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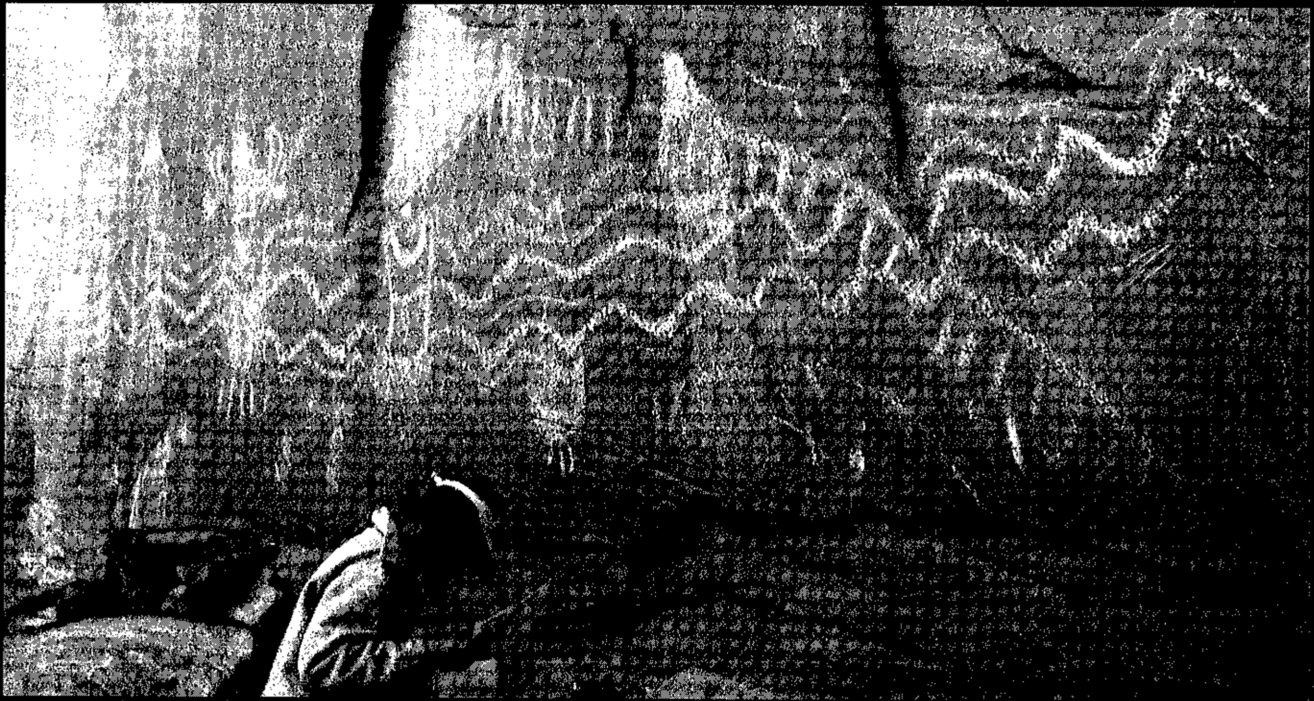

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Ceramics from Roman Galilee: A Comparison of Several Techniques for Fabric Characterization

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An extensive local provenience study of common pottery from Roman Galilee and Golan was carried out, employing neutron activation analysis. This pottery was then examined by binocular microscopy, xeroradiography, and thin-section analysis and the results compared with the grouping by neutron activation analysis in order to evaluate the effectiveness of the former techniques for classifying these ceramic fabrics. It was found that xeroradiography alone would have led to the incorrect categorization of the pottery corpus, even at the level of major fabric groups. Thin-section analysis, on the other hand, was seen to be an effective means for sorting the collection into major fabric categories that comport with those defined by neutron activation analysis. In some cases, the description of micromorphological subgroups, comparable to the compositional subgroups distinguished by neutron activation analysis, was also possible. This discriminating classification by thin-section analysis was achieved by study of both the pottery matrix and its mineral composition. A description of this dual approach and its importance for pottery classification is presented.

Introduction

One of the principal tasks of an excavation team is the publication of a meaningful classification of the recovered ceramic material. A number of techniques, involving visual examination as well as mineralogical, chemical, or structural and microstructural analysis, have been used for characterizing and subsequently classifying ceramic fabric (Bishop, Rands, and Holley 1982; Rice 1987: 371–446). This paper compares the effectiveness of several of these techniques.

The stimulus for this study was an ongoing project examining local provenience and trade in common pottery through the use of neutron activation analysis (NAA). This work made it possible to assign a site-specific manufacturing provenience to the majority of the common pottery (cooking, storage, and other wares) used in the Palestinian Galilee during Roman and early Byzantine times, ca. 50 B.C. through ca. A.C. 430. It has been shown that this Galilean pottery and the contemporaneous cooking ware from the central and southern Golan belong to three major chemical compositional groups, which include 12 distinct subgroups (Adan-Bayewitz and Perlman 1985, 1990; Adan-Bayewitz 1985, in press a). For this study, pottery vessels from these compositional groups were examined using thin-section analysis, xeroradiography, and binocular microscopy, and the results compared with the evidence from neutron activation analysis.

Previous work has shown that, in a region of relatively homogeneous soil composition, petrography compares favorably with neutron activation analysis as an effective means for distinguishing pottery made in that vicinity from other, imported wares (Goldberg et al. 1986; McGovern, Harbottle, and Wnuk 1986).[1] In the project described here, in contrast, much higher definition could be attained because of the heterogeneous soil composition in the regions of interest and the large number of analyzed samples (cf. Hughes and Vince 1986). These samples, as mentioned, could be assigned to several major compositional groups, including a number of subgroups. This discriminating categorization by NAA seemed useful for evaluating the effectiveness of other, more rapid and less costly techniques for fabric characterization.

Radiography and xeroradiography (Carr and Riddick 1990), the latter an edge-enhancing radiographic technique (Heinemann 1976; Alexander and Johnston 1982;

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[1] For a comparative fabric study of a collection of Punic amphoras found at Corinth, employing optical emission spectroscopy, petrological analysis, radiography, and other techniques, see Maniatis et al. 1984.

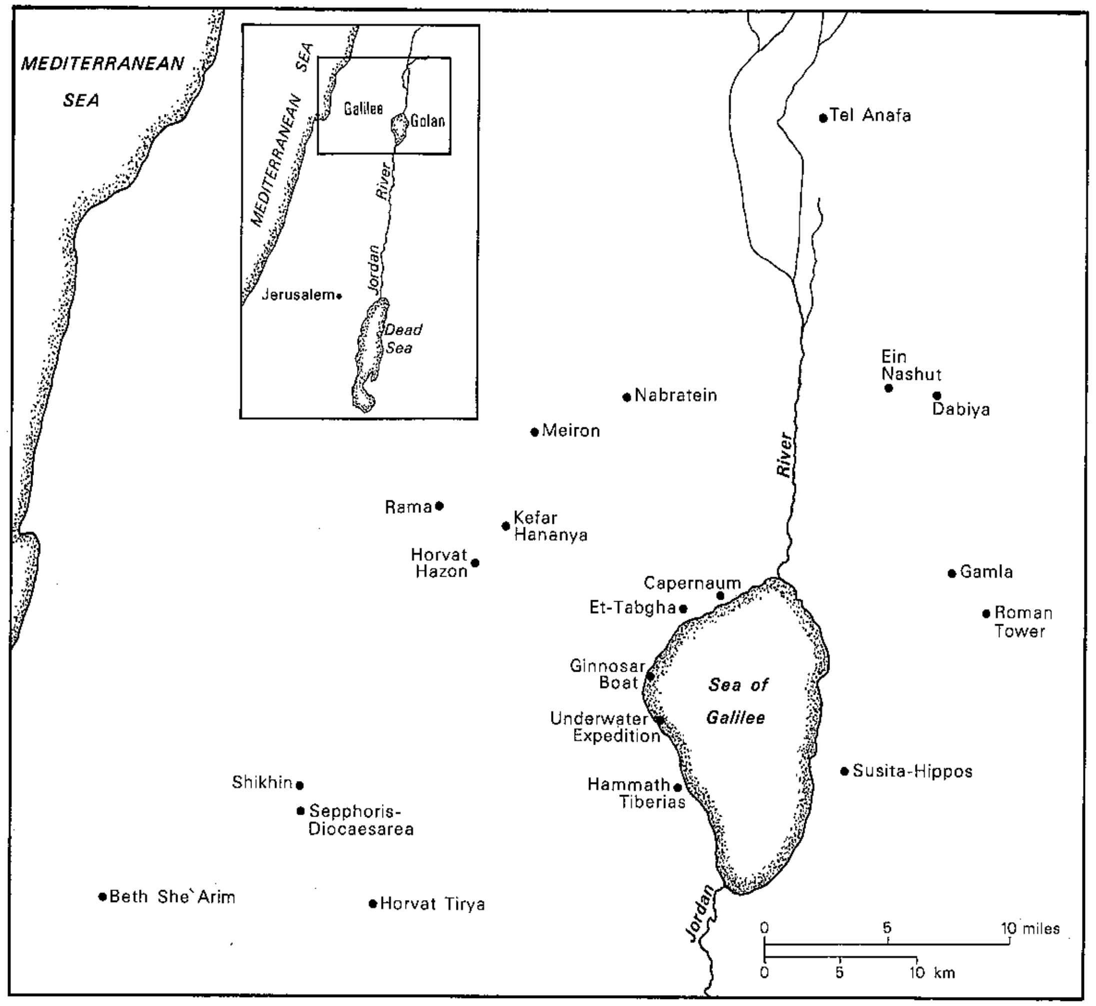

Figure 1. Map of the Galilee and Golan showing sites from which pottery samples were selected for neutron activation analysis. The boxed area in the inset is shown in the large map.

Foster 1985, 1986), have been effectively employed for elucidating pottery fabrication methods in a number of studies (Rye 1977; Betancourt 1982: 185; Foster 1983; Glanzman 1983, 1987; Glanzman and Fleming 1985, 1986a, 1986b; Carr 1990: 15–18).[2] Radiography has also been employed for a diachronic regional study of temper particle density in pottery distinctive for its variation in temper characteristics (Braun 1982). With varying degrees of success, radiography and xeroradiography have been used to compare different ceramic wares on the basis of fabric inclusions (Maniatis et al. 1984: 211, 213; Glanzman and Fleming 1986b: 170, 172, 174; McGovern, Harbottle, and Wnuk 1986: 178; Blakely, Brinkmann, and Vitaliano 1989; Carr 1990: 27–29). The effectiveness of xeroradiography as a routine method for classifying archaeological ceramics, however, has not been established by systematic comparison with other methods for fabric characterization. ~~For example,~~ Binocular microscopic examination is a rapid means for scanning a pottery collection (Shepard 1985: 140–141, 160–161; Bishop, Rands, and Holley 1982: 281, 283–284), and we wished to assess the effectiveness of this method for fabric classification.

A further purpose of the study was to seek effective and inexpensive techniques for quickly sorting vessel fragments into the provenience groups previously established by neutron activation analysis. Such rapid sorting would facilitate the processing of excavated collections from the general distribution area of the provenience groups. By expediting the classification of vessel fragments, including body sherds, it would also facilitate comparative studies of these provenience groups and of specific vessel forms, such as the investigation of thermal shock resistance (Schuring 1986), and identification of vessel contents from residues retained in the walls (e.g., Condamin et al. 1976).

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[2] For earlier applications of radiographic techniques to the study of ceramics, see the survey in Glanzman and Fleming 1986b. See also the recent survey by Carr (1990) on ceramic radiography.

Background: The Provenience Studies

The Galilee in the Roman period is associated with developments fundamental to the history of Western civilization. The extent and nature of contact between the Galilee and other regions, and within the Galilee itself, between its cities and villages, and between its Jewish, pagan, and early Christian communities, has for that reason been a subject of considerable scholarly interest (see, e.g., Schürer 1979: 52–80; Meyers 1976, 1985; Safrai 1983; Freyne 1988: 135–175). Extensive literary sources relate to the Galilee in this period, but with respect to interregional and intraregional contact these texts are often ambiguous and are in any case insufficient to provide an adequate picture (Goodman 1983: 41–46, 54–63). In order to learn more about such contact from the archaeological evidence, Adan-Bayewitz and Isadore Perlman set out to determine the origins, and trace the distribution, of the common pottery used in the Galilee and neighboring Golan during the Roman period.

It was realized at the outset that the problem of localization of provenience would not be easily resolved. The Galilee is a relatively small area (FIG. 1), and the pottery found at its many ancient settlements seemed indistinguishable from one site to another. The common pottery of the neighboring Golan, moreover, is much the same in form as that of the Galilee. Under these circumstances, it was decided to employ neutron activation analysis for the provenience work. This technique, although costly, features sensitive differentiation and accurate measurement of a wide array of chemical elements in pottery and clays, and is therefore particularly suitable for local provenience studies that require high resolution (Perlman and Asaro 1969; Bishop, Rands, and Holley 1982: 288–300).

The project, begun in 1981 at the Archaeometry Laboratory of the Hebrew University of Jerusalem, has continued, now with the collaboration of Frank Asaro and Helen V. Michel of the Lawrence Berkeley Laboratory in California. Elemental abundances measured by NAA at these two facilities have been shown to agree (Yellin et al. 1978).

Pottery collections from 19 excavated sites and one surveyed site in the Galilee and Golan (FIG. 1) have been sampled for NAA. Sites were selected with the aim of investigating modes of trade, markets, and socioeconomic relations (interregional and intraregional, urban-rural, and interethnic trade) in these locales, while samples were chosen to include the most common vessel forms recovered at these sites in Roman contexts. More than 350 pottery pieces have so far been analyzed.

The determination of manufacturing provenience by laboratory analysis depends upon matching the composition of the pottery of interest with that of source material. In the course of the present project, which eventually dealt with several distinct provenience problems, several different types of source material have been used. Thus, for one pottery compositional group, discussed below as the Kefar Hananya Group, source material included clay samples from the vicinity of the site of Kefar Hananya and kiln wasters from excavations at the site (see below). For a second pottery compositional group, discussed below as the Shikhin Group, pottery vessels of limited geographical distribution and kiln wasters served as source material.

Rabbinical literary sources from Roman Galilee provided important clues for locating the Galilean sites of Kefar Hananya and Shikhin[3] and indicated that both settlements were pottery-making centers. These texts also supplied supplementary information for localizing the provenience of one of the above pottery compositional groups. Three distinct pottery forms are specifically mentioned as having been made at Kefar Hananya, while a fourth form, a storage jar, is noted as a product of Shikhin. The "Shikhin storage jar" was so well known by about the mid-2nd century A.C. that the measure of its volume could be used as a standard for purposes of religious law (*Tosefta Terumot* 7.14; *Talmud Yerushalmi Terumot* 45d).[4] Neutron activation analysis of the most common class of storage jars found in Galilean contexts dating from the late 1st century B.C. to about the mid-3rd century A.C. showed that they share a common chemical composition. This composition matched that of the source material (wasters and pottery vessels of limited distribution) for the second pottery compositional group mentioned above (Adan-Bayewitz in press a; Adan-Bayewitz and Perlman 1990).

The matching compositions of the two pottery compositional groups and the respective source materials showed that most of the common pottery vessels used in

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[3] On the identification of Shikhin, see Strange, Groh, and Longstaff in press.

[4] *Tosefta*, literally, "addition," i.e., addition to the *Mishnah* (earliest rabbinic book of Jewish law, edited in the early third century A.D. by Judah the Patriarch), is a collection of laws and teachings, closely related to the Mishnah, of the rabbinic scholars of Palestine active from the first until the early third century A.D. *Talmud Yerushalmi* (literally, "Jerusalem Talmud," also known as the "Palestinian Talmud") is a work completed in the late fourth or early fifth century A.D., containing the commentary and discussions, mainly of the Palestinian rabbis, on the Mishnah. Both the Tosefta and the Talmud Yerushalmi were first printed in Venice, in 1521 and 1523–1524 respectively, and have since been republished many times.

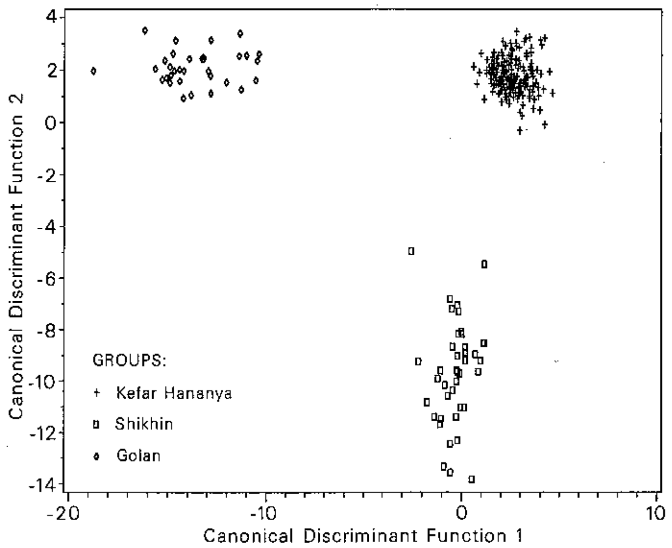

Figure 2. Discriminant analysis plot illustrating the compositional distinctiveness of the Kefar Hananya, Shikhin, and Golan provenience groups.

the Galilee in the Roman period were apparently made at two manufacturing centers, Kefar Hananya and Shikhin (FIG. 1). Although site-specific provenience has not been established for the Golan pottery groups, the similarity in composition between the Golan compositional groups and sampled Golan clays, as well as the limited geographical distribution of the Golan pottery groups (in marked contrast to the distribution patterns of the Kefar Hananya and Shikhin pottery groups), suggest that the Golan compositional groups were locally made (Adan-Bayewitz and Perlman 1985, 1990; Adan-Bayewitz in press a).

Consequently, most of the common vessel forms of Roman Galilee and Golan could be assigned to three major provenience groups: the Kefar Hananya, Shikhin, and Golan Groups (TABLES 1, 2). When comparing the compositions of these three groups, we note especially that the calcium abundances are unusually low in both the Kefar Hananya and the Golan Groups, ranging from about 1 to 2%, in contrast to the Shikhin Group in which the mean calcium abundance is about 9%, and the calcium values are quite variable.[5]

In the plot shown in Figure 2, these three groups are compared using discriminant (canonical variate) analysis (Adan-Bayewitz and Perlman 1990). The analysis includes 18 chemical elements, and each symbol represents one sampled vessel. The compositional distinctiveness of the three major groups is apparent.

Each of the two major Galilean provenience groups included compositional subgroups that deviated somewhat from each other (TABLE 1). The Kefar Hananya Group included a Main Group with 154 pieces, and two compact groups of 10 and 16 members, denoted Group Y and Group A respectively (TABLE 1, columns 1–3).[6] The Shikhin Group comprised three subgroups (with 24, 9, and 4 pieces respectively) whose elemental abundances were seen to differ from each other by constant factors (TABLE 1, columns 4–6). Such a systematic discrepancy can only be explained by simple dilution or concentration. Since the calcium abundances were quite variable in the Shikhin Group and calcium was generally higher in the subgroup with the lowest abundances for the other elements (Shikhin Group 2; TABLE 1, column 5), the diluent in the present case seemed to have been calcareous material, varying amounts of which were apparently added to the clay of the three subgroups (Adan-Bayewitz and Perlman 1990; see also below).[7]

The six Golan Groups differed significantly in composition (TABLE 2). All shared the same distinctive characteristics, however, and, as mentioned, there was good evidence that these groups were made in the Golan.

In the wake of the analytical study of the Kefar Hananya and Golan pottery groups and of clay samples from three areas of the Galilee and Golan (Adan-Bayewitz and Perlman 1985; Adan-Bayewitz 1985), excavations were initiated at Kefar Hananya with the aim of learning more about pottery manufacture at that site (modes of production, technology, typology and chronology of specific vessel forms) and of clarifying the settlement history. Among the finds unearthed in three seasons of excavations conducted by Adan-Bayewitz on behalf of Bar-Ilan University at Kefar Hananya were a pottery kiln of late Roman date with a stone-paved approach and remains of an outer structure apparently associated with the pottery workshop; two successive plaster-lined structures that may have served as clay soaking pools; a pottery dump overlying the destroyed kiln, including the estimated equivalent of 9500 to 13,000 whole vessels—about 98% of which were of two forms—apparently ruined in the process of manufacture; and pottery wasters (unfired fragments, partially vitrified pieces, warped examples, vessels fused to one another, and pottery cracked during firing) of early Roman, middle Roman, and late Roman-early Byzantine date (Adan-Bayewitz 1987, 1989, in press b).

Table 1. Element abundances of the Kefar Hananya and Shikhin compositional groups. The values for the elements in each group are the mean and standard deviation for the group. All elements are in units of parts-per-million unless indicated by the % sign.

	Kefar Hananya			*Shikhin*		
	Main Group 154 *members*	*Group Y* 10 *members*	*Group A* 16 *members*	*Group 1* 24 *members*	*Group 2* 9 *members*	*Group 3* 4 *members*
Ca%	1.4 ± 0.4	1.0 ± 0.3	1.4 ± 0.3	8.3 ± 1.8	10.2 ± 2.0	8.9 ± 0.4
Ce	143.4 ± 14.6	153.9 ± 11.0	122.5 ± 10.9	107.4 ± 7.8	91.6 ± 4.0	100.9 ± 2.6
Co	38.4 ± 6.0	42.9 ± 3.0	31.7 ± 5.0	29.8 ± 4.8	24.7 ± 1.8	27.5 ± 1.5
Cr	181.2 ± 7.2	199.2 ± 2.4	183.2 ± 4.4	203.9 ± 12.8	180.6 ± 9.5	195.1 ± 11.0
Cs	2.95 ± 0.52	3.18 ± 0.36	3.30 ± 0.19	2.73 ± 0.26	2.05 ± 0.34	2.53 ± 0.11
Eu	2.56 ± 0.15	2.68 ± 0.09	2.39 ± 0.07	2.07 ± 0.07	1.82 ± 0.04	1.93 ± 0.04
Fe%	6.31 ± 0.29	6.96 ± 0.34	6.60 ± 0.27	5.72 ± 0.22	5.09 ± 0.16	5.36 ± 0.06
Hf	15.46 ± 1.00	16.05 ± 0.90	14.13 ± 0.80	11.41 ± 0.84	9.38 ± 0.52	10.45 ± 0.40
La	54.76 ± 3.26	57.68 ± 2.36	50.98 ± 1.70	45.21 ± 1.56	39.99 ± 1.11	43.16 ± 0.94
Lu	0.76 ± 0.04	0.80 ± 0.04	0.76 ± 0.02	0.63 ± 0.03	0.54 ± 0.03	0.60 ± 0.03
Na%	0.27 ± 0.05	0.23 ± 0.02	0.22 ± 0.01	0.33 ± 0.07	0.31 ± 0.05	0.35 ± 0.15
Sc	20.37 ± 0.81	20.89 ± 0.89	21.48 ± 0.67	18.81 ± 0.68	16.74 ± 0.50	17.67 ± 0.12
Sm	10.32 ± 0.56	10.74 ± 0.34	9.60 ± 0.22	8.39 ± 0.26	7.26 ± 0.18	7.82 ± 0.15
Ta	2.28 ± 0.08	2.36 ± 0.05	2.29 ± 0.05	1.75 ± 0.10	1.53 ± 0.09	1.63 ± 0.04
Th	13.34 ± 0.51	14.27 ± 0.58	13.15 ± 0.17	11.03 ± 0.44	9.51 ± 0.28	10.01 ± 0.23
Ti%	1.06 ± 0.07	1.12 ± 0.05	1.08 ± 0.04	0.81 ± 0.05	0.73 ± 0.03	0.77 ± 0.02
U	3.47 ± 0.33	3.73 ± 0.19	3.65 ± 0.12	4.02 ± 0.52	3.72 ± 1.08	4.31 ± 0.32
Yb	5.26 ± 0.27	5.42 ± 0.29	5.00 ± 0.17	4.28 ± 0.19	3.84 ± 0.18	4.18 ± 0.26

On the data for the Kefar Hananya and Golan groups, see also Adan-Bayewitz, in press a, chapters IV and VII, Tables 1, 6, and 7, and figures 3–8. For the Shikhin group, see also Adan-Bayewitz and Perlman 1990.

Table 2. Element abundances of the Golan compositional groups. See Table 1 for explanation of data.

	Group 1A 13 *members*	*Group 1B* 5 *members*	*Group 2* 3 *members*	*Gamla 1* 3 *members*	*Gamla 2* 3 *members*	*Susita Group* 6 *members*
Ca%	1.2 ± 0.2	1.1 ± 0.2	1.6 ± 0.3	1.5 ± 0.2	1.9 ± 0.4	1.5 ± 0.3
Ce	150.2 ± 7.3	129.5 ± 8.7	163.8 ± 4.6	189.3 ± 5.8	121.3 ± 7.5	146.9 ± 6.0
Co	58.7 ± 6.6	48.2 ± 8.8	63.7 ± 1.3	78.8 ± 8.3	52.2 ± 4.2	69.7 ± 3.8
Cr	289.6 ± 15.3	284.3 ± 21.8	261.2 ± 6.5	266.0 ± 25.5	257.8 ± 15.4	349.5 ± 29.0
Cs	1.43 ± 0.35	0.86 ± 0.10	1.00 ± 0.18	1.61 ± 0.22	1.95 ± 0.35	1.53 ± 0.38
Eu	2.54 ± 0.12	2.25 ± 0.14	3.13 ± 0.18	2.92 ± 0.03	2.56 ± 0.03	2.43 ± 0.08
Fe%	6.50 ± 0.29	5.78 ± 0.20	8.22 ± 0.63	6.65 ± 0.38	8.05 ± 0.20	7.17 ± 0.38
Hf	18.56 ± 1.09	18.59 ± 0.82	15.88 ± 1.08	17.90 ± 0.31	12.97 ± 1.77	16.61 ± 0.58
La	48.49 ± 1.75	42.05 ± 1.93	57.45 ± 2.49	53.57 ± 1.24	45.45 ± 1.05	46.00 ± 1.52
Lu	0.65 ± 0.03	0.61 ± 0.02	0.60 ± 0.04	0.67 ± 0.06	0.64 ± 0.05	0.64 ± 0.03
Na%	0.35 ± 0.05	0.39 ± 0.02	0.28 ± 0.02	0.32 ± 0.05	0.42 ± 0.02	0.40 ± 0.05
Sc	17.18 ± 0.91	15.28 ± 0.38	18.65 ± 0.66	17.60 ± 0.30	22.15 ± 0.71	19.02 ± 0.73
Sm	9.27 ± 0.33	8.20 ± 0.37	10.67 ± 0.41	10.30 ± 0.08	9.06 ± 0.21	9.56 ± 0.87
Ta	2.45 ± 0.08	2.26 ± 0.08	3.12 ± 0.16	2.48 ± 0.06	2.36 ± 0.14	2.61 ± 0.10
Th	10.04 ± 0.51	9.25 ± 0.49	9.50 ± 0.43	10.08 ± 0.28	10.02 ± 0.36	10.29 ± 0.47
Ti	1.41 ± 0.07	1.32 ± 0.07	1.52 ± 0.07	1.41 ± 0.04	1.30 ± 0.08	1.39 ± 0.05
U	3.83 ± 0.18	3.36 ± 0.26	3.78 ± 0.15	3.67 ± 0.12	3.68 ± 0.28	3.04 ± 0.16
Yb	4.44 ± 0.18	4.13 ± 0.16	4.09 ± 0.22	4.53 ± 0.30	4.46 ± 0.21	4.26 ± 0.10

The Pottery Groups

The pottery repertory produced at Kefar Hananya in the course of the Roman period comprised six major functional types, including 18 distinct forms, most of which were used for cooking: cooking bowls, bowls, "casseroles," cooking pots, wide-bodied jugs with shoulder handles, and jugs (FIGS. 3, 4). The Golan repertory included

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[5] A comparison of the compositions of the two Galilean provenience groups shows that there is no overlap between the abundances of Ca, Hf, Sm, Ta, and Th for the two groups, the latter four elements being significantly lower in the Shikhin Group. With respect to the Golan Groups we note that the abundances differ from those of the Kefar Hananya Group particularly for Cr, Cs, Th, and Ti, which cover a range in the Golan Groups, but with no overlap with that of the Kefar Hananya Group (Cr and Ti are higher in the Golan Groups, while Cs and Th are lower). There is also no overlap between the Golan and Shikhin Groups for Ca, Cr, Ta, and Ti, the latter three elements being significantly higher in the Golan Groups (TABLES 1, 2; Adan-Bayewitz and Perlman 1985, 1990; Adan-Bayewitz in press a).

[6] Group Y could be differentiated from the Main Kefar Hananya Group by its higher values for mafic elements Fe and Cr, as well as Th and Ti, while Group A is lower than the Main Group for the lanthanide elements, particularly La, Ce, Sm, and Eu (TABLE 1, columns 1–3; Adan-Bayewitz and Perlman 1985; Adan-Bayewitz in press a).

[7] The values of the Shikhin subgroups have been normalized for Figure 2 (Shikhin Group 2 × 1.14; Shikhin Group 3 × 1.08) (Adan-Bayewitz and Perlman 1990).

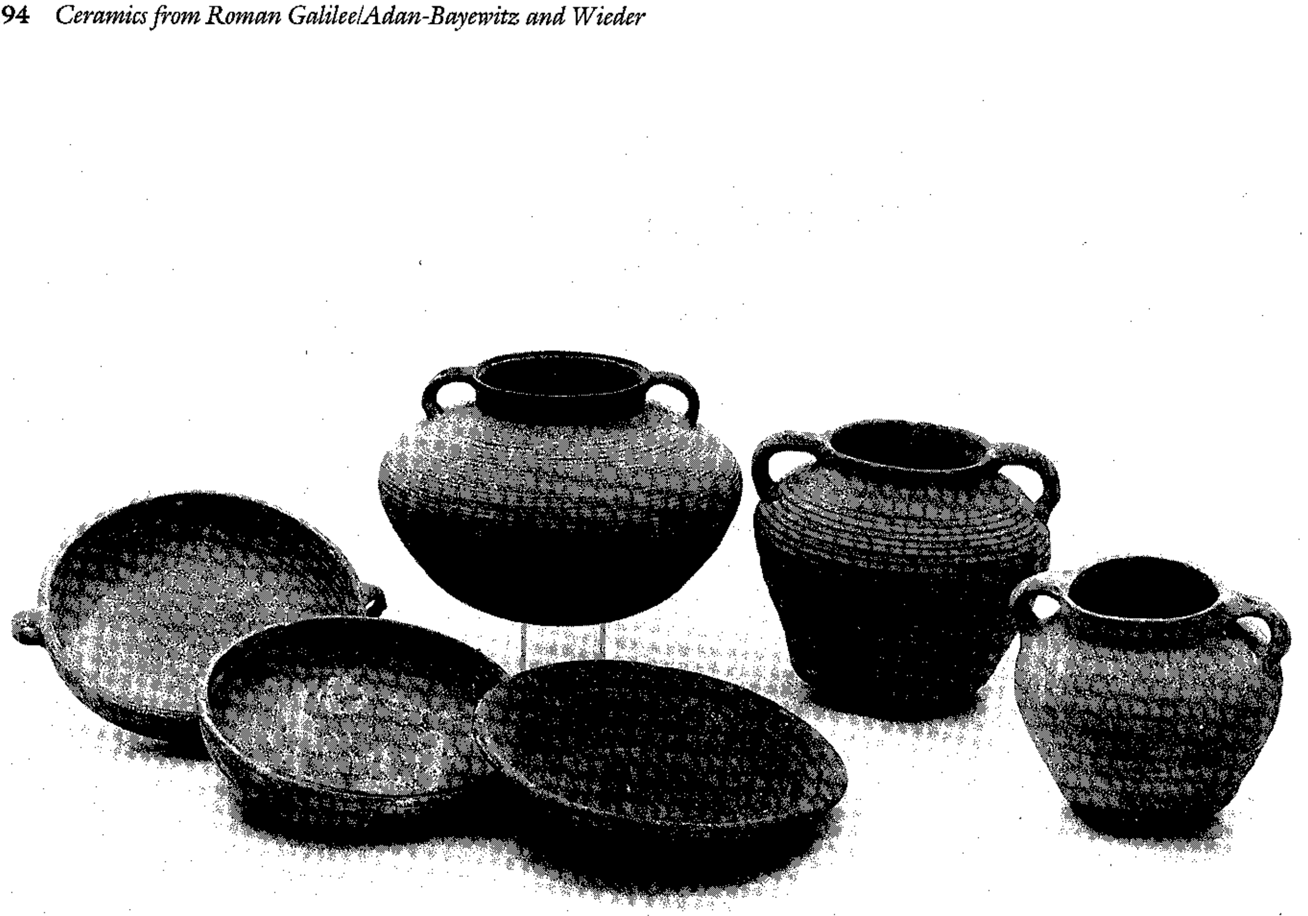

Figure 3. Complete examples of Kefar Hananya pottery: cooking bowls and cooking pots. Diameter of bowl at right: 20.5 cm. (Cooking bowls, left to right: Kefar Hananya Form 1B, 1A, and 1E; cooking pots, left to right: Kefar Hananya Form 4A, and 4D [two examples].) The vessels in Figures 3 and 4 are from eight sites in the Galilee and its vicinity; with the exception of the Form 1E bowl, from the Kefar Hananya excavations (Bar-Ilan University), all are from the collection of the Israel Antiquities Authority and are shown by permission. For registration numbers, see Adan-Bayewitz in press a. Photograph by Zev Radovan.

much the same forms as those of Kefar Hananya. The Shikhin Group, in contrast, included storage jars, kraters, bell-shaped bowls, jugs, and juglets (FIG. 5); there is no evidence for the manufacture of cooking ware at Shikhin.

The chronology of the Kefar Hananya ceramic repertory has so far been studied in the most detail. Pottery manufacture at that center began in the early Roman period, apparently around the mid-1st century B.C., and continued into the early Byzantine period, until about the early 5th century A.C. The manufacture of the Golan Groups seems to have been roughly contemporary, while production at Shikhin apparently ceased during the late Roman period (Adan-Bayewitz 1985, in press a; Adan-Bayewitz and Perlman 1990).

After their proveniences were determined, the pottery groups were examined to ascertain whether their fabrics could be distinguished by macroscopic inspection. Pottery of the Shikhin Group could be differentiated by both form and fabric from that of the Kefar Hananya and Golan Groups. With respect to the latter groups, however, it was found, on the one hand, that the majority of the pottery pieces of most of the Golan compositional groups were distinctly yellower in hue, darker in value, and duskier in chroma (purity) than the Kefar Hananya Group. In addition, certain Golan Groups could usually be distinguished by their gray interior cores. On the other hand, some of the Golan ware, and particularly the pottery from the Golan Susita Group, could not be differentiated by visual examination from that of Kefar Hananya. The fabrics of most of the Golan Groups could not be discriminated systematically from each other by visual inspection; and Groups A and Y could also not be systematically distinguished from the Kefar Hananya Main Group (Adan-Bayewitz in press a).

Figure 4. Complete examples of Kefar Hananya pottery. Front: "casseroles"; rear left and right: wide-bodied jugs with shoulder handles; rear center: cooking pot. Diameter of "casserole" at left: 16.5 cm. (Front, left to right: Kefar Hananya Form 3A and 3B; rear, left to right: Kefar Hananya Form 5B1, 4C, and 5A.) Photograph by Zev Radovan.

Methods

Thin-Section Analysis

Nineteen potsherds previously analyzed by NAA were chosen for petrographic analysis. The pieces were selected so that each of the 12 compositional groups would be represented by at least one sample; two or more samples were taken from the largest groups and from the Kefar Hananya subgroups. The analyzed examples came from 11 different sites in the Galilee and Golan and represented the principal chronological phases of each of the major compositional groups (Kefar Hananya, Shikhin, and Golan) (TABLE 3).

Thin-sections were prepared from each sherd and examined with a petrographic microscope by a petrologist unaware of the provenience of the individual pieces.

Previous petrographic reports on archaeological ceramics are based largely on mineralogical study, with minimal attention to the microfabric of the matrix. Although preparation and firing of pottery induced changes in the original microfabric of the soil materials, particularly with respect to density and especially in the fabric of the core area, most of the main features of the original soil materials could still be discerned, however. While taking these changes into account in our interpretation, the method developed by Brewer (1964) for thin-section analysis of soil materials could still be effectively employed for the description of the pottery samples.[8]

Xeroradiography

Thirty-nine pottery pieces previously analyzed by NAA were chosen for xeroradiography. All but two of the pieces analyzed by thin-section petrography, representing 11 of the 12 compositional groups, were also examined by xeroradiography. Three or more fragments were taken from

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[8] The relationship between soils and pottery will be dealt with in greater detail by the authors in a separate paper on pottery provenience.

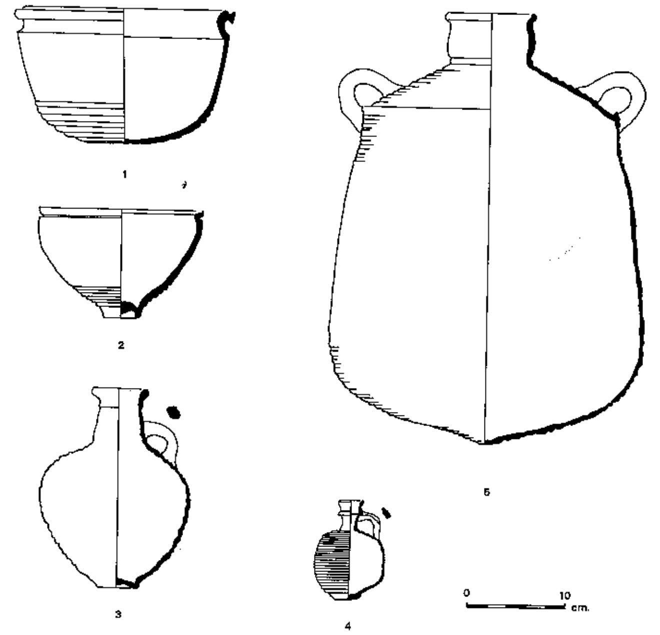


Figure 5. Complete examples of Shikhin pottery: krater, bell-shaped bowl, jug, juglet, and storage jar, respectively. The vessels shown are from four Galilean sites; for registration numbers, see Díez Fernández 1983: nos. 71, 191, 218, 538, 558.

10 of the groups. The samples came from 12 sites in the Galilee and Golan.

A General Electric Model 225 instrument was used with a Xerox 125 processor at the Mammography Section of the Ichilov Municipal Government Medical Center in Tel Aviv. The same exposure parameters were used for all pottery fragments: 100 milliamp.sec., 76 kV, and a 40-cm focal distance. Following the suggestions of Rye (1977: 210) and others, sherds were first grouped according to thickness, and each thickness group was exposed separately. It was found that variability in thickness did not significantly alter image quality.

Binocular Microscopy

An attempt was made to sort by binocular examination the vessels of the various compositional groups. A fresh break was examined for each piece.

Experimental Results

Thin-Section Description

KEFAR HANANYA GROUP

Samples 230 and 575 are very similar (TABLE 3); both are dense and red (2.5YR 4/8). The ratio of micromorphological components is about 60% plasma (clayey material), 35% skeleton grains (mineral grains and rock fragments) and 5% voids (pores). The skeleton consists almost exclusively of silt-size (30–100 μm) angular quartz grains. Other components are a few silt-size grains of augite, hornblende, and plagioclase. Occasional opaque silt-size grains and a few chert rock fragments also occur.

The plasmic fabric can be divided into two parts: the outer zones exhibit a mosepic, masepic, and skelsepic fabric, and the inner zone an asepic fabric (see Appendix for an explanation of technical terms). A few regular voids of about 500 μm appear as channels or vughs. Pedological features are iron nodules or concretions that include silt-size skeleton grains (FIG. 6).

Six other samples (TABLE 3) are very similar to samples 230 and 575, with the following differences:

Sample 366 has many short planes at carinated parts of the vessel. A few remnants of illuviation (clay accumulation in the B horizon) occur.

Sample 60 includes some carbonate rock fragments.

Sample 22 has occasional clear remnants of well-oriented red clay illuviation.

Table 3. Concordance showing grouping by neutron activation analysis of pottery samples also examined by petrographic microscopy. All sample numbers are prefixed by the "ADAN" project title, at Hebrew University and the Lawrence Berkeley Laboratory. The samples are from the following sites: Dabiya: 194, 196; Rama: 47; Kefar Hananya: 22, 121, 142; Horvat Hazon: 60; Gamla: 364, 366, 368, 378; Roman Tower: 274, 280; Ginnosar boat: 575; Susita-Hippos: 499; Hammath Tiberias: 327; Sepphoris-Diocaesarea: 529; Beth She‘arim: 230, 243. Samples 121, 194, 230, 274, and 499 are cooking bowls; 60, 196, and 368 are "casseroles"; 22, 243, 280, 364, 366, and 575 are cooking pots; 142 is a wide-bodied jug with shoulder handles; 327 and 378 are storage jars; and 47 and 529 are kraters.

Kefar Hananya	*Golan*	*Shikhin*
Kefar Hananya Main Group 60, 230, 366, 575	Golan 1A 196, 274	Shikhin 1 378, 529
Group A 22, 142	Golan 1B 280	Shikhin 2 327
Group Y 121, 243	Golan 2 194	Shikhin 3 47
	Gamla 1 368	
	Gamla 2 364	
	Susita 499	

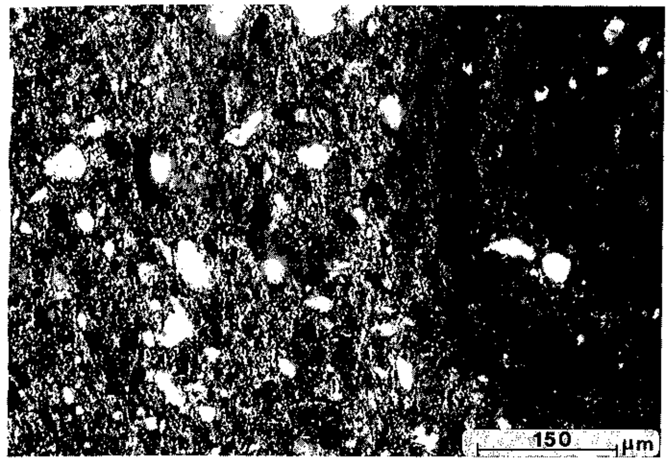


Figure 6. Pottery sample 575 (cooking pot from Ginnosar boat excavation). Photomicrograph of pottery (outer zone) prepared from Terra Rossa soil material, showing pronounced mosepic fabric (mosaic-like orientation), masepic fabric (zones with striated orientation), and iron nodule (large dark area on right, with inclusions of silt-size quartz grains). Note the similarity to the thin section of Terra Rossa soil material in Figure 7. All photomicrographs show thin sections under crossed-polarized light.

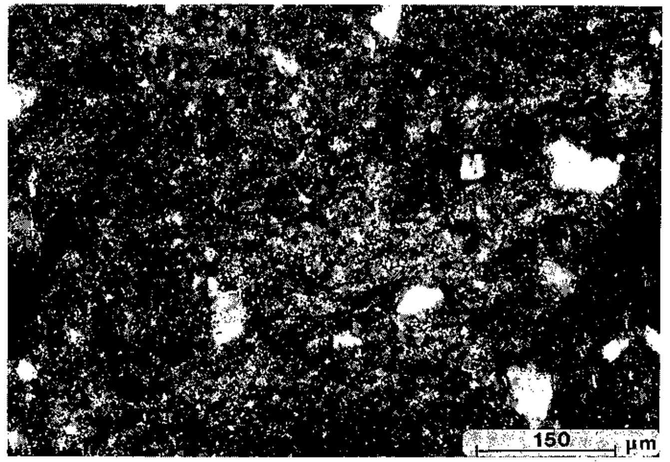


Figure 7. Pronounced mosepic and masepic fabric of Terra Rossa soil material from the Hananya Valley (a small valley bordering the site of Kefar Hananya to the west).

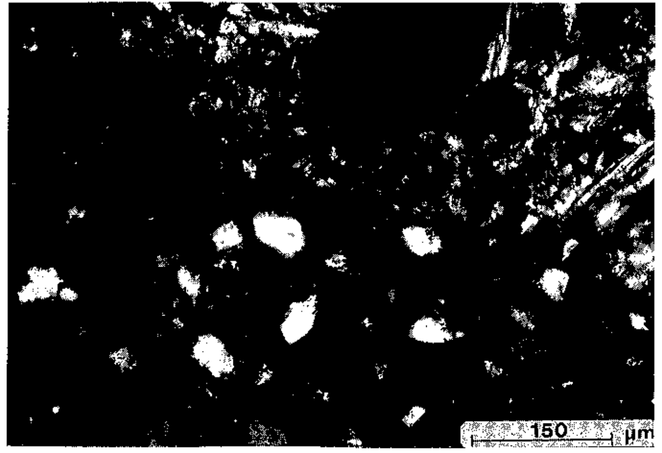


Figure 8. Pottery sample 368 ("casserole" from Gamla). The plasmic fabric is asepic to isotic (isotropic) with a basalt-derived rock fragment in the upper right corner. Note the similarity to the basalt-derived soil material in Figure 9.

Sample 121 includes somewhat more rock fragments.

Sample 142 has a somewhat more opaque plasma, and the plasmic fabric is more asepic. A few remnants of clay illuviation and a few calcareous rock fragments occur.

Sample 243 has a more opaque plasma, and the plasmic fabric is more asepic.

The microfabric of all the samples of this group is similar to that of Terra Rossa soils of the Galilee (FIG. 7), which are characterized by developed mosepic, masepic, and vosepic fabric. They contain many more voids (pores), in the form of vughs, channels, and planar voids (cracks), than are found in the fired pottery made from these soils. Following preparation and firing, the sepic fabric is still preserved in the outer zone, while the inner zone, although remaining optically anisotropic, now shows an asepic fabric. The voids have lost most of their natural distribution, and planar voids no longer occur. The change of the plasmic fabric from sepic to asepic by preparation and firing apparently indicates a partial destruction of the structure of the clay minerals.

GOLAN GROUP

Sample 368 is moderately dense. The material is red (10R 4/8) in the two outer zones and dark reddish brown (5YR 3/4) in the core. The proportions of components are about 60% plasma, 30% skeleton grains together with rock fragments, and 10% voids.

The skeleton consists mainly of silt-size quartz grains (50–100 μm). Silt-size augite grains are common, and a few large iddingsite and augite grains appear. Occasional basalt rock fragments and silt-size opaque grains also occur. The plagioclase crystals within the rock fragments are large.

The plasmic fabric is asepic to isotic (FIG. 8). The voids appear as channels or vughs of about 500–1000 μm. Very short planes (cracks), 2–10 μm wide and 200 to 300 μm long, also occur. The narrow voids are difficult to assess quantitatively, hence the voids may account for more than 10% of the total components. Pedological features are a few iron nodules and concretions.

Sample 364 differs from sample 368 in the following

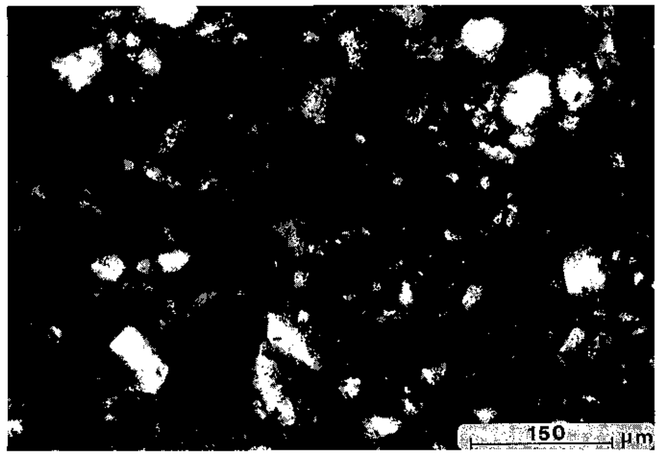


Figure 9. Asepic and isotic fabric of one type of basalt-derived soil material from the Golan.

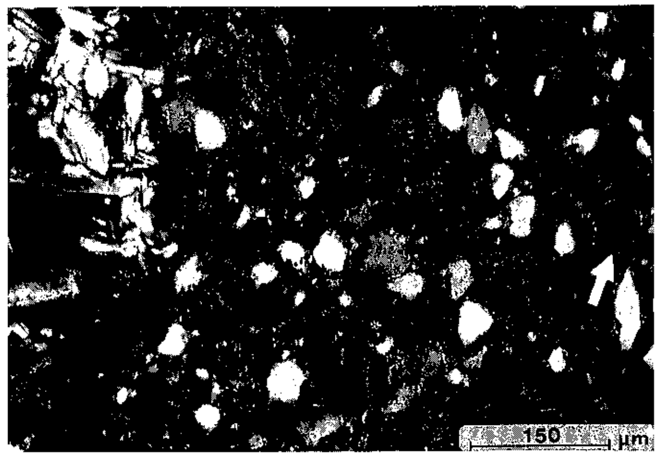


Figure 10. Pottery sample 280 (cooking pot from the Roman Tower), showing mosepic and skelsepic (see arrow, for example) fabric. A basalt-derived rock fragment appears at the upper left corner. Note the similarity to the basalt-derived soil material in Figure 11.

ways. The material is somewhat dense, dusky red (10R 3/4) in the outer layers and dark reddish brown (5YR 2.5/4) in the inner layer; some olivine grains occur, voids account for 35–40% of the fabric, and there are porous zones. The plasma is mostly opaque due to its higher iron content, and plasmic fabric is slightly asepic to strongly isotic. Some soil materials in the Golan are similar to samples 368 and 364 (FIG. 9).

Sample 194 differs from samples 368 and 364 in the following: the material is homogeneous and slightly to moderately dense with about 20% voids. Significantly more iddingsite grains occur. The plasma is red (2.5YR 4/6) to dark red (2.5YR 3/6) with many opaque iron oxide inclusions. The plasmic fabric is asepic.

Sample 280 is moderately dense and homogeneous, with red fabric (2.5YR 4/8). The ratio among the components is 60% plasma, 30% skeleton, and 10% voids. The skeleton grains consist mainly of silt-size quartz grains (50–100 μm) and occasional small augite and iddingsite grains. A few large sand-size quartz grains also occur. The plasmic fabric is sepic (skelsepic and mosepic) (FIG. 10) and locally asepic. Voids appear as channels and vughs of about 500 μm.

Sample 274 is similar to sample 280. The nonplastic components include some basalt rock fragments with large plagioclase and iddingsite crystals.

Sample 196 is dense to moderately dense. The two outer zones are red (2.5YR 4/8) while the inner zone is dark reddish brown (2.5YR 2.5/4). The ratio among the components is 60–65% plasma, 30% skeleton, and 5–10% voids. The skeleton grains consist mainly of silt-size quartz grains (50–100 μm), and occasional small and large augite grains, iddingsite, and basalt rock fragments occur. The plasmic fabric is sepic (skelsepic and mosepic) and partly asepic in the outer layers and isotic (isotropic) in the inner layer. The voids appear as channels, vughs, and short narrow planes (cracks).

Sample 499 is moderately dense, red (10YR 4/6) in the two outer zones and dark reddish brown (5YR 3/2) in the inner zone. The proportions of components are 60% plasma, 30% skeleton grains, and 10% voids. The skeleton grains consist mainly of silt-size quartz grains. Large augite and iddingsite grains and basalt rock fragments occasionally occur. The plasmic fabric is mosepic to asepic in the outer zone and isotic in the inner zone. The voids appear as vughs and short planes. A few iron concretions occur.

The microfabric of samples 280, 274, 196, and 499 is similar to most of the basalt-derived soils in the Golan area. The plasmic fabric of this soil material is mainly asepic, but also mosepic (FIG. 11), and occasionally insepic and vosepic. As a result of firing, iron-manganese oxides induce an isotropic and opaque appearance, with the exception of samples 280 and 274.

SHIKHIN GROUP

Sample 378 is moderately dense and gray in color (5YR 5/1). On both sides a narrow red layer of less than 500 μm occurs. The proportions of the components are about 60% plasma, 30% skeleton, and 10% voids. The skeleton consists mainly of silt-size quartz grains. Rounded calcite grains, relicts of Foraminifera fossils, commonly occur. A few silt-size grains of plagioclase and hornblende are also present.

Figure 11. Basalt-derived soil material from the Golan. Left side: mosepic fabric. Right side (dark area): a rock fragment.

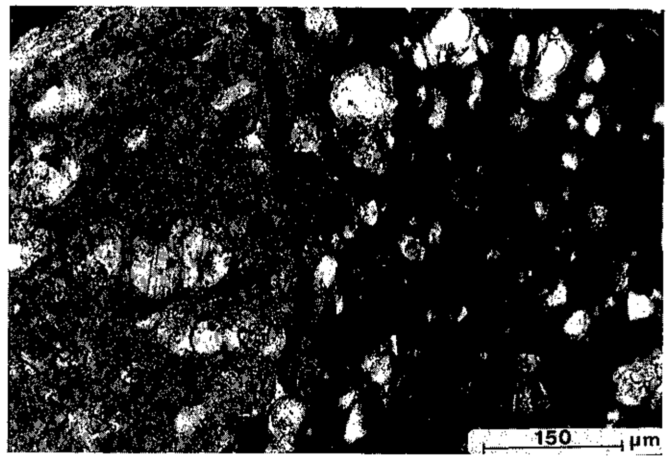


Figure 12. Pottery sample 378 (storage jar from Gamla). Right side: isotic fabric free of carbonates, with silt-size quartz grains. Left side: added temper of chalky-derived material including Foraminifera fossils.

The plasmic fabric is isotic. The voids appear as vughs and channels of 100–500 μm and as short planes about 10 μm in width. Calcareous material—mainly small crystals but with some large crystals as well—occurs, but not in the plasmic fabric. It seems that 15–20% calcareous chalky material was mixed with non-calcareous soil material (FIG. 12), filling the original pores of the soil material.

Sample 529 is similar to 378, but the following differences are evident: the material is less dense, with about 20% voids. These voids are larger than in sample 378, and many are filled with micritic carbonate material (FIG. 13). Fewer Foraminifera fossil relicts occur. The content of calcareous material is somewhat higher. The plasma shows some opaque zones, and some iron-manganese concretions occur.

Sample 327 is similar to 378, with the following differences: more short cracks appear, particularly surrounding nodules, and these are filled mainly with calcareous material. The Foraminifera have lost their large crystalline appearance and consist of small calcite crystals. These crystals, some of which are needle-shaped, are the result of recrystallization. Iron manganese nodules appear.

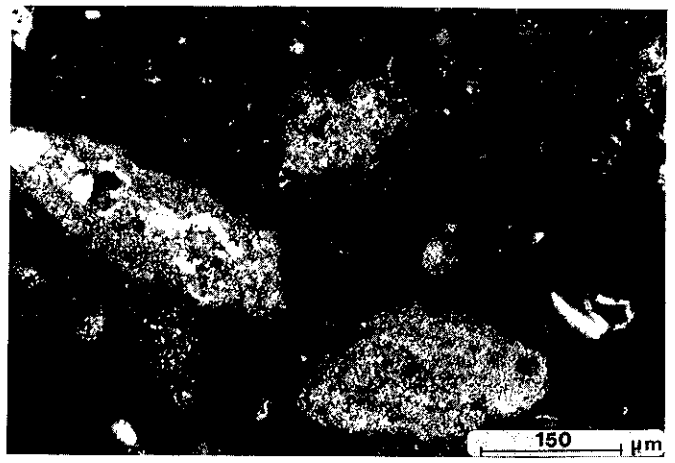
Sample 47 is mostly dense to moderately dense, red (2.5YR 4/8) in color, with an inner dark reddish gray (5YR 4/2 core). The material consists of 55–60% plasma, 10% skeleton, 5–10% voids, and 25% calcareous material. The skeleton consists of silt-size quartz grains. The plasmic fabric is asepic in the red zone and isotic in the inner core. Voids appear as vughs and short planes. The calcareous material, consisting mainly of micritic crystals but with larger crystals as well, is present in a greater amount than in the other samples and seems to have been added to the soil material. Foraminifera fossils occasionally occur and are better preserved in the darker zone.

The microfabric of all the samples of this group is similar to that of Grumusol (Vertisol) soil types, with calcareous material added as temper. The original microfabric of these soils is brown in color and shows a well-developed masepic, mosepic, and vosepic fabric. The material is free of carbonates. As a result of preparation and firing, the plasmic fabric becomes entirely isotropic, with the exception of sample 47 which is asepic in the outer zone. The isotropic appearance of the fired pottery is probably due to the large amount of manganese oxide that occurs in these soils.

Xeroradiography

Classification of the pottery pieces employing xeroradiography differed markedly from the grouping based on

Figure 13. Pottery sample 529 (krater from Sepphoris-Diocaesarea), showing isotic fabric free of carbonates to which micritic carbonate tempering material (the light bodies) was added.



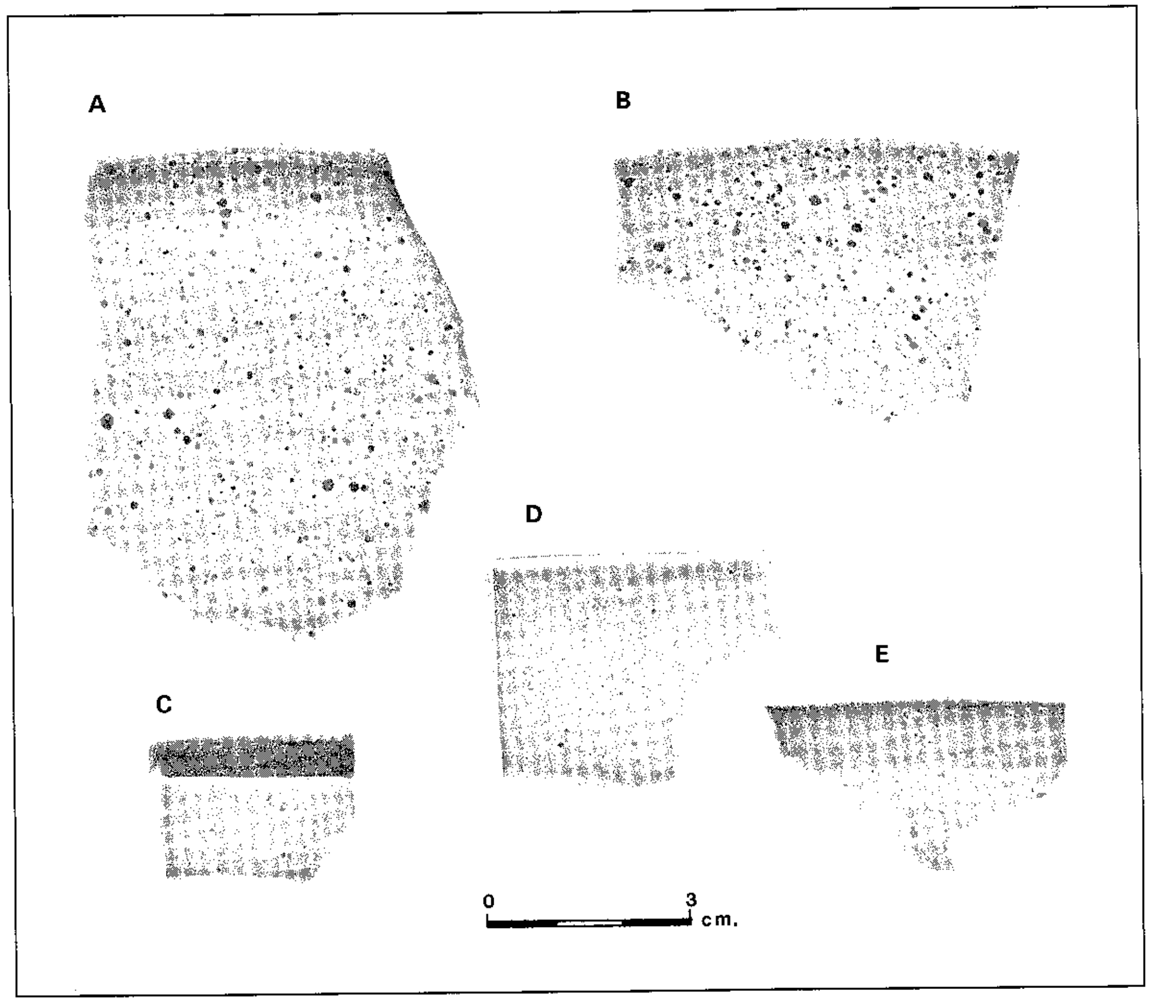


Figure 14. Xeroradiographs of pottery samples from Galilean and Golan compositional groups: A) Sample 140, Kefar Hananya Group A; B) Sample 276, Golan Group 1A; C) Sample 215, Kefar Hananya Main Group; D) Sample 499, Susita Group; E) Sample 210, Golan Group 1A. Sample 140 (bowl fragment) is from Kefar Hananya; 276 (cooking bowl fragment) is from the Roman Tower; 210 and 215 (cooking bowl and "casserole" fragments) are from Ein Nashut; and 499 (cooking bowl fragment) is from Susita-Hippos.

either neutron activation or thin-section analysis. Blind classification by the authors and by a senior radiologist,[9] based on size, shapes, frequency, and distribution of inclusions, yielded an essentially random grouping of the xeroradiographic images.

Most significant was the finding that the three major compositional groups could not be differentiated by xeroradiography. Thus a comparison of the xeroradiographic images of some pieces of the Kefar Hananya Group with others of the Shikhin or Golan Groups showed them to be similar (compare, for example, FIG. 14A of Kefar Hananya Group A with FIG. 14B of Golan Group 1A, and FIG. 14C of the Kefar Hananya Main Group with FIG. 14D of the Golan Susita Group). In contrast, vessels sharing the same chemical composition often had quite different xeroradiographic images (cf., for example, FIGS. 14B, 14E, both from Golan Group 1A).

It is worth noting that xeroradiographs of three pottery pieces from one of the Kefar Hananya compositional groups, Group A, differed significantly from images of the other Kefar Hananya vessels so examined (cf., for example, FIGS. 14A, 14C). Thus the discrimination of this group by xeroradiographic imaging agreed with that of neutron activation analysis. Thin-section analysis, in contrast, at first did not distinguish between Group A and the other Kefar Hananya Groups (see below). It should be added, however, that the xeroradiographic images of the Kefar Hananya Group A pieces were similar to those of some of the pottery of the Golan Groups (cf., for example, FIGS. 14A, 14B).

Binocular Microscopy

The three groups are very rich in clayey material, hence there was initial doubt as to whether binocular microscopy, a technique for rapid examination of large numbers of sherds, could be effectively employed for sorting the pottery (Shepard 1985: 141). Nevertheless, it was thought that identification of rock fragments and other features might allow assignment to major fabric groups.

Only the Shikhin Group, which includes calcareous material added as temper, could be easily discriminated by binocular microscopy. The Golan and Kefar Hananya Groups, on the other hand, often could not be distinguished, particularly because it was difficult to differentiate between basalt rock fragments characteristic of the former group and iron nodules found in the latter.

Discussion

Thin-Section Analysis

MICROMORPHOLOGICAL COMPARISON OF MAJOR FABRIC GROUPS

The evidence from micromorphological analysis seems to indicate that this technique can be effectively employed to classify pottery into major fabric groups. There are several prerequisites, however, for an accurate classification. Essential are a basic knowledge of the nature of the soils used to make the pottery and the pedogenic processes involved in the soil formation, as well as an acquaintance with the ceramic fabric micromorphology and the non-soil material contained in the paste. Restricting attention to rock and mineral inclusions can result in erroneous interpretations.

Most significant for the micromorphological classification of pottery is the correlation of fabric specimens with defined soil materials. In the present case the Kefar Hananya Group belongs to the Terra Rossa soil types, the Golan Group to the basalt-derived soils, and the Shikhin Group to Grumusols (Vertisols).

At the outset it should be mentioned that classification to groups depends on the characteristics of the parent material from which the soil is derived. Pottery made from soil materials developed from the same parent materials will belong to the same fabric group. Deviations from the composition of the original parent materials can be recognized, and pottery made from such different materials will be assigned to distinct groups.

The simpler the composition of the parent materials from which a certain soil material developed, the easier will be the classification of the pottery made from that material. Consequently, parent material derived from rock weathering in situ is easier to classify than parent material originating from an external source and mixed with in situ weathered parent material.

In the case of the Terra Rossa soils of the Galilee the parent material was derived from clay remaining after the dissolution of hard limestone or dolomitic limestone, mixed with aeolian dust material originating in the Sinai and Sahara deserts (Yaalon and Ganor 1973). This explains the large amount of silt-size quartz grains in the Kefar Hananya Group, a component not found in the rocks underlying the Terra Rossa soil material. Based on the micromorphology of the Terra Rossa soils it could be concluded that tempering material was not added to the soil used to make the pottery of the Kefar Hananya Group. The rock fragments and the large amount of silt-size quartz grains within the soil material act as natural temper (Rice 1987: 408), and additional temper was not needed for ceramic manufacture.[10]

At first glance the basalt-derived soil material used to make the Golan pottery group seems to resemble the Terra Rossa soil material, due to the large amount of silt-size quartz grains of aeolian dust origin that are also found in the basaltic soil material. Basalt, as a parent rock, does not contain quartz grains. Basalt rock fragments, however, occurring together with characteristic minerals such as augite, olivine, iddingsite, and plagioclase, indicate the basalt-derived origin of the Golan Group.

Basalt rock fragments are known to have been used as tempering material in pottery manufacture (e.g., Benyon et al. 1986). In the present case, however, the close similarity between the microfabrics of the Golan pottery group and the microfabric of the basalt-derived soil material of the Golan shows that no temper was added to the soil material in the process of ceramic manufacture. Here again the rock fragments and the silt-size grains naturally present in the soil prevent cracking by shrinkage, making the addition of temper unnecessary. It is interesting to note that although most of the Kefar Hananya and Golan Group pottery forms served as cooking vessels, they do not contain added temper.

The Kefar Hananya and Golan pottery groups could be distinguished by criteria other than mineral composition, however. Despite the changes undergone by the raw materials in the process of manufacture, the plasmic (clayey)

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[9] Dr. John M. Gomori of the Hadassah Medical Center in Jerusalem.

[10] On determining whether tempering material was naturally present or was added by the potter, see Rice 1987: 408–411; also Rye 1981: 31–32, 52.

fabric of the Kefar Hananya Group was seen to differ from that of the Golan Group. The iron released by the primary minerals in the basalt rock resulted in a more isotropic or opaque appearance in most specimens of the Golan Group (cf., for example, FIGS. 6 and 8).

The Shikhin Group specimens were closely similar in microfabric and could be readily discriminated from the Kefar Hananya and Golan Groups. Unlike the latter, however, varying amounts of temper were added to the soil material in the manufacture of the Shikhin Group. In order to properly evaluate this added temper, an acquaintance with the nature of the soil material is required.

The microfabric of the Shikhin Group, apart from the calcareous chalky material added to the soil material, is similar to that of the Grumusol soil types. These soils are rich in smectite (previously referred to as montmorillonite), a very plastic clay mineral which induces swelling and shrinkage in the soil material; such soils cannot be used alone for pottery-making (Shepard 1985: 376–377; Rice 1987: 48–49, 87). By adding the non-plastic calcareous material these changes are diminished, resulting in a more suitable raw material.

The calcareous material was added to the soil material, filling its original pores, but it does not occur in the clayey fabric of the ceramic. Consequently, the nature of the soil material and the respective amounts of temper added in the manufacture of the vessels of this group could both be determined.

Classifications at the group level, based on neutron activation analysis and thin-section analysis, showed close agreement. Thin-section analysis, moreover, was found to contribute information important for the interpretation of the compositional groups (see also Bishop, Rands, and Holley 1982; McGovern, Harbottle, and Wnuk 1986). This included the description of the relationship between the soil materials and each of the major pottery groups, and particularly the clarification of the apparent cause (i.e., the addition of varying amounts of temper) of the compositional variation encountered in the Shikhin provenience group (see also below).

The study of plasmic fabric, therefore, in addition to mineral composition and distribution, has been found useful for the classification of pottery groups. This combined approach, neglected in the past, would seem to increase the accuracy of classification of pottery fabric groups.

THE USE OF MICROMORPHOLOGY TO DEFINE SUBGROUPS

Classification to subgroups employing micromorphological techniques was possible in some cases. In this study, the occurrence of distinguishable pottery subgroups appears to be the result of differentiation of the soil material into soil horizons by pedogenic processes.

In the Kefar Hananya Group only sample 22 could be considered a subgroup, due to the significant amounts of clay illuviation remnants. Differences observed in the other samples did not warrant their classification into distinct subgroups (see also below).

In the Golan Group, three subgroups could be distinguished. Samples 368 and 364 are characterized by asepic to isotic fabric (without sepic fabric); sample 194 with asepic fabric and many free iron inclusions; and samples 280, 274, 196, and 499 with sepic and asepic or isotic fabric.

Members of the Shikhin Group could be classified into two subgroups, based on the relative quantities of added calcareous material. Samples 378, 529, and 327 contain about the same amount of added calcareous material, whereas sample 47 contains a significantly greater amount of such material. It is possible that the recrystallization processes recognized in sample 327 warrant its assignment to a separate subgroup.

The relationship between micromorphological and compositional subgroups is not sufficiently clear, and warrants further study. It is noteworthy, however, that for the Golan and Shikhin Groups the division into subgroups employing thin-section analysis was comparable to the classification by neutron activation analysis (see TABLE 3).

Xeroradiography and Binocular Microscopy

By revealing differences in paste not discernible in thin-section analysis, xeroradiography adds another dimension to the study of ceramic fabric. The principal issue addressed here, however, is whether these differences are significant and valid for the classification of excavated collections.

This study has shown that the use of xeroradiography to classify pottery based on inclusions would have led to the grouping together of pieces exhibiting grossly different mineralogical and chemical profiles. Findings for the Galilean and Golan Groups we have investigated, therefore, seem to call into question the value of this technique for initial classification of archaeological ceramics (cf., also McGovern, Vernon, and White 1985: 105; McGovern, Harbottle, and Wnuk 1986: 178; Carr 1990: 27–29).

Xeroradiography can play a role, however, in subsequent, more specialized ceramic analysis. Although the principal role of radiographic techniques in ceramic analysis has been for clarifying fabrication methods (see above), they may also be of value for the study of inclusions in specific fabric groups (Braun 1982; Carr 1990; cf. Foster 1985, 1986). In this study, for example, xeroradiographic examination alerted us to significant differences in the relative quantities of large (1–4 mm) dark inclusions found in the vessels of the Kefar Hananya Group (cf., for example, FIGS. 14A, 14C). With the aid of thin-section analysis the identity of these inclusions as iron nodules was determined. It was then possible to discriminate by petrographic microscopy one subgroup previously distinguished by xeroradiography. This subgroup corresponded to Kefar Hananya Group A.

Xeroradiography, therefore, although ineffective for primary classification of the fabric groups, nonetheless provided supplementary information for the subsequent study of one of those groups.[11]

As mentioned, the Shikhin Group, which includes calcareous material added as temper, could be readily discriminated by binocular microscopy. This group, however, could also be distinguished by macroscopic inspection.

Conclusions

A comparative study of several methods for classifying ceramic fabric has shown that sorting of pottery collections employing xeroradiographic analysis of inclusions can lead to incorrect categorization, even at the level of major fabric groups. Difficulties were encountered in classifying pottery rich in clayey material by binocular microscopy. Xeroradiography, however, did provide information useful for the further study of one of the fabric groups.

In contrast, thin-section analysis, including the study of ceramic plasmic fabric, and mineral composition and distribution, was found to be an effective means for classifying collections according to major fabric categories, which agree with those defined by neutron activation analysis. In some cases, the discrimination of micromorphological subgroups, comparable to the compositional subgroups distinguished by neutron activation analysis, was also possible. Petrographic microscopy, therefore, would seem to be a useful technique for classifying an excavated collection, following a preliminary sorting by visual examination of form and fabric (cf., Peacock 1984). This technique can also be employed for relatively rapid and inexpensive sorting of pottery fragments for assignment to major provenience groups previously established by NAA.

Thin-section analysis, moreover, was seen to supply supplementary data that contributed to the interpretation of the ceramic compositional groups.

This paper has focused upon the characterization and primary classification of archaeological ceramics. Subsequent, more specialized study of pottery collections requires a different array of analytical techniques. Identification of the sources of fabric groups, for example, often requires high compositional resolution not possible with petrography, and other analytical methods, such as neutron activation analysis, need to be employed. Such investigation, however, as well as the study of fabrication methods and a series of other specialized studies, is beyond the scope of the initial classification of excavated ceramic material.

Acknowledgments

We thank Ruth Shilo, Head of the Mammography Section of the Ichilov Municipal Government Medical Center in Tel Aviv, for her willing cooperation with the xeroradiography, and John M. Gomori, Professor of Radiology at the Hadassah Medical Center in Jerusalem, for his assistance with the evaluation of the images. Special thanks are due to the many archaeologists who graciously gave us access to the pottery collections used in this study. Expenses connected with this study were covered by research grants from the Israel Ministry of Science, and the Bar-Ilan University Dr. Irving and Cherna Moskowitz Chair in Land of Israel Studies.

Appendix: Definition of Petrographic Terms Employed

Asepic fabric: plasma (clayey material) fabric which does not exhibit, under crossed-polarized light, separation (preferred orientation [see Rice 1987: 68] of the clay mineral crystals) with regard to other components within the plasma and/or mineral grains, pores, and pedogenic features. The fabric is optically anisotropic (Rice 1987: 377).

Sepic fabric: a type of plasmic fabric that shows plasma separation (preferred orientation of the clay mineral crystals) under crossed-polarized light with regard to other components within the plasma and/or mineral grains, pores, and pedogenic features. The fabric is optically anisotropic.

Isotic fabric: a type of plasmic fabric that is optically isotropic. The following are subgroups of sepic fabric:

Insepic fabric: shows local isolated patches of plasma separation.

Mosepic fabric: shows a development of plasma separation in the form of a mosaic pattern.

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[11] Combining xeroradiograpic analysis of both fabrication methods (particularly by thick-section examination) and particle inclusions seems to enhance the possibility for distinguishing certain wares (Glanzman and Fleming 1986b; McGovern, Harbottle, and Wnuk 1986: 178).