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Filozofická fakulta

Ústav pro klasickou archeologii

Diplomová práce

Kristina Doležalová

O vulkanických horninách.

Mlecí kameny a jejich operační řetězec z období 2. tisíciletí př. n. l. v západní Anatólii

Část 1: TEXT

prof. PhDr. Peter Pavúk, Ph.D.

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CHARLES UNIVERSITY

Faculty of Arts

Institute of Classical Archaeology

Master thesis

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The tale of volcanic rocks.

Assessing the grinding stones and their chaîne opératoire in 2nd Millennium BC Western Anatolia

Part 1: TEXT

prof. PhDr. Peter Pavúk, Ph.D.

Prague 2023

Poděkování

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Prohlášení

Prohlašuji, že jsem diplomovou práci vypracovala samostatně, že jsem řádně citovala všechny použité prameny a literaturu a že práce nebyla využita v rámci jiného vysokoškolského studia či k získání jiného nebo stejného titulu.

V Praze 27.07.2023

Kristina Doležalová

Declaration

I declare that I have worked on the thesis independently and I have properly cited all the sources. The thesis was not used within another studies or to obtain another or the same university degree.

In Prague 27.07.2023

Kristina Doležalová

Abstrakt

Předkládaná práce se zaměřuje na soubor mlecích kamenů z Kaymakçı, turecké opevněné výšinné lokality pozdní doby bronzové, snaží se zrekonstruovat jejich operační řetězec a zasadit nové informace do kontextu poznání západní Anatólie v 2. tisíciletí př. n. l. Základní zpracování artefaktů zahrnovalo morfotypologickou, geologickou, traseologickou a prostorovou studii souboru v rámci tohoto sídliště. Jednotlivé zjištěné aspekty operačního řetězce mlecích kamenů z Kaymakçı byly následně porovnány s dvěma publikovanými soubory stejného typu artefaktů ze západní Anatólie (Afrodisias a Trója), aby byly zjištěny jeho opakující se vzorce pro dobu bronzovou.

Soubor mlecích kamenů z Kaymakçı odhalil, že tyto artefakty hrály důležitou roli v běžném životě i nadregionálních stycích a obchodu. Na sídlišti byly doloženy především aktivity spojené s jejich používáním, reutilizací a skartací, oproti tomu těžba suroviny a samotná výroba artefaktů zde doposud nebyly zdokumentovány. Vzhledem k provenienční analýze je zřejmé, že obyvatelé byli ochotni investovat mnoho času a energie na jejich transport ze značné vzdálenosti. Dá se také předpokládat určitá míra specializace produkce, která je nepřímo doložená standardizací tvarů horních mlecích kamenů. Tyto nástroje byly taktéž zručně tvarovány do ergonomických forem pro lepší úchop při mletí. Nicméně tyto aspekty nebyly pozorovány u souborů mlecích kamenů z Tróje a Afrodisiady, se kterými sledovaná lokalita sdílí pouze ojedinělé rysy (absence imobilních mlecích zařízení, výskyt pouze jamkovitých moždířů).

Klíčová slova: mlecí kameny; Kaymakçı; surovina; doba bronzová; traseologická analýza; Západní Anatólie

Abstract

The thesis examines grinding stones from the Anatolian Bronze Age site of Kaymakçı. It aims to reconstruct their *chaîne opératoire* and to place the new findings in the frame of Western Anatolia in the 2nd Millennium BC. The general processing of the assemblage included morphological, geological, use-wear and spatial study of the assemblage in the context of the settlement. The various aspects of the grinding stones *chaîne opératoire* identified at Kaymakçı were then compared with two published grinding stone assemblages from Western Anatolia (Aphrodisias and Troy) to identify their repeating patterns for the Bronze Age.

The grinding stone assemblage from Kaymakçı revealed that these artifacts played an important role in everyday life, as well as in trans-regional contacts and trade. While activities related to their use, reuse and disposal have been well attested, raw material extraction and production were not documented so far. As shown by the provenance analysis, people were willing to invest a lot of time and energy to transport them. A certain degree of specialization of production can also be assumed, which is indirectly evidenced by the standardization of the upper grinding stone shapes. These tools were skillfully shaped and enhanced with ergonomic adjustments suitable for comfortable holding during grinding. Interestingly, such aspects have not been observed in the grinding stone assemblages from Troy and Aphrodisias which share only singular features with Kaymakçı such as the absence of immobile grinding structures or the presence of hollowed mortars.

Key worlds: grinding stones; Kaymakçı; raw material; Bronze Age; use-wear analysis; Western Anatolia

Content

The catalogue of finds and database is in the second part of the thesis.

List of abbreviations:

GS: grinding stone

LGS: lower grinding stone

UGS: upper grinding stone

LGS: lower grinding stone

EA: excavation area

BA: Bronze Age

EBA: Early Bronze Age

MBA: Middle Bronze Age

LBA: Late Bronze Age

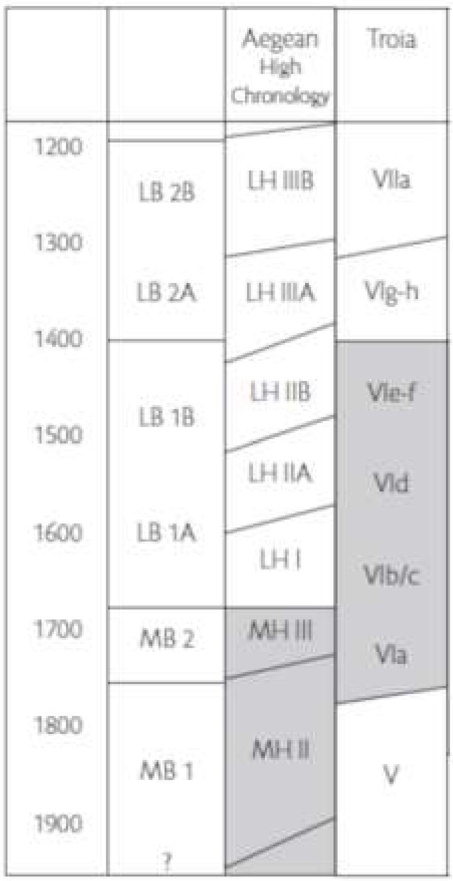


Fig. 1.1. Chronology of Aegean and West Anatolian area (Pavúk 2015, Fig. 1; altered).

1 Introduction

"*…saddle-querns of trachyte, of which the strata of debris of all the pre-historic cities of Hissarlik contain many hundreds.*" (Schliemann 1880, 234).

Archaeological assemblages from Anatolia have always been very rich in grinding stones (hereafter GS), and the Bronze Age is not an exception. Heinrich Schliemann already noticed this when he was excavating at Troy. In this respect, Schliemann was a little ahead of his time. Unfortunately, he did not have many followers, as GSs from the Anatolian Bronze Age have not yet gained enough attention.

Therefore, the aim of this thesis is to examine a whole assemblage of these finds from the site Kaymakçı (Western Anatolia), reconstruct the *chaîne opératoire* (chain of operations) that was associated with them, and place these artifacts within the context of Western Anatolia in the 2nd Millennium BC (late phase of MBA and LBA). GS assemblages from two other sites (Aphrodisias and Troy) were chosen for the comparative study. The goal is to find the fundamental patterns of Bronze Age GSs.

The following questions were asked regarding this issue:

- What phases of the *chaîne opératoire* can be traced from the Kaymakçı GS assemblage?
- What are the specific features of this assemblage?
- Were local raw materials used for production?
- Can we assume their specialized production in the Bronze Age?
- How were GSs used (kinematics, behaviour)?
- What secondary use was made of them?
- Is it possible to trace their use-locations or any patterns of discard?
- Can similar features of the different phases of the *chaîne opératoire* be observed in other Bronze Age assemblages of Western Anatolia?

The first part is focused on the theoretical aspect of this thesis. GSs are defined and the problem of terminology is emphasized. Subsequently, the history and state of GS research are presented and the new methods and analysis are outlined. Then, the development of GSs over time since the Neolithic in the Eastern Mediterranean is introduced.

The theoretical part is concluded by a chapter dealing with the origin of sequence models and the GS *chaîne opératoire*. The individual phases of the *chaîne opératoire* associated with GSs are described. The information was compiled from already published archaeological and ethnographic studies dealing with GSs.

The second part is focused on the GS assemblages from Western Anatolia in the 2nd Millenium BC. The Kaymakçı assemblage, in contrast to the other two, was studied "in the flesh" and because of that there were more possibilities for study. The Troy and Aphrodisias assemblages were studied only from the excavation publications (Joukowsky 1986a, 1986b; Pieniążek 2020) and therefore there are many limitations concerning the quality and quantity of the published data.

The first section is focused on the comprehensive study of the GSs found at the Bronze Age site of Kaymakçı. This study included provenance, morphotypological, use-wear, contextual and spatial analyses of the finds. The results are presented with regard to the described phases of the *chaîne opératoire* within the framework of the theoretical part of the study. First, the aspects concerning the procurement of the raw material for GSs are discussed. This includes a geological study of the area and search for the raw materials potentially used for production. The provenance study builds upon the defended bachelor's thesis "Ground stone tools from the Aegean Bronze Age". The next chapter considers the production process, which can be difficult to trace if the study is limited to finished products. Then follows the chapter about the use patterns of Kaymakçı GSs, which also includes the results of the experimental program and the small use-wear study. At the end, patterns of reuse and discard are discussed, which encompass a contextual and spatial analysis of the settlement.

This section ends with a comparative study of GS assemblages from the sites Aphrodisias and Troy. This includes geological, morphological and spatial analysis of the finds.

The Conclusion section summarizes the general picture of the *chaîne opératoire* of the Kaymakçı GSs and presents the identified patterns concerning GSs in the Bronze Age of Western Anatolia. At the very end, the most important findings are presented and potential future work is outlined.

In this thesis, the following hypotheses were put forward at the beginning:

- The distinguished aspects of the *chaîne opératoire* will be described and some of them will be identifiable in other archaeological assemblages.
- Complex Bronze Age societies will have been willing to invest time and energy in the extraction, transport and production of GSs.
- These tools will be used in large quantities and with an emphasis on labor efficiency.

2 Grinding tools

2.1 Introduction - Definition of ground stones

The division of stone artifacts into chipped and ground stones is an artificial division introduced by archaeologists. The boundary between these two groups is, according to many scholars (Wright 1992; Ebeling – Rowan 2004, 108; Delgado-Raack – Risch 2009, 1; Adams 2013; Rosenberg – Rowan – Gluhak 2016, 2), very problematic and based mainly on the raw material used, since the technique for the production of chipped stones is basically an initial stage in the production of some ground stones. However, ground stones represent an incoherent group of remaining archaeological stone artifacts that do not belong to chipped stones.

Macrolithics, or formerly named ground stone tools, represent important part of the ground stones. They include artifacts used for grinding, pounding, battering, chipping, smoothing, and polishing. They encompass not only grinding tools but also abraders, whetstones, hammers, and other stone pebbles used in different activities. The term "macrolithic artifacts" came into use at the end of the first decade of the 2nd Millennium. It was first introduced in 2009 in the collective article defining the ground stone use-wear approach (Adams *et al.* 2009). After a former period of inconsistent terminology, the term has become quite familiar to archaeologists (e.g. Hamon – Plisson 2008; Delgado-Raack – Gómez-Gras – Risch 2009; Dubreuil – Savage 2014; Řídký *et al.* 2014).

Grinding tools consist always of two parts: stationary and moving (Fig. 2.1). The terminology for GSs is rather inconsistent, which was pointed out by many scholars (e.g. Hamon – Plisson 2008, Tab. 1; Řídký *et al.* 2014, Tab. 1). Therefore, the tools definition and terminology used in this thesis will be introduced.

Stationary grinding tool named **lower grinding stone** (thereafter LGS) is not actively involved in the operation, they only serve as a support on which the substance is milled. Active grinding tool named **upper grinding stone** (thereafter UGS) are used as the upper part, which moves against the lower slab. UGS are further divided into one-handed termed **handstones** and two-handed the proper UGS (larger slabs, used mostly in back-and-forth movement). The handstones are excluded from this study as it is difficult to determine whether they were really used primarily for grinding.

Another passive grinding tool named **mortar** is formed by grinding in several directions and crushing at the same time. The most common type is a pebble mortar, which has a spherical shape with a large hole in the middle. Other types of mortars include bowl-shaped or hollowed (Fig. 2.2; Adams 2013, 135–137). The hollowed mortar is often difficult to distinguish from **door sockets** (pivot stones) as they have the same shape and can only be recognized by analyzing use-wear traces. Mortar is normally paired with pestle (also excluded from this work).

Grinding tools

Grinding stone (GS)
- Upper grinding stone (UGS)
- Lower grinding stone (LGS)

Mortar
Pestle

Fig. 2.1. Terminology and division of grinding tools.

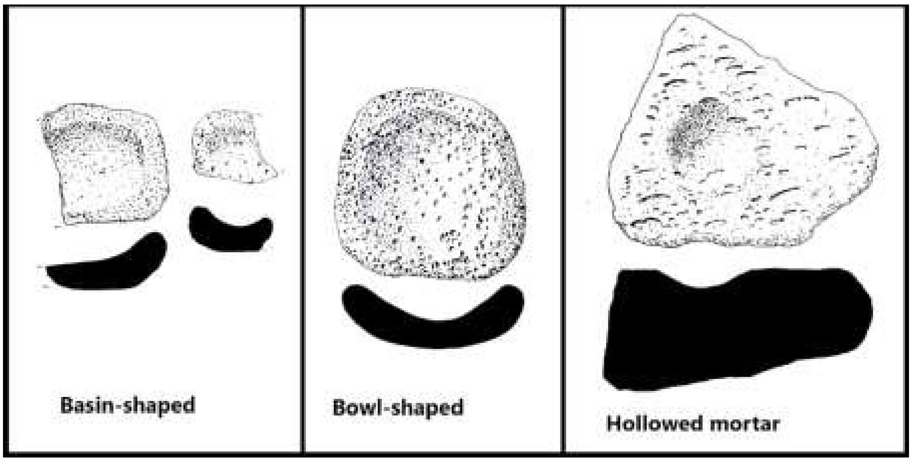


Fig. 2.2. Division of mortars (Baykal-Seeher 1996, Taf. 73; altered).

2.2 The history of research

2.2.1 General introduction

Grinding tools are the key to understanding everyday activities such as processing and preparation of food. Nevertheless, these objects have been rather neglected since the beginning of the study of human history. Even as early as the 20^{th} Century, many scholars pointed out the low interest in these objects (Curwen 1937, 133; Childe 1943, 19; Runnels 1981, 11–12; Hovers 1996, 171). In archaeological reports from Bronze Age settlements (hereafter BA), grinding tools were overlooked or ignored altogether, so they were placed outside the main material culture categories, usually appearing under "other", "small finds" or in the appendix.

The lack of attention to the study of GSs is for several reasons. As already mentioned, the objects were used in everyday life. These activities seemed female task, mundane, uninteresting to the point of being boring and therefore not worth studying (Rowan – Ebeling 2008, 2). Whether finds were processed or collected at all depended mainly on the focus of the research or the interests of the excavators (Lidström Holmberg 1998, 123). Due to ignorance, they were usually not even recognized as artifacts (Peterson 2008, 362). Often these objects were too large, heavy, and clumsy, creating problems with relocation and storage and, therefore, were more likely to be left on the site and not further processed (Rowan – Ebeling 2008, 2).

One of the great disadvantages of these artifacts is that they are very difficult to use as indicators of chronology, culture, or geographic location. This is due to less typological variation in individual objects and mainly to the neglect of the study (Rosenberg – Rowan – Gluhak 2016, 2). Compared to ceramics, there are rather little data for comparison, undeveloped artifact classification schemes, and inconsistent terminology (Lidström Holmberg 2008, 71). Material analysis is not performed or is limited to rock color. Therefore, the provenance of the raw material is not detectable.

The study of GSs has its roots in the late 19th Century at the time of the first important archaeological excavations in the Aegean region. H. Schliemann (1880, 234–236), who found many GSs at Troy, was probably one of the first archaeologists to recognize the saddle-shaped GS as a tool. A few years later, W. M. Flinders Petrie (1888) correctly identified the upper stone of Olynthus mill as a part of device for grinding grain, which many had previously explained as a window (Frankel 2003, 2). In 1898, the work "*History of Corn Milling*" dealing with the origin and development of grinding tools was published (Bennett – Elton 1898). Surprisingly, this work summarized the basic development and division of grinding tools, which is still valid today. R. Bennett and J. Elton distinguished GSs and mortars and recognized the chronological development from the reciprocal saddle-shaped GS to the rotary mill, which originated according to them somewhere in the Greco-Roman world.

After promising beginnings, however, there was a pause which E.C. Curwen (1937) broke with his study of the development of grinding tools based on the work of Bennett and Elton. A few years later, he published another article (Curwen 1941) dealing with the origins of rotary mills and made the first classification of them. G.V. Childe supported his theory of the Mediterranean origin of the rotary mill and followed this up with his study of grinding devices appearing in Classical Greece, which he called the hopper-rubber (Childe 1943). In 1958, L.A. Moritz comprehensively compiled all the new findings and the development of milling equipment from the beginning to today in his book "*Grain-Mills and Flour in Classical Antiquity*" (Moritz 1958).

Subsequently, there was finally a bit more interest in grinding tools. Further studies were conducted on grinding tools from the Classical period (White 1963) and Neolithic Europe (Hürlimann 1965; Hennig 1966). Towards the end of the 20th Century, there was another wave of new studies on Neolithic grinding tools (Zimmermann 1988; Pavlů – Rulf 1991; Lidström Holmberg 1998) and tool design (Horsfall 1983; Nelson – Lippmeier 1993; Stone 1994). In this period, the foundations of new methods of study were also laid, such as use-wear study and provenance studies. The methodology of these emerging trends has been well summarized in the book "*Moudre et broyer*" (Procopiou – Treuil 2002).

2.2.2 Ethnographical studies

Researchers from America and Australia had access to ethnographic data of indigenous populations and were not so much focused on chronology, but rather on culture and technology (Rowan – Ebeling 2008, 3). One of the pioneers in ethnographic GS data collection was W.H. Holmes, who published a study of the processing and distribution of raw materials and tools in North America (Holmes 1919). This was followed by many studies on GSs used by indigenous people (Barlett 1933; Stephen 1936; Aschmann 1949). For example, F.D. McCarthy studied the grinding tools of the Aboriginal population in Australia and summarized the results in his article (McCarthy 1941). In the Near East, the ethnographer G. Dalman (1933) gave a detailed account of the use of ground stones in everyday life in his book "*Arbeit und Sitte in Palästina III: Von der Ernte zum Mehl*". Shortly thereafter, interest in traditional subsistence and tool making waned and ethnography became irrelevant to understanding the human past (Rowan – Ebeling 2008, 4).

New interest in ethnography was initiated by the "New Archaeology" in the 1960s. However, most ethnographic studies on GSs did not appear until the late 20th Century. Ethnographic studies carried out on the American continent have played an important role in the research. Studies have been conducted on Native Americans (Horsfall 1983; Adams 1988; Schneider 1993) and indigenous Mesoamerican populations (Vogt 1970; Foster 1979; Cook 1982; Hayden 1987; Clark – Nelson 1988; Mauldin 1993). One of the important major long-term projects was led by B. Hayden between 1977 and 1979 in the Maya Highlands, where he investigated not only GSs but also lithics, household variability and ceramics (Hayden 1987). Many studies have also focused on the African continent (Haaland 1982; Schön – Holter 1988; Gronenborn – Fansa 1995; David 1998) or Anatolia (Ertug-Yaras 2002).

In recent years, M.T. Searcy built on the studies undertaken in the Maya Highlands and came up with his own ethnographic monograph summarizing the entire GS chain of operation (Searcy 2011). Research also continued in Africa, especially in Mali (Hamon – Le Gall 2013) and Ethiopia (Teklu 2012; Nixon-Darcus – Meresa 2020). Very recently, N. Alonso has collected a lot of ethnographic data (Alonso 2019) and an ethnographic database on GSs has been created as part of an ERC project (Alonso *et al.* 2020).

2.2.3 Provenance studies

In the beginning, the study of raw material sources was mainly carried out by comparative macroscopic analysis supplemented by field surveys. Petrographic thin-section analyses were rarely been used in the study of grinding tools (Nicotera 1950; Röder 1955; Zirkl 1963). These early studies pointed out that even concerning GSs, the quality of the raw material matters and the community is likely to invest time in transporting them. Some preliminary studies together with petrographic analyses were done on the Greek grinding tools by C. Runnels (1981). Furthermore, D.P.S. Peacock dealt with the main sources of rock for the Roman rotary mills and, in particular, the source from Orvieto (Peacock 1980, 1986).

The study of provenance has made great progress thanks to new scientific methods and analyses taken from the natural sciences. O. Williams-Thorpe and R.S. Thorpe were among the first to use these methods to study the sources of raw materials for GSs (Williams-Thorpe – Thorpe 1993a). They dealt with provenance analyses worldwide by measuring magnetic susceptibility (Williams-Thorpe – Thorpe 1993b; Williams-Thorpe *et al.* 1996) and using a portable XRF spectrometer (Williams-Thorpe – Potts – Webb 1999). In the same period in the Levant, M. Weinsteim-Evron *et al*. (1995; 2001) studied the rock sources among the Natufian population and found out that they used basalt sources of more distant better quality rather than closer ones.

Recently, interest in GS sources has increased, especially the study of grinding tools on the Apennine Peninsula (Oliva *et al.* 1999; Lorenzoni – Pallara – Zanettin 2000; Antonelli – Nappi – Lazzarini 2001; Renzulli *et al.* 2002; Buffone *et al.* 2003; Antonelli *et al.* 2004; Antonelli – Lazzarini 2010; Santi – Renzulli – Gullo 2013; Gluhak – Schwall 2015; Di Bella *et al.* 2016, 2018). Some studies were carried out on GSs from the Minoan BA sites (Dierckx – Tsikouras 2007; Tsoraki 2017). Furthermore, Ch. Tsoraki (2009) also performed the provenance analysis on the Neolithic assemblage from Makriyalos, N Greece.

Nevertheless, the provenance analysis of stone artifacts in Anatolia are not so much conducted. Notable exceptions are the raw material studies at Çatalhöyük (Türkmenoğlu *et al.* 2001) and Çukuriçi Höyük (Schwall *et al.* 2020).

2.2.4 Use-wear studies

Initially, the study of grinding equipment was focused on the morphology. The function was derived from the shape and raw material of the stone artifact. For a long time, the prevailing idea was that mortars were used to crush wild, gathered crops, and grinding slabs were used to grind domesticated cereals (Rowan – Ebeling 2008, 4). This assumption was refuted by K. Wright (1994) who proved through experimental and ethnographic observations that the morphology of objects is not a reliable measure of determining the function.

However, thirty years before S.A. Semenov (1964) has formed the foundation for modern determination of archaeological stone tool function. Based on many experimental programmes and microscopic studies, the roots of the use-wear analyses on chipped stones were laid (e.g. Hayden 1979; Keeley 1980; van Gijn 1989).

The first studies dealing with the use-wear on ground stones only appeared in the 1980s in USA (Adams 1988, 1989; Logan – Fratt 1993). J. Adams was one of the first to conduct experiments and macroscopic examination of use-wear traces on sandstone macroliths. At the beginning of the Millennium, she published a book summarizing all her observations (Adams 2002).

At the same time, L. Dubreuil started to create another experimental reference collection developed for Natufian basaltic grinding tools (Dubreuil 2001). The use-wear analysis moved also to Europe (Spain and France), where it built on the developed use-wear study on the chipped stones. In the 1990s, R. Risch (1995) and H. Procopiou (1998) completed theses that included use-wear analyses.

In the following years, many papers dealing with the analysis of use-wear traces on GMTs were published (Menasanch – Risch – Soldevilla 2002; Risch – Martínez Fernández – Gibaja Bao 2002; Zurro – Risch – Clemente Conte 2005; Hamon 2006; Hamon – Plisson 2008; van Gijn – Verbaas 2008; Liu *et al.* 2010, 2011). C. Hamon created a reference collection for French Early Neolithic LBK sandstone grinding equipment (Hamon 2008a) and R. Risch and S. Delgado-Raack carried out work on grinding tools in Spain (Delgado-Raack – Gómez-Gras – Risch 2009; Delgado-Raack – Risch 2009). In 2009, a collective article on use-wear analyses on GSs was published, summarising the state of research to date by the previously named experts (Adams *et al.* 2009).

In the last ten years, the study of use-wear traces has seen the highest increase in articles and experts dealing with this topic (Gilabert – Martínez-Moreno – Mora Torcal 2012; de la Torre *et al.* 2013; Smith – Hayes – Stephenson 2015; Delgado-Raack – Risch 2016; Fullagar – Stephenson – Hayes 2017; Hayes – Pardoe – Fullagar 2018; Li *et al.* 2019; Kufel-Diakowska *et al.* 2020; Zupancich – Cristiani 2020; Cristiani – Zupancich 2021; Santiago-Marrero *et al.* 2021). As they emerged, new technological tools such as confocal microscopy (Bofill 2012; Bofill *et al.* 2013; Dubreuil – Savage 2014; Macdonald – Xie – Gallo 2019) SEM (Dubreuil 2004; Bofill *et al.* 2013) and 3D modelling (Caruana *et al.* 2014; Benito-Calvo *et al.* 2015, 2018; Caricola *et al.* 2018; Zupancich *et al.* 2019) were used.

2.2.5 Aegean Region and Western Anatolia in the Bronze Age

"*Saddlestones of trachyte in the form of longitudinally divided egg, such as abound in prehistoric Troy and are common at Mycenae.*" (Schliemann 1886, 80).

Although Schliemann's excavations in Troy, Tiryns and Mycenae were not always adequately carried out, he was completely ahead of his time in his approach to GSs. In his book "*Ilios*" (Schliemann 1880, 234) a generalized metrical description and geological determination of the GSs can be found. Some parallels to these finds from other localities are also mentioned. Many archaeological reports from BA sites after Schliemann's do not even include these items as worthy of any note. Nevertheless, Schliemann's successor at Troy A. Götze followed up on his interest. He tried to develop a simple typology of them and even distinguished between upper and lower GSs (Götze 1902, 387–388). Unfortunately, his followers did not share this interest. C.W. Blegen did not pay any attention to these artifacts anymore; he only mentioned their large number (Blegen – Caskey – Rawson 1951, 1953).

During the 20th Century, there are only a few archaeological reports where a very brief inventory of GSs appears in the catalogue of the BA sites (Hawes *et al.* 1908; Blegen 1928; Bittel 1937, 22; Valmin 1938, 355; Mylonas 1959). More detailed studies on GSs appeared at the end of the 20th Century.

GSs of the Anatolian BA appeared for the first time in archaeological reports in the 1980s. One of the first progressive publications dealing also with the GSs is from the tell-settlement of Aphrodisias (Joukowsky 1986a, 1986b) including even the geological determination of the tools. At about the same time, the site of Demircihüyük was studied by archaeologist A. Baykal-Seeher, who specifically focused more on the BA GSs and who created their basic classification (Baykal-Seeher 1996). Unfortunately, these promising beginnings did not find enough followers. The exceptions are the recent studies on ground stones encompassing also GSs from Troy (Pieniążek 2020) and Tavşan Adası (Focke-Pellkofer 2022).

GSs from Mainland Greece were dealt with in detail by C. Runnels in his PhD thesis (Runnels 1981). He conducted a diachronic study based on GSs of the Paleolithic to Roman period from the Argolid, Greece. He focused predominantly on the development of shape, raw material preference and tool production and tried to examine this through recent economic studies. He found that size and raw material preference are more sensitive to change over time than shape, methods of production or type of motion (Runnels 1981, 130). Subsequently, GSs began to appear more in archaeological reports with their documentation and description, and more emphasis was placed on them (Hochstetter 1987, 55–56; Blitzer 1992; Taylour – Janko 2008, 463–464; Catling *et al.* 2009, 295; Wiersma *et al.* 2016, 139).

The Minoan grinding tools were studied more in detail by several scholars. R.D.G. Evely processed the assemblages from several Minoan (Evely 1984, 2012) and Greek sites (Evely 2006) and even published a general study about Minoan crafts, where he also discussed grinding tools (Evely 1993, 112). As mentioned before, H. Procopiou did her PhD thesis on Minoan grinding tools, which included also use-wear analysis (Procopiou 1998). She was dealing with grinding tools from Quartier Mu, Malia (Procopiou 2013). Furthermore, the Minoan stone industry was studied by H.M.C. Dierckx in her PhD thesis and article concentrating on the assemblage from the island Pseira (Dierckx 1992, 1995). Lately, she has been working mainly on the GSs and the connected mortuary practices from the cemetery Petras (Dierckx 2012, 2017). The assemblage of GSs was also elaborately documented by H. Blitzer (1995). Her work at Kommos significantly moved the ground stone research forward, as it created the first regional BA classification of ground stones that could be adopted by other researchers. Blitzer also worked on the assemblages from the Mainland Greece at Nichoria (Blitzer 1992).

In recent years, focus has also been placed on Northern Greece, where several scholars have worked on the GSs from Archontiko and Angelochori in the framework of the Plantcult ERC project (Bekiaris *et al.* 2022).

Finally, the GSs from the Aegean islands were the main focus of some studies and reports. The work was carried out mainly on the Cyclades islands (Rowan – Dixon – Dubicz 2013), especially Thera (Agouridis 1998; Devetzi 2000, 2007; Moudrea-Agrafioti 2007), the Dodecanese islands (Georgiadis 2017) and Lesbos (Hood 1982).

To sum up, in the last thirty years the interest in the GSs has increased, as evidenced by the number of published studies. Unfortunately, the BA is still neglected in compared to the Neolithic. Only a few studies also mostly concentrate on the EBA assemblages. The GSs of the MBA and LBA Western Anatolia represent a totally unknown world, which is very disappointing if we count the amount of tools coming from the cultural layers of the settlements.

2.3 The history of grinding tools from the beginnings to the rotary revolution - with the special reference to Levant, Anatolia and Mainland Greece

2.3.1 Emergence of macrolithics

Macrolithics played an important role in the life of the human from the beginning and continuously accompanied the man up to the present time. One of the first examples of the pounding tools used for crushing organic and inorganic matter is recorded in the Upper Paleolithic (45 000-20 000 BP) period in many parts of the world (Smith 1985; Wright 1994, 294; de Beaune 2004, 146; Ebeling – Rowan 2004; Piperno *et al.* 2004; Aranguren *et al.* 2007; Hayes *et al.* 2022). The equipment consisted mainly of a stone slab/anvil/mortar and a handstone/pestle, which was used in a free or circular motion. Subsequently, later in the same period flat upper stones with back-and-forth movement were introduced. They were coupled with large LGS and were predominantly shorter than the width of the lower stone (Pavlů 2008). These innovations all preceded neolithic revolution, and already at that time wild cereals, tubers, plants, minerals and other substances were pounded or ground (de Beaune 2004, 147; Ebeling – Rowan 2004; Piperno *et al.* 2004).

The development of the grinding equipment in early times is best attested and fully described in Levant (Wright 1994; Dubreuil 2004). In the Paleolithic, the mobile foragers either had to use portable, lightweight tools or they stored the heavy or fixed grinding equipment near wild harvest. The semisedentary way of life typical for the Early Natufian (approximately 13 000 – 12 000 BP) caused the decrease of time spent on travelling and searching for food, so more time could be invested in food treatment. With the gradual intensification in food processing and preparation, the number of these tools increased; mortars and pestles were still predominant (Wright 1994, 252). Ohalo II is a great example of the Early Epipaleolithic site where first traces of wild barley were found on the GS (Piperno *et al.* 2004, 670–672).

In the Pre-Neolithic Aegean, only a small number of macrolithics are published. Exceptional is the assemblage from Franchthi Cave processed by Ana Stroulia (2010) and partly also by Curtis Runnels (1981). The tools have irregular shape, are small and were already used in back-and-forth motion (Runnels 1981).

2.3.2 Grinding equipment from the Neolithic to Chalcolithic Period

The Early Neolithic is in the Levant and Upper Mesopotamia called the Pre-Pottery Neolithic (approximately 12 000 – 9 000 BP). The period is characterized by the first appearance of domestic cereals. Furthermore, the amount and higher variability of grinding equipment increased (Wright 1994, 254; Dietrich *et al.* 2019). The grinding slabs began to prevail and stone mortars were gradually disappearing. This change was probably due to the orientation towards the processing of seeds, mainly cereals, because the grinding slabs are more suitable for this purpose. However, mortars and pestles are also needed because they are better for crushing nuts and acorns and dehusking the seeds. So, this change was explained by Wright as a shift towards the wooden mortars (Wright 1994, 257).

This long-term process resulted in intensification of plant processing and incorporated a different type of diet into daily life (Wright 1994; Lidström Holmberg 2008). The sedentary way of life forced the community to exploit local dense plants and find a source of food that is storable for longer time. These conditions were fulfilled by widespread cereals. Seeds have little calorific potential unless they are processed into groats. If the grain is ground to flour, the calorific potential is not increased but the range of possible edible products is broadened (Wright 1994, 245–246). This laborious food processing technique has since then been fully accepted by the society (Wright 1994, 257).

The one-handed upper handstones were gradually replaced by the larger oval UGS. These two-handed tools started to occur already in previous period but in the Neolithic they became widespread. Their shape is an innovative step forward, as the larger the working surface, the more efficient the grinding (de Beaune 2004; Pavlů 2008). Additionally, ergonomic adjustments were introduced on the UGSs (Pavlů 2011). Examples of this UGS alteration were recognized in the Anatolian Neolithic assemblage of the Tepecik-Çıftlık site (Fig. 2.3; Řídký 2009).

The Neolithic Anatolian assemblages are very rich on GS. The large amount and dimensions of grinding equipment in Anatolia could be connected to large scale food preparation for communal/feasting activities. The oldest indications of this have already been preserved at some Aceramic Neolithic sites such as Aşıklı Höyük (Güldoğan 2011; Uzdurum 2018, 40) and Göbekli Tepe (Dietrich *et al.* 2019). On the other hand, the grinding equipment assemblage at the Neolithic site of Çatalhöyük seems to contain predominantly small GSs designed for small-scale, rather household food production (Baysal – Wright 2005).

In the Neolithic Anatolia, the grinding activities took place predominantly on the flat roofs of the buildings, which is evidenced in Göbekli Tepe (Dietrich 2021, 159) and Çatalhöyük (Baysal 2020, 167). However, in winter, when the weather was bad, special elevated places for grinding were set aside in the house, called grinding benches/features (Fig. 2.4; Pavlů *et al.* 2007, Fig. 8; Baysal 2020, 173).

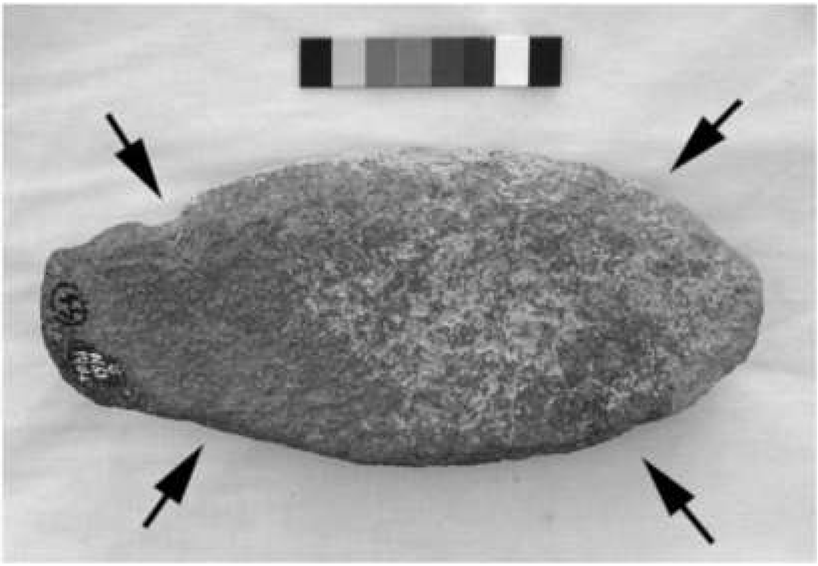


Fig. 2.4. Grinding stone with ergonomic adjustments from the Tepecik-Çıftlık site (Řídký 2009, Fig. 3A).

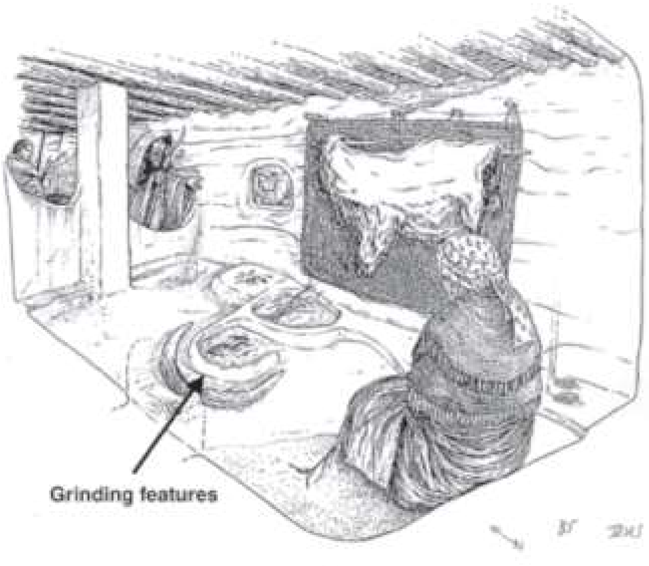


Fig. 2.3. Grinding benches (Baysal 2020, Fig. 1)

Not many studies have been published yet concentrating on Anatolian Chalcolithic grinding equipment. For instance, on the Chalcolithic site Güvercinkayası the neolithic traditions deepened even further, the grinding benches continued, mortars gradually disappeared from the assemblages and larger flat two-part GSs prevailed (Pavlů *et al.* 2007, 43).

In the Neolithic Aegean, grinding slabs paired with upper stones were prevalent and they were used in back-and-forth movement (Bekiaris *et al.* 2020, 144). The GSs were mostly small and ovate in shape and there was little variation in dimension (Runnels 1981, 121). The LGSs used with the upper stones in circular movement are rather rarely appearing. In addition, mortars are not common in the archaeological record. Few known have a very rough bulky shape and one or more cavities (Bekiaris *et al.* 2020, 144). The GSs were predominantly made of local material (sandstone). At the end of the Neolithic, however, andesite GSs began to appear more frequently (Runnels 1981, 104). The source of the raw material was probably located on the island of Aigina in the Saronic Gulf, Greece (Runnels 1981, 105, 1985b, 34).

2.3.3 Bronze Age grinding equipment

The BA is characterized by the appearance of heterogenic and very variable cultures through time and space. The period witnessed the emergence of highly sophisticated states and other political units, which gradually changed, collapsed and disappeared.

In the BA Levant, the first complex exchange system of GSs was documented. The GSs were among the items that were exported dozens of miles (Amiran – Beit-Ariah – Glass 1973, 197). In the EBA (3300-2500 BC), the production of GSs from outcrops near Maktesh Ramon and the transport to the Arad distribution center were attested (Rosen – Schneider 2001; Abadi-Reiss – Schneider 2009; Abadi – Rosen 2015). Furthermore, the Hazor and Beth Shean sites of the MBA and LBA (2000-1200 BC) located near the basalt lava flows are considered as an important production and distribution centers of basalt grinding tools in the Southern Levant (Hovers 1996; Ebeling – Rowan 2004, 113).

In this period, mortars (bowls) are becoming popular again and they are fashioned in well-made shapes not only in the Levant but also in the Aegean (Runnels 1988; Ebeling – Rowan 2004, 112; Bekiaris *et al.* 2020, 166). The typical tripod bowl-shaped mortar appeared in the Levant from the beginning of the 3rd Millennium (Ebeling – Rowan 2004, 113). In the LBA (1600-1000 BC), they were also present as an import at the sites in the Aegean (Buchholz 1963; Bekiaris *et al.* 2020, 167). In Thera (Akrotiri) and Crete there is even evidence of their own production of imitations (Devetzi 2000, 129).

The tradition of elliptical/ovate Neolithic grinding equipment continued in the Aegean BA (Runnels 1981, 106; Bekiaris *et al.* 2020, 165). However, both parts of the GSs tend to increase in size, which according to Runnels makes distinguishing between upper and lower GSs more difficult (Runnels 1981, 131). Nevertheless, two new exceptional types of LGSs appear in the assemblages of the Aegean BA. First, the triangular, three-legged and basin-shaped slab was found at Akrotiri in the West House, Thera (Fig. 2.5; Devetzi 2007). Second, the rectangular and basin-shaped slab (called palletes), sometimes with four perforations at the corners, was documented predominantly at the Cycladic sites but also on Crete and Mainland Greece (Fig. 2.6; Getz-Gentle 1996; Bekiaris *et al.* 2020, 166).

Fig. 2.5. Triangular, three-legged basin-shaped slab from Akrotiri, Thera (Bekiaris *et al.* 2020, Fig. 16).

Fig. 2.6. Rectangular basin-shaped slab (Bekiaris *et al.* 2020, Fig. 17).

The grinding became in the Aegean BA predominantly an inside activity, which is attested from the find contexts (Bekiaris *et al.* 2020, 173). Specialized rooms are appearing at the sites. At Akrotiri site, a clay grinding bench, a large immobile mortar and a large clay basin was found in a room of the Western House, that was called "Granaries" (Moudrea-Agrafioti 2007, 89). Furthermore, K. Harland found in EH III house at Tsoungiza, that he called "The House of Querns", accumulation of grinding tools (Krattenmaker 2011, 728) and another EH house at Agios Kosmas was by G. (Mylonas 1959) characterized as "Mill house" (Mylonas 1959, 163). According to Runnels the BA witnessed "*the emergence of specialized milling establishments within communities"* (Runnels 1985b, 40). Furthermore, T. Bekiaris *et al*. (2020, 173) pointed out that *"the food-processing activities perhaps acquired specialised character"*.

The number of non-local sources for GSs started to increase at the Aegean sites. The andesite GSs were transported to the Greek sites mainly from the Saronic Gulf (Aigina, Methana, Poros, Runnels 1981). The trade with these objects was confirmed by the discovery of the EH shipwreck at Dhokos that contained, among other things, these andesitic GSs (Agouridis 1998; Bekiaris *et al.* 2020, 170). In the LBA, two trade circuits connecting the Mainland Greece with the Cyclades islands, Crete and the East appeared (Davis 1979; Graziadio 1998). Through these circuits, products from various rock materials also flowed such as laconian *lapis lacedaimonius* and *antico rosso* and probably also andesite (Warren 1968, 51–52; Sakellarakēs 1976, 181). The production and distribution of GSs from local volcanic rocks are attested at Akrotiri, Thera (Devetzi 2000, 123).

Many BA settlements in Anatolia such as Troy (Schliemann 1880, 236; Dörpfeld 1902, 387–400; Blegen – Caskey – Rawson 1951, 24; Pieniążek 2020), Afrodisias (Joukowsky 1986a, 1986b) and Demirçihöyük (Baykal-Seeher 1996) have revealed large assemblages of GSs, but the artifacts have been published only in the form of catalogue without any specialized study.

2.3.4 Iron Age grinding equipment

The Iron Age is considered as an important period in which several major transformations of milling equipment occurred. This period witnessed the emergence of sophisticated grinding mechanisms.

After the collapse of the BA system in the Mediterranean area, there comes a period of major shifts, movements and changes. There are not as many data to compare, but in the beginning the heterogeneous grinding slab made of various materials prevails (Alonso – Frankel 2017, 3).

No change from the BA can be traced until the 9th Century BC, when the first lever mill appeared (Alonso – Frankel 2017, 3). This "Assyrian type" of mill consisted of a rectangular UGS with a groove parallel to the longer axis for a lever and a rectangular flat or slightly concave LGS. They occur in Mesopotamia and the Near East and were well documented at Tell Barri, Syria (Bombardieri 2010, 78–79). This form of GS lasted until the 5th-4th Century (Alonso – Frankel 2017, 3).

The Assyrian type of mill did not spread to the Mediterranean and the tradition of common GSs also dominated in the first half of the 1st Millennium BC. However, some changes in the form of morphological tendencies were observed. They were first recognized in the Greek colonies. White described at Morgantina one flattish elongated UGS with two ends shaped into proturbances and named it as the "Pre-Greek Saddle Quern" (Fig. 2.7; White 1963, 201). Similar types of almond-shaped or asymmetrically oval-shaped UGS with proturbances have also been recorded at Megara Hyblaia (Chaigneau 2019, 202–203). This design appeared according to Runnels on the Mainland Greece already in the 7th Century BC, for example, also on the Athenian Agora (Runnels 1981, 118). The proturbances should serve as handgrips for better manipulation of larger stones.

Later, in the 6th century BC, standardized form of this UGS was introduced (Alonso – Frankel 2017, 3). The type was called “boat-shaped” (Schwall – Gluhak 2019, 218) or the “Archaic Greek Quern” (Moritz 1958, 34–41; White 1963, 201; Alonso – Frankel 2017, 3). The UGS had the same elongated shape with pointed ends, but it had a triangular, carinated transverse cross section (Fig. 2.7). The tool was paired with a rectangular LGS. However, the first clear examples were found on the Mainland Greece at Olynthus (Robinson 1930, 70–71), in Athens and at Halieis (Runnels 1981, 117–119), then they probably spread in the Mediterranean with the Greek colonization. This type of GS was present in Sicily, for example at Morgantina (White 1963, 201), Selinunte (Schwall – Gluhak 2019, Fig. 2b) and Megara Hyblaia (Chaigneau 2019, Fig. 3), and along the north-eastern coast of Spain, for example at Puig de Sant Andreu close to Ullastret (Genís 1986, Fig. 4; Portillo 2006, Fig. 29.1-29.7), and the southern coast of France, for example at Lattes (Py 1992, 185).

The next forward step in the Iron Age is represented by the Olynthus mill. The grinding device is named after the site, where it was first described in the excavation report (Robinson – Graham 1938, 327–334). The mill was also named in the publications other terms such as hopper rubber (Childe 1943), the frame quern (Amiran 1956), lever mill (Frankel 2003; Alonso – Frankel 2017) or pushing mill (Moritz 1958, 52–63; White 1963, 202).

The Olynthus mill probably originated in the Eastern Mediterranean, Mainland Greece or Anatolia. The prototype of Olynthus Mill was probably the former common GS with handgrips and hopper (Fig. 2.7). The poorly dated still elliptical examples were found at Priene (Wiegand – Schrader 1904, Abb. 523). The island of Delos also played significant role in the development, where many, unfortunately not well dated, UGS with various innovations as groove for lever, dressings or hoppers were found (Deonna 1938, Pl. 49). The first rectangular example of UGS also with dressing comes from Thera (Gaertringen – Wilski 1904, Fig. 193). According to N. Alonso and R. Frankel (2017, 3), the Olynthus mill was formed by combining the hopper mill with the Assyrian type.

The first proper Olynthus mill was found in Athens (Runnels 1981, 122, Fig. 24) and Olynthus (Robinson – Graham 1938, 327–334). They are dated approximately to the 5th Century BC (Robinson – Graham 1938, 327–334; Runnels 1981, 122). The UGS of the Olynthus mill has predominantly a rectangular shape, a rectangular depression in the middle of the upper side named hopper, two grooves on two opposite sites for a lever and below the grooves small holes for securing the lever with wire. On the opposite working surface are located striations/furrows/dressing, which are manufactured in linear lines or herringbone pattern. The dressing appeared normally also on the rectangular LG. Nevertheless, how the mill worked was first deciphered by Kourouniotes (1917) from the relief on the Hellenistic Megarian bowl. The long lever attached to the UGS was on one site attached to a pivot fixed to the table or to the corner of the niche and the other end served as a handle. The Olynthus mill was operated by two men, one was putting the grain inside the hopper and the other one was moving the handle back-and-forth. Grains were captured between two stones in the grooves (dressings) and then cut by a shearing action. This innovation was so significant that it has lasted to the present day. At this point, all that was left was to go from reciprocal back-and-forth to continuous rotary motion.

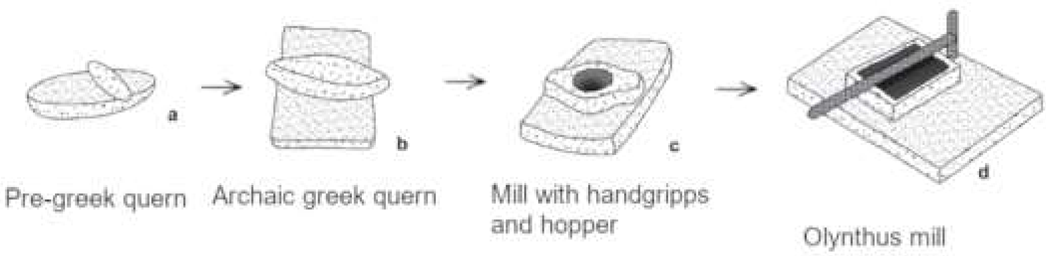


Fig. 2.7. Development of milling tools in the Iron Age (Schwall – Gluhak 2019, Fig. 7; altered).

3 Chaîne Opératoire

3.1 Introduction to sequence models

Sequence models were developed primarily as a response to insufficient results from traditional typologies. Greater emphasis was placed on the process, which consisted of activities that proceeded over time. The approach developed independently in three different countries (Japan, France, USA) in a couple of different ways (Bleed 2001).

3.1.1 Chaîne Opératoire

Chaîne opératoire belongs to the sequence models, which were developed in France from two research traditions by scholars dealing with lithic studies (Schlanger 1994, 145). One research group was interested in ethnological and anthropological studies and sought to understand human behavior. Certain basic ideas of the concept were established by M. Maus, who argued that the technical act is born for practical reasons and its gestures are a transmitted habit or way of doing (Mauss 1934). The term *chaîne opératoire* was introduced by A. Leroi-Gourhan in his book "*Le Geste et la Parole, Tome I : Technique et Langage*" (1964). He introduced the concept as a sequence of technical actions in the process of raw material transformation. The activities work as a dialogue between people and things (Schlanger 1994, 145).

In the following years, the concept was neglected and reappeared again in the 1980s (Sellet 1993, 107; Delage 2017, 160). The second research tradition focused on the lithic experimentation and replication. The influential contributors were from the School of Archaeology in Bordeaux, headed by the eminent archaeologist F. Bordes, and the research team "*Préhistoire et technologie*", led by another scholar J. Tixier (Schlanger 1994, 145; Delage 2017, 160–161). The aim of their studies was to redirect the view from the product to the processes. Emphasis was placed on the concept and knowledge that was involved in the production of the tool (Sellet 1993, 107). Besides them, P. Lemonnier contributed a lot to the concept and clarified the approach. He pointed out that the process does not need to be linear, but some activities can be flexible and variable. Furthermore, Lemonier perceived the tasks in the process as social actions composed of gestures, objects and specific knowledge (Lemonnier 1980, 1).

3.1.2 Behavioral chain and life histories

Sequence models in the USA developed mainly under the influence of the New Archaeology in the 1960s. The concept came from the *Behavioral Archaeology* and was initiated by M. Schiffer. The principle of the model had many similarities with the *chaîne opératoire*, but Schiffer described the **behavioral chain** as a sequence of processes from procurement to discard in the systematic context composed of activities that do not need to be unilinear (Schiffer 1976, 46). The approach was used as a way to examine not only the production sequence, but furthermore to understand the **use-life** of the artifact (Salisbury – Rebay-Salisbury 2017, 22). It also included the investigation of natural and post-depositional transformations (Bleed 2001, 107). The artifact was seen in some sense as a passive material that is morphologically and functionally transformed (Gosden – Marshall 1999, 169).

The use-life closely built on the concept of **object biographies**. The notion that objects accumulate histories goes back to I. Kopytoff (1986). He described the process as a creation of value between people and things. The social actions create the meaning of the artifact, and the aim is to find the process, that leads to it. Kopytoff also differentiated the notion between commodities, which are the items with the use and exchange value, and gifts, which generate a social obligation by transaction (Kopytoff 1986, 68–70).

The **life-history** approach, which integrates also the social aspects of people and objects, is seen as more historical and humanistic model. Not only the things are shaped, but also the people are transformed in interaction. This approach was developed by R. Tringham to investigate Neolithic houses (Tringham 1994).

3.1.3 Assimilation of approaches

In the 1990s, much of the emphasis in the *chaîne opératoire* model was placed on cognitive knowledge connected with the techniques and activities (Bleed 2001, 105). The concept no longer included only the production phases, but all processes from exploitation to discard (Pelegrin 1990; Sellet 1993; Boëda 1995; Sillar – Tite 2000). The study concentrated not only on the origin, but also the whole life-history of the artifact was in focus. Artifacts were no longer perceived as inert things but as objects hiding a lived reality (Coupaye 2015, 69).

The material, the person and the energy (gestures, tools and knowledge) involved in the activity were also investigated from the social and cultural point of view (Martinón-Torres 2002, 31). Behind the artifact was an effort to find gestures, knowledge and, of course, a human. Furthermore, the **technological choice/style**, that accompanies each stage of the operational chain, was more studied. According to B. Sillar and M. Tite (2000, 4) the choices can be made in the raw material, tool, energy, technique and sequence of gestures. Consequently, the final design of the artifact is not ideal, but arises as a compromise in response to technological choice. There are four dimensions of design: formal, spatial, quantitative and relational (Schiffer – Skibo 1997; Schiffer *et al.* 2001). Of course, social changes such as power differentials, gender, sex, social class, age and ethnicity, which are often hidden, also play an important role (Schiffer *et al.* 2001, 732). This view is related also to the **design theory** that was developed in the 1960s (Alexander 1964; Pye 1964; Jones 1970; Kleindienst 1975).

Knowledge of technology in the *chaîne opératoire* has always been an invaluable commodity that was not static but was shared in society. The **technology transfer** was defined by Schiffer as a process occurring between communities that includes six stages: knowledge transfer, experimentation, modification, replication, acquisition and use (Schiffer 2002, 1150; Skibo – Schiffer 2008, 128). The exchange of information between individuals could be vertical from parents to children, horizontal in the form of apprenticeship or oblique from unrelated older peers (Cavalli-Sforza – Feldman 1981; Riede 2006, 56; Lewis – Arntz 2020, 10). The exchange of knowledge can also be transmitted in the areas, where the crafts overlap. The **cross-craft interaction** can appear in all stages of the *chaîne opératoire* in the form of sharing of idea, knowledge, place, technique, skill, material and/or equipment (Brysbaert 2007, 331; Salisbury – Rebay-Salisbury 2017, 24). Furthermore, the transferred knowledge in the society can lead to similarities or changes in the material culture. Methods from biological evolutionary studies are frequently applied to investigate these cultural changes (Shennan 2002; Riede 2006; Mesoudi 2016; Manem 2020).

The *chaîne opératoire* model complemented the typological analysis by the analytical techniques as analysis of use-wear traces, waste products, experimentation studies, spatial analysis, (post)depositional studies and furthermore (Martinón-Torres 2002, 33). Alongside these analytical techniques, the material sciences such as geology, geochemistry, etc. were also integrated (Edmonds 1990; Sillar – Tite 2000, 15; Martinón-

Torres 2002, 38). The mechanical, chemical and thermal characteristics of the artifacts were investigated and the results could be universally applied in the problematics in other regions and periods (Sillar – Tite 2000, 15). The material analysis perfectly complemented the studies dealing with the technological chains (Martinón-Torres 2002, 38).

Nowadays, the divergences among the sequence models have been deconstructed and refashioned into a hybridized methodology. These models are investigated from many perspectives: sociocultural, economic, political and ideological (Lewis – Arntz 2020).

3.1.4 Sequence models in ground stone studies

Sequence models were first developed around the study of lithics because they survive in large amounts in the archaeological record due to their physical characteristics. The craft is always reductive and the whole process of production can be understood from debris (Bleed 2001, 118; Schlanger 2005, 28). On the other hand, applying these models on other materials and products such as ceramic, metal or bone requires another strategy of investigation, as there is, for example, a lack of production debris in the archaeological record. Although ground stones have similar properties to lithics, they still address different issues and have their own methods of study.

The sequence models appeared in the ground stones naturally at the early beginning of their greater interest. Runnels was one of the first to explore and outline the processes associated with GSs (Runnels 1985a). The great role in the study of ground stones had design theory mainly because the shape of the stones often did not correspond to the function of the object. Therefore, the scholars (e.g. Horsfall 1983; Nelson – Lippmeier 1993; Abadi-Reiss – Schneider 2009) began to investigate what all influenced the final shape of the artifact, which required a closer examination of each stage of the sequence models. In the last 20 years, sequence models gradually became widely used and started to be essential for the study of larger assemblages of ground stones (e.g. Adams 2002; Baysal – Wright 2005; Hamon 2008b; Lidström Holmberg 2008; Tsoraki 2009; van Gijn – Verbaas 2009; Řídký *et al.* 2014; Beller *et al.* 2016). Furthermore, this concept appeared many times in articles dealing with the use-wear analysis (e.g. Dubreuil – Savage 2014; Hayes 2015).

3.2 Chaîne Opératoire of grinding stones

Artifacts record not only the use of the object but the whole life history, which includes raw material choice, procurement, manufacture, use, maintenance and discard (Fig. 3.1; Runnels 1985a, 102; Adams 2002, 4; Baysal – Wright 2005; van Gijn – Verbaas 2009, 3–4; Dubreuil *et al.* 2015, 110). However, the reconstruction of the life history of the artifact is a challenging and complex quest because the traces overlap each other. Furthermore, stone artifacts belong to durable materials, so their life history does not have a straightforward line. Thus, they have mostly very complex histories, which encompass also reuse in another activity either by reshaping of the artifact or without reshaping (Schiffer 1972, 158; Adams 2013, 25; Smith – Hayes – Stephenson 2015, 71). Ethnographic studies are also an important source of information, providing comparative insights from living contexts of macrolithic use (e.g. Cook 1982; Horsfall 1983; Hayden 1987; Schneider 1993; Searcy 2011; Hamon – Le Gall 2013; Alonso *et al.* 2020). Understanding the life history of grinding equipment is a complex issue that requires involving many analyses. Even so, combining all possible analyses often yields only an approximate result, but yet much constructive information can be discovered for further study.

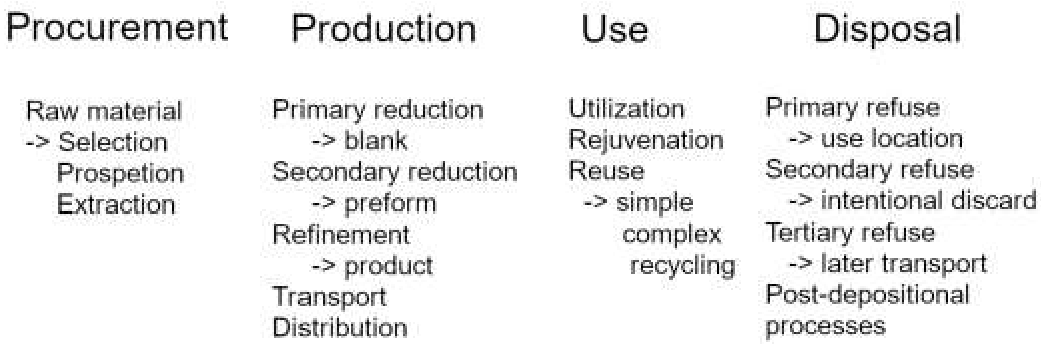


Fig. 3.1. *Chaîne opératoire* for grinding stones.

3.2.1 Procurement

According to the design theory, at the beginning of the sequence there must be some problem that needs to be solved through the artifact. The GS as a tool was used for many grinding activities not only for food processing. The proper function of the tool was closely linked to the characteristics of the raw material (Horsfall 1983, 127). Therefore, the raw material selection and prospecting of the surrounding area must necessarily precede the initial exploitation.

The **selection of raw material** depends on three factors. The first criterion is the cost, which is associated with the difficulty of extraction, transport and shaping. Sometimes, it is necessary to incur these costs if some properties of the raw material are required for the correct functioning of the artifact. These geological properties may include, for example, hardness, porosity, grain size, texture or weight. To be easily extractable and workable[1], the rock should not be too hard, rather homogeneous with no defects and with a higher density of pores/vesicles. Such characteristics were mainly fulfilled, for example, by andesites (Runnels 1981, 63). On the other hand, hard cohesive rocks with sharp-edged vesicles such as vesicular basalt were considered the most suitable for utilization of GSs (Hayden 1987, 14; Schneider – LaPorta 2008, 24; Delgado-Raack – Gómez-Gras – Risch 2009, 1830; Searcy 2011, 55). Other criteria may also include aesthetic appearance or cultural and religious traditions (Runnels 1985, 102).

Prospection, searching for and identifying possible sources, was initiated to select the right raw material. Potential sources of raw materials may be up to 5 km away from the settlement, collected on shorter walks and therefore classified as local raw materials. Regional sources can be collected during longer walks between 6 and 20 km. Raw materials more than 20 km away are considered supraregional and were collected during extended expeditions (Kandel *et al.* 2016, 636).

The **exploitation** of the raw material could be opportunistic during routine walks around the settlement or intentionally planned (Schneider 1993, 15; Abadi – Rosen 2015, 112). Opportunistic exploitation of local resources will include mainly the occasional collection of raw material from secondary sources such as riverbeds, streams, and blockfields or from primary sources around outcrops (van Gijn – Verbaas 2009, 3; Tsoraki 2011b, 234;

[1] Extractability is the potential of the material to be mined and workability is the potential of the material to be shaped (Runnels 1981, 62).

Beller *et al.* 2016, 14; Bekiaris – Stergiou – Theodoridou 2018, 428). However, the rock collected from this type of source was mostly highly weathered with bad workability, because the stone was brittle and the shaping was badly controlled (Schneider – LaPorta 2008, 22). For this reason, stones were sometimes soaked in water before shaping (Schneider – LaPorta 2008, 22). Another option was to obtain the raw material by digging a deep hole and extracting large boulders underneath many feet of soil (Searcy 2011, 39). This method of mining leaves behind large pits that are partially filled in overtime but still remain distinct in the landscape (Dworakowska 1975, 125).

The removal of soil and debris from the exposed bedrock provided the raw material of a better quality. Fresh unweathered stone retains a certain amount of moisture, which ensures better workability (Schneider – LaPorta 2008, 22). The outcrops also had to fulfil certain characteristics that were beneficial for the subsequent processing of the stone. The stone block during quarrying roughly corresponded to the joint pattern of the outcrop. If the block was too large, extra work was needed to reduce it to the required size. Therefore, the size of the joint spacing and breaks in the outcrop often corresponded to the dimensions of the GSs (Schneider – Altschul 2000, 179; Schneider – LaPorta 2008, 24–25).

For the extraction of the block, hammers, levers, wedges, chisels and picks made of stone, wood, antler or metal were used. The most commonly used tool was a hammer often made of some kind of tough stone, which did not have to be extra hard but mainly had a high rock density (Hayden 1987, 17–20). The stone was often modified to a chisel- or pic-shaped tool, which was suitable for stone extraction, because it allowed the strike to be concentrated in one place (Schneider 1993, Appendix A; Schneider – LaPorta 2008, 27–29; Řídký *et al.* 2014, 291). Tools were sometimes transported to the quarry, but more often they were picked up in the vicinity, because they were easily broken during the activity. Quartz or quartzite cobbles were often used and can be well differentiated on the quarry site (Schneider 1996, 303; Řídký *et al.* 2014, 291). However, if the material was the same as the extracted blanks for GS production, they are hard to identify (Schneider – LaPorta 2008, 29; Abadi – Rosen 2015, 112). Furthermore, the quarrying tools made of wood or antler as picks, wedges or levers were hardly preserved at all.

Sometime on the quarrying sites various mining waste, tested blocks, failed products or semi-finished products are present (Takaoğlu 2005, 426). But if the extraction was small-scale, it leaves almost no clear traces. In the Roman period, true large-scale extractive quarrying was introduced which left behind a lot of waste, tools and traces on the outcrop as channels and holes after the use of channeling and wedging techniques of extraction (Runnels 1981, 75).

The outcrops with rare and highly valued raw materials were often under the control of political entities or in the ownership by an individual or group of individuals, for example the Roman quarries of Mons Claudianus (Peacock 1988). In ethnographic studies, it is often encountered that *metateros*[2] owned or rented the land with the source of rock used for GSs (Cook 1982; Hayden 1987; Searcy 2011, 41). On the other hand, the quarries in the Antelope Hill were located on land that was not owned by anyone and therefore access was not restricted (Schneider – Altschul 2000). According to J. Schneider and P. LaPorta (2008, 32-33), ownership and control of the access to sources in egalitarian societies were probably absent. However, complex societies with the stratified social structure probably already had a well-developed system of ownership and control of sources in the landscape (Gilman *et al.* 1981).

3.2.2 Manufacture, transport and distribution

Based on the ethnographic studies, *metateros* in the Maya Highlands needed approximately one whole day for exploitation of blanks and it depended on how successful the extraction was (Hayden 1987, 25). The production sequence (Fig. 3.2) of one GS then took a minimum of one day, that is 10 to 24 working hours (Cook 1982; Hayden 1987, 26–42; Searcy 2011, 54). It was more economical to produce several GSs in one expedition. However, the failure rate of the production was quite high, according to the experiments between one and two success to four attempts (Schneider – LaPorta 2008, 33).

[2] The name for the specialists producing GSs in the Maya Highlands.

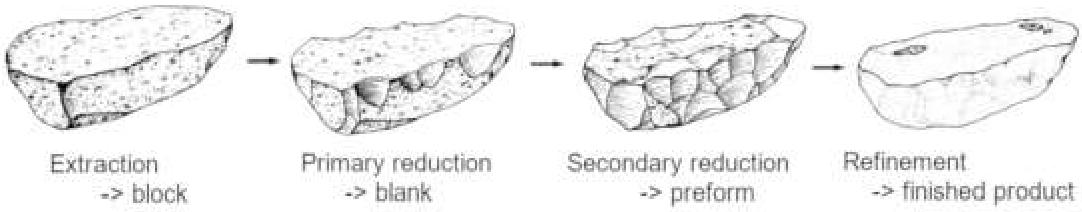


Fig. 3.2. Production sequence of grinding stones (Schneider 1996, Fig. 12; altered).

Firstly, the material had to be reduced so that the transport load was not so heavy and only quality material was taken. Therefore, the initial **primary reduction** of the block is expected to be carried out at the place of extraction of the raw material (e.g. Runnels 1981, 103; Schneider 1996, 304; Baysal – Wright 2005, 312; van Gijn – Verbaas 2009, 4; Tsoraki 2011a, 17; Hamon – Le Gall 2013, 112; Abadi – Rosen 2015, 112; Beller *et al.* 2016, 14). If the exploatation was from secondary sources, it was important to remove the weathered parts first by flaking. The boulder was then split into two parts to obtain the flat side as a working surface (Runnels 1981, 138). When the rock from the outcrop was too large, it was necessary first to divide the block into smaller blanks. The technique of heating the stone and then rapidly cooling it with water, which generated cracks and then split the stone, is well recorded in ethnographic studies (Searcy 2011, 39). Consequently, large percussion flakes were removed from the body of the quadrangular block to form a roughly ovate shape. Sometimes one side was kept naturally flat for the working surface (Schneider 1996, 306; Takaoğlu 2005, 429; Abadi – Rosen 2015, 112; Beller *et al.* 2016, 14).

During **secondary reduction,** the blank was shaped into the preform. Smaller flakes and amorphous fragments were removed by flaking and pecking (Wright 1992, 57; Schneider 1996, 306; Takaoğlu 2005, 429). According to the ethnographic studies, the working surface is always shaped first, then the sides are roughly knapped to line and at the end the material from the bottom is removed (Hayden 1987, 31; Searcy 2011, 32–65). For the shaping, hammerstones with pointed edges were used (Schneider 1996, 306; Takaoğlu 2005, 429).

In the next stage, called **thinning**, **dressing, refinement** (Runnels 1985a) **or finishing**, the surface of the GS was flattened and pecked to remove sharp edges and flaking scars (Schneider 1996, 306; Takaoğlu 2005, 429). Only little debitage was removed in the form of small fragments, grains or dust and very light tools as small pointed picks were used (Hayden 1987, 36; Searcy 2011, 47). This phase is the most time-consuming of all (Schneider – LaPorta 2008, 33). The product was then ground and smoothed with a small abrasive stone to hide the tool marks (Takaoğlu 2005, 429). In the end, the two counterparts of the GS were used in the dry-grinding activity to ensure that the pairs of stones fit together (Hayden 1987, 41).

The position of **transport** in the production sequence was variable. It mainly depended on how far the workshop was from the source. The unfinished GS could be transported as a blank after the primary reduction (Abadi – Rosen 2015) or as a preform after the second reduction (Hayden 1987; Takaoğlu 2005; Searcy 2011). The final refinement normally always took place in the home workshop. The distance of transport, weight and amount of the products was always reflected in the price of the finished product (Costin 1991, 14). Half of the total price of the GSs was often transport and distribution, as is known from ethnographic studies (Searcy 2011, 110). The load of the semifinished GSs had to be carried in the beginnings by human force. The movement was limited by various natural barriers, such as mountains. Therefore, most of the paths were chosen naturally over flat terrain or through valleys. As distances from the source increased, other alternatives began to be sought. The domestication of draught animals, such as donkeys, was one way of overcoming long distances with such heavy loads (Milevski 2008, 125).

The other option was to transport the load over water, rivers and the sea. In the Aegean, it is documented that GSs in whatever form (raw material/semi-/finished product) were transported already in the Neolithic across the sea from the island of Aegina to the Mainland Greece (Runnels 1981, 69). The first long distance transport over the sea appeared probably in the BA, when maritime trade was fully developed. Some GSs made of volcanic rock from the Levant were found in Cyprus more than 300 km away from the source (Williams-Thorpe – Thorpe 1993, 292). In the middle of the 1st Millennium BC, evidence of imports as far as 800 km from the source is documented, and, in the Roman times, even 1300 km (Williams-Thorpe – Thorpe 1993, 293–294).

According to the ethnographic studies from Mesoamerica, the GSs were manufactured by men part-time specialist (Cook 1982; Hayden 1987; Searcy 2011). The craft was often passed on from father to son. The young boys were apprenticed to make GSs in their tenth year of life. On the other hand, in Africa it was recorded, that the women were recorded to make their own GSs and obtain these skills from older women (Shoemaker – Davies – Moore 2017, 426).

The **organization of production** and the degree of specialization related to the GSs is mostly not well preserved in the archaeological record (Beller *et al.* 2016, 15). The production place with the debris from the primary or secondary reduction near the area of extraction was rarely recognized (exceptions are e.g. Schneider 1993; Takaoğlu 2005; Abadi – Rosen 2015; Beller *et al.* 2016). Some workshops existed in the settlements, but their identification is difficult because the production of GSs was mostly not so large-scale, and the finishing reduction left behind only a minimum of waste. Therefore, studying the degree of specialisation, scale, structure, intensity and concentration based on direct evidence is not common. Production is mainly examined from indirect indicators such as the variability of products in the assemblages, technological skills and labor investment projected into the artifacts (Costin 2005, 1064).

The **specialized production** was characterized as a phenomenon, which was defined in many publications (e.g. Evans 1978; Rice *et al.* 1981; Shafer – Hester 1986; Costin 1991; Clark 1995; Tosi 2009). The main and common characteristics of specialization are that the production is regularized and predictable, the goods are exchanged for some kind of material or service compensation and the artisan does not consume all the produced goods (Costin 1991, 4, 2001, 275). According to Runnels (1981, 125), specialized GS production in the Aegean started at least at 6th Century BC. In the second half of the 1st Millennium BC, specialized production became quite common because standardized grinding equipment such as the Olynthus and rotary mills appeared.

Product **standardization** is often referred to as one of the indirect indicators of specialized production (e.g. Costin 1991, 2001, 2005; Arnold – Nieves 1992, 1992; Blackman – Stein – Vandiver 1993). The hypothesis assumes that more uniform assemblages are associated with specialization. This is because product standardization among others increases repetition-induced skill, makes production more efficient, saves time, guarantees quality, minimizes the risk of failure, and creates a familiar mark on the market (e.g. Costin 1991, 33–35, 2005, 1064–1065; VanPool – Leonard 2002, 713–714).

With a higher degree of specialization in the society, the number of producers decreases, and the assemblage of products should be more standardized (Costin 2001, 33,36, 2005, 1065). According to C.L. Costin (1991, 33), the standardization hypothesis can be sometimes misleading because it can also be a byproduct of efficient technological form or consumer demand. Therefore, it is very important to compare more analytical units and consider which variables are chosen to compare (Costin 1991, 35). According to Costin (1991, 35), the performance characteristic of the tool are not good variables, because they can be related to the sociopolitical factors or functional concerns, better to choose unintentional differences in technology, gestures and patterning (Costin 2001, 35). On the other hand, variability in the correct functional design of an object is also undesirable in specialized production, which must also be taken into account (VanPool – Leonard 2002, 714). Of course, ground stones have many design options to make the product functional, but specialized producers, for commercial reasons, are trying to find the optimal solution and are spending more time and money on it.

The standardization hypothesis was used as an analytical tool to examine many archaeological assemblages, mainly ceramic manufacture (Rice *et al.* 1981; Blackman – Stein – Vandiver 1993; Costin – Hagstrum 1995; Arnold 2000) but also the production of GSs (VanPool – Leonard 2002; Searcy 2011). The relative degree of standardization is quantified as the coefficient of variation (CV), which measures the degree of tolerance for dispersion from a standard size taking into account the absolute size of the variables (Fig. 3.3). When the studied sample is small, the corrected coefficient of variation (CCV) is used to account for the tendency of the small assemblage to underestimate variability (Eerkens – Bettinger 2001). According to J.W. Eerkens and R.L. Bettinger (2001, 497-498), CV values for standardized manual production are between 1,7 and 57,7 percent. Higher values indicate greater variance and therefore a lower degree of standardization. The CV is influenced by many factors: design theory (the products do not always have the ideal shape), amount of producers, a large number of producers over a large period of time, comparing more types of artifacts, differences between materials (Searcy 2011, 125).

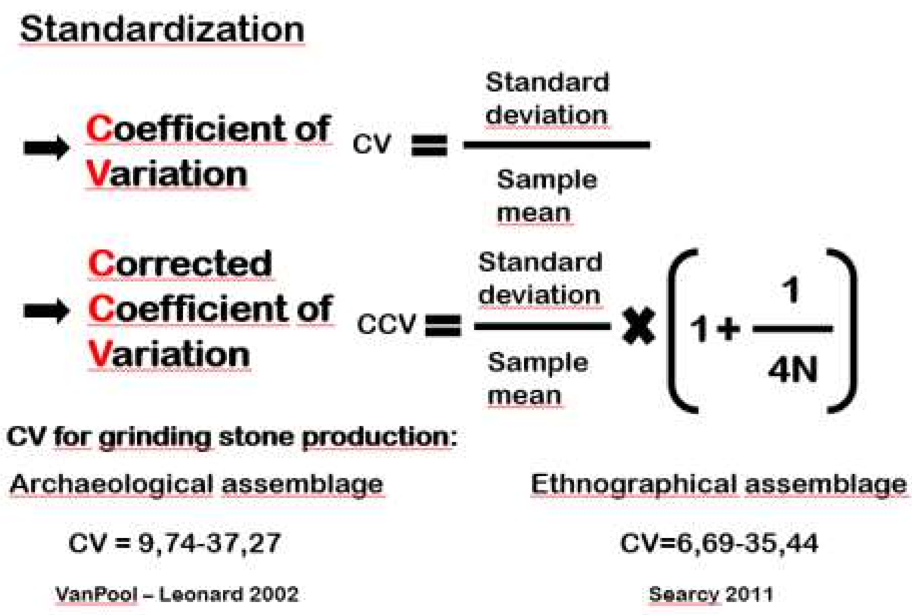


Fig. 3.3. Quantification of standardization using the coefficient of variation and the corrected coefficient of variation, counted CV results for GS assemblages in Mesoamerica.

GSs in comparison to ceramics are produced by the reductive techniques, which are hard to control, so the CV will be a little bit higher (Eerkens – Bettinger 2001, 500). In the ethnographic study, M. Searcy measured the GSs produced by the *metateros* in the Maya Highlands and obtained the CV values between 6,96 and 35,34. The least variation was in length and width and the greatest in thickness. This was probably related to the fact that the thickness of the GS is associated with the time of use (Searcy 2011, 124–135). Similar results were reached by T. Van-Pool and R. Leonard (2002) who studied the archaeological assemblage of GSs from the Paquimé.

After the production process, the GS entered the **distribution system**. Not only precious stones such as lapis lazuli, alabaster or carnelian but also GS have been involved in a wider complex trade network since the early days of mankind. The distribution patterns are very hard to access. The patterns of trade network with GSs in Mesoamerica were addressed by William Rathje (1971). He differentiated the commercial system between household units and complex network of merchants and stores. The network consisted of the periphery, where was the source of the raw material, and the core, where was the concentration of demand. Between these zones was the buffer zone that functioned as a production and distribution center of the GSs (Rathje 1971, 1972).

3.2.3 Use

The GSs were always used in pairs to grind the material inserted between them. LGS and UGS complement each other and their shape is adapted to fit together, to smoothly crush the substance inserted between them (Hürlimann 1965, 78–80). Therefore, the shape of the working surface of the LGS and the UGS can be predicted based on metric relations (Zimmermann 1988, 725). The easiest way is to compare the length and longitudinal shape of the UGS with the width and transverse shape of the LGS working surface. When using small UGS with a convex shape, the LGS acquires a concave working surface. It works similarly when using a straight UGS that creates a straight working surface. If the UGS length is longer than the LGS width, it creates a convex shape of the working surface (Fig. 3.4). Predicting the exact shape of the LGS and the UGS is not easy and depends on the wear of the material and the direction of movement of the UGS (Adams 1999, 492). Nevertheless, R. Risch (2008) established basic rules according to which shape and size can be predicted (Fig. 3.5).

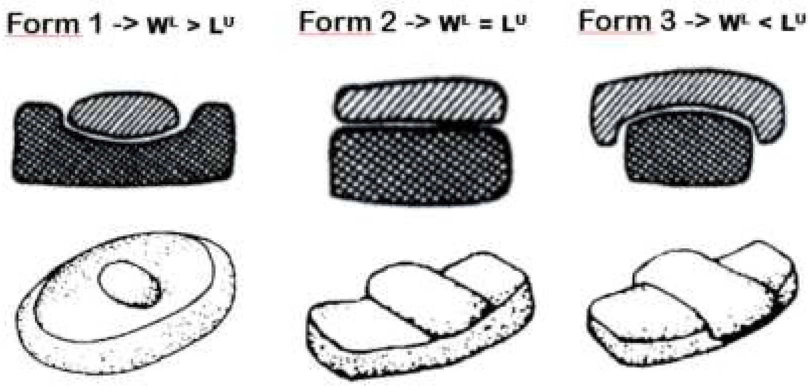


Fig. 3.4. Forms of GSs, W^L – width of LGS, L^U – length of UGS (Zimmermann 1988, Abb. 640; altered).

	Relativ dimensions	Shape of lower grinding stone	Shape of upper grinding stone
1	$W^L > L^U$	Cc/Cc or Str/Cc	Cx/Str or Cx/Cx
2	$W^L \leq L^U$	Str/Str or Cc/Str	Str/Str or Str/Cx
3	$W^L \leq L^U$	Cc/Cx or Str/Cx	Cc/Str, Cc/Cx or wooden
4	$W^L \geq L^U$	Cx/Cx	Cc/Str or Str/Str or Cc/Cc

Fig. 3.5. Predictive model of morpho-metrical coupling (longitudinal/transverse profile axis) between GS, W^L – width of LGS, L^U – length of UGS, Cc – concave, Cc – convex, Str – straight (Risch 2008, Tab. P0/14).

The **use-life** of the GS depended on many factors. Firstly, UGSs tend to be more abraded and, therefore, lasted for a shorter period of time than LGSs (Wright 1990). Another aspect was, of course, the frequency of use. Grinding often took up a large part of the day. The amount of time dedicated to grinding depended on many factors (Alonso 2019, 4322). In ethnographic Mesoamerican studies, three to six hours per day were reserved for corn grinding for a family of four (Vogt 1970; Foster 1979; Horsfall 1987; Smith 2003; Searcy 2011). B. Ramminger (2008, 38) came to similar results using the archaeoexperimental tests, calculating the average grinding time of an hour and a half per day for one person's supply of flour.

The life span of the tool can be estimated by the concavity of the GS. In simple terms, the tool with more concave surface was probably used long time (Hamon 2008b, 49). However, there are many influences that affect this assumption such as the initial curvature or the rate of abrasion. Furthermore, after a certain period of time the surface of GS flattened out, was polished and no longer worked as it should. In this case, it was necessary to restore the original condition of the surface by **roughening;** this activity is also sometimes called in the literature as **rejuvenation**, **resurfacing** or **resharpening** and was performed by pecking the surface with hard pointed stone (e.g. Schlanger 1991, 462; Hamon 2008b, 48; Ramminger 2008, 38; van Gijn – Verbaas 2009, 6; Searcy 2011; Hamon – Le Gall 2013, 113).

The important factor with respect to the lifetime of the GS was also the type of stone used for manufacture. In many articles, it is pointed out that the vesicular basalt lasts longer than other types of stone due to its hardness (Hayden 1987, 14; Schneider – LaPorta 2008, 24; Delgado-Raack – Gómez-Gras – Risch 2009, 1830; Searcy 2011, 55). The hardness ensures less abrasion and no need for the stone to be periodically roughened due to vesicles. According to ethnographic studies in the Maya Highlands, the roughening of the basalt working surface was maintained only one to four times per year (Searcy 2011, 83). B. Hayden noted that the use life of vesicular basalt GS is from 15 to 30 years (Hayden 1987, 193). Quartzites also lasted longer, because they have similar suitable properties (Ramminger 2008, 38). However, the soft, non-cohesive sandstones abraded quickly, they leave a lot of stone dust in the flour and needed to be often resharpened, sometimes every other day, so the lifetime is shorter (Ramminger 2008, 38; Hamon – Le Gall 2013, 113).

The morphology of GSs in the prehistory before the standardized Olynthus and rotary mill was very variable because many types of shape lead to the same function (Horsfall 1983, 117–119; Adams 2002, 10–11). There were occasionally two classes of GS sizes identified in archaeological assemblages (Kidder 1947, 33; Coe 1959, 34; Hamon 2008b, 50) and it was therefore often suggested that the function might coincide with the size of the GS. G. Horsfall (1987, 350) pointed out that the relationship between GS size and function is rather small, the sizes overlap and they reflect more quantities of needed processed product. However, M. Searcy noted that in some cases the size of the working surface really corresponded to the type of ground substance because the households in the Maya Highlands often had special sized GS for individual processed products (Searcy 2011, 120–123). On the other hand, the ethnographic study of GS producers in northern Africa by L. Nixon and Y. Merasa (2020, 4) recorded two variously named types of GSs with almost the same form, differing only slightly in thickness but used to process variable substances.

G. Horsfal (1983) and J. Adams (2002, 18) correctly pointed out that the design of the artifact is more important than the shape. Sometimes it can shed light on how the object was used in terms of behavior and kinematics. For example, in Mesoamerica, the LGSs had three legs to provide the sloping during the grinding (Hayden 1987; Searcy 2011). The slope of the GS based on ethnographic studies (Horsfall 1987, 348; Hamon – Le Gall 2013, 115) and experiments (Damon – McFarland – Stoudt 1966, 294) made grinding easier because, besides the hands, the back was involved in the movement, thus distributing the energy. If the GS did not have feet, often one part was elevated in mass, or the GS was supported by something (Fig. 3.6). For example, in the Maya Highlands, the tripodal LGSs were underlain by a donut-shaped object made of stone to further increase the sloping (Searcy 2011, 129). The tripod LGS had another advantage, as the legs raised the stone, bowls could be placed underneath to collect the ground product (Horsfall 1987, 353). Furthermore, to control and direct the fall of the ground product into the bowl, the LGSs were sometimes equipped on the sides with the elevated rim (Barlett 1933, 15; Aschmann 1949, 683; Horsfall 1987, 352; VanPool – Leonard 2002, 716).

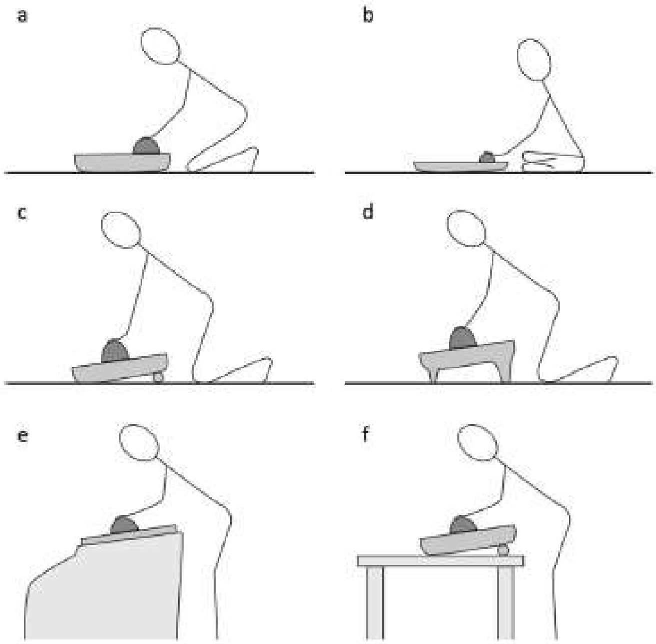


Fig. 3.6. Examples of postures and positions of GSs during grinding activity: a) kneeling on the floor. b) seated cross-legged on the floor. c) and d) on the floor with inclined LGS. e) standing with inclined LGS in grinding bench. F) standing with inclined LGS on a table (Alonso 2019, Fig. 7; altered).

Ergonomic features are among the other design elements that have appeared this time on the UGSs since Neolithic times to facilitate the grip of the tool. These ergonomic adjustments are represented by modifications of the end parts carried out after finishing of the product such as depressions and roughening on the stone. In the later period, proturbances appeared that served as a proper handgrip. The ergonomic adjustment location is on the side where the GS is held to direct its movement. More force is exerted at the other end, and therefore more abrasion occurs, which is sometimes seen on archaeological artifacts. Based on the location of the gripping part, the right-handedness or left-handedness of the person who used the GS can be determined (Pavlů 2011).

The design of the GS reflects more technological than the functional concerns. Based on the shape, the function or the dietary emphasis cannot be predicted (Horsfall 1983; Wright 1994; Adams 2002). The questions related to the function of the object are examined by the analysis of use-wear traces.

The GSs have been used in various activities and processed various substances. They had a special position in food preparation. Grinding of plant food was maintained to remove fiber, reduce particle size, aid detoxification, add or remove nutrients (Stahl 2014, 172–174). The ground plants included mainly cereal seeds, legumes, nuts, roots, herbs and fruits. Some of the plants required grinding to be edible like acorns or wild almonds (Zohary – Hopf – Weiss 1988, 161,176). Other foods such as cereals had to be dehusked and ground into groats to increase their calorific potential. However, grinding tools were not only used for processing plant stuff, but also animal stuff such as bones, hide, fat, dried meat or fish skin. They also occurred in other areas. They were used to process clay or to crush stones for temper in the ceramic production. In the textile production, pigments crushed on the GS were needed. Anvils or netherstones occurred in the metal production (Levy – Bettilyon – Burton 2016). Furthermore, the tools used to apply the plaster on the wall look morphologically the same as some of the GSs (Adams – Saed Mucheshi 2020). To sum up, they were used in many contexts not only domestic although the food preparation was of greater importance.

3.2.3.1 Use-wear analysis

Wear formation begins during manufacture and then other phases lead to accumulation and modification of the use-wear traces (Dubreuil *et al.* 2015, 110; Hayes – Pardoe – Fullagar 2018, 100). Each phase the artifact has gone through will leave certain wear traces on him, but the most visible wear is always related to the last activity before the discard (Adams 1988, 312).

To begin with, it is important to note that the visibility of use-wear traces depends mainly on the intensity and duration of use, as well as the properties and structure of the rock (Hamon 2008a, 1506). One of the main problems in the use-wear analysis on ground stone tools is the heterogeneity of the material. A rock is composed of many minerals with different properties; it also depends greatly on how it was formed or whether it is characteristically classified as igneous, metamorphic, or sedimentary. The origin of the rock has a great influence on the effectiveness of the tool and it also affects the formation of use-wear traces (Procopiou 1998; Hamon – Plisson 2008, 30; Delgado-Raack – Gómez-Gras – Risch 2009; Dubreuil *et al.* 2015, 116; Chondrou *et al.* 2021).

In addition to the exact geological determination of the rock, the structure and texture of the rock and its physical properties (grain size, cohesion, and porosity) must be recorded. Under better conditions, a description of the individual mineral components (precise mineral identification, orientation of axes, roundness of crystals) can also be carried out under a microscope (Adams *et al.* 2009, 45; Dubreuil – Savage 2014, 143; Dubreuil *et al.* 2015, 116–120).

3.2.3.1.1 Wear mechanisms

Wear is often defined as a continuous process of surface transformation caused by movement between two contact surfaces (Czichos 1978, 98; Adams *et al.* 2009, 46; Dubreuil – Savage 2014, 141). It is not a material property, but a response to a process and therefore must be seen as a phenomenon that is dependent on many parameters (Bhushan 2002, 331; Kato 2002, 349). Wear appears as very slow damage or material removal, but it is steady and continuous. From a tribological point of view, many classifications have already been put forward to distinguish different types and mechanisms of wear (Achard – Hirst 1956; Burwell 1957; Czichos 1978; Kostetskii 1981; Ashby – Lim 1990; Varenberg 2013). The most emerging classification applied to the GSs was introduced by Horst Czichos (Adams 2002, 27–33; Adams *et al.* 2009, 46–47; Dubreuil *et al.* 2015, 115). Four principal types of wear mechanisms affect development of wear on macrolithics: (1) adhesive (2) abrasive (3) fatigue and (4) tribochemical (Fig. 3.7).

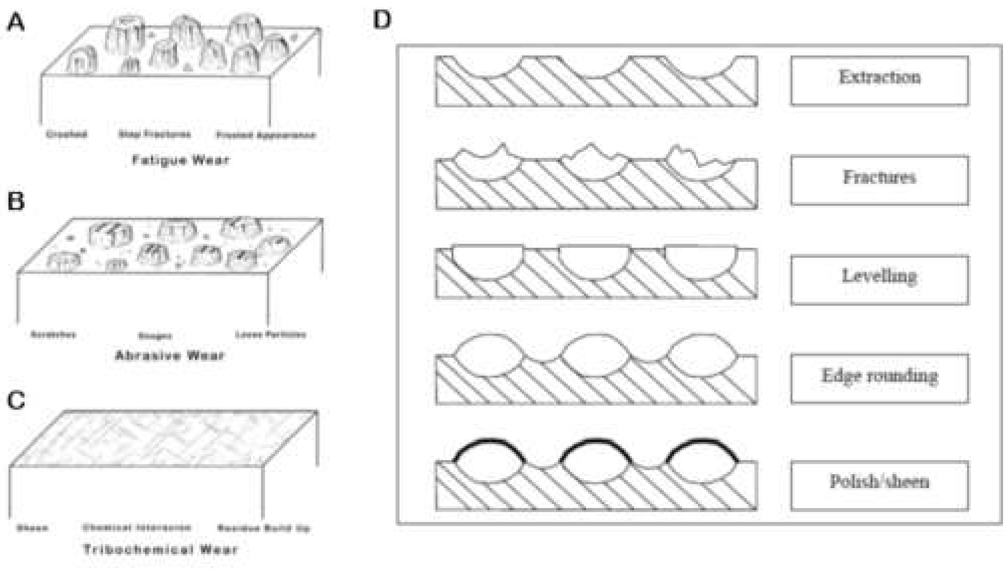


Fig. 3.7. Different kinds of wear mechanisms (A,B,C; Adams 2013, Fig. 2.4-2.6) and grain alterations (D; Adams *et al.* 2009, Fig. 6.4).

When two surfaces rub against each other, heat is generated that breaks the bonds between the grains. As a result, the softer grains separate and accumulate on the surface of the harder grains, forming a thin coating. This type of wear mechanism is called **adhesion**. **Abrasion** occurs when the asperities of the harder, rough surface, or released harder grains become embedded in the softer material. The damage of the softer material will result in various abrasions, grooves and scratches. Repeated loading and unloading cycle of contact stress create cracks, fissures, and fractures, which are distinctive for the **fatigue wear** (Adams *et al.* 2009, 46–47; Adams 2013, 33–34).

During wear, not only the two surfaces and the crushed substance interact, but also the surrounding environment, causing tribochemical wear, which, unlike the previous destructive wear, is additive. It is formed after long exposure to different types of mechanical wear mechanisms such as adhesion and abrasion (Varenberg 2013, 336). A special environment is created on the surface where chemical reactions take place, and the products form a smooth and shiny polymer film (Czichos 1978, 123–130; Bhushan 2002, 380).

In the study of chipped stones, understanding these mechanisms has still remained problematic. The individual mechanisms often overlap, making it difficult to recognize and understand how much influence they have on the observed manifestations of wear (Hayden 1979; Unger-Hamilton 1984; Astruc – Vargiolu – Zahouani 2003; Evans – Donahue 2005; Anderson *et al.* 2006).

3.2.3.1.2 Analysis procedure

The tools are first examined at a macroscopic level with the naked eye. Surface levelling and the distribution of irregularities were described. Using external low-angled light at a right angle to the objects helped us to identify the working surfaces, which bear linear traces, pits, homogeneous zones and occasionally also potential shiny areas.

One of the first aspects is the topography of the surface in profile, which may be flat, sinuous, or uneven, and the development of the microtopography is described (regular, irregular), which is connected with the roughness of the surface. (Adams *et al.* 2009, 48; Dubreuil – Savage 2014, 145).

Pits are remains after the extraction of grains and they are sometimes hard to differentiated from natural lower topography of rock. It is important to notice them, as they often indicate the kinematics and gestures of movement. The density, distribution, shape (irregular, linear, rounded) and depth (fine, deep) of the pits is described (Adams *et al.* 2009, 48; Dubreuil – Savage 2014, 145).

The large, levelled areas are named homogeneous zones. Their distribution indicates where the main contact with the second stone occurred (Adams *et al.* 2009, 48; Dubreuil – Savage 2014, 145).

Microwear analysis is characterized by the use of optical microscopes and it involves two levels of observation. The first level of observation is at low magnification, i.e., less than 100x magnification. The low magnification approach commonly employs the stereomicroscope with an external light source at a right angle, which allows us to comprehensively observe in 3D the relief, topography and use-wear traces (e.g. striations and grain alteration) across the whole surface of the object. The reflected-light metallographic microscope for viewing opaque specimens is used in the high magnification approach, enabling a focus on the surface of up to 100x magnification (Fullagar 2004; Dubreuil *et al.* 2015, 124; Hayes 2015; Li 2020, 14). For identification of distinctive and diagnostic use-wear patterns, especially polish, higher magnifications are needed.

The topography of the natural rock surface consists of protruding mineral grains dispersed within finer grains (matrix). The raised areas in the matrix are called asperities and between the asperities are spaces called interstices. In its natural state, each asperity has a different shape (Adams 2013, 32). When subjected to mechanical wear, the surface of the asperities can become abraded, levelled, rounded, or can develop cracks (Fig. 3.7). With tribochemical wear, deposits will form on the surface and a conspicuous sheen develops (Hamon 2008a, 1506).

Moving to the microscopic scale under low power magnification, the focus should be on the features that emerged from macroscopic observation and on the grain alteration, mainly on the faces (levelled, fractured, unaltered) and edges (rounded, sharp).

The analysis under high power magnification is focused on the polish, striations and crystal alteration. Firstly, the development of the micropolish is described in terms of its density, distribution, dimension, brightness and the appearance of the patches, under 100x magnification. Then, attention is shifted to the texture (smooth, rough) and topography (flat, domed, reticular, pitted) of polished areas. If striations are present, their dimensions (length, width, depth), occurrence (frequent, occasional, scarce), polishing, appearance (polish, crystals) and orientation (parallel, oblique, chaotic) are noted. Finally, the appearance and modification of grains should also be described for their faces (abraded, fractured, polished, striated) and edges (rounded, abraded, sharp, fractured; terminology used from (Adams *et al.* 2009; Dubreuil – Savage 2014; Hayes – Pardoe – Fullagar 2018; Zupancich *et al.* 2019).

Finally, these observations should allow to interpret the kinematics of the grinding set and the gestures involved in its use and to identify the substance being ground. According to the classification developed by A. Leroi-Gourhan (1971) and further elaborated by other scholars (Nierle 1982; de Beaune 1989; Dubreuil 2001) perpendicular, chaotic or longitudinal (back-and-forth, circular movement) gestures can be distinguished (Dubreuil – Savage 2014, 145). Determining the exact substance that was ground can sometimes be difficult. At the very least, it is possible to differentiate its hardness and to distinguish between plant, animal and inorganic matter.

As already outlined above, the determination of the function of macroliths by means of use-wear analysis is very complex and needs good **reference libraries**. Unfortunately, these collections can differ from each other mainly due to the heterogeneity of the raw material. Different variations have to be taken into account for each rock type separately. Nevertheless, it is possible to identify general features associated with a particular activity on which to base one's own interpretation.

It is also important to acquire a reference collection of samples prior to the actual analysis of the use-wear traces. First, the raw material used for production, which should include fresh cut and weathered surfaces, which will allow better recognition of post-depositional changes (Adams *et al.* 2009, 45; Dubreuil *et al.* 2015, 110). Furthermore, it is also important to build a collection of tools from the raw material itself, for which wear traces after tool creation and after tool use are described and compared (Dubreuil *et al.* 2015, 112).

As regards the raw materials, the experimental study collections have principally concentrated on the development of use-wear on sandstone (Adams 1988, 1989; Hamon 2008a; Liu *et al.* 2010, 2011; Gilabert – Martínez-Moreno – Mora Torcal 2012; Zupancich – Cristiani 2020), basalt (e.g. Dubreuil 2004), mica schist (Risch 2002; Delgado-Raack 2009), gabbro (Risch 2002; Delgado-Raack 2009), granite (Chondrou *et al.* 2021), andesite (Chondrou *et al.* 2021), conglomerate (Delgado-Raack 2009), limestone (Cristiani – Lemorini – Dalmeri 2012; Gilabert – Martínez-Moreno – Mora Torcal 2012) or quartzite (Zurro – Risch – Clemente Conte 2005; Gilabert – Martínez-Moreno – Mora Torcal 2012; de la Torre *et al.* 2013).

3.2.3.2 Social aspects

Grinding activities were predominantly always associated with women, as indicated in many ethnographical studies (e.g. Hayden 1987, 193; Horsfall 1987, 352; Ertug-Yaras 2002, 211; Searcy 2011; Hamon – Le Gall 2013, 20; Alonso 2019, 4321). In exceptional cases, men were also involved in grinding (Hamilton 1980, 5; David 1998, 23; Alonso 2019, 4321). However, the tool was often seen as a highly valued **property of women**. It was a very expensive but necessary investment when a new family was being formed. Therefore, GSs were acquired as a wedding gift or were inherited over generations, passed through mother to daughter (Cook 1982; Hayden 1987; Baysal – Wright 2005; Searcy 2011, 72–74; Hamon – Le Gall 2013, 117).

There were always several UGSs in one household as they wore out quickly. However, multiple LGS were not as common and may have depended on the financial wealth of the family (Searcy 2011, 105–110; Wright 2014). M. Searcy was trying to determine the **economic status** by the number of owned GSs and partially proved the assumption that wealthier households could afford to acquire more tools (Searcy 2011, 110). Unfortunately, his results are biased because the studied population had access to modern milling technologies.

GSs were not only economically valuable but also of great **symbolic importance**. They may have been involved in ritual practices such as communal grinding for feasts or ceremonies. Sometimes they are concentrated in large numbers in some special, monumental or communal buildings. This is attested, for example, at Göbekli Tepe (Dietrich 2021, 164). This tool with the qualities of turning the inedible/raw material into the edible/usable symbolized the life, transformation, fertility and the reproduction (Lidström Holmberg 2004, 227; Watts 2012, 79).

According to C. Lidström Holmberg (2004), the dual grinding complementary set represented the female and male material part. In Mesoamerica, the GSs represented also the gender complementarity, which was expressed by different gender roles. The manufacture was dedicated to a man and the use to a woman. Furthermore, it worked similarly with grain that was harvested by a man and processed by a woman. Therefore, the tools were costly valued and called “the life-giving stones” (Searcy 2011).

Grinding was often a **social issue**. The entire community of women gathered together, strengthening relationships by singing and sharing new information during the activity. Young girls who were already strong enough for this activity were taught by older women. Knowledge and skills have been transmitted from generation to generation, usually from mother to daughter (Searcy 2011, 84).

Although the GSs inherently belonged to the domestic environment, they were portable, so their location of use differed. In the summer, they could be used outside in open areas such as courtyards or roofs (Baysal 2020, 173). In addition, they were also used inside in the rooms devoted to food preparation. These rooms were often provided with raised earthen structures, which are called grinding benches or features (Pavlů *et al.* 2007, 25; Baysal 2020, 173). After use, they were placed somewhere nearby to keep them close at hand, often leaning vertically against a wall in the kitchen or in some storage room. On the other hand, large immobile LGSs are also attested and they are expected to be used by multiple household units as a shared property (Wright 2014).

Grinding activities were a time consuming and **labor-intensive routine**. A. Baysal has well pointed out that although the human is creating objects, the object also shapes the human (Baysal 2020, 163). The repetitive task of grinding could cause several body deformations and diseases, which were apparent, for example, on the skeletal remains from Abu Hureyra, Syria (Molleson 1994). Grinding in some societies could also have negative connotations and was considered low-prestige work. For instance, in the Egyptian New Kingdom, grinding activities were sometimes reserved for hired women or slaves (Lang 2016, 285).

3.2.3.3 Reuse

Some objects that have a history of use are reused after a certain period of time instead of being thrown away. The reused tools remain in the process, but they return to the phase of manufacture or/and of another use. Reuse can take many forms, as discussed by J. Adams (2002, 25–27) or M. Schiffer (1972, 158–159). The types described below are modified and adapted to fit for the case of GSs.

Simple reuse is characterized by two different successive activities without major changes in utilization. For example, GS was firstly used for grinding cereals, but then it was used for pigments (Adams 2002, 25; Hamon 2008b, 50). **Complex reuse (redesign)** is characterized by reshaping during use and/or after breakage. For example, the LGS has been used for so long that it has broken and then reshaped and reused as UGS (Adams 2002, 25). Reuse is hard to recognize, because the last activity hides the traces of the previous activity (Adams 1988, 312).

Another form of reuse is **recycling**. Recycled GS is no longer used in grinding activities and completely changes its function and therefore also its location of use. In some cases, they can be reshaped in another object as a pestle, a door socket or a sharpener. The GSs often end up also in some stone structures. Whether because of their good heat conducting properties, when they are inserted into fire installations (hearth, oven, roasting pit, etc.) or because of their durability, when they become part of an architectural features (wall, pavement, pit lining, etc.); in these cases, alteration can occur during use, such as thermal heating or chipping due to mechanical stress (Schlanger 1991, 463; Adams 2002, 27; Baysal – Wright 2005, 315; Wright 2014, 14).

3.2.4 Disposal

The tools did not have to go through all the stages of the sequence model, but at some point, their life ended. The life cycle of GSs is closed as soon as the object is abandoned and enters the archaeological context.

Some of the tools are intentionally discarded and abandoned. This happens often when the cost of recycling outweighs the replacement costs (Schiffer 1972, 159). It depends on many factors, but one of the most important is the availability of raw materials. GSs are often made of rocks with specific properties. If these rocks are not found nearby and have to be imported, fewer tools will be just discarded as they are reused.

Artifacts that are **intentionally discarded** were mainly relocated from their original use location ('secondary refuse' after Schiffer 1972, 161; Pfälzner 2001, 50). The GSs were discarded in pits, ditches and postholes mainly as rubbish (Schiffer 1976). However, these tools are quite difficult to destroy. Exceptionally, they naturally break into two halves in the transverse direction. Longitudinal breakage is very rare (Schlanger 1991, 462). Therefore, the extensive and deliberate fragmentation of the assemblages leads many scholars (Adams 2002, 46; Baysal – Wright 2005, 321; Watts 2012, 85; McCarthy 2020) to the idea of deliberate breaking and **structured deposition** of GSs for some ritual or symbolic reasons. Furthermore, only a few paired GSs are found in the same context, and they tend to be deposited separately. This practice suggests some likelihood of special meaning, as the separation of the stones renders them useless (Watts 2012, 85). GSs are also often found buried with the dead, where they are ritually "killed" (destroyed) or placed as a pillow under the head of the dead (Watts 2012; Dierckx 2017, 198).

The tools were also abandoned at the **use location**, where the activity took place ('primary refuse' Schiffer 1972, 161; Pfälzner 2001, 49). These exceptional finding circumstances include, for example, a GS found in a building on the floor or in a grinding bench. These finds are also mostly well preserved.

The recovery context is highly influenced by the **abandonment process** of the site. The quickly abandoned sites tend to recover more artifacts in manufacture, use or maintenance locations. On the other hand, the slowly abandoned sites will have more contexts in the performance of discard activities/secondary refuse (Schiffer 1972; Schlanger 1991). In this case, access to the site is usually allowed for a long time and the removal of parts from the assemblage continues, so fewer whole preserved artifacts are recovered and the assemblage is more fragmentary (Schlanger 1991, 470). Furthermore, the longer the occupation period of a site, the more artifacts are discarded and taken away from their original use location (Schlanger 1991, 468).

UGSs usually prevail over LGSs in the assemblage, which is due to several factors. Firstly, UGSs wear out faster than LGSs, therefore, they need to be replaced more often and kept in reserve (Wright 1990). Another explanation for abundance may be that UGSs were used in different ways and for the preparation of different categories of ground substances (Pavlů *et al.* 2007, 33). According to ethnographic data, the number of GSs for the household unit is highly variable and depends on many factors, but UGSs always prevail. For example, as standard in Minyanka villages in Mali, two UGSs are made for one LGS (Hamon – Le Gall 2013). In the archaeological record, I. Pavlů *et al*. (2007, 33) identified at neolithic site of Güvercinkayası the basic functional set consisting of two or three UGSs, one LGS and bowl-shaped stone. This functional set is considered to be the repeating basic equipment for the household unit (Pavlů *et al.* 2007, 40).

Deposited objects can later be transported to another location ('tertiary refuse' after Pfälzner 2001, 50) due to ongoing human activity on the site (terracing, rebuilding, etc.) or natural processes (solifluction, bioturbation, sediment movement, etc.). These **post-depositional processes** can cause alteration on the artifact. Mechanical alterations can be caused by weathering, ploughing or various other movements that cause scratches, abrasion of the material and/or cracks. Chemical alteration involves chemical weathering or the creation of taphonomic residues such as oxide accretions (calcareous crust) or surface patina (van Gijn 2010, 41–42; Hayes – Pardoe – Fullagar 2018, 100).

3.3 Bronze Age sites

3.3.1 Context of Western Anatolia

In the BA, Western Anatolia always represented an important connection between Eastern civilizations (Hittite Empire, Mesopotamia) and civilizations in the Aegean region (Mycenaean and Minoan culture). Already during the EBA, there were 3 main routes within the *Anatolian Trade Network* (Şahoğlu 2005) that led through Western Anatolia. One route led through the northern part of Anatolia to Troy around the Sea of Marmara, and two lower ones that led through the valleys of the Meander and Hermos rivers. This trade network persisted in some aspects into later times although trade routes have shifted more to the sea (Şahoğlu 2005; Pavúk 2015).

During the MBA and especially in the LBA, there were political units about which little was known until B. Hrozný deciphered the Hittite language. The Hittite cuneiform tablets provided information about the political events and contacts between the Hittite Empire, the Aegean, the Near East and even Egypt and, most importantly, the names of regions, cities and rulers in Anatolia were included. The decipherment of the Hittite tablets, together with the decipherment of the inscriptions on the Karabel relief, helped to reconstruct the approximate historical distribution of the regions of Western Anatolia (Fig. 4.1; Garstang – Gurney 1959; Starke 1997; Hawkins 1998).

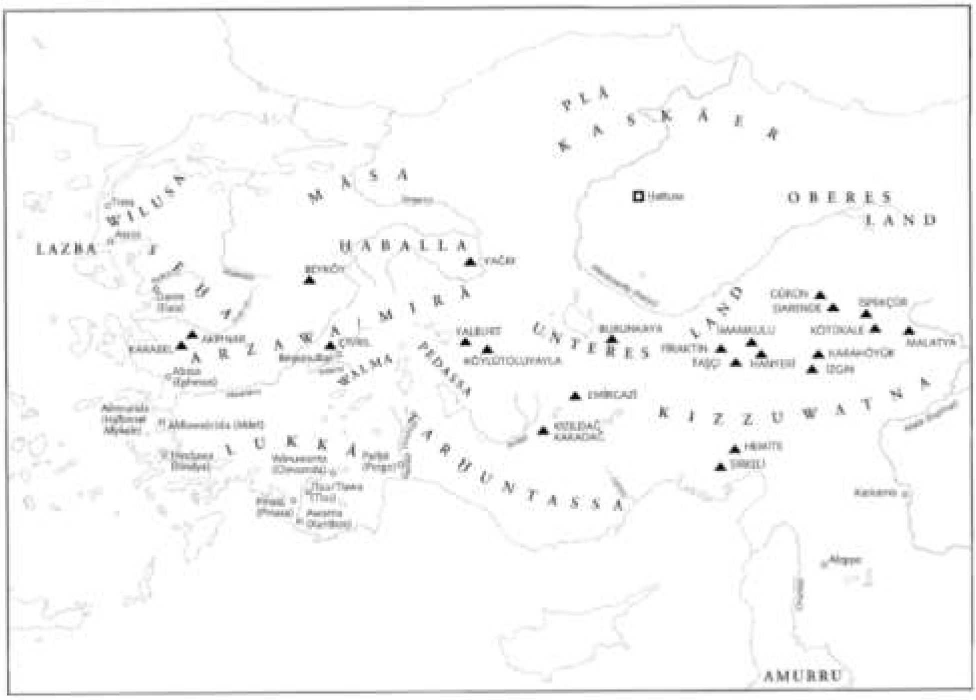


Fig. 4.1. Map with distribution of political units in Western Anatolia (Starke 1997, Abb. 1).

Since at least the 17th Century BC, a political entity known to the Hittites as Arzawa existed in Western Anatolia (Heinhold-Krahmer 1977). From the beginning, it probably consisted of multiple political units. The political scene was mainly dominated by political regions such as Mira, the Šeha River Land, and Wiluša (Starke 1997, 455; Easton *et al.* 2002, 94–102; Alparslan 2015, 132). The Šeha River Land should be located around the valley of the Hermos river and Mira is located to the south of it (Starke 1997; Hawkins 1998; Alparslan 2015; Meriç 2021). Wiluša is considered to be the region around the Troy (Fig. 4.1, Starke 1997; Hawkins 1998; Easton *et al.* 2002). However, the exact location of these lands is still speculative and this issue still remains a topic of debate (Gander 2017). Arzawa's boundaries probably changed frequently, but its greatest flowering occurred in the 16th-14th Centuries BC, when it expanded and established Aššuwa coalition (Alparslan 2015, 134).

The Hittite Empire often sought to engage in Western Anatolia and wanted to keep the area under their control, as evidenced by the campaigns to the Western Anatolia of the king Tuthaliya I/II and Muršili II (Alparslan 2015; Meriç 2021). The Hittites sought to dominate Western Anatolia, probably to gain access to the trade crossroads connecting the Aegean region. However, a political entity, called Ahhiyawa by the Hittites, had a similar intention (Maner 2015, 837–838). Therefore, there were constantly various frictions and short wars.

The problem of the identification and location of Ahhiyawa has been addressed by many scholars since the early 1920s (Forrer 1924; Sommer 1932; Schachermeyr 1935; Huxley 1960; Macqueen 1968; Mellaart 1968; Güterbock 1983; Mountjoy 1998; Easton *et al.* 2002; Simpson 2003; Bryce 2006; Popko 2010 etc.). This land was certainly somehow linked to Mycenaean culture, but exactly where it was located is not entirely clear (Popko 2010, 285). However, this great naval power located somewhere across the sea had a great influence on western Anatolia and even controlled the city of Miletus for some time (Hawkins 1998, 2; Easton *et al.* 2002, 100; Simpson 2003, 221–222).

Fig. 4.2. Map with marked locations of studied sites.

3.3.2 Kaymakçı

Kaymakçı is located in the central part of western Anatolia approximately 100 km east from the shore (Fig. 4.2). The site is strategically situated on top of a hill from where it has an excellent view down to the lake basin, but also to the valley of the Gediz River (ancient name Hermos River; Fig. 4.3).

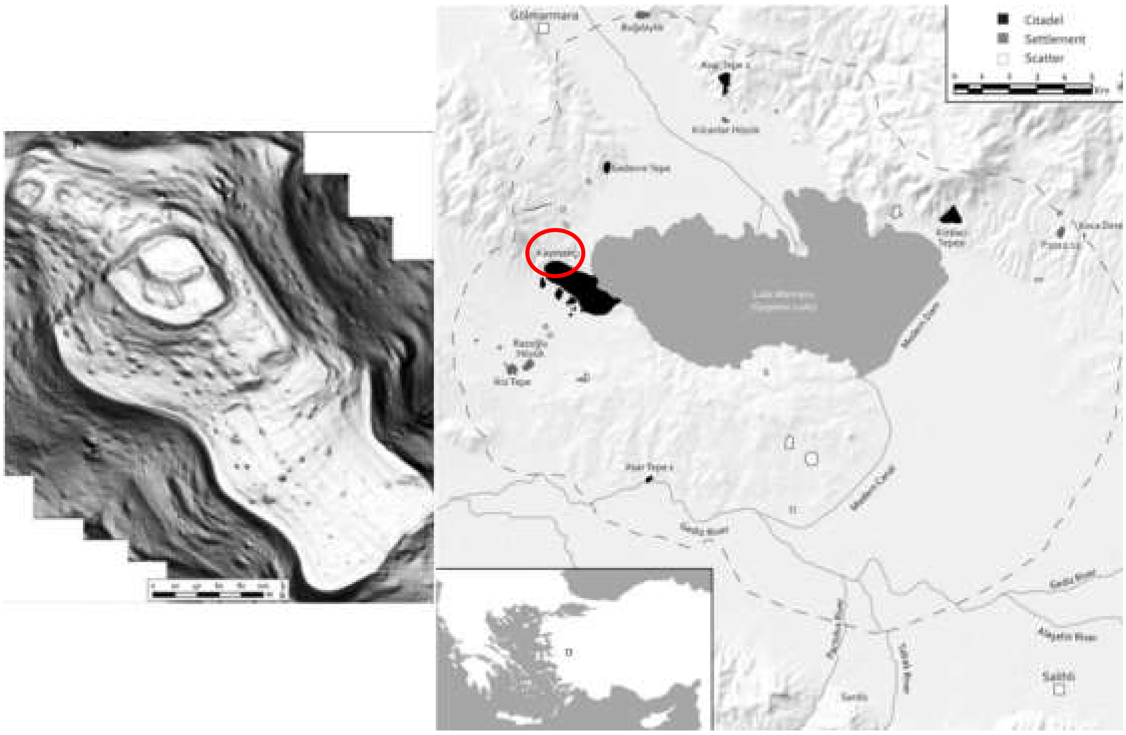


Fig. 4.3. Location of the Kaymakçı site (Roosevelt – Luke 2017, Fig. 2, 12).

Research at Kaymakçı has been led from the beginning by Chris Roosevelt and Christina Luke, originally from Boston University, later Koç University in Istanbul. The first non-destructive survey of the site was carried out as part of the CLAS (Central Lydia Archaeological Survey) project, which aimed to map human activity in the area around Lake Marmara and the middle part of the Gediz River from the Palaeolithic to recent (Roosevelt – Luke 2017). During the mapping of BA sites, six fortified settlements located on elevated positions surrounding the basin were identified, including Kaymakçı. The survey of Kaymakçı began in 2006 and continued until 2013. It included QuickBird image analysis, gridded surface collections and microtopographic and geophysical surveys (Roosevelt – Luke 2017, 136). Archaeological excavations have been carried out at the site since 2014 using the fully digital recording system (Roosevelt *et al.* 2015).

This settlement covers an area of 8.6 ha. Seven excavation areas (EA) have been opened until 2019 (Fig. 4.4) named after the pair coordinates representing the southwest corner of the EA. The site is enclosed by a thick wall with towers and possible bastions, which is interrupted by spaces where gates or entrances to the settlement could have been located. The fortification wall was exposed in the EAs 81.551 and 95.555 (Roosevelt *et al.* 2018, 649).

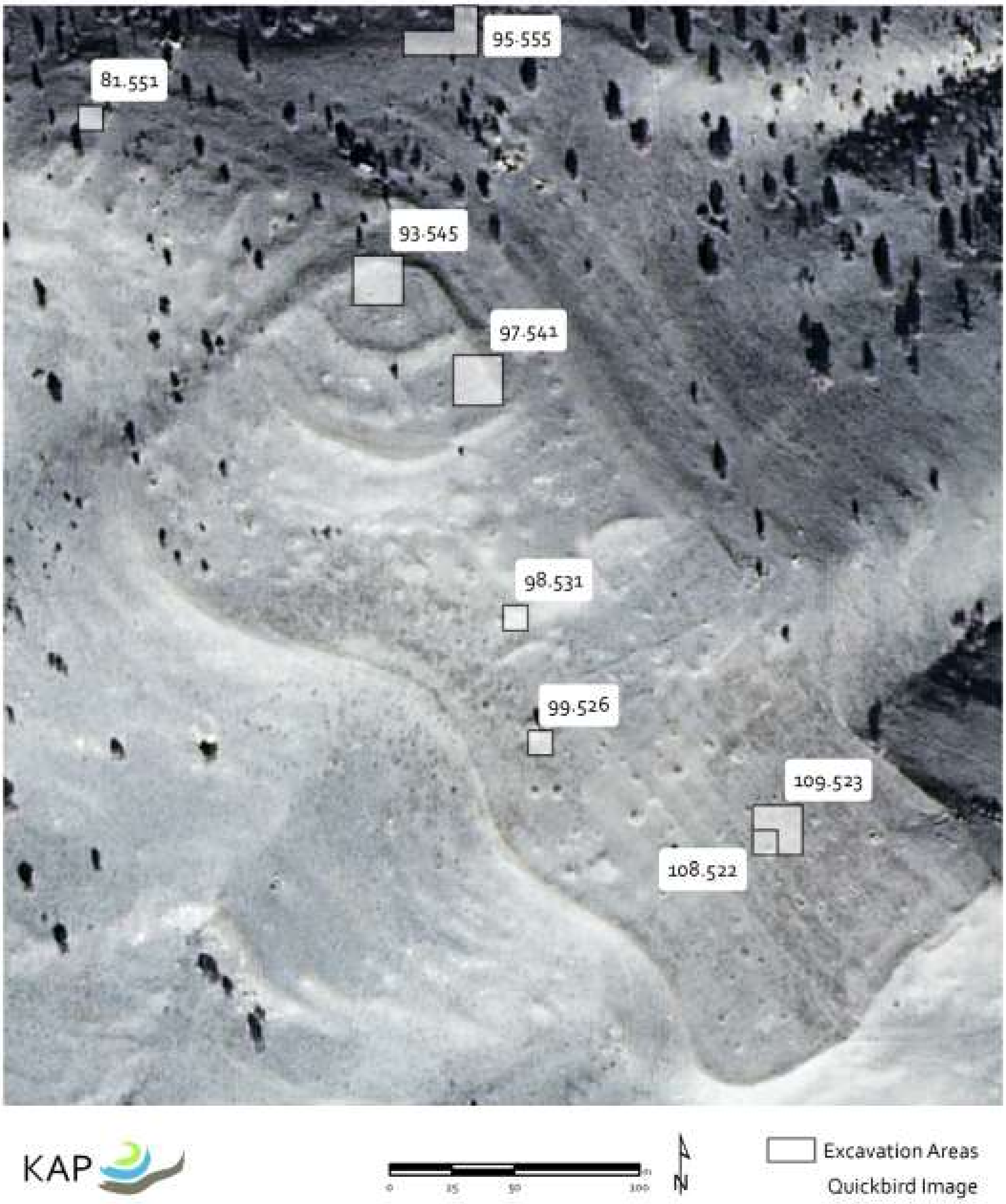


Fig. 4.4. Quick Bird satellite image of Kaymakçı with EAs (Roosevelt *et al.* 2018, Fig. 2).

At the highest point of the site, there is an inner citadel in the shape of a quarter circle, which is enclosed by a wall. The inner citadel is further divided into an outer and almond-shaped upper walled terrace. The upper terrace exposed in the EA 93.545 is largely eroded and therefore not well preserved. In particular, there were found circular features filled with material that were interpreted as grain silos. (Roosevelt *et al.* 2018, 652; Shin *et al.* 2021, 2). Further circular features and three buildings were excavated in the EA 97.541

that represents the outer terrace. On the slopes of the inner citadel buildings with storage facilities were exposed in the EA 98.531 (Roosevelt *et al.* 2018, 655).

In the southern part of the settlement, there are larger complexes of buildings and free-standing buildings intersected by streets and alleys. The main road 3-5 m wide runs through this area from the southeast to the northwest (Roosevelt et al. 2018, 658). The EA 109.523 (including 108.522, later expanded to 109.523) revealed the stratigraphy of the main road and part of the large building complex divided by small and larger roads. Another building with three rooms was exposed in the EA 99.526.

The occupation of the settlement started in the MBA and flourished in the LBA. The development of the settlement is continuous, no widespread destruction or fire layers have been recorded. The earlier MBA is so far attested mainly by redeposited material on the southern terrace. The habitation evidence increases in the later part of the MBA, resp. in the transitional period into the LBA. In the LBA, the settlement reached its greatest expansion and complexity and probably became the central site for the whole Gediz valley, or at least its middle part. It can be tentatively identified with the capital of the Šeha River Land, mentioned in Hittite texts (Roosevelt – Luke 2017, 141). At the end of the BA and the beginning of the Iron Age, the settlement is gradually abandoned and has not been reoccupied (Roosevelt *et al.* 2018, 648).

3.3.3 Aphrodisias

Aphrodisias is located in the valley of the Dandalas River (ancient Dandalos River) and is spread over two hills (Fig. 4.2). Excavations at the site began in the early 1960s and initially concentrated on Classical and Early Christian monuments. However, it soon became clear to the director of the excavation K.T. Erim that Aphrodisias also contained remains of a prehistoric settlement. The first excavations were conducted in 1966 under the supervision of S. Page. They were later passed on to B. Kadish and R. Marchese, who continued excavations there until 1974. However, their results have only been published in preliminary reports (Kadish 1969, 1971; Marchese 1976). In the following years, excavations were interrupted to process the previous ones. M. Sharp Joukowsky was put in charge of the research and processing of the finds. The final publication with a catalogue was published in 1986 (Joukowsky 1986a, 1986b).

The prehistoric excavations were located on the Pekmez Hill, the Acropolis Hill and in the Kuşkalesi area. A total of 13 trenches were opened (Fig. 4.5). The occupation of the site began in the Late Neolithic and is attested on the Pekmez Hill. The BA strata were excavated primarily on the Acropolis Hill. Unfortunately, the upper part of the settlement (LBA) is largely damaged by later building activity in the Classical period.

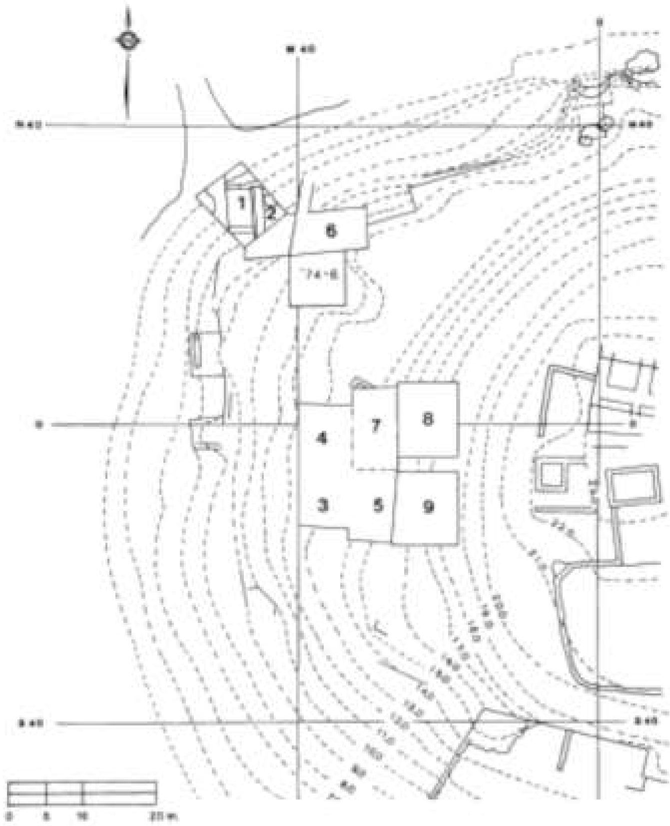


Fig. 4.5. Plan of Acropolis with EA at Aphrodisias (Joukowsky 1986a, Fig. 61).

The MBA was exposed in Trenches 5 and 7 with complexes D, C, C', B, B' and A. In the early phase (complex D), pits in poorly preserved architectural remains with a large amount of artifacts were found (Joukowsky 1986a, 133–135). These were followed by a megaroid building (complex C) with a large hearth in the center (Joukowsky 1986a, 137). The LBA was exposed only in Trench 8 represented by several pits and scarce architectural remains (Joukowsky 1986a, 149–150).

3.3.4 Troy

Troy is located on the northern coast of Western Anatolia on the Biga Peninsula (the historical region Troad; Fig. 4.2). Homer's verses about the Trojan War caused the myth of this city to persist even when its location was forgotten. The discovery of the site of Troy can be attributed to F. Calvert, but the first extensive archaeological excavation was conducted by H. Schliemann (Allen 1995; Easton 2002). The location of Troy was associated with the settlement on the hill of Hissarlik, situated in a strategic spot about 5 km from the shore between two rivers (Scamander and Simoeis).

The archaeological site has a very long history of excavations. Extensive research by Schliemann and, after his death, by his assistant W. Dörpfeld, dates back to the end of the 19th Century (Schliemann 1880; Dörpfeld 1902). Later excavations were carried out by American archaeologist C. Blegen from the University of Cincinnati between the years of 1932-38 (Blegen – Caskey – Rawson 1951, 1953). A fifty-year hiatus followed, interrupted by the new phase of excavations in 1988 by German archaeologist M. Korfmann from the University of Tübingen with the collaboration of a team from the University of Cincinnati. Korfmann's campaign aimed to reexamine and investigate the site with modern methods and techniques and excavate the lower town of the settlement. Unfortunately, Korfmann unexpectedly died in 2005 and the direction of the excavation fell to E. Pernicka and P. Jablonka from Tübingen University, who continued the survey until 2012 with the aim to publish the results of the Korfmann's and their campaigns together. Since 2012, the Çanakkale 18 Mart University has been in charge of the excavation (the whole history of excavation in Pernicka *et al.* 2014, 18–190).

Troy is multi-layered tell (Troy I-IX) continuously inhabited for almost four Millennia. The occupation of the site starts at the beginning of the EBA. By mid-3rd Millenium, Troy ranked among the central seats of the elite and was involved in the interregional Anatolian trade network. Its great importance is reflected especially in its monumental architecture in the citadel (system of courtyards, propylaea and megara) and, of course, famous Schliemann's treasures (Easton 2014, 79–89). During the period of Assyrian trade colonies (beginning of the 2nd Millennium BC), the settlement developed independently and in isolation from what was happening in the east. But this changed at the end of the MBA (Pavúk – Pieniążek 2020, 1103–1104).

The LBA layers are represented in the Troy VI and VIIa. The late phase of the Troy VI probably witnessed the flourish of the settlement. The settlement consisted of the citadel and the lower town (Fig. 4.6). The citadel was enclosed by thick walls and on the lower terrace large two-storied buildings were situated (for example the Pillar House, Pavúk – Pieniążek 2020, 1106). Unfortunately, the architecture at the highest point of the citadel has not survived, having been destroyed by later Hellenistic buildings, but it is certain that some monumental building(s) must have stood on this central spot (Pavúk – Pieniążek 2020, 1085). The densely populated lower town was surrounded by a rock-cut ditch accompanied by a moat with a palisade on the inner side (Pavúk – Pieniążek 2020, 1106).

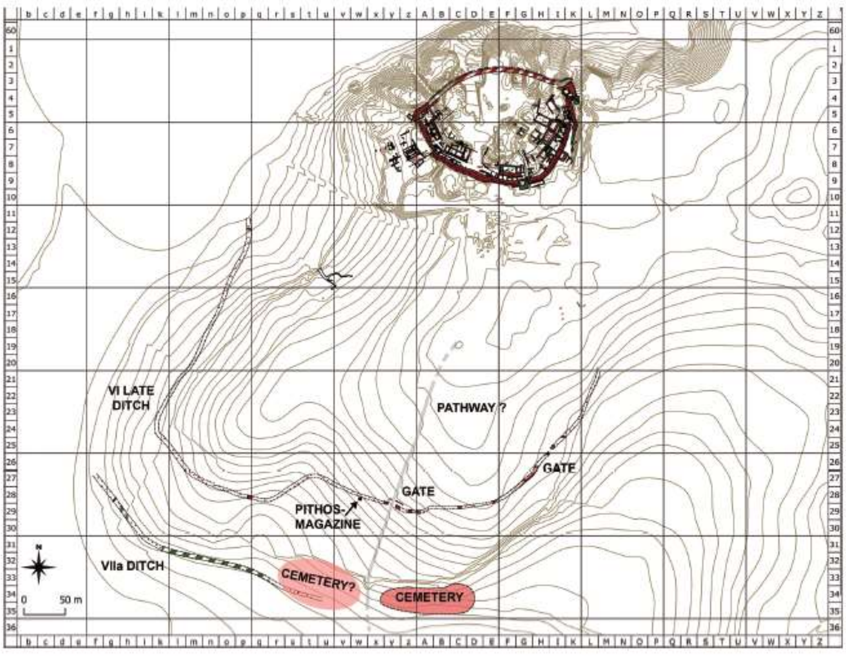


Fig. 4.6. Plan of Troy VI late (red) and VIIa (green) (Pavúk – Pieniążek 2020, Fig. 3).

At the end of the Troy VI, the settlement was destroyed by an earthquake. The newly built town had a different character. The houses in the citadel were smaller and more densely built in an urban pattern. At the same time, more emphasis was placed on storage, as many rooms full of pithoi were discovered. This could indicate a troubled period with a tendency to control reserves. This period ends with a destruction that is not unique in the Mediterranean and is associated with the collapse of the BA system (Pavúk – Pieniążek 2020, 1109–1110).

4 Kaymakçı grinding stones

4.1 Introduction and the methodology of study

The Kaymakçı assemblage contains around 300 large stone artifacts[3] including 281 grinding tools, 5 drilled discs, 1 socket stone and 3 torus stones, which were recovered in only five excavation seasons between 2014 and 2019. These artifacts were investigated directly by the author of this thesis. The majority of them have not been washed so that residue analyses can be performed in the future. Furthermore, many artifacts are covered with a calcareous crust that covers the surface, which increases the possibility of residue preservation. However, these circumstances make it difficult to carry out deeper analyses of the working surface. In the morphological study, the basic dimensions (length, width, maximal and minimal thickness, weight) were taken and the form was described in cross sections[4] (concave, convex, straight) and in front view[5] (rounded, oval, quadrangular, asymmetrical). Design and ergonomic adjustments were also observed[6].

Raw material was determined according to the standard geological classification (granularity, texture, structure, cohesion, porosity and minerals). To correctly distinguish the raw material, the magnetic susceptibility meter[7] (kappameter) was used to indicate the degree of magnetization of the rock. As a rule, the more mafic minerals the rock contains, the higher the magnetic susceptibility value.

Artifacts representing each phase of production sequence (raw material, blanks, preforms) were searched for in the assemblage. Traces of production (flaking scars, smoothing) were also studied on sides and bottom of the GSs. The working surface was also studied to know whether the object was used at all and, if so, how much and for how long. Some of the washed artifacts without the calcareous crust were selected for the preliminary use-wear analysis.

[3] Other artifacts than grinding tools are also included in the assemblage because they are made of same raw material and are related to the second life of the grinding tools.
[4] Cross sections of GSs were taken by Bc. Ján Bobik (ICAR CUNI) using Laser Aided Profiler.
[5] The photos of GSs were taken by Camera of Samsung Galaxy S8.
[6] The recording strategy is described in detail in the appendices.
[7] KM-7 magnetic susceptibility meter.

Finally, the spatial contextual analysis was conducted, which was made possible by the fact that most of the artifacts were GPS localised. However, the excavation at the Kaymakçı site is still ongoing. So, the interpretation, chronology and stratigraphy of the EAs, structures, buildings are not entirely solved. Therefore, this analysis must be taken with a cushion.

The collected primary data together with photos of the artifacts are available in the second part of this thesis in the catalogue.

4.2 Procurement of the raw material

4.2.1 Geological setting of Western Anatolia with special reference to the Menderes Massif

Western Anatolia consists of four main tectonic units, which are separated by two sutures along the extinct oceans: Istanbule Zone, Sakarya Zone, Anatolide-Tauride Block and Cycladic Blueschist unit (Fig. 5.1) (e.g. Şengör – Yilmaz 1981; Xypolias – Dörr – Zulauf 2006; Jolivet – Brun 2010; Gessner *et al.* 2013). The area was greatly affected by the Cimmerian and Alpine orogeny, which was characterized by the opening and closure of the ocean basins of the Paleotethys and Neotethys and the collision of the continental blocks (Şengör – Yilmaz 1981). The inner part of the Anatolide-Tauride Block consists of the metamorphic complex Menderes Massif, which is surrounded by multiple zones of highly metamorphosed rocks (Tavşanli Zone, Bornova Flysch Zone, Afyon-Ören Zone). At the southern end are the Lycian Nappes, formed by sedimentary rocks and ophiolitic mélange (Bozkurt – Oberhänsli 2001; Candan *et al.* 2005; van Hinsbergen 2010; Okay *et al.* 2012).

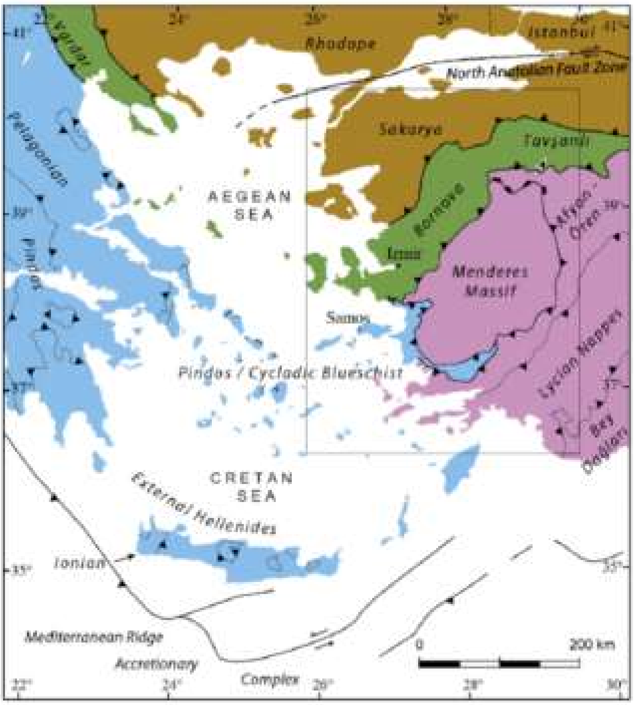


Fig. 5.1. Map of tectonic units in Aegean (Gessner *et al.* 2013, Fig. 2).

The oldest core forms the Menderes Massif, and the development started already in the Precambrian. The main phase of magmatism and metamorphism is associated with Pan-African orogeny and closure of the Mozambique Ocean, which dates between 580-520 Ma (e.g. Koralay *et al.* 2011; Zlatkin – Avigad – Gerdes 2013). The layers of the cover then form a continuous sedimentary record from the Lower Paleozoic to the Lower Triassic. These rocks are composed mainly of quartzites, phyllites and marbles (Candan *et al.* 2011; Koralay *et al.* 2011).

In Triassic, the intrusion of leucocratic granites occurred in the northern and central parts of the Menderes Massif, which was caused by the subduction of the Izmir-Ankara Ocean Basin (Koralay *et al.* 2011). At the end of the Cretaceous, this subduction culminated in the collision of the Anatolide-Tauride Block with the Sakarya Block (Şengör – Yilmaz 1981; Okay – Tüysüz 1999; Candan *et al.* 2005). Meanwhile, extensive deformation was going on in the Menderes Massif and green schist-to-amphibolite facies metamorphism occurred, which is related to the burial of the Massif under the Lycian Nappes. Compressive deformation created a large horizontal fold (Gessner *et al.* 2001; Okay 2001) and a nappe structure (nappe **Bayındır, Bozdağ, Çine, Selimiye)** with metamorphic inversion (Ring – Willner – Lackmann 2001).

After the compression, the extension of the thickened continental crust of the Anatolide-Tauride Block started. From the Late Oligocene, the Lycian Nappes started to move south and the buried Massif was gradually exhumed (van Hinsbergen 2010; Gessner *et al.* 2013). The Menderes Massif was divided into 3 parts, which were separated by the Küzey and Güney detachment (Fig. 5.2). In the first stage, the exhumation proceeded asymmetrically along the N-dipping Simav detachment fault (van Hinsbergen 2010; Ersoy *et al.* 2014). This extensional stage caused NE-SW striking strike slip faults, where the basins (Selendi, Demirçı, and Gördes) started to develop (Fig. 5.3). Furthermore, the first main phase of igneous activity occurred (Borsi *et al.* 1972; Innocenti *et al.* 1982, 2005; Seyitoğlu *et al.* 1997; Ersoy *et al.* 2014). Volcanic and plutonic rocks with Ca-alkaline affinity and orogenic character intruded the basins in the form of lava flows and domes in the Early and Middle Miocene. The successions were cut by ultrapotassic and lamproitic dykes (Bozkurt – Mittwede 2005; Innocenti *et al.* 2005).

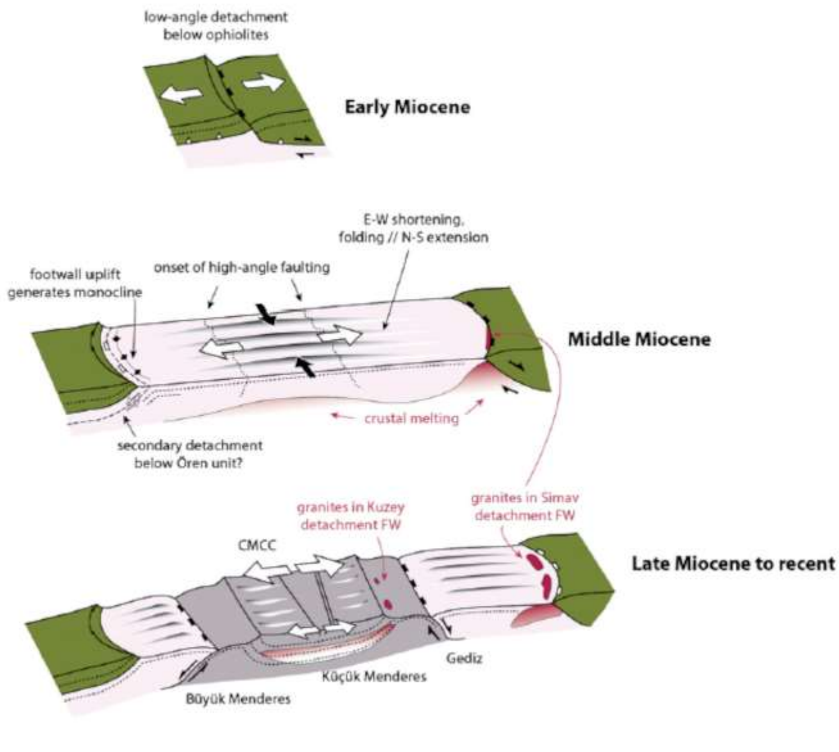


Fig. 5.2. Development of massif exhumation (Gessner *et al.* 2013, Fig. 23).

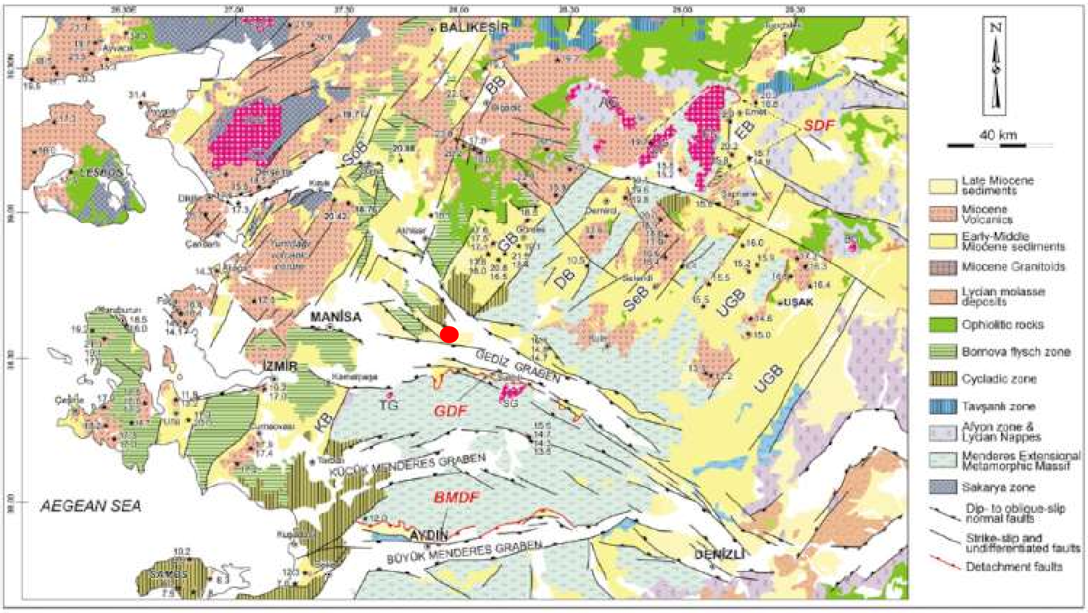


Fig. 5.3. Geological map of Central Western Anatolia with Neogene basins (KB: Kemalpaşa Basin, SoB: Soma Basin, GB: Gördes Basin, DB: Demirci Basin, SeB: Selendi Basin, UGB: Uşak–Güre Basin, EB: Emet Basin) and detachments (GDF: Gediz (Alaşehir) Detachment Fault, SDF: Simav Detachment Fault, BMDF: Büyük Menderes Detachment Fault) and marked (red dot) Kaymakçı (Ersoy *et al.* 2014, Fig. 2).

Subduction of the African lithospheric plate beneath the Eurasian plate probably began in the Middle to Late Miocene. The Anatolian microplate was compressed from the east by the northward motion of the Arabian plate. As a result, the Hellenic tectonic units are moving southward and Anatolia westward along the two strike slip fault systems (McKenzie 1972; Taymaz – Yilmaz – Dilek 2007; van Hinsbergen 2010).

The overthickened crust in the Menderes Massif was spreading and thinning as a consequence of the orogenic collapse. The asthenosphere beneath the massif was upwelling, which caused the second main igneous phase (Alıcı – Temel – Gourgaud 2002; Bozkurt – Mittwede 2005). The igneous activity was characterized by intrusion of Na-alkali basalts with the OIB type signature in the Kula region (Alıcı – Temel – Gourgaud 2002; Bozkurt – Mittwede 2005; Tokçaer – Agostini – Savaşçın 2005).

4.2.2 Raw material of Kaymakçı assemblage

4.2.2.1 Geological setting around Kaymakçı

Kaymakçı is located on the border between the central and northern Menderes Massif above the Gediz Graben near the border with the Bornova Flysch Zone (Fig. 5.4).

Fig. 5.4. Location of Kaymakçı (Gessner *et al.* 2013, Fig. 5; altered).

The site lies directly on the bedrock of Paleozoic mica schists, which change into marble in the north. In the area of 25 km around Kaymakçı (Fig. 5.5) on the northwest side is the Mount Cal Dağı formed by mafic rocks such as peridotite and ophiolitic melange belonging to the Bornova Flysch Zone. On the northeast side, there is the Keçi Dağı mountain made up of schist and marble and the Dibek Dağı mountain characterized by the augen gneisses of the Precambrian. In the southern part there are Precambrian migmatized pelitic gneisses, Paleozoic shales, marbles and quartzites (Bayındır nappe), which are lined from the south by the Precambrian schist Bozdağ mountains with amphibolite lenses (Hetzel *et al.* 1998). These rock lithologies are covered by Neogene clastic sediments such as conglomerates and sandstones. They appear mainly in the northern part of the Graben and near the Lake Marmara. The contact of Neogene sediments and schists in the south is lined by a cataclastic zone 100 to 300 m wide, which is formed in the upper part by a hematite breccia (Hetzel *et al.* 1998). On the southeastern edge near the cataclastic zone Salihli granodiorite intruded in the Miocene. In the Quaternary, alluvial sediments with fluvial gravel and sand were deposited in the river valley and lacustrine limestones were deposited in the lake basin.

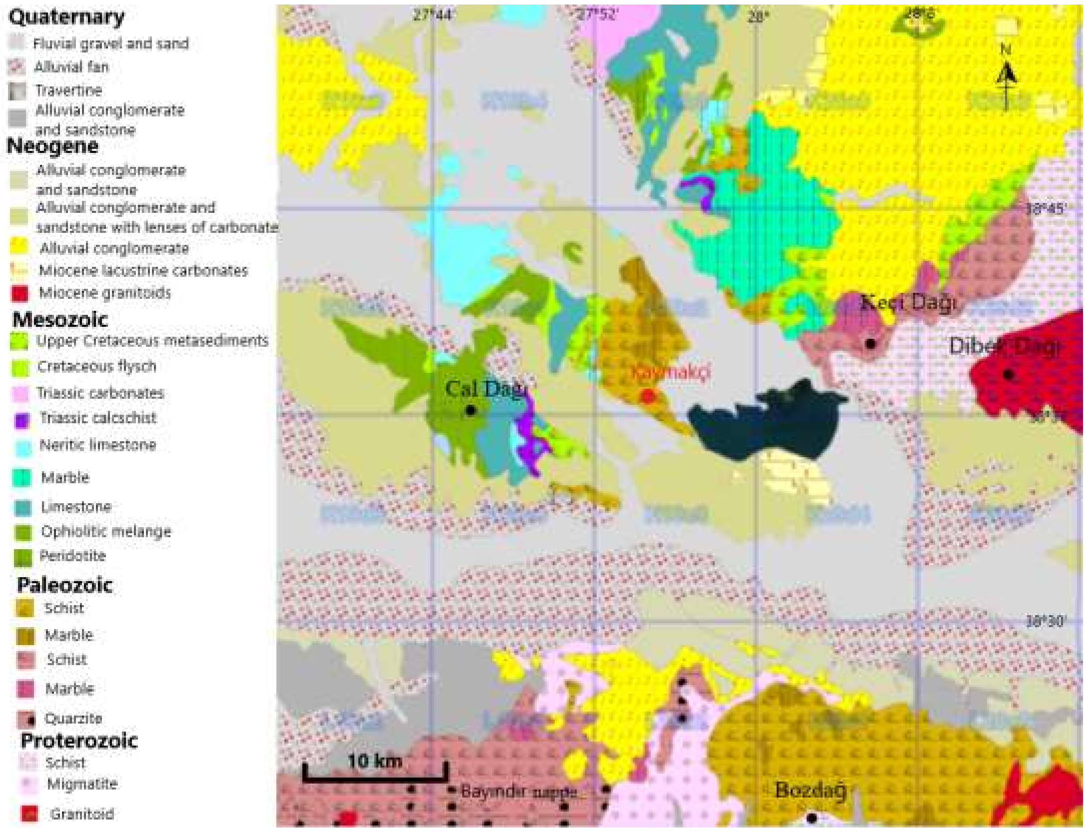


Fig. 5.5. Geological map of the area around Kaymakçı (approx. 50×50 km; Akbas *et al*. 2011, altered).

4.2.2.2 *The assemblage*

At Kaymakçı, the representation of raw materials in the assemblage does not seem to be very variable, mainly igneous rocks predominate (81 %). Sedimentary rocks are represented by only 10 % and metamorphic rocks by only 6 %. (Fig. 5.6)[8].

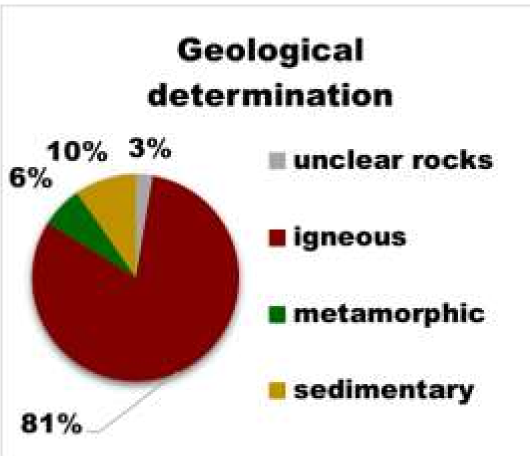


Fig. 5.6. Geological determination of Kaymakçı large stone finds by mass (N=795 kg).

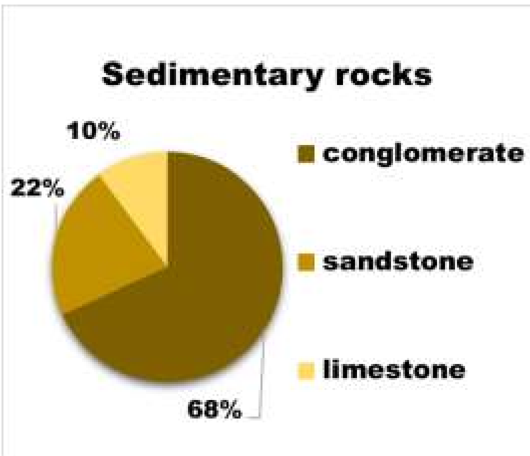


Fig. 5.7. Types of sedimentary rocks in the assemblage of large stone finds, (N= 84 kg).

[8] The exact description of the raw materials can be found in the Catalogue.

Sandstone and conglomerate are among the most common sedimentary rocks used for GSs (Fig. 5.7). Surprisingly, many of the LGSs were made of these sedimentary rocks. Exceptionally, limestone also appears which was used as a raw material for two tools, the mortar and the drilled disc.

Metamorphic rocks are represented mainly by schist and gneiss (Fig. 5.8). The schist was mostly used only for drilled discs and socket stones. Only one single GS was made of schist (chlorite schist). On the other hand, in the assemblage four GSs appear made of gneiss.

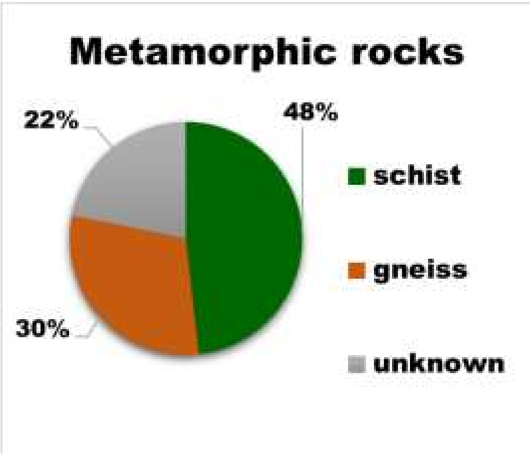


Fig. 5.8. Types of metamorphic rocks in the assemblage of large stone finds (N= 53 kg).

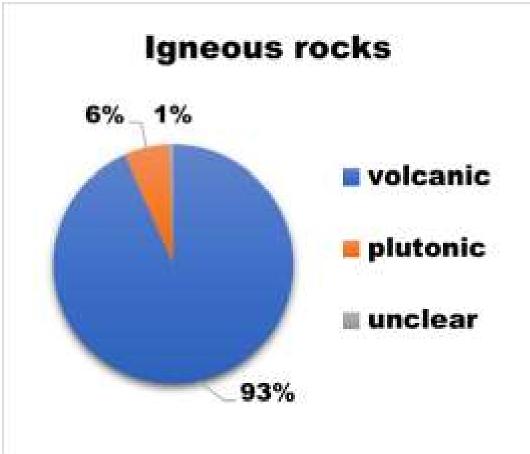


Fig. 5.9. Types of igneous rocks in the assemblage of large stone finds, (N= 659 kg).

Igneous rocks are the most abundant raw material (Fig. 5.9). Among the plutonic rocks, eight GSs were made of granite and one possibly of diorite. Nevertheless, 93 % of igneous rocks have a volcanic origin. The variability of volcanic rocks is very large and exact proper determination with the naked eye is not possible. The volcanic rocks were thus roughly divided according to the approximate proportion of silica into felsic (rhyolite, dacite), intermediate (andesite), and mafic (basalt, Fig. 5.10).

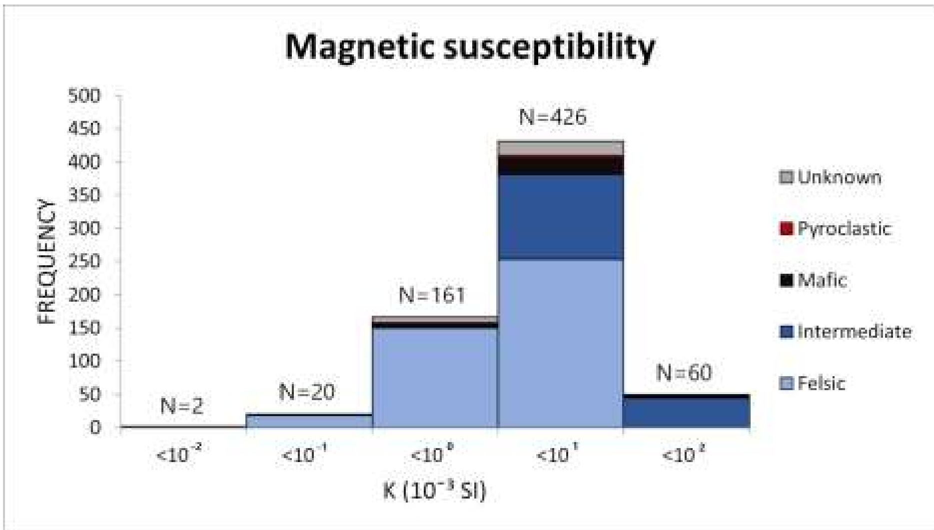


Fig. 5.10. Magnetic susceptibility of volcanic rocks (N=671).

The GSs were mostly made of felsic volcanic rocks such as rhyolite and dacite. The properties of these rocks for GSs are not ideal, because they are soft and not as cohesive. Basalts and andesites are harder, more cohesive, and sometimes also porous, which is suitable for grinding. However, only 30 % of mafic/intermediate volcanic rocks appear in the assemblage. Furthermore, only three GSs were made of vesicular basalt, which is the best raw material for grinding according to the literature (Hayden 1987, 14; Schneider – LaPorta 2008, 24; Delgado-Raack – Gómez-Gras – Risch 2009, 1830; Searcy 2011, 55).

The large portion of the volcanic rocks led to the assumption that one source could supply the whole settlement. However, as pointed before, the variability of the volcanic rocks is quite large. The dispersion of magnetic susceptibility measurements indicates also more sources even between each type (Fig. 5.10). Furthermore, the dimensions of the artifacts made of volcanic rocks do not give an exact answer. The length of all volcanic GSs (also fragments) is approximately between 10 and 35 cm with a smaller cluster of 17 cm (Fig. 5.11). On the other hand, the large concentration of stones falls within a width of about 17 cm and the second large cluster is about 12 cm (Fig. 5.12). The most uniform is the thickness, which ranges from 4 to 8 cm (Fig. 5.13). To conclude, the measured dimensions could correspond to the potential size of the spacing of joints and breaks in the outcrop. It seems that there were at least two sources of volcanic rocks and that the raw material could be extracted from the rock outcrop. Nevertheless, no similar data has yet been published to compare the results with.

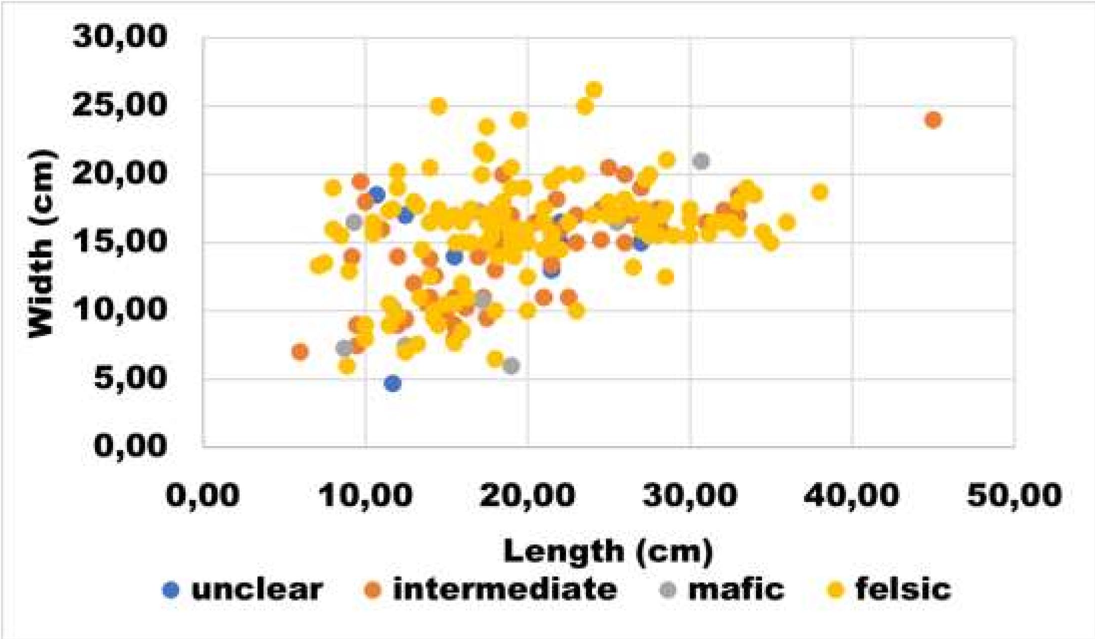


Fig. 5.11. Length and width of volcanic GSs (N=210).

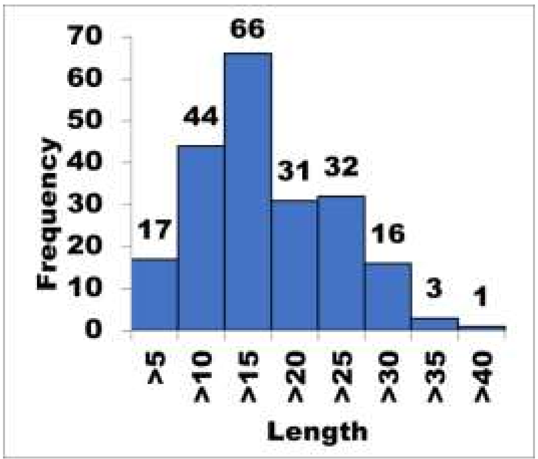


Fig. 5.12. Frequencies of GSs lengths (N=210).

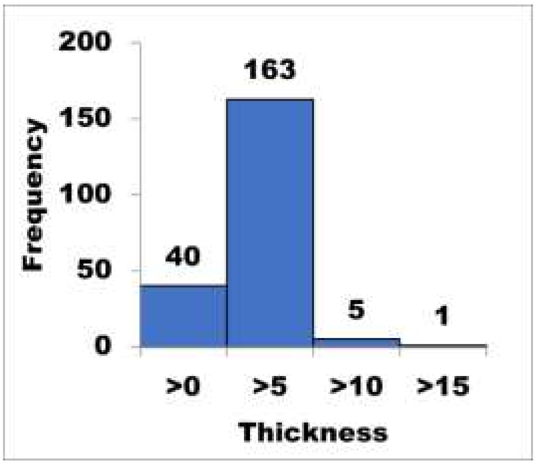


Fig. 5.13. Frequencies of GSs thicknesses (N=209).

4.2.2.3 The provenance study

All the sedimentary rocks used as raw material were probably gathered in the vicinity of the site down in the valley of the River Gediz and Lake Marmara. Surprisingly, the local mica schist, which are the most easily available raw material in the vicinity of the site, were not used at all for GSs. On the other hand, four gneiss GSs appear in the assemblage. The nearest source of gneiss is located in the Dibek Dağı mountain, which is more than 25 km away from the site. The possible source of the plutonic rocks for the rest of GSs could be located in the eastern part of the Bozdağ mountains, where the Salihli granodiorite is located (Fig. 5.5).

However, volcanic rocks are absent within a radius of 25 km from the site (Fig. 5.14). Therefore, the search area of raw materials has been expanded. Volcanic regions within 100 km of the settlement were selected and studied in detail. They have been subsequently reduced in terms of accessibility to nine regions of potential raw material occurrence (Fig. 5.15). The volcanic regions were visited and the rocks macroscopically described. Where the rock was exposed in the outcrop, the magnetic susceptibility was measured.

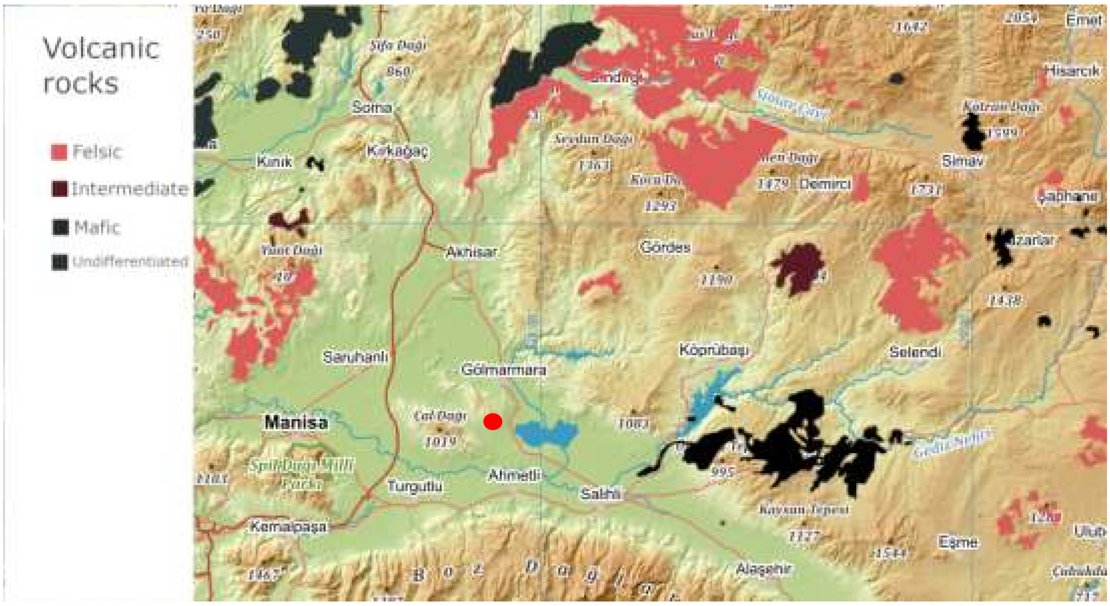


Fig. 5.14. Topographical map showing volcanic regions with marked Kaymakçı (red dot); modified from 1/500 000 scaled geological map of Turkey (MTA).

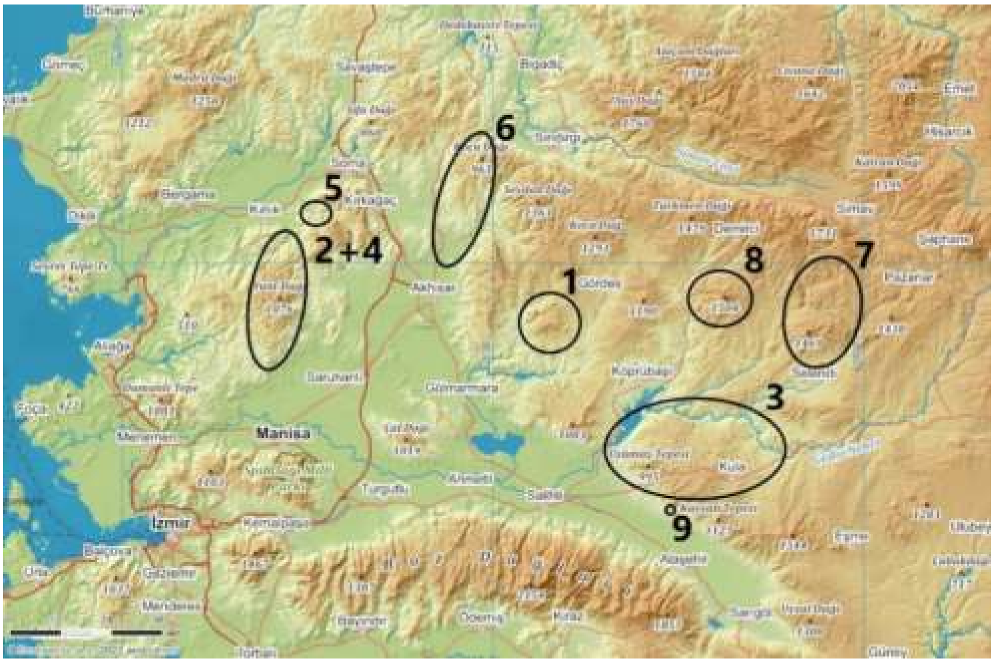


Fig. 5.15. Topographic map with selected volcanic regions 1. Gördes region, 2+4. Yunt Mountains, 3. Kula region, 5, Soma region, 6. Akhisar region, 7. Selendi region, 8. Demirçi region, 9. Toygar village.

4.2.2.3.1 Gördes region

The NE-SW striking Gördes basin is located in the northern part near the town of Gördes (Fig. 5.15). The volcanic rocks are situated in the center of the basin and cut the ophiolite basement and sedimentary succession. They were emplaced in the basin in the Early Miocene, in the first igneous phase, as dome-shaped extrusions (Fig. 5.16; Seyitoğlu *et al.* 1997; Purvis – Robertson – Pringle 2005; Ersoy *et al.* 2014). These dacitic-rhyolitic rocks of the Kayaçik volcanics are characterized by phenocrysts of quartz, feldspar, and biotite and have a yellowish grey or white color of matrix (Av Mag Sus=2,189 × 10^{-3} SI). The outcrops are column-shaped and are quite suitable for mining.

Fig. 5.16. Kayaçik volcanics in the Gördes basin (photo by author).

4.2.2.3.2 Akhisar region

The Akhisar volcanics are located to the north of Akhisar (Fig. 5.15). They are dated to the Early Miocene (Ersoy *et al.* 2014). They all seem to be felsic rocks like dacite and rhyolite. They have a quiet fine-grained porphyritic texture with the phenocrysts of quartz, biotite and feldspar.

4.2.2.3.3 Kula region

Kula volcanic rocks cover an area of 350-400 km^2 (Fig. 5.15; Tokçaer – Agostini – Savaşçın 2005) . Their origin is connected with the orogen collapse and subduction of the African plate beneath the European. The spreading and thinning of the overthickened crust were accompanied by the upwelling of the asthenosphere. The magma was derived from the mantle source without continental contamination and is characterized by the OIB type signature (Alıcı – Temel – Gourgaud 2002; Bozkurt – Mittwede 2005). The eruptions in the Kula region started 1,6 Ma and continue to recent (Tokçaer – Agostini – Savaşçın 2005). The main period of volcanism can be divided into 3 phases: Burgaz volcanics (lava flows), Elekçitepe volcanics and Divlittepe volcanics (cinder cones, maars, and fissure related lava flows). These sodic-phonolitic basalts often contain phenocrysts of olivine, clinopyroxene, amphibole, and sometimes also plagioclase and have a vesicular or compact texture (Av Mag Sus=6,893 × 10^{-3} SI;). Some of the outcrops are column-shaped and are quite suitable for mining (Fig. 5.17).

Fig. 5.17. Column-shaped basalt extrusions (photo by Tunç Kaner).

4.2.2.3.4 Toygar region

On the northern margin of the Gediz graben is located the Toygar village, which lies on the volcanic bedrock (Fig. 5.15). This andesitic dome intruded into the basin in the Late Miocene-Pliocene (Purvis – Robertson – Pringle 2005). Toygar andesite is characterized by pinkish color and porphyritic texture with medium-large phenocrysts of feldspar and amphibole.

4.2.2.3.5 Demirçi region

In the central part of the Demirçi basin, N of the Kula region, two volcanic centers of the Asitepe volcanics are located (Fig. 5.15). These andesitic-dacitic rocks were emplaced in the basin in the Early-Middle Miocene and were followed by lava flows of the Naşa basalt. In the southern part of the Asitepe volcanics, the Taşokçular basalt intruded in the Late Miocene (Ersoy *et al.* 2014). The andesitic rocks have mostly dark grey color with white phenocrysts of feldspar or quartz and turn to more felsic rocks of brighter color (violet/grey/pink) with phenocrysts of pyroxene (Av Mag Sus=3,707× 10^{-3} SI; Fig. Fig. 5.18).

Fig. 5.18. Banded volcanic rocks in the Demirçi region (photo by author).

4.2.2.3.6 Selendi region

The northeast-southwest striking Selendi basin is located to the east of the Demirçi basin and is composed mainly of volcanic rocks (Fig. 5.15). In the north, there can be found dacitic-rhyolitic domes, lava flows, and pyroclastic rocks of the Egreltidağ volcanics that intruded this area in the Early Miocene. In the same period, lamproitic lava flow was emplaced in the vicinity of Küzeyır village. Later, the Yagcidağ volcanics represented by dacitic lava flows, dykes, and volcanic necks cropped out the south area. In the north of the Yagcidağ volcanics, the Orhanlar basalt was emplaced (Fig. 5.19; Ersoy – Helvacı – Sözbilir 2010).

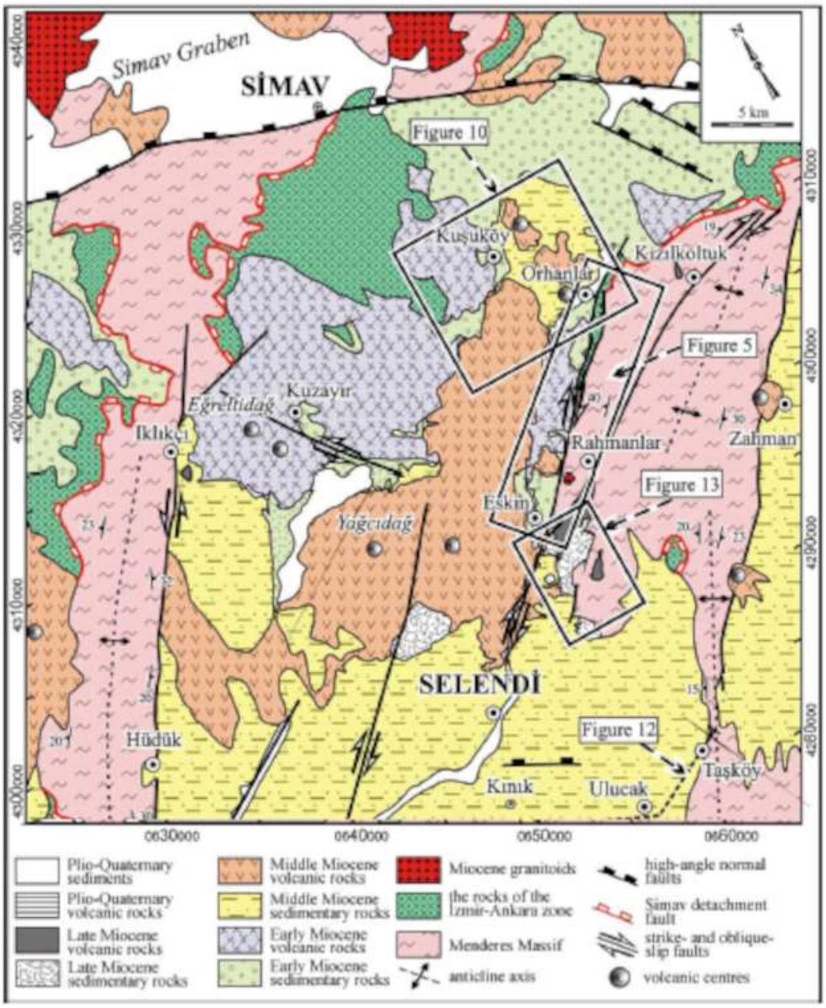


Fig. 5.19. Geological map of Selendi volcanics (Ersoy – Helvacı – Sözbilir 2010, Fig. 2).

The rhyo-dacitic Egreltidağ rocks are characterized by a light pinkish or grey color of a matrix with phenocrysts of quartz, feldspar, or biotite and sometimes also amphibole (Av Mag Sus = 1,606 × 10^{-3} SI). The Küzeyır lamproite is fine-grained and contains minerals of biotite (Av Mag Sus = 0,565 × 10^{-3} SI). The Orhanlar basalt is fine-grained with white phenocrysts probably of some feldspathoid (Av Mag Sus = 2,52 × 10^{-3} SI). The Yagcidağ volcanics are characterized by a reddish pink or grey matrix with phenocrysts of feldspar, quartz, and biotite (Av Mag Sus = 0,263 × 10^{-3} SI).

4.2.2.3.7 Yuntdağ region

Between the valley of the Gediz and Bakir Çayı rivers lies the Yunt mountains (Fig. 5.15). Most of the area is covered with volcanic rocks from the Early Miocene. These rocks are characterized by andesitic to rhyolitic magmatic association (Akay – Erdogan 2001; Akay – Erdoğan 2004; Ersoy *et al.* 2014).

The northern part of the eastern area close to Kinik horst is covered mainly by andesitic or dacitic rocks (Fig. 5.20), which are characterized by fine to medium-grained porphyritic texture, grey matrix. and phenocrysts of amphibole/pyroxene, quartz or feldspar (Av Mag Sus = 6,65 × 10^{-3} SI).

Fig. 5.20. Outcrop of volcanic rocks in the Yunt mountains (photo by Tunç Kaner).

The southern part is dominated by rhyolites and dacites, which are occasionally replaced by andesite and pyroclastic or epiclastic rocks. The felsic volcanic rocks have a pink or grey color of a matrix, a porphyritic texture with large phenocrysts of quartz, feldspar, amphibole, and biotite (Av Mag Sus = 5,595 × 10^{-3} SI). Andesites have a grey (exceptionally violet) matrix with phenocrysts of amphibole, biotite, or feldspar (Av Mag Sus = 8,712 × 10^{-3} SI).

4.2.2.3.8 Soma region

The coal-bearing Soma basin is located north of the Yunt mountains and was in the Early Miocene intruded by several basalt units (Ersoy *et al.* 2014). The basaltic rock has a fine-grained vesicular texture (Av Mag Sus = 4,923 × 10^{-3} SI).

4.2.2.3.9 Summary

The macroliths were made mainly of felsic volcanic rocks such as rhyolite and dacite, which have a pink or grey matrix and porphyritic texture with phenocrysts of quartz, biotite, and amphibole (Av Mag Sus = 1,826 × 10^{-3} SI, Fig. 5.21, 5.22).

Fig. 5.21. Macrofocus on the texture of rhyolitic grinding stones (photo by author).

Fig. 5.22. Macrofocus on the texture of dacitic grinding stones (photo by author).

The nearest source of felsic volcanic rocks is in the Gördes basin. Unfortunately, it is not probable that it is the main source of volcanic rocks for Kaymakçı. The volcanic rocks of the Gördes mountains have a yellowish grey color of a matrix, a high content of yellowish quartz phenocrysts, and a smaller amount of amphibole phenocrysts. This raw material was probably used only in a minor way, since only two artifacts have been macroscopically identified as similar looking rocks (99.526.188.1, 97.541.336.1).

Other possible sources of felsic rocks are from the Akhisar region, the Selendi basin, and the Yunt mountains (Fig. 5.23).

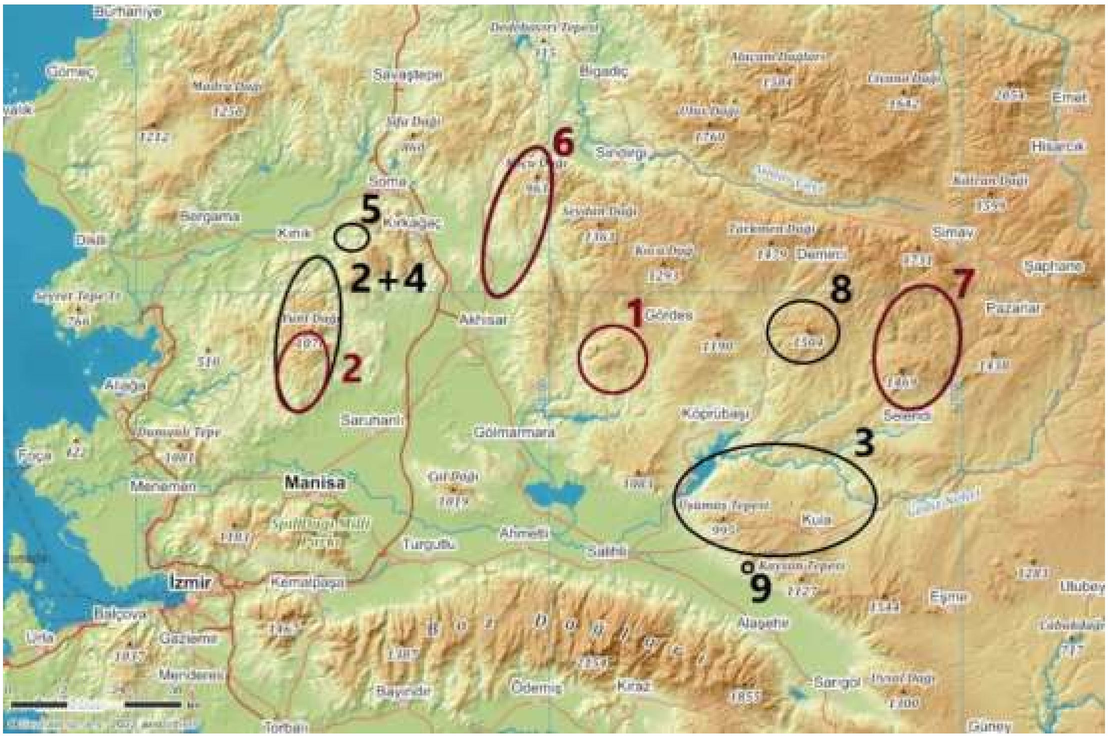


Fig. 5.23. Topographic map with marked felsic volcanic rocks, 1. Gördes region, 2. Yunt Mountains, 6. Akhisar region, 7. Selendi region.

The volcanic rocks from the Akhisar region do not seem to be the probable source because their texture is more fine-grained, and the phenocrysts are smaller.

The Selendi basin is located more than 100 km from the site and is accessible by quite rough terrain. The volcanic rocks from there are very weathered and unsolid, and often turn into unconsolidated epiclastic rocks. There are not that many places suitable for raw material extraction. On the other hand, the rocks appear quite close to the raw material on the site.

The nearest sources of rocks from the Yunt mountains are reachable downstream to the west. The felsic volcanic rocks of the southern part have an appearance that is closest to the raw material used at Kaymakçı. The rhyolitic and dacitic rocks have a pink or grey color of matrix and large phenocrysts of quart, biotite and amphibole.

The intermediate and mafic volcanic rocks (andesites and basalts) from the site Kaymakçı were used in one third of the cases. Andesites and basalts have generally smaller silica content, they are harder and more cohesive.

Andesites from Kaymakçı are characterized by a fine-grained glassy grey or violet matrix with a phenocryst of feldspar, amphibole or pyroxene (Fig. 5.25). The sources can be found in the Demirçi basin, the Yunt mountains and near the village of Toygar (Fig. 5.24). It is hard to say which source is the most probable. The Toygar andesite looks extraordinary and different with his pinkish color and porphyritic texture with medium large phenocrysts of feldspar and amphibole. The andesites from Demirçi and Yunt mountains are closer in appearance to the Kaymakçı raw material, they have mostly a dark grey color of a matrix and phenocrysts of feldspar or pyroxene/amphibole. In both mountains, there are banded rocks that change a color from grey to violet. There is at least one artifact in the Kaymakçı assemblage that was made from such a rock (Fig. 5.26). Unfortunately, both mountains are far from Kaymakçı.

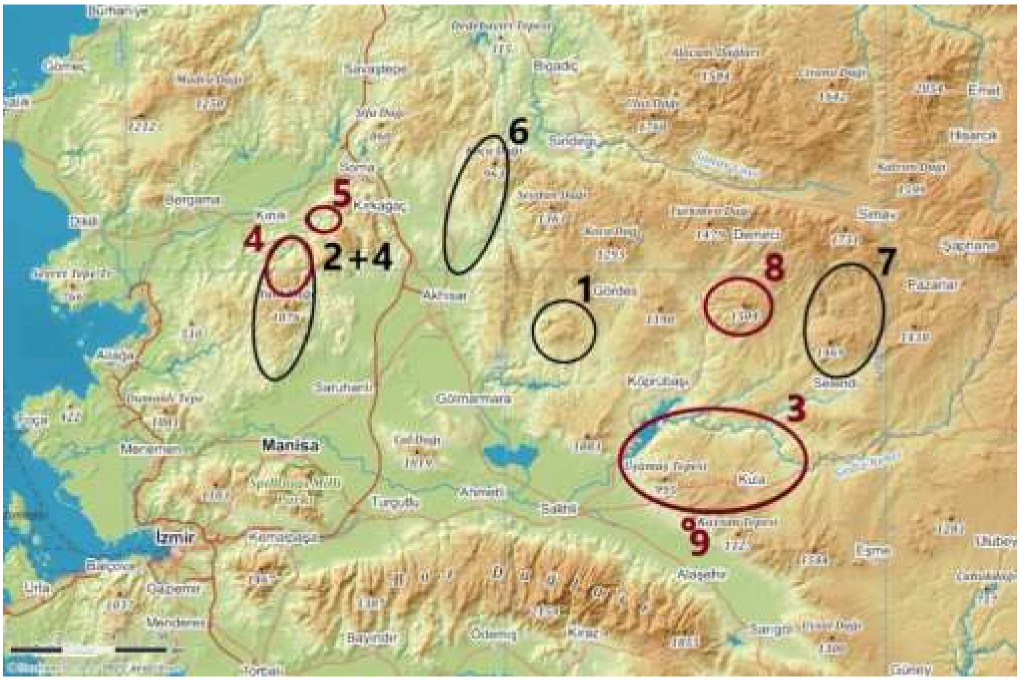


Fig. 5.24 Topographic map with marked intermediate and mafic volcanic rocks, andesite- 4. Yunt Mountains, 8. Demirçi region, 9. Toygar; basalt – 3. Kula region, 5. Soma region.

Fig. 5.25. Macrofocus on the texture of andesitic grinding stones (photo by author).

Fig. 5.26. Grinding stone 97.541.245.1, banded texture of the raw material.

Artifacts made of basalt represent only a very small part of the Kaymakçı assemblage. The Kaymakçı basalts are fine-grained and have the vesicular or compact texture sometimes with phenocrysts of olivine and pyroxene. It is unlikely that these basalts were brought from the Soma region due to the distance and different appearance of the rock. The source of these rocks was most likely located somewhere in the Kula region (Fig. 5.24). The closest location of these rocks from Kaymakçı in the Kula region is near the Adala village. However, it seems that the most seemingly similar sources are located more to the west. Since this raw material occurs in such small quantities at the site, it is quite possible that the rock could have been collected from the riverbed, where it was moved by the Gediz river.

4.3 Manufacture, transport and distribution

The main sources of raw material for GSs were located far from the settlement, at least 30 km away through rough terrain. Part of the way could have been made easier by transport on the river. Still, they probably tried to reduce the carry load to minimum, and therefore probably both reduction phases of production took place near the source and only finished products or preforms flowed into the settlement.

The assemblage has not yet provided clear evidence of the production process that took place at the site. No blank, preform or half-finished stone were detected in the assemblage. It can be assumed that only the refinement (the last stage of production sequence) was done at Kaymakçı, which left no traces. Therefore, the study concentrated on the finished GSs.

Ten finished and unused GSs were identified in the assemblage. Their bottoms and sides seem to be finished, but their working surface does not show signs of use. They could represent almost finished GSs, which broke during the last sequence of production. However, most of them were found on the topsoil in the form of fragments. Only one big nicely shaped LGS was preserved whole (99.526.1.36) but also found on the topsoil. Another three GSs were recovered in a good state of preservation (2x half, part of edge) in a stone structure as recycled products (93.545.232.5, 93.545.232.5) or in a fill (109.523.430.1).

The production traces are not well preserved on the finished Kaymakçı GSs, because the surfaces of the bottoms and sides were mostly nicely smoothed and levelled during the refinement phase. The pecking traces on the bottom side were identified mostly only on the LGSs (Fig. 5.27) The minority of the UGSs have preserved the pecking scars on the sides (Fig. 5.28).

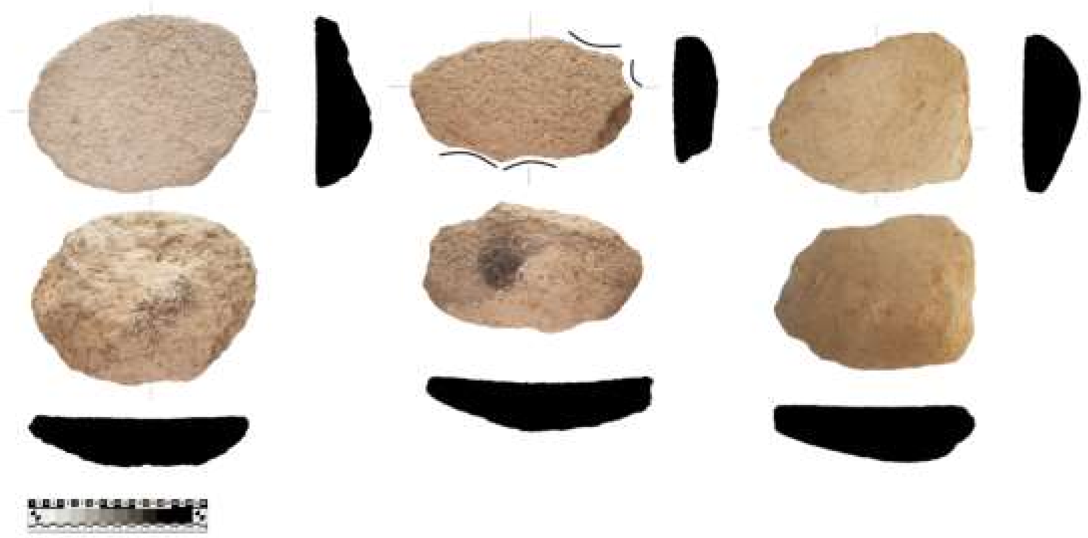


Fig. 5.27. Pecking traces on the bottom of GS 97.543.537.1.

Fig. 5.28. Pecking traces on the sides of GS 93.545.168.1.

Fig. 5.29. GS 97.541.307.1 of granite with minor production treatment.

Some of the GSs show minimal treatment regarding the production process. Raw material in the form of boulder was probably picked up from the river or from some stone field, split in half and then only casually pecked on the sides. This modification is especially common in the case of raw materials such as granite (97.541.307.1) and gneiss (97.541.124.1), exceptionally pelitic sedimentary rocks (Fig. 5.29). Some volcanic rocks may also have been collected in the same way as boulders, but most were more likely to have been extracted from the outcrop, as their uniform dimensions suggest (Fig 5.11). However, their production process was more demanding, as evidenced by their complex designs, predominantly concerning the UGSs.

The UGSs were mostly shaped in some specific forms, which are repeating. In the assemblage of whole preserved stones 4 main classes of forms were recognized with several variations (Fig. 5.30). The most abundant form was oval with the eliptical dominant variant (Fig. 5.31). Therefore, a certain degree of specialized production can be assumed.

The standardization hypothesis was used as an analytical tool to examine Kaymakçı UGS production. The coefficient of variation was counted for the measured dimensions of the whole preserved UGSs (Fig. 5.33). The CV results are low and correspond to values associated with standardized manual production. However, the results are also affected by the issue that the dimensions as variables are connected to the functional concerns and also probably to potential size of the spacing of joints and breaks in the outcrop. The standardized UGS forms occur in all types of raw material, not only among the volcanic rocks. However, the UGSs from other types of rock seem to be not as nicely shaped.

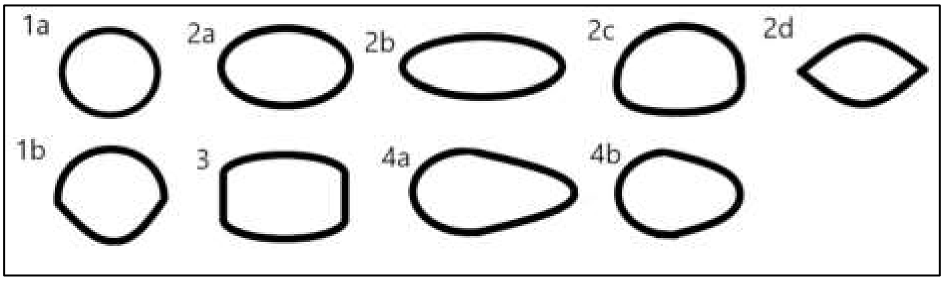


Fig. 5.30. Shape forms of UGSs, 1: rounded (a: circular, b: triangular) 2: oval (a: ovate, b: elliptical, c: loaf-shaped, d: boat-shaped), 3: rectangular, 4: trapezoidal (a: with long arm, b: with short arm).

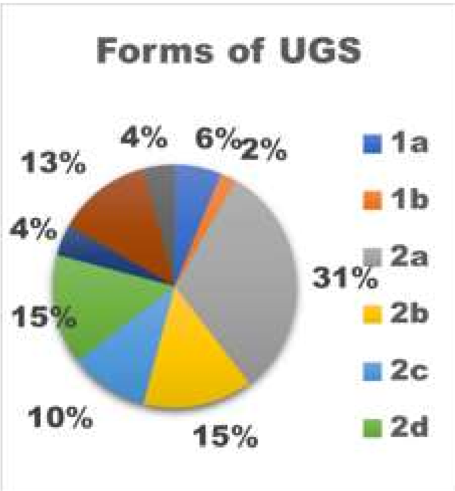


Fig. 5.31. Identified shape forms among the complete preserved UGSs, N=48.

Fig. 5.32. GS 99.526.76.9 with a bottom shaped like a pedestal.

UGS, N=48	length	width (cm)	thickness (cm)	weight (g)
standard deviation	3,65	1,80	1,07	925,55
sample mean	28,06	16,89	5,85	3 937,65
CV	13,02	10,67	18,26	23,51
CCV	13,09	10,73	18,36	23,63

Fig. 5.33. The coefficient of variation counted for complete preserved UGSs, N=48.

LGSs do not show the same trend (Fig. 5.34) probably because the assemblage is very fragmentary and not so many whole preserved pieces were found. In general, a lot of LGSs were also well designed, for example, the LGSs with a bottom shaped in a pedestal form (Fig. 5.32; 99.526.412.1, 109.523.4.430, 108.522.11.6, 99.526.76.9) or the largest one LGS (97.541.245.1) in the complete state of preservation (Fig. 5.26). However, compared to UGSs, much more LGSs are not well-worked and the raw material is slightly more variable.

LGS, N=12	length (cm)	width (cm)	thickness (cm)	weight (g)
standard devia	5,91	2,60	2,66	4 737,19
sample mean	31,10	18,97	7,40	6 730,75
CV	19,00	13,71	35,91	70,38
CCV	19,10	13,78	36,10	70,76

Fig. 5.34. The coefficient of variation counted for complete preserved LGS, N=12.

In summary, there was probably no large-scale specialized production of GSs at the settlement. Most of the production phases probably took place outside. Kaymakçı may have served more as a center where demand was concentrated. Specialized craftspeople were probably absent from the settlement and commuted seasonally for repairs or sharpening and to sell their products in the market. At the same time, there may have also been part-time craftspeople who tried to reproduce their products with regional and local raw materials (sedimentary, metamorphic and plutonic rocks).

4.4 Use patterns

The complementarity of the Kaymakçı GSs is hard to investigate, due to the imbalance in the LGSs and UGSs preservation. The length of UGSs does not correspond at all to the width of the LGSs, as they are usually at least 5 cm longer (Fig. 5.35). Therefore, in the Figure 5.36 only roughly recognized potential grinding pairs are presented.

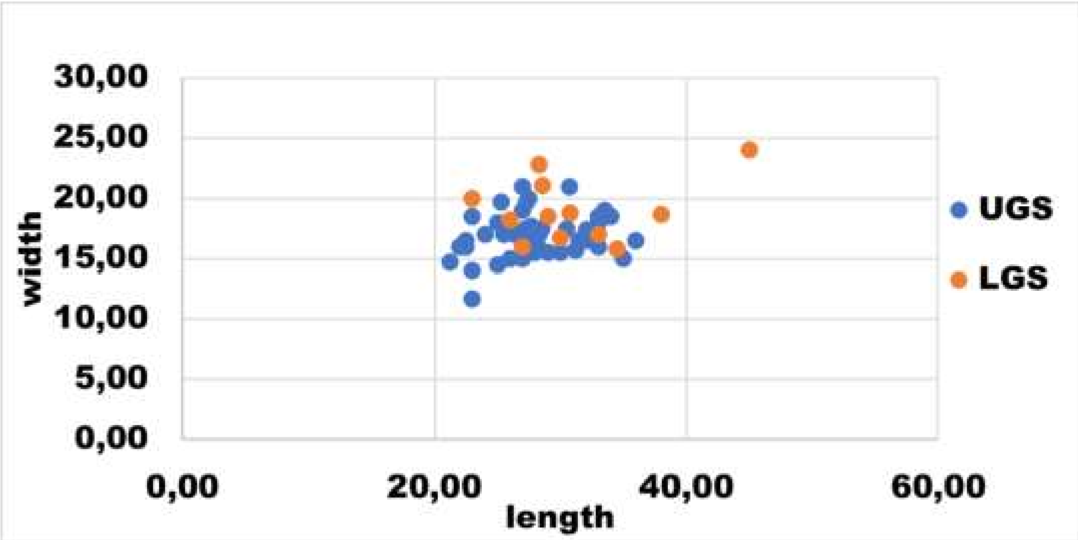


Fig. 5.35. Comparison of the lengths and widths of the complete preserved GSs, N(UGS)=48, N(LGS)=12.

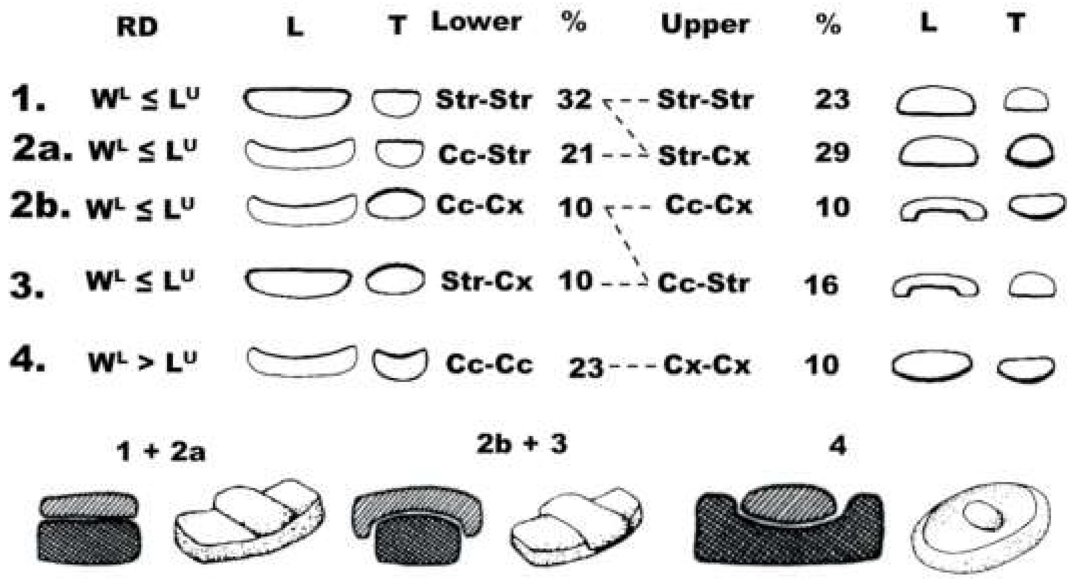


Fig. 5.36. Predictive model of morphometric coupling (longitudinal/transverse cross section) for Kaymakçı GSs. RD – relative dimensions, W^L – width of LGS, L^U – length of UGS, Cc – concave, Cc – convex, Str – straight, L – shape in the longitudinal cross section, T – shape in the transverse cross section, % – percentage in the assemblage (Zimmermann 1988, Abb. 640; altered).

The most abundant is the oval or rectangular LGS with the straight longitudinal cross section (part of grinding set 1, Fig. 5.36). These LGSs sometimes have a nicely shaped bottom in the form of a pedestal (e.g., 109.523.4.430, 108.522.11.6, 99.526.76.9, 98.531.97.6). The others, like the big rectangular LGS 97.541.245.1, have the bottom part rounded. They could have been supported by something which could provide a sloping for easier grinding, or they were embedded in the ground. The paired UGSs would probably be ovate, elliptical, loaf-shaped, rectangular or trapezoidal (Fig. 5.37).

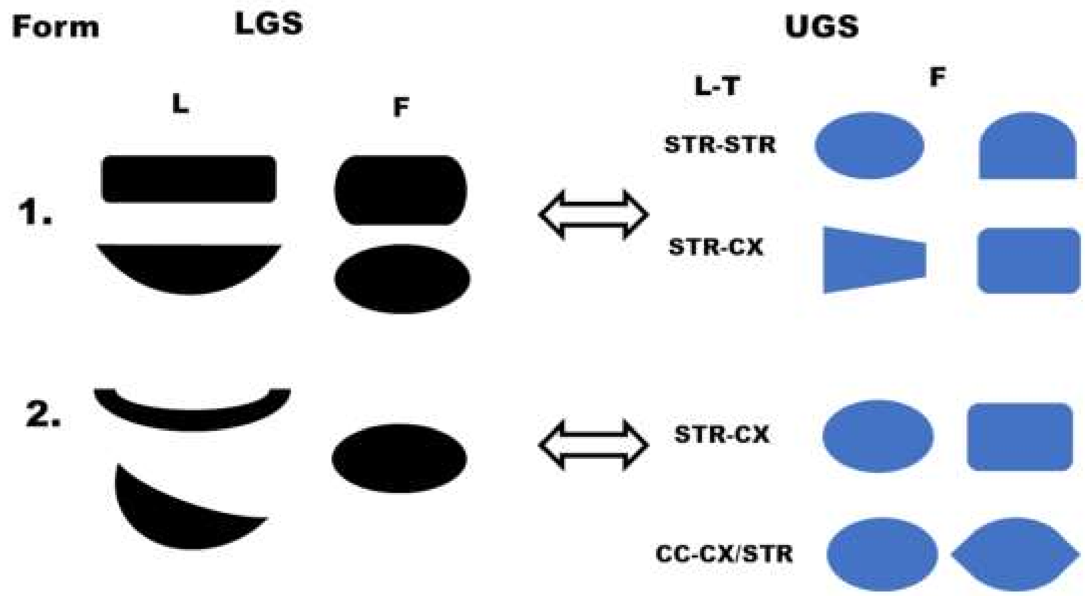


Fig. 5.37. The shapes of the complementary sets, L – shape in the longitudinal cross section, F – shape in the front view, L-T – shape in longitudinal and transverse cross sections.

The second class of GS sets includes LGS with the concave longitudinal axis and straight or convex transverse cross section (grinding set 2, Fig. 5.36). Two variants of the LGSs were distinguished in the assemblage (Fig. 5.37). The first variant involved large GSs that were elevated in mass on one side to provide an inclination for grinding. The second had an oval and saddle-shaped form and were too large and heavy to classify these GSs as upper. They were paired with the ovate, rectangular or boat-shaped UGSs with straight or concave longitudinal cross section and convex transverse cross section (Fig. 5.37).

LGSs with a straight shape in the longitudinal cross section and convex in the transverse cross section appear very few and fragmentary in the assemblage (part of grinding set 3, Fig. 5.36). Occasionally, they appear in special shapes, such as GS with a pointed end (95.555.279.1) or GS with a bottom part shaped into a pedestal (99.526.412.1).

LGSs, concave in all cross sections, were also present (grinding set 4, Fig. 5.36) and could be paired with convex UGS or some small handstones (not included in the study). The movement on the LGS was probably not back and forth, but circular. Small grinding basins with shaped elevated margins were distinguished as a variant (99.526.241.1; 97.541.410.1; 93.545.330.6; 98.531.87.11). It was probably for some small-scale grinding/pounding/rubbing. The container/mortar-like GS (99.526.373.1) of limestone represents an exceptional piece belonging to this group. The other variant included the large concave roughly shaped grinding slabs (e.g. 95.555.198.3; 99.526.76.9).

The GSs were well designed to be used comfortably. In the assemblage, almost one fourth of all UGSs (also fragments counted) have some ergonomic adjustment in the form of depressions or protrusions (Tab. 01).

H1 – handle on the right side	H1a - depression	H1b - protrusion	Right-handed
H2 – handle on the left side	H2a – depression	H2b - protrusion	Left-handed
H3 – depression on both sides			
H4 – depression at the top center			
H5 – handle on both sides but opposite to each other			
H6 – protrusion in the middle			

Tab. 1. Variants of ergonomic adjustments.

The depressions are located either on the right or on the left side. They rarely appear on both sides at the same time or in the middle near the edge (Fig. 5.38). Some of them appear to have been created by flaking the edge and gently smoothing (Fig. 5.39). Others, however, represent an already better-defined handle, such as the trapezoidal shape form 4 (Fig. 5.30; Fig. 5.40). An exceptional piece is the boat-shaped GS, which has handles on both sides (Fig. 5.40). This design is very functional, which will become apparent later. Approximately in the 6th Century BC, this boat-shaped form but with carinated transverse cross-section, sometimes called Archaic Greek quern, spread through the Mediterranean area and appeared on many sites as a part of standardized production (Moritz 1958, 34–41; White 1963, 201; Portillo 2006, Fig. 29; Alonso – Frankel 2017, 3; Chaigneau 2019, Fig. 3; Schwall – Gluhak 2019, 218).

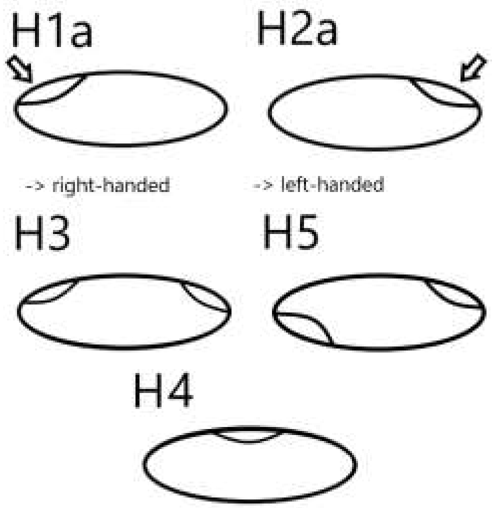


Fig. 5.38. Variants of ergonomic adjustments in the form of depressions.

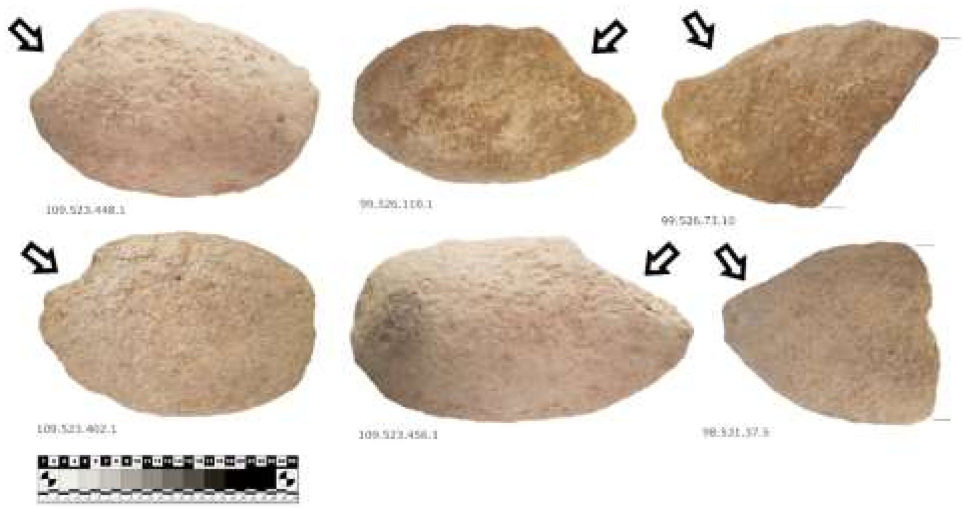


Fig. 5.39. The GSs with ergonomic adjustments in the form of depressions.

Fig. 5.40. The UGS (99.526.626.1.) with trapezoidal form.

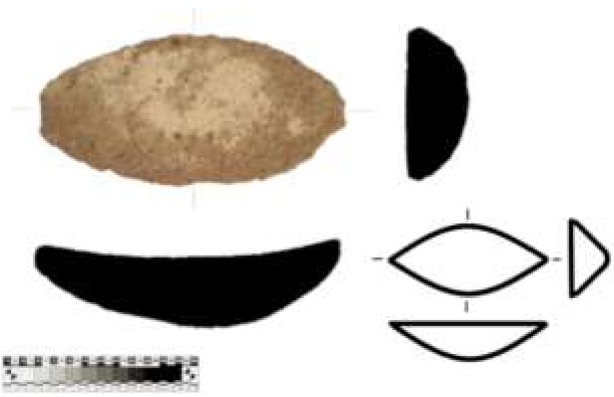


Fig. 5.41. The UGS (97.541.5.1.) with boat-shaped form, simplified drawing of a boat-shaped form from the 6^{th} C. BC.

The next design of ergonomic adjustments are the protruding features like handles on the edges or in the whole body of the bottom part (Fig. 5.42: A, Fig. 5.42: B). The positioning of the ergonomic adjustments is related to where we put more force when grinding. According to this assumption, most of the people at Kaymakçı were probably right-handed, as the Type 1 handle predominates (Fig. 5.42: C).

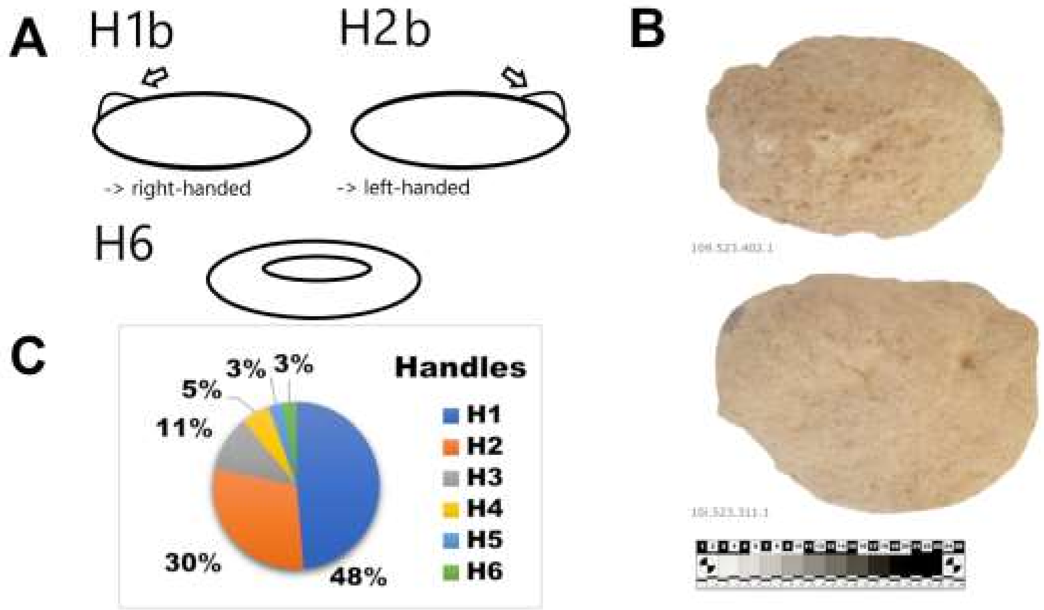


Fig. 5.42. A: Variants of ergonomic adjustments in the form of protrusions; B: The GSs with ergonomic adjustments in the form of protrusions; C: Proportion of ergonomic adjustment designs (N=37).

Some of the tools show a long time of use based mainly on the wear of their working surface. The LGSs with concave surfaces show sometimes a depth of concavity up to 4 cm (99.526.129.1). Unfortunately, the concavity is not good indicator of life span among the Kaymakçı GSs, because some of the tools were produced from the beginning with some curvature of the working surface. This is good evidenced on the unused LGS (109.523.430.1) or slightly used UGS (99.526.110.1).

The working surface of the GSs had to be resharpened from time to time to restore their effective grinding. Some raw materials such as soft felsic and sedimentary rocks were more prone to frequent resharpening. The traces were in the assemblage recognized, for example, on the UGS made of sandstone (97.541.749.1). The hard materials such as the vesicular basalt did not have to be resharpened at all or not as often. Nevertheless, there is a UGS of hard vesicular andesite in the assemblage with clear traces of resharpening (109.523.532.1).

LGSs tend to be smaller in size in comparison with Neolithic Anatolian assemblages, but this may be influenced by their poor state of preservation (Fig. 5.43). On the other hand, the UGSs have similar sizes, which could indicate the same amounts of ground products (Fig. 5.44).

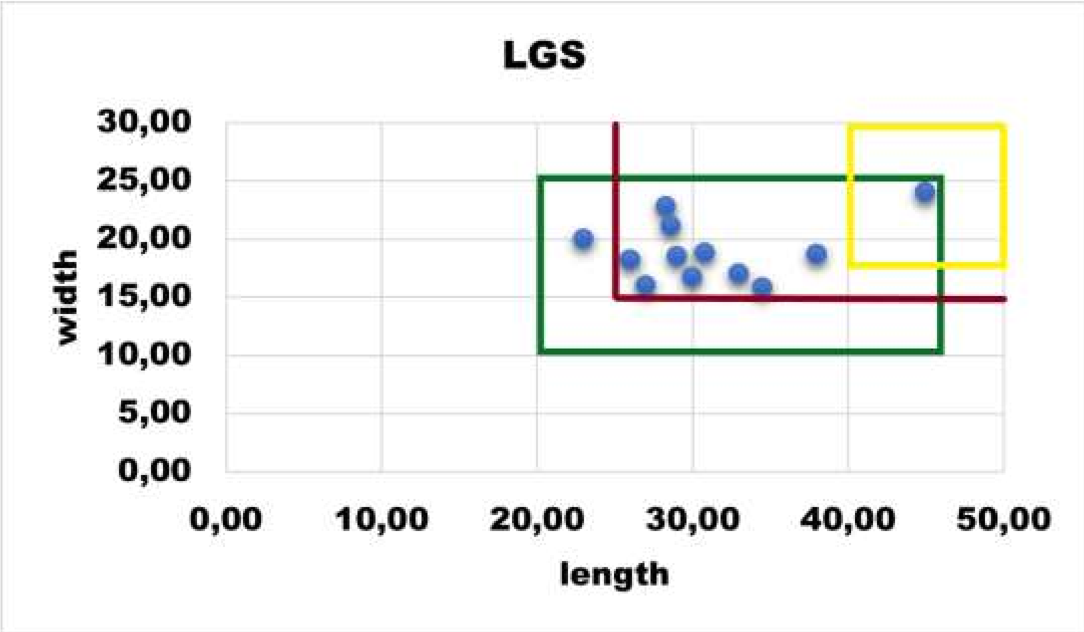


Fig. 5.43. Lengths and widths of whole preserved LGSs from Kaymakçı (blue dots), approximate lengths and widths of whole preserved LGSs from Neolithic sites: Güvercinkayası, Anatolia(red square), Parisian basin, France (green square), Bylany, Czech Republic (yellow square), data compiled from (Hamon 2006; Pavlů 2008).

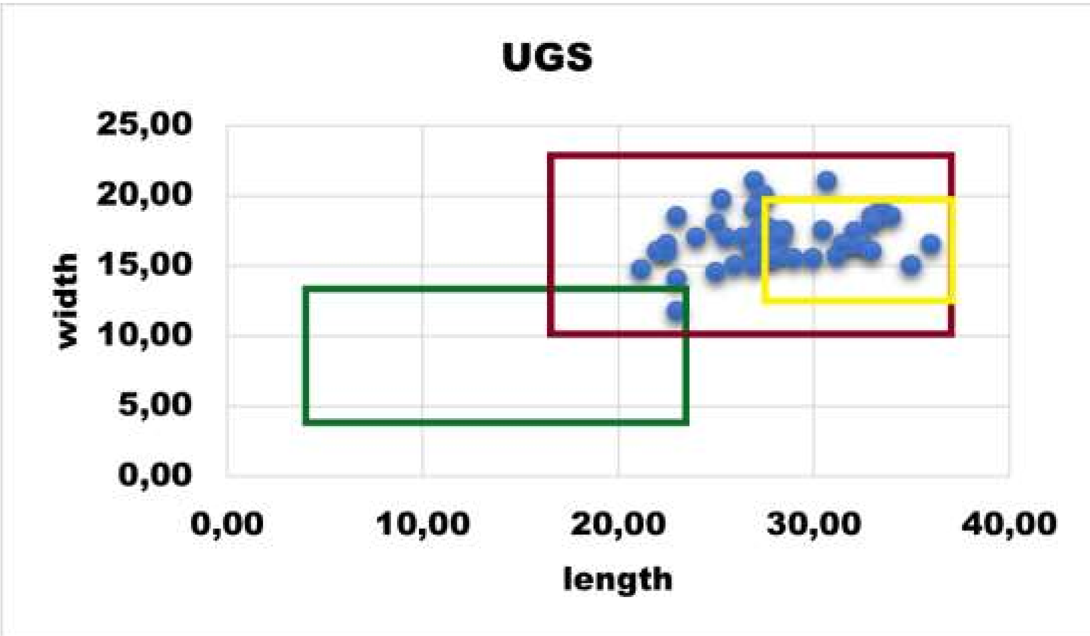


Fig. 5.44. Lengths and widths of whole preserved UGSs from Kaymakçı (blue dots), approximate lengths and widths of whole preserved UGSs from Neolithic sites: Güvercinkayası, Anatolia(red square), Parisian basin, France (green square), Bylany, Czech Republic (yellow square), data compiled from (Hamon 2006; Pavlů 2008).

4.4.1.1 Use-wear study

Two complete preserved Kaymakçı UGSs were selected for the use-wear study. Prior to the actual analysis, an experimental program of eincorn wheat grinding was carried out to investigate the patterns of use-wear traces as well as their spatial development on the surface over time to understand the kinematics of the paired tools and their relation to the user.

4.4.1.1.1 Experimental program

The rock, used for hand-made replicas of GSs, comes from the Oparno valley situated in the northwestern part of Czech Republic and was used for manufacturing GSs from the Neolithic until the early Middle Ages (Šreinová *et al.* 2013; Řídký *et al.* 2014). The middle-grained, vesicular rhyolite with a porphyritic texture resembles the raw material used for Kaymakçı GSs.

The experimental set (S1; Fig. 5.45: A, B) is composed of a "saddle-shaped" lower stone (L1) and an elliptical upper stone (U1) with only one active surface. The metrics are given in Table 2.

ID	Feature	Type	Preservation	Length (cm)	Width (cm)	Thickness (cm)	Weight (kg)	Longitudinal	Transverse
L1	replica	LGS	-	50	20	15	17,5	concave	convex
U1	replica	UGS	-	30	15	11	5,3	concave	straight
99.526.110.1	artifact	UGS	whole	28	15,5	24	2,6	concave	convex
95.555.127.1	artifact	UGS	whole	28,3	17	5,9	3,9	straight	convex

Tab. 2. Characteristics and dimensions of replicas and GSs included in the use-wear analysis.

In order to observe not only the patterns but also the spatial development of the wear, it was necessary to develop a recording strategy:

1. Before the experiments both of the tools were documented in detail, using photogrammetry, macro and micro photos, and 3D modelling.

2. The active surfaces of the L1 and U1 were divided into 5 areas (WSA) - one at each end, two on the margins and one at the center (Fig. 5.45: C, D). Three locations were subsequently selected within each WSA, where the development of wear was to be observed microscopically.

3. The active surfaces of replicas were investigated under an Olympus SZX7 Stereomicroscope and an Olympus BXFM Optical Microscope. The microphotos were taken using a CANON EOS 1200D camera. Each tool was observed at low and high magnification: before the start of the experiments, then after 4 hours of use (phase one), and after 12 hours of use (phase two). In the case where the observed replica was too large for the manipulation space of the microscope used for high magnification (Olympus BXFM), silicon casts (3M™ Express™ Light Body Regular Set VPS Impression Material; i.e. Fig. 5.46: F, G) were taken of the tool's active surface.

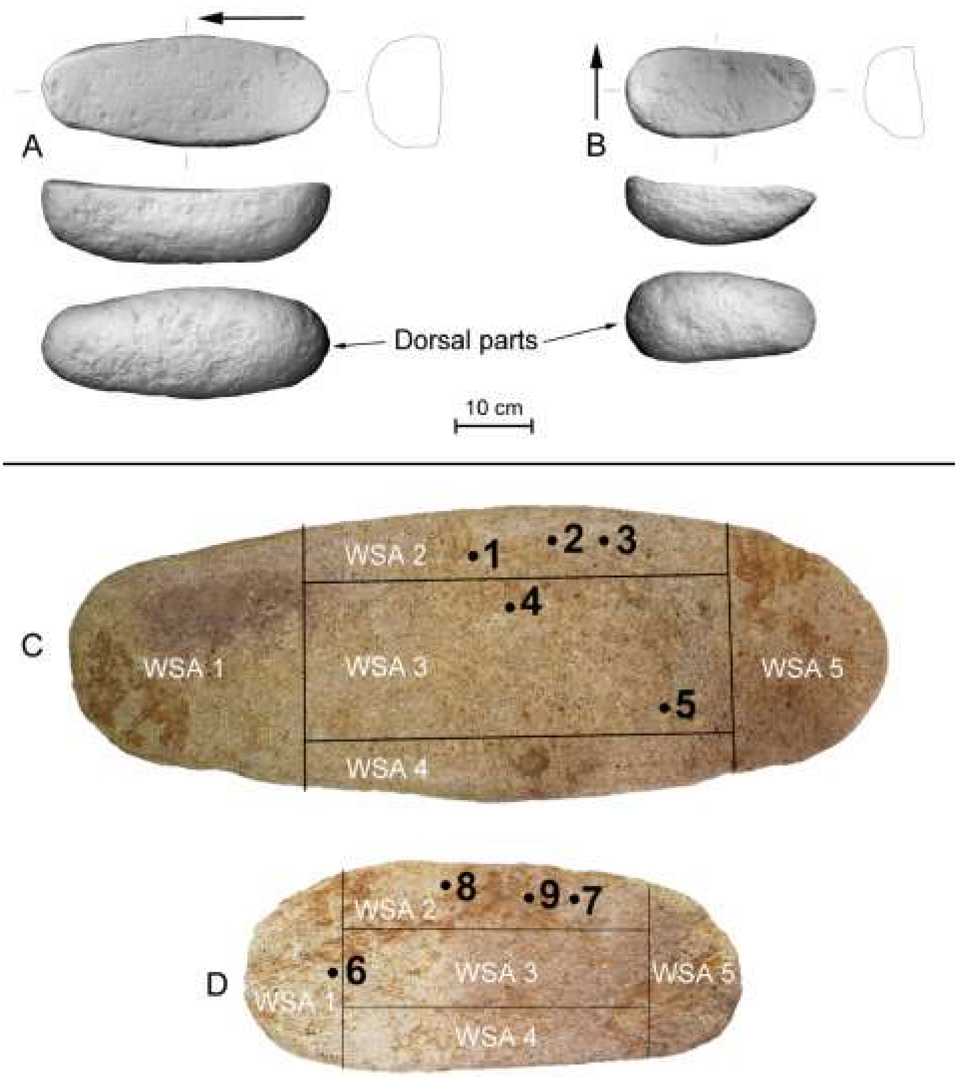


Fig. 5.45. Rhyolite replicas used in this study. A: 3D documentation of L1 - lower stone, the arrow indicates direction of grinding from the position of the user; B: 3D documentation of U1 - upper stone, the arrow indicates direction of grinding from the position of user; C: L1 with marked WSA and locations mentioned in the text. See Fig. 3, and 4; D: U1 with marked WSA and locations mentioned in the text (3D documentation by Daniel Pilař) .

The experiment using husked einkorn wheat was divided into two phases. In the **phase one** lasting four hours, 1 kg of grain was ground into 977 grams of flour which was then sieved using a one millimeter mesh. In the **second phase**, 4 kg were ground into 3869 grams for approximately 12 hours. The wheat grains were ground in a back-and-forth motion. Because it was difficult for the inexperienced user to remain in one position all of the time, altogether three positions were rotated: kneeling, squatting and sitting. In general, the U1 moved mainly along the central part of the L1, closer to the person who was using it. However, an important observation from this part of the experiment is that each change in position slightly shifted the point of contact between the upper and lower stone.

A) First phase

After four hours of use, no major changes were observed macroscopically, but the active surface of L1 seemed to be a little more roughened and the production grooves were showing through. The edges of the central part of the tool seemed to be more levelled and larger homogeneous zones were concentrated there. The most striking changes took place in_the middle section. The surface was more abraded and the protruding mineral grains (mainly feldspar) were slightly levelled, striated, and polished (Fig. 5.46: A). The edges of the grains did not seem to be greatly affected. The grains of quartz minerals seemed to be more fractured and not so levelled (Fig. 5.46: B, C). The abrasion of the material was most significant in the part closer to the person operating the GMT, so even in this first phase after several hours of work it was possible to identify the orientation of the tool relative to the user and the way in which the tool was manipulated (motion). However, the left side of the tool was not significantly affected, which is probably due to the fact that the user was right-handed. This in itself is another important finding.

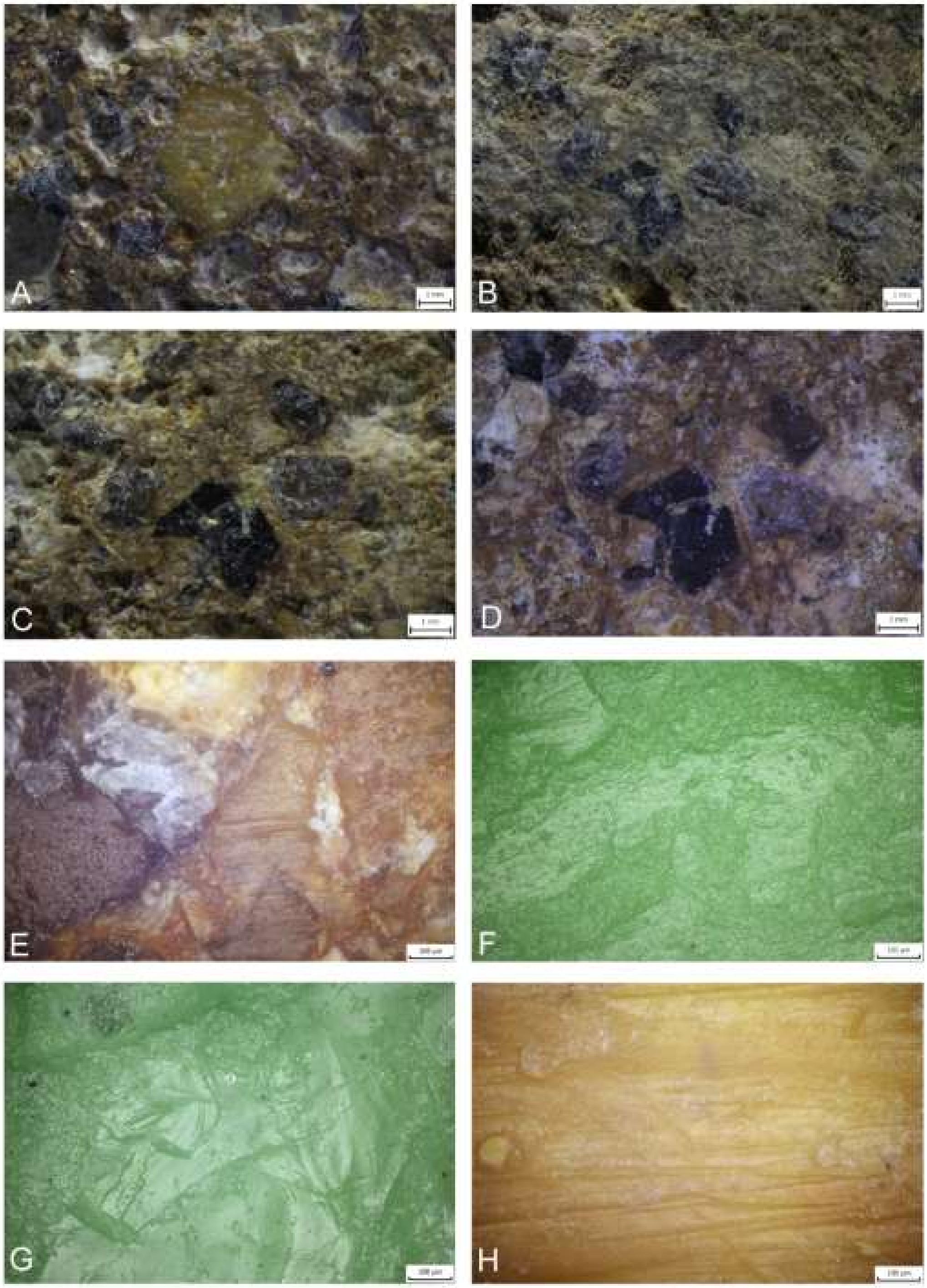


Fig. 5.46. Lower stone, L1, locations marked in the Fig. 1: C. A: Location 1, after first phase, levelled surface with striated feldspar grains, OLYMPUS SZX7 Stereomicroscope, 16x magnification; B: Location 2, before first phase, uneven surface with quartz grains, OLYMPUS SZX7 Stereomicroscope, 16x magnification; C: Location 2, after first phase, levelled surface with fractured quartz grains, OLYMPUS SZX7 Stereomicroscope, 20x magnification; D: Location 2, after second phase, levelled quartz grains, OLYMPUS SZX7 Stereomicroscope, 20x magnification; E: Location 3, after second phase, micropolish on quartz grains, OLYMPUS BXFM Optical Microscope, 200x magnification; F: Imprint of the active surface on silicon casts, Location 1, after second phase, micropolish on the high topography, OLYMPUS BXFM Optical Microscope, 200x magnification; G: Imprint of the active surface on silicon casts, Location 4, after second phase, polished crystal with abraded faces and rounded edges. OLYMPUS BXFM Optical Microscope, 200x magnification; H: Location 1, after second phase, deep long striations on the feldspar grain. OLYMPUS BXFM Optical Microscope, 200x magnification.

On the active surface of U1, the changes were more apparent than on the lower stone, even macroscopically. The active surface was irregularly smooth, and the margins were highly levelled into homogeneous zones. The left side of the tool (WSA 1) was mainly affected by abrasion of the material (Fig. 5.48: A). There were clear pits on the surface from extracted grains and the faces of the grains were sometimes very fractured. This abrasion was probably due to direct stone-on-stone contact that was not inhibited by the presence of a layer of ground substance. There was also much more pressure on this side because of the fact that the user was right-handed. However, the greatest changes occurred on WSA 2, where enough ground substance had probably accumulated to form a protective layer on the working surface. Large homogeneous zones were created at the edge of this area. The grain minerals had levelled faces with fine striations and polished areas (Fig. 5.48: B, C, D). Towards the middle part of the tool, the surface had become uneven and irregular. There was some minor abrasion, which appeared as pits from dropped grains. However, the quartz grains had levelled faces with fine polish. The area (WSA 4) close to the user was also highly abraded and levelled. The quartz grains remained fractured.

B) Second phase

After twelve hours of use, the active areas were much more defined on both parts of the experimental set. The active surfaces were still partially roughened, but grooves from production were no longer observable.

On the L1 type large homogeneous zones formed in the parts where the stone-on-stone contact was most intensive, mainly at the edges. The central part was partially levelled, but still sufficiently rough. Moving to the microscopic level, the development of the wear intensified and became more pronounced. The surface became increasingly levelled. Spreading amalgamation of mineral grains occurred on homogeneous zones; the asperities started to merge with the matrix, and their edges could not be distinguished. Although there were still dark fractured quartz crystals present, even these grains gradually became homogeneous with a smooth surface (Fig. 5.46: C, D). The polish began to intensify and densely covered the active surface in large patches. It had a smooth texture and domed to flat topography (Fig. 5.46: E, F). The edges of large crystals were abraded and rounded (Fig. 5.46: G). Long, deep, polished, parallel striations appeared in the polished areas from the stone-on-stone contact (Fig. 5.46: H). In the part located closer to the user the abrasion of the material was even more significant (Fig. 5.47: A, B).

The U1 type was much more affected by abrasion of the raw material. WSA 2, located further from the user, was highly abraded primarily at the edges. Many pits from dropped grains occurred in this part, and some crystals were still fractured (Fig. 5.48: E). On the homogeneous zones the grains were levelled and the asperities merged with the matrix. The large grains had rounded edges and polished and striated faces (Fig. 5.48: F). In the middle part, the active surface was more uneven and irregular with a lot of pits and fractured crystals. Homogeneous zones with levelled and polished grains, but without striations, also occurred. The area of WSA 4 located close to the user was affected in the same way as the middle part. The grip areas of the upper stone were smoothed.

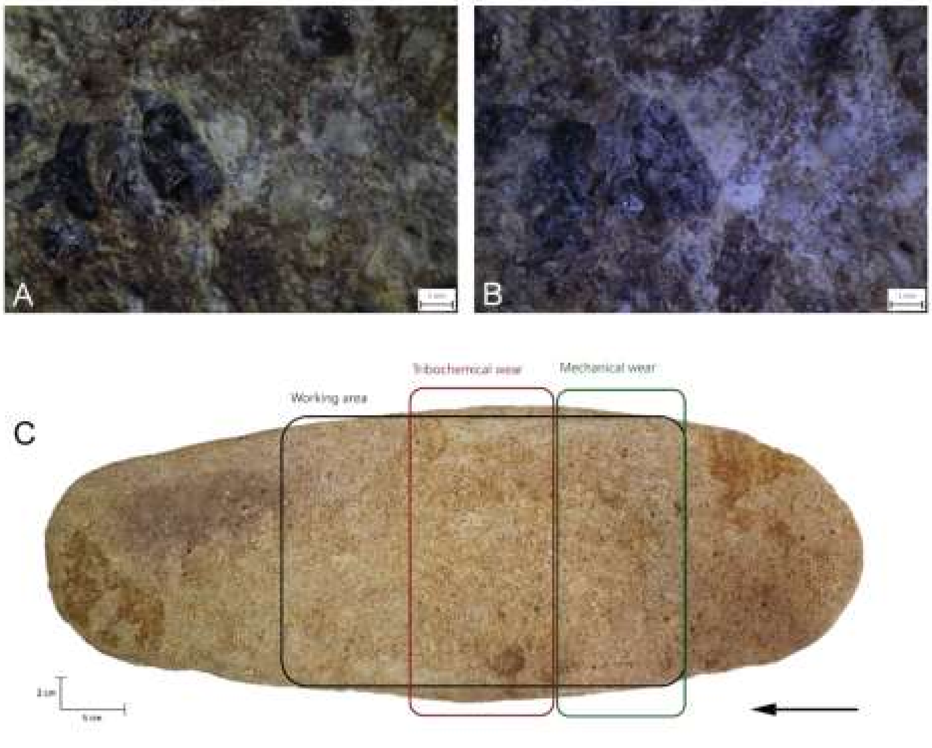


Fig. 5.47. Lower stone, L1, locations marked in the Fig. 1: C. A: Location 5, after first phase, abraded surface with fractured grains. OLYMPUS SZX7 Stereomicroscope, 16x magnification; B: Location 5, after second phase, abraded surface with fractured grains. OLYMPUS SZX7 Stereomicroscope, 16x magnification; C: Active surface of lower stone L1 with distribution of prevailing mechanisms of wear, the arrow indicates direction of grinding from the position of user.

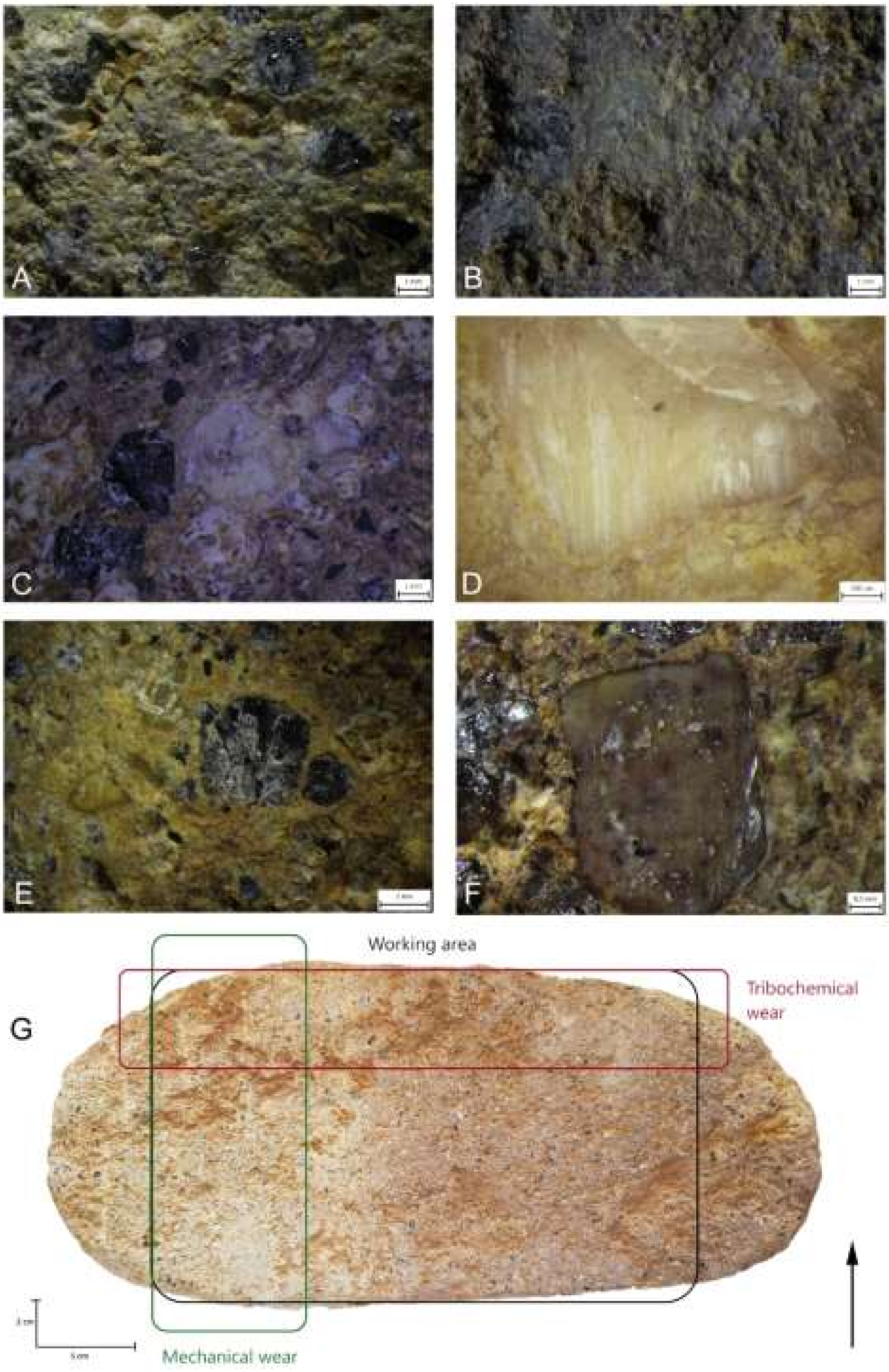


Fig. 5.48. Upper stone U1, locations marked in the Fig. 1: D. A: Location 6, after first phase, surface with lot of pits and fractured grains, OLYMPUS SZX7 Stereomicroscope, 16x magnification; B: Location 7, before first phase, uneven surface, OLYMPUS SZX7 Stereomicroscope, 16x magnification; C: Location 7, after first phase, surface with levelled feldspar and quartz grains, OLYMPUS SZX7 Stereomicroscope, 16x magnification; D: Location 7, after first phase, micropolish with striations. OLYMPUS BXFM Optical Microscope, 100x magnification; E: Location 8, after second phase, levelled surface with fractured quartz grain, U1, OLYMPUS SZX7 Stereomicroscope, 12,5x magnification; F: Location 9, after second phase, striated feldspar grain with rounded and polished edges, OLYMPUS SZX7 Stereomicroscope, 32x magnification; G: Active surface of lower stone U1 with distribution of prevailing mechanisms of wear, the arrow indicates direction of grinding from the position of user.

4.4.1.1.1.1 Results of the experiment

Both phases of the experiment yielded several important findings:

- The use-wear traces after the first phase of grinding were difficult to distinguish macroscopically, probably due to the hardness and cohesion of the raw material. On closer observation, patterns that were not apparent on first inspection began to emerge. On the one hand, the area close to the user was greatly affected by mechanical wear (see Fig. 5.47: C). On the other hand, the middle part, where the accumulation of ground substance occurred, was much more affected by tribochemical wear. Therefore, the orientation of the lower GS relative to the user can be determined (Fig. 5.47: C).

- Each change of the position of the user shifted the point of contact between the upper and lower stones.

- Due to the application of different levels of pressure, reflected in differential mechanical wear, it was possible to determine whether the operator was left-handed or right-handed (Fig. 5.48: G). The non-dominant hand just maintained the correct direction of the grinding motion and therefore applied little pressure.

- Wider homogeneous zones, caused by stone-on-stone contact, gradually appeared on the longitudinal edges of the lower stone. It is therefore possible to determine that the compatible upper stone extended beyond the edges of the lower stone.

- After the second phase of the experiment, the wear sequence started to intensify. However, it became more complicated to decipher the wear patterns because of the hardness of the raw material.

4.4.1.1.2 Kaymakçı GS use-wear study

The purpose of this part of the study was to use the findings of the experiment to analyze the microscopic use-wear on the original archaeological tools. Two GSs were selected for this analysis (99.526.110.1; 95.555.127.1). The working surfaces were investigated under a Zeiss Stemi 508 Stereomicroscope. The silicon casts (3M™ Express™ Light Body Regular Set VPS Impression Material) of the working surfaces were taken and transported to the Czech Republic for observation at high magnification under an Olympus BXFM Optical Microscope.

GS 99.526.110.1

This whole preserved oval UGS of some soft felsic rock (probably dacite) has the ergonomic feature on the right side in the form of a depression. The uneven and rough working surface is 27 cm long and 15 cm wide. By closer microscopic examination, it is possible to distinguish a homogeneous zone that extends almost across the entire margin (Fig. 5.49: A). The grains are mainly levelled or fractured and have slightly rounded edges (Fig. 5.49: B). The levelling affects only high topography and is well developed on biotite minerals (Fig. 5.49: C). The micropolish is predominantly distributed on high topography in loose connected small patches (Fig. 5.49: D). It has a smooth texture and a domed topography (Fig. 5.49: E). However, the micropolish on the biotite minerals tends to be more extensive, flat and striated (Fig. 5.49: G). Crystals are fractured and have abraded edges (Fig. 5.49: F).

The tool was probably used only shortly because the use-wear traces are not macroscopically well developed. The user was probably left handed, as indicated by the distribution of the homogeneous zone and confirmed by the positioning of the ergonomic adjustment (Fig. 5.49: A). The paired LGS was probably wider or as wide as the length of this UGS. However, the use-wear from stone-on-stone contact was not identified. Furthermore, the developed wear does not correspond to the typical wear patterns of cereal grinding. To sum up, the movement during the activity was longitudinal and the possible ground substance was plant matter, but the micropolish does not give an exact answer, what was ground and on what.

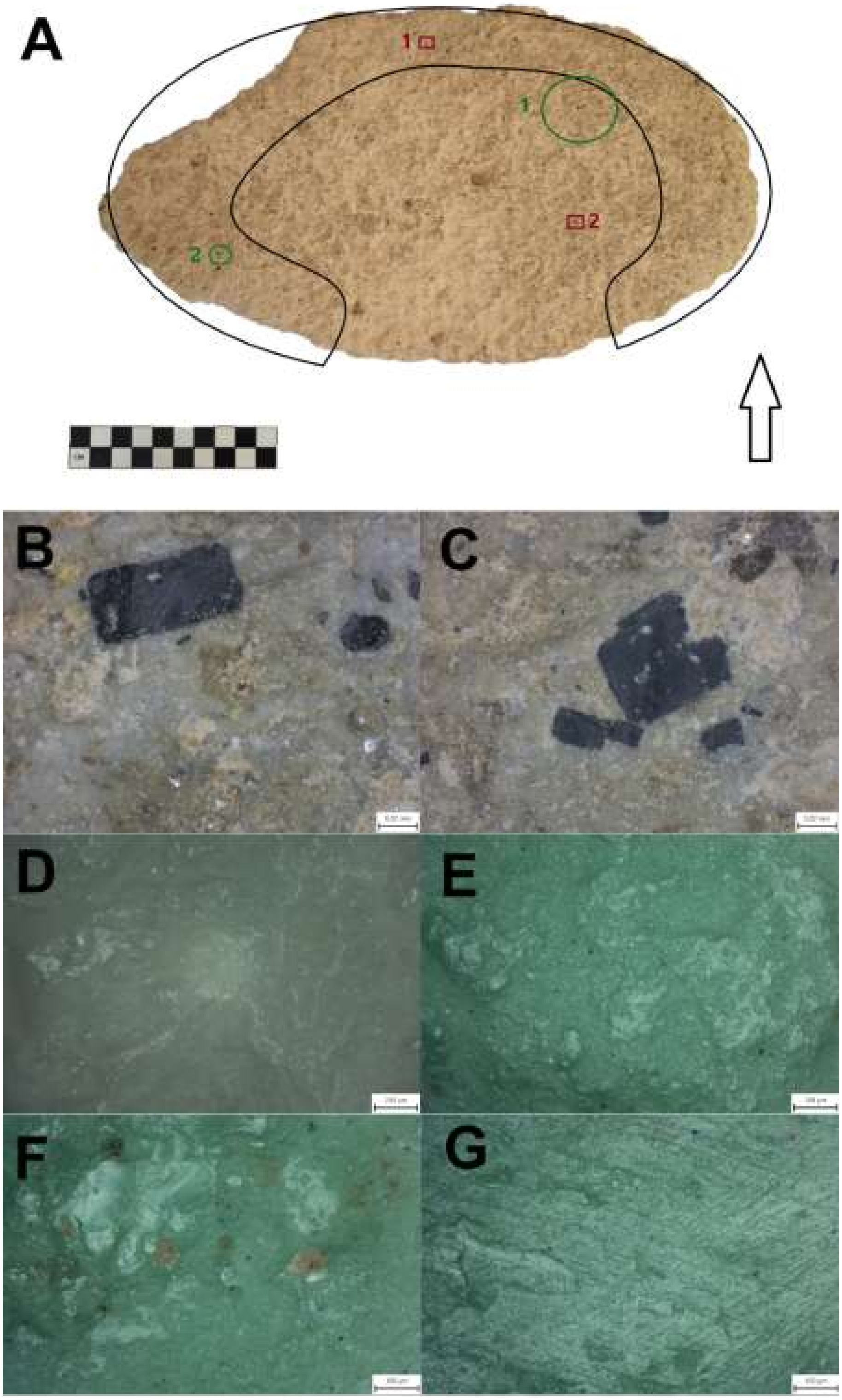


Fig. 5.49. The use wear analysis of UGS 99.526.110.1, A: front view with marked homogeneous zone (black line), location of silicon casts (green circles) and locations of photos (red squares), the arrow indicates the direction of the movement; B: Location 1, levelled surface in the homogeneous zone, Zeiss Stemi 508 Stereomicroscope, 25x magnification; C: biotite minerals with striations, Zeiss Stemi 508 Stereomicroscope, 25x magnification; D: Silicon cast from location 1, the distribution of the micropolish, OLYMPUS BXFM Optical Microscope, 100x magnification; E: Silicon cast from location 1, the domed micropolish, OLYMPUS BXFM Optical Microscope, 200x magnification; F: Silicon cast from location 1, the abraded crystal, OLYMPUS BXFM Optical Microscope, 200x magnification; G:

Silicon cast from location 2, the flat and striated micropolish on the biotite crystal, OLYMPUS BXFM Optical Microscope, 200x magnification.

GS 95.555.127.1

This whole preserved UGS is nicely worked into the concave oval shape and was made of vesicular volcanic rock. The working surface is flat with regular roughness. It is also densely covered by perpendicular parallel scratches (Fig. 5.50: A, C). The homogeneous zones appear on the margins and in the center (Fig. 5.50: A). The grains are mostly levelled and have rounded edges (Fig. 5.50: B). The smooth, domed micropolish is distributed in loose connected small patches on the high topography and predominantly on the edges (Fig. 5.50: D). Crystals are fractured and have abraded edges (Fig. 5.50: E).

The tool was used in the longitudinal movement. According to the distribution of the homogeneous zones the LGS was probably slightly concave in all directions. The margin of the UGS without homogeneous zones was probably closer to the user (Fig. 5.50: A). The ground substance was possibly hard and plant matter (some seeds).

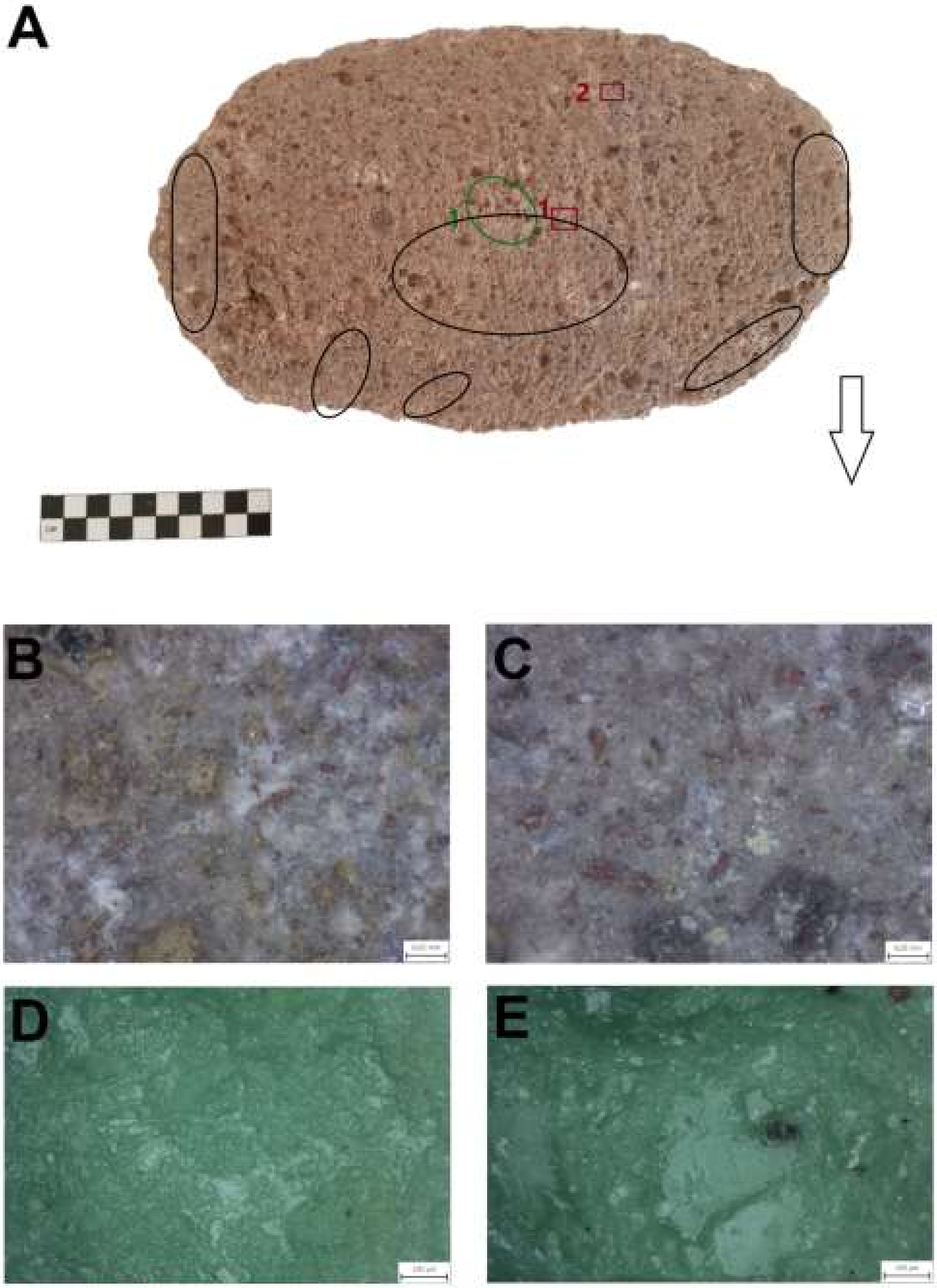


Fig. 5.50. The use wear analysis of UGS 95.555.127.1, A: front view with marked homogeneous zones (black circles), location of silicon casts (green circles) and locations of photos (red squares), the arrow indicates the direction of the movement; B: Location 1, levelled grains with rounded edges, Zeiss Stemi 508 Stereomicroscope, 25x magnification; C: Location 2, levelled surface with scratches, Zeiss Stemi 508 Stereomicroscope, 25x magnification; D: Silicon cast from location 1, the domed micropolish, OLYMPUS BXFM Optical Microscope, 200x magnification; E: Silicon cast from location 1, the fractuered crystal with abraded edges, OLYMPUS BXFM Optical Microscope, 200x magnification.

4.4.1.2 Reuse

The GSs were made of rocks imported from far away. The raw material was hard, cohesive and had good thermal properties, which was also suitable for other purposes than only for GSs. Therefore, the reuse of this raw material probably formed an important part of the chain.

According to the use-wear study, the upper GS97.541.749.1 belongs to the category of simply reused tools (Fig. 5.51: A). At first it appeared that this GS was for pulverizing ceramic, because the uneven working surface was covered by fractured quartz minerals (Fig. 5.51: E) and residues of ceramic (Fig. 5.51: C). But originally it must have been used to grind some plant matter substance, as some of the grains show a residual domed polish (Fig. 5.51: B, D).

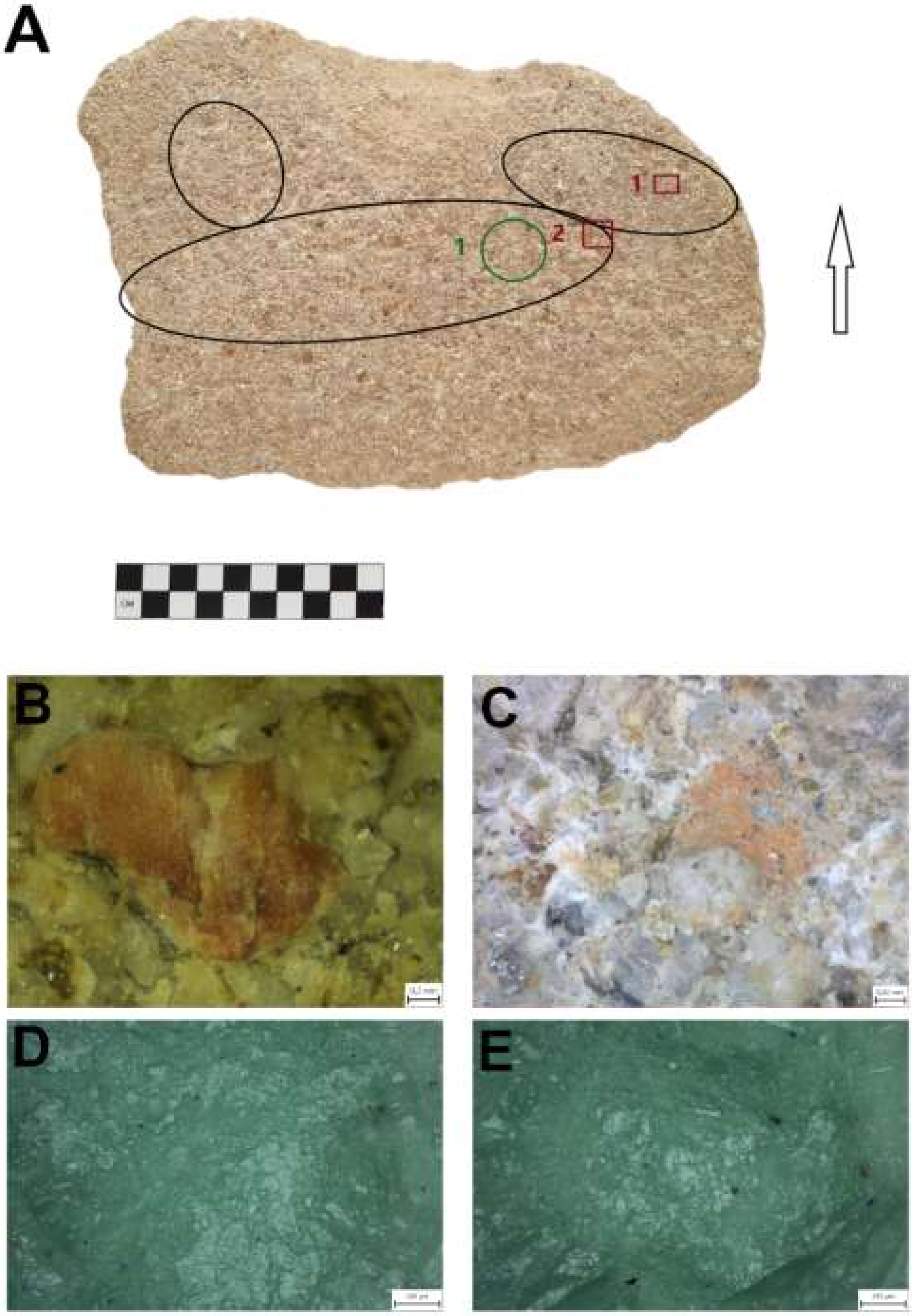


Fig. 5.51. The use wear analysis of UGS 97.541.749.1, A: front view with marked homogeneous zone (black line), location of silicon casts (green circles) and location of photos (red squares), the arrow indicates the direction of the movement; B: Location 1, levelled and polished quartz mineral, Zeiss Stemi 508 Stereomicroscope, 32x magnification; C: Location 2, residues of ceramic, Zeiss Stemi 508 Stereomicroscope, 20x magnification; D: Silicon cast from location 1, micropolish, OLYMPUS BXFM Optical Microscope, 200x magnification; E: Silicon cast from location 1, fractured crystals, OLYMPUS BXFM Optical Microscope, 200x magnification.

The complex reuse was probably practiced frequently, because of scarcity of the raw material. At least three GSs (97.541.542.1; 109.523.532.1; 109.523.545.1) were found to have been originally used as LGSs. but were probably later broken, so they continued to be used as UGSs.

However, reuse is most noticeably recorded in the frequency of recycling. Four GSs were secondary used as some kind of mortar (99.526.129.1; 97.541.69.1; 97.541.134.1; 97.541.550.1). The GSs 97.541.69.1, 97.541.134.1 and 97.541.550.1 have in the center of the fragment a small hollow (between 4 and 5,5 cm) from pecking or crushing something (Fig. 5.52). The other concave grinding basin 99.526.129.1 has the hollow, 12 cm large in diameter and 4 cm in depth, located just in the center (Fig. 5.53). Unlike the others, the hollow seems to have been made before the tool was broken. It was probably used for finer grinding, but broke around the middle of the hollow. Some GSs have even preserved the initial stage of hollow formation (109.523.117.1; 109.523.152.1; 93.545.253.5). The shallow hollows on the whole preserved GSs 109.523.117.1 and 109.523.152.1 could be natural, which is not distinguishable due to the large layer of sinter on the surfaces. However, the GS 93.545.253 have clearly preserved the initial stage of the hollow only 2,5 cm in diameter.

Fig. 5.52. GS 97.541.134.1 with hollow in the center.

Fig. 5.53. GS 99.526.129.1 with hollow.

Two other GSs were used secondarily as some abraders or sharpeners (97.541.550.1; 95.555.18.1). On the working surface, they have a long groove with width of 2,5 cm and depth of 0,5 cm. The GS 97.541.550.1 also has a hollow (also d=55 cm) near the asymmetrically orientated groove from crushing or pecking something (Fig. 5.54).

Fig. 5.54. GS 97.541.550.1 secondarily used as sharpener/abrader.

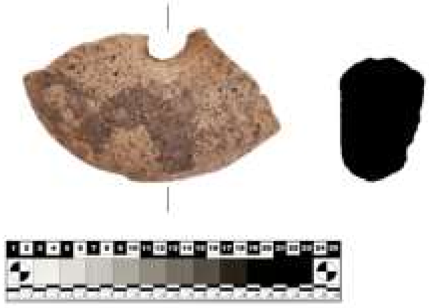


Fig. 5.55. Drilled GS 95.555.3.1.

The completely drilled GSs are also present in the assemblage. The hole was drilled from both sides in the shape of an hourglass. The drilling was not always successful, which is apparent on the three GSs (97.541.331.1, 99.526.225.1, 109.523.146.1), which broke in half during the activity. The successfully drilled GSs were reshaped to a round form, but the GS working surface is still visible. One drilled GS (95.555.3.1, Fig. 5.55) was washed and deeply examined under the microscope, but no diagnostic use-wear traces were observed, so, the function is not entirely clear, probably some kind of weight. The artifacts in the torus shape could also have a similar function (109.523.260.8, 109.523.531.1, 97.541.99.1). They were probably also made from GSs, as the same raw material appears. However, they were completely reshaped and their working surface is not visible anymore (Fig. 5.56). Four drilled discs with a similarly sized hole (d=30-60 cm) would also belong to this category with the same unclear function, but they were made of local raw materials such as schist or limestone.

Fig. 5.56. Torus stone 97.541.99.1.

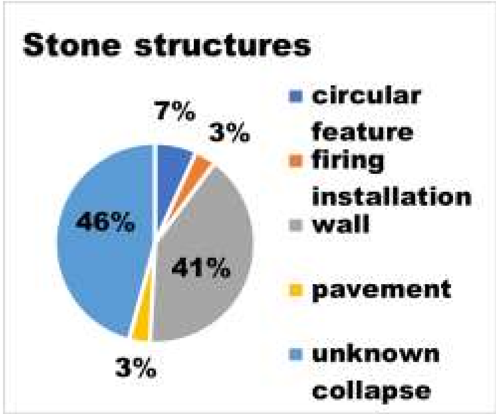


Fig. 5.57. Types of stone structures where were GSs found (N= 59).

Almost 20 % of GSs were used secondarily as building material in various stone structures (Fig. 5.57). Very often it is not clear what kind of stone structure it is, but mainly architectural walls prevail. They are rarely found as part of a so-called circular feature. Only twice they have appeared in a fire installation and in a pavement.

4.5 Disposal patterns

Kaymakçı belongs to the sites that were slowly abandoned without a destruction horizon. Therefore, it is expected that more contexts in the performance of discard activities/secondary refuse are present on the site and the tools are mostly not found in the location of use.

The UGSs slightly prevail over the LGSs at Kaymakçı (Fig. 5.58). The large difference is in the level of preservation (Fig. 5.59). Almost half of the UGSs are whole or mostly whole preserved. On the other hand, LGSs were preserved predominantly only in fragments. The ones in complete state of preservation comprise only 15 % of the assemblage.

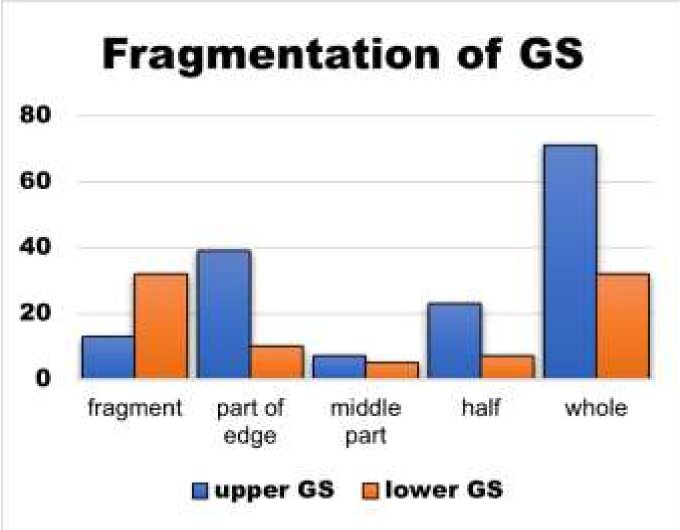


Fig. 5.58. Preservation of UGS (N=153) and LGS (N=86).

Fig. 5.59. Degree of preservation of UGS (N=153) and LGS (N=86).

The preservation of the artifacts (Fig. 5.60) is more fragmentary in the upper citadel (areas 93.545 and 97.541) and in the fortification area on the slopes (area 95.555). Most of the whole preserved GSs were deposited in the lower southern part of the citadel (area 109.523 and 99.526). GSs are represented especially in the EAs 109.523, 97.541 and 99.526. (Fig. 5.61). When the numbers of finds are recalculated according to the size of the EAs, area 99. 526 has the highest number of finds (Fig. 5.62). Unfortunately, nearly 20 % of all finds come from topsoil (mostly modern rock pile), of which almost 70 % was found in the EA 109.523.

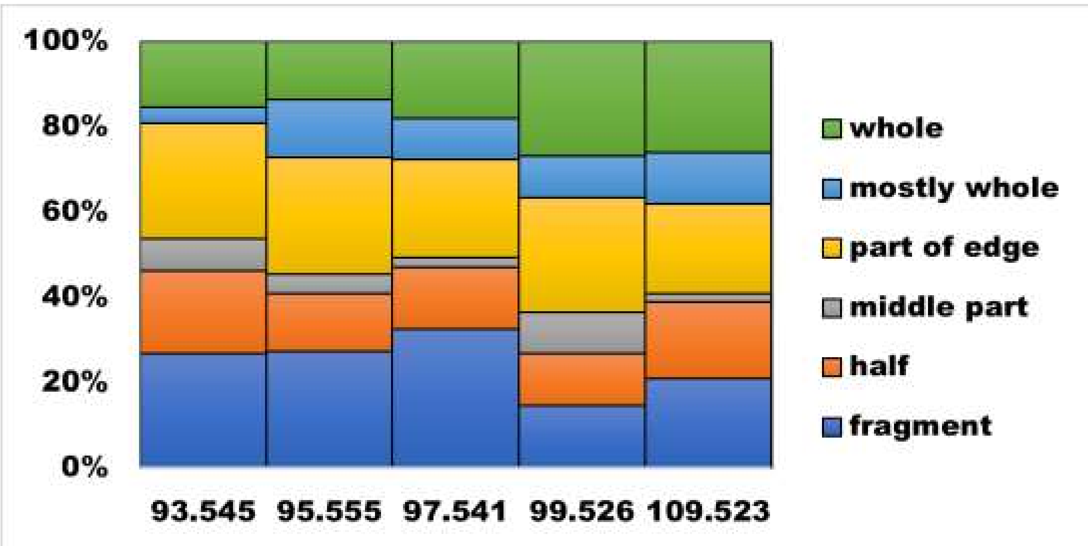


Fig. 5.60. Distribution of large stone finds in the EAs according to fragmentation (N=288).

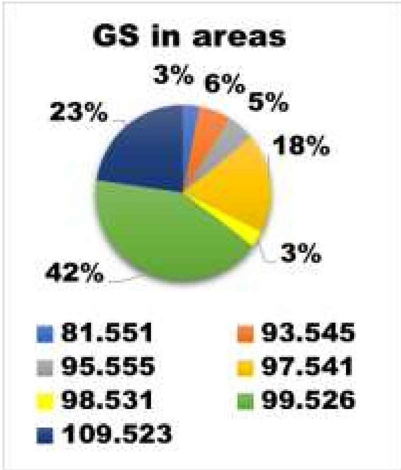
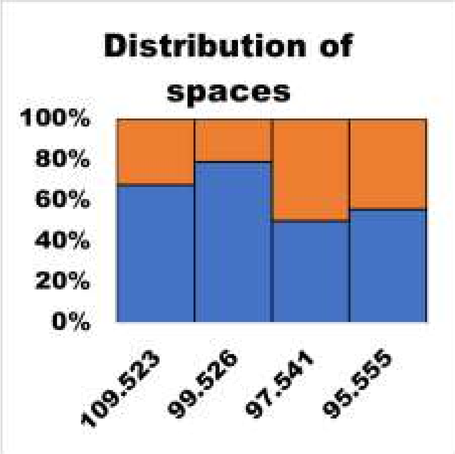


Fig. 5.61. Distribution of grinding tools within the site in excavation areas (N=281).

Fig. 5.62. Distribution of grinding tools within the site in EAs recalculated according to the area size (N=281).

The grinding activities played a very important role at Kaymakçı, which is apparent from the size of the assemblage. However, no structure dedicated solely to grinding, such as a grinding bench, has yet been found in any room. Large stationary immobile LGSs are not present in the assemblage. The largest LGS is only 45 cm long and weighs 20 kg and was found as part of a stone collapse (Fig. 5.26). Therefore, it is difficult to locate some spaces devoted to grinding activities.

The use location is not apparent from the direct traces. Therefore, the indirect patterns such as the distribution of the GSs in the EAs and the accumulation in the exterior and interior of the buildings were investigated. The GSs found in the fill not in some structure or topsoil (pits, collapse, etc.) were included in this study. The GSs occur slightly more in the interior parts of the EAs (Fig. 5.62, Fig. 5.63).



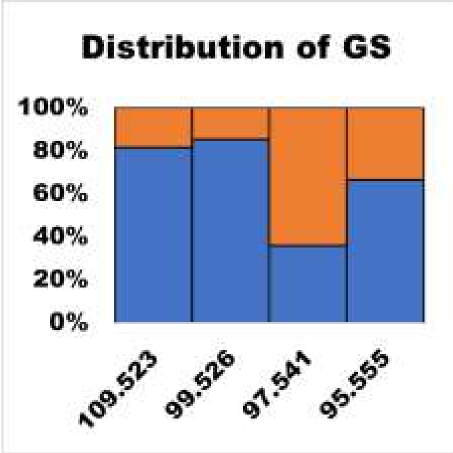


Fig. 5.63. Aproximate distribution of the interior (blue) and exterior parts (orange) of the EAs, N(interior)=600 m2, N(exterior)=400 m^2.

Fig. 5.64. Distribution of the GSs in the interior (blue) and exterior parts (orange) of the EAs, N(interior)=77, N(exterior)=38.

This trend is most pronounced in the EA 109.523 (Fig. 5.65). The accumulation of GSs is concentrated through all phases of occupation in the southern building 227 (Fig. 5.73). Two important contexts (396 and 440) from the earlier phase with a large amount of well-preserved GSs were found in the fill of the central room (Fig. 5.66, Fig. 5.67). The presence of firing installation leads to assumption that grinding activities may be taking place here.

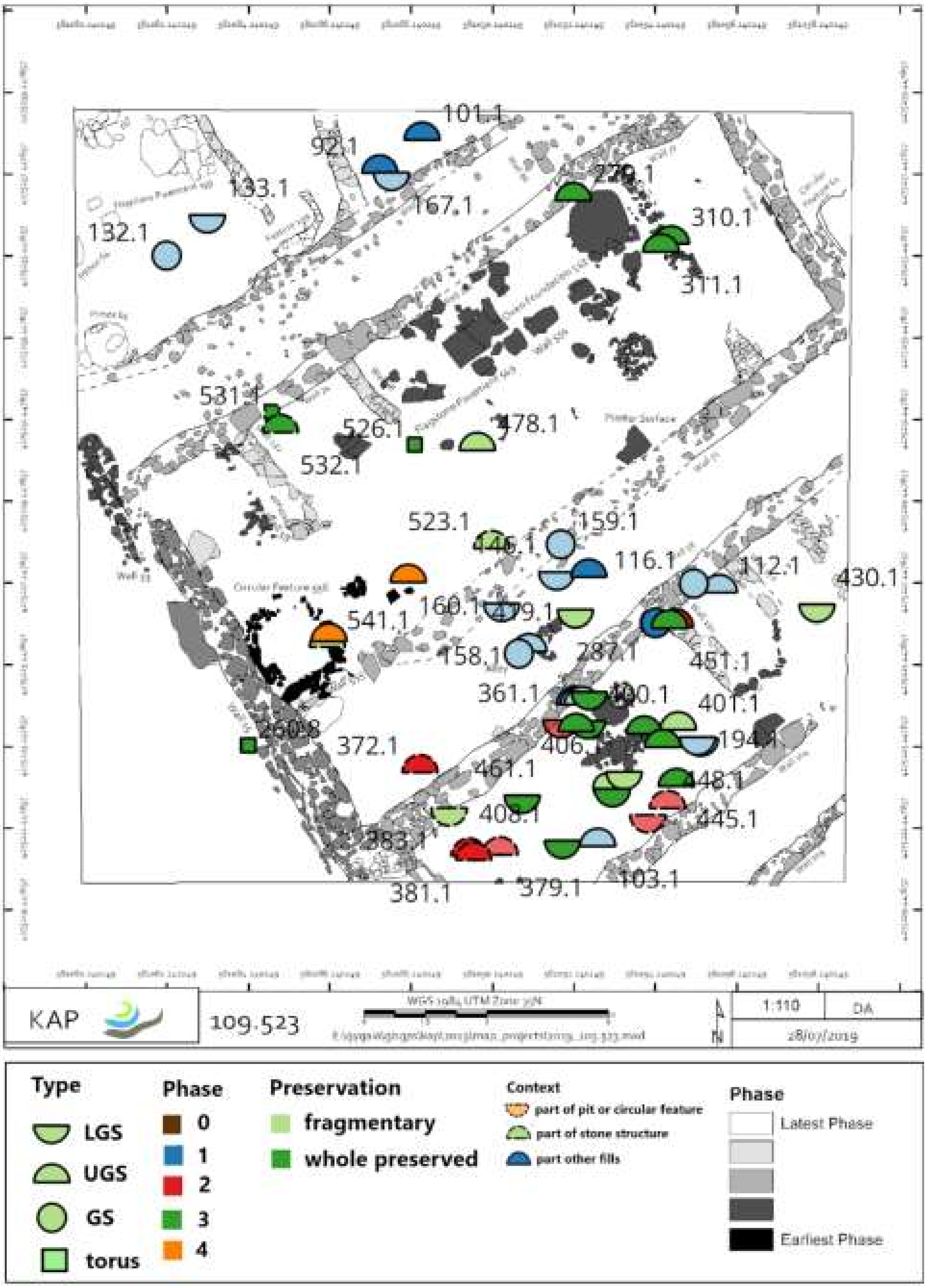


Fig. 5.65. The distribution of GSs in the EA 109.523 (N=88).

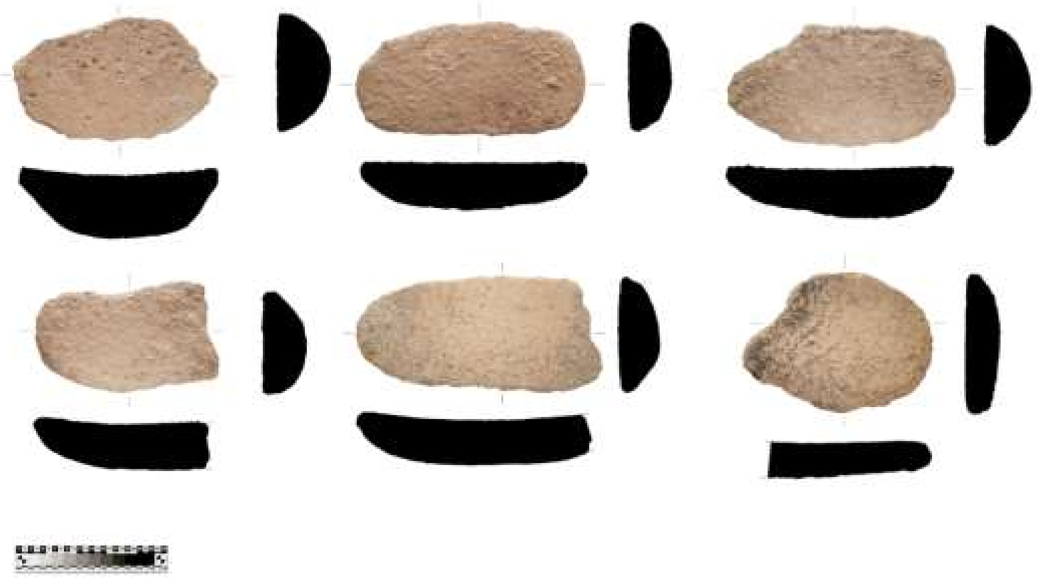


Fig. 5.66. The GSs from the context 440.

Fig. 5.67. The GSs from the context 396.

In the EA 99.526, most of the well-preserved relevant GSs come from the later phase and were concentrated in the northern corridor of the building (Fig. 5.68). The GSs in the EA 95.555 with the fortification occur more in the interiors (Fig. 5.69).

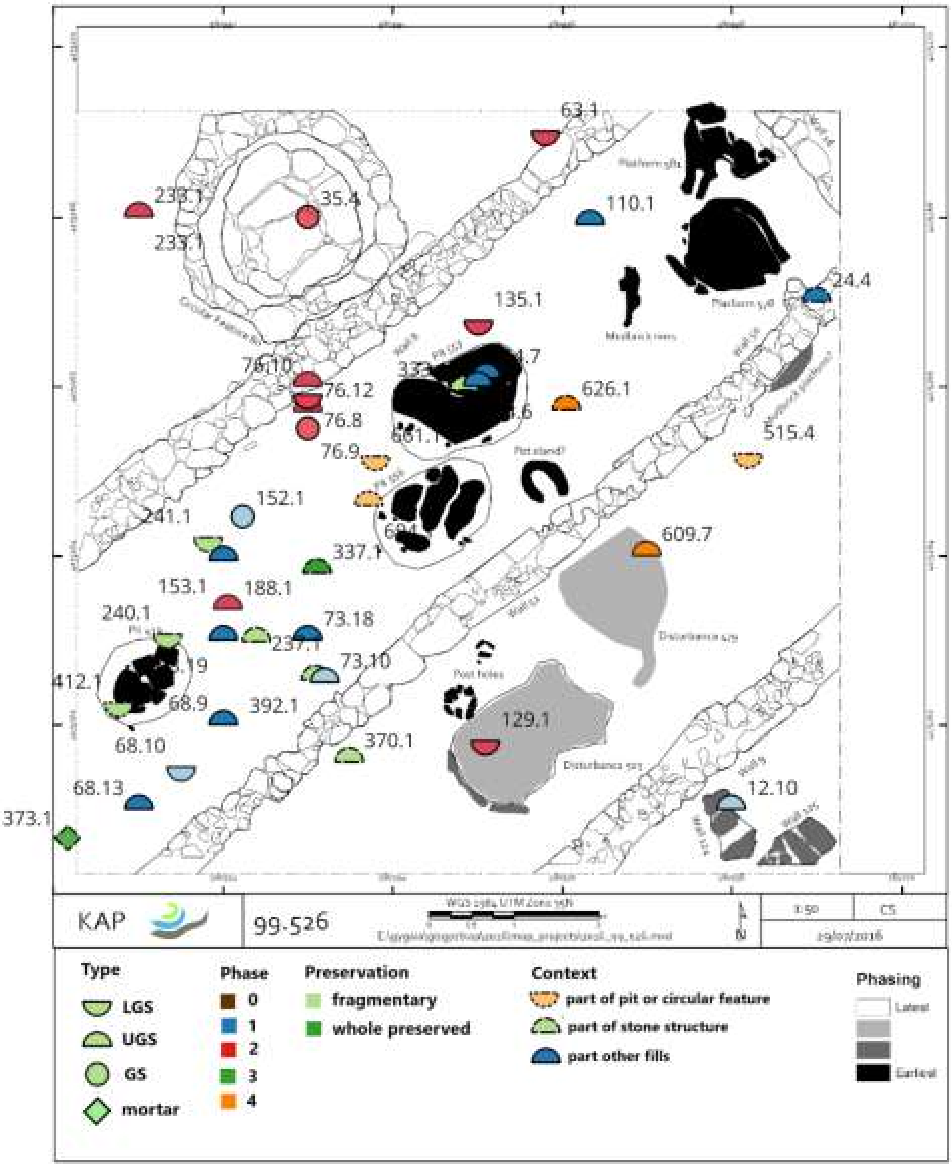


Fig. 5.68. The distribution of GSs in the EA 99.526 (N=25).

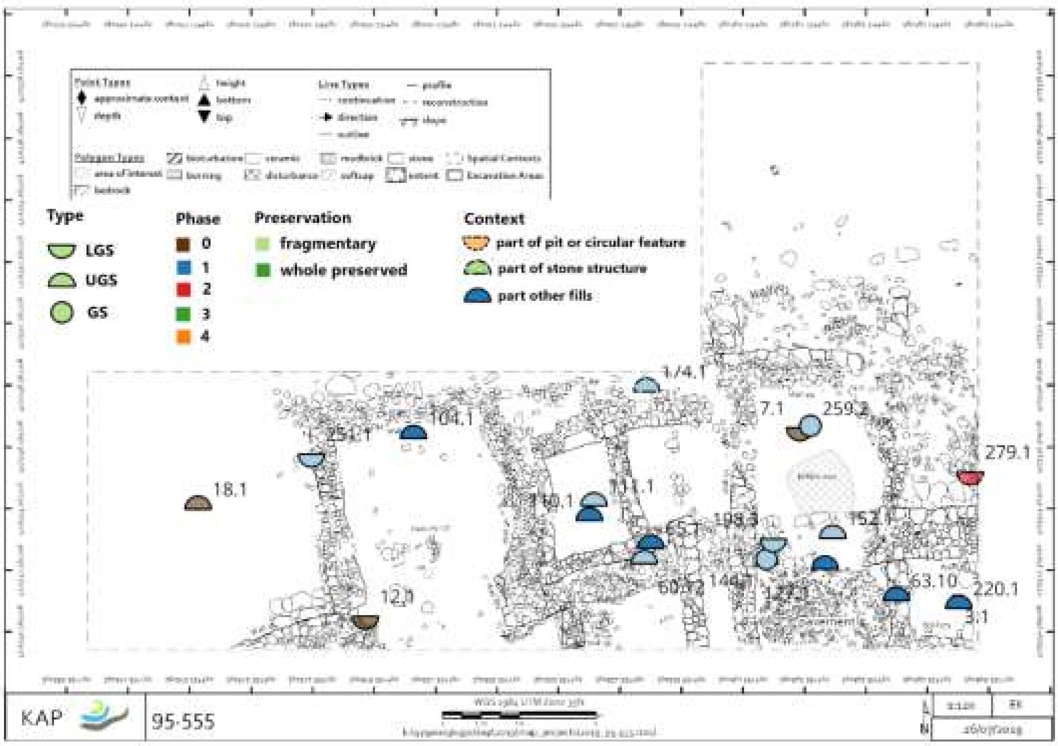


Fig. 5.69. The distribution of GSs in the EA 95.555 (N=19).

Unlike other EAs, many of the GSs in the EA 97.541 are located in the open area between the two buildings (Fig. 5.70). However, they are mostly in fragmented state of preservation. Grinding activities based on the distribution of well-preserved GSs dated predominantly to the later phase could take place mostly in the interiors of the southwest and northeast building.

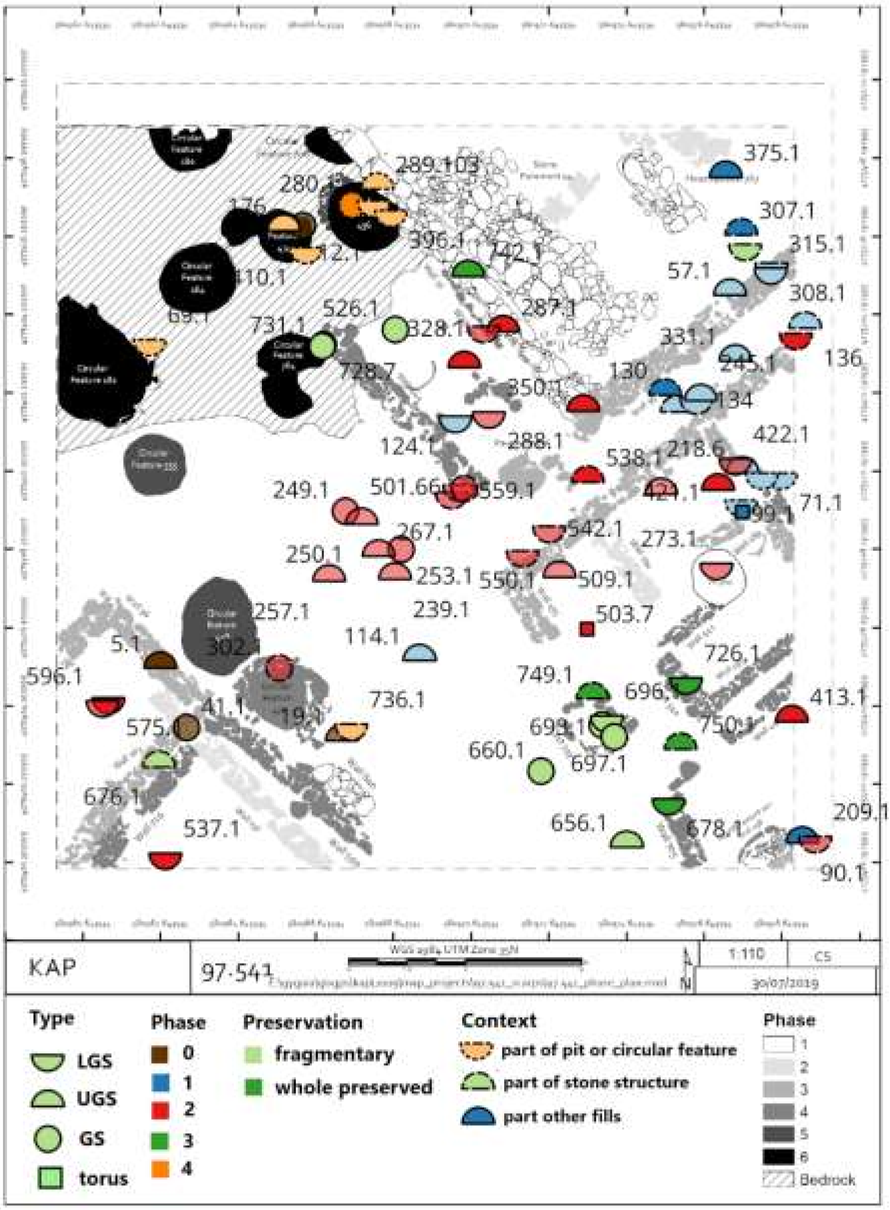


Fig. 5.70. The distribution of GSs in the EA 97.541 (N=78).

Intentionally discarded artifacts were mostly found built in some stone structures. Surprisingly, many well preserved GSs, almost 25 %, were found in this type of context, for example, also the largest GS 97.545.245.1 (length=45 cm; Fig. 5.71). The average length of the finds is also high, 20 cm. On the other hand, the finds in the fills of structures (pits, circular features, pithoi and firing installations) are very fragmentary (Fig. 5.72). Only two complete preserved GSs were found in the fill of the firing installation. The average length of this group of finds is smaller, 17 cm. Four of the GSs found in the pit also have traces of fire damage.

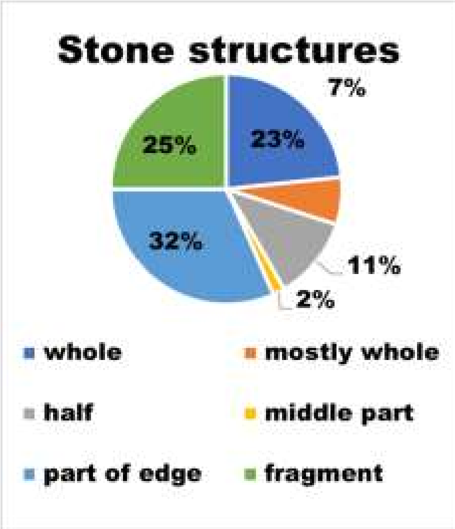


Fig. 5.71. Preservation degree of GSs found as part of some stone structure, N=60.

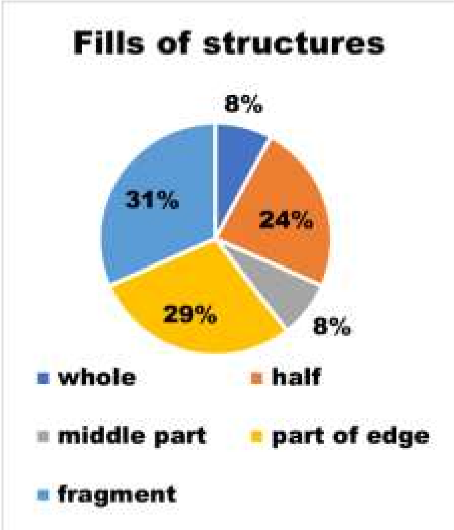
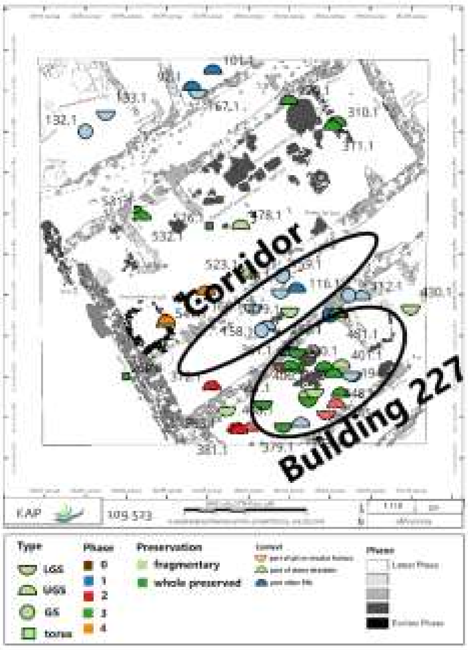


Fig. 5.72. Preservation degree of GSs found in the fill of pit, circular feature, firing installation or pithos, N=38.

Some of the GSs concentrate in the southern corridor of area 109.523 and in the corridor of area 97.541 (Fig. 5.73; 5.74). Circumstances suggest that these were discarded useless pieces, as the group is quite fragmentary (Fig. 5.75) and its average length is only approximately 17 cm. Many of these GSs were found only half preserved. This group of finds also contains a large number of LGSs and GSs with complex life history (drilled and hollowed GS). Compared to this group, the GSs from the open space in the area 97.541 are even more fragmentary (Fig. 5.76). This group contains predominantly undiagnostic and unclear fragments. It is not clear what was going on in this place, but there are no clear traces of intentional breaking and the fragmentary state of the findings was rather due to the greater predisposition to weathering and damage in the open area.



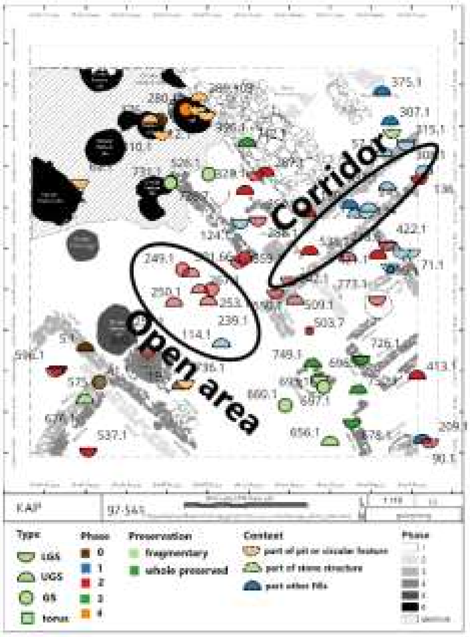
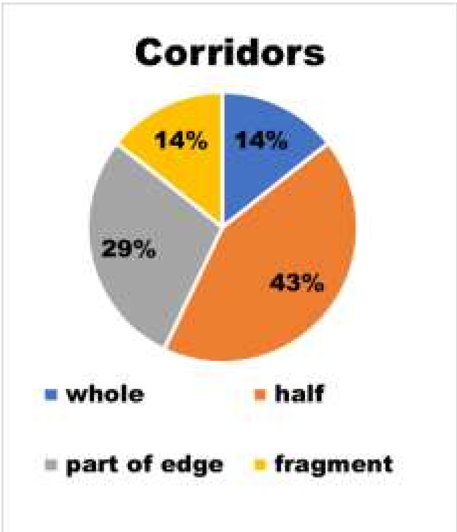


Fig. 5.73. Location of the building 227 and corridor in the EA 109.523.

Fig. 5.74. Location of the open area and corridor in the EA 97.541.



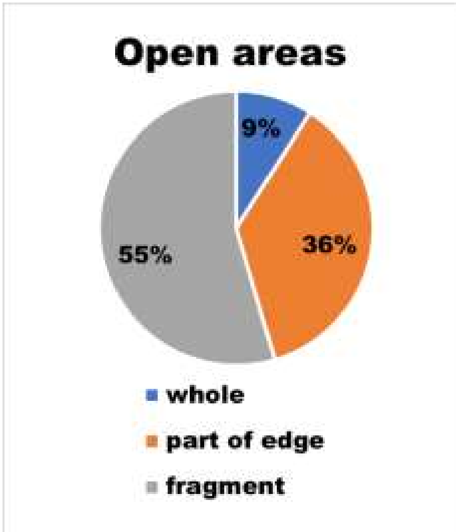


Fig. 5.75. Preservation degree of GSs found in the corridors between houses, N=14.

Fig. 5.76. Preservation degree of GSs found in the open space in the area 97.541, N=11.

Two unused finished GSs with clear traces of intentional breaking were identified in the assemblage. GS 93.545.232.5 was probably deliberately broken and recycled in some stone structure, as it was found in the stone collapse in the southeast part of the EA 93.545. GS 109.523.430.1 was found in the building 227 in the EA 109.523 with the accumulation of other GSs. This nicely shaped GS was finished from all sides, but for some reason it was intentionally broken.

To sum up, structured deposition of GSs for some ritual or symbolic reasons was not noticed during the contextual analysis of the finds. Special places or rooms for grinding activities were not securely identified, but well-preserved tools generally concentrate more in the interiors of the buildings. Of course, there is a possibility that these stones have fallen into the interior of the building from the roof. The poor preservation of LGSs was first thought to be a consequence of primary reuse because of the scarcity of good raw material for GSs. However, the large recycling of GSs as a part of stone structures suggests that there was also a great shortage of suitable building material. The gradual abandonment of the settlement must also have played a role, as some of the LGSs may have been carried away. Given these points, the LGSs were probably a highly valued commodity.

5 Comparative study

5.1 Aphrodisias grinding stone assemblage

5.1.1 Introduction

The Aphrodisias assemblage contains in total 98 grinding tools from the MBA and LBA layers. In the published report (Joukowsky 1986a, 221–227) these artifacts are named *grindstones*, but the term is not entirely defined. Many categories of artifacts, such as pestles, small pebbles (polishing, abrading, percussive stones), were placed in this group. Furthermore, in the enclosed catalogue the terms are mixed and many names of the same category of artifacts are used. Since this thesis focuses primarily on the GSs, only artifacts longer than 10 cm were included in this study. This procedure eliminates small fragments of GSs, but it reduces the risk of admixture of other artifacts categories. In total, 49 artifacts mentioned in the catalogue such as grindstone, quern, mortar, pivot stone[9] or mano are included in the discussion here.

Since the author of this thesis did not have the opportunity to examine the artifacts herself, only published data was processed. While all these artifacts have indications of length, width and thickness, their weight is missing. Many of the artifacts have a photo or drawing with front view and cross section. Unfortunately, the listed sizes of the artifacts often do not match the drawing (especially the thickness and width values are often completely irrational). Sometimes their state of preservation is recorded, such as whole or fragment. With most of them the raw material determination is noted. Also included is the excavation area/trench, complex[10] and dating, but a better description of its design or context of the find is mostly lacking. Applying the methodology and terminology used in this thesis, the Aphrodisias assemblage includes 40 GSs, one mortar and eight socket stones. In case of the GSs, the grinding position (upper/lower stone) is not distinguished and only in the case of the minority is this apparent from the picture and dimensions.

[9] The terminology used in this thesis is socket stone.
[10] Complex is major coherent element of the trench (building, courtyard).

5.1.2 Geographical setting and geological study

Aphrodisias is located on the border between the Menderes Massif and the Lycian Nappes in the Karacasu Basin (Fig. 6.1). The River Geyre çay (the Classical Dandalos) runs through the valley, which is formed by the succession of sedimentary rocks of the Neogene to the Quaternary (mudstone, sandstone, conglomerate, limestone). It is bounded to the north by the Karıncalıdağ Mountain range and to the south by the Babadağ Mountain range of metamorphic rocks of the Menderes Massif (mainly schist, marble and gneiss). The blue-veined marble from Dağ Kesimi Mountain is located 2,6 km NE of the site and has been quarried since prehistoric times (Joukowsky 1986a, 28). The Lycian Nappes, composed of ophiolitic (serpentinites) and carbonate rocks, extend to the southeast (Joukowsky 1986a, 25–29; Alçiçek – Jiménez-Moreno 2013; Ocakoğlu *et al.* 2014).

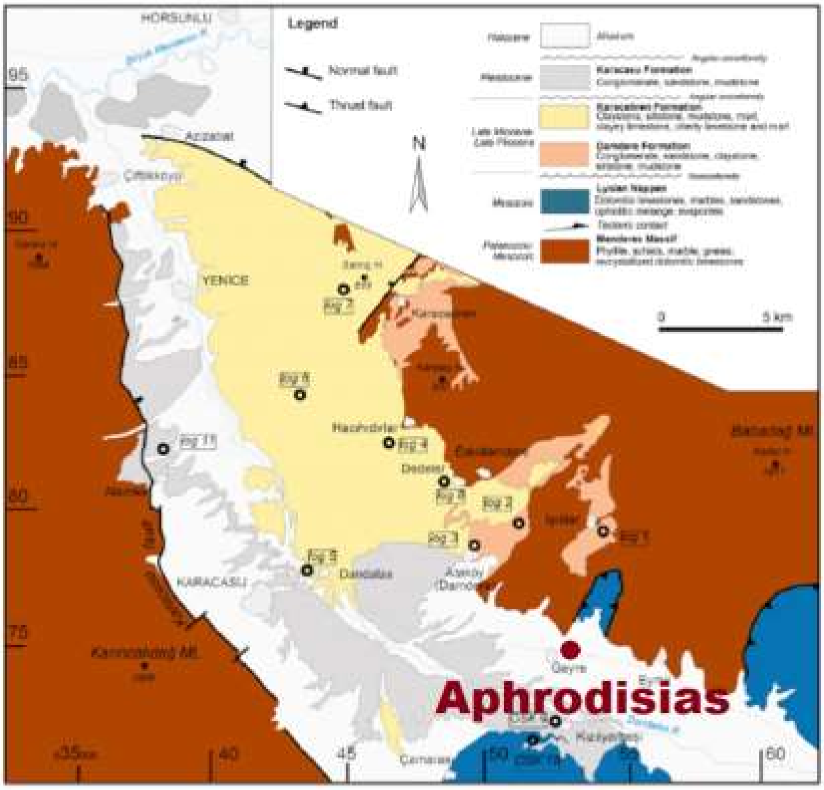


Fig. 6.1. Geological map of Karacasu basin and the location of Aphrodisias (Alçiçek – Jiménez-Moreno 2013, Fig. 2; altered).

As indicated by Joukowsky (1986), the grinding tools were made of various raw materials (Fig. 6.2). The most commonly used ones were the local metamorphic rocks such as schist and serpentinite. The schist is specified in the catalogue only if it is garnet schist.

This type of rock was possibly more suitable for grinding due to the hard garnet minerals inside. While the schist came probably from the mountain ranges of the Menderes Massif, the serpentinite was gathered from the rocks of the Lycian Nappes. Exceptionally, GSs of marble and quartzite are also recorded, including the marble mortar. Marble and schist are also the only two raw materials linked with the socket stones. Local sedimentary rocks from the Geyre çay river valley were used in much smaller quantities for the production of GSs. Recorded were only three GSs made of conglomerate.

The only raw material imported from far away was basalt and almost a quarter of the GSs were made of this raw material. However, the largest GSs were not made from basalt but from local raw materials such as schist, marble and conglomerate.

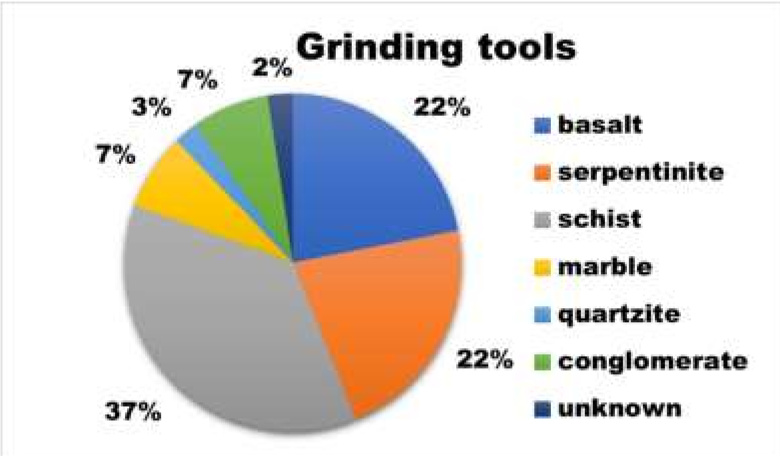


Fig. 6.2. Raw material representation of Aphrodisias grinding tools (N=41).

5.1.3 Morphological study

The GSs reach large sizes (Fig. 6.3). The lengths of the five GSs even exceed 40 cm (GSs 648m, 695y, 704gg, 704hh and 714jj). These stones were probably used as LGSs. The LGSs 704gg and 648m have oval shape with straight longitudinal cross section, their bottoms appear to be shaped into a pedestal (Fig. 6.4: A). On the other hand, the LGSs 714jj and 704hh have a roughly rectangular shape with a concave longitudinal cross section and are elevated in mass on one side to provide an inclination for grinding (Fig. 6.4: B). In general, there are also quite a lot of smaller GSs with rectangular shapes in the assemblage. Some artifacts are so square in shape that one might question whether they are really GSs (for example 695y or 735nn). The other GSs (possible UGS) tend to be generally nicely shaped and are often even made of basalt, for example (700ff and 706dd).

However, ergonomic adjustments (protrusions and depressions) were not clearly identified on any GS.

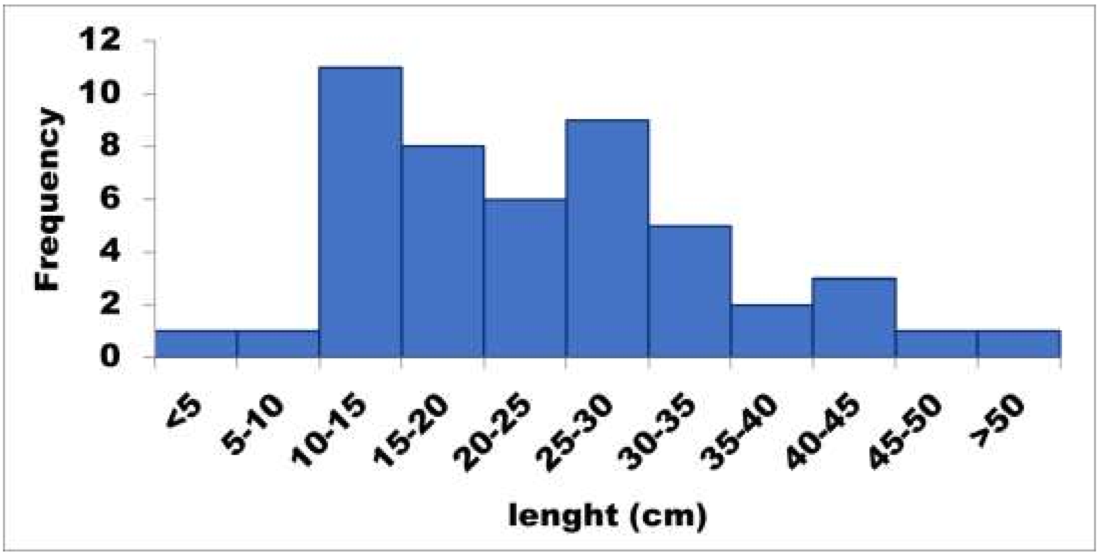


Fig. 6.3. Length frequencies of the Aphrodisias grinding tools (N=49).

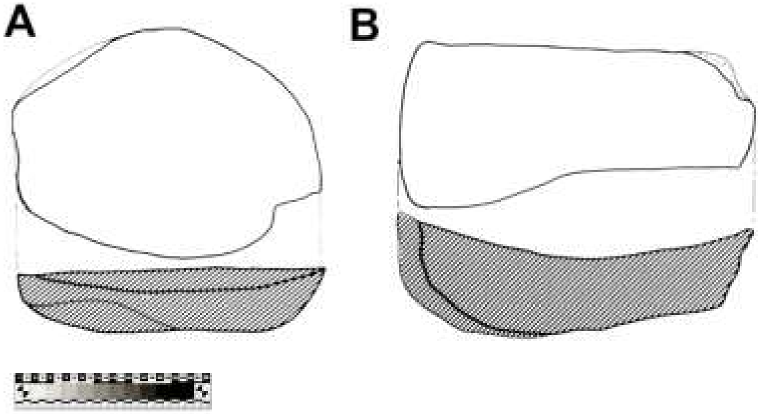


Fig. 6.4. A: GS 648m with the bottom shaped into a pedestal; B: rectangular GS 714jj.

5.1.4 Contextual study

The assemblage is very fragmentary, only 20 % of the GSs were preserved whole (Fig. 6.6). All except one are dated back to the MBA. Surprisingly, only mortar 2182A.1 was found in the LBA strata (Acropolis Trench 8). The majority of the MBA finds was recovered in the Acropolis Trench 7 (Fig. 6.5). Only GS 485.9 comes from Acropolis Trench 5 (complex C).

	PEKMEZ		ACROPOLIS								KUŞKALESİ		Anatolian Periods
Period	1	2	1/2	3	4	5	6	7	8	9	1	2	
LN (?)		VIIIC											Late Neolithic
GAP												?	
LC1		VIIIB-VIIIA											
LC2		VIIID-VIIC											Late Chalcolithic
LC3		VIIB-VIIA											
LC4		VII											Early Bronze I
BA1	X	VI											Early Bronze II
GAP												?	
			19-B	XII							11		Early Bronze IIIA
BA2	IX VIII VII	? V ? Pithos IV*		XI X IX VIII (?)VII			4*				10 9	10 9 8	
BA3	VI Pithos	IVd IVc IVb Pithos (?)		VI V IVa	VI V IV		4*				8	7	
				III	III						7	6	
BA4	V	IVa	? *	II	II*						Pithos		
Destruction												?	
BA4-MB	IV*		? *	I*	I E	I F, E		Ia-Ib				5	Early Bronze IIIB
MB						D C B		D C', C B, B'					Middle Bronze
MB Mixed			? *		A/A1		A-4/A-1						
GAP													?
			? *						A-4 III				Late Bronze
LB									A-4 II A-4 I				?
IA										A-5 II A-5 I			Iron Age
GAP													?
			I				Lydian III D « Carian » jar						Lydian

Fig. 6.5. Periodization of the complexes in the Aphrodisias trenches (Joukowsky 1986a, Tab. 5).

Fig. 6.6. Preservation degree of grinding tools (N=33).

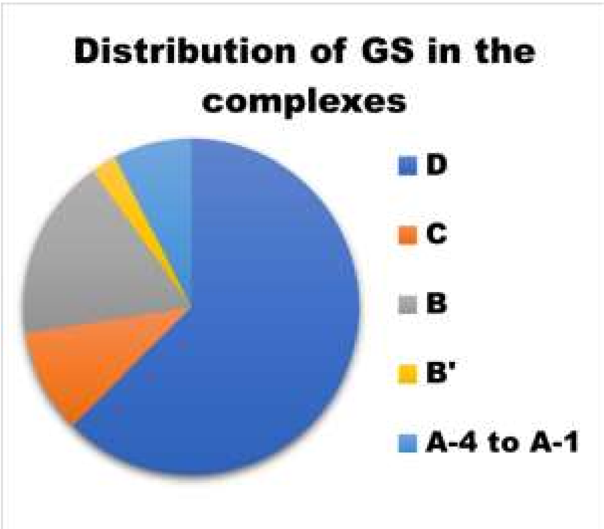


Fig. 6.7. Distribution of grinding tools in the complexes of the Acropolis Trench 7 (N=40).

In the Acropolis Trench 7, most of the GSs come from the early phase of the MBA, i.e. from complex D with lots of pits and poorly preserved architectural traces (Fig. 6.7). The largest GSs were recovered from this complex. For example, GS 704gg and GS 704hh were found next to the wall A (Fig. 6.8). Furthermore, many GSs made of basalt and garnet schist also belong to this phase.

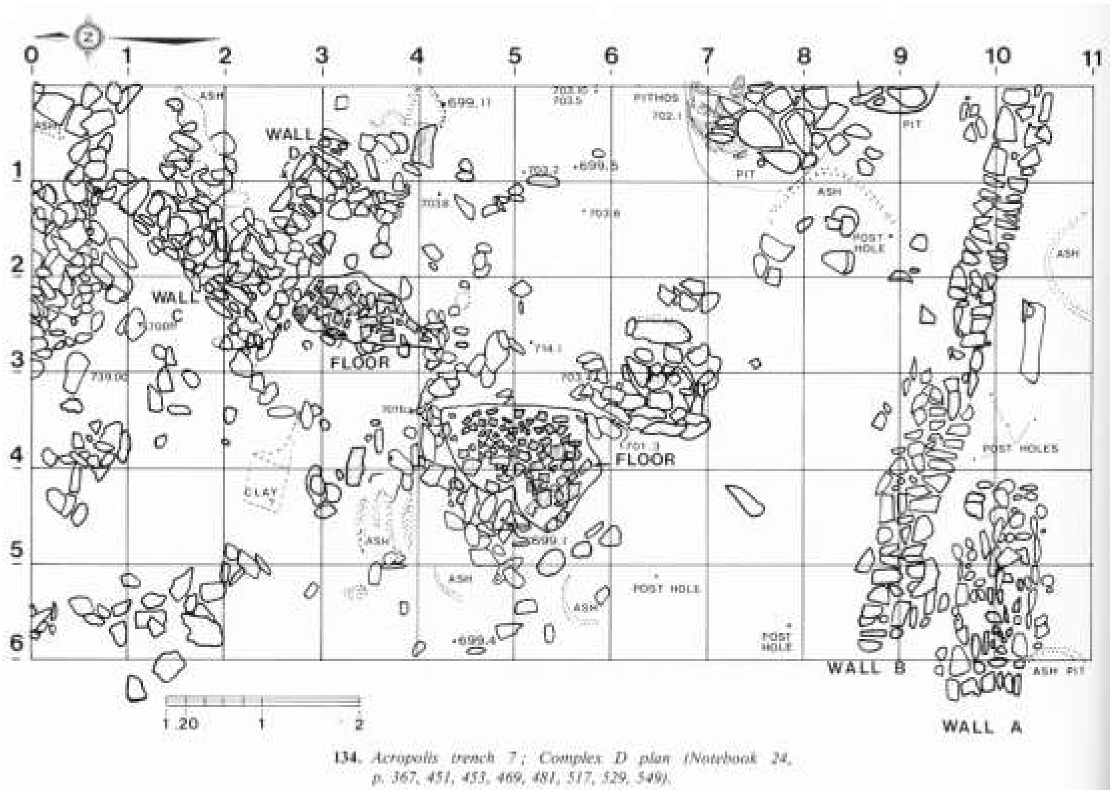


Fig. 6.8. Complex D in the Acropolis Trench 7 (Joukowsky 1986a, Fig. 134).

In the next phase, when the megaroid building was built (complex C), the number of GSs decreased a lot, only four were recorded. The grinding activities probably had declined, and the space started to be used for other purpouses (Fig. 6.9). In the next phase (complex B, B') the situation did not change much (Fig. 6.10), the number of GSs slightly increased, but the assemblage is very fragmentary. Only GS 648m is preserved in its whole state. Furthermore, they are mostly made of local raw materials, only one GS (627x) was produced of basalt. Most of the GSs were recovered near the wall D inside the building (Fig. 6.10). The last complex (A-4 to A-1) was disturbed by later activities and only three fragments of GSs were recorded.

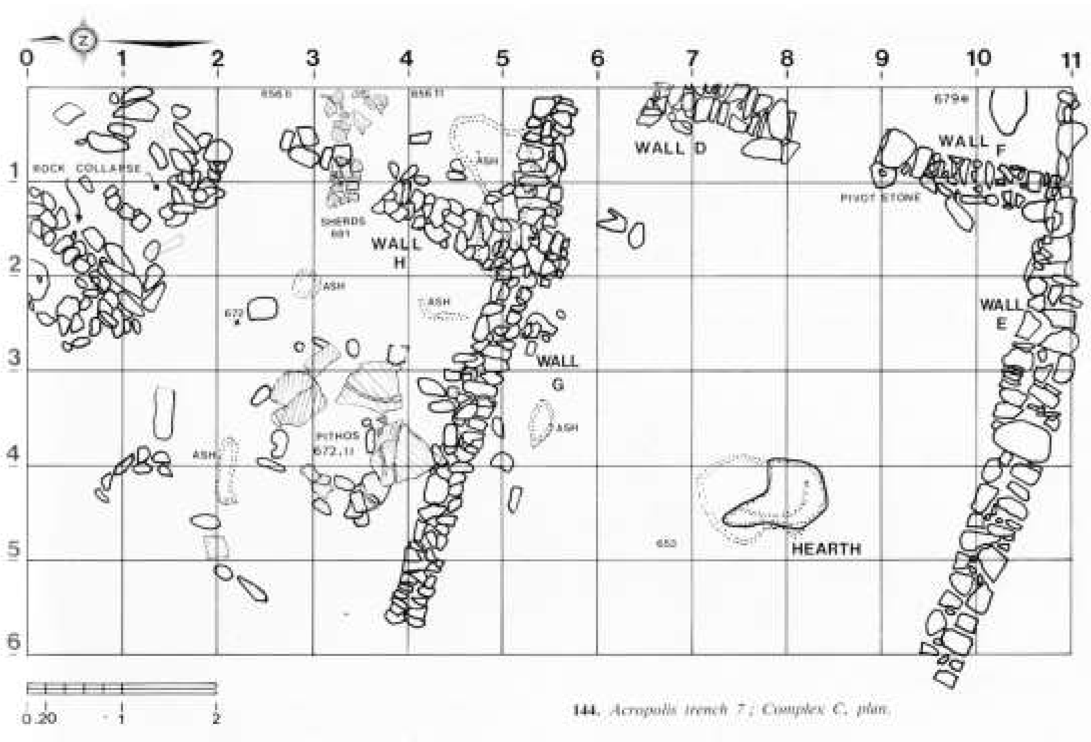


Fig. 6.9. Complex C in the Acropolis Trench 7 (Joukowsky 1986a, Fig. 144).

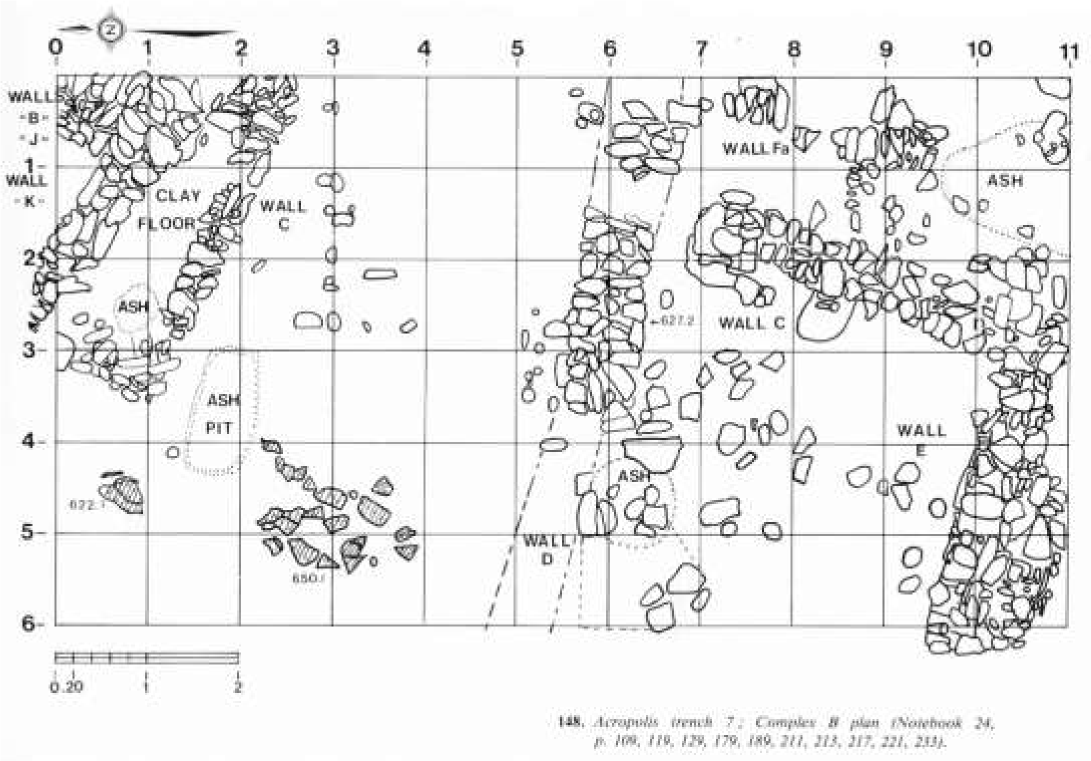


Fig. 6.10. Complex B in the Acropolis Trench 7 (Joukowsky 1986a, Fig. 148).

As for the refuse patterns, the assemblage does not show any clear ones. Only two GSs from the complex D (Acropolis Trench 7) were found in a fill of pit. Surprisingly, no GS was found embedded in any of the stone structures, such as a wall. However, there is slight indication that the GSs were secondarily used as socket stones (for example, GS 706a ee). The majority of such socket stones comes from the complex C and D (Acropolis Trench 7).

5.2 Troy grinding stone assemblage

5.2.1 Introduction

The studied **Troy grinding stone assemblage** includes 41 grinding tools, consisting of 31 GSs and 10 mortars (handstones excluded). All information are taken form the chapter about small lithic finds (Pieniążek 2020, 871–881) in the monograph about the Troy in the LBA (Pernicka *et al.* 2020). Most of the published grinding tools were described (with shapes in front view and cross section), measured (length, width, thickness) and have an enclosed photo or drawing. The raw material is geologically determined for less than half of the artifacts. All artifacts are chronologically classified and the context of the finds is described. Furthermore, a detailed summary with spatial analysis of grinding tools distribution was enclosed to the catalogue (Pieniążek 2020, 872–877).

5.2.2 Geographical setting and geological study

Troy is situated on the Biga peninsula (Fig. 4.2), which is part of two major tectonic units. Most of the peninsula belongs to the tectonic mosaic of the Sakarya Zone (Fig. 5.1; Okay – Siyako – Bürkan 1991; Şengün – Koralay 2017). The NE part of the peninsula represents westernmost segment of the Pontides (van Hinsbergen 2010; Ocakoğlu *et al.* 2014). This segment consists of a large plain formed by marine sediments (mudstone, sandstone, limestone), which continues across the isthmus to the Gelibolu (Gallipoli) peninsula. Two rivers Karamenderes (Scamander) and Dümrek (Simois) cut the plain into 3 ridges: Yeniköy, Kumkale and Troia (Fig. 6.11; Kayan 2014, 697).

The settlement is located at the NW corner of the Troia Ridge, where the Dümrek River flows into the Karamenderes. These rivers brought a great amount of sediment and created a large alluvial plain around the settlement. The river delta of Karamanderes was gradually filled in and the deltaic coastline prograded towards the sea (Kayan 2014, 714). Already in the BA, Troy did not have direct access to the sea and therefore it had to have a harbor somewhere on the nearby Aegean coast (Fig. 6.12).

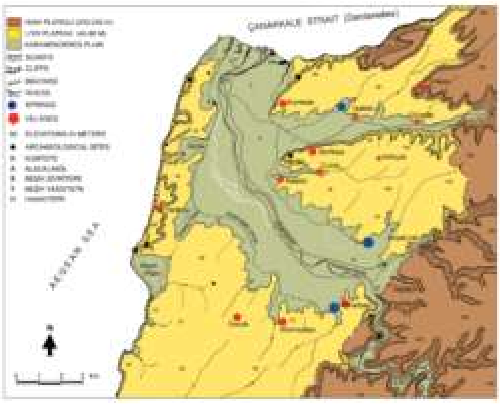


Fig. 6.11. Geomorphological map of area around Troy (Kayan 2014, Fig. 1).

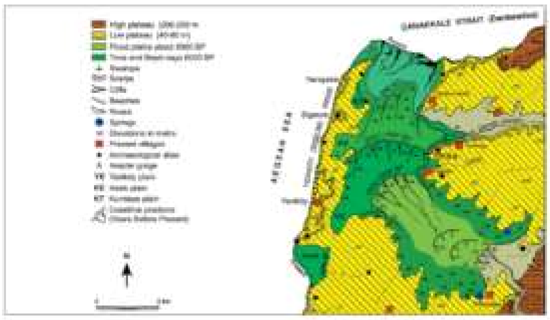


Fig. 6.12. Progradation of the delta (Kayan 2014, Fig. 16).

Mountains with metamorphosed rocks extend to the south and east of the settlement (Fig. 6.13). To the south, there is a sequence of metamorphosed sedimentary rocks representing the Permo-Triassic Erzin group (Karadağ unit) formed by recrystallized limestones and metashales (Beccaletto – Jenny 2004). This unit is overlain on the north by meta-ultramafic rocks of the Cretaceous Denizgören ophiolite. To the east, other metamorphic rocks of the Çamlıca unit are exposed, formed predominantly by schist and marble (Şengün – Koralay 2017).

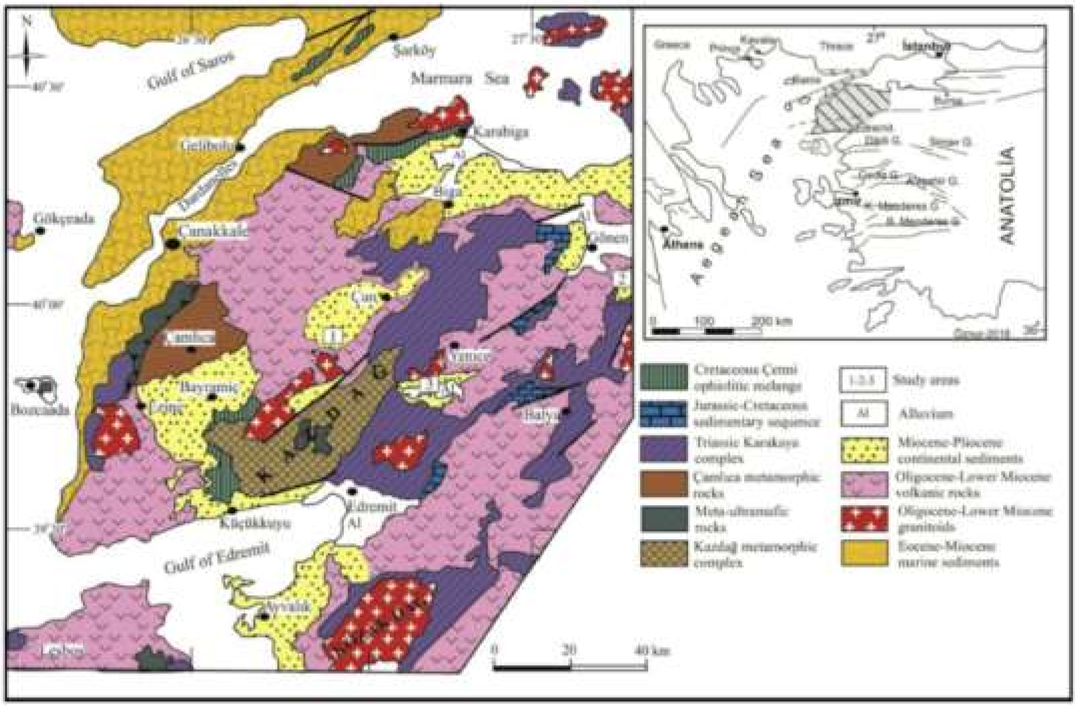


Fig. 6.13. Geological map of Biga peninsula (Karaca – Cameselle – Bozcu 2019, Fig. 1).

The Biga Peninsula was also affected by strong magmatic activity, mainly from the Late Oligocene to the Early Miocene due to the postcollisional continental extension (Akal 2013). Many intrusions of volcanic and plutonic rocks are located close to the settlement. For example, the Taştepe Basalt erupted along the zones of extension near the Denizgören ophiolite (Aysal – Ongen – Keskin 2011). Furthermore, the Erzin group was intruded by granodioritic Kestanbol Pluton and tephriphonolite dykes (Akal 2013).

Only a small part of the assemblage (ten pieces) is geologically determined. Within those that were determined, volcanic rocks, such as basalt and andesite, predominate in terms of volume (Fig. 6.14). These rocks may have been well accessible in the area of the settlement to the east and south, where volcanic areas are located. One GS made of granite was also recorded in the assemblage. The nearest plutonic rocks are located approx. 20 km to the south. Some GSs were made from local materials, such as conglomerate and limestone. Potential mortars (maybe socket stones) were also made of local raw materials.

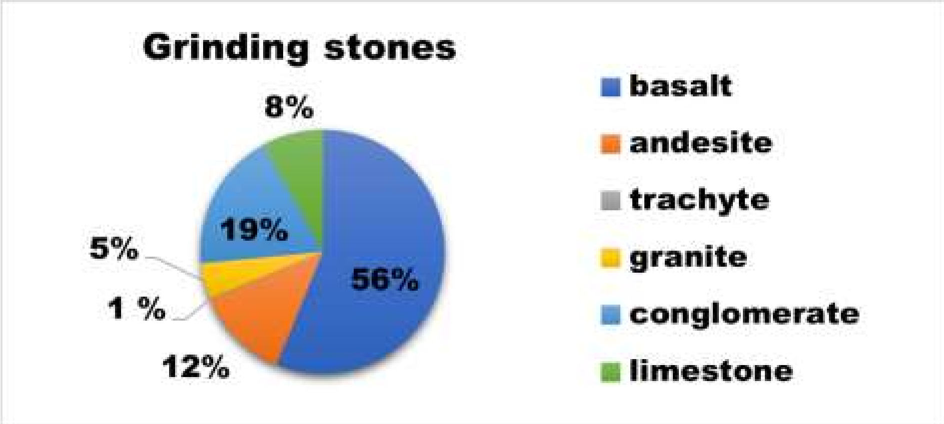


Fig. 6.14. Raw material representation of Troy GSs by mass (N=86 kg).

5.2.3 Morphological study

The dimensions of the grinding tools are rather smaller, in range between 10 and 20 cm (Fig. 6.15), with only three GSs (E09.1202, E09.1249, z07.1287) out of this range, reaching over 50 cm. Almost all of them seem to be made very roughly without clear shape. Only the LGSs z07.1287 was shaped into the oval form (Fig. 6.16: D) and the LGS E09.1249 has a triangular longitudinal cross section (based on the written description, Pieniążek 2020, 878). Two other much smaller GSs (D08.1641, KL16/17.0601) have a similarly designed bottom, although it is not entirely certain whether they are not just broken in this way (Fig. 6.16: A). These GSs have a triangular longitudinal cross section to provide sloping when grinding.

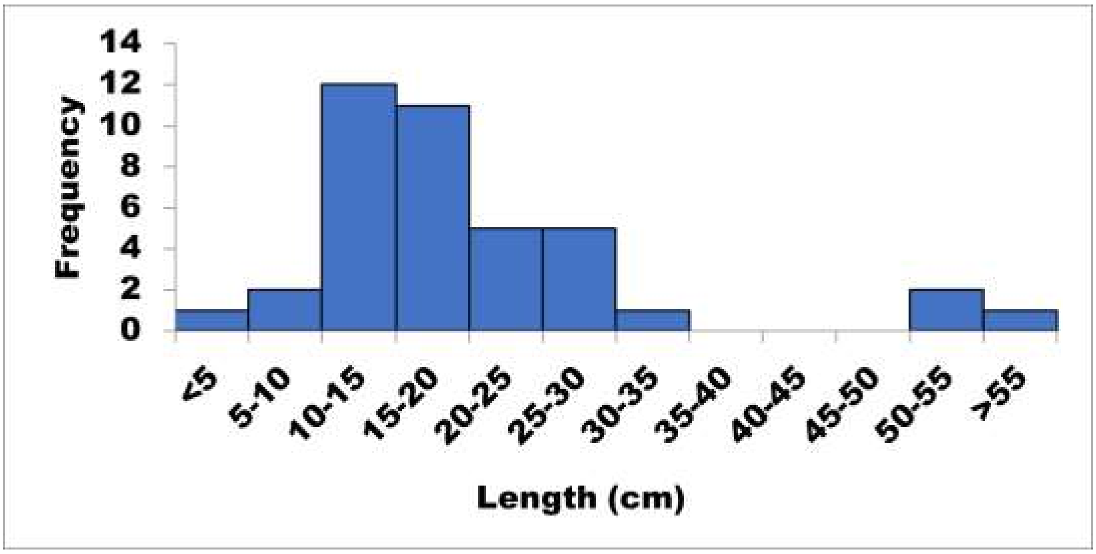


Fig. 6.15. Length frequencies of the Troy grinding tools (N=41).

The other GSs with a few exceptions also seem to be just rather worked into irregular shape, but roughly rounded and oval shape seem to be the most common. Some GSs can be highlighted as special pieces with a better defined and shaped form. For example, the robust oval GSs K04.0583 and K04.0584 are almost identical in dimension and shape (Fig. 6.16: B, C). Furthermore, the half-preserved GS EF10.601 and the GS EF10.604 have both protruding features like handles on the edges (Fig. 6.16: E, F). These cases confirm that we cannot exclude the standardization of shapes and some specialized production.

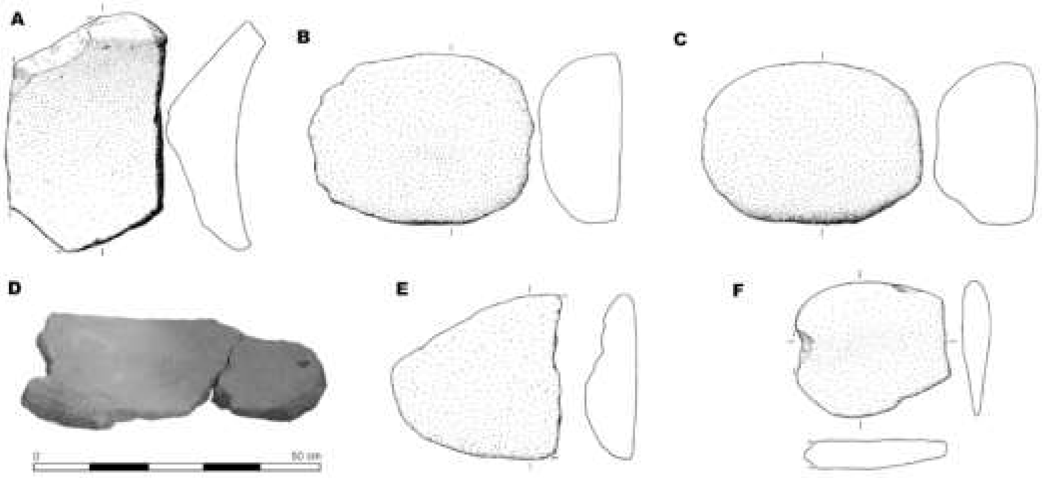


Fig. 6.16. GSs, A : GS D08.1641 with triangular cross section; B: oval GS K04.0583; C: oval GS K04.0584; E: GS EF10.601 with ergonomic adjustment; F: GS EF10.604 with ergonomic adjustment, scale 1:4 (Pieniążek 2020, Taf. 16-20); D: saddle shaped GS z07.1287 (Pieniążek 2020, Taf. 33.1).

Mortars have not been heavily worked, as they usually have various irregular shapes with a round hollow in the center. In most cases, these were probably secondary used GSs. There is also some likelihood that they were confused with the socket stone (Pieniążek 2020, 875).

5.2.4 Contextual study

The assemblage of GSs is relatively well preserved, which may be due to the selective processing, e.g., focusing only on the well-preserved ones. Almost one third of the GSs have been preserved whole. The GS A07.1464 is the only one chronologically from the MBA (Fig. 6.17), the rest of the grinding tools belong to the LBA, mainly to its developed phase (Late Troy VIg and VIIa). Only five artifacts were found inside the citadel (Pieniążek 2020, 876). These include the two largest GSs (E09.1202, E09.1249) found in the Room B (Fig. 6.18, Fig. 6.19: B). GSs of this size were probably immobile, so it can be assumed that this room may indeed have been used for grinding activities.

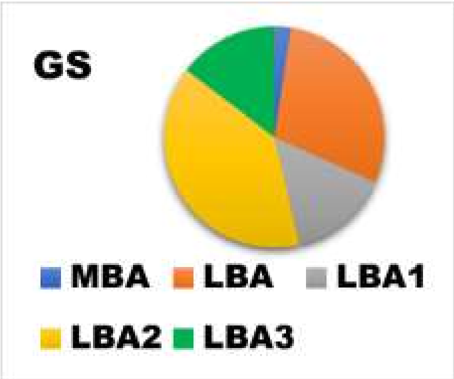


Fig. 6.17. Representation of grinding tools in the MBA and LBA (N=41).

Fig. 6.18. Areas excavated between 1988 and 2007 with marked EAs mentioned in the text (Becks 2020, Taf. 1; altered).

Most of the other grinding tools were found outside the citadel along the walls, primarily in the EAs EF10, K04 and z07. In the EA EF10, mortars and two nicely shaped GSs with potential ergonomic adjustments (EF10.601, EF10.604) were recovered. In the EA zA07/08 the so-called Terrace House was uncovered (Fig. 6.19: A), inside of which many roughly made GSs were found. The last large LGS z07.1284 comes somewhere from this EA.

The EA K04 with the fortification features revealed other interesting finds (Fig. 6.19: C). Besides the two robust identical GSs (K04.0583 and K04.0584), a GS with purple pigment residues were also found (Pieniążek 2020, 877). It was discarded together with another GS into a well, which indicates the intentional refuse of the artifact. Seven grinding tools also occur in pits, but interestingly they are mostly well preserved. Not a single artifact was recorded from the excavation as incorporated into a stone structure. Some GSs were found in relation to the stone pavement, but it is not entirely clear in what.

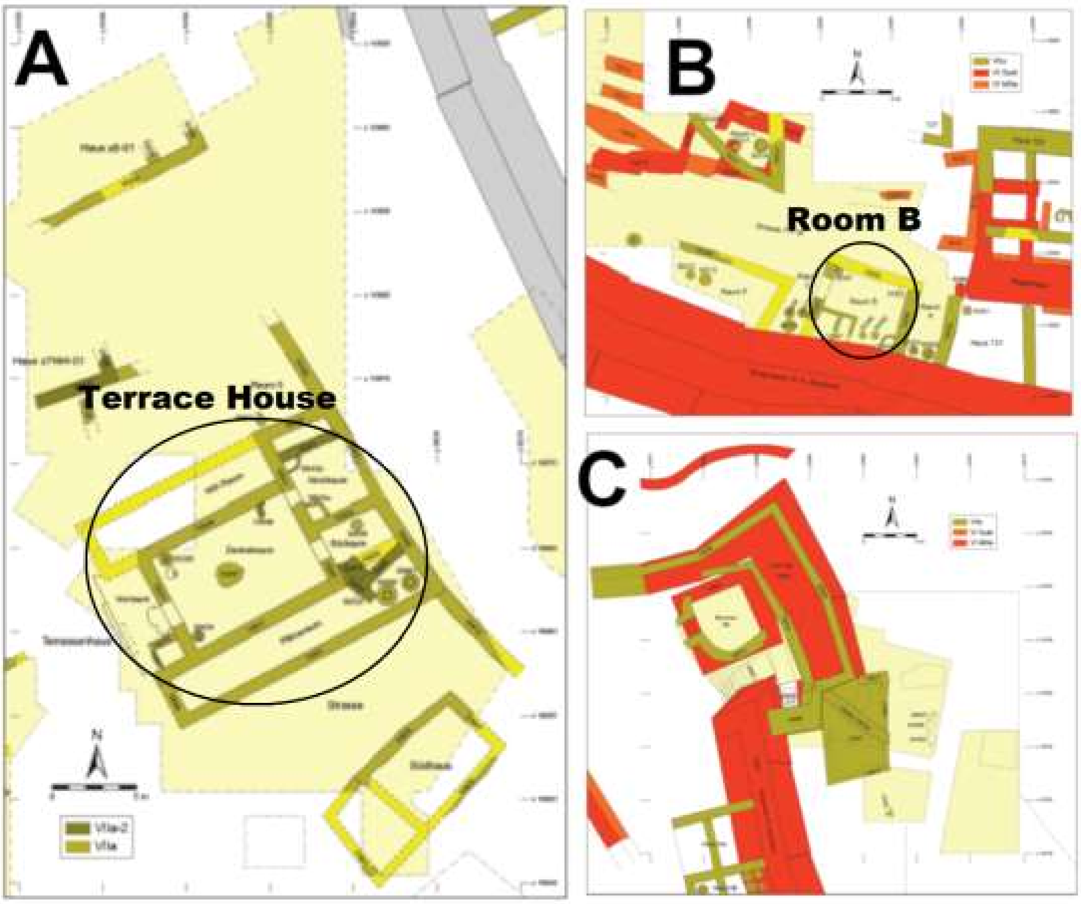


Fig. 6.19. Mentioned EAs, A: EA z07 with the Terrace house (Becks 2020, Taf. 13; altered); B: EA E09 with the Room B (Becks 2020, Taf. 6; altered); C: EA K04 with the fortification (Becks 2020, Taf. 19).

6 Conclusions and final remarks

6.1 Summary

This thesis has sought to compile the data about the GS *chaîne opératoire* in the light of the literature published so far. The Kaymakçı GS assemblage was comprehensively studied and presented with regard to the theoretical framework. The evaluation has brought several important findings that have been summarized and placed in the context of Western Anatolia in the 2nd Millennium BC.

6.1.1 *Chaîne Opératoire* of grinding stones at Kaymakçı

The life history of GSs includes all the phases from their origin, when the raw material is selected, to their demise, when the artifact is discarded. All phases leave some traces on the artifact that accumulate and overlap. The distinguished aspects of the *chaîne opératoire* for the Kaymakçı GSs are presented retrospectively from the moment when the object is discarded and enters the archaeological context.

Around 300 grinding tools were recovered at Kaymakçı in only five excavation seasons between 2014 and 2019. Most of the complete preserved GSs were deposited in the lower southern part of the citadel, because the upper parts were probably affected by extensive erosion. UGSs (upper grinding stones) are slightly more numerous than LGSs (lower grinding stones) and they are much better preserved. The poor preservation of LGSs was probably caused by the scarcity of quality raw material, recycling into stone structures and the nature of the gradual abandonment of the site.

The site of Kaymakçı was slowly abandoned as demonstrated by the fact that many of the artifacts were found in locations linked to discard activities: incorporated within stone structures (walls), placed in pits or discarded in corridors (passage ways) or in open areas of EA (excavation area) 97.541. Furthermore, grinding benches and large immobile LGSs (lower grinding stones) were not present at the site, which means that the use locations are hard to trace. Based on the distribution of finds in the EAs, it could be assumed that grinding activities may have taken place more in the interiors of buildings. The best evidence for this situation was found in the EA 109.523 in the building 227, where a large concentration of GSs was found, as well as a firing installation nearby. However, the GSs are portable tools, therefore the fact that grinding became an indoor activity, which is attested in the find contexts of Aegean BA settlements (Bekiaris *et al.* 2022, 173), cannot be confirmed.

The reuse of the Kaymakçı GSs was most apparent as recycling for building material. Exceptionally, they were secondarily used as abraders/sharpeners, mortars or drilled into so-called torus stones whose function is not clear.

Oval-shaped GSs predominate in the assemblage, which corresponds to the Neolithic tradition that also persists in the Aegean region (Runnels 1981, 106). However, in terms of size the GSs do not appear to be larger than in the Neolithic. At the same time, mortars are not very popular at this site, as only two mortar-like grinding basins and three hollowed GSs are attested.

Most of the UGSs were well designed and enhanced by ergonomic adjustments to render the holding and handling of the tool more comfortable during use. Examples of this UGS alteration have already been recognized in Anatolian assemblages dating to the Neolithic (Řídký 2009). However, some of the Kaymakçı GSs are even worked into more sophisticated shapes, e.g. the boat-shaped form, which later (in 6^{th} Century BC) appeared on many Mediterranean sites as part of standardized production (Alonso – Frankel 2017, 3).

The location of ergonomic adjustments in the form of protrusions or depressions can provide information about whether the user was right-handed or left-handed. According to this assumption, most of the people at Kaymakçı were probably right-handed. GSs that do not have these elements can be subjected to use-wear analysis. The experimental program showed that, based on the degree of abrasion of the material on one particular side and the distribution of the use-wear patterns, it is possible to determine the orientation of the GS relative to the user and whether the user of the tool is right-handed or left-handed.

The GSs, especially some of the UGSs, seem to be skillfully made. The counted coefficient of variation used for whole preserved UGSs corresponds to values associated with standardized manual production. Therefore, some degree of specialized production of GSs can be assumed, rather than home-made production. However, the GSs have so far provided no clear evidence for production at Kaymakçı: no roughouts, preforms or debris from the primary or secondary shaping have been found on site. Therefore, it is assumed, that the production "workshops" were more likely to have been localized somewhere outside the settlement – e.g. near the raw material extraction sites. Kaymakçı probably served only as a center of demand.

Felsic volcanic rocks constitute the largest proportion of the raw materials used for the production of GSs. The sources of this raw material are most probably located somewhere in the Yunt Mountains, close to the coast at least 50 km away from the site of Kaymakçı. It is very surprising that the vesicular basalt, with sources 30 km to the east in the Kula region and normally the most widely used raw material for GSs, is rare on the site. There are many explanations as to why it was more economical to transport objects from the west rather than from the east. One of the reasons could be that the vesicular basalt was harder to extract than the commonly used felsic volcanic rocks. The properties of felsic volcanic rocks could have rendered them more suitable for this function, or the site may have been more closely connected to the coastal area, to Aegean culturally, politically and/or commercially. Furthermore, certain local social traditions may also have affected the choice.

6.1.2 Grinding stones in the 2nd Millenium BC – the comparative study

The comparative study evaluated two published GS assemblages from the sites of Aphrodisias and Troy. Compared to the GSs from Kaymakçı, these archaeological assemblages are very small, which may be due to many factors.

First, this may be linked to the excavation strategy used at the sites. If less emphasis was placed on these artifacts, fewer would have been recorded. It must be noted that no GSs were found reused as building stone, which is one of the most common secondary use of the raw material/artifact. They were probably simply left in place without any excavation record being made of their presence.

Secondly, of course, the limited numbers of GSs recorded may simply indicate that grinding activities did not take place to such an extent on these settlements or in the EAs. In the case of Troy, this can be doubted, since in older excavations the excavators often mention the presence of large numbers of GSs (Schliemann 1880; Götze 1902; Blegen – Caskey – Rawson 1953), but these have never been systematically published. In the case of Aphrodisias, only three EAs with the strata from the MBA and LBA were opened up. A relatively large number of GSs have been found dating back to the MBA, considering the size of the EA, while in the LBA strata only one mortar was found. This may be partly due to the intervention of building activities in the younger periods, but the reason is not entirely clear.

Despite the limitations caused by the small sample size and the quality of the published data, some observations should be highlighted.

- Mostly local and regional raw materials were used for the production of GSs at Aphrodisias and Troy. The data do not suggest that the other settlements in Western Anatolia tended to expend much energy on importing better quality raw material or products from distant sources, as might be assumed for the Kaymakçı assemblage.
- The LGSs from Aphrodisias and Troy tend to have larger dimensions than those from Kaymakçı, which may be due to their better preservation.
- Grinding benches were not recorded in any of these settlements. However, two large immobile GSs were found in the citadel of Troy in Room B, where some grinding activities could potentially have taken place.
- The shapes of GSs from Aphrodisias and Troy tend not to be sophisticated, with mainly oval forms prevailing. Of course, there are exceptions in the form of rectangular LGS from Aphrodisias and two GSs with ergonomic adjustments from Troy.
- Mortars, which appear in large numbers in the BA of the eastern Mediterranean, are rather rare in these three settlements. Their designs are not as finely crafted and mostly take the form of secondarily used hollowed GSs.

6.2 Conclusion and future research outlook

This thesis has provided a significant first step forward in the study of GSs from the 2nd Millennium BC in Western Anatolia. The Kaymakçı GS assemblage offered good evidence for the selection of the raw material and for the use, reuse and discard of GSs. Other phases of the *chaîne opératoire*, such as the extraction of the raw material and production had to be studied from indirect evidence, as these activities probably did not take place at the site.

The results suggest that grinding activities definitely played an important role at Kaymakçı. The people invested a lot of time and energy in the transportation of the raw material or rather the final artifacts. Most of the grinding tools were skillfully made and finished on all sides. The standardization of the forms suggests the likelihood of specialized production. Furthermore, a lot of these tools were enhanced by ergonomic adjustments, which improved the comfort of holding and handling the tools during use.

However, these characteristic features could not be traced in other assemblages from Western Anatolia probably due to the state of knowledge. Future research should aim to place more importance on these artifacts and they should be the focus of more specialized studies. This thesis provides a comprehensive methodological approach to GS research and is intended to be a source of data and inspiration for future studies on GSs from the 2nd Millennium BC in Western Anatolia.

7 References

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8 List of figures and tables

Fig. 5.43. Lengths and widths of whole preserved LGSs from Kaymakçı (blue dots), approximate lengths and widths of whole preserved LGSs from Neolithic sites: Güvercinkayası, Anatolia(red square), Parisian basin, France (green square), Bylany, Czech Republic (yellow square), data compiled from (Hamon 2006; Pavlů 2008).

Fig. 5.44. Lengths and widths of whole preserved UGSs from Kaymakçı (blue dots), approximate lengths and widths of whole preserved UGSs from Neolithic sites: Güvercinkayası, Anatolia(red square), Parisian basin, France (green square), Bylany, Czech Republic (yellow square), data compiled from (Hamon 2006; Pavlů 2008).

Tab. 2. The dimensions of the replicas and selected Kaymakçı GSs for the use-wear analysis.

Fig. 5.45. Rhyolite replicas used in this study. A: 3D documentation of L1 - lower stone, the arrow indicates direction of grinding from the position of the user; B: 3D documentation of U1 - upper stone, the arrow indicates direction of grinding from the position of user; C: L1 with marked WSA and locations mentioned in the text. See Fig. 3, and 4; D: U1 with marked WSA and locations mentioned in the text.

Fig. 5.46. Lower stone, L1, locations marked in the Fig. 1: C. A: Location 1, after first phase, levelled surface with striated feldspar grains, OLYMPUS SZX7 Stereomicroscope, 16x magnification; B: Location 2, before first phase, uneven surface with quartz grains, OLYMPUS SZX7 Stereomicroscope, 16x magnification; C: Location 2, after first phase, levelled surface with fractured quartz grains, OLYMPUS SZX7 Stereomicroscope, 20x magnification; D: Location 2, after second phase, levelled quartz grains, OLYMPUS SZX7 Stereomicroscope, 20x magnification; E: Location 3, after second phase, micropolish on quartz grains, OLYMPUS BXFM Optical Microscope, 200x magnification; F: Imprint of the active surface on silicon casts, Location 1, after second phase, micropolish on the high topography, OLYMPUS BXFM Optical Microscope, 200x magnification; G: Imprint of the active surface on silicon casts, Location 4, after second phase, polished crystal with abraded faces and rounded edges. OLYMPUS BXFM Optical Microscope, 200x magnification; H: Location 1, after second phase, deep long striations on the feldspar grain. OLYMPUS BXFM Optical Microscope, 200x magnification.

Fig. 5.47. Lower stone, L1, locations marked in the Fig. 1: C. A: Location 5, after first phase, abraded surface with fractured grains. OLYMPUS SZX7 Stereomicroscope, 16x magnification; B: Location 5, after second phase, abraded surface with fractured grains. OLYMPUS SZX7 Stereomicroscope, 16x magnification; C: Active surface of lower stone L1 with distribution of prevailing mechanisms of wear, the arrow indicates direction of grinding from the position of user.

Fig. 5.48. Upper stone U1, locations marked in the Fig. 1: D. A: Location 6, after first phase, surface with lot of pits and fractured grains, OLYMPUS SZX7 Stereomicroscope, 16x magnification; B: Location 7, before first phase, uneven surface, OLYMPUS SZX7 Stereomicroscope, 16x magnification; C: Location 7, after first phase, surface with levelled feldspar and quartz grains, OLYMPUS SZX7 Stereomicroscope, 16x magnification; D: Location 7, after first phase, micropolish with striations. OLYMPUS BXFM Optical Microscope, 100x magnification; E: Location 8, after second phase, levelled surface with fractured quartz grain, U1, OLYMPUS SZX7 Stereomicroscope, 12,5x magnification; F: Location 9, after second phase, striated feldspar grain with rounded and polished edges, OLYMPUS SZX7 Stereomicroscope, 32x magnification; G: Active surface of lower stone U1 with distribution of prevailing mechanisms of wear, the arrow indicates direction of grinding from the position of user.

Fig. 5.49. The use wear analysis of UGS 99.526.110.1, A: front view with marked homogeneous zone (black line), location of silicon casts (green circles) and locations of photos (red squares), the arrow indicates the direction of the movement; B: Location 1, levelled surface in the homogeneous zone, Zeiss Stemi 508 Stereomicroscope, 25x magnification; C: biotite minerals with striations, Zeiss Stemi 508 Stereomicroscope, 25x magnification; D: Silicon cast from location 1, the distribution of the micropolish, OLYMPUS BXFM Optical Microscope, 100x magnification; E: Silicon cast from location 1, the domed micropolish, OLYMPUS BXFM Optical Microscope, 200x magnification; F: Silicon cast from location 1, the abraded crystal, OLYMPUS BXFM Optical Microscope, 200x magnification; G: Silicon cast from location 2, the flat and striated micropolish on the biotite crystal, OLYMPUS BXFM Optical Microscope, 200x magnification.

Fig. 5.50. The use wear analysis of UGS 95.555.127.1, A: front view with marked homogeneous zones (black circles), location of silicon casts (green circles) and locations of photos (red squares), the arrow indicates the direction of the movement; B: Location 1, levelled grains with rounded edges, Zeiss Stemi 508 Stereomicroscope, 25x magnification; C: Location 2, levelled surface with scratches, Zeiss Stemi 508 Stereomicroscope, 25x magnification; D: Silicon cast from location 1, the domed micropolish, OLYMPUS BXFM Optical Microscope, 200x magnification; E: Silicon cast from location 1, the fractuered crystal with abraded edges, OLYMPUS BXFM Optical Microscope, 200x magnification.