	2,820
1 YEAR			
Knossos	540	480	670
Phaistos	190	170	230
	Einkorn	Emmer	barley

Table 7. Number of people that could have subsisted by grain stored in the kouloures.

87 These numbers also take into account that the organic wrapping to protect the grain has to be subtracted from the total diameter and height. The thickness of the wrapping was determined to be 10 cm, although both more (Seeher 2006, 78) and less (Willerding 1998, 17) has been recorded.

88 Different results from calculations by Curtis (2001, 262) with an average capacity of 112,710 l for every single kouloura at Knossos are unfortunately not reproducible.

89 Militello (2012, 259 tab. 8.3) calculates a total capacity of 120,000 l for the kouloures at Phaistos.

90 In order to produce the daily demand of 540 g of wheat (Einkorn or Emmer) or 610 g of barley it takes 1.5 l Einkorn, 1.7 l Emmer, or 1.25 l barley–each one stored "in the glume".

As we see, the numbers are astonishingly low: only 480 to 670 people could have been supplied for one year through the Knossian kouloures. The picture at Phaistos is much reduced, where yearly rations even range between 170 and 230.

Depending on the height of the upper part of the silos at Mallia, the complex as a whole had a capacity between 186,000 l (with two meters height) and 279,000 l (with three meters height).[91] Table 8 is based on the same premises as those considered for the kouloures.

	RATIONS FOR		
	1 DAY		
2 m-silos	122,370	109,410	151,220
3 m-silos	183,550	164,120	226,830
	1 WEEK		
2 m-silos	17,480	15,630	21,600
3 m-silos	26,220	23,450	32,400
	1 MONTH		
2 m-silos	4,080	3,650	5,040
3 m-silos	6,120	5,470	7,560
	1 YEAR		
2 m-silos	340	300	410
3 m-silos	500	450	620
	Einkorn	Emmer	barley

Table 8. Number of people that could have subsisted on grain stored in the silo complex at Mallia.

Also in the case of the silo complex, the number of people that could be supported over a year did not exceed 620 (with a 3 m high upper structure), which certainly did not exceed far beyond the population of the palace and the surrounding settlement.

5. CONCLUSIONS

We can infer that the *internal* storage rooms of the Minoan palaces, i. e. the magazines suitable for daily use, throughout their history were meant to secure their own self-sufficiency.[92] In the cases of Phaistos and Mallia even that goal is somewhat questionable given their low capacities, especially during Protopalatial times, although this in part may be affected by their bad state of preservation. A slight trend in increasing capacities from the Old to the New Palace period can be seen, but is has no effect on the overall conclusions.[93] This leads us to the assertion that an economic system of general redistribution of subsistence products to a major part of the wider population is, in contrast to the redistributive system of Mesopotamian Larsa,[94] highly improbable.[95] Rather, it was the residents of

91 The question of the height of the structure cannot be answered definitely, but the wall thickness of up to one meter would allow for the 3m variant.

92 Differently, i.e. with the early palaces as guarantors for a certain community-wide safety: Walberg 1995, 158.

93 This picture is neither changed by constructions like the Northeast Building at Knossos or the *Bastione* at Aghia Triada which seem to have been erected with a certain focus on storage as the mass of storerooms present implies. For the Northeast Building: Evans 1928, 414-430; for the *Bastione*: Watrous 1984, 131; but criticized by Puglisi 2003, 518; see also Privitera 2014 who argues convincingly for an interpretation of the *Bastione* as a granary. According to my calculations the Northeast Building would have kept 27 yearly rations at a maximum, the *Bastione* only 20. Tylissos Building B might have served a similar purpose, at least as indicated by the layout of the rooms, cf. Hayden 1984, 51.

94 In one case a yearly amount of 1.6 million litres of barley is documented as being delivered to Larsa: Breckwoldt 1995-96, 64. This argues strongly for a palatial role as supply guarantor.

95 Likewise for Malia, Effenterre 1980, 458-462. See also Christakis 2008, 120-121.

the palaces themselves, and perhaps some neighbouring buildings,[96] who lived on these stocks, not even those in the surrounding settlement or the region.[97] Even more if we consider palatial oil production of higher importance than that reflected in the Minoan 'menu' (cf. section 2.1.2).[98]

How does the evidence of *bulk* grain storage at the west courts of the palaces – both the kouloures which have been interpreted as granaries above and the silo complex at Malia – fit into this picture? Could that testify to the redistribution of subsistence goods for the good of the whole society? Firstly, it must be kept in mind that the structures in question are nearly exclusively of Protopalatial date.[99] Secondly, we must differentiate between hermetic and ventilated storage methods since the former is meant for long-term use while the latter serves daily needs. The volumes of the silo complex at Malia can be added, accordingly, to the internal storage capacities. The opening towards the west court, however, does point to a somewhat more public focus than the internal magazines. But the number of people that could have been supplied with a year's ration is far below 1,000 – still far too little for a region-wide significance.[100] The Knossian and Phaistian kouloures on the other hand must have been installed with another purpose in mind. The following scenario could be imagined: once filled and sealed, the kouloures had to be kept this way for a certain time – at least to establish the oxygen-poor atmosphere needed to terminate microbiological activity and the germination process. Then, after a year or more,[101] when the pits were reopened, their contents had to be removed in their entirety. Quite suddenly a vast amount of edible or germinable grain was on hand and awaited processing. What was the reason for the opening?

One possibility is their function as food reserve for the inhabitants of the palaces in times of need, such as during crop failures for example. At Phaistos, however, the volumes of each reopened kouloura would have exceeded the maximum storage capacities of the palace by far and hence could not have been transferred into the internal magazines. The storage of seed for the next growing season could offer an alternative proposition. As calculations of the area that could have been cultivated using the grain from the kouloures demonstrate, such volumes would not allow for more than the surrounding Knossos plain, and only a small part of the Messara plain in the case of Phaistos.[102] Both of these scenarios would thus, in any case, be limited to the residents and perhaps the servants of the palaces. A third possibility is the interpretation of the kouloures and the silo complex at Malia as central elements of collective ritual activity taking place in the west courts.[103] If we assume the distribution of a day's rations, that would lead to a number of people far beyond the number of inhabitants of the palatial settlements.[104] In spite of the difficulties in pinpointing the exact size of such rations, festivals of this extent "probably involved the community at

96 As the study of the storage capacities of Neopalatial elite buildings indicates, some of them lacked a solid subsistence basis so that a certain dependency from the palatial stocks might be inferred. Cf. the Royal Villa (Evans 1928, 396-413) with a maximum storage volume below 2,000 l, with room D and the paved areas in room H as the only storage spaces which could house not more than 17 small pithoi or 14 small and 3 middle-sized pithoi. For the interpretation of the building, Fotou 1987; Westerburg-Eberl 88-90.

97 The population of the Neopalatial settlement at Knossos is calculated by Christakis to about 15,000 people: Christakis 2008, 120-121. For a similar result, Whitelaw 2004; 2012.

98 Several cases have been documented where traces of burning seem to point to the storing of oil: Evans 1921, 321; 1935, 632; Halbherr, Stefani, Banti 1977, 137; Kirsten 1951, 38; the later Linear B-texts also divulge a more important role of oil in the palatial economy.

99 As mentioned above (section 4.3), the silos at Malia might have been in use until the beginning of the Neopalatial period.

100 On the basis of the Minoan villages known in the region van Effenterre (1980, 455) estimates a rural population of about 3,000 inhabitants.

101 Grain preserved in controlled atmospheres can last for decades, see section 4.1.

102 These calculations have been conducted by taking an amount of 70150 kg of Einkorn, 100200 kg of Emmer, or 120210 kg of barley as necessary for the cultivation of one hectare: cf. Niederösterreichische Landes-Landwirtschaftskammer 2009.

103 Marinatos 1987; Moody 1987. For the significance of the west courts as spaces of interaction between palace and people, see: Panagiotopoulos 2006, 37.

104 One ration of 0.8-1.6 l (depending on the kind of grain) would provide the daily energy demand (cf. section 2.1.6). Accordingly, opening only one kouloura at Knossos would have supplied between 34,640 and 70,460 people, at Phaistos between 12,960 and 25,300 people.

large" (Schoep 2004, 264).[105] By making a symbolic gift which had no noteworthy impact on the subsistence economy of the population the palatial authorities would have had the opportunity to legitimize their position at the top of the society while the recipients, by taking it, confirmed their rank within the societal hierarchy.[106] The pits were, hence, both means of communal integration and expression of status of those allowed to join the rituals.[107]

To sum up, it seems that the subsistence strategies of the Minoan palaces did not change with the transition from Protopalatial to Neopalatial times.[108] A slight increase of capacities has been documented, although this does not allow for the provision of a larger group of people than before. The palaces steadily arranged for their own needs, as did the elite buildings of both periods.[109] The only thing that changed concerning storage strategies[110] was the tendency now to include not the many – through communal feastings from the contents of the kouloures – but just the few that afforded the privilege. These few have been able – more so than in the Protopalatial period – to stand out from the ordinary population as the increased presence of elite buildings demonstrates. The reason why the palaces gave up the opportunity to bind larger parts of the population into a gift-and-gift-in-return relation remains, at least for the time being, to be seen.

Acknowledgements

This article is based on parts of my dissertation which I submitted in February 2013 under the title "Subsistenz und Macht. Palatiale und elitäre Vorratshaltung auf Kreta während der Alt- und Neupalastzeit" at the Ruprecht-Karls-Universität Heidelberg. I would like to thank Tom Strasser for his collegial effort in reading the manuscript and sharing some of his thoughts with me.

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105 The role of feasting has recently been criticised by Christakis (2014, 212) as being "over-emphasized", an assumption that seems to be supported by the lack of equipment required to process the grain once removed from the kouloures (Privitera 2014, 443-444). The mere distribution of grain rations, however, would not necessarily need such equipment.

106 Fundamental for the ideology of giving and taking applied here: Mauss 1990.

107 A similar idea might be behind the case of the *Crypte Hypostyle* at Malia where presumably communal activities (like athletic competitions in the neighbouring court and banquets in the rooms above the crypt) took place, even if not of the scale present at Knossos and Phaistos: Schmid 2012. Ritual feastings organized and performed by the palace or king are also identifiable at Nuzi (Klein 2012) and in the New Kingdom (Bleiberg 1988; Pagliari 2010). An ethnographical analogy of the phenomenon of food stores utilized as representations of the household's wealth might be seen in the yam (sweet potato) stores of the Trobriands. The prestigious yams are saved in stores visible from the outside while the usual foodstuffs are kept within the houses: Hendon 2000.

108 Interestingly, the Linear B texts indicate a similar situation in postpalatial Knossos, where the subsistence economy is left in the hands of the local producers: Driessen 2001, 112.

109 This impression derives from the study of the capacities of many of the elite buildings of Protopalatial (Building A at Apodoulou, Monastiraki, Quartier Mu at Malia) and Neopalatial times (Achladia, Klimataria-Manares, Makrygialos, Myrtos-Pyrgos, Vathypetro) which showed in most cases a solid subsistence basis demonstrating their economic independence from the palaces.

110 There are, naturally, various other changes to be traced between the Old and New Palace period that cannot be discussed here: see *e.g.* Dabney 1995, 46-47.

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