The Old Kingdom of Egypt (Dynasties 4–6, c. 2600–2180 BC) is famous as a period of the builders of the largest Egyptian pyramids. It is generally accepted that the evidence on the use of copper alloy tools from this era is meagre. Martin Odler gathers the textual, iconographic and palaeographic evidence and examines Old Kingdom artefacts in order to revise this view on the use of copper alloy tools and model tools. Furthermore, he provides updated definitions of tool classes and tool kits, together with the context of their use. Besides rare specimens of full-size tools, the largest corpora of the material have been preserved in the form of model tools in the burial equipment of the Old Kingdom elite and were most probably symbols of their power to commission and fund craftwork. Moreover, the size and elaboration of the model tools were probably connected to the social status of the buried persons. The long-standing division in the Egyptological literature between full-size tools and model tools is questioned. The ancient sources also enable to show that the preservation of material culture from the Old Kingdom was largely dependent on a conscious selection made within the past culture, with completely different settlement and funerary contexts and a conspicuous absence of weapons. The volume is completed by co-authored case studies on archaeometallurgy of selected Old Kingdom artefacts in the collection of the Egyptian Museum of Leipzig University, on morphometry of Old Kingdom adze blades and on the finds of stone and ceramic vessels associated with the findings of so-called Old Kingdom model tools.
OLD KINGDOM COPPER TOOLS AND MODEL TOOLS

Martin Odler

with contributions by

Jiří Kmošek, Ján Dupej, Katarína Arias Kytnarová, Lucie Jirásková, Veronika Dulíková, Tereza Jamborová, Šárka Msallamová, Kateřina Šálková and Martina Kmoničková
To my parents
and grandparents
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is 91 HV0.1. Microhardness of the intensively worked razor ÄMUL 5513 with the average content of 3.6% As has a surprisingly high value of 157 HV0.1. The standard deviation of the measured microhardness values is caused by the inhomogeneous structures of the artefacts, from the point of view of inclusion distribution and non-uniform thermo-mechanical processing. The results clearly indicate that microhardness depends more on the thermomechanical processing of the artefacts than on the content of arsenic, in accordance with the results of other studies.  

The production technology of the selected artefacts was probably divided into several individual steps consisting of alloy preparation, casting, forging and recrystallization annealing operations. Various combinations of these operations could have resulted in very different mechanical properties of the final products, depending on the different functions of the artefacts. We have not enough data to compare the thermomechanical processing technologies of working tools and their models, because all microstructural analyses involved working tools.

Conclusion

The results of the analysed collection of artefacts from ÄMUL provided insight into the fields of corrosion deterioration, material composition, microstructure features and mechanical properties of Egyptian working tools and their models dated to Dynasty 5 and 6. Out of the set of more than thirty artefacts from the Giza necropolis, only eight artefacts could be sampled for the purposes of the analysis, due to the considerable degree of corrosion deterioration. The metallic cores of the other artefacts were completely transformed into corrosion products. The corrosion products of the analysed artefacts consist on the one hand of a mixture of copper oxide minerals (cuprite and tenorite) with higher amount of arsenic, and on the other hand of a mixture of copper chloride minerals (atacamite, clinoatacamite and paratacamite). The corrosion products contain a certain portion of sand particles, represented by quartz, gypsum and rutile. The chemical composition of the alloys in the analysed set indicates a fairly consistent composition, corresponding to arsenic copper alloys containing arsenic up to 3.6%, iron up to 0.5% and admixtures of tin, silver, nickel and lead. There is only one exception – the razor ÄMUL 2131, which contains higher portion of arsenic, tin and silver and surprisingly does not contain lead. The chemical composition of the working tools and their models seems to be unstable in the proportion of arsenic and there is no visible correlation between the chemical composition and the function of the artefacts. Two out of the three examined microstructures were annealed and contain slip lines on the surface. The third microstructure was fully worked and contains a large amount of slip lines. An As-rich γ phase in the intergranular regions was documented in one case, related to the presence of inverse segregation during solidification after casting. Two types of inclusions were identified in the structure of metallic cross sections. The first type is represented by mixed oxides of copper and iron, and the second type by copper-iron sulphide inclusions with a portion of selenium, tellurium and lead in some cases. The results of Vickers microhardness tests of three artefacts are comparable with the results obtained earlier by other authors and confirm that the hardness of the artefacts was intentionally achieved by mechanical hardening rather than by the alloying effect of alloys with a higher portion of arsenic. The techniques of casting, alloying, hot or cold working, annealing, final cold working and surface finishing were used in the production of the artefacts. From the obtained results it is not possible to distinguish which technology was used for the production of the arsenic copper alloys, but at least the artefacts ÄMUL 2129, 2131 and 5513 were made from rich sulphide ores, which is indicated by the presence of selenium and tellurium.

11.2. Morphometrical and statistical case study of Old Kingdom adze blades

Martin Odler827 and Ján Dupej828

Introduction

The tools of geometric morphometry have been used in anthropology and biology for decades now. On the other hand, their application in other fields, such as archaeology, has been somewhat slower. Geometric morphometry is the quantitative study of shape with the application of multivariate statistical and geometric approaches in the evaluation of the data. The historically earlier traditional morphometry used distances, lengths and angles to describe a particular specimen in the set. In contrast, geometric morphometry (GM) describes shapes using landmarks. The term originates in geography and refers to a well recognizable feature used for navigation. In GM, this term is used for an anatomically significant locus, present and repeatable in all the studied specimens.829 Each specimen in the set must be described by an equal number of landmarks, placed in these anatomically equivalent loci. This property, referred to as homology, is crucial for a successful application of statistics on the data.

The configurations of landmarks describing a specimen are generally in random locations and orientations

826 Pereira et al. (2013); Lechtman (1996); Junk (2003).
<table>
<thead>
<tr>
<th>Context</th>
<th>Site</th>
<th>Part of site</th>
<th>Structure</th>
<th>Owner</th>
<th>Social status</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR6</td>
<td>Abu Rawash</td>
<td>Cemetery F, Old Kingdom necropolis</td>
<td>Mastaba F 19</td>
<td>unknown</td>
<td>unknown</td>
</tr>
<tr>
<td>AR7</td>
<td>Abu Rawash</td>
<td>Cemetery H</td>
<td>Rock tomb H1</td>
<td>unknown</td>
<td>unknown</td>
</tr>
<tr>
<td>AR9</td>
<td>Abu Rawash</td>
<td>Cemetery F, Old Kingdom necropolis</td>
<td>Mastaba F 21</td>
<td>ḫḫ-kṣ-f</td>
<td>legal department</td>
</tr>
<tr>
<td>AR10</td>
<td>Abu Rawash</td>
<td>Cemetery F, Old Kingdom necropolis</td>
<td>Mastaba F 21</td>
<td>ḫḫ-kṣ-f</td>
<td>unknown</td>
</tr>
<tr>
<td>A2</td>
<td>Abusir</td>
<td>AC 22: Pyramid complex Lepsius 24</td>
<td>Burial chamber of pyramid Lepsius 24</td>
<td>most probably queen</td>
<td>royal family – queen ?</td>
</tr>
<tr>
<td>A15</td>
<td>Abusir</td>
<td>Cemetery of pyramid of Nyuserra</td>
<td>AC 10: Princesse Khaemerkemebty and Meretites, and Kahotep</td>
<td>Ḫš(ṣ)-ḥtp</td>
<td>high-ranking dignitary</td>
</tr>
<tr>
<td>A17</td>
<td>Abusir</td>
<td>Royal cemetery</td>
<td>AC 25: Tomb Q</td>
<td>Nh.t-ss-R.ṣ.w</td>
<td>royal family – king’s son</td>
</tr>
<tr>
<td>A21</td>
<td>Abusir</td>
<td>Royal cemetery</td>
<td>AC 24: Lepsius no. 25/2</td>
<td>unknown</td>
<td>royal family – king’s daughter or sister of Hanub</td>
</tr>
<tr>
<td>A28</td>
<td>Abusir</td>
<td>Djedkara’s family cemetery</td>
<td>Tomb AC 15</td>
<td>Ḥkr.t-Nb.ty</td>
<td>woman from the royal court</td>
</tr>
<tr>
<td>A31</td>
<td>Abusir South</td>
<td>AS 68d, Tomb of Nefer</td>
<td>Nfr-Hwt-Hr.w</td>
<td>priestess, wife of a high-ranking dignitary</td>
<td></td>
</tr>
<tr>
<td>A32</td>
<td>Abusir South</td>
<td>Tomb AS 67</td>
<td>Nfr-šps</td>
<td>high ranking dignitary, department of organization of labour</td>
<td></td>
</tr>
<tr>
<td>A37</td>
<td>Abusir South</td>
<td>AS 27: Tomb Lake of Abusir 5, Shaft 2</td>
<td>unknown</td>
<td>unknown</td>
<td></td>
</tr>
<tr>
<td>A40</td>
<td>Abusir South</td>
<td>AS 17: Tomb of Qar Jr.</td>
<td>Ḫšr</td>
<td>legal department</td>
<td></td>
</tr>
<tr>
<td>A41</td>
<td>Abusir South</td>
<td>AS 17: Tomb of Qar Jr.</td>
<td>Ḫšr</td>
<td>legal department</td>
<td></td>
</tr>
<tr>
<td>A45</td>
<td>Abusir South</td>
<td>AS 22: Tomb of Inti</td>
<td>Jn.tj</td>
<td>legal department</td>
<td></td>
</tr>
<tr>
<td>A46</td>
<td>Abusir South</td>
<td>AS 22: Tomb of Inti</td>
<td>Jn.tj</td>
<td>legal department</td>
<td></td>
</tr>
<tr>
<td>A48</td>
<td>Abusir South</td>
<td>AS 22: Tomb of Inti</td>
<td>Jn.tj ‘nb-Pp.y</td>
<td>department of royal documents</td>
<td></td>
</tr>
<tr>
<td>A49</td>
<td>Abusir South</td>
<td>AS 22: Tomb of Inti</td>
<td>Jn.tj ‘nb-Pp.y</td>
<td>department of royal documents</td>
<td></td>
</tr>
<tr>
<td>Ay1</td>
<td>Abydos</td>
<td>Middle cemetery</td>
<td>Tomb 918</td>
<td>unknown</td>
<td>unknown</td>
</tr>
<tr>
<td>Ay11</td>
<td>Abydos</td>
<td>unknown</td>
<td>unknown</td>
<td>unknown</td>
<td>unknown</td>
</tr>
<tr>
<td>Ay14</td>
<td>Abydos</td>
<td>Middle cemetery, Garstang tombs</td>
<td>Tomb 747, A.09</td>
<td>unknown</td>
<td>unknown</td>
</tr>
<tr>
<td>Ay18</td>
<td>Abydos</td>
<td>Temple of Osiris</td>
<td>Building west of structure H</td>
<td>settlement</td>
<td>~</td>
</tr>
<tr>
<td>An1</td>
<td>Aniba</td>
<td>Cemetery N</td>
<td>Grave N 958 b</td>
<td>unknown</td>
<td>unknown</td>
</tr>
<tr>
<td>B15</td>
<td>Balat</td>
<td>Cemetery of the governors in Dynasty 6</td>
<td>Mastaba III</td>
<td>Dir.w II</td>
<td>governor of the oasis</td>
</tr>
<tr>
<td>B25</td>
<td>Balat</td>
<td>Cemetery of the governors in Dynasty 6</td>
<td>Mastaba II</td>
<td>Jmt-Pp.y</td>
<td>governor of the oasis</td>
</tr>
<tr>
<td>B28</td>
<td>Balat</td>
<td>Palace of governors in Dynasty 6, ka sanctuaries</td>
<td>Ka sanctuaries, first alignment of service structures, zone west, Room 11</td>
<td>settlement</td>
<td>~</td>
</tr>
<tr>
<td>Ba4</td>
<td>Bubastis</td>
<td>Tombs of season 1970, west of the El–Mu’ahada road and to the east of the Cat Cemetery</td>
<td>Tomb 161</td>
<td>Mr(y)-Mr-n-R.ṣ.w</td>
<td>rank title, no further data</td>
</tr>
<tr>
<td>Dd5</td>
<td>Dendera</td>
<td>Old Kingdom necropolis</td>
<td>Tomb 304</td>
<td>Mrw (?)</td>
<td>unknown</td>
</tr>
<tr>
<td>Ed2</td>
<td>Edfu</td>
<td>Old Kingdom necropolis</td>
<td>Mastaba IX</td>
<td>unknown</td>
<td>nomarch ?</td>
</tr>
</tbody>
</table>

**Figure 235: Old Kingdom contexts with complete adze blades. The category of social status was determined by Veronika Dulíková (1).**
<table>
<thead>
<tr>
<th>Code</th>
<th>Location</th>
<th>Context</th>
<th>Age</th>
<th>Nom</th>
<th>Title</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>EK1</td>
<td>el-Kab</td>
<td>Silo concentration at the north-west corner of Nekhbet temple enclosure</td>
<td>silo L</td>
<td>settlement</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>EK2</td>
<td>el-Kab</td>
<td>Old Kingdom necropolis</td>
<td>Tomb of Kaimen</td>
<td>Ks(j)-mn.j</td>
<td>hem-netjer priest; only partly survived titulary</td>
<td></td>
</tr>
<tr>
<td>G5</td>
<td>Giza</td>
<td>West field, Cemetery G 1200</td>
<td>G 1201</td>
<td>Wp(j)-m-nfr.t</td>
<td>royal family – king’s son</td>
<td></td>
</tr>
<tr>
<td>G10</td>
<td>Giza</td>
<td>West field, Cemetery G 4000</td>
<td>G 4610 A</td>
<td>unknown</td>
<td>unknown</td>
<td></td>
</tr>
<tr>
<td>G20</td>
<td>Giza</td>
<td>Eastern cemetery of Khufu</td>
<td>G 7530-7540</td>
<td>Mr(y)-sj-&quot;nh</td>
<td>royal family – queen</td>
<td></td>
</tr>
<tr>
<td>G25</td>
<td>Giza</td>
<td>Pyramid complex of Menkaura</td>
<td>Valley temple of Menkaura, Magazine III-6</td>
<td>Mn-k.t-w-R.w</td>
<td>king</td>
<td></td>
</tr>
<tr>
<td>G33</td>
<td>Giza</td>
<td>Central field</td>
<td>G 8260</td>
<td>Bs-bz-f-Hnmm-w-bz-f</td>
<td>royal family – king’s son</td>
<td></td>
</tr>
<tr>
<td>G34</td>
<td>Giza</td>
<td>East field</td>
<td>G 7560</td>
<td>unknown</td>
<td>unknown</td>
<td></td>
</tr>
<tr>
<td>G35</td>
<td>Giza</td>
<td>West field, Cemetery G 4000</td>
<td>G 4140</td>
<td>Mr(y).t-jt(j)=s</td>
<td>royal family – king’s daughter</td>
<td></td>
</tr>
<tr>
<td>G37</td>
<td>Giza</td>
<td>South field</td>
<td>Mastaba V (Junker) / G IV S (Reisner) / Lepsius 52</td>
<td>N(y)-&quot;nh-R.w</td>
<td>unknown</td>
<td></td>
</tr>
<tr>
<td>G39</td>
<td>Giza</td>
<td>Central field</td>
<td>G 8250</td>
<td>unknown</td>
<td>royal family – king’s daughter ?</td>
<td></td>
</tr>
<tr>
<td>G41</td>
<td>Giza</td>
<td>Central field</td>
<td>G 8980</td>
<td>Hip-Wt</td>
<td>rank title, no further data</td>
<td></td>
</tr>
<tr>
<td>G44</td>
<td>Giza</td>
<td>West field</td>
<td>G 5232, Shaft A</td>
<td>Nfr-bz.w-Pth</td>
<td>priest, steward of the great estate</td>
<td></td>
</tr>
<tr>
<td>G46</td>
<td>Giza</td>
<td>West field, Cemetery G 4000</td>
<td>G 4631</td>
<td>Nn-sdr-ks(s)</td>
<td>priestess, wife of high-ranking dignitary</td>
<td></td>
</tr>
<tr>
<td>G50</td>
<td>Giza</td>
<td>West field</td>
<td>G 4920</td>
<td>Tn.tj</td>
<td>high-ranking dignitary</td>
<td></td>
</tr>
<tr>
<td>G53</td>
<td>Giza</td>
<td>Central field</td>
<td>Mastaba of Shaft 559</td>
<td>unknown</td>
<td>unknown</td>
<td></td>
</tr>
<tr>
<td>G55</td>
<td>Giza</td>
<td>West field, Cemetery G 6000</td>
<td>G 6051</td>
<td>unknown</td>
<td>unknown</td>
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</tr>
<tr>
<td>G57</td>
<td>Giza</td>
<td>East field</td>
<td>G 7112, Shaft A</td>
<td>unknown</td>
<td>unknown</td>
<td></td>
</tr>
<tr>
<td>G59</td>
<td>Giza</td>
<td>West field, Cemetery G 6000</td>
<td>G 6010</td>
<td>Nfr-bz.w-Pth</td>
<td>priest, steward of the great estate</td>
<td></td>
</tr>
<tr>
<td>G61</td>
<td>Giza</td>
<td>West field</td>
<td>D 20, Shaft 1</td>
<td>Tp-m-&quot;nh</td>
<td>titles connected to pr-rs, jry lt nswt pr-rs</td>
<td></td>
</tr>
<tr>
<td>G63</td>
<td>Giza</td>
<td>Central field</td>
<td>G 8656, Shaft 585</td>
<td>S:im</td>
<td>privacy of King</td>
<td></td>
</tr>
<tr>
<td>G66</td>
<td>Giza</td>
<td>West field</td>
<td>D 37, Shaft 1</td>
<td>R.w-ht-k.t(s)</td>
<td>legal department</td>
<td></td>
</tr>
<tr>
<td>G68</td>
<td>Giza</td>
<td>West field, Cemetery G 4000</td>
<td>G 4520</td>
<td>Hw(j)-f-wj-&quot;nh</td>
<td>sphere of entertainment</td>
<td></td>
</tr>
<tr>
<td>G69</td>
<td>Giza</td>
<td>Central field</td>
<td>G 8402, Mastaba of Shaft 648</td>
<td>unknown</td>
<td>unknown</td>
<td></td>
</tr>
<tr>
<td>G71</td>
<td>Giza</td>
<td>Central field</td>
<td>G 8853</td>
<td>Ks(s)-pr</td>
<td>legal department, chief of one of six administrative pillars</td>
<td></td>
</tr>
<tr>
<td>G86</td>
<td>Giza</td>
<td>West field</td>
<td>G 4733, Shaft E</td>
<td>unknown</td>
<td>unknown</td>
<td></td>
</tr>
<tr>
<td>G92</td>
<td>Giza</td>
<td>Central field</td>
<td>G 8640</td>
<td>&quot;nh-hss-f - Ks</td>
<td>department of treasury</td>
<td></td>
</tr>
<tr>
<td>G97</td>
<td>Giza</td>
<td>West field, Cemetery 2300</td>
<td>G 2381, Shaft A</td>
<td>Mr(j)-Pth-&quot;nh Mr(j)-R.w Spss-Pth Imp.y</td>
<td>vizier</td>
<td></td>
</tr>
<tr>
<td>G98</td>
<td>Giza</td>
<td>West field, Cemetery 2300</td>
<td>G 2381, Shaft Z</td>
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<td>unknown</td>
<td></td>
</tr>
<tr>
<td>G107</td>
<td>Giza</td>
<td>West field</td>
<td>Shaft 316 at G 5070</td>
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<td>unknown</td>
<td></td>
</tr>
<tr>
<td>G109</td>
<td>Giza</td>
<td>West field</td>
<td>Mastaba of Setka and Ptahhetep, Shaft 890A</td>
<td>Št-ji-kssj, Hip-Pth</td>
<td>legal department</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 235:** Old Kingdom contexts with complete adze blades. The category of social status was determined by Veronika Dulíková (2).
with respect to one another. Therefore, the information contained in these landmark coordinates includes not only the shape and size of a particular object but also the location and orientation of the object at the time it was digitized (with respect to a coordinate system). This introduces considerable unwanted variability into the data and, therefore, individual translation and rotation, which must be in some cases removed by performing a rigid alignment. Generalized Procrustes analysis (GPA)\(^8\) is ideal for this task, as it calculates rigid transformations (rotation, translation and scaling) for each specimen that would ideally align the landmark configurations (in least-squares sense). The landmark configurations transformed with these fitted rigid transformations are ideally aligned and suitable for further processing.

Unfortunately, many biological objects offer very few landmarks, which makes them difficult to analyse with landmark-based methods. This is both due to uneven coverage of the particular specimen and placement error of landmarks on non-salient features. We face a similar problem with archaeological material, such as the outlines of ancient Egyptian adzes. The shape consists of a smooth butt and a blade, usually with blunt edges. There are no obvious landmarks. These situations are usually addressed using algorithms that place landmarks automatically, according to specific rules, which are then considered homologous and used as if they were identified manually. Such landmarks are dubbed semilandmarks.

We have applied GM to represent the shape of 199 complete Old Kingdom adze blade outlines (Figure 235).

\(^8\) Gower (1975).
Furthermore, we have used multivariate statistics to compare the form\textsuperscript{831} and shape\textsuperscript{832} of the adzes within these representations across the periods and sites. Before we approach the description and interpretation of the results, it needs to be noted that a thorough reassessment of the category of models and full-size tools will be possible only if more analyses of the chemical composition of the material itself are published. From typology alone, we cannot infer sufficient information about the division between models and full-size tools. It can be inferred that very small objects are models and rather big artefacts are full-size tools or their models (different possibly only in alloy). But artefacts of a middle-size between these outliers can have traits of both models and full-size tools.

**Related work**

The adze outlines were digitized as closed curves. Several approaches handling automatic landmark placement on such curves have been proposed. A simpler class of algorithms places semilandmarks according to a common rule. Several of these rules have been tested and the resulting representations analysed in terms of their discriminative power for sex estimation.\textsuperscript{833} Two automatic semilandmark placement rules and four other methods of deriving shape variables have been tested.

If the curves are more irregular, more sophisticated methods such as sliding semilandmarks need to be used.\textsuperscript{834} The curves are represented as semilandmarks that are initially automatically placed on the curves, for instance using equal curvilinear increments. This procedure is iterative, repeating two stages until a satisfactory alignment has been achieved.\textsuperscript{835} The first stage aligns the curve representations using GPA and calculates the mean curve by averaging the corresponding semilandmarks. The second stage refines the representation of each curve by sliding the semilandmarks along the curve in such a way that would minimize the alignment error. The implementations of the sliding semilandmark method vary in this aspect. Some use the Procrustes distance as the error metric,\textsuperscript{836} while others used TPS bending energy.\textsuperscript{837} A lengthy discussion of these approaches is beyond the scope of this paper; a good comparison has been presented by Perez, Bernal and Gonzalez.\textsuperscript{838}

**Material and methods**

We have used 199 outlines of ancient Egyptian adzes. These outlines were digitized in Morphome3cs (www.morphome3cs.com) using closed cubic Hermitian splines.\textsuperscript{839} Furthermore, two landmarks were placed on each outline, one on the butt and one on the blade midpoint. The landmarks served only to pre-align the shapes and accelerate the convergence of sliding semilandmarks. No shape information was inferred from these landmarks. Sliding semilandmarks represented each curve with 30 landmarks homologous across the sample, which we will refer to as the form. We have also created a representation called the shape, which is the form rescaled to a unified size. To calculate the size of an object, we used the widely accepted metric, centroid size (CS), where is the landmark coordinate of a specimen and is the centroid of these landmarks (Figure 236).\textsuperscript{840}

The following analyses were performed twice, once for the shape and once for the form.

The dimension of each specimen is still high. Some statistical methods, such as the Hotelling’s $T^2$ test, require that the dimension of the data not exceed the specimen count of the smaller group. A dimension reduction is therefore usually performed after GPA or sliding semilandmarks. The most commonly applied method is the principal component analysis (PCA),\textsuperscript{841} which finds mutually independent directions in the dataset with the greatest variability. Using those directions, the data set can be transformed into scores. Depending on how structured the data are, they can be represented with a handful of principal component scores while maintaining most of the variability. We visualized the PC scores in the first two principal components in scatter plots.

The question of how many principal components should be kept is a nontrivial one, and many rules have been proposed that address it. A good review is presented by Peres-Neto, Jackson and Somers.\textsuperscript{842} We have used the broken-stick rule to ascertain the amount. According to that rule, both form and shape are sufficiently represented with four principal components.

We have used MANOVA to assess the dependence of the shape and form on the period and site where the adze was found. MANOVA, however, does not specify which groups are responsible for the differences. Therefore, we use nonparametric two-sample Hotelling’s $T^2$ test to check whether specific two group means differ. The statistical significance at the level $\alpha = 0.05$. The statistical

$$CS = \frac{1}{\sqrt{m}} \sum_{i=1}^{m} ||p_i - \bar{t}||^2$$

**Figure 236: Formula of centroid size.**

\textsuperscript{831} Form is defined as a shape assessed together with size.

\textsuperscript{832} Shape is defined as a shape assessed with the mean size of the specimens.

\textsuperscript{833} Velemínská, Krajíček, Dupej et al. (2013).

\textsuperscript{834} Bookstein (1997b).

\textsuperscript{835} Perez, Bernal and Gonzalez (2006).

\textsuperscript{836} Andersen, Bookstein, Conradsen et al. (2000).

\textsuperscript{837} Perez, Bernal and Gonzalez (2006).

\textsuperscript{838} Perez, Bernal and Gonzalez (2006).

\textsuperscript{839} E.g. Bookstein (1997a).

\textsuperscript{840} The data were entered by Bc. Markéta Kobierská, and we would like to thank for her invaluable help in the project.

\textsuperscript{841} Bookstein (1997b).

\textsuperscript{842} Bishop (2006).

\textsuperscript{843} Peres-Neto, Jackson and Somers (2005).
processing has been performed in the open-source statistical software R.\textsuperscript{843}

Finally, we plotted the mean shapes and forms with groups by averaging the corresponding semilandmarks within groups.

**Results and discussion**

**Form**

The PC analysis of the form of adze blades (Figure 237) has shown that the size of the adze blades, which is mostly expressed in PC 1, is the decisive component in the corpus covering 97.51\% of its variability. The cluster of most adze blades is probably reflecting the existence of a category of model blades with minor differences in size. The cluster of adze blades under the factor loading 100 can be explained by the existence of a category of model blades of a regularized size. Outliers occurred throughout the Old Kingdom, representing full-size blades and their models in Dynasty 6. The PC analysis of adzes according to the sites shows that the largest adzes have been found at Giza, Saqqara and Balat (Figure 238). The range of adze blades from Giza covers everything from the smallest to the largest adze blades.

Figure 239 displays the effects of the first principal component, which is the size of the adze blades in this case. The second most important principal component was the width of the blade with 1.77\% of the variability in the corpus, which was confirmed also by the archaeological evidence (Figure 240).

The enlargement of adze blades can be observed on the mean shapes of the periods. The adze blades were getting progressively larger through Dynasties 4–6; the butts were larger and the blades wider in Dynasty 6 (Figure 241). The variant means reflect the difference in size among the variants; Variant D4 is significantly larger and with wider blade than other variants. The mean shapes of Variants D1 and D3 are smaller than the mean shape of the adze blades (Figure 242).

\textsuperscript{843} Team RC (2015).
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Figure 239: Form of Old Kingdom adze blades, effect of the principal component 1 (Ján Dupej, © Faculty of Arts, Charles University, Czech Institute of Egyptology).

Figure 240: Form of Old Kingdom adze blades, effect of the principal component 2 (Ján Dupej, © Faculty of Arts, Charles University, Czech Institute of Egyptology).

Figure 241: Form of Old Kingdom adze blades, mean forms of the periods (Ján Dupej, © Faculty of Arts, Charles University, Czech Institute of Egyptology).

Figure 242: Form of Old Kingdom adze blades, mean forms of variants (Ján Dupej, © Faculty of Arts, Charles University, Czech Institute of Egyptology).
The differences among the sites are displayed using the site means (Figures 243). The mean shape of the Old Kingdom adze blades is closest to the sites Giza and Abusir, which comprise the largest corpora of the material. Yet nonparametric two-sample Hotelling’s $T^2$ test has shown that there are significant differences even between Giza and Abusir. The mean shape of Saqqara adze blades is larger than the general mean shape, which can be explained by high social status of the persons buried at Saqqara and possibly better access to the copper sources. The adzes from Abu Rawash, Abydos and el-Kab were smaller than the mean shape, whereas the adzes from Balat were larger, which once again shows differences in the production of Old Kingdom adze blades.

<table>
<thead>
<tr>
<th>Site</th>
<th>Shape Description</th>
<th>Figure 243: Form of Old Kingdom adze blades, mean forms of the sites (Ján Dupej, © Faculty of Arts, Charles University, Czech Institute of Egyptology).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Giza, Eastern field, Dynasty 4, N=2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Giza, Central field, Dynasty 4, N=2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Giza, Central field, Dynasty 5, N=7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Giza, Western field, Dynasty 5, N=11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Giza, Western field, cemetery G 6000, Dynasty 5, N=5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abusir, royal cemetery, Dynasty 5, N=9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abusir, pyramid complex, Lepsius 24, Dynasty 5, N=3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abusir South, Dynasty 5, N=2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saqqara, Teti cemetery, Dynasty 6, N=7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Giza, Central field, Dynasty 6, N=4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Giza, Western field, Dynasty 6, N=6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balat, cemetery of the governors in Dynasty 6, N=2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abusir South, Dynasty 6, N=32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saqqara, West of Netjerkyhet pyramid complex, Dynasty 6, N=2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Giza, Western field, cemetery 2300, Dynasty 6, N=4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>unknown, N=78</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

FIGURE 244: Form of Old Kingdom adze blades, mean forms of the parts of sites (Ján Dupej, © Faculty of Arts, Charles University, Czech Institute of Egyptology).
Differences are apparent also if we compare tools according to the parts of sites (Figure 244). Forms significantly larger than the mean form come from unprovenanced contexts; in these cases, we suppose a presence of full-size blades. The mean is exceeded also by adze blades from Balat and from the West Field at Giza, Cemetery 2300; both site parts are from the reign of Pepy II of late Dynasty 6. The adze blades from the royal cemetery at Abusir and Teti pyramid cemetery are slightly larger than the mean form. The forms from the Central Field at Giza are roughly comparable to the mean, while the adzes from other West Field parts than Cemetery 2300 are below the mean. The adze blades from Abu Rawash and the Middle Cemetery at Abydos are also significantly smaller than the mean form of the adze blades. Morphometry has confirmed differences in the size of adze blades. Morphometrical analysis shows significant dissimilarities in the shapes of the Old Kingdom adze blades from the individual sites and parts of sites. These typological differences need to be confirmed by the analyses of the chemical composition and supposedly different craft traditions at the Old Kingdom sites.

The categorization of full-size adze blades, gilded model blades and model blades was included in the descriptive fields of the database on the basis of the artefact size. Full-size artefact blades were significantly larger than so-called model blades (Figure 245). Gilded model blades were longer than the mean shape. They have occurred in the burials of high officials from the Teti pyramid cemetery.

**Shape**

The digitized adze blades were ‘normalized’ in the following phase of the analyses, disregarding their size. The results of this morphological analysis *sensu stricto* are somewhat surprising, because they did not provide clear groupings or clusters of the adze blades throughout the Old Kingdom, except for the slightly clearer case of wide adze blade edges in late Dynasty 6. The morphology of adze blades in itself does not seem to be a sufficient basis for the dating of these artefacts.

A rerun of the principal component analysis provided another set of principal components. No apparent clusters occurred for the periods; the better represented adzes of Dynasties 5 and 6 appear along the loadings of the first component on the x axis (Figure 246). No apparent grouping is visible on the PCA diagram for the Old Kingdom sites, either (Figure 247). The most important component, with 68.45% of the variability of the corpus, was the width of the blade (this component was second in the first run of the PCA, after the size of the adze blades) (Figure 248). The second component with 9.30% of the variability covers the size and width of the adze butt and neck (Figure 249). The period mean of the adze blades is closest to the shapes of the adzes from Dynasties 5 and 6, which comprise the bulk of the specimens (Figure 250). The variant means are mostly influenced by Variants D1 and D3 (Figures 251). The...
Case studies

Site means are closest to Abusir and Giza; the adzes from Balat and Abydos were wider, the adzes from Abu Rawash and el-Kab narrower (Figures 252). The shapes of the adze blades from parts of sites clearly differentiate Dynasty 6 adze blades (Giza, Cemetery 2300; Saqqara, pyramid complexes of Netjerykhet; Abydos, Middle Cemetery; Balat). The most numerous adze blades from the Central Field at Giza and Abusir South had the greatest influence on the mean shape and are closest to the mean (Figure 253). Older blades, even from early Dynasty 6 (Teti pyramid cemetery) or earlier (the West Field at Giza, except Cemetery 2300; the East Field at Giza) tend to be narrower than the mean. The form and shape of the Old Kingdom adze blades show that full-size blades were generally wider than plain and gilded model blades (Figure 254). Altogether, the PCA of the shape of adze blades points to the importance of the size of adze blades in the interpretation of their morphology and, most of all, chronology in the Old Kingdom. Interplay of different variables will require further statistical research in the future.

Social status

If we compare the form of the adze blades by the social status of the buried persons (Figure 255), a pattern of increasing size emerges with a higher social status, with most of the high ranking officials having adze blades bigger than the mean form. The sharpest divide is between high and low rank officials. It is also interesting to note that adze blades of royal daughters are smaller than the mean form of the adze blades. When reduced to shape (Figure 256), differences of adze blades are less visible, with exception of two late Dynasty 6 adzes of governors of oasis Balat.

Conclusion

The case study of Old Kingdom complete adze blades has shown that morphometry can provide significant results. The differences in the size and morphology of the tools can be evaluated on the basis of statistics, using controlled and repeatable analyses. Morphometrical analysis confirms differences in the synchronic and diachronic phenomena in the Old

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844 Viziers and holders of the six highest titles in the Old Kingdom administration – Strudwick (1985).

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Figure 247: Shape of Old Kingdom adze blades, results of the PCA analysis for sites (Ján Dupej, © Faculty of Arts, Charles University, Czech Institute of Egyptology).

Figure 248: Shape of Old Kingdom adze blades, effect of the principal component 1 (Ján Dupej, © Faculty of Arts, Charles University, Czech Institute of Egyptology).
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Figure 249: Shape of Old Kingdom adze blades, effect of the principal component 2 (Ján Dupej, © Faculty of Arts, Charles University, Czech Institute of Egyptology).

Figure 250: Shape of Old Kingdom adze blades, mean shapes of the periods (Ján Dupej, © Faculty of Arts, Charles University, Czech Institute of Egyptology).

Figure 251: Shape of Old Kingdom adze blades, mean shapes of variants (Ján Dupej, © Faculty of Arts, Charles University, Czech Institute of Egyptology).

Figure 252: Shape of Old Kingdom adze blades, mean shapes of the sites (Ján Dupej, © Faculty of Arts, Charles University, Czech Institute of Egyptology).
An increase in the size and width of blades is observable on the corpus, while significant differences among the sites indicate different approaches of the craftsmen in the production of model and full-size blades. The next phase of the research needs to be focused on the chemical composition of the artefacts and the supposedly differing Old Kingdom craft traditions.

If the material culture found would be presented in comparable way (which is not always the case in excavation reports) and certain rules of the publication of artefacts are applied to material culture (not only in the case of metal artefacts), it will be possible to do morphometrical and statistical studies not only on the intra-site but also on the inter-site level.

**Figure 253:** Shape of Old Kingdom adze blades, mean shapes of the parts of sites (Ján Dupej, © Faculty of Arts, Charles University, Czech Institute of Egyptology).

**Figure 254:** Shape of Old Kingdom adze blades, mean shapes of full-size blades and model blades (Ján Dupej, © Faculty of Arts, Charles University, Czech Institute of Egyptology).
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**Figure 255**: Form of Old Kingdom adze blades, mean forms of the social status categories, as defined by Veronika Dulíková (Ján Dupej, © Faculty of Arts, Charles University, Czech Institute of Egyptology).

<table>
<thead>
<tr>
<th>Royal Family - King's Son, N=5</th>
<th>Royal Family - Queen, N=3</th>
<th>Royal Family - King's Daughter or Sister of Hanub, N=2</th>
<th>Royal Family - King's Daughter ?, N=2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legal Department, N=14</td>
<td>Department of Royal Documents, N=3</td>
<td>Department of Treasury, N=3</td>
<td>Vizier, N=6</td>
</tr>
<tr>
<td>Department of Provisioning, Storage and Redistribution, N=4</td>
<td>Privacy of King, N=6</td>
<td>Unknown, N=122</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 256**: Form of Old Kingdom adze blades, mean shapes of the social status categories, as defined by Veronika Dulíková (Ján Dupej, © Faculty of Arts, Charles University, Czech Institute of Egyptology).

<table>
<thead>
<tr>
<th>Royal Family - King's Son, N=5</th>
<th>Royal Family - Queen, N=3</th>
<th>Royal Family - King's Daughter or Sister of Hanub, N=2</th>
<th>Royal Family - King's Daughter ?, N=2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legal Department, N=14</td>
<td>Department of Royal Documents, N=3</td>
<td>Department of Treasury, N=3</td>
<td>Vizier, N=6</td>
</tr>
<tr>
<td>Department of Provisioning, Storage and Redistribution, N=4</td>
<td>Privacy of King, N=6</td>
<td>Unknown, N=122</td>
<td></td>
</tr>
</tbody>
</table>
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http://www.giza-projekt.org/Mastaba/Mastaba_D20.html
http://www.giza-projekt.org/Mastaba/Mastaba_D203.html
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http://www.giza-projekt.org/Mastaba/Mastaba_D24.html
http://www.giza-projekt.org/Mastaba/Mastaba_D37.html
http://www.giza-projekt.org/Mastaba/Mastaba_D44.html
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The Museum of Fine Arts, Boston, Collections online: http://www.mfa.org/collections
TLA – Thesaurus Linguae Aegyptiae: http://aaew.bbaw.de/tla/index.html
UCL Petrie Museum Online Catalogue: http://petriecat.museums.ucl.ac.uk/
Catalogue

The catalogue is available at http://bit.ly/2cT1NFz