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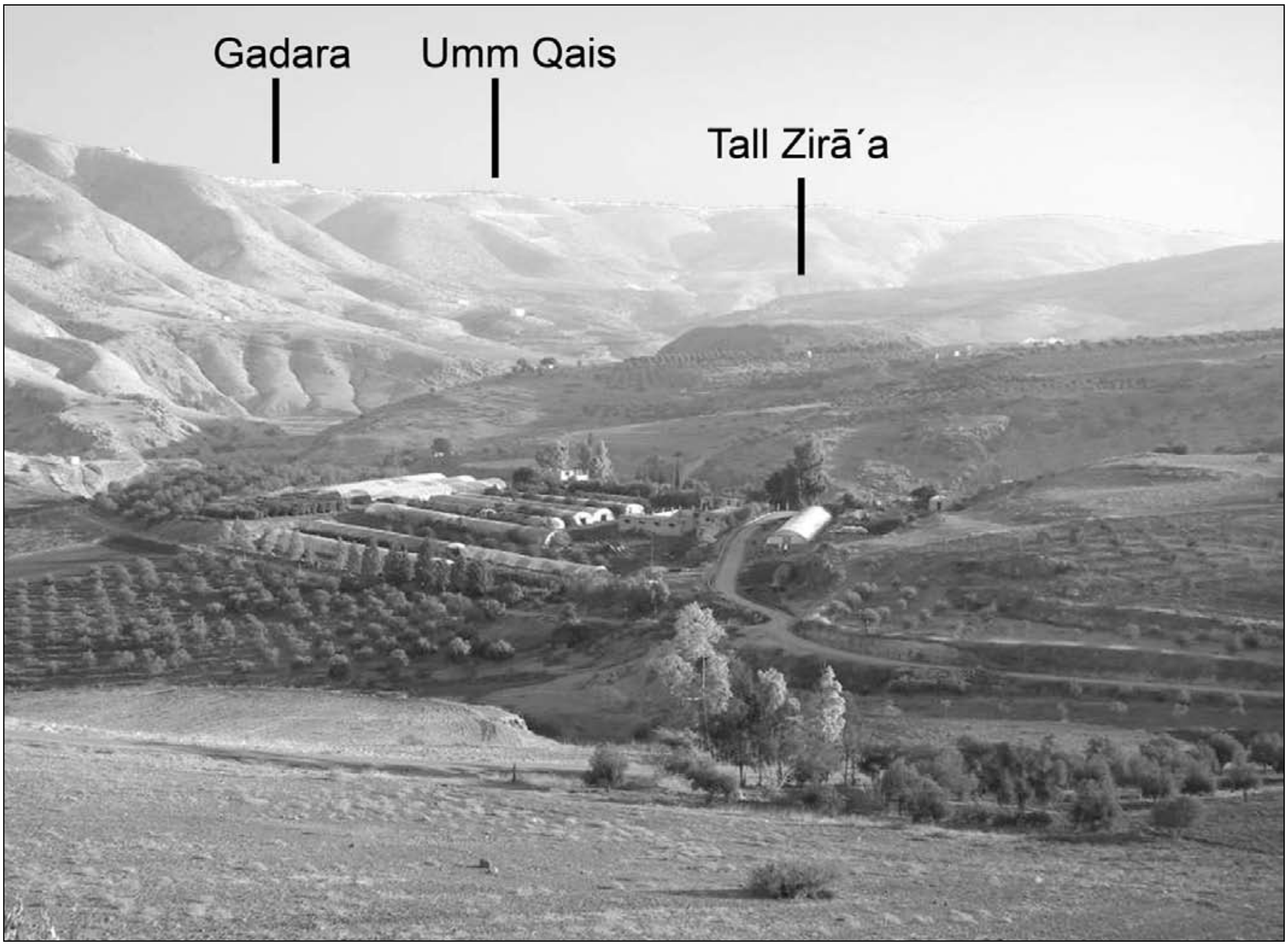
Archaeometry in Archaeological Research 5000 Years of History on Tall Zar‘a Pottery – Everyday Life, Trade and Technology in Northern Jordan

Introduction (FIG. 1)
The ruins of the Decapolis city of Gadara have fascinated generations of visitors due to their history and their extraordinary scenic location. Gadara is situated on the north-eastern spur of the transjordanian mountains high above the Sea of Galilee. Many people know this famous city, but only few know its earlier and later counterpart, Tall Zar‘a. This settlement was the central place of this region for millennia until the foundation of Gadara and acquired this role again after Gadara’s demise (Dijkstra 2005). The impressive tall dominates the Wādī al-‘Arab, an unusually fertile valley in the south of Gadara. But up until recently, hardly any attention had been



1. The Wādī al-‘Arab with Gadara, Umm Qays and Tall Zar‘a.

paid to Tall Zar‘a, its relation to Gadara and its pre- and post-classical development (FIG. 2).

The tall rises about 25 metres above the surrounding area. Its highest point is situated at 15 metres below sea level. Its foundation is a natural limestone hill with a diameter of about 240 metres at its base. Over a period of 5000 of years, various settlements were built on top of each other, shaping today’s tall. The plateau measures 160 metres in diameter and the cultural layers are approximately 12 metres thick.

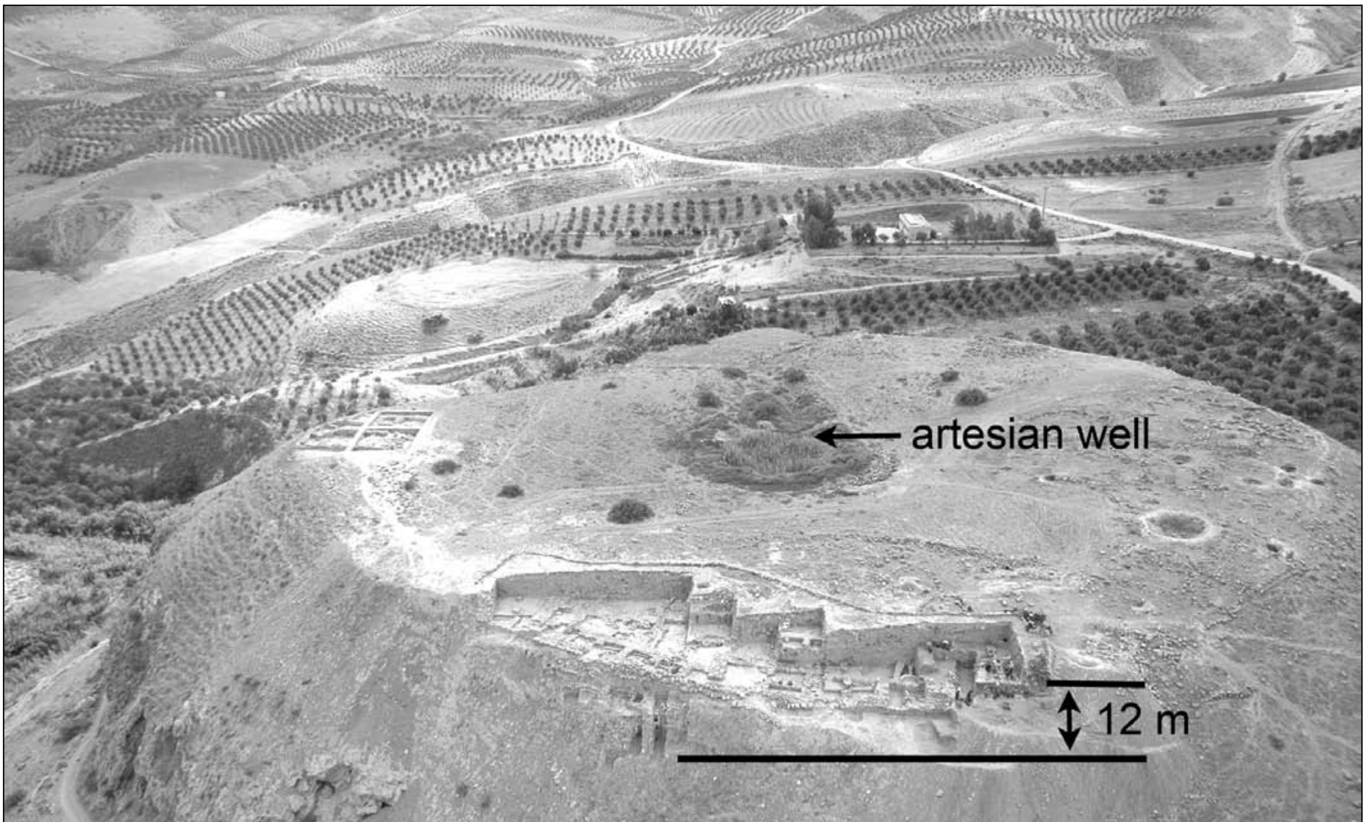
The special importance of Tall Zar‘a is based on the following four exceptional features:

First, it is located in an area characterized by fertile soil and two freshwater-bearing wadis: Wādī al-‘Arab and Wādī az-Zaḥar (FIG. 3). Both rendered possible an intensive level of agriculture, which guaranteed not only food supply but was also the basis for a certain economic wealth.

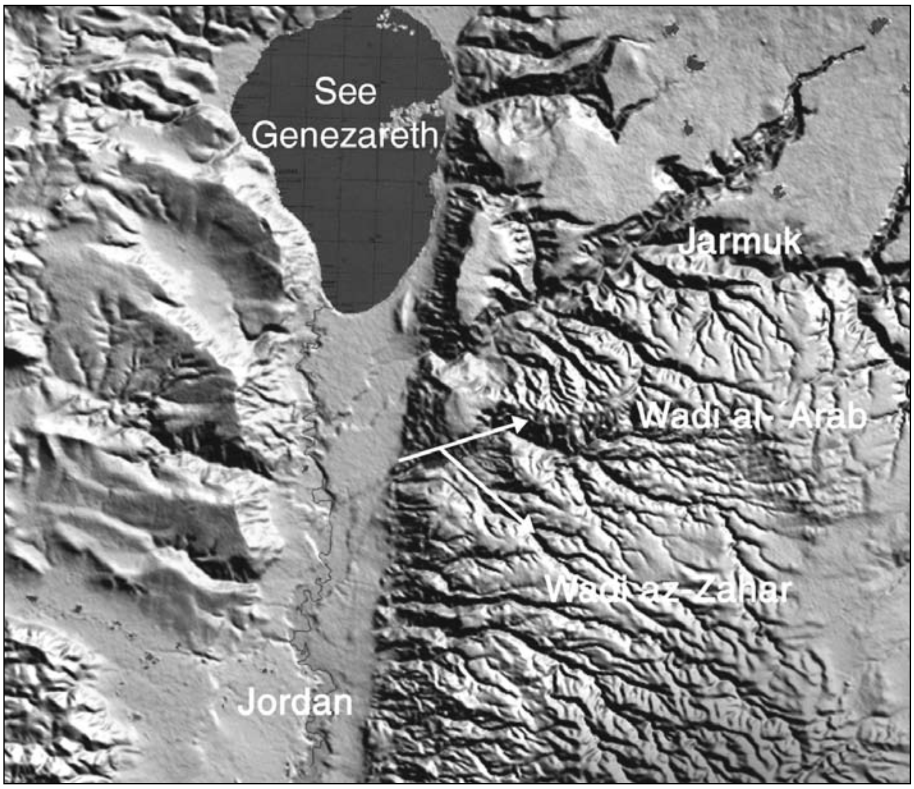
Second, there is an artesian spring on top of the tall. This was certainly an important strategic factor in the past and perhaps also was perceived as an attractive, beneficial and wondrous phenomenon.

The third fact is the tall’s strategic position along an ancient and highly important trade route. The tremendous ascent from 290 metres below sea level in the Jordan Valley to the Irbid-Ramtha-Area and the hills west of Bayt Rās at 560 and 612 metres above sea level can be surmounted via the Wādī al-‘Arab without steep or narrow passages. This makes it an ideal route, connecting the trade routes along the Mediterranean via the Jordan Valley with Transjordan and, further to the north-east, Damascus and Mesopotamia. Just as important is the shortcut via Hauran to the east and the centre of Mesopotamia, used since the fifth millennium BC (Eichmann *et al*. 2000: 9-44).

Finally, the tall is quite important from an archaeological point of view as it gives evidence of over 5000 years of continuous settlement — and



2. Tall Zar‘a in Northern Jordan, viewing from South-West to North-East.



3. Map of Northern Palestine.

that probably with only one minor gap (persian period). Thus, it is possible to observe not only all the different cultural periods in one place, but also the transitions between them (Häser and Vieweger 2005a: 16-21, 2005b: 135-146, 2007: 526-530; Steuernagel 1926: 80-83; Vieweger 2002: 157-177, 2007: 497-502).

An Ideal Opportunity for Pottery Research

As a result of its particular characteristics, the tall provides perfect conditions for a large-scale pottery study applying the most common archaeological as well as archaeometric investigation methods. By interpreting the pottery of millennia of settlement — together with the non-ceramic finds — it is possible to produce an image of the tall's cultural and political development.[1]

Regarding the pottery research, it is worth mentioning that the tall also has particular geological features. The clays used for mud bricks, tiles and *ṭābūn*(s) (non-pottery clay products) and for some of the pottery found on the tall came from the surrounding area. They are the product of millions of years of weathering of minerals and rocks, washed down from higher up into the wadis. As such, the tall is surrounded by fine, sandy, silty and clayey sedimentary deposits that are more or less rich in calcite, quartz and feldspars (Lucke 2007).

Objectives

Basically, the pottery project has two main objectives:

First: After having split up the pottery into resemblance groups (wares), the archaeological analysis addresses several questions regarding dating on the one hand, and prevailing socioeconomic conditions on the other.

Second: The archaeometric investigations will address questions such as: How much of the pottery was produced locally? Were there dependencies or relations with other communities? Was pottery traded on a regional basis or was it imported from areas like Mycenae, Cyprus, Syria or Egypt.[2]

And, if there was local/regional production, was there a visible development in vessels' shape over time? Is it possible to ascertain advancements with regard to utility and/or aesthetics and, with them, in pottery technology?

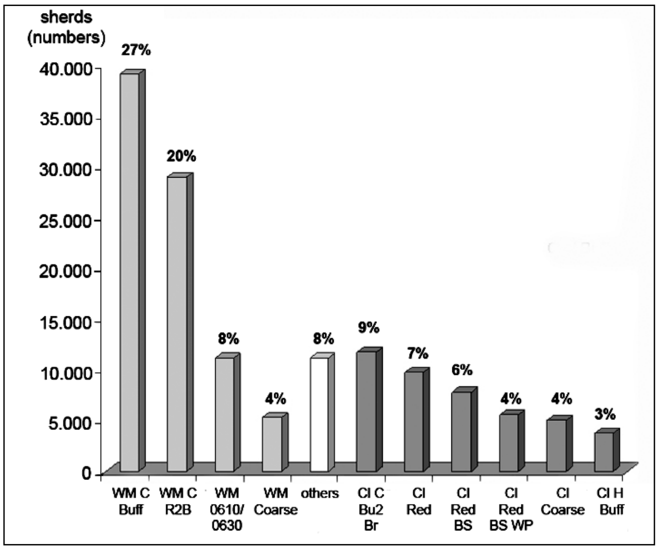
[1] About 140l,000 sherds were found in five excavation periods until spring 2007.

[2] Similar investigations have been carried out, e.g., with pottery from, e.g., Northern Jordan (Tall al-Fukhār from EB to LB, see McGovern 1997: 421-425) or Northern Mesopotamia (Tall ash-Shaykh Ḥamad/Dūr-Katlimmu, see Kreppner 2006).

Archaeological Analysis (FIG. 4)
The archaeological analysis of pottery starts with the classification of the sherds and is mainly based on dating (production method/shape), function and surface design. However, the way it was processed as well as the colour of the surface play a crucial role. Based on this, the tall's pottery can be classified into 77 ware groups.

All of the information is combined with other archaeological data in a relational database and therefore can be evaluated statistically.

As a result, it is easy to identify that the majority of pottery (59%) belongs to five ware groups: wheel made common buff (WM C Buff), wheel made common red to brown (WM C R2B), wheel made cooking vessels 0610 (WM 0610), wheel made cooking vessels 0630 (WM 0630) and wheel made coarse (WM Coarse) — all five dating from the Middle Bronze to the Iron Age. They are followed by 'classic' pottery (33%), dating to the Hellenistic, Roman and Byzantine periods: classic common buff to brown (Cl C Bu2Br), classic red (Cl Red), classic red black slipped (Cl Red BS), classic red black slipped white painted (Cl Red BS WP), classic coarse (Cl Coarse) and classic hellenistic buff (Cl H Buff).[3]



4. Distribution of pottery wares from Tall Zar'a.
Cl C Bu2Br = classic common buff to brown
Cl Red = classic red
Cl Red BS = classic red black slipped
Cl Red BS WP = classic red black slipped white painted
Cl Coarse = classic coarse
Cl H Buff = classic hellenistic buff
WM C Buff = wheel made common buff
WM C R2B = wheel made common red to brown
WM 0610 = wheel made (cooking vessels) 0610
WM 0630 = wheel made (cooking vessels) 0630
WM Coarse = wheel made coarse.

As the overwhelming majority of recorded pottery consists of vessels for everyday use (C = common ware), it seems that the settlement had a more rural structure, i,e, a village or at times a small rural town, over several millennia. Therefore it is not surprising that big storage containers (e.g. large pithoi) and a lot of cooking pots were found — representing the periods between Late Bronze Age IIA and Iron Age II. In contrary to that, however, an apparently unique painted jar is only one example of the fine ware from Late Bronze Age (FIG. 5).

Archaeometric Investigations[4]
Before moving on to the results of archaeometric investigations, the potentials and limitations of applying scientific methods to the investigation of pottery must briefly be discussed. In principle, the application of scientific methods to pottery is a way of scrutinizing or even of complementing the results of macroscopic (and as such often subjective) methods of traditional pottery diagnostics with more additional and detailed (more objective) information. Although logical and simple, in reality it is much more difficult.

Already a microscopic view of a section from a cooking pot (ware WM 0610) revealing the heterogeneity of the texture (FIG. 6) shows the complexity of the problem the investigating scientist is facing.

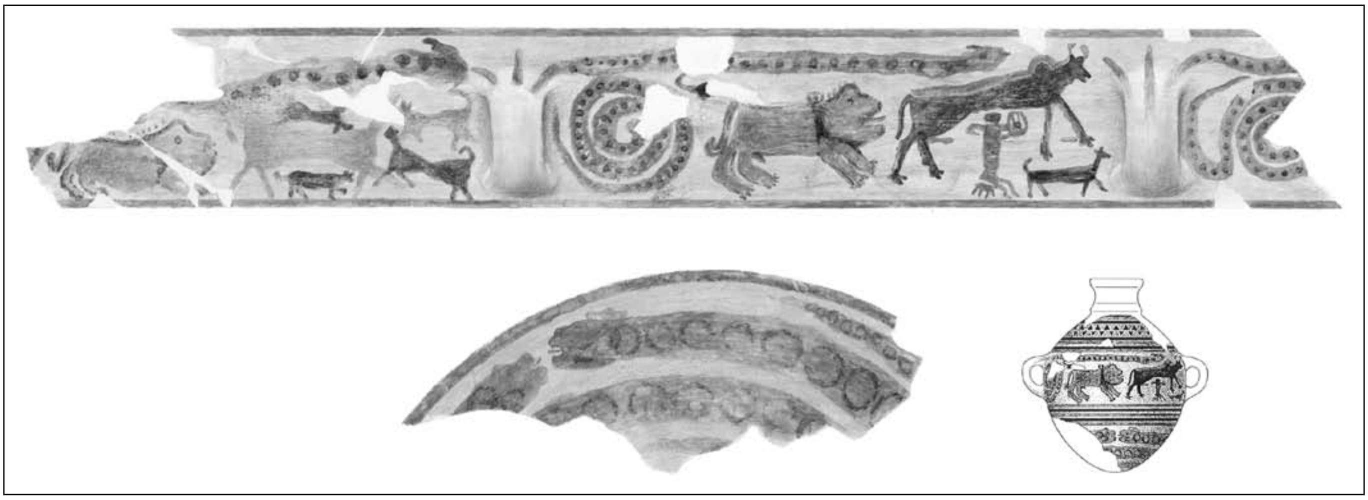
Alongside large, relatively intact crystals are finer ones, some of them are vitrified and as such have already ceased to be in a mineralogical sense. The following table (FIG. 7) shows exemplarily that during the firing process partial or even total decomposition of mineral phases may occur — but in the same way new mineral phases can be formed[5] (Klenk 1987; Magetti 1982: 121-133; Noll 1991: 99).

Thus, decomposition of minerals like quartz, il-

[3] Up to now, 77 ware groups have been defined. While 92% of the sherds can be assigned to 24 ware groups, the rest ('others' = 8%) has been split up into 53 minor ware groups.

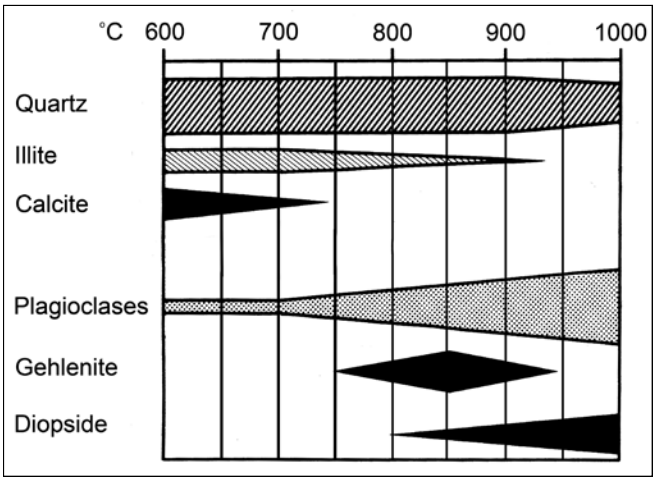
[4] All the scientific investigations were carried out at the Research Laboratory for Archaeology and Material Science, German Mining Museum, Bochum.

[5] This graph shows only examples of possible thermal reactions of mineral phases. The way mineral phases actually decompose or are formed largely depends on the actual conditions during the firing process, e.g., chemical and mineralogical composition of pottery, distribution of particle sizes, composition of the gas atmosphere (oxidizing or reducing conditions) etc.



5. Painted jar from the Late Bronze Age (Tall Zar'a).

6, Microscopic view onto a section from a wall of a cooking pot (WM 0610).



7. Thermal decomposition and formation of several mineral phases.

lite and calcite can start at 600°C, 700°C and 900°C. In this case, information is lost during the firing process and therefore it is very difficult to ascertain the mineralogical composition of the original material, which would help to find out where it came from ('provenance postulate' — see McGovern 1997: 421-425).[6] On the other hand, new mineral phases, e.g., plagioclases, gehlenite and diopside can emerge up to 700°C.[7] Basically, the existence of such mineral phases roughly gives evidence of the temperature the pottery was fired at. In this latter case information is gained.

Then there is the chemical composition: apart from some minor exceptions, none of the chemical components is lost during the firing process of pottery (based on long-term considerations).[8] Hence, the chemical analysis is the only method to show the composition of the original material. However, the drawback is that pottery with very similar chemical compositions can be different regarding their mineralogical compositions. Thus, the originally applied material is not necessarily the same and the origin of the pottery can be quite different.

That makes clear that 'absolute' information as to the origin of pottery cannot solely be gained from mineralogical or chemical analysis of the ap-

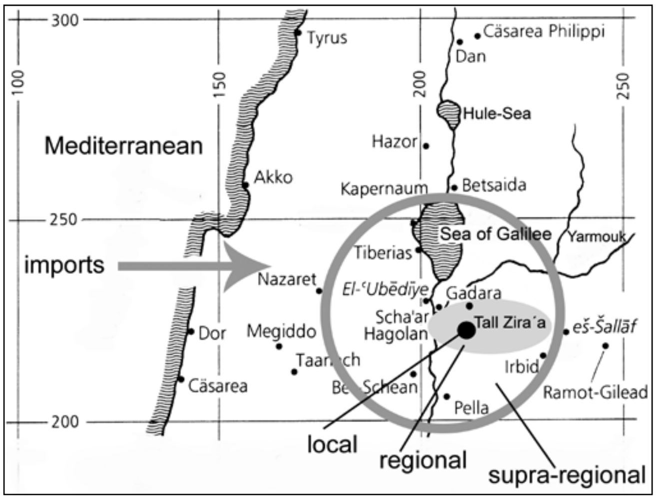
6 'Provenance postulate': If there is a correspondence between the mineralogical and/or chemical composition of a particular ancient pottery sample and a given clay source, the location of this source is the presumed place of manufacturing.

7 Calcite: $CaCO_3$, Illite (K, H_3O) Al_2 (Si_3 Al) O_{10} (H_2O, $OH)_2$, Plagioclases: (Na, Ca) (Si, Al)$_4$ O_8, Gehlenite: Ca_2Al (Si, Al) O_7, Diopside: $CaMgSi_2O_6$

8 Carbonates (e.g. calcite) can decompose during the firing process to CaO + CO_2. While being used or buried pottery quantitatively regains the CO_2 out of the atmosphere.

propriate pottery, but only from comparison with a selection of different source materials in question: For instance clay and non-pottery clay (mass) products like bricks, tiles and *ṭābūn*(s) from the site under investigation (local), pottery from other ancient settlements (in regional or supra-regional distance from the tall) and/or even imported wares (FIG. 8). Moreover, joint chemical or mineralogical properties, so called 'geochemical fingerprints', which have their origins in the specific geology of the location have to be found out. The following two examples shall demonstrate how such 'geochemical fingerprints' can be used for evaluating the origin of pottery by cross-comparison.

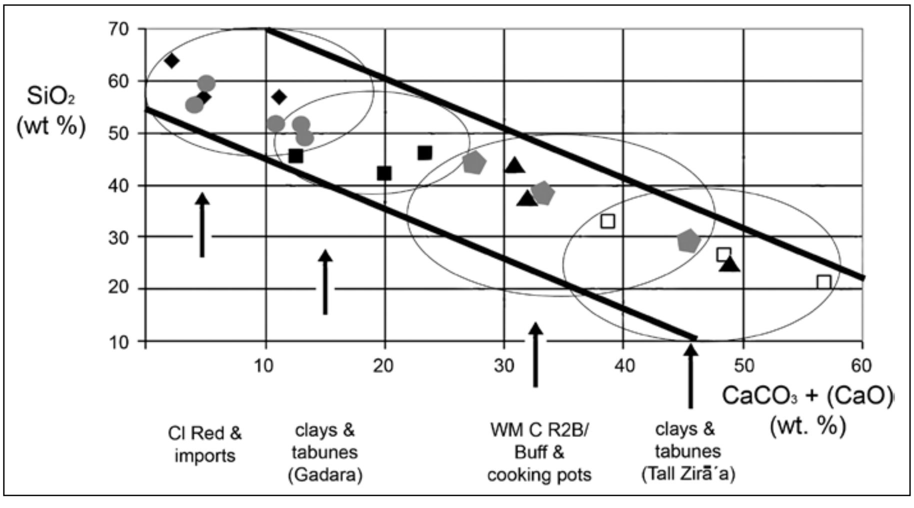
If one looks at the concentration of the two important pottery components SiO_2 and $CaCO_3$ (+CaO)[9] it is clear that (FIG. 9):



8. Origins of examined clays, pottery and non-pottery (clay) products.

- First, clay and non-pottery clay objects (mud bricks, *ṭābūn*(s), tiles) from Tall Zar'a have a very high $CaCO_3$ (+CaO) content compared with those of Gadara (both rectangles).
- Second, the composition of the utilitarian pottery wares like wheel made common red to brown/ wheel made common buff (WM C R2B/WM C Buff) and cooking pots (pentagons and triangles) lie somewhere between the specific non-pottery clay objects from Tall Zar'a and Gadara. So this pottery could have been produced from clay from either site.
- And third, classical red (Cl Red, rhombi) and imported wares (circles) have besides lower $CaCO_3$ (+CaO) — much higher SiO_2 — contents than the specific clay objects from the tall. Therefore local production (Tall Zar'a) can be excluded.

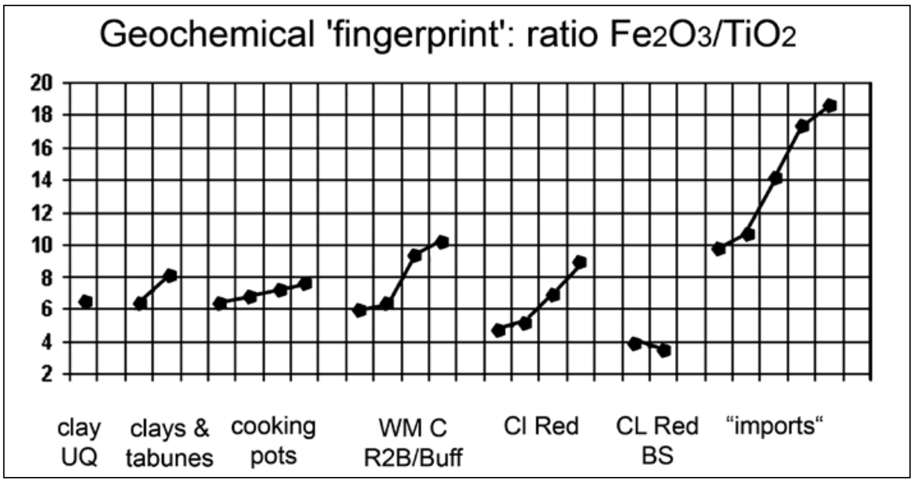
Turning to the ratio of Fe_2O_3 and TiO_2, a similar picture emerges (FIG. 10): It is conspicious that in clay and non-pottery objects from Tall Zar'a and Gadara, Fe_2O_3 and TiO_2 always occur together in a ratio of 5.5 to 8.0 — independent of the absolute concentration of both. The reason for this is presumably a geological feature of the material: The clays around Gadara and Tall Zar'a are mainly formed by the decomposition of basaltic rocks, which cover the Gadara plateau (Bender 1968; El-Akhal 2004; Wiesemann 1985: 79-80).[10] This basalt shows more or less the same Fe_2O_3/TiO_2-ratio as the clays from Gadara and the Tall Zar'a — and so do all non-pottery clay products as well as the majority of the utilitarian pottery from the tall. The imported wares ('imports') as well as two of each of the following wares – wheel made common red



9. 'Geochemical fingerprint': SiO_2 vs. $CaCO_3$+CaO.
wt.% = weight per cent

[9] The Ca^{2+}-ion can be bound as $CaCO_3$ in, e.g., calcite and/or as CaO in, for example, clay minerals like anorthite, augite etc.

[10] Weathering basalt delivers mineral phases like augite, anorthite, montmorillonite etc.



10. ‘Geochemical fingerprint’: Ratio Fe_2O_3/TiO_2.
UQ = Umm Qays
TZ = Tall Zar‘a
wt.% = weight per cent

to brown/wheel made common buff (WM C R2B/ WM C Buff), classic red (Cl Red) and classic red black slipped (Cl Red BS) — do not obey this rule. This indicates that (some) pottery of the latter wares probably not derives from ‘local’ clays.

These two examples reveal that one ‘fingerprint’ is not enough to be able to adequately characterize pottery, clay or non-pottery clay products. Consequently, various chemical and mineralogical parameters have to be used to characterize clay materials.

Up to now 320 samples of pottery, clays and non-pottery clay products have been examined.[11]

The principles and methods of analysing pottery and clay samples have already been described in detail in various publications (e.g. Rice 1987; Wagner 2007; Hauptmann and Pingel 2008).

Having applied the methods of Inductively Coupled Plasma Atomic Emission (ICP-AES) — and Ion Chromatography (IC),[12] 26 chemical elements (oxides) were recorded per sample (FIG. 11). Elementoxides like MgO, Al_2O_3, Fe_2O_3, K_2O and Na_2O, which are used to characterize clay materials, show similar but in some cases different concentrations for Tall Zar‘a and Umm Qays.

By means of the X-Ray Diffraction (XRD) method more than 33 different mineral phases could be identified.[13] In many cases, the mineralogical composition of clay materials from Tall Zar‘a and Umm Qays differ significantly.

chemical analysis			mineralogical analysis		
ICP- AES / IC:	26 elements (oxides)		XRD:	> 33 mineral phases	
elements (oxides)	Tall Zirā´a (wt %)	Umm Qais (wt %)	mineral phases	Tall Zirā´a	Umm Qais
MgO	0.5 – 3	1 – 5	Albite	+	(+)
Al_2O_3	4 – 13	8 – 18	Anorthite	+	
Fe_2O_3	2 – 7	3 – 13	Hematite	+	+
K_2O	< 2	< 2	Illite	+	+
Na_2O	< 1	< 3			
			Mikrokline	+	(+)
			Montmorillonite	+	(+)

+ frequently (+) rarely

11. Chemical and mineralogical ‘fingerprints’ for Tall Zar‘a and Umm Qays.

[11] 160 sherds from Tall Zar‘a were examined. A point was made when selecting pottery samples, of choosing representative specimens. Almost every pottery ware group is represented and the number of samples taken was determined by the statistical distribution of those pottery wares.

[12] The IC = Ion Chromatography method was applied for the determination of alkali- and earth alkali-elements like Na, K, Ca and Ba.

[13] All investigations were supported by a number of thin section studies. In addition, the thermal behaviour (determination of potteries’ original firing temperature) was studied by a great number of firing and refiring experiments.

Interpretation of the Results

Pottery classification

When interpreting the results of the scientific investigations, it should first of all be returned to the question of how archaeological pottery classification is supported by chemical and mineralogical analyses.

In the case of the cooking pot wares, for example, the situation is quite clear (FIG. 12). The wares can also be distinguished by their chemical and mineralogical composition. Moreover, it emerged that the (archaeological) cooking pot ware WM 0610 consists of at least two main subgroups (WM 0610-1 and WM 0610-2) that can be clearly defined (from an archaeometrical perspective) and dated: WM 0610-1 belongs to Iron Age I/II and WM 0610-2 to Iron Age II.

The cooking pot ware WM 0610TZ-f as far as it is known at this stage, unique to Tall Zar‘a, is chemically and mineralogically relatively uniform but shows a certain similarity to the subgroup WM 0610-2 (both Iron Age II).

From an archaeological point of view, each one of the other main wares wheel made common red to brown/wheel made common buff (WM C R2B/WM C Buff)[14] and classic red (Cl Red) must be divided in several subgroups which are relevant for determining the location of production but not for dating (FIG. 13).

In summary it can be concluded that the current (macroscopic/archaeological) pottery classification is logical, generally useful, fairly crude and adequate for archaeological purposes like dating. However, a more detailed classification is possible by using chemical and mineralogical analysis, which helps to answer questions regarding the ori-

cooking pot wares	dating
WM 0650	Middle Bronze II
WM 0630	Middle Bronze II / Late Bronze
WM 0610 (archaeometric split →	
WM 0610 – 2	Iron Age I / II
WM 0610 – 1	Iron Age II
WM 0610TZ-f	Iron Age II

12. Archaeological/archaeometric definition and dating of cooking pot wares.

archaeology	archaeometry	origin			
ware groups	number of subgroups	local	regional	supra-regional	import
WM 0650	(1)	(+)	+		
WM 0630	(1)	+	(+)		
WM 0610	4	+	+	(+)	
WM 0610TZ-f	(1)	+	(+)		
WM Eggshell	(1)	(+)	+		
WM Choc Wh	2		+	+	(+)
WM WP	(1)			+	(+)
Wh Sl (Cyprus)	(1)				+
WM Myc	(1)				+
R/B-group	5	+	(+)		
(WM C R2B- and	F1		+	(+)	
WM CBuff)	F2			+	(+)
Cl Red	3		+	+	(+)
Cl Red BS	2			+	(+)
Cl Amph	(1)			(+)	+
Cl ETS	2			+	+

(1) = main group/no subgroups origin: + = most probable
F1/ F2 = subgroups (non-local) (+) = less probable origin

13. Origins and numbers of subgroups of different ware groups.
WM 0650 = wheel made (cooking vessels) 0650
WM 0610TZ-f = wheel made (cooking vessels) 0610 from Tall Zar‘a — fine
WM Eggshell = wheel made eggshell
WM Choc Wh = wheel made chocolate on white
WM WP = wheel made white painted
Wh Sl (Cyprus) = white slipped (Cyprus)
WM Myc = wheel made mycenae
Cl Amph = classic amphora
Cl ETS = classic eastern terra sigillata

[14] From an archaeometric point of view, no difference between the two ware groups WM C R2B and WM C Buff can be noticed.

gins of the materials used and the technical history of pottery in the area.

Origins of the pottery (FIG. 13)
After having compared the chemical and mineralogical composition of the tall's pottery with that of clay and non-pottery clay products from Gadara and Tall Zar‘a, as well as with that of pottery from Gadara and other archaeological sites, the origins of the pottery could be divided into four categories: Local, regional, supra-regional and imported (see FIG. 8).

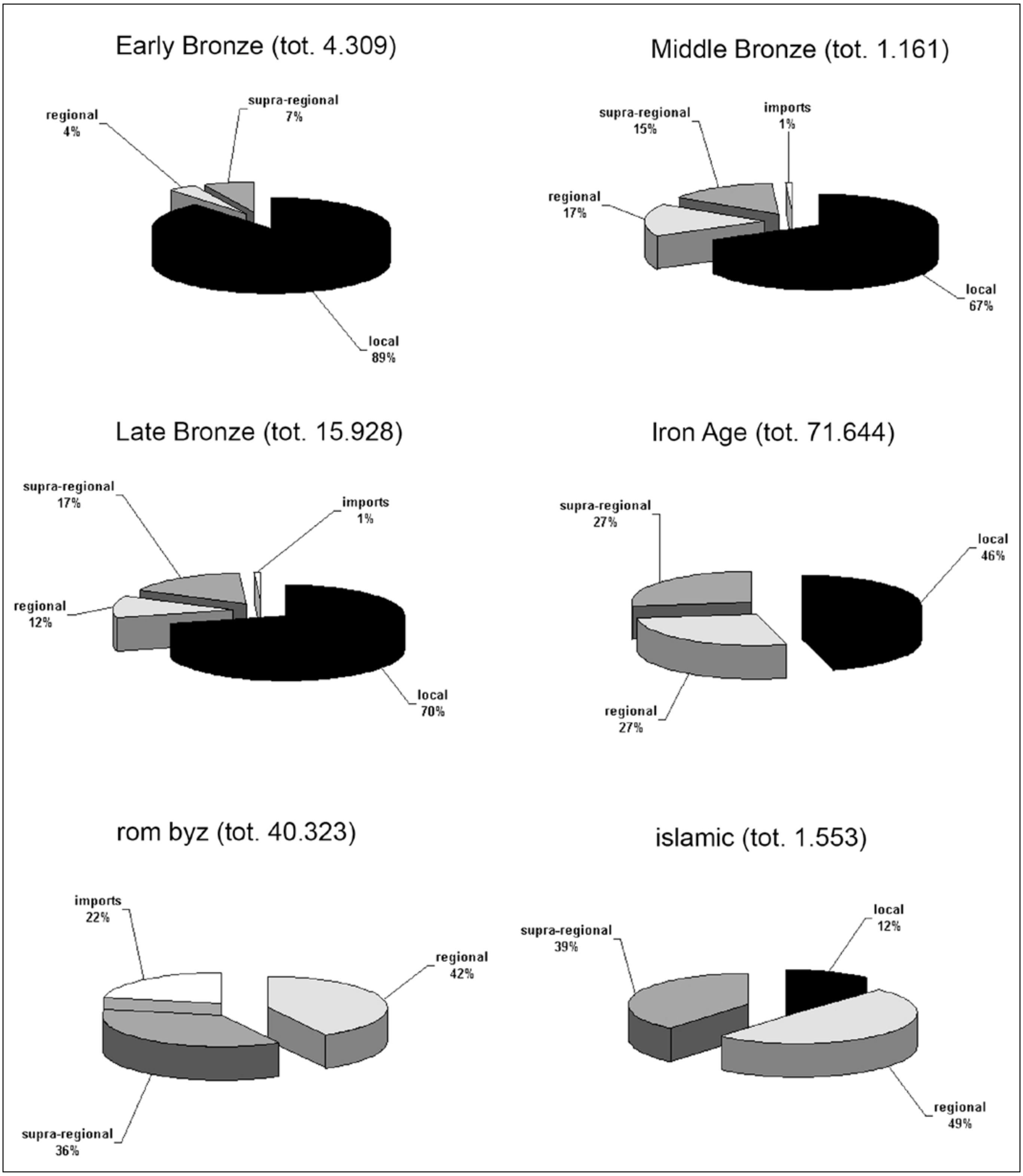
For instance, most of the cooking pot wares (WM 0630 and the two subgroups WM 0610-1 and WM 0610-2) were of local origin, whereas the cooking pots WM 0650 and two single pots of WM 0610 were of regional or supra-regional origin. ‘Local’ applies especially to WM 0610TZ-f, which is specific to the tall.

It became clear that five subgroups of wheel made common red to brown and wheel made common buff (WM C R2B/WM C Buff = R/B-groups) were of local origin (R/B-1 to R/B-5). These groups make up a large portion of the pottery from the tall and are basically utilitarian wares. On the other hand, from two further subgroups one is of regional origin (R/B-F1), while the other (R/B-F2) consists more of fine wares and probably comes from outside the immediate region (supra-regional).

There is no doubt that the more sophisticated pottery like wheel made slipped (Cyprus) (WM Sl [Cyprus]) and wheel made Mycenae (WM Myc) was imported, whereas most of the (likewise sophisticated) pottery of wheel made white painted (WM WP), wheel made chocolate and white (WM Choc Wh) was probably of supra-regional (or even imported) and wheel made eggshell (WM Eggshell) of supra-regional (or even regional) origin.

None of the investigated pottery from the Roman and Byzantine periods was locally (Tall Zar‘a) produced. Some of it was certainly imported. There was obviously no (or only few) pottery manufacture on the tall during the classical period.

- In the following, the results of the investigation concerning the origins and the dating of the pottery are briefly summarised (FIG. 14):
- In the Early Bronze Age there was mainly locally produced pottery — besides some regionally and even supra-regionally produced. Thus, it can be concluded that in this period the tall accommodated a settlement of some importance, which was involved in regional or even in supra-regional trade.
- In the Middle Bronze Age the regional and supra-regional portion of pottery clearly increased. With regard to the origins of the pottery, there is no great difference between the Middle Bronze and the Late Bronze Age. But especially in the Late Bronze Age the variety of pottery (number of ware groups) increased significantly and most of the regional/supra-regional (especially the fine wares) and nearly all of the imported wares derive from this era because the settlement on the tall experienced a period of prosperity. The imported pottery stems from (among other places) Mycenae and Cyprus. This confirms that in the Late Bronze Age (probably also already in the late Middle Bronze Age) the tall was involved in long-distance trade and as such it must apparently have been an important town.
- In Iron Age I prosperity decreased drastically and apparently the tall lost its status as an important town. The variety of pottery (number of ware groups) diminished and mainly common ware was found. But the settlement was not as modest as originally presumed (village of small-scale farming). Besides local pottery, an equal part of regional and supra-regional pottery was found (nearly the same distribution was found in Iron Age II). The transition to Iron Age II, in which the settlement again took on a more urban character and became more prosperous, can be seen in the appearance of fine wares and increasing number of additional ware groups. In this period, cooking pots were also subject of a very interesting development: The number of different types increased impressively and changes in pottery technology could be noticed.
- As already mentioned above, during the Roman and Byzantine periods the tall stood not only in the geographical, but also in the political, economic and cultural shadow of the nearby Decapolis city of Gadara. Local pottery nearly disappeared. Regional, supra-regional and imported wares made their way to the tall, either directly or via Gadara. The large amount of high quality and even imported pottery let Tall Zar‘a appear as an important subsidiary of Gadara.
- During the entire Islamic period, the tall remained sparsely settled and the amount of pottery found is small. It seems that the tall possessed a small local production again in some periods — but



14. Origins of tall's pottery in different eras.

only for utilitarian wares. The main part of the pottery found appears to be produced regionally and supra-regionally.

Development of Pottery Technology (FIG. 15)
Generally, pottery consists of plastic (pc) and non-plastic (npc) components. The interaction of these

two types of components can be illustrated using the example of a wall:[15] The plastic components are like mortar — it can be moulded when wet, but during the drying and firing process its form can alter and has no outstanding strength by itself. The pc consists of minerals, which basically contain aluminium and silicon (e.g. feldspars). The npc are like the bricks, which gives its hold and strength to a wall; the most frequent non-plastic components are calcite and/or quartz.

One of the potters' skills was finding or mixing clays that had the right ratio of plastic to non-plastic components, so that it was both workable and durable. They also had to make sure the clay contained the different types of non-plastic components, e.g., quartz and calcite in the right concentration.[16]

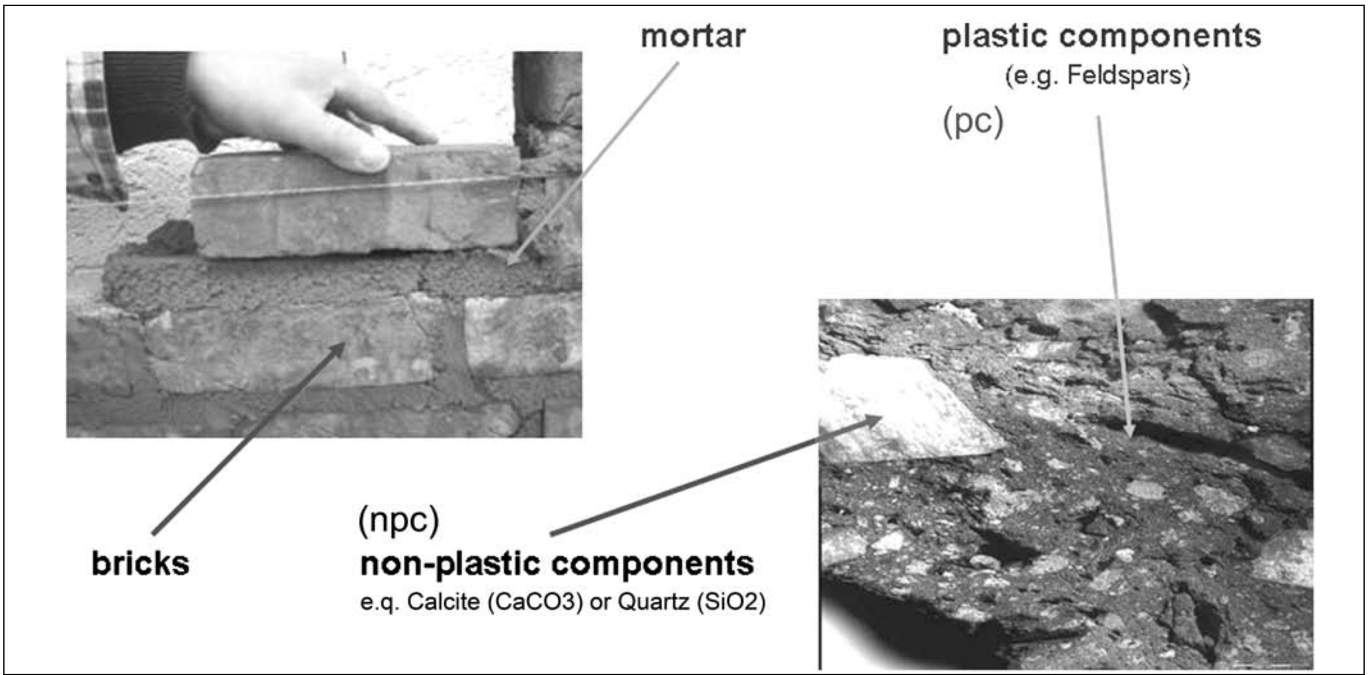
These skills were especially important for processing the cooking vessels, as they had to be very resistant (Vilders 1991/2: 69-81). They were used on a daily basis and were in so far subject to a great deal of strain. The walls of such vessels were put under great thermal (temperatures on the fireside of more than 1000°C and internal <100°C) and sometimes also under mechanical stress (when toppled or dropped).

The knowledge of the chemical and mineralogical composition makes it possible to estimate the proportion of the non-plastic (and plastic) components as well as the content of quartz and/or calcite.

The following diagram (FIG. 16) shows that the cooking pot ware developed during the Middle/Late Bronze (MB/LB) and Iron Age (IA) by reducing the part of non-plastic components (npc/triangles) from >60% to 40-45% and remaining at this level until the Roman Byzantine (rom-byz) period. Until the Iron Age I/II, the calcite content (rhombi) remained at a high level (approx. 48%) and the quartz content (rectangles) remained at a low level of 3-14%.

It seems that in all cooking pot wares of these periods of time, high calcite contents were a guarantee of good thermal behaviour and were — so to say — the trademark of the cooking vessels.[17]

The cooking pot wares WM 0610-1/WM 0610-2 as well as the cooking pot type WM 0610TZ-f, which was first discovered on the tall, appear to indicate a certain paradigm shift: The share of npc

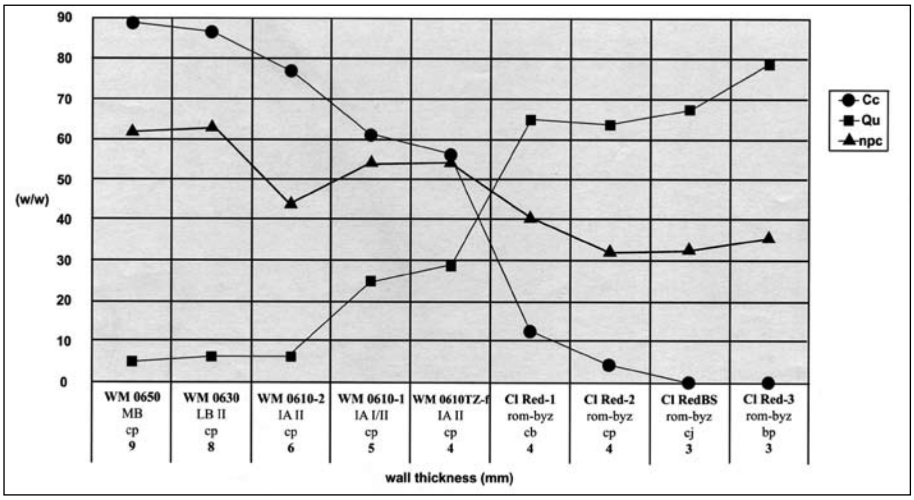


15. Plastic and non-plastic components in pottery.

[15] It is obvious that in a wall the ratio of pc and npc as well as the chemical and mineralogical composition is quite different to pottery.

[16] Beside that, potters intentionally add materials (temper) to the clay, for example to decrease the plasticity, to reduce shrinkage in drying, to increase the strength of the fired pottery, etc. The temper can be quartz, crushed rocks (e.g. calcite), organic materials (e.g. straw), etc.

[17] According to common theory, calcite, included in form of smaller or larger crystals (temper), has an optimal thermal expansion coefficient — like many other inclusions (Rice 1987: 228-230). A similar effect is apparently caused by mica which is present in most of the examined cooking pots from the tall in the form of the mineral illite.



16. Correlation between content of non-plastic components, calcite, quartz and wall thicknesses of cooking vessels in various eras.
npc = non-plastic components
Cc = Calcite
Qu = Quartz
cp = cooking pot
cb = cooking bowl
cj = cooking jar
bp = baking plate

shrinks to values of about <45% and the quartz content increases up to 16% at the expense of the calcite content of approx. 30%.

The real paradigm shift, however, was to occur in the Roman period. Some Roman classic red (Cl Red 1) cooking vessels still have a relatively high npc share (40%) but their quartz content is already high (25%) and accordingly the calcite content low (<5%). However, it can generally be said that in most of the Roman cooking vessels of classic red (Cl Red 2 + 3) and classic red black slipped (Cl Red BS) the non-plastic shares lie at approx. 30%, whereas quartz increases up to approx. 25% at the expense of calcite which is as low as 0%.

With both decreasing calcite (and the non-plastic part) and increasing quartz content, the walls of the vessels became thinner so that WM 0610TZ-f already reached a thickness of vessels' wall comparable to those of the Roman-Byzantine wares.[18] With thinner walls (and optimized composition) the cooking vessels became lighter and thermal properties improved.

The analyses of many firing and refiring experiments show that pottery with high calcite contents (WM 0610TZ-f/WM 0610/WM 0630/WM 0650; MB, LB, IA) was fired at temperatures between 550-700°C (Rice 1987: 98)[19] and that with high quartz contents like classic red and classic red black slipped (Cl Red and Cl Red BS/Roman-Byzantine) at temperatures up to 900°C, sometimes even more than 1000°C.

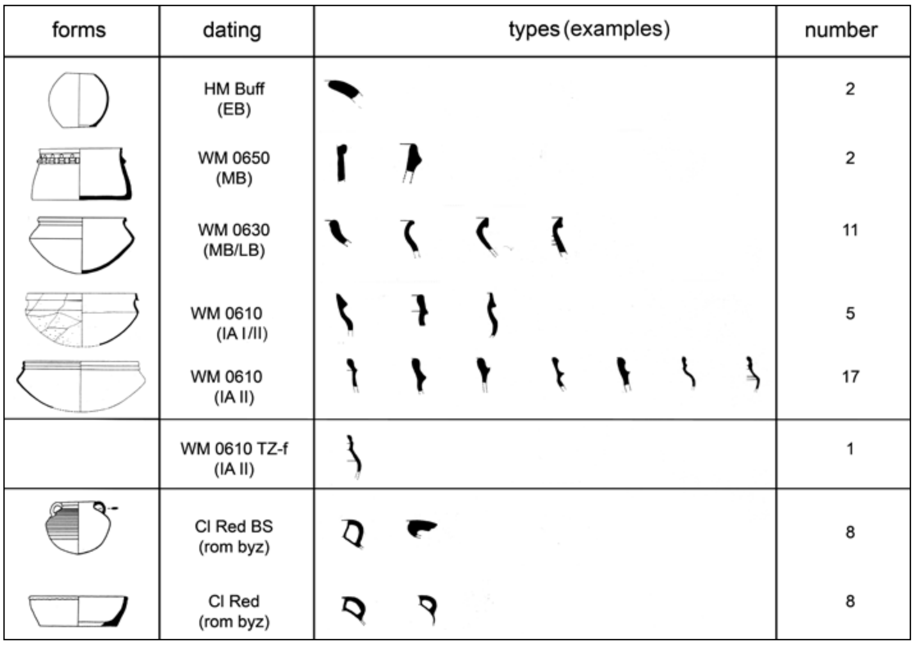
Altogether, it seems that over time better and better workable clays as well as improved processing techniques supported potters' creativity enormously (FIG. 17). This cannot only be shown by the decrease of the thickness of vessels' wall but also by an increasing number of types/shapes: From two during EB (HM Buff) to 23 during IA I/ II (WM 0610-1/WM 0610-2, inclusive WM 0610TZ-f).

Amazingly, the number of Roman-Byzantine cooking vessel types is lower than that of Iron Age I/II, although the Romans seemed to have the knowledge of optimal clay composition and of adequate (especially firing) technology at their disposal. The reason for this apparently lies in the fact that Romans' processing of common ware was already mechanised and standardized — and in the late Roman era already "industrialized". Therefore individual creativity (in form of small local workshops) in terms of various types was no longer needed (Homès-Fredericq and Franken 1986: 227f).

The development of the Roman cooking vessels cannot be seen in the context of the regional 'evolution' of Palestinian cooking pot wares as their origins lay in Europe (Italy) and more or less 'standardized' processing methods were exported to all parts of the Roman Empire. That is why imports from all parts of the Near East can be found (Schneider 2000: 525-536).

[18] According to the statistical analyses of the thickness of the vessels' wall of the cooking pot wares from the tall, the values in Figure 16 are the most frequent ones (Gauss distribution). Therefore it is obvious that there also exist thinner and thicker walls. The second most frequent thickness of WM 0610TZ-f is 3mm, whereas the Roman cooking vessels sometimes are thinner.

[19] Calcite ($CaCO_3$) decomposes at temperatures of >700°C forming CO_2 and CaO (lime). As lime is hygroscopic, it absorbs H_2O and forms 'quicklime' [$Ca(OH)_2$]. This process is accompanied by volume expansion, so that the surrounding clay body can be cracked if the lime particles are comparatively large ('lime popping').



forms	dating	types (examples)	number
	HM Buff (EB)		2
	WM 0650 (MB)		2
	WM 0630 (MB/LB)		11
	WM 0610 (IA I/II)		5
	WM 0610 (IA II)		17
	WM 0610 TZ-f (IA II)		1
	Cl Red BS (rom byz)		8
	Cl Red (rom byz)		8

17. Development of types of cooking pot wares during various eras.

Such a ‘Roman’ development of cooking vessels could not take place on Tall Zar‘a (or on a regional basis) in the Iron Age or later because:

- Local clays have high calcite and relatively low quartz contents and
- High firing temperatures (>900°C) were necessary, but could not be achieved by using the kilns, which were common during Iron Age.

In summer 2006 it was demonstrated that the only pottery that could be formed and fired using the clays from Gadara and Tall Zar‘a was similar to the ancient local utilitarian wares (FIG. 18). Firing temperatures of up to 650-750°C were achieved with a Late Bronze Age-style kiln (Eiland 1998/1999: 69-83) that was built (solely) out of clay. The kiln worked perfectly and the yield of undamaged vessels was over 90%. The kiln failed to produce higher temperatures (>900°C) because with a 6 cm thick clay wall insulation was not sufficient; too much of the heat was emitted.

In order to achieve higher (‘Roman’) temperature (>900°C), the design of the kiln would have to be different, for example, by making the walls out of stones (and clay) to achieve an improved insulation and/or by adding one or two firing chambers

18. Building a prehistoric kiln (for pottery) and scrutinizing the burning process.

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