QUMRAN AND JERICHO POTTERY: A PETROGRAPHIC AND CHEMICAL PROVENANCE STUDY

This book is dedicated to
my daughter
Katia

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Jacek Michniewicz

QUMRAN AND JERICHO POTTERY: A PETROGRAPHIC AND CHEMICAL PROVENANCE STUDY

WYDAWNICTWO NAUKOWE

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ABSTRACT. Michniewicz Jacek, *Qumran and Jericho Pottery: a Petrographic and Chemical Provenance Study* [Ceramika z Qumran i Jerycho – badania petrograficzno-chemiczne nad jej pochodzeniem], Poznań 2009. Adam Mickiewicz University Press. Seria Geologia nr 20. Pp. 169. ISBN 978-83-232-2002-2. ISSN 0239-7560. Text in English with a summary in Polish.

The Hasmonean and then Herodian ceramics from Jericho as well as the Herodian ceramics from Qumran were made alternatively of one of the three kinds of raw material: (1) slightly silty foraminiferous clay (pottery assigned to Petrographic Group I), (2) rich clay tempered with quartz-carbonate sand or carbonate sand (pottery assigned to Petrographic Groups II and III), and (3) silty, ferruginous terra rossa soil (pottery assigned to Petrographic Group IV). These three types of raw material differ, both petrographically and in terms of their chemical composition. The rich, variably marly clay of Petrographic Groups II and III was used to make most of the 'scroll jars', bowls, juglets, kraters, pitchers, and goblets. Storage jars made of this clay have been found in Qumran, Jericho, Khirbet Mazin as well as ez-Zara/Callirrhoe. Rich-clay outcrops closest to Qumran and Jericho can be found in the Judean Mountains between Hebron and Ramallah. These are Cenomanian clays of the Moza Formation. In the eastern part of the Dead Sea basin they correlate with the Fuheis (Naur?) Formation exposed above Zarga Main. An alternative source of the pure rich clay can be sought in the Lower Cretaceous (Albian) shales of the Kurnub Group. Those clays outcrop in Trans-Jordan, especially between the northern Dead Sea and Zarga and Eastern Samaria i.e. the north eastern part of the West Bank. The results of the petrographic observations seem to be especially significant in the context of the discussion about the function of the Qumran in the Herodian period and the scale of the ceramic production carried out there. Undoubtedly, most of the Qumran pottery, including the majority of 'scroll jars', was made of the pure clay (the ceramic paste assigned to Petrographic Groups II and III), displaying a residual parallel orientation of clay minerals and containing abundant coarse fragments of shales. Their presence, the absence of microfossils typical of the Wadi Qumran deposit as well as a quite different chemical composition are evidence that the vessels were not made of Wadi Qumran clay deposited in the form of suspension i.e. they could not be transported by the aqueduct.

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1. INTRODUCTION

The Dead Sea region is an area of archeological excavations of special interest to public opinion because of the events recorded on the pages of the Bible.

In the 1940s, near the stone ruins (Arabic 'khirbeh') called Qumran, the famous manuscripts were discovered that contained both biblical and non-biblical manuscripts. The questions of the genesis of the scrolls, their connection with Qumran residents, who and why inhabited this settlement, and what function it performed: that of a prayer site, a production site, or a summer residence, have not been settled yet in a definite and convincing manner. With new discoveries, increasingly irreconcilable opinions are being formed.

Until recently, the generally accepted hypothesis has been that of the Essene nature of Qumran. Its founder was the Qumran excavator, Roland de Vaux (1953a, b, 1954, 1955, 1959, 1973). De Vaux distinguished the chief periods of expansion of the settlement and its habitation separated by layers of destruction (cf. Table 1):

- The period of Iron Age II, lasting from the 8th century B.C. to the end of the 7th century, when an Israeli fort existed here, ultimately destroyed and burnt down;
- Period Ia, corresponding to the time of rule of John Hyrcanus;
- Period Ib, lasting till the buildings had been destroyed by an earthquake[1] or Herod's battles, i.e. to about 31 B.C.;
- a hiatus between Periods Ib and II marked by a layer of alluvium;
- Period II, from ca. 10-4 B.C. to 68 A.D. when Qumran was demolished by a Roman invasion and the collection of manuscripts hidden in nearby caves;
- Period III of a Roman occupation or perhaps that of insurgents of the Second Jewish revolt in A.D. 132-135.

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[1] This conception is rejected today, cf. Humbert (2003a: 436-437, 2006: 31), Magen and Pelleg (2006: 107); as to earthquakes in this region, see Karcz and Kafri (1978), Migowski et al. (2004: 310), Ambraseys (2006: 1014).

Table 1. Chronology of Qumran according to de Vaux's synthesis and Humbert's reassessment (Humbert, Gunneweg 2003: 444).

<table>
<tr><th colspan="3">DE VAUX'S SYNTHESIS</th><th colspan="2">HUMBERT'S REASSESSMENT</th><th colspan="2">HUMBERT'S PROPOSITION FOR LEVELS</th></tr>
<tr><th>Dates</th><th>History</th><th>De Vaux</th><th>Archaeo-logy</th><th>Revision for Qumran</th><th>Level</th><th>Dates</th></tr>
<tr><td>800 BC?</td><td>2 Chron. 26, 10</td><td rowspan="3">small Israe-lite fort Iron Age II</td><td rowspan="3">pottery</td><td rowspan="3">small fort Iron Age II</td><td rowspan="3">LEVEL 1</td><td>800 BC?</td></tr>
<tr><td>700 BC</td><td></td><td>700 BC?</td></tr>
<tr><td>580 BC?</td><td></td><td>580 BC?</td></tr>
<tr><td></td><td colspan="4">GAP</td><td rowspan="2">135 BC</td></tr>
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<tr><td>104 BC</td><td>Alexander Jannaeus</td><td rowspan="4">PERIOD Ib</td><td rowspan="3">an aristo-cratic Hasmo-naean residence</td><td rowspan="2">LEVEL 2 PHASE A</td><td>104 BC</td></tr>
<tr><td>63 BC</td><td>Pompey at Jerusalem</td><td>63 BC</td></tr>
<tr><td>56 BC</td><td>Gabinius destroys Hyrcania</td><td rowspan="3">but-tressing in the central building com-plete restora-tion of the set-tlement</td><td rowspan="3">after one of the three possible destruc-tions: Qumran re-settled with a refuge camp</td><td rowspan="3">LEVEL 2 PHASE B</td><td>56 BC</td></tr>
<tr><td>40 BC</td><td>Parthian raid</td><td>40 BC</td></tr>
<tr><td>34 BC</td><td>Antony assigns Dead Sea to Cleopatra</td><td>34 BC</td></tr>
<tr><td>31BC</td><td>Herod subdues the Dead Sea

second destruc-tion of Hyrca-nia EARTH-QUAKE according to Jose-phus</td><td>end of Period Ib. seque-nce: "earth-quake-fire-exile"</td><td>begin-ning of the ceme-tery

"bone depo-sits" (locus 135)</td><td>occupa-tion by "a new group"</td><td>LEVEL 3 PHASE A</td><td>31 BC</td></tr>
</table>

table 1 continued

DE VAUX'S SYNTHESIS			HUMBERT'S REASSESSMENT		HUMBERT'S PROPOSITION FOR LEVELS	
Dates	History	De Vaux	Archaeo-logy	Revision for Qumran	Level	Dates
30 BC 10 BC	GAP		sectarian installations loci 77, 86, 111, 120, 121, 122, 135 and elaborated water system	a sectarian center worship?	LEVEL 3 PHASE B	30 BC 10 BC
From 1 to 50 AD without precision	reinstallation and development of the installations	PERIOD II	progressive abandonment of the worship activities: loci 77, 86/89, 122, 135	climax of the site Essenism (?) according to the historical sources	LEVEL 3 PHASE C	From c. 1 to 50 AD
			excavation of the artificial caves			c. 50 AD
c. 60 AD			hiding scrolls			c. 60 AD
68 AD	DESTRUCTION AND DISPERSION					68 AD
132-135 AD		PERIOD III Roman outpost? presence of rebels	Roman outpost	reduction in size	LEVEL 4	132-135 AD
			earthquake	several cracks on the marl terrace	gap?	?

De Vaux was sure of a connection between the texts discovered and the Qumran residents. Its proof for him was reports of the ancient authors Pliny, Philo and Josephus, as well as the presence with the scrolls of untypical, slender

'scroll jars', a stylistic similarity between the ceramics from the ruins and those discovered with the manuscripts in the nearby caves, the location of the caves with the manuscripts (4Q and 7Q) at a distance of a mere tens of metres from the buildings[2], the layout of the settlement, and the very contents of the manuscripts.

According to de Vaux, Qumran was inhabited from the start of 'period Ia' by Essenes, a Jewish religious group whose members supposedly lived in isolation following a rule similar to monastic, meditating in the nearby caves in which they also left or hid the texts they had written.

Among the adherents of the conception put forward by de Vaux is Jody Magness: "All of the available evidence supports de Vaux's interpretation of Qumran as a sectarian settlement. Although the other interpretations could account for some of the evidence" (Magness 2002: 15).

The first significant reinterpretation of the Essene genesis of Qumran was the publication by Karl Rengstorf (1960) suggesting that the scrolls could come from the temple in Jerusalem.[3] This theory was ultimately elaborated by Norman Golb (1980), who rejected the religious character of the settlement. According to him, Qumran had nothing to do with the Essene community, but was used for military purposes: "It had been a fortress in the Israelite times, also during the period when Essene sectarians were supposed to be inhabiting it" (Golb 1994: 55-56).

In 1994 Pauline Donceel-Voute proclaimed Qumran to be a 'villa rustica' par excellence.

In the same year 1994, Jean Baptiste Humbert[4] described the site as a Hasmonean villa (cf. Humbert 1994: 166, 169, 174; 2003a: 432-433, 2003b: 421-423) settled again, this time by the Essenes, only after it had been destroyed, whether during the pacification by Gabinius in 56, or a Parthian raid in 40, or Herod's conquest in 31 B.C. According to Humbert, Qumran could perform the function of a regional centre of worship for the entire Dead Sea basin[5] up to 68 A.D., with only a short break about 31 B.C. (cf. Table 1). The proof of the sectarian character of the 'new group' that came to live in the settlement would be the layout and equipment of loci 77 and 86 (cf. Humbert 2006: 31-38).

In his recent paper on the presence of the Essenes in Qumran, Humbert states: "The theory of the Essene settlement is more than probable, but in the absence of decisive evidence, everything we attribute to the Essenes could, in fact, be attributed to any Jewish sect" (Humbert 2006: 36).

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[2] Many manuscripts discovered in the vicinity of Qumran come from karstic caves that have developed within the Shivta formation. The 'caves' situated below the site are man-made in origin and were dug in conglomerate sediments of the Dead Sea Group in the slopes of the Wadi Qumran erosional dissection. Cf. Humbert, Chambon (1994: 200), Bélis (2003: 409-415).

[3] Cf. the opinion of de Vaux concerning this hypothesis (1973: 105).

[4] J.-B. Humbert is de Vaux's successor responsible for conducting archeological research by the French École Biblique et Archéologique.

[5] Hence, it was not inhabited by a community living in isolation.

Among the proponents of the conception repudiating the religious character of Qumran are Yizhar Hirschfeld (1998, 2004, 2006) and Lena Cansdale, according to whom Qumran "[...] can no longer be regarded as a secluded settlement, away from the political and economic life of the country, and may reasonably be assumed to have been a stopping place on an international trading route" (Cansdale 1997: 123).[6]

In turn, according to Hirschfeld, "Qumran functioned as the centre of an estate, although in the Hasmonean period it may have served as a fort, a way-station and centre of economic activity" (2004: 241, cf. also Hirschfeld 1998: 189). "(...) The scrolls were brought for concealment in the nearby caves from some public library, probably located in Jerusalem (i.e. they do not represent a remote desert sect but one of the socio-religious factions) (...); the inhabitants of Qumran may have rendered assistance in concealing the scrolls, but it is doubtful whether they should be identified as writers of the scrolls; (...) the owners were certainly not ascetic but, on the contrary, affluent people, probably belonging to the ruling class in Judaea at that time" (2006: 239). What Hirschfeld claims was the place of living of the Essenes are the ruins of En Gedi he has discovered (Hirschfeld 2000).

A different vision of Qumran was presented by Magen and Peleg (2006, 2007), who decided, after ten seasons of archeological studies in the settlement area, that Qumran was first a fortress and then a pottery factory for many decades. In the Hasmonean period, "Qumran was part of Hasmonean military presence along the Jordan valley and the Dead Sea, (...) after the Roman occupation the site was no longer used for military purposes and the building deteriorated". The new pools built there served no ritual purposes, but were reservoirs of clay supplied in the form of a suspension by an aqueduct. "There was sufficient clay to produce tens of thousands of clay vessels", so the pottery making was the main activity of the site. "In years that were rainy and in which the streams flooded, the quantity of clay collected in the pools of Qumran was beyond the site's production ability for pottery vessels. In those years the clay was transferred to other production centres, such as Jerusalem (sic!), Jericho or other sites" (cf. page 94). The cylindrical jars "were mistakenly called scroll jars, whereas they were used for storing fresh and dried dates as well as honey" (Magen, Peleg 2006: 109-113).

In the context of the usually contradictory theories about the function of Qumran and the role this settlement performed, a significant argument verifying at least some of the above hypotheses can be provided by the results of studies of variations in the mineral and chemical composition of ceramic vessels in relation to their shape, stratigraphic position and place of discovery:

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[6] On the location of Qumran within the road system of Judea in the late Hellenistic and early Roman periods, see Harel (1967), Cansdale (1997: 104-107), Broshi (1999), Hirschfeld (2004: 12-14).

– Were vessels of the same shape discovered in Qumran, Jericho, Khirbet Mazin, and on the other shore of the Dead Sea, in Callirrhoe, made of the same raw material?

– Can we identify a set of petrographic or chemical properties of this pottery that would help to establish its age with reference to stratigraphic determinations?

– Can we indicate the place of production of the pottery of Qumran and Jericho, or at least the place of origin of the raw material used?[7]

– Does the petrography of the pottery from the settlement and the caves corroborate or disprove the connection of the manuscripts with Qumran residents? and

– Could the clay from Wadi Qumran support manufacturing activity in the settlement?

There are also more detailed issues:

– What was the raw material used to make the lamps from Qumran locus 130, whose shapes, indicative of the late Hellenistic period, according to Humbert (2003: 435) have no parallels in Palestine or elsewhere, and most likely are not local at all?[8]

– Are the storage jars from the Hasmonean context made of different clay than the Herodian ones, as suggested by Bar-Nathan (2002: 199)?

– Is the raw material used to make the Jericho 'genizah' or 'scroll jars' similar to the raw material of which the Qumran 'scroll jars' were made?

Answering the above questions is the aim of the present dissertation. Sixty two specimens of Qumran pottery, mostly representing de Vaux's Periods II and III, were compared in it with 46 fragments of pottery from Jericho dated by the stratigraphic-architectural stages of development of winter palaces (Netzer 2001; Bar-Nathan 2002). The research also embraced a small amount of sherds of Roman jars from Khirbet Mazin and jars from the Herodian hot springs at ez-Zara/Callirrhoe[9] (cf. Clamer 1989, 1997).

Samples of the Qumran pottery were provided by Jean Baptiste Humbert OP of the École Biblique et Archéologique de Française de Jérusalem, the pottery from Jericho came from Dr Rahel Bar-Nathan of the Israel Antiquity Authority and Prof. Ehud Netzer of the Hebrew University, while specimens from ez-Zara were supplied by Dr Christa Clamer, the École Biblique et Archéologique de Française de Jérusalem.

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[7] An individual character of the range of the Qumran ceramics would be another argument for the sectarian origin of the inhabitants of Qumran indicative of their hermetism or at least limited contact with the external world, restricted trade exchange and, perhaps, monastic character of the community. In turn, the presence of ceramics from outside Qumran, e.g. Jericho, and particularly ceramics imported from afar, would prove lack of isolation.

[8] Humbert described them as lamps of the Qumran locus 130 type, suggesting that they could have come from Egypt or were imitations of Egyptian models.

[9] This is the place of the last attempts to cure Herod the Great, where he stayed just before his death.

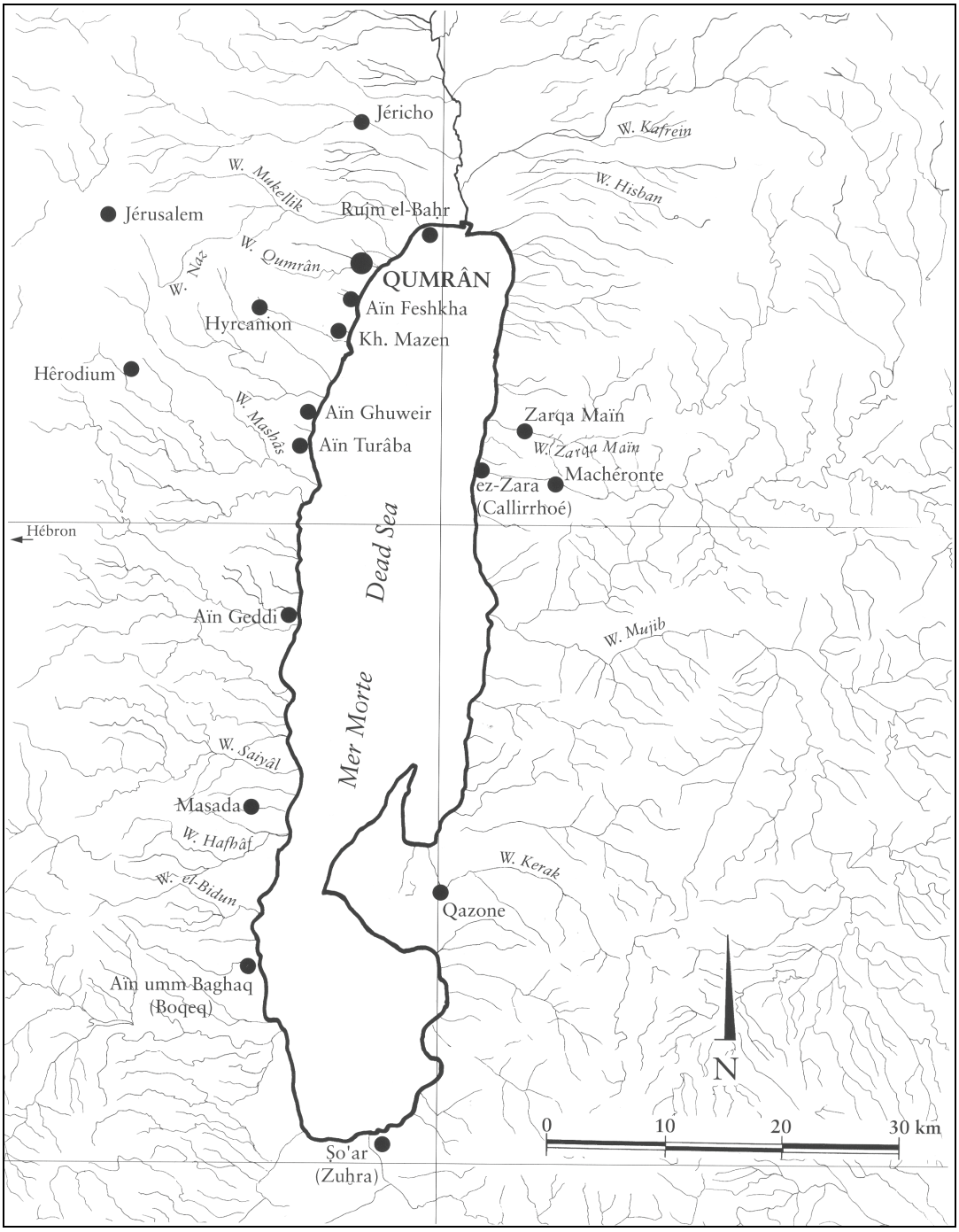

Fig. 1. Map of the study area (after Humbert, Gunneweg 2003)

1.1. Location of Qumran in the light of the geological structure of the region

Qumran is situated on the NW margin of the Dead Sea basin, on a sand-gravel plateau, at a distance of some 2 km from the seashore, about 90 m above the surface of the Dead Sea waters. On the west the plateau is bounded by steep fault escarpments over two hundred metres high, and on the south by a precipitous bank of a dry stream (Arabic 'wadi', Hebrew 'nachal') flowing to the Dead Sea. The panorama from this place embraces the Jordan valley with Jericho in the north, and the far shore of the Dead Sea in the east, dominated by the towering wall of the Moab Mountains.

Located towards the south, near the coast, is the oasis of Ein Feshkha.[10] Farther on, invisible from Qumran beyond a rock bar reaching the sea water, there are remnants of the Khirbet Mazin harbour docks (cf. Netzer 1999: 77-78)[11] beyond which, at a distance of some 15 km, we would find the small ruins of Ein el-Ghuweir (cf. Bar-Adon 1977: 226-227) and Ein at-Turaba, then, at a similar distance, the oasis of Ein Gedi (cf. Mazar, Dothan, Dunayevsky 1966; Hirschfeld 2000), followed by the fortress of Masada towering over the Dead Sea valley (cf. Yadin 1966, Netzer 1991), and finally the oasis of Ein Boqeq (cf. Fisher, Gichon, Tal 2000).

On the eastern bank of the Dead Sea, 2 km south of the Wadi Zarga Main, lies the oasis of Ein ez-Zara (ancient Callirrhoe), watered by about 40 springs. In the antiquity a harbour was built there for the fortress of Machaerous as well as baths which were frequented by Herod the Great for their curative properties (cf. Strobel, Clamer 1986; Clamer 1989; 1997; Amr et al. 1996).

In terms of the geological structure, the Dead Sea basin (DSB) is located along the left-lateral transform fault, which is a boundary separating the Arabian plate from the Sinai sub-plate (Garfunkel 1981; Garfunkel 1998; Garfunkel, Ben-Avraham 1996). The transform extends 1000 km, from the Red Sea divergence to the Taurus-Zagros plate convergence.

The northern part of the DSB is bounded on both sides by high longitudinal fault scarps revealing:

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[10] Those two sites were linked by a long wall, about one metre broad and more than one metre high (cf. de Vaux 1973: 59-60), whose function has not been established with certainty, but whose presence is indicative of their direct association (cf. Humbert 2003: 419-425; Humbert 2006: 20-29; Hirschfeld 2004: 183).

[11] According to Netzer, Khirbet Mazin was probably built in the period of the Hasmonean rule, under Alexander Jannaeus. The recent dating of the rendering of a Khirbet Mazin cistern, performed with a contribution by the present author, yielded an older age, 330 B.C.-200 B.C. (68.7%), which probably results from the occurrence of 'dead carbon' in the sample analysed.

– in the west, a sequence of Cenomanian-Early Coniacian platform rocks of the Judea Group, and

– in the east, the Lower Cretaceous Kurnub Group covered with Upper Cretaceous carbonate rocks of the Ajlun Group, largely isochronous with the Judea Group (cf. Fig. 2, Table 2).

In the Early Cretaceous, the northern regions of Sinai, Israel and Jordan were the north-east passive continental margin of the African-Arabian Plate. Then, this part of the continent was in tropical-subtropical climates. It was surrounded by the waters of the Tethys ocean, whose shelf edge, with an accentuated seaward slope, was situated a few kilometres east of the present east Mediterranean coastline (Buchbinder et al. 2000: 816; Schulze et al. 2003; Bachmann, Hirsch 2006). From the land area in the south and south-east, the basin was being filled by various fluvial deposits. The Kurnub Group sediments (cf. Table 2) take the form of alternating layers of terrestrial sandstone, mixed carbonate-siliciclastic sediments, and tidal marsh-coastal swamp black shales. The arrangement of those rock layers reflects variations in the level of the Tethys at that time (Amireh, Abed 1999).

In the Late Aptian, sedimentation of carbonate deposits developed on the subsiding shelves. Limestone, dolomite and marly chalks were deposited, representing facies of bioherms, backreef lagoons and hyper-saline shallow water basins (Begin 1975; Flexer et al. 1986,1989; Mor 1987; Braun, Hirsch 1994; Bauer et al. 2003; Schulze et al. 2003, 2004). Those rocks form the Late Albian-Coniacian rock sequence of the Judea / Ajlun Group. Nearer the land, towards the south, an increased input of nearshore siliciclastics was still in progress (Schulze et al. 2003: 642).

Sea-level perturbations are reflected in the deposition of Cenomanian marls and clays of the Moza Formation in the Judean Hills (Braun, Hirsch 1994), clayey Cenomanian strata of the Fuheis Formation and marls of the Cenomanian – early Turonian Shueib Formation in west-central Jordan (Schulze 2003; Perrilliat et al. 2006), as well as argillaceous paleosols and karstic voids at the top of the Shivta Formation[12], covered again by clay and sand making up the base of the Nezer Formation (Mor 1987; Sandler 1996; Buchbinder et al. 2000: 814). In most of this argillaceous sediment, illite is the dominant clay mineral, while kaolinite is a major component only in the Moza Formation (Taitel-Goldman et al. 1995) and the Kurnub Group (Khoury 2002).

Following the opening of the South Atlantic Ridge and the convergence of Afro-Arabia and Eurasia, the area was affected by compressive tectonics. This compression moderately folded the deposited sediments, creating anticlinal ridges and synclinal basins of the Syrian Arc fold system (Flexer et al. 1986; Rosenthal et al. 2000; Bauer et al. 2003). Due to this compressional

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[12] It is the rocks of the Shivta Formation that form the karstified cliff in the caves in which the Qumran manuscripts were hidden.

Table 2. Cretaceous stratigraphic units in Israel and Northern Jordan (after Arkin 1976; Hirsch 1983; Mor, Burg 2000; Batayneh, Al-Zoubi 2001: 144; Pufahl et al. 2003: 178).

<table>
<tr><th colspan="2" rowspan="2">AGE</th><th colspan="3">Judea Hills</th><th colspan="3">Dead Sea</th><th colspan="2">Jordan</th></tr>
<tr><th>Group</th><th colspan="2">Formation</th><th>Group</th><th colspan="2">Formation</th><th>Group</th><th>Formation</th></tr>
<tr><td rowspan="2">Paleogene</td><td>Paleocene</td><td rowspan="6">MOUNT SCOPUS</td><td rowspan="3">Hatrurim Fm.</td><td>Taqiye Fm.</td><td rowspan="6">MOUNT SCOPUS</td><td rowspan="3">Hatrurim Fm.</td><td>Taqiye Fm.</td><td rowspan="4">BELQA</td><td>Muwaggar Fm.</td></tr>
<tr><td rowspan="5">Cretaceous</td><td rowspan="3">Senionian</td><td>Ghareb Fm.</td><td>Ghareb Fm.</td><td rowspan="2">Amman Fm.</td></tr>
<tr><td colspan="2">Mishash Fm.</td><td colspan="2">Mishash Fm.</td><td>Ghudran Fm.</td></tr>
<tr><td colspan="2">Menuha Fm.</td><td colspan="2">Menuha Fm.</td><td rowspan="9">AJLUN</td><td>Wadi As Sir Fm.</td></tr>
<tr><td>Turonian</td><td rowspan="8">JUDEA</td><td colspan="2">Bina Fm.</td><td rowspan="8">JUDEA</td><td>Nezer Fm.</td><td>Shuaib Fm.</td></tr>
<tr><td rowspan="7">Cenomanian</td><td colspan="2"></td><td>Shivta Fm.</td><td rowspan="2">Hummar Fm.</td></tr>
<tr><td colspan="2">Weradim Fm.</td><td>Derorim Fm.</td></tr>
<tr><td colspan="2">Kefar Sha'ul Fm.</td><td>Tamar Fm.</td><td rowspan="3">Fuheis Fm.</td></tr>
<tr><td colspan="2">Amminadav Fm.</td><td>Avnon Fm.</td></tr>
<tr><td colspan="2">Moza Fm.</td><td>Zafit Fm.</td></tr>
<tr><td colspan="2" rowspan="2">Bet Me'ir Fm.</td><td>En Yor-qeam Fm.</td><td rowspan="2">Naur Fm.</td></tr>
<tr><td>Hevyon Fm</td></tr>
</table>

table 2 continued

AGE		Judea Hills		Dead Sea		Jordan	
		Group	Formation	Group	Formation	Group	Formation
Cretaceous	Albian		Kesalon Fm.			KURNUB	Subeihi Fm.
			Soreq Fm.				
			Giv'at Ye'arim Fm	KURNUB	Hatira Fm.		
			Kefira Fm.				
			Qatana Fm.				
			En Qinya Fm				
			Tamun Formation				

event, the floor of the sea in the Levant started to consist of basins and swells (Abed et al. 2005). Platform sedimentation ended definitely in the Early Coniacian, typical inner-shelf facies moved southwards. In the northern Levant, deep-water hemipelagic chalks of the Mt. Scopus /Belqa Group were deposited. This sediment overlies the Judea / Ajlun Group unconformably (Begin 1975; Flexer et al. 1986, 1989; Bauer et al. 2003).

Marine sedimentation persisted until the Eocene. Senonian to Eocene sediments are widely exposed, mainly in the structural lows of the Syrian Arc, whose crests of anticlines have even been eroded in many places. There is no clear lithological break at the Cretaceous-Tertiary boundary (Garfunkel 1988).

In the Paleocene, calcareous shales interbedded with smectite-rich clays of the Taqiye /Muwaqqar Formation were deposited. In contrast to the Cretaceous platform clays, the clay minerals of the Taqiye /Muwaggar Formation were largely derived from argillised marine volcanic rocks erupted during the convergence of the Tethys Ocean and transported from the open marine environment (Shoval 2004).[13] These sediments are widespread over the Levant region and contain a profusion of foraminifers, *Loxostomoides applinae* (Plummer), *Truncorotalia angulata* (White) and *Bulimina midwayensis* (Cushman and Parker) (cf. Bentor 1966; Flexer 1968; Shoval 2002a, b, 2004). The sedimentation of those deposits took place in the zone of influence of marine currents favourable to upwelling and the intensive development of plankton connected with it. Owing to the intensive deposition of organic matter under oxic conditions, phosphorite facies were deposited, whereas in other, anoxic parts of the basin, deposits of future oil shales accumulated.

[13] As a result, one can expect a clear geochemical difference between those clays and the detrital clays of the Cretaceous platform.

In the Late Miocene, during the opening of the Dead Sea basin, those rocks with the underlying Maastrichtian Ghareb Formation chalks were locally affected by combustion metamorphism of the low-pressure/high-temperature type caused by sub-surface oxidation of the organic and sulfidic components. On geological maps they are indicated as the 'Mottled Zone' or Hatrurim Formation (Bentor et al. 1963; Bentor et al. 1972; Gur et al. 1995). This rock sequence contains an abundance of trace elements among which Ag, V, Ni and Cr are prominent. Chromium, in particular in the form of green chromium silicates, is found in many veins up to 1 m thick and may make up 6% of the vein material (Bentor et al. 1963: 924).

In the Eocene times, chalk and limestone were again deposited all over the region. Then in the Dead Sea area a regional emergence took place, resulting in erosion towards the end of the Neogene. In the surrounding area there developed a lagoon environment.

The Dead Sea basin was formed in the Early Miocene as a result of the breakup of the Arabian plate, separating Sinai and Arabia as sub-plates (Garfunkel 1997). Its area is covered with marly sediments of the Dead Sea Group: Ein Feshkha conglomerates, the Samra Formation, and the Lissan Formation. They are limy-dolomitic rock debris cemented by calcite and aragonite, brown calcareous silt with some unconsolidated pebble and hard conglomerates, or unconsolidated pebble with calcarenite (the Samra Formation). Sediments of Lake Lissan, the Pleistocene precursor of the Dead Sea, are distributed across the scarps and along the shore. They are built of light friable conglomerate units alternately bedded with marly units (cf. Begin 1975).

The formation of the Dead Sea basin was accompanied by very little igneous activity. However, along its eastern side about 9-6 Ma basalt flows were extruded. A younger activity at 3.5-0.5 Ma has produced several cones and minor flows observed on the plateau and slopes (e.g. the Zarga Main canyon). The presence of small basaltic volcanics buried at shallow depths under the Dead Sea is indicated by magnetic anomalies; they are located mostly along the southern part of the Sea (Garfunkel, Ben-Avraham 1996: 170; Ben-Avraham 1997: 24). In the Jordan rift valley an outcrop of olivine basalt was also recorded some 2 km east of the Jordan River, near the Jericho Sheet's eastern boundary at coord. 202/158 (Begin 1975: 26).

1.2. What knowledge can be gained from petrographic and chemical investigations, and what are their limitations?

For many years standard typological analyses of pottery have been verified by various types of study of its mineral and chemical compositions (cf. Tite 1999). Their chief purpose is to determine the provenance of vessels, or at

least to highlight differences in the raw material employed and thus to identify potters' workshops.

For a long time the basic role in this respect has been played by petrographic studies of tempers, to a lesser degree of the chemical composition of the so-called paste, which is mainly made of a clay substance (cf. Shepard 1956). This method is especially useful when the pottery contains a substantial proportion of polymineral, coarse temper (Peacock, Williams 1986; Porat 1989; Porat et al. 1991; Goren 1995; Whitbread 1996; Rautman 1997; Day et al. 1999; Dickinson, Shutler 2000; Cuomo di Caprio, Vaughan 1993).

Technological advances in chemical equipment allowing a great accuracy in determining the concentrations of trace elements, together with parallel development of numerical techniques have caused many laboratories to abandon the standard method of microscopic studies and switch to chemical analyses (cf. e.g. Mommsen 2001, 2004; Mommsen et al. 1984; Yellin 1994, 1995; Glascock et al. 1996). However, in many works both these methods were and still are employed simultaneously, often supplemented with X-ray diffraction methods, or with thermoluminescence (TL) or optically stimulated luminescence (OSL) dating techniques (Goldberg et al. 1986; Pena 1992; Adan-Bayewitz 1993; Troja et al. 1996; Buxeda i Garrigós et al. 2003; Barone et. al. 2004; Gliozzo et al. 2004).

Chemical analyses of ceramics are usually performed using one of the three methods:

(1) X-ray fluorescence (XRF),

(2) induction-coupled plasma spectrometry (ICP), or

(3) instrumental neutron activation analysis (INAA).

Each of them has its strong and weak points. Basically, they differ in the level of detection of individual elements, which is connected with differences in the mode of spectrum excitation, preparation of samples for analysis, and mode of detection of the spectrum. The results obtained give the concentrations of a dozen or so – if not tens of – elements. They are then interpreted with the help of several mathematical methods, the most popular being hierarchical cluster analysis (cf. Ward 1974; Bieber et al. 1976; Hammond et al. 1976; Amr 1987; Mommsen et al. 1988; Gunneweg et al. 1994) and several eigenvector methods, especially principal components analysis (Bieber et al. 1976; Reutman et al. 1993; Beier, Mommsen 1994; Neff 1994; Neff et al. 1994; Glascock et al. 1996; Cau et al. 2004; Schwedt, Mommsen 2004).

With reference to the above-mentioned limited use, or even abandonment, of petrography in favour of chemical analyses, a problem that appears is to what extent the recently available research methods, specifically chemical composition analyses, can answer questions posed by archeologists. And these have not changed for years: they concern the age, place of production, i.e. location of workshops, and identification of imported vessels.

From the point of view of a geologist, a fragment of a ceramic vessel is a piece of a synthetically altered argillaceous rock, chiefly composed of clay,

whose initial properties have also been modified by an admixture of temper and firing at a temperature of several hundred degrees centigrade. Irrespective of the place of production, the basic chemical composition of such artificially formed 'rocks' is in principle similar: a mixture of SiO_2 (silica), Al_2O_3, and their accessory oxides of potassium, sodium, calcium and magnesium.

In the study of the origin of pottery, a much more useful method of determining its basic chemical composition is one consisting in a comparison of the proportions of trace elements, i.e. those present in amounts smaller than 0.1%. The differences they exhibit are like the human genetic code or papillary ridges. Unfortunately, the excessive use of this metaphor has led to much abuse, probably as a result of a misunderstanding of geochemical processes and hence of the actual possibilities of reading such a 'code'. The authors of many publications on the provenance of pottery state that they have based their conclusions on the assumption that each place on the Earth has its own unique code, and so the place of manufacture of each fragment of pottery can be identified with an almost 100 percent precision.

To understand the actual usefulness of the chemical methods, let us say a few words about factors affecting the ultimate chemical and mineral composition of clay minerals. They are determined by the fundamental laws of geology.

The surface of the Earth is made up of lithospheric plates built of rocks of the continental and the oceanic crust; the two differ significantly in their chemical composition. Those differences involve primarily the proportions of silica (SiO_2) as well as Al_2O_3, FeO, CaO, Na_2O, K_2O and MgO. Generalising, we may state that the continental crust is built of silica-rich rocks similar to granitoids in their overall composition, while ocean floors are covered with rocks of the oceanic crust, much lower in silica and closer to basalt in their average composition. In turn, the zones of plate collision are sites of volcanic activity in which the rising magma forms rocks of a more diversified, usually intermediate, chemical composition.

In each of the groups of rock mentioned the content of trace elements[14] is different. In the process of weathering, the minerals building those rocks lose some of their silica and release cations, mostly of sodium, potassium, calcium and magnesium; they turn into clay minerals, which are the basic ceramic raw material (cf. Nesbitt 1979, Nesbitt and Young 1984, 1989; White and Blum 1995; Fedo et al. 1996; Sharma, Rajamani 2000a, b). They have the form of very fine, macroscopically invisible crystals showing such properties as plasticity resulting from their ready absorption of water, and hence of the elements it contains. Without going into details, the clay composition can be said to reflect the chemical composition of the rock from which it has evolved and the water it has met.

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[14] Trace elements are defined as those elements which are present at less than the 0.1% level. Their concentrations are expressed in parts per million (ppm) or parts per billion (ppb), cf. Rollinson (1993: 2).

Clay can also be a product of readily weathering volcanic glass, hence volcanic episodes are quite clearly recorded in the structure and chemical composition of clay minerals. With time, this composition undergoes further modification during the transport of a deposit, its lithification, new weathering processes, redistribution, vegetation, soil-forming processes, biological activity, etc.[15]

Whereas sand and quartzitic or carbonate dust usually contribute to the dispersal of the trace elements contained primarily in the clay mass (since the levels of silica, calcium and possibly strontium increase), the presence of polymineral sand (high in e.g. feldspars, pyroxenes, amphiboles, olivine and fragments of such rocks as basalts, granitoids or amphibolites) can alter the initial composition significantly enough to change the proportions of the elements (cf. McLennan 1989: 179).

Depending on the pH of the environment and the oxidation-reduction conditions, most elements pass to an aqueous solution and hence travel freely, even long distances. That is why not all elements are useful in provenance-oriented geochemical interpretations. Especially valuable are those whose content in a clay rock generally does not change much under the influence of external factors, specifically weathering processes. Such elements are hard to remove from the structure of clay minerals, and they usually do not appear in the form of an aqueous solution. Therefore their content may reflect that of the parent rock from which they have developed. This group includes the rare-earth elements as well as Th, Sc, Co and Cr (cf. Taylor, McLennan 1985: 12-56; McLennan 1989: 184-185; Rollinson 1993: 132-142; Condie et al. 1995; Piovano et al. 1999; Vital et al. 1999; Vital, Stattegger 2000).

However, pH variation, especially aggressive pore water, can significantly alter the initial mineralogy and geochemistry of sediments (Nesbit 1979; Morey, Setterholm 1997; Dia et al. 2000, Muñoz-Meléndez et al. 2000; Aubert et al. 2004), including the formation of REE-rich phases like apatite and monazite (Milodowski, Zalasiewicz 1991; Lev et al. 1998, 1999, 2008).

Also useful in studies of deposit provenance are the proportions of elements whose content is different in rocks of the continental crust, the oceanic crust, and those formed in the zones of collision of the lithospheric plates. Hence a special role in provenance studies is played by the La/Sc, La/Co, Th/Sc, Th/Co, and La/Th-Th/Yb ratios (McLennan et al. 1980; McLennan 1989; Condie 1991; Condie et al. 1995; Cullers 1995; Fedo et al. 1996, Nesbitt, Markovics 1997).

Can we speak, therefore, of the uniqueness of clays in each place of the Earth? This claim must be rejected as wrong. True enough, the clays used in pottery in the many regions of the world have formed in different geographical latitudes, but the concentration of trace elements in them is controlled by the same laws of nature, which manifest themselves in chemistry as their geo-

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[15] In the case of ceramic products, an additional source of modification of the initial composition of the raw material is the potter's practice of adding a tempering material, usually sand.

chemical affinities to one another. Thus, the method of correlation of those elements cannot be relied on to meet all the expectations of archeology.

To interpret the results of chemical analyses, one must understand the basic laws controlling geochemical processes. The chemical 'papillary ridges' of pottery are primarily a reflection of the set of processes which have formed the raw material, and to a lesser extent of the place of its occurrence. Hence, we must consider false the opinion that the provenance of each fragment of pottery can ALWAYS be determined to an accuracy of a few hundred, and in many cases even just a few, kilometres. Concentrations of trace elements and their mutual proportions reflect less a provenance in the sense of a geographical location than a geotectonic provenance understood as an area where a set of geological events has combined to produce the rock under analysis, here the clay ceramic raw material.

In the face of the difficulties presented, are chemical studies of pottery worthless, then? Certainly not, but one must be aware that out of the host of studies of the provenance of ceramic products only some can bring the expected result.

1.3. Prior investigations

Most of the typological analyses of the Qumran pottery made to date have indicated its analogy to the shape of the wares present on the entire territory of Judea and termed 'Judean Pottery' (Bar-Nathan 2002: 1). The typology of pottery manufactured in this area was outlined by Lapp (1961). Typological similarities of the Qumran pottery to the finds from other sites have been observed both in the case of wares representing the Hasmonean period as well as those dated to the Roman Herodian period (Kelso, Baramki 1955: 20-41; Pritchard 1958: 21-23; Bar-Adon 1961: 25-35, 1977: 5-7; Lapp 1961: 10-13, 50-52, 1968: 77-80; Yadin 1963:11-114; Rahmani 1967: 77, 81-83; de Vaux 1973; Bar-Nathan 1981: 54-70, 2002: 203-204, 2006a: 263-277, 2006b; Bar-Nathan, Adato 1986: 160-175; Hachlili, Killebrew 1999; Fischer et al. 2000: 30-43; Hirschfeld 2000: 126-130). According to Bar-Nathan (2006b: 375-377), the pottery industry developed in the Jordan Valley and the Dead Sea region might be defined as a regional one. The distribution of the vessels was from Jericho via Qumran to Ein Feshkha, Khirbet Mazin, Ein el-Ghuweir, En Gedi, Masada and En Boqeq on the Dead Sea's western shore, and via Callirrhoe to Machaerous on the eastern one. In this context she also sees the 'scroll jars' (cf. Bar-Nathan 2002: 23-27), of the ovoid shape characteristic of the period of the Hasmoneans and Herod the Great, found in Qumran and Jericho, and the jars of a slim, cylindrical shape known mainly from Qumran, but also from Masada (Bar-Nathan 2006a: 275).

Earlier chemical investigations of the Jericho pottery by the method of instrumental neutron activation analysis (INAA) were conducted by Yellin

and Gunneweg (1989) on a set of 15 wares. Those studies aimed at finding locations where flowerpots uncovered in a garden had been produced. The authors wondered whether they had been made in Jericho or imported. Four cooking pots, two jars and one pitcher (F128-3552/1, F128-3572/1, F128-3549/1, F128-3550/1, F128-3551/1, F128-3553/1) explored from a pottery furnace (Pl.11: c) were used for comparison. The differences in the chemical compositions of the pots from the furnace and the flowerpots were considered to be the effect of a 'dilution' caused by the admixture of a silty material. The authors considered the composition of the two jars and the pitcher as significantly different. It was concluded that this difference was the effect of using a different type of clay or a special preparation of clay, and that the flowerpots had been made in the vicinity of Jericho.

The first chemical work on the provenance of the Qumran pottery, which was analysed using the INAA method, was published by Yellin, Broshi and Eshel in 2001. The authors examined 31 samples from Qumran and 8 from Ein Ghuweir. For comparison they used the 'Jerusalem reference group', i.e. the data obtained during earlier investigations (Mommsen et al. 1984). Out of the 20 elements considered, the authors eliminated Ni, Rb, Ca and chromium from their statistical analysis, attributing the abnormally high concentration of the last element to the contamination of the samples by the drill with which they had been taken. Some of the specimens were analysed after a recalibration of the geometry detector. On the basis of cluster analysis, a bivariate plot, and element patterns similar to the pottery from Jerusalem, the authors stated that some of the pottery from the two sites, i.e. Qumran and Ein Ghuweir, originated in Jerusalem.

The second volume of the Final Report Series of Qumran excavations appeared in 2003, and contained the results of the INAA of pottery provenance presented simultaneously by Jan Gunneweg and Marta Balla (Hebrew University and the Budapest University of Technology and Economics, in collaboration), and Jacek Michniewicz and Mirosław Krzyśko (Adam Mickiewicz University, Poznań). The chapter by Gunneweg and Balla contains an interpretation of the chemical analyses of 200 common pottery items and scroll jars, while the Poznań team concentrated on the analysis of the chemical composition and petrography of 50 scroll jars, which were compared with samples of clay sources from Qumran, Moza Adoraim (Jerusalem), el-Jib, and Hebron. It must be emphasised that the conclusions formulated by the two teams were entirely different.

Apart from the 200 samples of the Qumran pottery, Gunneweg and Balla drew 18 samples from other archeological sites, such as Ein Feshkha (4 samples), Jericho (4) and ez-Zara (6), as well as one brick from Jericho, one piece of bituminous rock from the Qumran quarry, one sample of clay from a dried-up puddle, one sample of clay from the Qumran plateau, one sample of the black Dead Sea mud, and two samples of Hebron clay. Some pottery data included in previous works and termed a 'data bank' were also taken into consideration.

Ultimately, Gunneweg and Balla distinguished five chemically different groups, and stated that there was no difference in the chemical composition between the pottery analysed from the khirbet and from the caves; about 33 percent of all the analysed pottery showed a chemical relation to the Qumran site; and a relatively large proportion of the pottery had associations with Jericho, so either the pottery was imported from that city or the potters used the same clay from somewhere around Jericho. Only two ovoid jars found in Qumran were local to Jericho, eight other ovoid jars did not match Jericho, two bulging scroll jars found in caves 1 and 3 came from Jericho, ten jars were locally present at Qumran itself, twenty other jars resembled the chemical fingerprint of clay and certain pottery made of the Moza Clay Formation, as it occurs in the area of Beit 'Ummar (Hebron) (Gunneweg, Balla 2003: 24).

Regrettably, Balla and Gunneweg's conclusions are corroborated neither by information about which elements were taken for statistical interpretation and which determined the division particularly strongly (an exception is the information about two mobile elements, i.e. potassium and sodium, diagnostic in their opinion for the Moza Formation), nor by the reference data or statistical computation. Therefore it is practically impossible to form an opinion about their results. The most surprising is the association of a large quantity of Qumran pottery with the 'Jericho pottery group' based only on the chemical data concerning four (!) pottery specimens from the Hasmonean and Herodian palaces in Jericho[16] (Gunneweg, Balla 2003: 18).

This team also studied 9 lamps from locus 130. In their opinion, the Hellenistic lamps KhQ Q43 and KhQ5087 were similar to the pottery of 'Group III' with a composition typical of the Jericho area, lamps KhQ1008 and KhQ5084 were assigned to 'Group I' typical of the Qumran area, while lamps KhQ5085 and KhQ2206 came from Jericho as well (2003: 23). The authors also state that the two Herodian lamps, KhQ2093 (Qum 194, Qum 293) and KhQ2541 belonging to the 'Chemical Group II', show high potassium (3.74-1.95%) and low sodium values (0.61-0.75%), which is, in their opinion, typical of the Moza Formation. They assign Jerusalem origin to lamp KhQ2093 (2003: 17).[17]

The conclusions drawn by Michniewicz and Krzyśko (2003) were different. We found that the Qumran jars were made using the same technology and a similar raw material which is not present in the vicinity of the Qumran site. The scroll jars were made with the same technique from a similar but not homogeneous material, which was non-silty clay with an admixture of quartz sand (about 10%). Most of the jars were probably made of the Moza

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[16] Two of the Jericho samples signed 'TERRA' (cf. Balla 2005: 93) were previously described by Yellin and Gunneweg (1989: 87) as coarse wares of a composition different from the finer Jericho wares (1989: 89).

[17] In the present study, analyses were made of two lamps previously examined by the Gunneweg-Balla team: KhQ5085 and KhQ5087.

Formation clays; neither terra rossa clays nor the sediments of the Lissan Formation were used in their production. The clays from several wadis situated along the Dead Sea coast, even within Wadi Qumran, were not used either. Michniewicz stated: "The clayey materials from the region of Judea are highly homogeneous from the geochemical point of view; hence, no precise determination of the provenance of local pottery is possible (e.g. it is not possible to differentiate the ceramics made of the clay of the Moza Formation taken in the vicinity of Hebron from the clay of the same formation taken in the vicinity of Jerusalem). On the other hand, it is easier to distinguish the top level of this formation from the bottom level owing to the varying redox conditions in which the deposition of the sediment took place" (2003: 76).

It seems that the opposing conclusions drawn by the two teams result from different interpretations of chemical data rather than from differences in the NAA data obtained.

1.4. Analytical methods

Comparative petrographic and chemical analyses of 127 specimens were performed. A thin section was made from each pottery fragment. Microscopic studies were conducted to establish the mineral composition of tempers, the structure of the pottery, and the temperature of its firing. An identification was also made of the foraminifers found in some of the samples; this type of study was carried out by Prof. Barbara Olszewska from the Institute of Geological Sciences, Polish Academy of Sciences in Cracow.

Another part of each sample was cut off with pincers[18], then ground in an agate mortar and sent to a chemical laboratory. The variation of the selected chemical elements was interpreted mathematically and compared with the results of observations under an Olympus AX-70 Provis polarising microscope coupled with the AnalySIS 3-1 software.

The INAA analyses were performed by the ACTLABS Activation Laboratories in Ancaster, Ontario (Canada). The 34 trace elements were determined after exposure to a stream of neutrons 7 x 1012 n/cm2/s in a McMaster nuclear reactor. After seven days of decay gamma radiation was measured with a Ge Ortec detector linked to a Canberra multi-channel analyser. The precision of determinations was monitored using the CANMET WMG-1 standard.

Since 1997, when I started conducting the Qumran pottery research, the INAA has always been carried out by the Activation Laboratories. Unfortunately, ACTLABS have recalibrated their equipment and now use a set of new standards. Despite their assurances that the results were comparable,

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[18] Experiments have proved this method to prevent contamination while making it possible to take a sample of the desired size.

statistical analyses revealed differences that made a correlation of the results obtained before and after the calibration impossible. Therefore, some samples of jars and samples drawn in the field that had been studied during the earlier investigations (Michniewicz, Krzyśko 2003) had to be reanalysed.

The lamps and the clay samples collected in the field were tested using a different method, namely inductively coupled plasma-optical emission spectroscopy (ICP-OES) and inductively coupled plasma-emission mass spectrometry (ICP-MS). The analyses of 31 trace elements were made after melting the samples in $LiBO_2$. The certified reference material SO-17/CSB, SO-17 was used. The ICP analysis was performed by the ACME Analytical Laboratories Ltd. in Vancouver (Canada).

One of the reasons for using the ICP was the intention to define a much broader spectrum of rare-earth elements than was possible with the INAA method. Another was the small mass of the lamp samples. Furthermore, it was decided that this method would help to corroborate the conclusion obtained by the NAA method, which was that the clays of the Dead Sea area revealed considerable chemical homogeneity (Michniewicz, Krzyśko 2003).

The body of the chemical data was interpreted mathematically using a spanning tree and principal components analysis. The statistical computations were performed using Statistica 6.0 and Principal Components Analysis (Maćkiewicz, Ratajczak 1992).

1.5. Search for potential clay deposits and laboratory tests of the clay samples collected in the field

Moza Formation clay deposits in the Judean Mountains seem to be the most natural raw material for the potters in Qumran. Their exploitation for the purposes of ceramic manufacture has lasted in this area since time immemorial (cf. Porat 1989; Eisenberg 1993; Zorn et al. 1994; Gunneweg et al. 1994; Goren 1995). Today the Formation can be observed especially in the vicinity of Ramallah and Hebron. On the maps comprising the Dead Sea basin and the Negev Desert, the Moza Formation has its counterpart in the En Yorqe'am Member of the Hazera Formation (Arkin et al. 1965; Begin 1975). The counterpart of those rocks in the Moab Mountains area seems to be the Fuheis Formation (cf. Schulze et al. 2003: 648). The other potential pottery-making clay resources include:

1. Lower Cretaceous (Upper Albian) shales of the Kurnub Group, widely outcropping in upper Jordan Valley i.e. in Eastern Samaria e.g. in Wadi Far'ah, Wadi el Malikh and in Trans-Jordan, especially between the northern Dead Sea and Wadi Zarga, e.g. two kilometres east of the Arda-Karama highway (east of the Jordan River) and in the Mahis village area; they are characterised by a variable content of Fe and the presence of quartz grains of

the 0.063-0.2 mm fraction (cf. Fig. 2 and Porat 1989: 28; Goren 1995: 302; Greenberg, Porat 1996: 5-26; Amireh 1997; Amireh, Abed 1999; Goren, Zuckermann 2000: 170; Khoury 2002: 20-27);

2. the Taqiye Formation of Danian-Paleocene age consisting of calcareous shales with a clay content varying between 30% and 80%. It is characterised by a rich planktonic and benthic Paleocene foraminifer content (*Loxostomoides applinae* (Plumer), *Truncorotalia angulata* (White), and *Bulimina midwayensis* (Cushman and Parker)). The Taqiye clays and their equivalents are extremely widespread along the entire southern and eastern shores of the Mediterranean, as far west as Morocco (Bentor 1966: 72-73; Flexer 1968: 106; Goren 1995: 302);

3. Pleistocene loess (northern Negev, the content of clay minerals is locally up to 38%);

4. rendzina soil and accumulations of the terra rossa type;

5. alluvial accumulations of individual intermittent streams (Yaalon 1959; Bentor 1966; Dan et al. 1972; Porat 1989); and

6. marls from the lower level of the Nezer Formation, covering laterally the top of the Shivta Formation (Begin 1975: 14).

The search for the potential ceramic raw material was conducted in the vicinity of Hebron and alongside the western bank of the Dead Sea, between Qumran and En Gedi. It was a continuation of the fieldwork carried out in Moza Adorayim and the vicinity of Qumran presented in volume two of *Khirbet Qumran et Ein Feshkha* (Michniewicz, Krzyśko 2003: 62-63).

The list of samples used ultimately as a comparative material and on which chemical analyses were performed is presented in Table 3.

1.5.1. Hebron

Pottery making has been known in the vicinity of Hebron since the ancient times; it is also practised today (cf. Chadwick 1992).

The Hebron Mountains (700-1,000 m above sea level) are characterised by a morphology of terrace slopes resulting from the alternating rock layers with different resistance to weathering. A deep wadi of the WNW orientation uncovers formations from the Albian to the Turonian that represent the Judea Group. Within this group there is the early-Cenomanian Moza Formation (15 metres in thickness), composed of marls and clayey rocks that originated from the abrasion of older rocks (Hirsch 1983: 4-5). Clays of the Moza Formation occur in several horizons separated by layers of limestone. The clays of this formation show variable colour – the top part of the profile is yellow, whereas towards the bottom the colour changes to blue-green. The clays contain thin, grey to blue layers of shales with up to 1.7% of pyrite and organic matter. The pyrite is sometimes oxidised to gypsum and limonite in surface samples (Rosenfeld et al. 1993; Scarpa 1995).

Table 3: List of clay samples taken in the field and subjected to INAA analyses.

Lab no.	Sample	Place	Description
132	H1A	Hebron	Moza Formation, yellow clays
133	H1A/1	Hebron	
134	HFPO	Hebron	same clays, after levigation and addition of quartz sand (tempering material)
135	HFPO/2	Hebron	
136	HFP1	Hebron	
137	H2A/1	Majnuna	terra rossa soil from level of karstic limestones
138	H2A/2	Majnuna	
139	H2C/1	Majnuna	Moza Formation, yellow clays 10 m below samples H2A
140	H2D	Majnuna	Moza Formation, same level (yellow clays), opposite eastern slope of outcrop
141	H2D/1	Majnuna	
142	H2F	Majnuna	Moza Formation, yellow-green clays, 20 m east of sample H2E
143	H2F/1	Majnuna	
144	H2J	Majnuna	Moza Formation, 50 m east of H2G, green-yellow clays
145	HEB/2001	Tamini Factory	Moza Formation, yellow clay, shale fragments
146	HEB/2001/A	Tamini Factory	
147	HEB/2001/B	Tamini Factory	
148	P4/2/2002	Moza Adoraim	Moza Formation, yellow marls
149	P4/2/2002/A	Moza Adoraim	
150	QUM2001	Wadi Qumran	contemporary clay sediments sampled from bottom of gorge, over Dead Sea Group sediments
151	QUM2001/A	Wadi Qumran	

The outcrops of the Moza Formation are reflected in a morphology of gentle slopes covered with many orchards and vineyards (Hirsch 1983: 4). Some of the outcrops of dolomite layers of Amminadav Formation are cut by numerous karstic caverns, filled with soils of the rendzina and terra rossa types (Fig. 4).

The clays of the Moza Formation as well as the rendzina and terra rossa soils are also used today. Many small workshops in the vicinity of Hebron manufacture pottery using a technology which has probably not changed for centuries (Figs 3, 5). Nevertheless, one should remember that in the Roman period any manufacture carried out by the Jews had to comply with the Talmud law (Vitto 1986: 47-61; Adan-Bayewitz 1993).

The Moza Formation is covered by dolomites of the Amminadav Formation (Late Cenomanian) with a thickness of 90 m. In the SE direction the layer gradually becomes thinner until it reduces to 40 metres (Hirsch 1983: 5).

Fig. 3. Kilns of a contemporary potter's workshop in Hebron.

Fig. 4. Top of light clays of the Moza Formation outcropping from under karstic Amminadav Formation rocks filled with terra rossa.

Fig. 5. Raw material stored behind a potter's workshop in Hebron, red terra rossa soil with light Moza Formation clays.

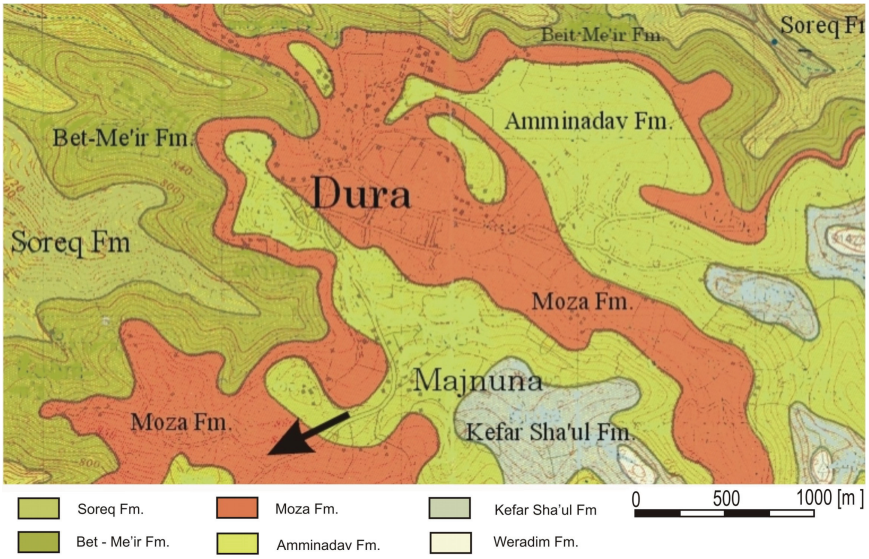

Fig. 6. Geology of the Dura area, a fragment of a geological map (after Hirsch 1983, slightly modified). The arrow indicates the Moza Formation outcrop under study.
Soreq Formation (Albian) – dolomite, marl; Bet-Me'ir Formation (Lower Cenomanian) – dolomite, chalk; Moza Formation (Upper Cenomanian) – marl; Amminadav Formation (Upper Cenomanian) – dolomite; Kefar Sha'ul Formation (Upper Cenomanian) – chalk; Weradim Formation (Upper Cenomanian) – dolomite.

The clay samples of the Moza Formation were taken in the vicinity of the settlement of Majnuna, located 2 km south of Dura, 8 km SW of Hebron (Fig. 6). Twelve samples were drawn within an area of several dozen metres. The weight of each sample was approximately 0.5 kg. The samples were taken at equal distances from the top and central parts of the profile (the floor of the formation was never uncovered). Samples of the deposits that fill the karstic caverns crossing the rocks of the Moza Formation were taken as well. Furthermore, during a visit to one of the potter's workshops in Hebron a few samples of clays imported to that workshop from the vicinity of Hebron were taken, as well as some samples of clays with quartz sand mixed in.

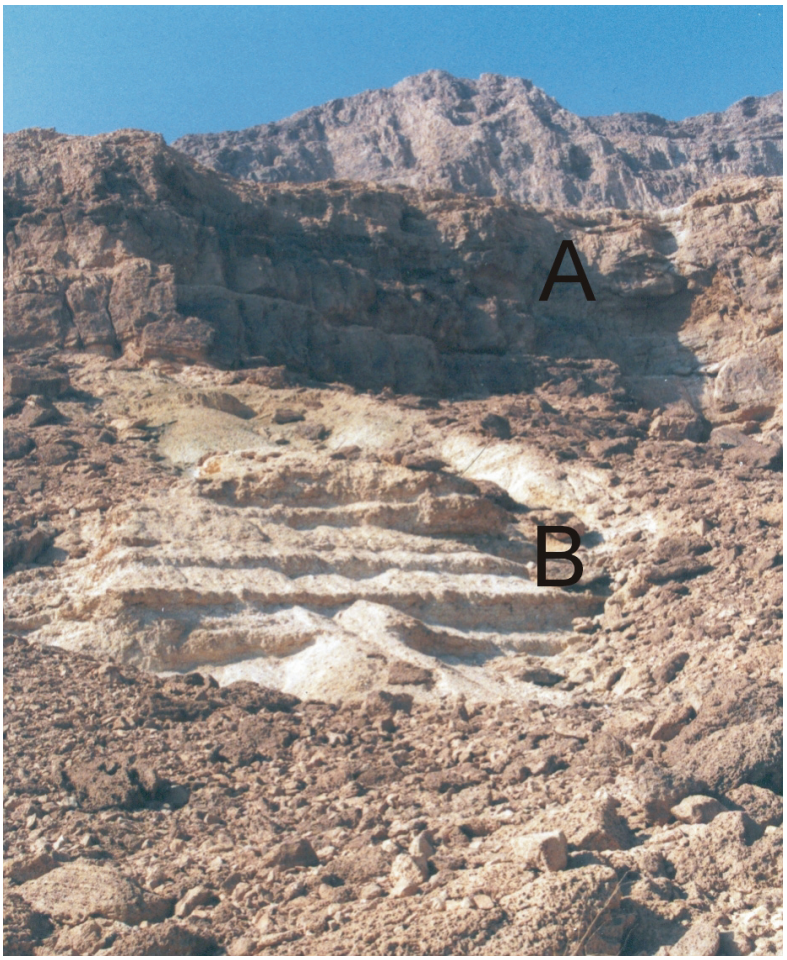

Fig. 7. En Gedi Spa. Marls of the En Yorge'am Formation (B), covered by the dolomites of the Zafit Formation (A).

1.5.2. En Gedi

The search for clay-bearing outcrops of the En Yorqe'am Formation (Mor 1987: 3), which are counterparts of the Moza Formation, was carried out along the coast of the Dead Sea, starting in Qumran and going south along a distance of 25 km. The rocks of the En Yorqe'am in this area are covered with rock rubble and hence are inaccessible. They are uncovered near Wadi Darga (an oral report by Uri Mor). Two samples (G1, G2) of these rocks were taken over En Gedi Spa (Fig. 7).

In the basin of the Dead Sea, marl shales occur also in the Avnon Formation. The shales of this formation contain thin layers of light-green clay. In the floor part, they are interbedded with a-few-centimetre-thick laminae of gypsum (Mor 1987: 5). Fifteen samples (Nos 31-45) of the Avnon Fm. were taken from the outcrop located by the red trail going along Nahal David, over the Field School in En Gedi (Fig. 8).

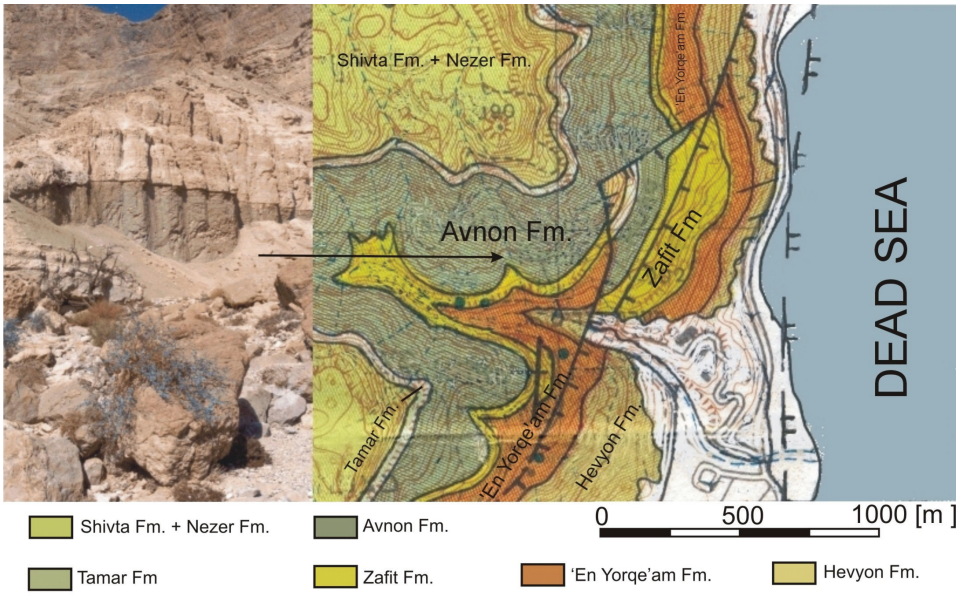

Fig. 8. En Gedi area, the studied outcrop of the Avnon Fm. A fragment of a geological map (Raz 1986), slightly modified after Mor and Burg (2000).
Hevyon Fm. (Cenomanian) – clay, dolomite; 'En Yorqe'am Fm. (Cenomanian) – limestone, chalk, clay; Zafit Fm. (Cenomanian) – dolomite; Avnon Fm. (Cenomanian) – chalk, limestone, dolomite; Tamar Fm. (Cenomanian/Turonian) – dolomite; Shivta Fm. (Turonian) – dolomite, limestone; Nezer Fm. (Turonian) – dolomite, limestone.

1.5.3. Wadi Qumran

Clay specimens sampled in Wadi Qumran (Fig. 9) constitute an alluvium originating from the accumulation of clayey deposits derived from Cenomanian, Turonian and Senonian carbonate rocks (Roth 1970). They were analysed four times. Those sampled in 1996 were irradiated in their unfired state[19] (Qum96/1, Qum96/2), then (1997) they were reanalysed after previous firing at up to 750°C (Qum 97). The next samples were collected in 1998 (Qum98) and 2001(Qum2001). Those collected in 2001 were irradiated with the remaining group of vessels and included in the calculations (cf. Chapter 5, Table 21).

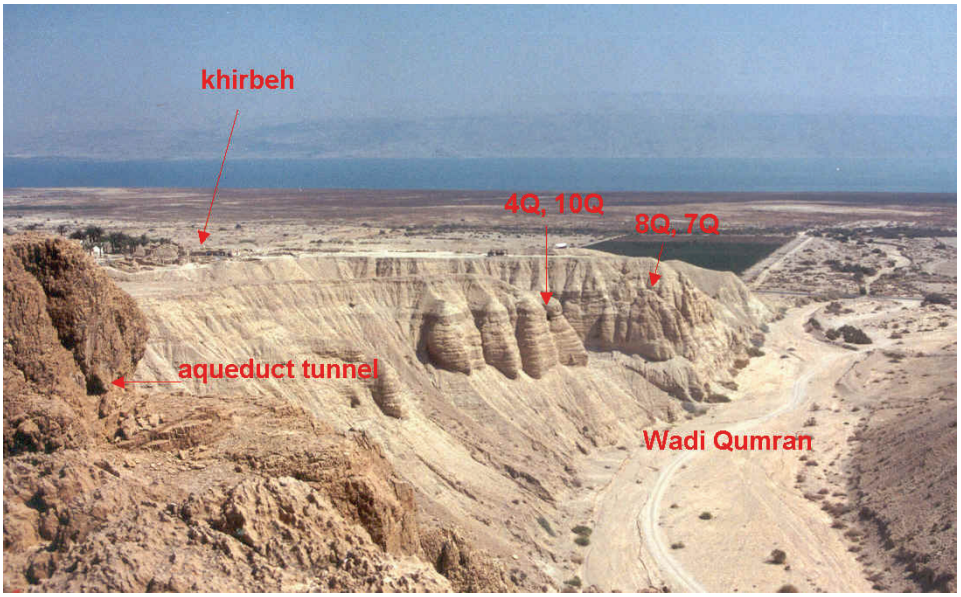

Fig. 9. View from the aqueduct dam towards the Dead Sea.

1.6. Experimental clay firing

The raw samples of terra rossa soil, H2 and H2A, are reddish-brown. They contain evenly distributed, single, differently sized particles of white carbonates which react violently with HCl. After firing at a temperature of 650°C, the bricks turned dark red. The carbonates in the bricks remained in

[19] Firing of raw clays before a geochemical analysis is used as a standard method of eliminating the diluting effect of structural water.

the form of milky-white grains. The bricks obtained from this material were very fragile. Their bad quality could be attributed to lack of levigation before the bricks were finally formed.

All the clay rocks of the Moza Formation throughout the entire area of their occurrence reveal a more or less readily visible bedding-plane fissility.

After firing, samples H2C and H2D, originally dark yellow, turned light red.

Samples H2E, H2F, H2G, H2H, H2J, and H2L contain alternating yellow and light-blue laminae. After firing the samples turned red and were darker than samples H2C and H2D.

The clay samples collected from the potter in Hebron, H1A and HFPO, turned pale red after firing.

In most cases, the clay samples from En Gedi disintegrated after firing. Only bricks formed from the Avnon Member (samples 32 and 33) turned pale red after firing at a temperature of 900°C; when rubbed, they left white traces on the fingers despite the high temperature of firing.

The samples taken above En Gedi Spa, which represent the En-Yorqe'am Formation, turned light brown after firing. The bricks were fragile, they partly retained their earthy fracture. They could not be used as pottery material.

In microscopic observations, the bricks made of the terra rossa soil (H2A, H2B, H2K) revealed a high percentage of quartz silt (<0.01 mm), namely 15-20%. Apart from silt, single sandy-fraction quartz and carbonate grains were observed. Sandy quartz grains were rounded or subrounded, whereas carbonate grains were angular.

The non-fired samples H1, H2C and H2D revealed under the microscope a high percentage of 0.03-0.08 mm rhombus-shaped dolomite crystals. This feature is considered diagnostic in the identification of the Moza Formation (Porat 1989). In the fired bricks dolomite rhombi were embedded in the light-red mass of clay minerals. No quartz grains or larger grains of carbonate rocks were observed.

The remaining samples, taken from the deeper parts of the profile, constituted pure clay minerals; only single dolomite rhombi were present there. Small silt grains of quartz were encountered sporadically. In none of the samples was sandy quartz found.

2. OIL LAMPS FROM THE QUMRAN SITE AND THE JERICHO WINTER PALACES

2.1. Object of study

The investigations focused on a comparison of petrographic and chemical features of lamps from the Qumran site and the Jericho winter palaces. The research embraced a set of 18 oil lamps from Qumran and 5 lamps from Jericho, as well as a sample of a lamp from Ein Feshkha. Three samples of clays of the Moza Formation and 3 samples of Roman storage jars from Khirbet Mazin were used as chemical comparative material. The following lamps were examined (Table 4):

Table 4. Descriptive information and group assignment of the analysed samples of lamps from Qumran and Jericho.

Lab no.	Registration no.	Locus	Shape	Petrographic group
Qumran				
1	KhQ 211	Tr A	Herodian	2
2	KhQ 538	22	Hasmonean	2
3	KhQ 661	34	Herodian	2
4	KhQ 941	52	Qm. loc. 130 type	1
5	KhQ 1012	Tr. B	Herodian	2
6	KhQ 1285	145	Herodian	?
7	KhQ 1409	81	Roman (I-II^{o} c. AD)	?
8	KhQ 1619	40	Herodian	?
9	KhQ 2034	104	Qm. loc. 130 type	?3
10	KhQ 2270	130	Qm. loc. 130 type	3
11	KhQ 2295	130	Qm. loc. 130 type	3
12	KhQ 5066	25	Herodian	3

table 4 continued

Lab no.	Registration no.	Locus	Shape	Petrographic group
13	KhQ 5083	52	Qm. loc. 130 type	3
14	KhQ 5085	66	Qm. loc. 130 type	1
15	KhQ 5087	130	Qm. loc. 130 type	1
16	KhQ 5091	60	Qm. loc. 130 type	3
17	KhQ 5100	Tr. S	Herodian	2
18	KhQ 5110	Tr. A/c5	Hasmonean	2
Ein Feshkha				
19	F305	5	Herodian	2
Jericho				
20	JR B71-188/1	B71	Herodian	2
21	JR F56-2395/1	F56	Hasmonean	1
22	JR F158-4144/1	F158	Herodian (stylistically similar to Qumran lamps)	1
23	JR F216-5197/4	F216	Herodian	1
24	JR F266-5852/2	F266	Herodian	2

2.2. Results of petrographic examination

The lamps studied show petrographic differences in such parameters as: temper frequency, temper and groundmass composition, and presence or absence of foraminifer shells. Those differences make it possible to distinguish three petrographic groups of lamps.

2.2.1. PETROGRAPHIC GROUP I (Foraminiferous Clay Group)

The presence of foraminifers, 5-10% quartz silt and a few per cent of the coarse sand fraction < 2 mm are the diagnostic features of this group of lamps.

Specimens: **4, 14, 15, 21, 22, 23**

Archeological typology:

Hasmonean	sp. 21
Qumran locus 130 type	sp. 4, 14, 15

Herodian 1 (JLP4)	sp. 22
Herodian	sp. 23

Hand specimen analysis:

Colour:		
reddish yellow	5YR 6/6	sp. 4
light red	2.5YR 6/6	sp. 14
reddish brown	2.5YR 4/4	sp. 15
yellowish red	5YR 5/8	sp. 21
dark reddish grey	5YR 4/2	sp. 22
red	2.5YR 5/6	sp. 23
Hardness:	hard	
Feel:	rough	
Fracture:	irregular to smooth	
Inclusion frequency:	<5%	
Inclusion composition:		
specimens 4, 14, 21, 22:	dominant (50-70%) white carbonates + grey foraminifers, few to common (15-30%) grey quartz	
specimens 15, 23:	predominant (>70%) grey quartz, few to common (15-30%) – white carbonates	

Thin section analysis:

Groundmass:	in plane polarised light (pp) brown, reddish brown or dark brown, under crossed polars active specimen 14), slightly active (sp. 23), inactive (sp. 4 [Fig 10], 15, 21 [Fig. 10], 22 [Fig. 11]).
Inclusion frequency:	Quartz silt constitutes about 5-10% of the field. The coarse fraction frequency varies from about 2-5% (sp: 4, 21, 22, 23), to 10% (sp. 14, 15).
Coarse inclusions:	
– Size:	<0.2 mm
– Composition:	
specimens 4, 21, 22:	predominant foraminifer shells, a few fine decomposed fragments of limestone.
specimens 14, 15, 23:	frequent (50%) monocrystalline quartz, frequent (50%) foraminifer shells. Monocrystal line quartz, 0.1-0.3 mm, subrounded and well rounded, mostly with uniform extinction. Carbonate rock grains, angular and oval, have

	usually undergone decomposition and been replaced with secondary micrite. In sample 23, a fragment of foraminifer-limestone is preserved. Foraminifer shells 0.1-0.16 mm in size. Rare flints built of fine aggregates of chalcedony.
Fine inclusions:	Dominant (50-70%) monocrystalline, angular quartz, frequent (30%-50%) carbonate silt + fine foraminifer shells; their proportion hard to establish owing to different firing tempera tures of the individual lamps.
Microfossils:	
specimen 4:	
– foraminifers:	*Heterohelix* sp., *Hedbergella cf. planispira* (Tap pan)
– age:	raw material is not older than the highest level of the Lower Cretaceous (Albian).
specimen 14:	
– foraminifers:	*Hedbergella cf. delrioensis* (Carsey), *Heterohelix* sp.
– age:	not older than the Upper Albian
specimen 15:	no identifiable remains have been found
specimen 21:	
– foraminifers:	*Gavelinella* sp., *Globigerinelloides aff. ultramicra* (Subbotina), *Hedbergella aff. delrioensis* (Carsey), *Heterohelix* sp.
– age:	Upper Albian – Lower Santonian
specimen 22:	
– foraminifers:	*Heterohelix* sp., *Globigerinelloides* sp.
– age:	not older than the Upper Albian
specimen 23:	
– foraminifers:	*Gavelinella* sp.?, *Angulogerina* sp.
– age:	Albian-Turonian

Remarks: According to Porat (1989) and Goren (1995: 302), an abundance of foraminifers is diagnostic for the Paleocene Taqiye Formation. These clays are exposed especially near Bet-Shemesh, some 60-70 km from Jericho. However, the results of micropaleontological studies of the preserved foraminifers show unambiguously the presence of representatives of the genera *Hedbergella, Heterohelix* and *Globigerinelloides*. Considering the fact

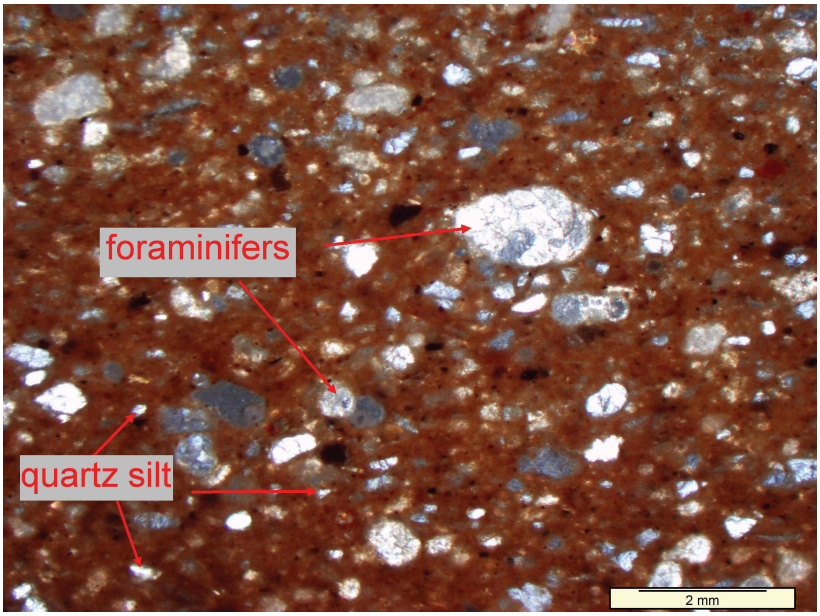

Fig. 10. Petrographic Group I. Qumran loc. 130 type lamp KhQ941 (specimen 4). Polarising microscope, crossed nicols.

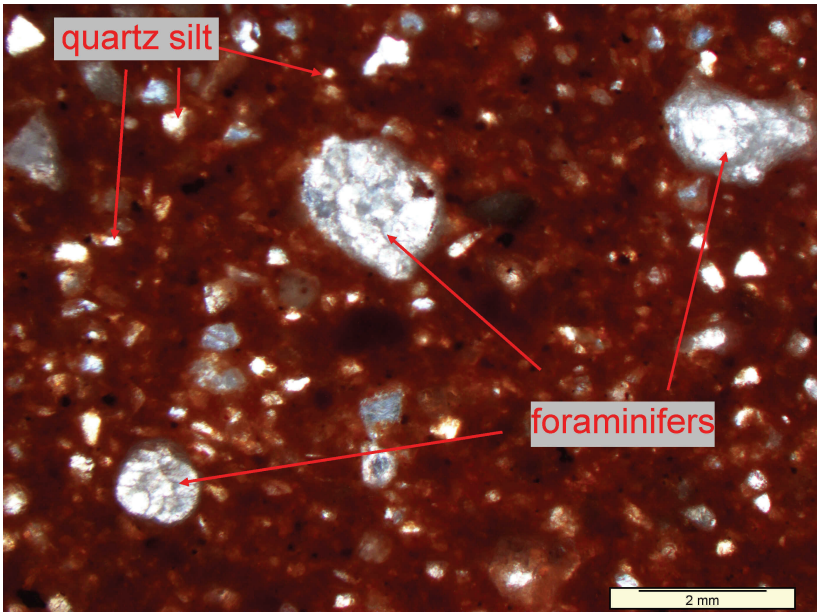

Fig. 11. Petrographic Group I. Jericho Hasmonean lamp JR F56-2395/1 (specimen 21). Polarising microscope, crossed nicols.

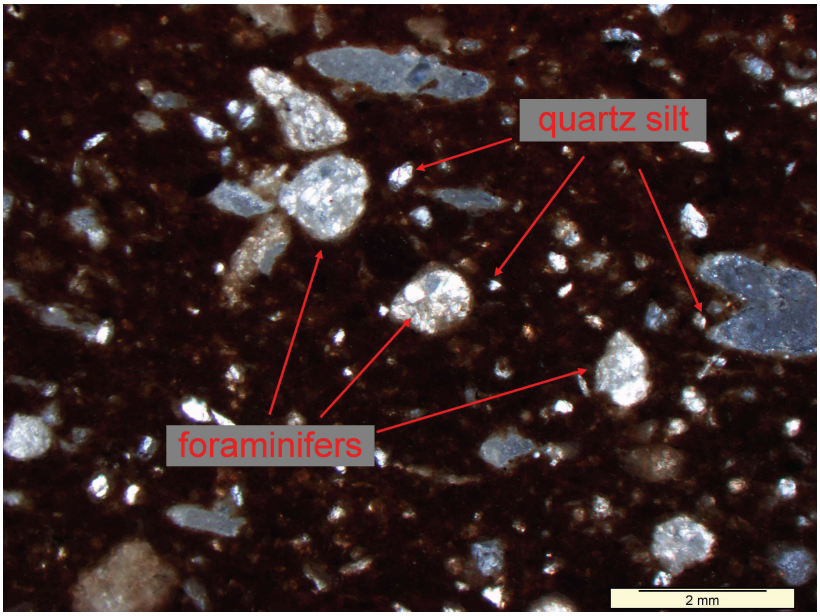

Fig. 12. Petrographic Group I. Jericho Herodian lamp JR F158-4144/1 (specimen 22). Polarising microscope, crossed nicols.

that *Heterohelix* appeared in the late Albian to become extinct, together with *Globigerinelloides*, at the top of the Cretaceous, it should be concluded that the raw material used was clay of Cretaceous age.

It should be emphasised that at least some of the remaining lamps can also belong to this petrographic group because a proportion of them were fired at a temperature at which carbonates, including foraminifer shells, undergo decomposition. This problem concerns especially sample no. 9, ultimately assigned to group III, but in chemical and stylistic terms highly similar to lamps no. 15, 14 and 4 of group I.

2.2.2. PETROGRAPHIC GROUP II (Rich Clay – Calcareous Sand Group)

This fabric is characterised by the presence of fine decomposed dolomite crystals in a clayey background, coarse carbonates, often rhombus-shaped, observed in a majority of specimens, very rare (<0.5%) coarse quartz grains,

and absence of quartz silt (in some of the samples its rare grains can be found).

Specimens: **1, 2, 3, 5, 17, 18, 19, 20, 24**

Archeological typology:

Hasmonean	sp. 2, 18
Herodian	sp. 1, 3, 5, 17, 19, 20, 24

Hand specimen analysis:

Colour:	
light red	10R 7/6 – 10R 6/8 sp. 1, 2, 5, 17, 19, 20
reddish yellow	5YR 6/6 sp. 3
red	10R 5/8 sp. 18
reddish grey	2.5YR 5/1 sp. 24
Hardness:	hard
Feel:	rough
Fracture:	irregular to smooth
Inclusion frequency:	
specimens 3, 5, 18, 19, 20:	< 5%
specimens 17, 24:	< 10%
specimen 2:	about 15%
specimen 1:	devoid of inclusions
Inclusion composition:	white grits of carbonates

Thin section analysis:

Groundmass: light red, orange-red, mottled grey (pp), active (sp. 1, 18 [Fig. 13]), partially active (sp. 2, 17 [Fig. 14], 19), inactive (sp. 3, 5, 20, 24).

Inclusion frequency: sand inclusions 0-10%

Coarse inclusions:

– Size	0.1-0.2 mm
– Composition:	Predominant irregular and rhombohedral grains of carbonates, sample 1 has no grains of the sand fraction.

Fine inclusions: Carbonate silt, small amounts in samples 2, 18, 19, 20 and 24, and a substantial proportion

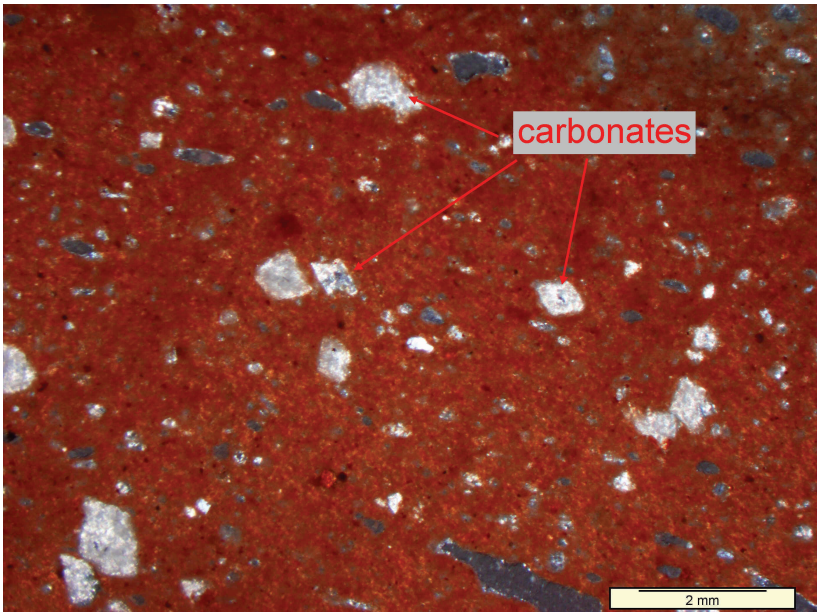

Fig. 13. Petrographic Group II. Qumran Hasmonean lamp KhQ 5110 (specimen 18). Polarising microscope, crossed nicols.

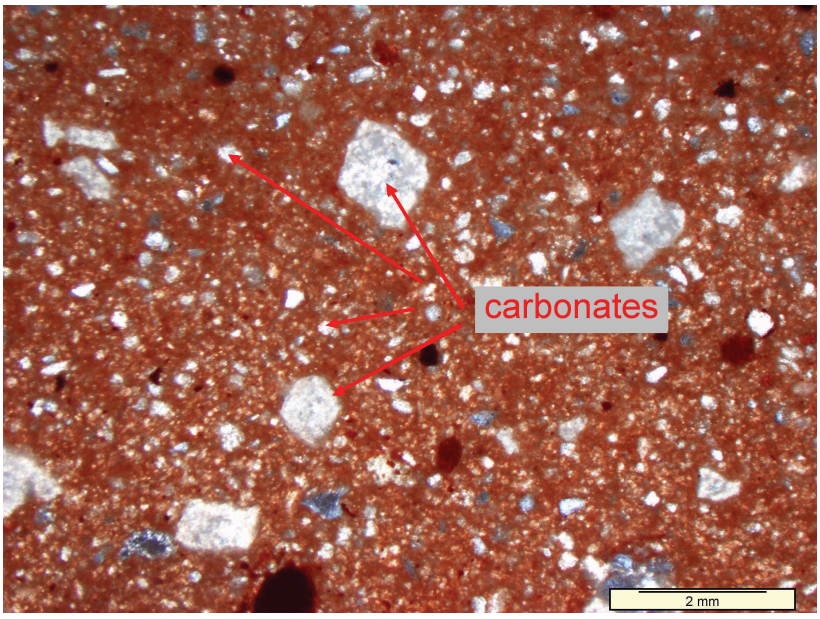

Fig. 14. Petrographic Group II. Qumran Herodian lamp KhQ 5100 (specimen 17). Polarising microscope, crossed nicols.

in samples 1, 3, 5 and 17; hence the raw material of samples 2, 18, 19, 20 and 24 should be identified as clay, whereas that of samples 1, 3, 5, 17 as marl. In sample no. 3 a small (<2%) amount of quartz silt.

Remarks: Most of the lamps of this group contain a coarse admixture consisting of decomposed, often rhombus-shaped carbonates. Although a potter would use calcite from veins cutting through the levels of carbonate rocks[1], the rhombohedral carbonate sand is primarily a product of weathering of limestone and dolomite rocks. Similar clay formations containing rhombus-shaped carbonates are known from Slovakia, near the town of Moitiu, as well as from Hungary, where they are found on the pre-Eocene weathering surface of limestone and dolomite rocks of the Middle Triassic (J. Głazek, personal communication).

The same process of Cenomanian rock weathering in the Judean Mountains is described by Goren (1995: 300-301, after Bentor 1945 in Hebrew). Goren states that such phenomena are fairly common in the Cenomanian section of the Judean Mountains. The ceramics of the Chalcolithic period from the Judean-Samarian mountain ridge containing an admixture of coarse crystalline dolomites are believed to be part of the Moza clay-dolomitic-sand group (Goren 1995: 291, 300-1). This type of pottery made of the Moza clays, sometimes with dolomitic sand, is also known from the early Roman period ceramic workshops at Binyanei ha-'Uma and Giv'at ha-Mivtar, and medieval workshops at Ramot and Timnah (cf. Mazar et al. 2001: 16).

The rhomboidal shape is characteristic of two minerals, calcite and dolomite, similar with respect to optical features. Their differentiation is usually made using the colouring technique, which fails to be sufficient after the carbonates dissociate. Dolomite is less durable than calcite and decomposes at 800°C, creating particles of calcite and periclase (MgO), then calcite becomes more turbid. What speaks for dolomite as the admixture in the lamps from Qumran and Jericho is the partially preserved anisotropy of the surrounding clay minerals, which indicates a relatively low temperature of firing in which calcite stays unchanged.

Irrespective of the origin of the rhombohedral carbonates of the sand fraction contained in the paste of the lamps, their presence should be considered a distinguishing characteristic.

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[1] This admixture is popular in Israel in the ware from the Chalcolithic and Early Bronze Ages (Porat 1989: plate 2.3, Killebrew 2000: 105).

2.2.3. PETROGRAPHIC GROUP III (Rich Clay – Quartz Sand Group)

The fabric is characterised by a high content of quartz sand and very little quartz silt.

Specimens: **9 (?), 10, 11, 12, 13, 16**

Archeological typology:

Qumran locus 130 type	sp. 9, 10, 11, 13, 16
Herodian	sp. 12

Hand specimen analysis:

Colour:		
reddish brown	5YR 5/3	sp. 9
light red	2.5YR 6/6	sp. 10
weak red	10R 5/3	sp. 11
reddish brown	2.5YR 5/4	sp. 12
dark reddish grey	2.5YR 4/1	sp. 13
light brown	7.5 YR 6/4	sp. 16
Hardness:	hard	
Feel:	rough	
Fracture:	hackly	
Inclusion frequency:	5-15%	
Inclusion composition:		
specimens 9, 10, 11, 13	grey quartz	
specimens. 12, 16	grey quartz + white carbonates	

Thin section analysis:

Groundmass: (pp) brownish grey (sp. 9), reddish brown (sp. 10), grey (sp. 11), dark brown (sp. 12 – Fig. 15), dark grey – mottled black (sp. 13 – Fig. 16), and light grey (sp. 16), under crossed nicols inactive. Numerous white stains left by decomposed carbonates are observed.

Inclusion frequency: Coarse sand constitutes 10-20% of the field, quartz silt observed in traces (<2%).

Fig. 15. Petrographic Group III. Qumran loc. 130 type lamp KhQ5066 (specimen 12). Polarising microscope, crossed nicols.

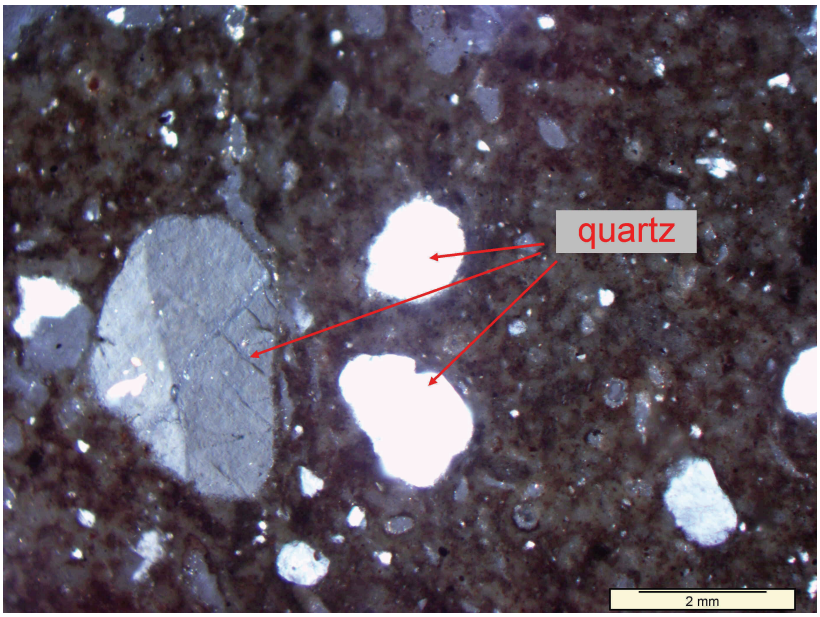

Fig. 16. Petrographic Group III. Qumran Herodian lamp KhQ5083 (specimen 13). Polarising microscope, crossed nicols.

Coarse inclusions:	Predominant in all specimens is quartz of < 0.2 mm diameter, usually subrounded, with undulose extinction. Specimens 12 and 16 contain a few (15%) and very few (5%) well-rounded and angular grains of micrite limestone.
Fine inclusions:	Traces of quartz silt, carbonate silt has undergone decomposition.

Remarks: A distinctive feature of this petrographic group is a 10-15% admixture of quartz sand we do not meet near Qumran and Jericho in the form of a loose deposit.

2.2.4. LAMPS NOT ASSIGNED TO ANY OF THE GROUPS

LAMP No. 6

Archeological typology: Herodian (wheel-made)

Hand specimen analysis:

Colour:	very pale brown 10YR 7/4
Hardness:	hard
Feel:	rough
Fracture:	smooth
Inclusion frequency:	<2%
Inclusion composition:	very few black particles of limestone (?), 0.1-0.2 mm fraction

Thin section analysis:	The diagnostic features are a rich-clay groundmass devoid of quartz silt and the presence of very few decomposed particles of limestone
Groundmass:	light grey, inactive, devoid of silt particles
Inclusion frequency:	silt – traces, sand <2%
Coarse inclusions:	angular decomposed limestone

Remarks: The presence of small, black grains of limestone makes the lamp different from the remaining lamps, but similar to the Jericho Herodian bowl Jr F182 (cf. chapter 3).

LAMP No. 7

Archeological typology: Roman (1-2 AD)

Hand specimen analysis:

Colour:	black 5YR 2.5/1
Hardness:	hard
Feel:	rough
Fracture:	smooth
Inclusion frequency:	<1%
Inclusion composition:	white dots of carbonates, <0.1 mm fraction

Thin section analysis: The diagnostic feature is a rich-clay groundmass, with some quartz silt and very few decomposed particles of carbonates.

Groundmass: greyish-black, inactive, with white stains left by decomposed carbonates

Inclusion frequency: silt <2%, sand <2%

Coarse inclusions: monocrystalline quartz + decomposed carbonates

Fine inclusions: quartz silt

Remarks: Despite a substantial proportion of carbonates, the presence of single quartz grains of the fine-sand fraction makes this sample different from the lamps of group I.

LAMP No. 8

Archeological typology: Herodian wheel-made

Hand specimen analysis:

Colour:	reddish brown margins 5YR 4/3, dark reddish brown core 5YR 3/2
Hardness:	hard
Feel:	rough
Fracture:	smooth
Structure:	porous
Inclusion frequency:	?

Table 5. Selected petrographic features of lamps from Qumran and Jericho.

Laboratory no.	Registration no.	Munsell colour	Silt frequency*	Silt composition**	Sand composition***	Foraminifers****	Textural concentration features *****
1	KhQ 211	10R 6/8	2	2	0	1	1
2	KhQ 538	10R 6/8	1	2	3	0	1
3	KhQ 661	5YR 6/6	2	2	2	0	1
4	KhQ 941	5YR 6/6	2	3	2	2	0
5	KhQ 1012	10R7/8	2	2	2	1	1
6	KhQ 1285	gley2 8/10G	2	2	0	0	1
7	KhQ 1285	5YR 2.5/1	2	2	3	0	1
8	KhQ 1619	5YR 4/3	2	3	2	?	0
9	KhQ 2034	5YR 5/3	2	3	1	0	0
10	KhQ 2270	2.5YR 6/6	1	3	1	0	0
11	KhQ 2295	gley1 7/10Y	2	2	1	0	0
12	KhQ 5066	5YR 4/4	1	1	3	0	0
13	KhQ 5083	2.5Y 5/1	2	2	1	0	0
14	KhQ 5085	2.5YR 6/6	2	3	3	2	0
15	KhQ 5087	2.5Y 5/3	2	3	3	2	1
16	KhQ 5091	7.5YR 6/4	0	0	1	0	0
17	KhQ 5100	10R 7/6	2	2	2	1	1
18	KhQ 5110	10R 5/8	1	2	2	0	1
19	Fesh 305 malo	10R 7/8	1	2	3	0	0
20	Jr B71. 188/1	10R 6/8	1	2	2	0	1
21	Jr F56. 2395/1	5YR 5/8	2	3	3	2	0
22	Jr F158. 4144/1	5YR 4/2	2	3	3	2	0
23	Jr F216. 5197/4	2.5YR 5/6	2	3	3	2	1
24	Jr F266. 5852/2	2.5YR 5/1	2	2	2	0	0
			* 0. absent 1. some 2. common	** 0. absent 1. Qz only 2. Ca only 3. Qz + Ca	*** 0. absent 1. Qz only 2. Ca only 3. Qz + Ca	**** 0. absent 1. few 2. common	***** 0. absent 1. present

Inclusion composition: numerous fine decomposed carbonates, <0.1 fraction

Thin section analysis: The diagnostic feature is a rich-clay groundmass, devoid of quartz silt and with numerous white rims around pores that have developed as a result of decomposition of carbonates.

Groundmass:	dark grey, mottled black, inactive
Inclusion frequency:	silt: <2%
Coarse inclusions:	not detected
Fine inclusions:	angular quartz

The main petrographic features of the lamps are presented in Table 5.

2.3. Chemical data and mathematical interpretation

The chemical data are presented in Table 6.

Among the 31 elements tested, the content of Sn and Ta in most samples was lower than the detection level of the method used. The presence of tungsten could be due to contamination during the mashing of Khirbet Mazin samples in a tungsten mortar. Therefore, those elements were not taken into further consideration. Besides, the small number of samples (math. *cases*) made it necessary to reduce the elements considered (math. *variables*), so as to meet the condition that the number of variables should be smaller than the number of cases. That is why out of the elements usually connected with the occurrence of heavy minerals (Zr, Hr, Nb, Y) only Hf was chosen for mathematical analyses.[2] Ultimately, the analysis was made on the basis of 24 elements: Ba, Co, Cs, Ga, Hf, Rb, Sr, Th, U, V, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu.

Before proceeding to mathematical correlation, the content of individual elements had been converted to common logarithms. This was done to avoid the discriminant effect of elements the content of which was higher than the others, e.g. Ca (%) in relation to Th (ppm). It also served to bring the statistical variability of the analysed chemical data closer to the normal distribution (Ahrends 1954a, b, Glascock et al. 1996: 20).

2.3.1. Principal components analysis

In the research on the correlation of ceramics, the principal components method (PCA) is now a standard procedure employed. It helps our imagination to visualise the mutual location of points (math. *cases*) in a multidimensional space.

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[2] The choice of Hf was prompted by the fact that its concentrations had been examined using the INAA method in the remaining Jericho and Qumran ceramics.

Table 6. Trace elements in the lamps from Qumran and Jericho – results of the ICP-MS analyses.

Lab no.	Element	Ba	Co	Cs	Ga	Hf	Nb	Rb	Sn	Sr	Ta	Th	Tl	U	V
	Registration no.\ Mass unit	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
1	Khq 211	63.10	8.70	2.40	11.80	3.10	8.70	45.30	< 1.00	282.20	<0.10	5.20	0.20	1.70	89.00
2	Khq 538	111.70	10.00	3.10	16.40	2.20	8.50	76.80	< 1.00	176.60	<0.10	5.70	0.50	2.80	128.00
3	Khq 661	106.50	9.80	4.10	16.00	3.90	10.80	79.10	< 1.00	227.10	0.20	5.90	0.10	2.50	108.00
4	Khq 941	259.10	8.60	1.40	9.50	3.30	17.90	53.20	< 1.00	416.80	<0.10	7.90	0.10	4.10	83.00
5	Khq 1012	72.50	9.70	2.80	9.90	1.70	6.50	41.40	< 1.00	364.60	<0.10	4.30	0.10	1.30	68.00
6	Khq 1285	135.20	14.60	5.00	17.70	3.00	10.20	37.80	< 1.00	283.40	<0.10	6.60	0.10	2.20	119.00
7	Khq 1409	150.90	9.20	3.20	12.00	1.80	8.60	73.50	< 1.00	201.90	<0.10	7.90	0.10	1.70	101.00
8	Khq 1619	334.70	19.20	3.60	19.90	7.70	26.70	75.80	< 1.00	305.80	0.40	10.40	0.30	3.80	174.00
9	Khq 2034	266.70	13.70	2.70	17.40	7.10	22.20	67.90	< 1.00	374.30	<0.10	7.50	0.80	4.70	150.00
10	Khq 2270	110.40	10.80	4.50	16.30	5.00	11.80	70.00	< 1.00	209.90	<0.10	5.70	0.30	2.10	108.00
11	Khq 2295	97.90	4.50	4.80	7.20	1.30	3.90	59.70	< 1.00	352.30	<0.10	4.10	0.10	0.60	41.00
12	Khq 5066	106.00	10.20	3.30	14.70	4.50	11.00	56.80	< 1.00	288.10	<0.10	6.10	0.10	2.70	108.00
13	Khq 5083	99.40	15.90	3.90	16.40	3.20	8.40	62.10	< 1.00	183.00	<0.10	5.70	0.10	1.80	87.00
14	Khq 5085	244.70	11.00	1.50	13.20	7.20	17.60	39.30	< 1.00	405.80	<0.10	6.30	<0.10	3.30	112.00
15	Khq 5087	359.80	13.70	3.10	15.30	5.50	18.50	58.70	< 1.00	406.40	0.70	7.70	0.30	3.30	131.00
16	Khq 5091	72.30	11.20	3.10	13.70	3.00	10.10	53.00	1.00	351.50	0.10	6.00	0.20	2.80	90.00
17	Khq 5100	1492.00	2.10	0.70	1.50	< 0.50	1.70	41.80	< 1.00	394.70	<0.10	2.90	<0.10	0.90	22.00
18	Khq 5110	136.50	8.50	6.50	17.60	1.30	6.50	107.20	< 1.00	165.30	<0.10	7.20	0.10	1.10	112.00
19	Fesh 305	15.80	1.50	0.40	1.30	< 0.50	0.90	6.20	< 1.00	30.90	<0.10	0.40	0.10	0.40	12.00
20	Jr B71. 188-1	153.50	14.40	3.00	17.40	3.70	9.90	69.20	2.00	551.10	0.60	7.50	0.30	1.70	116.00
21	Jr F56. 2395-1	225.70	5.80	0.80	6.40	4.00	9.00	22.70	2.00	242.40	0.50	4.10	0.20	1.70	51.00
22	Jr F158. 4144-1	154.00	6.20	1.50	8.60	2.90	9.60	33.50	2.00	199.40	0.60	4.00	0.20	2.40	69.00
23	Jr F216. 5197-4	1171.80	20.00	4.90	28.20	6.80	19.40	121.00	4.00	726.00	1.50	12.90	0.60	4.90	176.00
24	Jr F266. 5852-2	268.50	12.80	4.50	17.80	3.80	10.80	88.00	4.00	262.30	0.90	7.50	0.10	2.90	124.00
25	H2F-3	123.00	11.00	9.70	22.00	4.60	12.60	92.10	2.00	45.60	0.80	9.00	0.50	1.80	163.00
26	H2J-2	129.00	15.60	7.80	23.00	4.20	13.90	97.60	2.00	43.10	0.80	9.00	0.20	2.10	187.00
27	HFPO-1	110.00	10.40	8.70	27.10	3.80	12.50	113.10	2.00	52.50	0.70	7.90	0.30	2.80	160.00
28	QY3-1	134.00	22.50	3.70	15.10	4.90	9.50	64.70	1.00	265.80	0.50	5.80	0.10	2.90	100.00
29	QY7-1	219.00	21.30	3.80	19.20	3.60	10.60	66.30	2.00	238.50	0.60	7.00	0.30	3.20	141.00
30	QY2-1	161.00	22.90	2.60	16.90	6.10	14.20	55.60	10.00	308.90	0.80	6.80	0.20	3.30	137.00

Each dimension of this space corresponds to the concentration of one chemical element. The method involves a replacement of this multi-dimensional space with a system of a few vectors, principal components, which are a linear combination of the original variables and on the basis of which one can map actual differences among the original variables with the smallest possible error.

While useful, this method loses the mapping of mutual distances and angles between objects, analogously to the difference between the actual shape of an object in a three-dimensional space (its length, width and height) and the image of its shadow, which is a projection onto a plane. Simplifying, the PCA method can be said to consist in the choice of such an 'illumination angle' for samples lying in a multi-dimensional space as to make their 'shadows' reflect their mutual positions as closely as possible (Krzyśko, a comparison used during a conversation, cf. Krzyśko et al. 2008: 360-384, Cogswell et al. 1995).

The first results of principal components analysis revealed that the lamp samples from Ein Feshkha (19) and Qumran KhQ 5100 (17) were clearly dif-

table 6 continued

Lab no.	W	Zr	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
1	2.00	105.60	18.10	17.80	36.80	4.04	19.20	3.90	0.82	3.15	0.50	3.08	0.58	1.87	0.24	1.70	0.22
2	5.00	92.80	19.80	20.10	40.80	4.35	21.10	3.60	0.93	3.60	0.53	3.08	0.64	1.98	0.28	1.75	0.24
3	6.00	136.90	24.00	23.60	46.80	5.40	25.40	5.20	1.21	4.64	0.71	3.94	0.80	2.45	0.36	2.24	0.34
4	6.00	286.10	33.80	33.50	67.60	7.03	34.20	6.30	1.15	5.50	0.85	5.35	0.53	3.15	0.14	2.86	0.46
5	3.00	109.80	17.90	17.60	38.00	4.11	20.20	3.40	0.59	3.24	0.51	2.79	0.31	1.81	0.10	1.68	0.13
6	13.00	119.40	22.90	23.20	47.90	5.07	24.70	4.60	1.16	4.21	0.67	3.59	0.72	2.35	0.29	2.05	0.31
7	10.00	194.10	28.80	25.70	55.30	6.06	28.80	4.20	1.04	4.48	0.74	4.76	0.39	2.68	0.10	2.68	0.25
8	62.00	305.70	42.70	44.50	83.90	9.37	44.20	8.60	2.04	7.93	1.16	6.57	1.34	4.25	0.40	3.46	0.50
9	18.00	265.40	36.10	34.40	67.60	7.64	36.20	6.50	1.71	6.33	0.91	5.62	1.08	3.38	0.45	3.04	0.44
10	10.00	192.30	27.00	24.30	50.70	5.50	26.70	5.20	1.27	4.65	0.75	4.61	0.92	2.69	0.41	2.38	0.36
11	28.00	156.80	20.90	20.50	64.20	4.63	22.10	2.80	0.64	3.62	0.51	3.45	0.34	1.70	0.09	2.03	0.10
12	14.00	175.30	22.90	21.10	43.30	4.83	23.00	4.40	1.09	4.28	0.61	3.85	0.69	2.22	0.30	2.06	0.28
13	21.00	187.30	21.40	21.10	43.10	4.56	21.40	3.90	1.04	3.77	0.62	3.21	0.58	2.20	0.17	2.07	0.28
14	12.00	266.70	29.90	26.60	52.70	5.92	27.40	5.00	1.31	4.64	0.72	4.59	0.92	2.82	0.41	2.59	0.41
15	20.00	217.30	33.70	31.30	60.50	6.76	31.90	5.80	1.55	5.75	0.85	5.10	0.95	3.10	0.42	2.86	0.42
16	8.00	118.80	19.30	22.10	45.00	4.80	22.70	3.90	1.12	3.95	0.62	3.17	0.64	2.02	0.27	1.69	0.26
17	8.00	154.60	19.80	9.40	37.00	4.03	10.90	0.90	0.22	2.76	0.25	2.47	< .05	0.61	< .05	0.63	< .01
18	41.00	116.40	23.50	23.40	51.60	5.40	24.50	4.80	0.78	4.56	0.67	4.48	0.37	2.30	0.12	1.83	0.15
19	3.00	16.10	2.40	2.20	5.90	0.46	2.20	0.50	0.08	0.52	0.05	0.38	0.07	0.23	< .05	0.21	0.04
20	4.00	137.80	25.80	22.80	49.00	5.60	25.40	5.10	1.33	4.81	0.77	4.05	0.85	2.40	0.35	2.33	0.34
21	< 1.0	148.30	17.40	15.90	30.80	3.38	15.10	2.90	0.83	2.78	0.49	2.71	0.52	1.55	0.24	1.32	0.24
22	7.00	106.40	18.30	16.80	32.20	3.65	16.60	2.90	0.79	3.19	0.51	2.67	0.59	1.55	0.27	1.67	0.21
23	9.00	244.90	47.60	40.70	88.90	10.01	44.60	11.00	2.48	8.10	1.34	8.30	1.47	3.95	0.65	4.39	0.67
24	4.00	136.00	27.00	24.20	50.00	5.90	27.20	5.30	1.37	4.99	0.75	4.65	0.89	2.30	0.40	2.48	0.39
25	18.00	142.90	25.90	27.20	54.10	6.73	29.50	5.90	1.41	4.89	0.84	4.99	1.03	2.75	0.38	2.64	0.40
26	11.00	144.10	26.70	28.40	57.20	6.83	30.10	6.20	1.44	5.18	0.79	5.07	0.92	2.63	0.39	2.67	0.40
27	20.00	124.20	20.60	22.60	48.50	5.95	24.90	5.50	1.15	4.27	0.73	4.11	0.76	2.22	0.33	2.14	0.33
28	190.00	167.70	21.40	19.60	39.20	4.58	20.20	4.20	1.04	3.82	0.60	3.34	0.67	1.93	0.30	2.03	0.30
29	20.00	117.50	23.20	23.60	46.80	5.47	23.80	5.00	1.19	4.95	0.70	4.32	0.87	2.25	0.33	2.31	0.31
30	78.00	222.60	28.10	26.30	53.50	5.98	25.90	5.40	1.29	4.89	0.76	4.46	0.94	2.64	0.39	2.66	0.34

ferent from the others. Considering the fact that those were samples of a mass of 0.02 mg, much smaller than that required by the laboratory, which also displayed elevated levels of heavy minerals as shown by a high content of Zr, they were skipped in subsequent calculations. The remaining set of the oil lamps, together with three samples of the Moza Formation clays taken near the Majnuna village (10 km north of Dura, H2J-2, H2F-3, HFPO) and three storage jars from Khirbet Mazin (Qasr el Yahud, QY2, QY3, QY7) were analysed again. The calculations were made on the basis of the correlation matrix obtained.

The geometric relations between the objects (i.e. the specimens analysed) in a 24-dimensional space after projection onto the plane of the first two principal components PC1 and PC2 were preserved in 79% (Table 7). Together with the third dimension, the mapping of the real reciprocal location of the samples was 89.5% (Figs 17, 18).

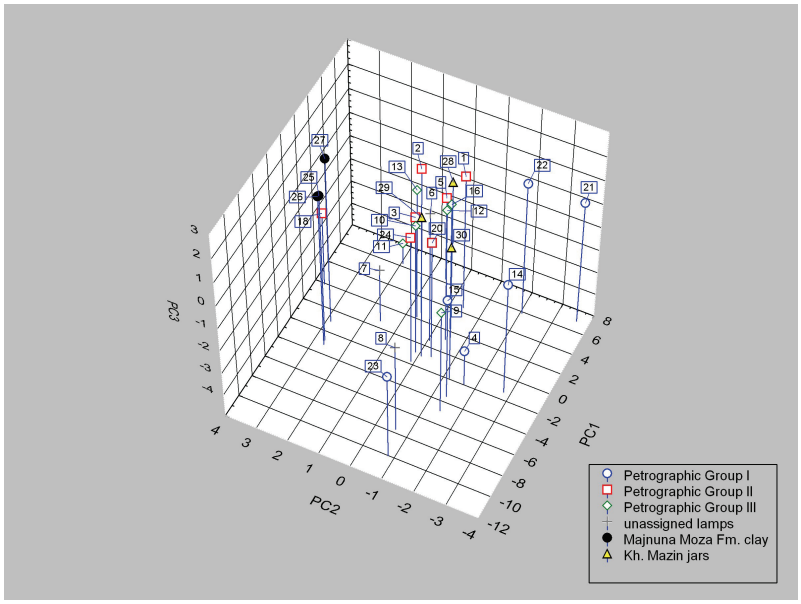

Fig. 17. Lamps from Qumran and Jericho in the space of the first three principal components. Separate marks distinguish the individual petrographic groups, samples of Majnuna clay, and samples of Khirbet Mazin jars.

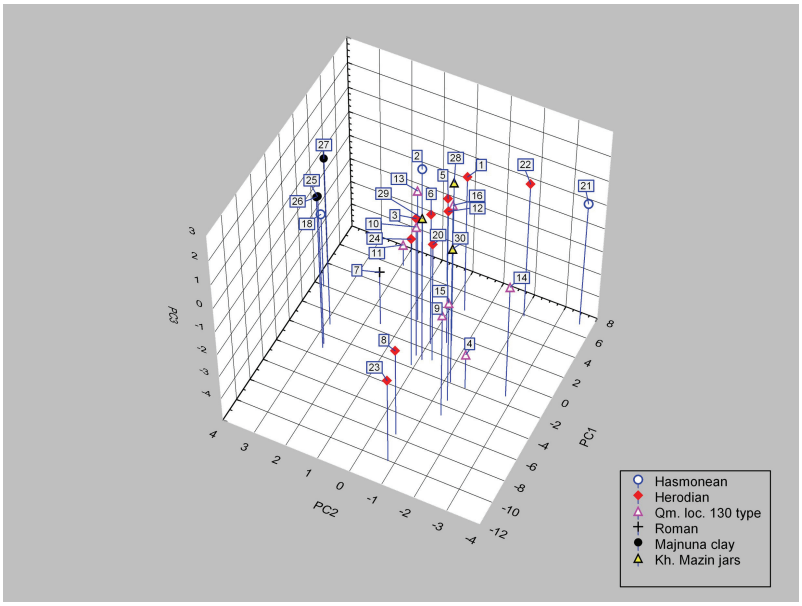

Fig. 18. Lamps from Qumran and Jericho in the space of the first three principal components. Separate marks indicate different shapes of the lamps.

Table 7. Results of principal components analysis based on the correlation matrix of Qumran and Jericho lamps, Majnuna clay, and Khirbet Mazin sherds.

Principal component number	Eigenvalue	Percentage of variance explained	Cumulative % of total variance
1	15.5543	67.21	67.21
2	2.8154	12.17	79.38
3	2.3373	10.10	89.48
4	0.6668	2.88	92.36
5	0.4364	1.89	94.25
6	0.3885	1.68	95.93
7	0.2519	1.09	97.02
8	0.1569	0.68	97.70
9	0.1326	0.57	98.27
10	0.0982	0.42	98.69
11	0.0730	0.32	99.01
12	0.0617	0.27	99.28
13	0.0430	0.19	99.47
14	0.0345	0.15	99.62
15	0.0268	0.12	99.74
16	0.0228	0.10	99.84
17	0.0142	0.06	99.90
18	0.0104	0.05	99.95
19	0.0077	0.03	99.98
20	0.0045	0.02	100.00
21	0.0039	0.00	100.00
22	0.0013	0.00	100.00
23	0.0006	0.00	100.00
24	0.0002	0.00	100.00

The first principal component PC1 is mostly determined by variations of Th and rare earths; the second, PC2, is determined by three elements: Cs, Rb and Sr; whereas the third, PC3, by Tm, Ce and Sr (cf. Table 8).

Table 8. Values of the determination coefficient R^2 x 100%.

Element	PC1	PC2	PC3
Ba	50.28	15.94	6.74
Co	45.02	0.25	14.91
Cs	11.96	74.34	4.18
Ga	56.53	17.71	19.33
Hf	48.80	25.98	14.27
Rb	36.56	48.12	0.11
Sr	0.36	41.58	22.33
Th	85.88	5.28	0.11

table 8 continued

Element	PC1	PC2	PC3
U	47.64	24.22	7.63
V	69.98	5.74	16.33
La	87.01	0.01	9.34
Ce	67.20	2.19	24.97
Pr	91.72	1.33	5.74
Nd	86.50	0.77	10.26
Sm	95.02	0.19	0.10
Eu	91.62	2.67	1.93
Gd	92.92	0.04	4.49
Tb	94.87	0.01	2.52
Dy	88.10	0.76	7.42
Ho	69.25	5.93	17.38
Er	88.39	0.10	5.23
Tm	44.45	9.84	34.76
Yb	86.82	0.00	6.29
Lu	76.18	9.00	5.99

2.3.2. Spanning tree

While principal components analysis (PCA) makes it possible to visually grasp the basic differences within the set of ceramics studied, it does not provide an objective criterion of distinguishing groups of vessels significantly dissimilar in statistical terms. Besides, the reduction of the multidimensional space distorts the actual angles and distances between the variables, and thus distorts the degree of their similarity.

Hence, PCA was supplemented with a method of dendritic ordering free of the distortions resulting from the reduction of spatial dimensions. The method is known as the Wrocław taxonomy (Florek et al. 1951; Perkal 1958: 79-82). With the help of a table of between-point Euclidean distances, successively closest pairs of points were connected, thus producing a dendrite (a spanning tree) (cf. *Encyclopedia of Statistical Sciences* 1982: 302-305, Krzyśko et al. 2008: 384). The distances between the points are a measure of their similarity: the shorter the distance, the greater the similarity. The distances (D) between the lamp specimens are presented in Table 9[3].

In the analysis based on the 24 elements, the mean (M) of all the shortest distances between points equalled 2.71, while the standard deviation (δ) = 0.84. If we set the criterion of a division into subgroups at $M + 2\sigma = 4.39$, which corresponds to a 95.5% probability that the lamps separated in this way are actually different, then, apart from the completely dissimilar samples 17 (KhQ5100) and 19 (F 305), the only specimen significantly different statistically is no. 11 (lamp KhQ 2295, loc. 130).

[3] e.g. the Euclidean distance D between lamps 1 and 5 equals 3.50.

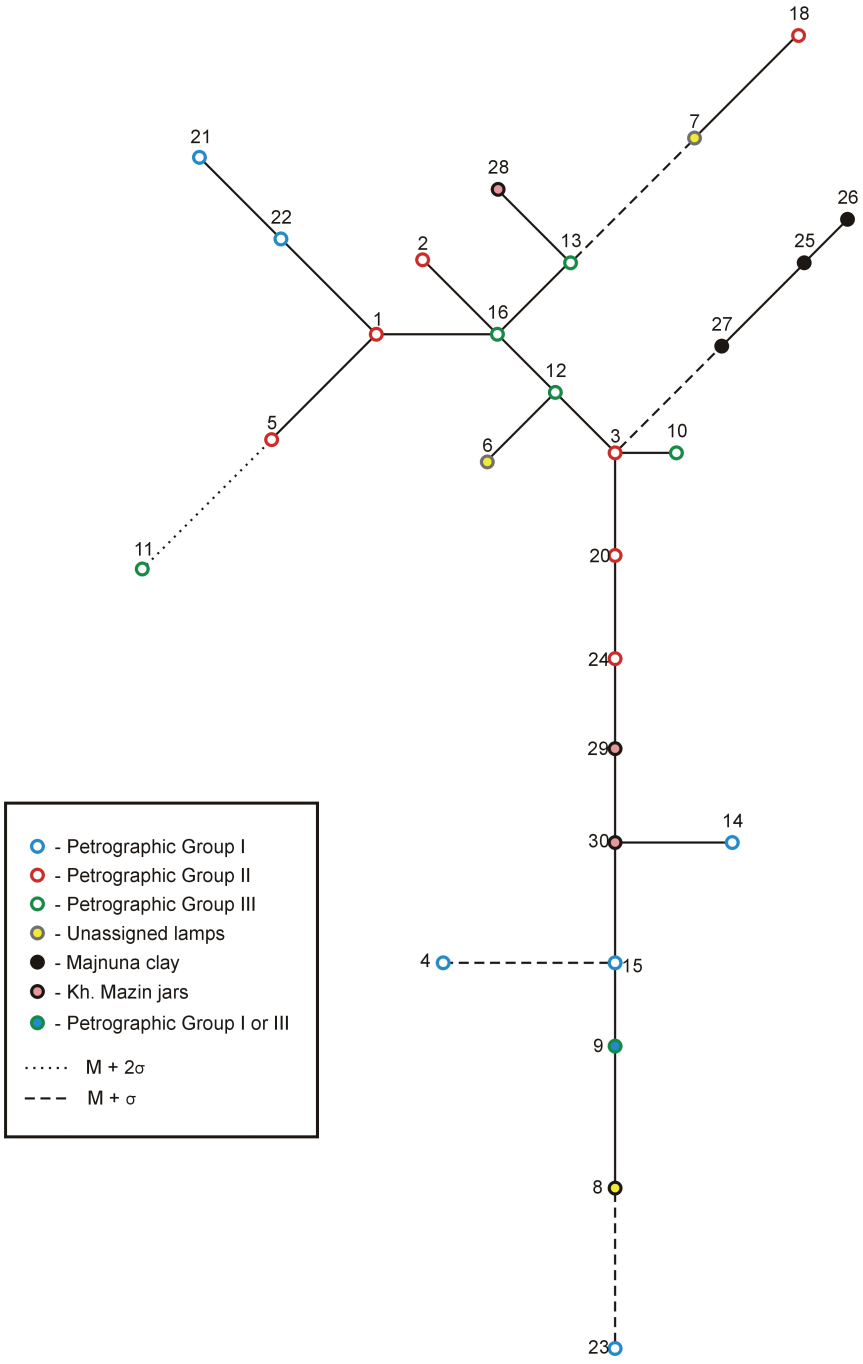

Fig. 19. Spanning tree presenting the greatest similarity (closeness) between the lamps from Qumran and Jericho. The diagram skips the completely dissimilar samples 17 and 19.

Table 9. Values of the shortest Euclidean distances between the successively closest points representing the ceramic samples in the 24-dimensional space of the elements analysed.

Pairs	Distance
1 - 5	3.50
5 - 11	4.38**
1 - 16	2.80
16 - 2	2.41
16 - 12	1.82
12 – 3	1.88
3 - 10	1.27
3 - 20	2.33
20 - 24	2.30
24 - 29	2.01
29 - 30	2.08
30 - 14	2.70
30 - 15	2.78
15 - 4	4.10*
15 - 9	1.83
9 - 8	3.33
8 - 23	3.81*
3 - 27	3.56*
27 - 25	2.72
25 - 26	1.26
12 - 6	2.19
16 - 13	2.35
13 - 7	4.20*
7 - 18	3.44
13 - 28	2.34
1 - 22	3.15
22 - 21	2.65
MEAN (M) = 2.71 Standard deviation(σ) = 0.84 * M + σ = 3.55 ** M + 2 σ = 4.39	

With a probability of 68% (M + σ = 3.55), also different will be lamps 7 and 18 (KhQ 1409 - Roman, unassigned, KhQ 5110 - Hasmonean, Petrographic Group II); 4 (KhQ 941 - Qumran loc. 130 type, Petrographic Group I); 23 (Jr F216-5197/4 Herodian, Petrographic Group I), and 25, 26 and 27 (Majnuna clays).

The remaining lamps make up a fairly homogeneous set. Visually standing out against it, apart from the samples listed above, are the remaining lamps of Petrographic Group I: the pairs 21 and 22 as well as 14 and 15, together with lamp 9 similar to Petrographic Group III (?)[4].

[4] Owing to a high firing temperature of this lamp and the resultant disintegration of carbonates, it is not unlikely that it was made of clay containing foraminifers; hence, it would belong to group I.

2.4. Comparison of the results of chemical analyses with those of petrographic observations

The lamps of the three petrographic groups show quite big intra-group chemical variability. This is especially striking against the homogeneity of the three clay samples taken in the field (cf. Figs 17-19).

A central clustering, and the greatest intra-group similarity, is shown by lamps 3, 20 and 24 and 2, 1, 5 of Petrographic Group II as well as lamps 10, 12, 13 and 16 of Petrographic Group III. This similarity suggests that they were made of a similar (the same?) clay raw material, while the difference in the admixture in the two groups may be due to the different practices of the potters.

In turn, lamps of Petrographic Group I occupy marginal locations in the diagrams. These are lamps from Qumran: 4, 14 and 15, and those from Jericho: 21, 22 and 23. What characterise those lamps are a brown hue and the presence of foraminifer shells[5]. Within this group, the Jericho lamps are different in chemical terms from the Qumran lamps.

The three samples of Khirbet Mazin jars used as a comparative material are similar to groups II and III. This may be evidence that the lamps were made of a similar raw material coming from the area of Judea or the Dead Sea basin. In turn, without a systematic study of the geochemical variability of the Moza Formation clays, the visual dissimilarity of the Majnuna clays cannot be treated as proof that it was not this raw material that was used[6].

2.5. Summing up

Three groups of lamps can be distinguished (cf. Table 4):

(1) a group of lamps made of slightly silty clay (5-10% quartz silt) containing Cretaceous foraminifers, tempered with fine quartz or quartz-carbonate sand;

(2) a group of lamps made of rich, more or less marly clay with an admixture of rhombohedral-shaped carbonate grains of the sand fraction rather than of quartz; and

(3) a group of lamps made of rich clay tempered in 10-20% with quartz sand.

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[5] A petrographically similar raw material can be found among some of the common wares from Jericho and Qumran (cf. chapters 3 and 4), hence this finding partly corroborates the results of Gunneweg and Balla (2003), who set apart lamps KhQ5085 and KhQ5087, but described them as local to Jericho (which is rather surprising to the present author).

[6] The present author's research to date has shown the marls and clays of this formation to display great geochemical variability, probably a reflection of the variable oxidation-reduction conditions of their sedimentation.

In chemical terms, the lamps made of foraminiferous clay are the most dissimilar. The remaining lamps are chemically similar.

The absence of chemical dissimilarity between lamps assigned to Petrographic Group II and those assigned to Petrographic Group III suggests that the difference between them is due to different pot-making practices, i.e. a difference between workshops using a similar (the same?) raw material.

In the light of the results obtained, the lamps from Qumran and Jericho can be supposed to have been made in workshops using the same, at least two, varieties of clay raw material.

Lamps of the Qumran locus 130 type, which stand out from all the others because of their shape, are made of the same raw material as the remaining lamps, i.e. two varieties of clay: foraminiferous clay and pure clay tempered with quartz sand.

3. JERICHO – COMMON CERAMICS FROM HASMONEAN AND HERODIAN PALACES

3.1. Object of study

The study comprised 37 jars and 9 bowls (Table 10). Chronologically, they are divided into five typological-chronological groups, correlative with the stratigraphic-architectural stages (cf. Netzer 2001: 1-10, Bar-Nathan 2002: 4-5):

HS1 – Hasmonean 1 (100 – 95/85 BC),
HS2 – Hasmonean 2 (85/75 – 31 BC),
HR1 – Herodian 1 (31 – 15 BC),
HR2 – Herodian 2 (15BC – 6 AD), and
HR3 – Herodian 3 (6 – 48 AD).

3.2. Petrography

Differences in the fabrics of the Jericho ceramics involve primarily the amount and composition of temper, quartz silt content, presence of foraminifers, and colour. We have here the same petrographic varieties of fabric that we have distinguished in the lamps when assigning them to three petrographic groups. However, the fabric of the cooking pots from Jericho turned out to be completely different, resembling a terra rossa type of ceramics. Those vessels formed a new, fourth, petrographic group. This classification was also maintained in the description of the Qumran, ez-Zara and Khirbet Mazin ceramics.

3.2.1. PETROGRAPHIC GROUP I (Foraminiferous Clay Group)

Petrographic group I (Foraminiferous Clay Group) – ceramics made of slightly silty (5-10% of quartz silt), calcareous clay containing foraminifer shells, a few percent of coarse limestone, and quartz grains.

Table 10. Descriptive information and group assignment of the analysed samples of Jericho pottery.

Lab no.	Registration no.	Stratigraphic level	Type	Petrographic group
1	JR A(A) 209-1326/1	Hasmonean 1	bowl	1
2	JR A(A) 209/9	Hasmonean 1	bowl	1
3	JR A(A) 209/1199	Hasmonean 1	bowl	1
4	JR A(B)93-660/9	Hasmonean 2	bowl,	1
5	JR F 176-5108	Herodian1	storage jar	2
6	JR F182	Herodian1	bowl	1
7	JR F182B	Herodian1	bowl	1
8	JR F176-5104	Herodian1	storage jar	3
9	JR F176- 5108/3	Herodian1	storage jar	3
10	JR F176- 5108A	Herodian1	storage jar	2
11	JR F176-5108 B	Herodian1	storage jar	3
12	JR B154- 399	Herodian2	storage jar	2
13	JR B154- 399A/B	Herodian2	storage jar	1
14	JR B154- 399B	Herodian2	storage jar	1
15	JR B154- 399B′	Herodian2	rage jar (bowl?)	1
16	JR B154-300A	Herodian2	storage jar	1
17	JR B154-399A/A	Herodian2	bowl	1
18	JR B154-399-C	Herodian2	storage jar (bowl?)	1
19	JR B154-399C′	Herodian2	bowl or jar	1
20	JR B154-399D	Herodian2	storage jar	1
21	JR B154-399E	Herodian2	storage jar	1
22	JR A 541- 4553/1	Hasmonean 2 Twin Palaces	storage jar,	2
23	JR AE 304-700/1	Hasmonean 2 Twin Palaces	storage jar	2
24	JR AE 34- 4617/1	Hasmonean 2 Twin Palaces	storage jar	2
25	JR AE 47- 4720/1	Hasmonean 2 Twin Palaces	storage jar	2
26	JR AE 57- 5276/1	Hasmonean 2 Twin Palaces	storage jar	3
27	JR AE 59- 8260/1	Hasmonean 2 Twin Palaces	storage jar	2
28	JR AE57-5276/2	Hasmonean 2 Twin Palaces	storage jar	3
29	JR B215- 9193	Herodian3	storage jar	1
30	JR B25-9143	Herodian3	storage jar	1
31	JR B215- 9193A	Herodian3	storage jar	3
32	JR B215- 9193B	Herodian3	storage jar	1
33	JR B214- 9188	Herodian3	storage jar	1
34	JR F 128- 3548/1	Herodian3 tanur (kiln)	cooking pot	4
35	JR F 128- 3548A	Herodian3 tanur	cooking pot	4
36	JR F 253-5774/1	Herodian 1\2?	‘genizah’ jar	3
37	JR F258-5780	Herodian 1\2 ?	‘genizah’ jar	3
38	JR F128- 3548/2	Herodian 3 tanur	cooking pot	4
39	JR F403	tabun	bowl	1(?)
40	JR A(A) 81- 1164	Hasmonean 2	storage jar	3
41	JR A(A) 81 -1156	Hasmonean 2	storage jar	3
42	JR A(A) 81- 1161	Hasmonean 2	storage jar	3
43	JR A(A) 81- 1407	Hasmonean 2	storage jar	3
44	JR A(A) 81- 1413	Hasmonean 2	storage jar	3
45	JR A(A) 81- 846C	Hasmonean 2	storage jar	3
46	JR A(A) 81- 846D	Hasmonean 2	storage jar	3
47	JR A(A) 81-1004	Hasmonean 2	storage jar	3

table 10 continued

Lab no.	Registration no.	Stratigraphic level	Type	Petrographic group
48	JR A(A) 81-1064	Hasmonean 2	storage jar	3
49	JR A(A) 81-1154	Hasmonean 2	storage jar	3
50	JR A(A) 81-1175	Hasmonean 2	storage jar	3
51	JR A(A) 81-1175	Hasmonean 2	storage jar	3
52	JR A(A) 81-846A	Hasmonean 2	storage jar	3
53	JR A(A) 81-846B	Hasmonean 2	storage jar	3

Specimens: **1, 2, 3, 4, 6, 7, 13, 14, 15, 16, 17, 18, 19, 20, 21, 29, 30, 32, 33**

Archeological stratigraphy:

Hasmonean 1 (bowls)	sp. 1, 2, 3, 4
Herodian 1 (bowls)	sp. 6, 7
Herodian 2 (storage jars)	sp. 13, 14, 15, 16, 20, 21
Herodian 2 (bowls)	sp. 17, 18, 19
Herodian 3 (storage jars)	sp. 29, 30, 32, 33

Hand specimen analysis:

Colour:	
light brown to strong brown	7.5YR 6/4-7.5 YR 5/6 sp. 1, 2, 3, 6, 7, 15, 16, 18, 20
light red to red	2.5YR 6/8 – 2.5YR 5/8 sp. 4, 13, 14, 17, 19, 21, 29, 30, 32, 33
Hardness:	hard
Feel:	rough
Fracture:	irregular to smooth
Inclusion frequency:	2-5%
Inclusion composition:	predominantly white carbonates + grey foraminifers

Thin section analysis:

Groundmass: in plane polarised light (pp), light brown (sp. 1 [Fig. 20], 2, 3, 6 [Fig. 22], 7, 13 [Fig. 23], 15, 20), under crossed polars inactive; red (14, 30, 32), inactive; light red with a brown core (4 [Fig. 21], 16, 17, 18, 21, 33), partially active and inactive.

Inclusion frequency: Quartz silt constitutes about 5-10% of the field, the coarse fraction varies from about 1-5% (sp. 1, 2, 3, 4, 6, 7, 13, 14, 19, 20, 21, 30, 33) to 10-20% (sp. 15, 18, 32).

Coarse inclusions: Predominantly foraminifer shells 0.05-0.16 mm in size and decomposed fragments of limestone.

Fine inclusion composition: Monocrystalline, angular quartz silt.

Microfossils:

specimen 1:
- foraminifers: *Hedbergella* sp., *Globigerinelloides aff. ultramicra* (Subbotina)
- age: a trace of microfauna making it practically impossible to determine the age; the index species known since the Upper Albian

specimen 2:
- foraminifers: *Hedbergella* sp., *Heterohelix* sp.
- age: the index genus suggests an age not older than the Upper Albian (probably within the Upper Albian- Lower Turonian range)

specimen 3:
- foraminifers: ? *Praebulimina* sp., *Hedbergella* sp., *Heterohelix* sp., *Globigerinelloides* sp. Other: radiolarians (single)
- age: The youngest of the genera has been known since the Upper Albian However, the presence of a few foraminifers can suggest the Cenomanian.

specimen 4:
- foraminifers: *Hedbergella* sp., *Heterohelix* sp., a fragment of a big form, possibly *Praeglobotruncana* sp.
- age: the range of the index genus embraces the Upper Albian-Middle Turonian

specimen 6:
- foraminifers: ? *Heterohelix* sp., ? *Hedbergella* sp., ?? *Rotalipora* sp./ ? *Globotruncana* sp. (oblique cutting
- age: the age range of the index genus limits the sample age to the Cenomanian

specimen 7:
- foraminifers: *Hedbergella cf. delrioensis* (Carsey), ? *Blefuscuiana infracretacea* (Glaessner), *Heterohelix* sp.

– age: the presence in the assemblage of the genus *Heterohelix* restricts its age to the Upper Albian; the Albian also marks the end of the occurrence of *B. infracretacea*

specimen 15:
– foraminifers: not found

specimen 19:
– foraminifers: *Heterohelix* sp.
– age: cf. specimen 2

specimen 20:
– foraminifers: *Globigerinelloides aff. ultramicra* (Subbotina), *Heterohelix cf. moremani* Cushman, *Hedbergella* sp.
– age: although the index species has an Upper Albian- Middle Turonian range, it is the most abundant in the uppermost Cenomanian; therefore the sample may be of Cenomanian age

Owing to a higher firing temperature, it was impossible to determine the remains in samples 16, 17, 18, 21, 30, and 32.

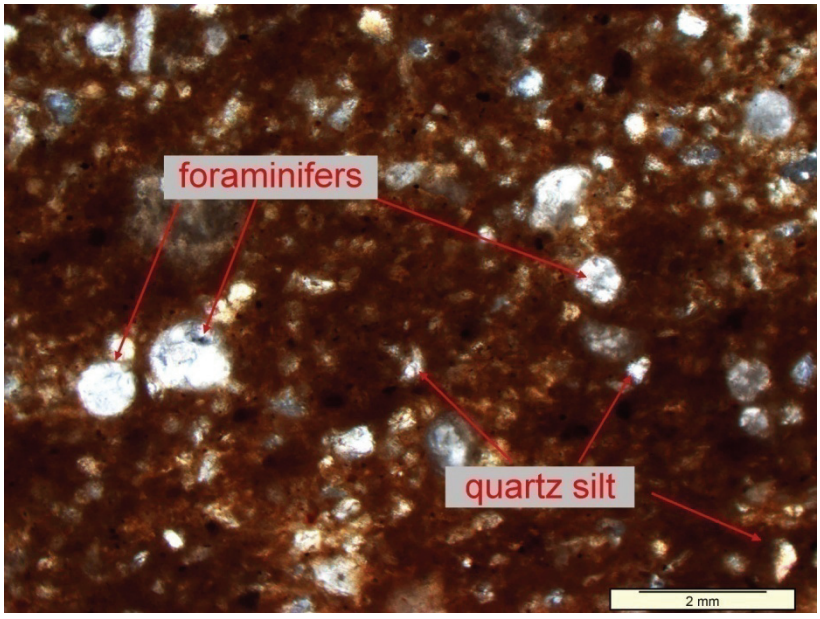

Fig. 20. Petrographic Group I. Jericho Hasmonean (HS1) bowl JR A(A) 209-1326/1 (specimen 1). Polarising microscope, crossed nicols.

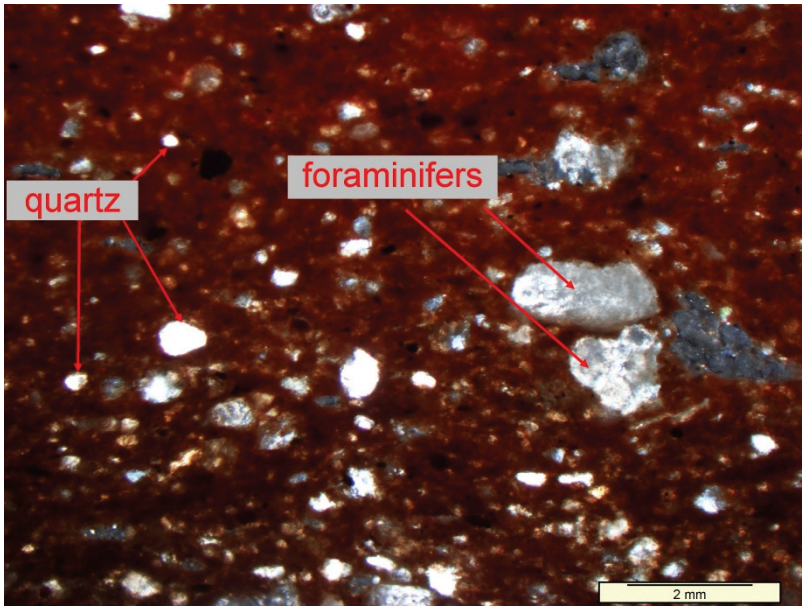

Fig. 21. Petrographic Group I. Jericho Hasmonean (HS2) A(B)93-660/9 (specimen 4). Polarising microscope, crossed nicols.

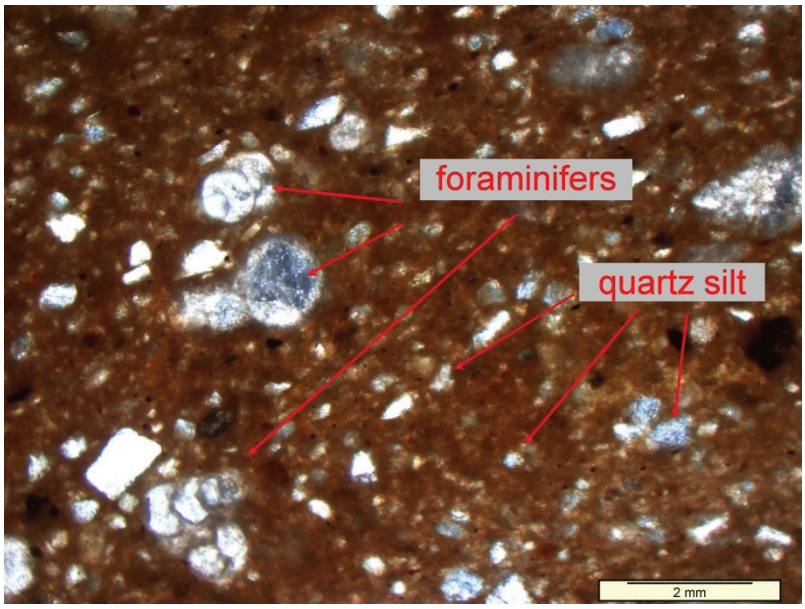

Fig. 22. Petrographic Group I. Jericho Herodian (HR1) bowl JR F182 (specimen 6). Polarising microscope, crossed nicols.

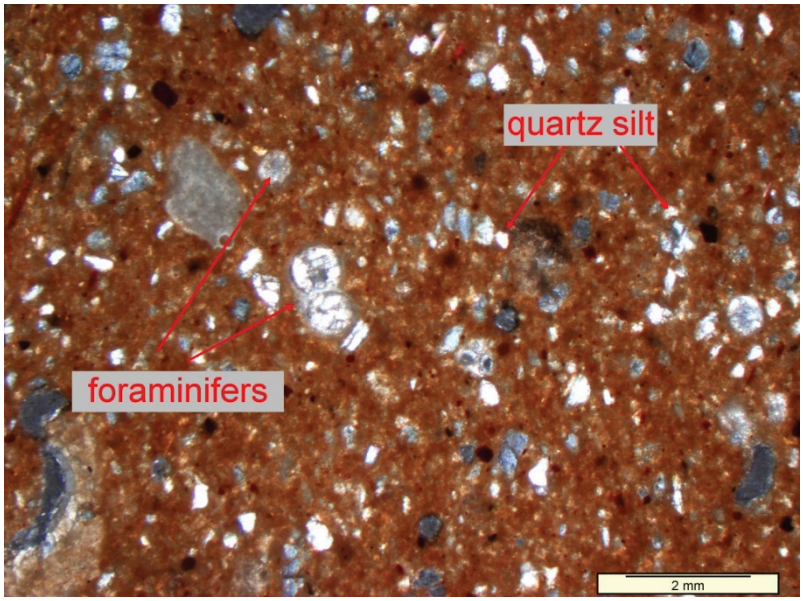

Fig. 23. Petrographic Group I. Jericho Herodian (HR2) jar B154-399A/B (specimen 13). Polarising microscope, crossed nicols.

3.2.2. PETROGRAPHIC GROUP II (Rich Clay – Calcareous Sand Group)

Petrographic Group II (Rich Clay – Calcareous Sand Group) – ceramics made from pure, non-silty clay containing very fine sand-sized carbonates (often rhombohedral ones).

Specimens:	**5, 10, 12, 22, 23, 24, 25, 27**
Archeological stratigraphy:	
Hasmonean 2 (storage jars)	sp. 22, 23, 24, 25, 27
Herodian 1 (storage jars)	sp. 5, 10
Herodian 2 (jar)	sp. 12
Hand specimen analysis:	
Colour:	
red to light red	2.5YR 5/8 – 2.5YR6/8 sp. 5, 10, 27
reddish grey – reddish brown	2.5YR 6/1 – 2.5YR 5/2 sp. 12, 22, 23, 24, 25
Hardness:	hard
Feel:	rough
Fracture:	irregular to smooth
Inclusion	frequency: 2-5%
Inclusion composition:	predominant white angular carbonates

Thin section analysis:

Groundmass (pp):	light red (5, 10, 27); grey (12 [Fig. 24], 22); yellow (23 [Fig. 25]); brownish red (24); and reddish grey (25), inactive.
Inclusion frequency	
– Sand inclusions:	15-30%, in specimen 27 less than 5%.
– Silt:	0-2%.
Coarse inclusions:	
– Size:	0.1-0.2 mm
– Composition:	Predominant: rhombohedral grains of carbonates (5, 10, 12, 22, 23, 25).
Fine inclusions:	Traces of quartz silt (< 2%), carbonate silt has disintegrated; on the basis of white stains it has left, one can conclude its level was elevated in samples 12, 24, 25, and 27.
Textural concentration features (Tcf):	Reddish brown soil pellets in specimens 5, 10, 22, 25, and 27.

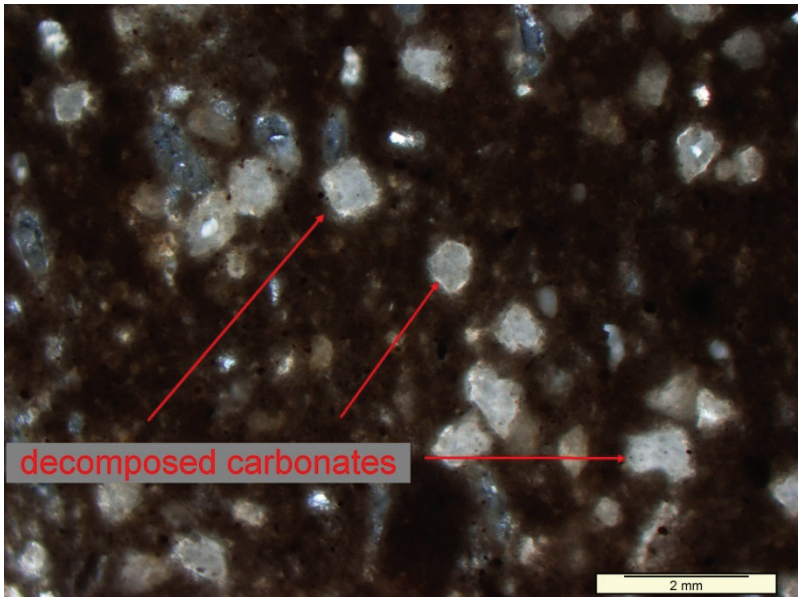

Fig. 24. Petrographic Group II. Jericho Herodian (HR2) jar JR B154-399 (specimen 12). Polarising microscope, crossed nicols.

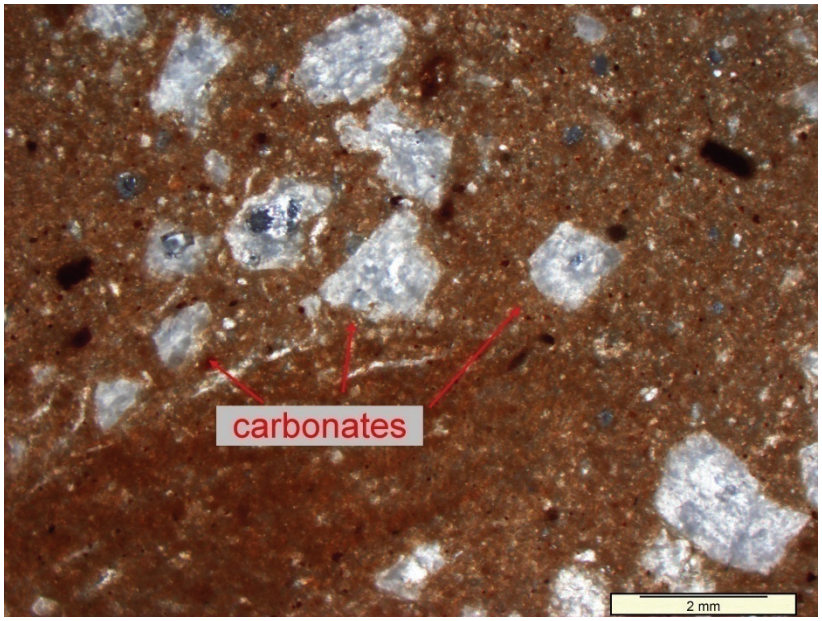

Fig. 25. Petrographic Group II. Jericho Hasmonean (HS2) jar JR AE 304-700/1 (specimen 23). Polarising microscope, crossed nicols.

3.2.3. PETROGRAPHIC GROUP III (Rich Clay – Quartz Sand Group)

Petrographic group III (Rich Clay – Quartz Sand Group) – ceramics made of pure calcareous clay containing 10-20% of quartz or quartz-limestone sand.

Specimens:	**8, 9, 11, 26, 28, 31, 36, 37, 40, 41, 42, 43,44, 45, 46, 47, 48, 49, 50, 51, 52, 53**
Archeological stratigraphy:	
Hasmonean 2 (storage jars)	sp. 26, 28, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53
Herodian ½? ('genizah' jars)	sp. 36, 37
Herodian 1	sp. 8, 9, 11
Herodian 3	sp. 31,
Hand specimen analysis:	
Colour:	
red	2.5YR 4/8 to 5/8 sp. 28, 37, 41, 47, 48

dark reddish gray	2.5YR 4/1 to 5/1	sp. 8, 11, 36, 44, 45, 46, 49, 52, 53
pale red	2.5YR 6/2	sp. 9
light red	2.5YR 6/6 to 6/8	sp. 31, 40, 50
reddish brown	2.5YR 4/2 – 5/4	sp. 43 51
light reddish brown	2.5YR 6/3	sp. 26
Hardness:	hard	
Feel:	rough	
Fracture:	irregular to smooth	
Inclusion frequency:	10-20%	
Inclusion composition:	grey quartz predominates	

Thin section analysis:

Groundmass (pp):	inactive: red (28, 41, 47, 48); greyish brown (8, 9, 50, 52); brownish red (40, 42, 43, 44, 49); brown (1); brownish black (26 [Fig. 26], 45, 46); grey (53); grey mottled red (31 [Fig. 27]); active: red (37).
Inclusion frequency:	
Sand inclusions:	10-30%
Quartz silt:	less than 2%
Carbonate (dolomitic) silt:	high content
Coarse inclusions:	
Size:	0.1-0.2 mm
Predominant (>80%):	monocrystalline quartz
Common (<20%):	limestone
Fine inclusions:	Angular quartz silt, decomposed carbonate silt

Remarks: Numerous fine (0.02-0.03 mm) rhombus-shaped pores left by decomposed dolomite make it similar to the Moza Formation clays. In the two 'genizah' jars, foraminifer shells (0.1-0.15 mm) are observed. What makes the paste of the two jars distinct from that of the ceramics of foraminiferous group I is the practical lack of quartz silt; foraminifer shells could have been added with the temper.

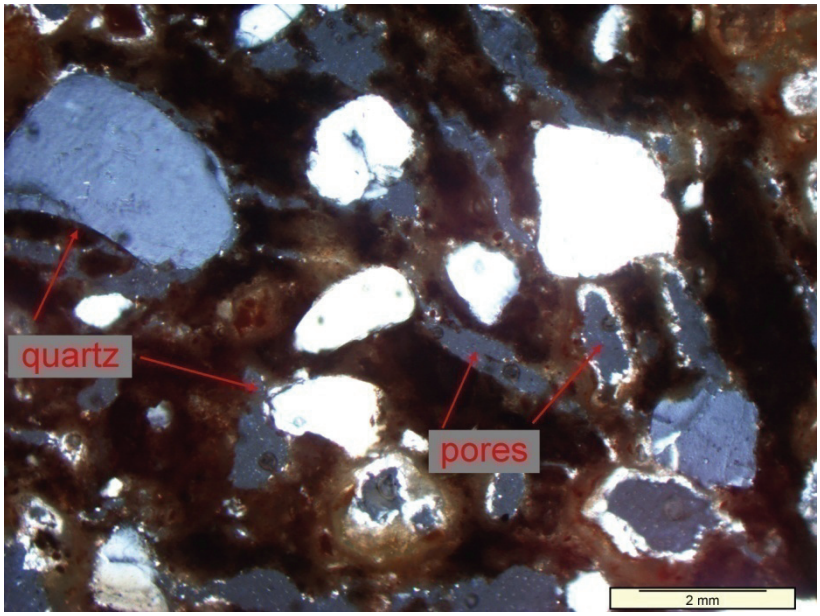

Fig. 26. Petrographic Group III. Jericho Hasmonean (HS2) jar JR AE 57- 5276/1 (specimen 26). Polarising microscope, crossed nicols.

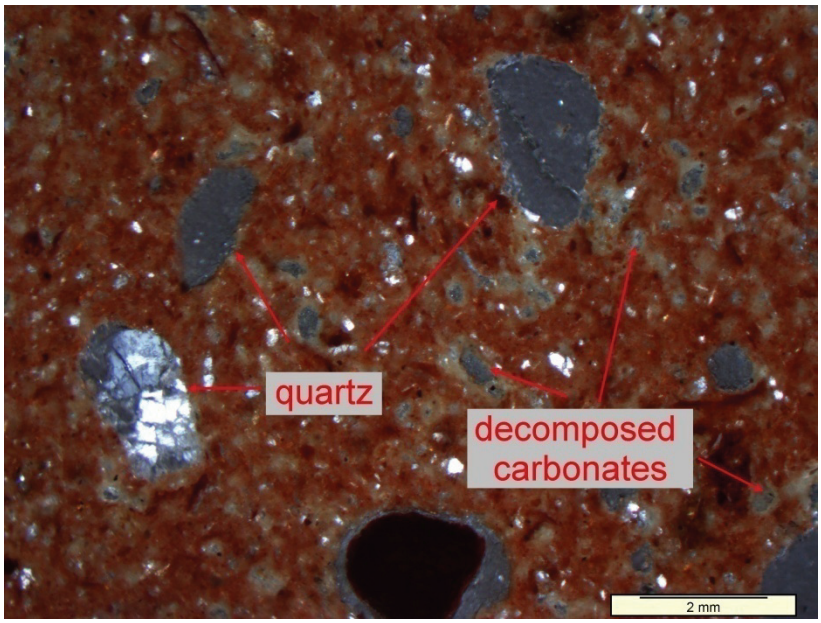

Fig. 27. Petrographic Group III. Jericho Herodian (HR3) jar JR B215- 9193A (specimen 31). Polarising microscope, crossed nicols.

3.2.4. PETROGRAPHIC GROUP IV (Terra Rossa Group)

Petrographic group IV (Terra Rossa Group)– vessels made of silty clay, devoid of sandy temper.

Specimens: **34, 35, 38** (Fig. 28).

Archeological stratigraphy:

Herodian 3 (cooking pots from a kiln),	34, 35, 38

Hand specimen analysis:

Colour:	red (2.5YR 4/8)
Hardness:	hard
Feel:	rough
Fracture:	irregular
Inclusion frequency:	2%
Inclusion composition:	fine white carbonates

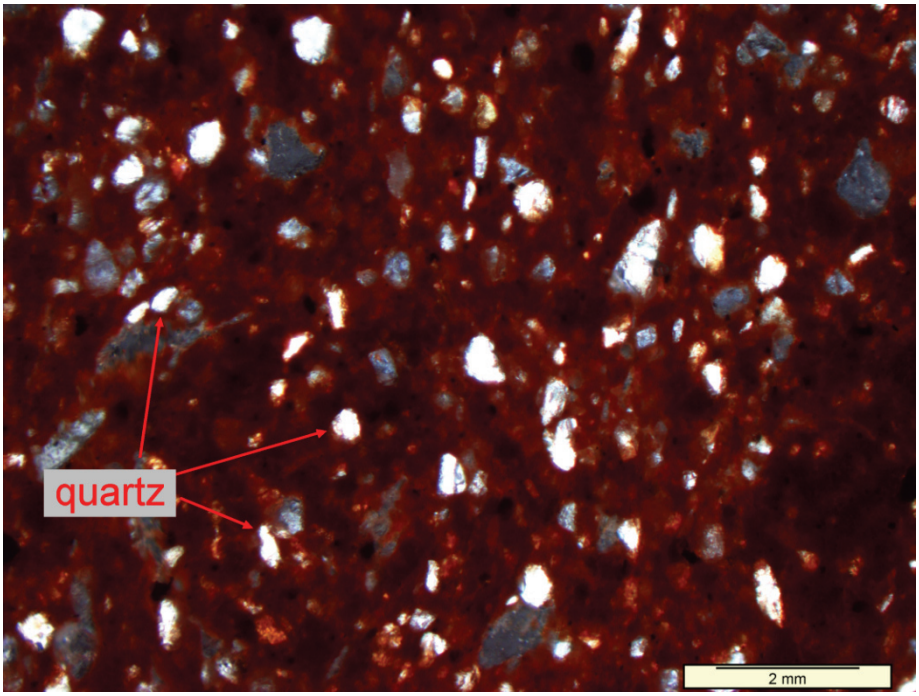

Fig. 28. Petrographic Group IV. Jericho Herodian (HR3) cooking pot, from a kiln, JR F128-3548/2 (specimen 38). Polarising microscope, crossed nicols.

Thin section analysis:

Groundmass (pp): dark red, inactive

Inclusion frequency:
- Sand inclusions: < 2%
- Silt inclusions: about 30%

Coarse inclusions: Decomposed irregular limestone grits (0.1-0.15 mm)

Fine inclusions: Angular quartz silt

The petrographic features of the analysed ceramic assemblage are compiled in Table 11.

Table 11. Petrographic properties of the Jericho ceramics.

Lab no.	Registration no.	Munsell colour		Sandy admixture			Quartz silt frequency (%)	Fine dolomites*	Foraminifers**	Rhomb-shape grits
				Frequency (%)	Quartz (%)	Carbonates (%)				
1	A(A) 209-1326/1	7.5YR 6/4	light brown	0	0	0	<5	0	1	0
2	A(A)209/9	705YR 5/6	strong brown	<5	0	100	<5	0	1	0
3	A(A) 209-1199	7.5YR 6/4	light brown	<1	0	100	<5	0	1	0
4	A(B)93-660/9	2.5YR 6/8. 2.5YR 5/1	light red/ reddish gray	<5	50	50	<5	0	1	0
5	F176-5108	2.5YR 5/8	red	15 - 20	0	100	0	0	0	1
6	F182	10YR 6/6	brownish yellow	<2	0	100	<5	0	1	0
7	F182B	10YR 6/6	brownish yellow	<2	100	0	<5	0	1	0
8	F176-5104	2.5YR 4/8 - 2.5YR 4/1	red / dark reddish gray	10-15	50	50	<2	1	0	0
9	F176- 5108/3	2.5YR 6/2	pale red	10-15	80	20	<2	1	0	0
10	F176 –5108A	2.5YR 5/8 - 2.5YR 6/4	red/ reddish brown	5-10	0	100	0	0	0	1
11	F176-5108 B	2.5YR 4/1	dark reddish gray	<10	80	20	<5	0	0	0
12	B154-399	2.5YR 6/1	reddish gray	30-40	0	100	0	0	0	1
13	B154-399A/B	2.5YR 5/8 - 2.5YR 5/1	red/ reddish gray	0	0	0	<10	0	1	0
14	B154-399B	2.5YR 5/8	red	<2	0	100	<5	0	1	0
15	B154-399B'	7.5YR 5/4	brown	10-20	0	100	<5	0	1	1
16	B154-300A	7.5YR 5/4 - 5YR 5/6	brown/ yellowish brown	10	0	100	<10	0	1	0
17	B154-399A	2.5YR 5/8 - 2.5YR 5/2	red/ weak red	<2	0	100	<10	0	1	0
18	B154-399C	7.5YR5/4 - 2.5YR 5/6	brown/ red	<10	0	100	<5	0	1	1

table 11 continued

Lab no.	Registration no.	Munsell colour		Sandy admixture			Quartz silt frequency (%)	Fine dolomites*	Foraminifers**	Rhomb-shape grits
				Frequency (%)	Quartz (%)	Carbonates (%)				
19	B154399-C′	2.5YR 5/8	red	<5	0	100	<5	0	1	0
20	B154-399D	7.5YR 5/6	strong brown	<2	0	100	<5	0	1	0
21	B154-399E	7.5YR 6/6	reddish yellow	<2	0	100	<5	0	1	0
22	A541-4553/1	2.5YR 6/1	reddish gray	30	0	100	0	1	0	1
23	AE304-700/1	2.5YR 5/2 - 2.5YR 6/6	reddish brown	20-30	0	100	0	0	0	1
24	AE34-4617/1	2.5YR 4/1	dark reddish gray	20-30	0	100	<2	1	1	0
25	AE47-4720/1	2.5YR 6/6 - 2.5YR 6/1	light red/ reddish gray	15-20	0	100	<10	1	0	1
26	AE57-5276/1	2.5YR 6/3	light reddish brown	20	100	0	<2	1	0	0
27	AE59-8260/1	2.5YR 6/8	light red	<5	0	100	0	1	0	0
28	AE57-5276/2	2.5YR 5/8	red	15-20	80	20	<2	1	0	0
29	B215-9193	2.5YR 5/9	red	<2	100	0	<2	0	1	0
30	B215-9143	2.5YR 4/8	red	<2	0	100	<5	0	1	0
31	B215-9193A	2.5YR 6/8	light red	<15	100	0	<1	1	?	0
32	B215-9193B	2.5YR 6/8	light red	<15	0	100	<5	0	1	1
33	B214-9188	2.5YR 5/6 - 2.5YR 5/1	red/ reddish gray	<2	0	100	<5	1	1!	0
34	F128-3548/1	2.5YR 5/8	red	0	0	0	<10-15	0	0	0
35	F128-3548A	2.5YR 4/8	red	0	0	0	<10-15	0	0	0
36	F253-5774/1	2.5YR 4/8 - 2.5YR 3/1	red/ dark reddish gray	<10	10	90	<1	0	1!	0
37	F258-5780	2.5YR 5/8	red	<10	60	40	<5	1	1	0
38	F128-3548/2	2.5YR 4/8	red	0	0	0	<10-15	0	0	0
40	A(A)81-1164	2.5YR 6/6	light red	20-30	80	20	<2	0	0	0
41	A(A)811156	2.5YR 5/8	red	<10	80	20	<2	0	0	0
42	A(A)81-1161	2.5YR 7/6	light red	20-30	80	20	<2	1	0	0
43	A(A)81-1407	2.5YR 4/2	reddish brown	20	90	10	<2	0	0	0
44	A(A)81-1413	2.5YR 5/1	reddish gray	20-30	100	0	<2	0	0	0
45	A(A)81-846C	2.5YR 4/1	dark reddish gray	20-30	100	0	<2	0	0	0
46	A(A)81-846D	2.5YR 5/1	reddish gray	20-30	100	0	<2	0	0	0
47	A(A)81-1004	2.5YR 5/8	red	20	60	40	<2	1	0	0
48	A(A)81-1064	2.5YR 5/8	red	20-30	80	20	<2	1	0	0
49	A(A)811154	2.5YR 5/1	reddish gray	20-30	80	20	<5	0	0	0
50	A(A)81-1175	2.5YR 5/1 - 2.5YR 6/8	reddish gray/ light red	20	60	40	<5	0	0	0
51	A(A)81-1175#	2.5YR 5/4	reddish brown	10	100	0	<1	0	0	0
52	A(A)81-846A	2.5YR 4/1	dark reddish gray	30	100	0	<1	1	0	0
53	A(A)81-846B	2.5YR 3/1	dark reddish gray	20-30	50	50	<2	0	0	0
								0 - absent 1 - present	0 - absent 1 - present 1! - commmon	0 - absent 1 - present

3.3. Results of chemical analyses and their mathematical interpretation

The chemical INAA data are presented in Table 12.

Out of the 34 elements measured, only 16 were chosen for statistical analysis. Those whose concentrations in many Jericho or Qumran samples were below the detection level were eliminated. They included: Au, Ag, Ba, Hg, Ir, Mo, Ni, Sb, Se, Sn, Sr, Ta, W, Zn, and Tb. Sodium was eliminated because of its considerable mobility.

A problem with iron and calcium appeared when selecting the elements. Iron was included in the analysis because of its diagnostic concentration in the terra rossa deposits, which could be used in the ceramics under analysis. A similar problem concerned calcium. Usually calcium is not analysed in provenance investigations as it is a very mobile element which precipitates from evaporating water very easily, especially in dry climatic conditions. The decision to include calcium in the analysis was motivated by the results of petrographic investigations in which a diagnostic quantity of carbonate rock grains (a natural or an artificial admixture) was found.

In three wares from locus 128, the calcium content was lower than the detection level, i.e. 1%. This was considered a diagnostic feature and it was assumed for the mathematical analysis that Ca in those samples was equal to 1%.

Eventually, the following elements were used in the analysis: As, Ca, Co, Cr, Cs, Fe, Hf, Rb, Sc, Th, U, La, Ce, Nd, Sm, Eu, Yb, and Lu. As a standard, the data were converted to common logarithms.

3.3.1. Principal components analysis

The content of trace elements, treated as 18 features describing 77 fragments of the ceramics, was used to calculate the correlation matrix.

Geometric relations among the objects existing in the 18-dimensional space[1], after projection onto the plane of the first two principal components PC1-PC2, were explained in 70.29% (Table 13, Fig. 29, 30), whereas in a three-dimensional space those relations were preserved in 78.32%.

The first principal component PC1 is mostly determined by variations of Cr, Fe, Hf, Th and rare earths (REEs); the second, PC2, is determined by three elements: Cs, Rb and Sc; whereas the third, PC3, by U, Hf and Ca (cf. Table 14).

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[1] Each dimension of this space corresponds to the concentration values of one chemical element (cf. Cogswell et al. 1995: 14; Mommsen 2001: 659).

Table 12. Selected major and trace elements in the Qumran ceramics.

Lab no.	Element	Ca	Fe	Na	Sn	Sr	Au	Ag	As	Ba	Br	Co	Cr	Cs	Hf	Hg	Ir
	Registration no. / Mass unit	wt %	wt %	wt %	wt %	wt %	ppb	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppb
1	A(A)209-1326/1	13.0	3.67	0.63	<0.01	0.06	28.0	<5.0	11.0	480.0	11.7	10.0	150.0	2.0	7.0	<1	<5
2	A (A) 209/9	10.0	4.15	0.53	<0.01	<0.05	12.0	28.0	11.1	<50.0	12.8	13.0	150.0	3.0	7.0	<1	<5
3	A(A)209-1199	9.0	4.46	0.75	<0.01	<0.05	2.0	<5.0	6.6	<50.0	11.1	15.0	177.0	<1.0	5.0	<1	<5
4	A(B)93-660/9	11.0	4.43	0.54	<0.01	<0.05	30.0	<5.0	8.7	310.0	10.7	14.0	170.0	2.0	7.0	<1	<5
5	F176- 5108	10.0	4.05	0.16	<0.03	<0.05	<2.0	<5.0	14.1	<77.0	22.8	23.0	100.0	4.0	<1.0	<1	<5
6	F182	12.0	2.99	0.45	<0.01	0.09	3.0	<5.0	33.6	590.0	10.6	13.0	136.0	1.0	6.0	<1	<5
7	F182B	13.0	2.65	0.37	<0.01	<0.05	<2.0	<5.0	38.9	660.0	13.0	12.0	107.0	<1.0	4.0	<1	<5
8	F176-5104	7.0	3.86	0.31	<0.01	<0.05	12.0	<5.0	10.7	170.0	11.0	13.0	117.0	6.0	4.0	<1	<5
9	F176-5108/3	9.0	3.19	0.24	<0.01	<0.05	<2.0	<5.0	12.0	<50.0	6.2	15.0	113.0	3.0	4.0	<1	<5
10	F176-5108A	8.0	4.72	0.21	<0.02	<0.05	26.0	<5.0	21.4	330.0	15.0	14.0	157.0	7.0	3.0	<1	<5
11	F176-5108 B	9.0	3.81	0.25	<0.01	<0.05	<2.0	<5.0	20.7	290.0	7.4	15.0	131.0	5.0	3.0	<1	<5
12	B154-399	11.0	3.78	0.3	<0.01	<0.05	<2.0	<5.0	6.8	<50.0	17.4	17.0	87.0	4.0	3.0	<1	<5
13	B154-399A/B	12.0	4.6	0.62	<0.01	<0.05	<2.0	<5.0	6.3	<50.0	16.3	15.0	186.0	3.0	7.0	<1	<5
14	B154- 399B	12.0	5.19	0.69	<0.02	<0.05	<2.0	<5.0	10.5	340.0	16.0	22.0	220.0	3.0	7.0	<1	<5
14	B154-399B'	11.0	4.37	0.74	<0.01	<0.05	<2.0	<5.0	7.5	440.0	17.1	12.0	150.0	2.0	8.0	<1	<5
16	B154-300A	12.0	4.32	0.67	<0.01	<0.05	89.0	<5.0	10.5	<50.0	18.2	13.0	160.0	2.0	7.0	<1	<5
17	B154-399A/A	8.0	5.2	0.59	<0.01	<0.05	<2.0	<5.0	10.5	230.0	14.9	15.0	180.0	2.0	7.0	<1	<5
18	B154-399-C	13.0	4.24	0.54	<0.01	<0.05	<2.0	<5.0	8.4	320.0	12.5	16.0	175.0	2.0	6.0	<1	<5
18	B154-399-C'	9.0	4.72	0.7	<0.01	<0.05	8.0	<5.0	9.6	330.0	15.7	16.0	172.0	3.0	6.0	<1	<5
20	B154-399D	10.0	3.46	0.81	<0.01	<0.05	5.0	<5.0	9.4	280.0	17.1	15.0	169.0	2.0	6.0	<1	<5
21	B154-399E	9.0	3.69	0.85	<0.01	<0.05	<2.0	<5.0	7.4	270.0	18.1	16.0	147.0	2.0	7.0	<1	<5
22	A541-4553/1	12.0	3.48	0.41	<0.01	<0.05	5.0	<5.0	7.5	<50.0	26.1	14.0	100.0	5.0	3.0	<1	<5
23	AE304-700/1	12.0	3.19	0.23	<0.01	<0.05	<2.0	<5.0	5.6	260.0	18.9	15.0	99.0	3.0	2.0	<1	<5
24	AE34-4617/1	7.0	3.76	0.37	<0.01	<0.05	<2.0	<5.0	5.9	<50.0	20.4	13.0	128.0	5.0	4.0	<1	<5
25	AE47-4720/1	7.0	3.98	0.21	<0.01	<0.05	4.0	<5.0	11.7	310.0	15.0	15.0	99.0	2.0	4.0	<1	<5
26	AE57-5276/1	7.0	3.52	0.34	<0.01	<0.05	<2.0	<5.0	4.7	170.0	8.8	12.0	130.0	5.0	6.0	<1	<5
27	AE59-8260/1	8.0	3.71	0.37	<0.01	0.06	<2.0	<5.0	8.9	270.0	10.9	12.0	110.0	5.0	3.0	<1	<5
28	AE57-5276/2	6.0	3.44	0.33	<0.01	<0.05	<2.0	<5.0	3.8	190.0	10.2	10.0	106.0	4.0	4.0	<1	<5
29	B215- 9193	8.0	5.89	0.53	<0.02	<0.05	<2.0	<5.0	11.3	<50.0	23.1	19.0	211.0	3.0	6.0	<1	<5
30	B215-9143	16.0	6.96	0.7	<0.03	<0.05	5.0	<5.0	11.5	1100.0	9.6	30.0	218.0	<1.0	7.0	<1	<5
31	B215-9193A	5.0	4.49	0.95	<0.01	<0.05	14.0	<5.0	4.3	380.0	6.1	17.0	320.0	8.0	5.0	<1	<5
32	B215-9193B	12.0	4.37	0.65	<0.01	<0.05	<2.0	<5.0	12.3	280.0	13.1	15.0	170.0	3.0	8.0	<1	<5
33	B214-9188	8.0	4.77	0.58	<0.01	<0.05	<2.0	<5.0	6.7	280.0	10.4	13.0	160.0	2.0	8.0	<1	<5
34	F128-3548/1	<1.0	5.65	0.56	<0.01	<0.05	<2.0	<5.0	10.8	330.0	7.9	24.0	170.0	3.0	16.0	<1	<5
35	F128-3548A	<1.0	5.76	0.5	<0.01	<0.05	<2.0	<5.0	8.2	450.0	10.1	29.0	170.0	3.0	15.0	<1	<5
36	F253-5774/1	7.0	4.32	0.54	<0.01	<0.05	<2.0	<5.0	8.2	390.0	13.4	14.0	120.0	6.0	6.0	<1	<5
37	F258-5780	10.0	4.31	0.48	<0.01	<0.05	<2.0	<5.0	6.3	<50.0	12.6	11.0	124.0	5.0	5.0	<1	<5
38	F128-3548/2	<1.0	5.55	0.53	<0.02	<0.05	5.0	<5.0	8.4	510.0	6.7	30.0	183.0	2.0	14.0	<1	<5
39	F403	9.0	4.09	0.8	<0.01	<0.05	<2.0	<5.0	6.0	250.0	8.4	14.0	130.0	2.0	8.0	<1	<5
40	A(A)81-1164	11.0	3.28	0.71	<0.01	<0.05	5.0	<5.0	6.8	240.0	13.9	12.0	100.0	3.0	5.0	<1	<5
41	A(A)81-1156	2.0	3.75	0.42	<0.01	<0.05	<2.0	<5.0	7.5	<50.0	8.7	10.0	120.0	4.0	5.0	<1	<5
42	A(A)81-1161	14.0	3.14	0.55	<0.01	<0.05	<2.0	<5.0	5.2	140.0	28.1	12.0	100.0	4.0	4.0	<1	<5
43	A(A)81-1407	4.0	3.89	0.47	<0.01	<0.05	<2.0	<5.0	7.2	<50.0	12.7	10.0	120.0	4.0	6.0	<1	<5
44	A(A)81-1413	6.0	4.23	0.57	<0.01	<0.05	<2.0	<5.0	7.8	<50.0	6.2	11.0	130.0	5.0	6.0	<1	<5
45	A(A)81-846C	8.0	3.59	0.43	<0.01	<0.05	23.0	<5.0	5.7	190.0	18.0	12.0	110.0	5.0	5.0	<1	<5
46	A(A)81-846D	6.0	3.58	0.41	<0.01	<0.05	<2.0	<5.0	8.3	<50.0	12.5	10.0	100.0	4.0	5.0	<1	<5
47	A(A)81-1004	4.0	3.56	0.62	<0.01	<0.05	<2.0	<5.0	6.3	150.0	10.5	13.0	110.0	5.0	5.0	<1	<5
48	A(A)81-1064	4.0	3.52	0.87	<0.01	<0.05	16.0	<5.0	4.3	<50.0	16.4	12.0	122.0	4.0	4.0	<1	<5
49	A(A)81-1154	4.0	4.08	0.49	<0.01	<0.05	2.0	<5.0	7.3	<50.0	14.5	12.0	140.0	5.0	4.0	<1	<5
50	A(A)81-1175	5.0	3.54	0.49	<0.01	<0.05	<2.0	<5.0	7.2	<50.0	8.3	10.0	113.0	5.0	4.0	<1	<5
51	A(A)81-1175	5.0	3.72	0.58	<0.01	<0.05	<2.0	<5.0	8.5	<50.0	6.7	10.0	120.0	4.0	5.0	<1	<5
52	A(A)81-846A	7.0	3.42	0.41	<0.01	0.05	14.0	<5.0	6.9	110.0	16.8	10.0	100.0	4.0	4.0	<1	<5
53	A(A)81-846B	7.0	3.76	0.31	<0.01	<0.05	<2.0	<5.0	3.9	<50.0	7.5	18.0	145.0	6.0	4.0	<1	<5

table 12 continued

Lab no.	Mo	Ni	Rb	Sb	Sc	Se	Ta	Th	U	W	Zn	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
1	5.0	<68	43.0	0.5	12.3	<3	<0.5	5.9	4.8	<1.0	170.0	31.5	63.0	30.0	5.5	1.7	<0.5	2.8	0.43
2	14.0	<68	32.0	0.6	11.9	<3	<0.5	6.6	3.3	6.0	96.0	31.2	58.0	30.0	5.5	1.5	<0.5	2.7	0.41
3	4.0	<55	44.0	0.8	14.1	<3	1.5	7.6	4.2	7.0	226.0	32.0	63.0	31.0	6.2	1.5	0.8	3.1	0.47
4	8.0	<65	55.0	0.7	14.4	<3	<0.5	7.6	4.6	<1.0	160.0	37.6	74.0	34.0	6.3	1.6	1.2	3.0	0.46
5	<1	<111	82.0	0.5	16.2	<3	<0.6	7.1	4.7	1.0	122.0	20.5	43.0	14.0	4.8	1.0	<0.5	1.5	0.23
6	5.0	<48	56.0	0.7	11.0	<3	2.6	6.6	4.9	5.0	152.0	27.9	54.0	26.0	5.2	1.1	0.9	2.6	0.39
7	4.0	<43	<15	0.5	9.1	<3	<0.5	5.4	4.7	<1.0	135.0	23.7	46.0	19.0	4.3	0.9	<0.5	2.3	0.35
8	11.0	<43	103.0	0.3	17.0	<3	<0.5	7.6	3.2	10.0	<50.0	24.5	51.0	27.0	5.5	1.3	<0.5	2.5	0.38
9	19.0	<50	55.0	0.4	13.9	<3	<0.5	6.3	2.0	15.0	104.0	21.3	44.0	23.0	4.3	1.0	<0.5	2.0	0.31
10	15.0	<67	114.0	<0.1	17.5	<3	<0.5	7.3	4.1	9.0	169.0	21.4	43.0	18.0	4.4	1.0	<0.5	2.1	0.32
11	14.0	<53	70.0	0.6	15.8	<3	<0.5	6.8	3.7	11.0	80.0	23.2	48.0	21.0	4.8	1.2	<0.5	2.3	0.36
12	5.0	<62	52.0	0.3	14.7	<3	<0.5	5.7	2.6	3.0	87.0	20.5	47.0	19.0	3.9	1.0	<0.5	2.0	0.30
13	6.0	<58	76.0	0.6	14.0	<3	<0.5	7.9	4.9	13.0	130.0	33.8	65.0	26.0	6.3	1.5	1.0	3.3	0.50
14	24.0	<110	<15	0.8	15.3	<3	<0.7	7.9	5.1	17.0	238.0	39.8	77.0	49.0	8.2	1.7	1.0	3.5	0.53
14	7.0	<66	62.0	0.3	13.2	<3	<0.5	6.3	4.1	4.0	220.0	34.5	68.0	33.0	5.9	1.6	<0.5	3.2	0.47
16	12.0	<70	61.0	0.8	13.2	<3	<0.5	6.8	5.3	6.0	130.0	34.1	70.0	28.0	5.7	1.6	0.9	3.1	0.46
17	20.0	<78	55.0	0.5	15.4	<3	<0.5	8.2	2.6	9.0	200.0	38.4	76.0	35.0	7.0	1.8	<0.5	3.2	0.48
18	7.0	<48	45.0	0.8	13.6	<3	<0.5	8.1	4.1	6.0	126.0	33.6	62.0	28.0	6.2	1.5	<0.5	3.2	0.47
18	12.0	<54	54.0	0.7	15.0	<3	2.2	9.0	2.4	11.0	128.0	36.9	70.0	36.0	7.0	1.7	0.8	3.6	0.54
20	8.0	<55	38.0	0.6	11.3	<3	<0.5	7.0	3.9	9.0	162.0	29.4	54.0	26.0	5.3	1.2	<0.5	3.1	0.46
21	7.0	<57	37.0	0.5	12.9	<3	<0.5	7.7	3.2	9.0	147.0	31.9	65.0	30.0	6.0	1.3	1.1	3.3	0.49
22	5.0	<62	79.0	0.4	15.1	<3	<0.5	6.0	3.3	4.0	123.0	20.5	50.0	20.0	4.0	1.0	<0.5	2.1	0.31
23	4.0	<52	60.0	0.3	13.3	<3	1.1	5.5	2.5	<1.0	60.0	18.7	36.0	16.0	3.7	0.8	<0.5	1.9	0.28
24	11.0	<58	41.0	0.3	16.5	<3	<0.5	7.2	3.8	10.0	70.0	25.0	46.0	21.0	5.3	1.4	0.8	2.6	0.38
25	8.0	<73	41.0	0.4	15.5	<3	<0.5	6.8	5.2	6.0	<50.0	24.3	53.0	25.0	4.6	1.3	<0.5	2.5	0.36
26	9.0	<50	54.0	0.5	14.2	<3	<0.5	6.4	3.5	10.0	85.0	22.4	44.0	18.0	4.4	1.0	0.6	2.7	0.41
27	4.0	<70	64.0	0.4	17.0	<3	<0.5	7.1	3.2	<1.0	<50.0	26.4	58.0	22.0	5.0	1.4	<0.5	2.3	0.35
28	6.0	<45	71.0	0.3	15.0	<3	<0.5	6.8	3.4	5.0	82.0	21.7	43.0	24.0	4.7	1.1	0.5	2.5	0.37
29	<1	<71	61.0	0.9	17.8	<3	<0.5	9.4	3.9	11.0	158.0	43.3	81.0	36.0	8.0	1.9	<0.5	3.8	0.56
30	<1	<100	87.0	1.7	21.8	<3	<0.5	11.3	6.2	<1.0	200.0	52.1	91.0	50.0	10.0	2.5	1.1	4.7	0.69
31	2.0	<72	120.0	0.8	15.0	<3	2.9	13.3	3.9	9.0	<50.0	42.6	87.0	31.0	5.8	1.3	<0.5	2.8	0.43
32	3.0	<70	70.0	0.6	13.0	<3	1.3	7.3	5.9	5.0	160.0	34.4	69.0	31.0	6.0	1.3	0.9	3.1	0.46
33	3.0	<69	30.0	0.5	13.9	<3	<0.5	7.2	4.8	<1.0	210.0	35.5	71.0	31.0	6.2	1.6	<0.5	3.1	0.46
34	15.0	<78	42.0	0.6	15.6	<3	<0.5	11.3	2.4	9.0	110.0	41.7	100.0	34.0	7.3	1.9	<0.5	4.2	0.64
35	3.0	<78	84.0	0.9	17.6	<3	<0.5	11.8	3.4	10.0	130.0	48.9	110.0	39.0	7.7	2.3	<0.5	4.3	0.65
36	12.0	<72	100.0	0.4	19.1	<3	0.9	8.1	3.3	<1.0	<50.0	30.2	73.0	24.0	5.5	1.6	<0.5	2.8	0.42
37	7.0	<78	93.0	<0.1	19.3	<3	<0.5	6.9	3.1	<1.0	100.0	28.1	66.0	21.0	5.5	1.4	<0.5	2.8	0.42
38	11.0	<67	52.0	0.8	16.1	<3	3.9	11.6	2.8	16.0	<50.0	41.5	96.0	38.0	7.9	1.7	1.1	4.3	0.67
39	11.0	<72	44.0	0.6	13.0	3.0	<0.5	7.4	2.7	<1.0	170.0	33.0	73.0	26.0	5.7	1.6	1.7	3.0	0.45
40	5.0	<67	68.0	0.4	15.4	<3	<0.5	5.5	4.1	8.0	<50.0	23.6	47.0	20.0	4.4	1.0	<0.5	2.0	0.31
41	16.0	<64	68.0	0.4	15.0	<3	<0.5	6.5	3.5	9.0	86.0	24.5	55.0	22.0	5.2	1.2	1.1	2.5	0.39
42	8.0	<53	68.0	0.3	14.8	<3	<0.5	5.8	3.4	8.0	<50.0	22.6	49.0	22.0	4.4	0.9	<0.5	2.1	0.33
43	12.0	<66	54.0	0.4	15.4	<3	<0.5	7.0	3.2	6.0	83.0	25.4	55.0	28.0	5.1	1.3	<0.5	2.7	0.41
44	13.0	<67	85.0	0.5	16.3	<3	<0.5	6.2	2.9	9.0	110.0	26.1	62.0	24.0	5.4	1.3	<0.5	3.0	0.46
45	5.0	<70	56.0	0.4	15.6	<3	<0.5	5.8	3.3	8.0	77.0	23.8	49.0	20.0	4.4	1.2	<0.5	2.4	0.35
46	9.0	<62	64.0	0.4	15.0	<3	<0.5	5.5	3.4	8.0	<50.0	23.4	51.0	24.0	4.3	1.2	<0.5	2.3	0.33
47	6.0	<52	89.0	0.4	15.9	<3	<0.5	6.6	3.0	<1.0	77.0	25.8	53.0	21.0	5.3	1.4	0.8	2.7	0.41
48	8.0	<51	95.0	0.3	14.2	<3	<0.5	5.8	2.6	9.0	78.0	20.1	42.0	23.0	4.5	1.0	<0.5	2.2	0.34
49	12.0	<71	69.0	0.3	16.3	<3	2.2	6.7	2.8	16.0	92.0	25.7	59.0	27.0	5.5	1.4	<0.5	2.8	0.43
50	5.0	<50	58.0	<0.1	16.0	<3	<0.5	6.6	2.3	8.0	<50.0	21.3	45.0	20.0	5.0	0.9	0.6	2.4	0.36
51	12.0	<66	99.0	0.4	14.6	5.0	<0.5	5.9	3.4	9.0	<50.0	23.6	47.0	22.0	4.4	1.2	0.5	2.4	0.37
52	<1	<57	54.0	0.3	14.7	<3	<0.5	6.2	3.1	8.0	<50.0	22.0	46.0	20.0	4.2	0.9	<0.5	2.1	0.32
53	15.0	<48	46.0	0.4	15.9	<3	1.5	6.5	3.1	18.0	102.0	22.8	46.0	23.0	4.6	1.0	<0.5	2.3	0.35

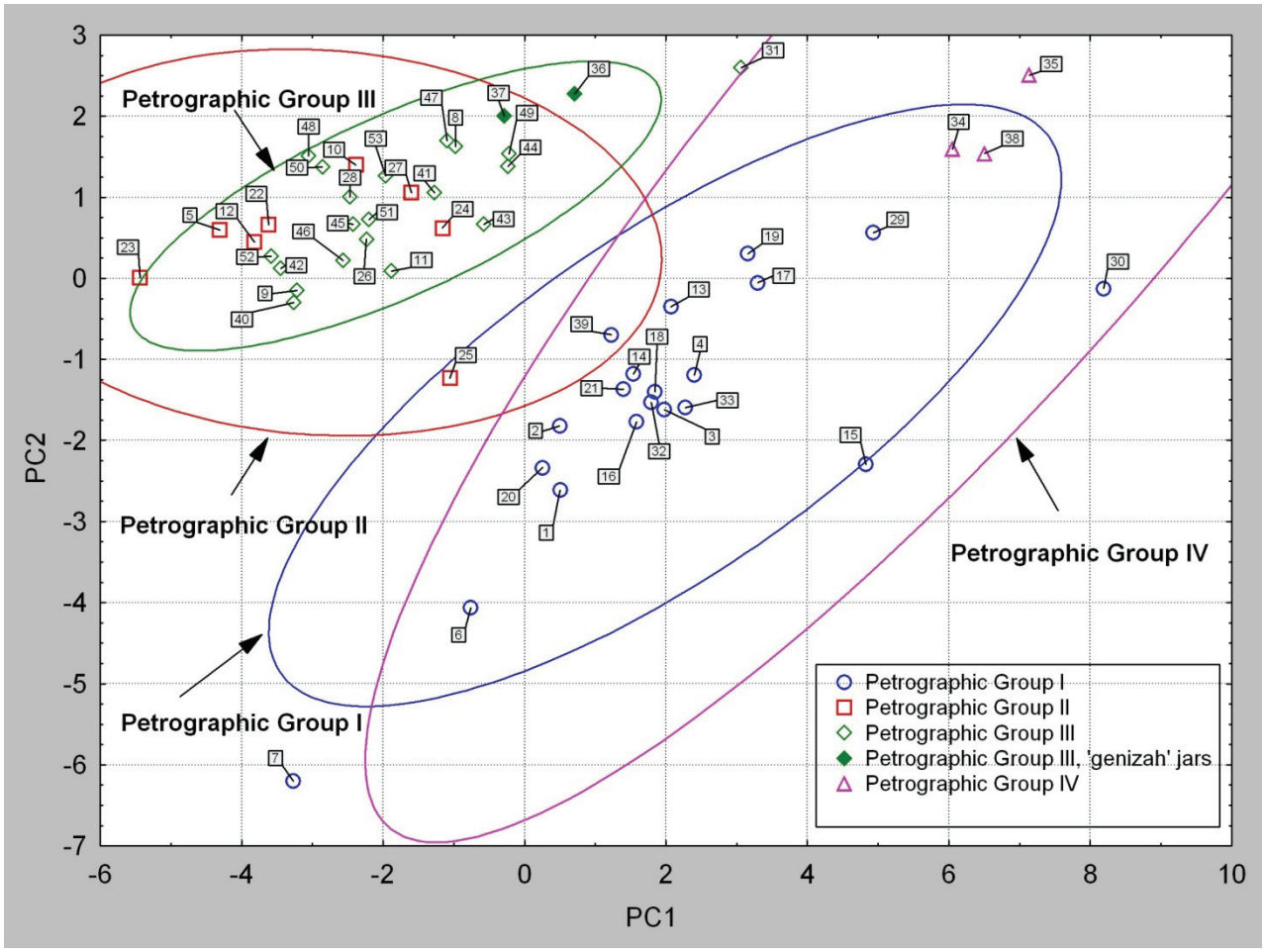

Fig. 29. Projection points of the Jericho ceramics on the plane of the first two principal components. Separate marks indicate the individual petrographic groups. Elipses represent the 90% confidence level for membership in each group after projection onto twodimensional plane.

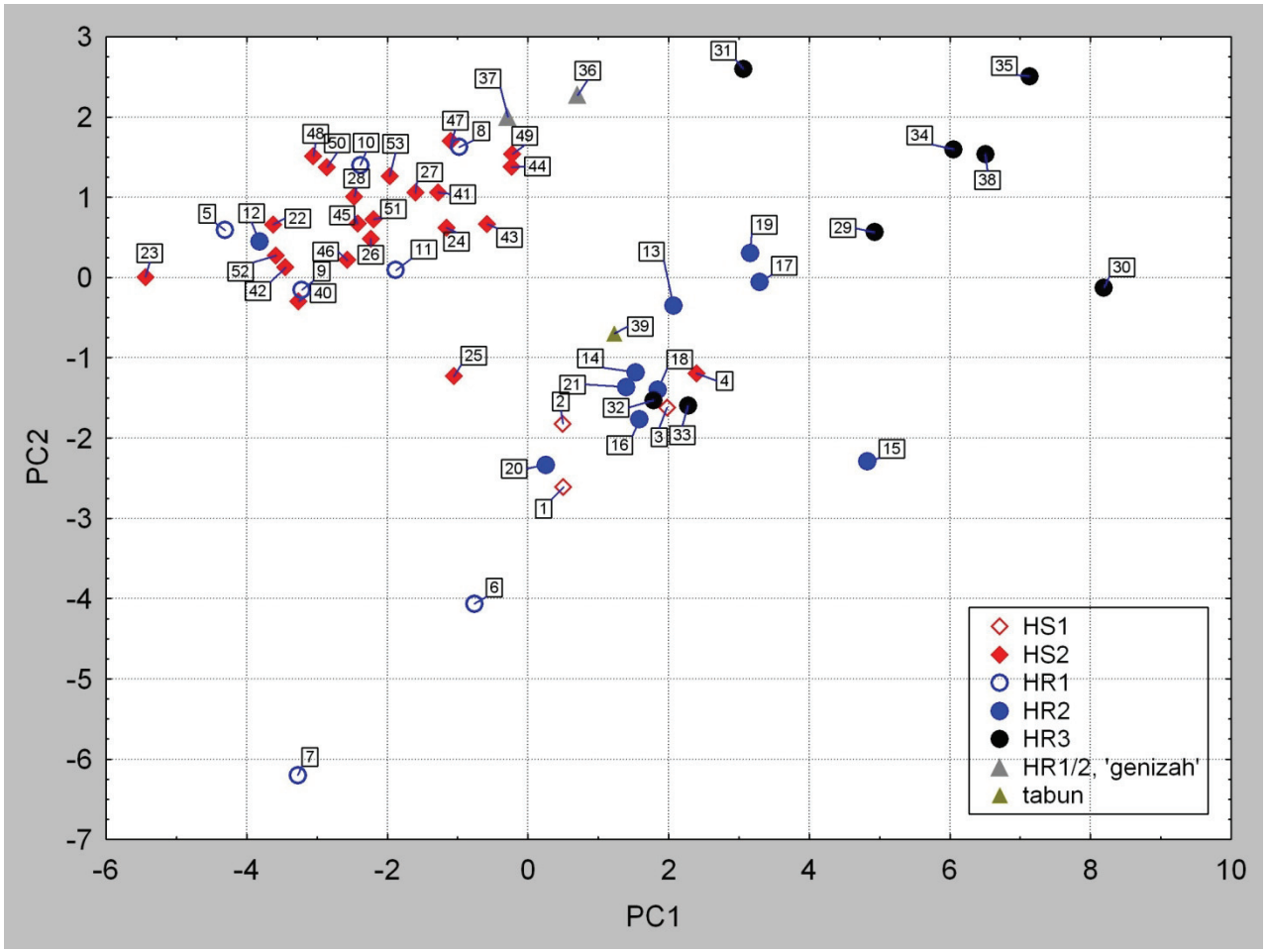

Fig. 30. Projection points of the Jericho ceramics on the plane of the first two principal components. Separate marks indicate the chronology of the vessels.

Table 13. Principal components based on the correlation matrix of the chemical composition of the Jericho pottery.

Principal component number	Eigenvalue	Percentage of variance explained	Cumulative % of total variance
1	9.643	54.60	54.60
2	2.770	15.69	70.29
3	1.418	8.03	78.32
4	0.970	5.49	83.81
5	0.680	3.85	87.66
6	0.552	3.13	90.79
7	0.420	2.38	93.17
8	0.332	1.88	95.05
9	0.201	1.14	96.19
10	0.173	0.98	97.17
11	0.137	0.78	97.95
12	0.124	0.70	98.65
13	0.095	0.54	99.19
14	0.052	0.30	99.49
15	0.047	0.26	99.75
16	0.036	0.20	99.95
17	0.010	0.05	100.00
18	0.002	0.00	100.00

Table 14. Determination coefficient R^2 x 100%.

Element	PC1	PC2	PC3
As	0.7	29.5	12.2
Ca	8.5	31.3	24.1
Co	41.4	0.9	6.9
Cr	68.7	0.4	1.8
Cs	17.2	60.0	0.0
Fe	75.8	7.4	6.0
Hf	62.9	0.9	21.5
Rb	1.4	50.9	14.5
Sc	5.3	61.9	13.6
Th	71.5	8.9	1.7
U	5.3	26.8	33.8
La	94.6	0.9	0.2
Ce	89.6	0.3	0.1
Nd	83.2	1.9	0.6
Sm	92.7	0.0	0.7
Eu	83.4	0.1	0.3
Yb	90.1	0.1	3.0
Lu	90.6	0.0	3.5

At the next stage a spanning tree was constructed showing the nearest Euclidean distances, whose values are presented in Table 15:

Table 15. Values of the shortest Euclidean distances between the successively closest points representing samples of the Jericho ceramics in the 18-dimensional space of the elements analysed. Significant differences are marked with an asterisk.

Pairs	Distance	Pairs (ct)	Distance
1 - 16	2.00	11 - 10;	2.49
16 - 4	1.52	10 - 5;	**4.61****
4 - 17	2.69	45 - 26;	1.78
17 - 19	1.50	45 - 28;	2.02
17 - 29	2.85	28 - 48;	2.07
29 - 30	**4.75****	45 - 53;	2.44
29 - 38	**4.83****	46 - 52;	1.83
38 - 34	1.74	52 - 42;	1.74
38 - 35	2.29	42 - 22;	1.68
4 - 18	1.60	22 - 12;	1.83
18 - 3	1.77	12 - 9;	2.58
18 - 13	1.94	12 - 23;	2.42
13 - 31	**4.89****	42 - 40;	1.50
18 - 21	1.85	52 - 50;	1.97
21 - 20	2.01	43 - 49;	1.73
20 - 2	2.23	49 - 44;	1.53
2 - 43	**3.34***	44 - 37;	1.89
43 - 41	1.77	37 - 36;	1.78
41 - 51	2.09	49 - 47;	1.86
51 - 46	1.54	20 - 6;	3.76
46 - 45	1.58	6 - 7;	**4.36****
45 - 24	2.10	21 - 39;	1.81
24 - 25	3.15	4 - 33;	1.85
24 - 27	2.16	33 - 15;	**4.02***
27 - 8	1.95	16 - 14;	1.40
27 - 11	2.53	16 - 32;	1.57
MEAN (M) = 2.33 Standard deviation (σ) = 0.94 M + σ = 3.27* M + 2 σ = 4.22**			

Assuming a distance D equal to M + 2σ = 4.22 to be the criterion of the statistical separateness of the samples, those standing out are cooking pots of Petrographic Group IV made of silty terra rossa (samples 34, 35, 38), and samples 5, 7, 30, 31 (cf. Figs 29, 31). When the criterion employed is M + σ = 3.27, then statistically distinct are also the bowls and jars belonging to the foraminiferous Petrographic Group I.

3.4. Summing up

By the criterion of a close mineral and chemical similarity, we can distinguish four petrographic-chemical groups of fabric of the Jericho vessels. The division thus obtained is presented in Table 10.

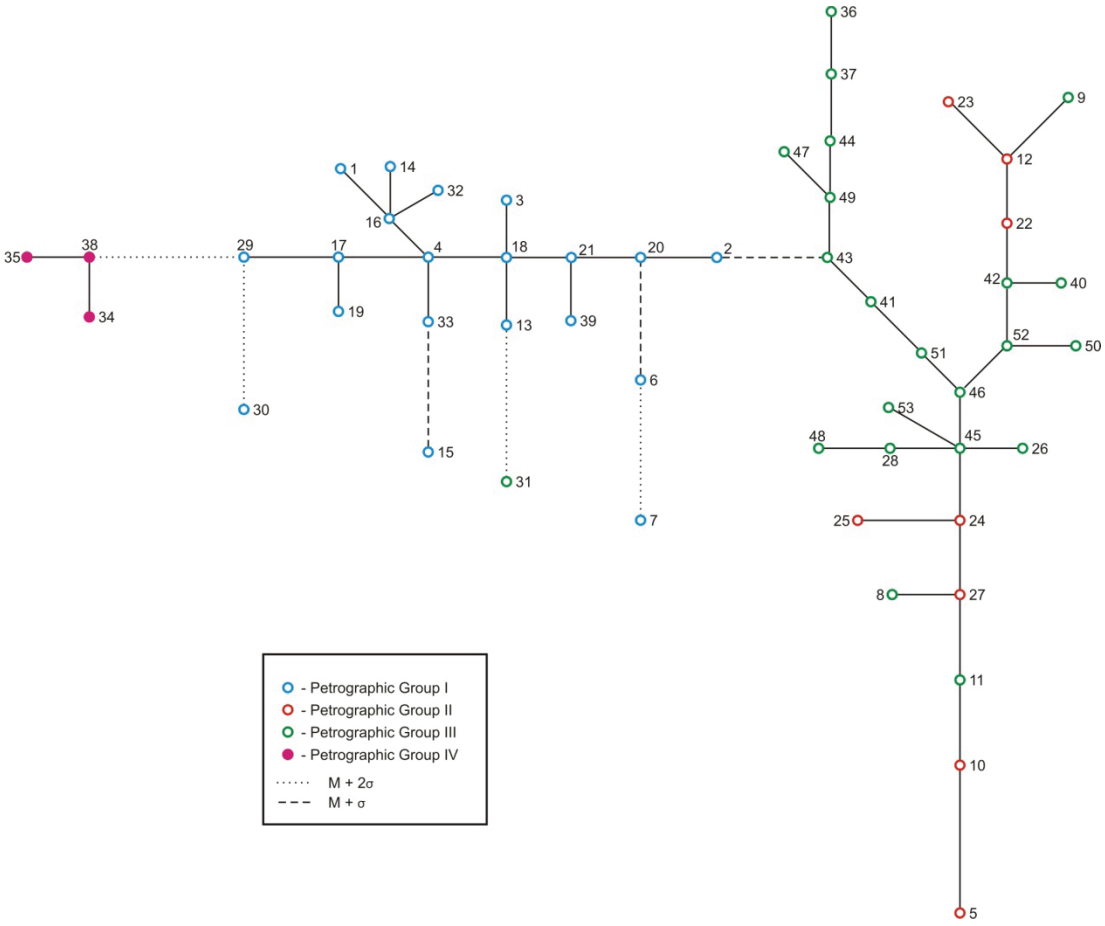

Fig. 31. Spanning tree presenting the greatest similarity (closeness) among the pottery from Jericho.

1. The ceramics assigned to Petrographic Group I were made of foraminiferous clay containing an elevated content of silt (<10%). This material was used to make the bowls and some of the storage jars in the HS1, HR1, HR2 and HR3 periods. Chemically, this group is clearly distinct from the other groups.

2. The ceramics of Petrographic Groups II and III were made of rich, non-silty clay. The two groups differ in the mineral composition of the tempering admixture. The fabric of Petrographic Group II contains pure carbonate sand, whereas that of Petrographic Group III is tempered with quartz or quartz-carbonate sand. The fabric of Petrographic Group II can be found in jars representing the periods HS2, HR1, HR2. The fabric of

Petrographic Group III is displayed by jars from the periods HS2, HR1, HR3. Group III also embraces the two 'genizah' jars (JR F253-5774/1, JR F258-5780).

3. The cooking pots making up Petrographic Group IV were made of paste displaying the petrographic features of a terra rossa soil. This group shows the greatest chemical dissimilarity.

The causes of the inter-group chemical differences are discussed in section 4.4.

4. QUMRAN COMMON WARES AND COMPARISON WITH THE JERICHO POTTERY

4.1. Object of study

The study comprised 62 fragments of pottery from Qumran, including 8 jugs and juglets, 7 cooking pots, 6 bowls, 5 storage jars, 5 kraters, 4 pitchers, 2 goblets, 1 kettle, 1 lid, 1 base of some dish, 20 'scroll jars', and 2 lids of 'scroll jars' (Table 16).

Table 16. Descriptive information and group assignment of the analysed samples of Qumran pottery.

Lab. no.	Registration no.	Locus	Stratigraphic level	Type	Petro-graphic group
54	KHQ 1587	89	3c	a goblet	4
55	KHQ 2422	134	3c	a fragment of a painted jar	3
56	KHQ 2996	62	4	a handle of a cylindrical jar	3
57	KHQ 3009	61	3c	a lid of a scroll jar	3
58	KHQ 3231	27	without stratigraphy	a rim of a cooking pot	4
59	KHQ 3237	27	without stratigraphy	a rim of a cooking pot	4
60	KHQ 3250	27	3b	a kettle	4
61	KHQ 3398	23	3c	a rim of a jar	4
62	KHQ 3487	16	4	a base of a dish	1
63	KHQ 3520	19	3c	a cooking pot?	1
64	KHQ 3521	19	3c	a rim of a cooking pot	4
65	KHQ 3531	19	3c	a cooking pot	4
66	KHQ 3544	19	3c	a juglet	3
67	KHQ 3574	93	3c	a base of a large bowl	3
68	KHQ 3662	1	3c	a rim of a goblet	3
69	KHQ 3748	4	3c	a spout of a jug	1
70	KHQ 3838	8	3c	a bottom of a juglet	3
71	KHQ 3872	13	4	a fragment of a crater	1
72	KHQ 3968	15	3c	a base of a crater	3
73	KHQ 4001	44	without stratigraphy	a fragment of a "scroll jar"	3
74	KHQ 4013	110	3c	a bowl	3
75	KHQ 4060	101	3c	a base of a crater	1
76	KHQ 4325	76	without stratigraphy	a lid of a "scroll jar"	3
77	KHQ 4517	TrA	without stratigraphy	a jug	1
78	KHQ 4524	TrAc.1	without stratigraphy	a rim of a crater	3

table 16 continued

Lab. no.	Registration no.	Locus	Stratigraphic level	Type	Petro-graphic group
79	KHQ 4525	TrAc.1	without stratigraphy	a large bowl	3
80	KHQ 4533	TrAc.1	without stratigraphy	a bowl	1
81	KHQ 4584	TrAc.5	3c	a juglet	1
82	KHQ 4590	TrAc.5	3b?	a cooking pot	4
83	KHQ 4605	TrAc 6	3c	a rim of a cooking pot	4
84	KHQ 4608	TrAc 6	3c	a rim of a juglet	1
85	KHQ 4645	130	3a	a jug	3
86	KHQ 4647	130,5B	3a	a rim of a cooking pot	4
87	KHQ 4649	130,1B	3a	a rim of a large bowl	3
88	KHQ 4671	130,5B	3a	a crater, a pot	3
89	KHQ 4797	TrE	3c	a handle of a "scroll jar"	3
90	KhQ 4870	19	4	a compella	3
91	KHQ 4880	10	4	a fragment of a jar	3
92	KHQ 4881	10	4	a "scroll jar"	3
93	KHQ 4889	10	4	a pitcher	2
94	KHQ 5146	22	4	a pitcher	3
95	GQ3-8/1	cave 3	3c	a "scroll jar"	3
96	GQ8-11/1	cave 8	3c	a "scroll jar"	3
97	GQ8-45/1	cave 8	3c	a "scroll jar"	3
98	GQ8-57/1	cave 8	3c	a "scroll jar"	3
99	GQ8-81/1	cave 8	3c	a "scroll jar"	3
100	GQ8-82/1	cave 8	3c	a "scroll jar"	3
101	GQ8-84	cave 8	3c	a "scroll jar"	3
102	GQ8-84/1	cave 8	3c	a "scroll jar"	3
103	GQ8-86/1	cave 8	3c	a "scroll jar"	1
104	GQ8-88/1	cave 8	3c	a "scroll jar"	3
105	GQ8-90	cave 8	3c	a "scroll jar"	3
106	GR7-5/1	cave 7	3c	a pitcher	3
107	GR8 Q15	cave 8Q	3c	a bowl	1
108	GR8 QB	cave 8Q	3c	a "scroll jar"	3
109	GR8QA	cave 8Q	3c	a "scroll jar"	3
110	GQ12-9/1	cave 12	3c	a "scroll jar"	3
111	GQ28-3/1	cave 28	3c	a "scroll jar"	3
112	GQ28C/1	cave 28	3c	a "scroll jar"	3
113	GQ29-8/1	cave 29	3c	a "scroll jar"	3

4.2. Results of petrographic examinations

As with the ceramics from Jericho, among the Qumran wares the following petrographic groups can be identified:

4.2.1. PETROGRAPHIC GROUP I (Foraminiferous Clay Group)

Petrographic group I (Foraminiferous Clay Group)

– specimens: 62, 63, 69, 71, 75, 77, 80, 81[1], 84, 103, and 107.

[1] Oval milky grains may be remnants of foraminifer shells, but owing to the high temperature of firing their presence has not been definitely confirmed.

The common distinguishing feature of the fabric of the vessels of this group is the presence of foraminifer shells. As to the content of a coarse admixture (0.1-0.3 mm) and silt, the group is not homogeneous. Thus:

Specimens 62, 81, 84 (Fig. 32) and 103 (Fig. 33) were made of rich clay, almost totally devoid of any temper (<2%), only single coarse grains of carbonate rocks 0.1-0.3 mm in size can be observed.
Samples 71 and 75 were made of rich clay with a 10-15% admixture of carbonate sand.
The paste of samples 63, 69, 77, 80 (Fig. 34) and 107 contains more quartz pelite (5-10%) and a great amount of coarse inclusions, i.e. 10-15%.
Sample 77 contains about 5% of quartz pelite and single coarse grains of quartz.

The colour of the vessels varies from light red, through red and reddish yellow to grey.

Microfossils:

specimen 69:
– foraminifers: *Gaudryina* sp., *Gavelinella* sp., *Globigerinelloides* sp., *Gümbelitria* cf. *cenomana* (Keller), *Heterohelix* sp., *Hedbergella* sp.
– age: Cenomanian

specimen 77:
– foraminifers: *Globigerinelloides* sp., *Heterohelix* sp.
– age: Upper Albian-Maastrichtian

specimen 80:
– foraminifers: *Gavelinella* sp., *Hedbergella* sp., *Globigerinelloides* sp.
– age: Barremnian-Maastrichtian

specimen 84:
– foraminifers: *Globigerinelloides* aff. *bentonensis* (Morrow)
– age: Albian-Cenomanian

In the remaining samples, the state of preservation of microfossils makes an identification impossible. The presence of the species *Globigerinelloides aff. bentonensis* (Morrow) indicates the Lower and Upper Cretaceous (Albian/Cenomanian) boundary as the age of the raw material of those samples.

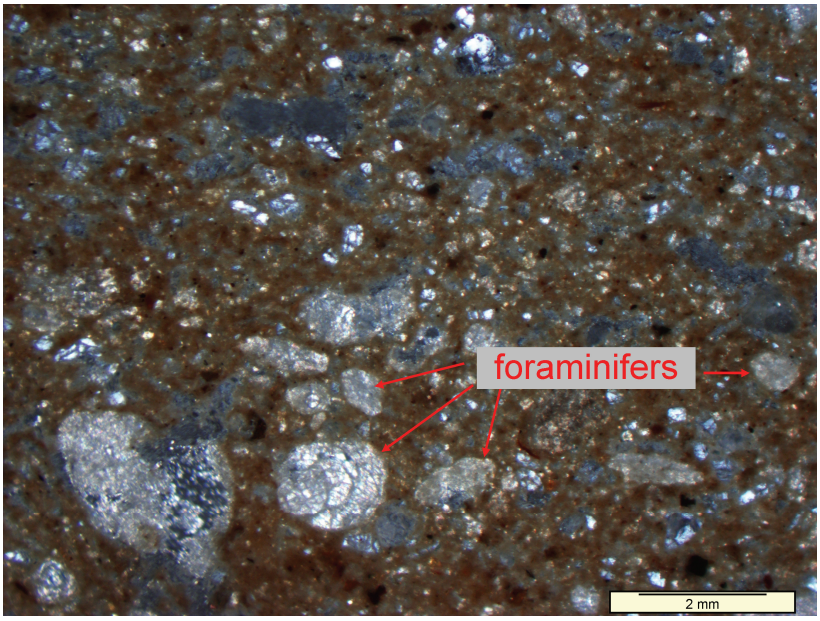

Fig. 32. Petrographic Group I. Qumran juglet KhQ4608 (specimen 84), loc. TrAc6, level 3c. Polarising microscope, crossed nicols.

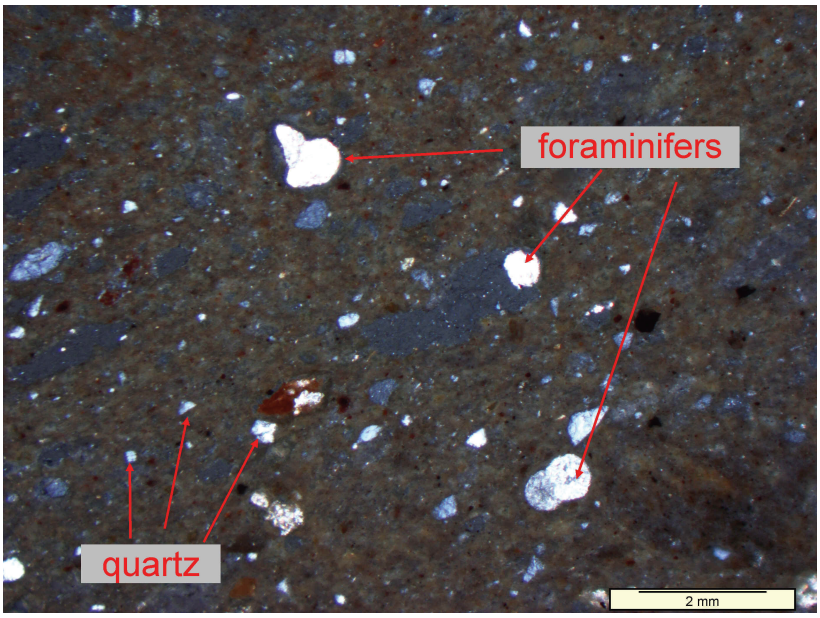

Fig. 33. Petrographic Group I. Qumran, 'scroll jar' GQ8-86/1 (specimen 103), cave 8. Polarising microscope, crossed nicols.

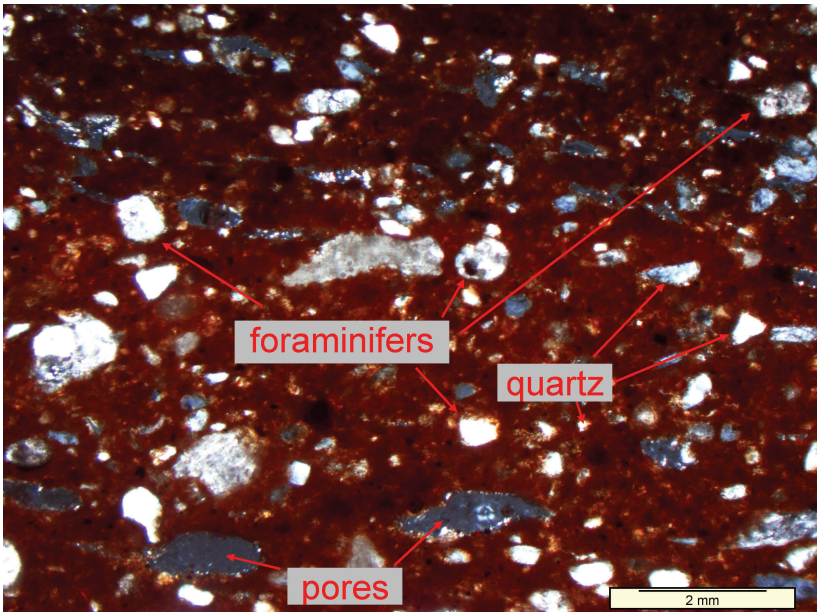

Fig. 34. Petrographic Group I. Qumran, bowl KhQ4533 (specimen 80), loc. TrAc1, without stratigraphy. Polarising microscope, crossed nicols.

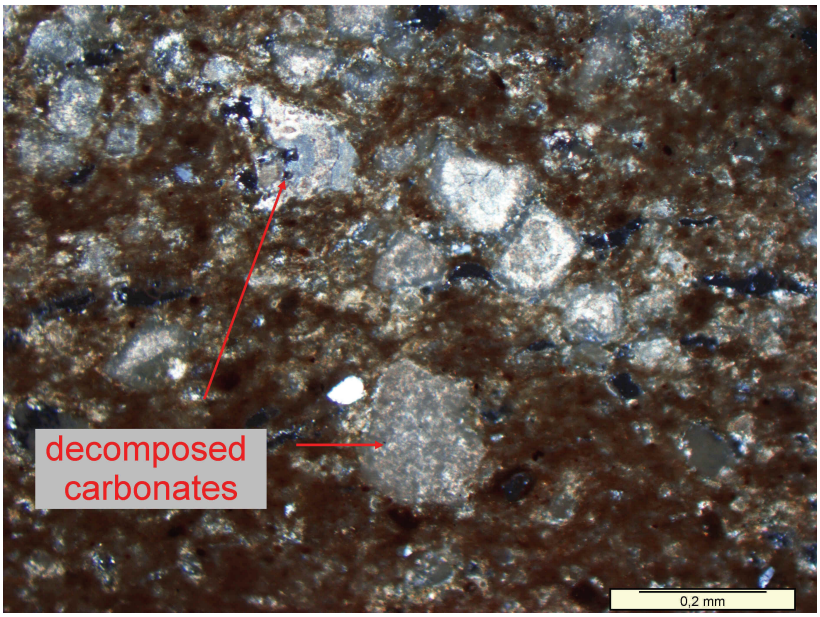

Fig. 35. Qumran, compella KhQ4889 (specimen 93), loc. 10, level 4. Polarising microscope, crossed nicols.

4.2.2. PETROGRAPHIC GROUP II (Rich Clay – Calcareous Sand Group)

Petrographic Group II (Rich Clay – Calcareous Sand Group)

– specimen **no. 93** (Fig. 35),

Colour light brown, with light red margins, made of fine clay containing fine sand-sized, carbonate grits – in petrographic terms, the sample is an equivalent of the Jericho ceramics constituting the rich clay – calcareous sand group (Petrographic Group II).

4.2.3. PETROGRAPHIC GROUP III (Rich Clay – Quartz Sand Group)

Petrographic Group III (Rich Clay – Quartz Sand Group)

– specimens: **55, 56, 57, 66, 67, 68, 70, 72, 73, 74, 76, 78, 79, 85, 87, 88, 89, 91, 92, 94, 95, 96, 97, 98, 99, 100, 101, 102, 104, 105, 106, 108, 109, 110, 111, 112, 113).**

This group is characterised by rich-clay paste, more or less marly, almost totally devoid of quartz silt, with a partially preserved shale fragments, tempered by a few to several percent of sand. It is a quartz or quartz-calcareous type of sand, also containing single grains of cherts and quartzose sandstones cemented with a carbonate binder. Those vessels were fired light red, red, reddish brown, reddish grey, and grey (cf. Table 16).

Out of this group, specimens 90 and 112 were made without a coarse admixture.

The paste of specimens 55 (Fig. 36), 57, 78, 79, 85, 87, 88, 89, 92, 94, 106, and 108 (Fig. 37) was tempered with a 10-25% addition of quartz sand.

In the paste of the remaining samples of this group (91, 56, 66 [Fig. 38], 67, 68, 70, 72 [Fig. 39], 73, 74, 76, 95, 96, 97 [Fig. 40], 98, 99, 100, 101, 102, 104, 105, 109, 111, 112, 113), the content of the sandy admixture is under 5%, and in some of the samples even under 2%.

Microfossils:

specimen 88:
- foraminifers: *Hedbergella* sp., *Heterohelix* sp.
- age: Albian – Maastrichtian

specimen 89:
- foraminifers: *Gümbelitria cf. cenomana* (Keller), *Hedbergella* sp.,*Heterohelix* sp., *Globigerinelloides* sp.
- age: Albian?, rather Cenomanian

specimen 108:
- foraminifers: *Globigerinelloides* sp., *Hedbergella aff. delrioensis* (Carey)
- age: the Lower and Upper Cretaceous (Albian/Cenomanian) boundary

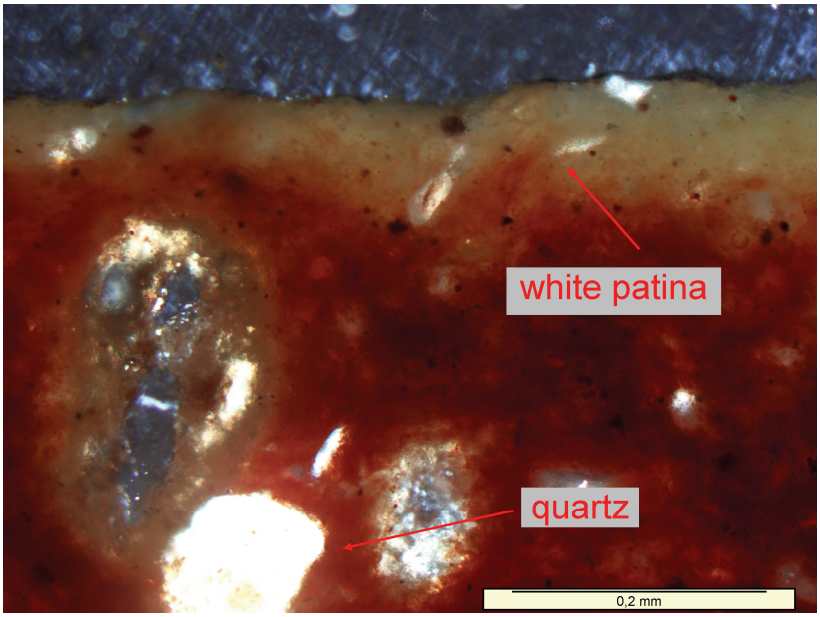

Fig. 36. Petrographic Group III. Qumran, painted jar KhQ2422 (specimen 55), cave 8. Cross-section across white patina covering the sherd. Polarising microscope, crossed nicols.

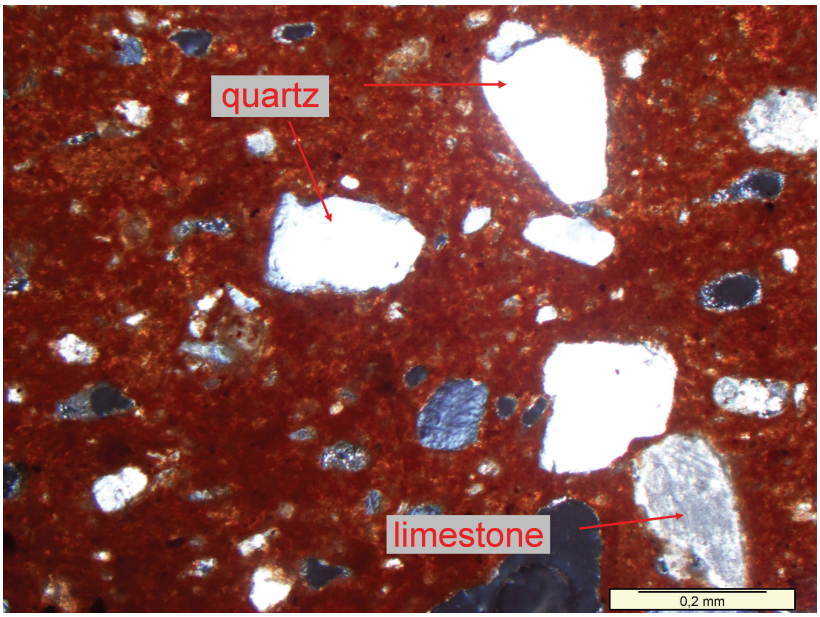

Fig. 37. Petrographic Group III. Qumran, scroll jar Gr8QB (specimen 108), cave 8Q. Polarising microscope, crossed nicols.

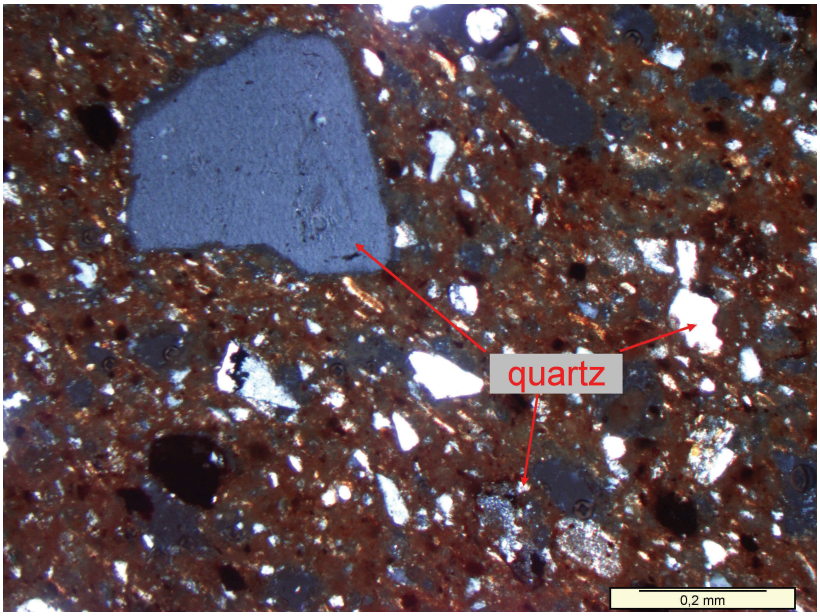

Fig. 38. Petrographic Group III. Qumran, juglet KHQ 3544 (specimen 66), loc. 19, level 3c. Polarising microscope, crossed nicols.

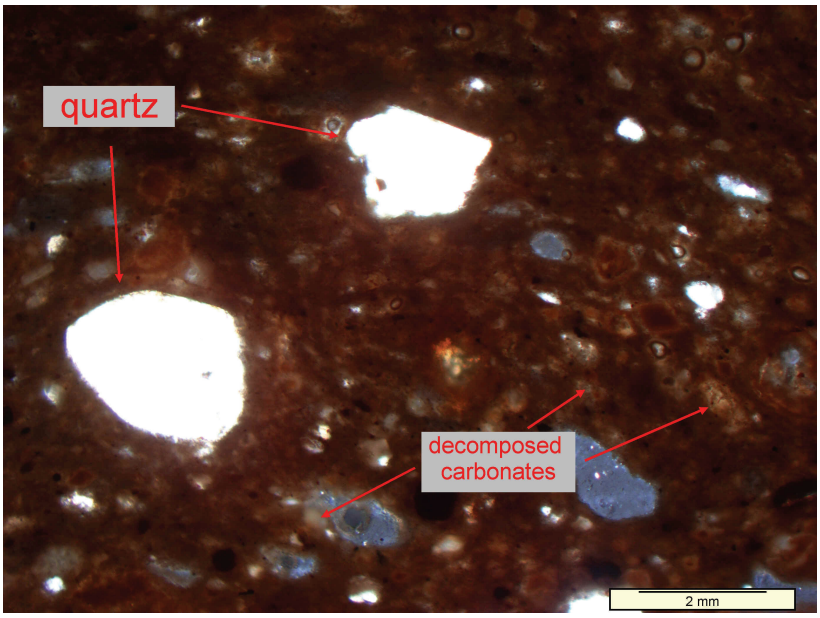

Fig. 39. Petrographic Group III. Qumran, crater KHQ 3968 (specimen 72), loc. 15, level 3c. Polarising microscope, crossed nicols.

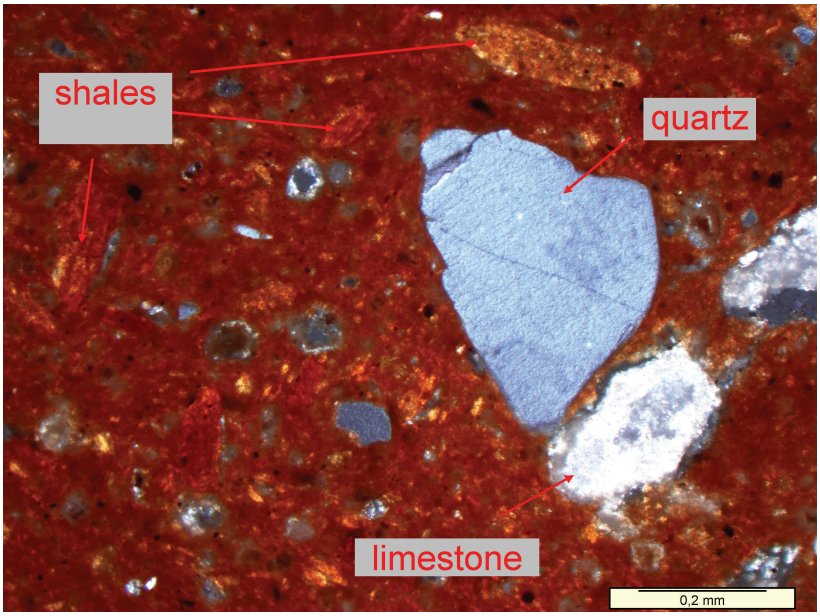

Fig. 40. Petrographic Group III. Qumran, 'scroll jar' GQ8-45/1 (specimen 97), cave 8. Polarising microscope, crossed nicols.

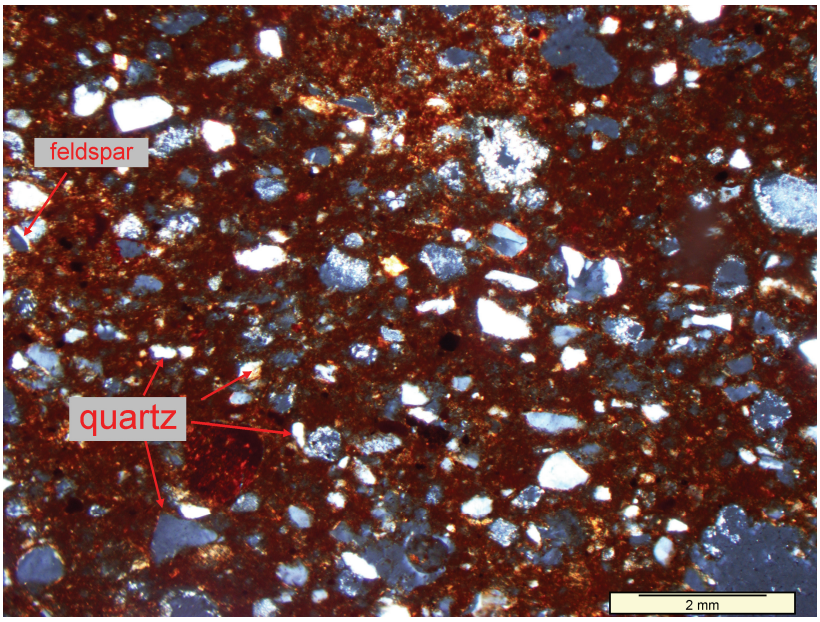

Fig. 41. Petrographic Group IV. Qumran, goblet KhQ1587 (specimen 54), loc. 89, level 3c. Polarising microscope, crossed nicols.

4.2.4. PETROGRAPHIC GROUP IV (Terra Rossa Group)

This group includes primarily specimens of cooking pots: 58, 59, 61, 64, 65, 82, 83, 86, one goblet (54 – Fig. 41), one kettle (60), and one jar (61) made of lean clays, rich in iron oxides, containing a high amount of quartz silt (10-30%). The proportion of the coarse admixture is variable and ranges from <2% in sample 8 to 20% in sample 5.

During the firing in oxidising conditions the raw material of those vessels assumed a red colour, and in more reducing conditions, reddish brown or grey. Two vessels of this group, 54 and 82, contain temper in the form of rhombus-shaped carbonate grits.

4.2.5. The remaining specimen no. 90

Specimen 90 (Fig. 42) is a ceramic fragment fired to a light red colour, made of fine clay rich in fine rhombus-shaped dolomite. The sample has no coarse admixture. Structurally, it resembles Moza Formation clay.

The main petrographic features of the Qumran ceramics are compiled in Table 17.

Table 17. Petrographic features of the Qumran ceramics.

Lab no.	Registration no.	Munsell colour		Sandy admixture			Quartz silt frequency (%)	Fine dolomite	Foraminifera	White overcolours	Rhomb-shape grits
				Frequency (%)	Quartz (%)	Carbonates (%)					
54	KHQ 1587	2.5YR 4/8	red	5	0	100	20-25	0	0	0	1
55	KHQ 2422	2.5YR 5/8	red	10	80	20	<2.0	0	0	1	0
56	KHQ 2996	2.5YR 5/8 - 2.5YR 4/1	red/ dark reddish gray	<5	80	20	<2.0	1	0	1	0
57	KHQ 3009	2.5YR 5/8	red	<10	70	30	<2.0	0	0	0.5	0
58	KHQ 3231	2.5YR 4/8	red	20	100	0	10.0	0	0	0	0
59	KHQ 3237	2.5YR 3/1	dark reddish gray	10	100	0	25.0	0	0	0	0
60	KHQ 3250	2.5YR 6/8	light red	5	50	50	25.0	0	0	1	0
61	KHQ 3398	2.5YR 5/8-2.5YR 5/4	red / reddish brown	<2	100	0	30.0	0	0	0.5	0
62	KHQ 3487	10R 5/8	red	<2	50	50	<10.0	0	1	0	0
63	KHQ 3520	2.5YR 4/6	red	15-20	20	80	<10.0	0	1	0	0
64	KHQ 3521	2.5YR 4/8 - 2.5YR 5/3	red / reddish brown	<2	100	0	15-20	0	0	1	0
65	KHQ 3531	2.5YR 4/6	red	<2	0	100	10.0	0	0	1	0
66	KHQ 3544	5YR 5/4	reddish brown	<2	100	0	5.0	0	0	1	0
67	KHQ 3574	5YR 6/1	gray	<5	100	0	<2.0	0	0	1	0
68	KHQ 3662	2.5YR 5/8	red	<5	90	10	<2.0	1	0	1	0
69	KHQ 3748	5YR 6/6	reddish yellow	10	0	100	<5.0	0	1	0	0
70	KHQ 3838	2.5YR 5/8 - 2.5YR 5/1	red - reddish gray	5	90	10	2-5	0	0	0	0
71	KHQ 3872	2.5YR 6/8 - 5YR 6/4	red - reddish yellow	10-15	0	100	<5.0	0	1	1	0

table 17 continued

Lab no.	Registration no.	Munsell colour		Sandy admixture			Quartz silt frequency (%)	Fine dolomite	Foraminifera	White overcolours	Rhomb-shape grits
				Frequency (%)	Quartz (%)	Carbonates (%)					
72	KHQ 3968	2.5YR 6/1 - 2.5YR 6/6	reddish gray - light red	<5	100	0	<5.0	1	0	1	0
73	KHQ 4001	2.5YR 6/1 - 2.5YR 6/6	reddish gray - light red	<2	100	0	<1.0	0	?	0	0
74	KHQ 4013	2.5YR 5/1 - 5YR 5/4	reddish gray - reddish brown	<5	80	20	<1.0	?	?	1	0
75	KHQ 4060	2.5YR 4/8	red	10	10	90	<10.0	?	1	0	0
76	KHQ 4325	2.5YR 4/1	dark reddish gray	<5	20	80	<2.0	1	0	1	0
77	KHQ 4517	2.5YR 5/1	reddish gray	<2	100	0	5.0	0	1	0	0
78	KHQ 4524	2.5YR 5/8 - 2.5YR 4/1	red margin . dark gray core	20-25	90	10	<2.0	0	0	1	0
79	KHQ 4525	2.5YR 5/1	reddish gray	15	90	10	<2.0	0	0	1	0
80	KHQ 4533	2.5YR 5/8	red	<5	0	100	10.0	0	1	0	0
81	KHQ 4584	10YR 6/2	light brownish gray	<1	0	100	2-5	?	?	1	0
82	KHQ 4590	2.5YR 5/8 - 2.5YR 5/4	red / reddish brown	5	0	100	15.0	0	0	0	1
83	KHQ 4605	2.5YR 5/2 - 2.%YR 5/4	weak red - reddish brown	10	90	10	20-30	0	0	0	0
84	KHQ 4608	2.5YR 7/8 - 2.5YR 6/3	light red / light reddish brown	<2	0	100	<5.0	0	1	1	0
85	KHQ 4645	2.5YR 4/8 - 2.5YR 5/2	red / weak red	10-15	100	0	<2.0	0	0	1	0
86	KHQ 4647	2.5YR 4/8	red	<10	100	0	15.0	0	0	0	0
87	KHQ 4649	2.5YR 5/6	red	10-15	100	0	<2.0	0	0	0	0
88	KHQ 4671	2.5YR 6/6	light red	<10	100	0	<1.0	0	1	0	0
89	KHQ 4797	2.5YR 7/8	light red	10	100	0	0.0	0	1	0	0
90	KhQ 4870	2.5YR 6/8	light red	0	0	0	<0.5	1	0	1	0
91	KHQ 4880	10YR 7/3	very pale brown	<2	100	0	<1.0	?	?	1	0
92	KHQ 4881	2.5YR 5/1	reddish gray	20-30	100	0	<2.0	?	?	1	0
93	KHQ 4889	2.5YR 7/6 - 7.5YR 7/4	light red / reddish yellow core	<5	0	100	<0.5	?	?	1	1
94	KHQ 5146	2.5YR 6/8	light red	10	90	10	<0.5	0	0	0	0
95	GQ3-8/1	2.5YR 5/8 - 2.5YR 4/2	red / weak red	<2	50	50	<0.5	1	0	0	0
96	GQ8-11/1	2.5YR 5/2	weak red - reddish brown	<2	30	70	<0.5	?	?	1	0
97	GQ8-45/1	2.5YR 5/8	red	<5	50	50	<0.5	1	0	0	0
98	GQ8-57/1	2.5YR 5/8	red	<5	50	50	<0.5	1	0	0	1
99	GQ8-81/1	2.5YR 5/8 - 2.5YR 5/1	red / reddish gray	<5	50	50	<0.5	1	0	0	0
100	GQ8-82/1	2.5YR 5/1	reddish gray	<5	20	80	<0.5	?	?	1	0
101	GQ8-84	2.5YR 5/8	red	<2	20	80	<0.5	1	0	1	0
102	GQ8-84/1	2.5YR 5/8	red	<5	20	80	<0.5	1	0	1	0
103	GQ8-86/1	2.5YR 7/8 - 2.5YR 6/3	light red / light reddish brown	<2	10	100	<2.0	?	1	1	0
104	GQ8-88/1	2.5YR 5/8	red	<2	50	50	<2.0	1	0	0	0
105	GQ8-90	10R 4/8	red	<5	100	0	<0.5	?	?	1	0
106	GR7-5/1	10R 6/8 - 10R 4/1	light red / dark reddish gray	15	60	40	<1.0	1	1	0	0
107	GR8 Q15	2.5YR 5/8	red	<10	0	100	10.0	0	1	0	0
108	GR8 QB	2.5YR 6/8 -2.5YR 5/1	light red / reddish gray	15	80	20	<2.0	0	1	0	0
109	GR8QA	2.5YR 7/8 - 2.5 YR 6/1	light red / reddish gray	<5	70	30	<1.0	0	0	1	0
110	GQ12-9/1	2.5YR 6/8	light red	<10	30	70	<2.0	1	0	0	1
111	GQ28-3/1	2.5YR 7/8 - 2.5 YR 6/1	light red / reddish gray	<10	50	50	<2.0	1	0	1	0
112	GQ28C/1	5YR 6/4 - 5YR 6/1	light reddish brown / gray	<2	100	0	<0.5	?	?	1	0
113	GQ29-8/1	10R 6/4	pale red	<5	60	40	<0.5	1	?	1	0

4.3. Results of chemical analyses

The chemical INAA data are presented in Table 18.

Table 18. Selected major and trace elements in the Qumran ceramics.

Lab no.	Element	Ca	Fe	Na	Sn	Sr	Au	Ag	As	Ba	Br	Co	Cr	Cs	Hf	Hg	Ir
	Registration no.\ Mass unit	wt %	wt %	wt %	wt %	wt %	ppb	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppb
54	KHQ 1587	9	4.71	1.17	<0.01	<0.05	<2	<5	11.4	400	41.1	16	160	3	8	<1	<5
55	KHQ 2422	6	4.03	0.63	<0.01	<0.05	<2	<5	7.2	<50	35.3	14	146	6	4	<1	<5
56	KHQ 2996	6	3.52	0.71	<0.01	<0.05	18	<5	5.5	<50	57.9	13	100	4	6	<1	<5
57	KHQ 3009	5	3.52	0.55	<0.01	<0.05	<2	<5	7.2	<50	50.3	13	109	4	4	<1	<5
58	KHQ3231	<1	6.85	0.19	<0.01	<0.05	<2	<5	15.2	370	18.6	31	173	3	12	<1	<5
59	KHQ3237	<1	6.13	0.48	<0.01	<0.05	2	<5	11.9	410	50.1	27	180	4	15	<1	<5
60	KHQ3250	<1	5.84	0.64	<0.01	<0.05	<2	<5	9.4	410	45.7	24	170	1	15	<1	<5
61	KHQ3398	1	5.76	0.48	<0.01	<0.05	<2	<5	10.0	500	15.8	27	160	3	15	<1	<5
62	KHQ3487	13	4.48	0.61	<0.01	<0.05	3	<5	9.2	250	33.4	16	191	3	6	<1	<5
63	KHQ3520	9	5.15	0.77	<0.02	<0.05	<2	<5	10.5	<50	36.1	18	213	3	9	<1	<5
64	KHQ 3521	2	5.41	0.41	<0.01	<0.05	5	<5	8.2	370	11.3	26	192	3	16	<1	<5
65	KHQ 3531	2	5.61	1.00	<0.01	<0.05	<2	<5	7.4	390	43.0	26	150	3	13	<1	<5
66	KHQ3544	3	4.12	0.73	<0.01	<0.05	<2	<5	8.3	320	26.3	14	90	10	7	<1	<5
67	KHQ 3574	7	4.62	0.86	<0.01	<0.05	<2	<5	6.2	330	62.1	19	160	6	7	<1	<5
68	KHQ 3662	5	5.17	0.6	<0.01	<0.05	2	<5	10.6	320	34.1	18	162	4	7	<1	<5
69	KHQ 3748	11	3.56	0.92	<0.01	<0.05	4	<5	9.7	240	66.7	19	152	<1	5	<1	<5
70	KHQ3838	5	4.44	0.61	<0.02	<0.05	<2	<5	9.0	<50	36.1	14	153	6	5	<1	<5
71	KHQ 3872	7	4.65	0.71	<0.01	<0.05	<2	<5	6.8	410	30.3	17	200	3	7	<1	<5
72	KHQ 3968	7	4.03	0.86	<0.01	<0.05	3	<5	12.3	360	71.0	14	130	4	5	<1	<5
73	KHQ 4001	3	3.87	0.73	<0.01	<0.05	4	<5	5.8	220	58.6	17	110	3	5	<1	<5
74	KHQ 4013	5	4.71	0.81	<0.01	<0.05	2	<5	4.4	<50	54.8	20	140	7	5	<1	<5
75	KHQ 4060	10	4.44	0.83	<0.01	<0.05	<2	<5	8.1	340	49.8	14	194	2	7	<1	<5
76	KHQ 4325	4	4.19	0.43	<0.01	<0.05	<2	<5	8.6	<50	28.9	12	121	4	6	<1	<5
77	KHQ 4517	8	4.46	0.62	<0.01	<0.05	<2	<5	8.5	390	68.3	16	172	3	6	<1	<5
78	KHQ 4524	5	4.14	0.47	<0.01	<0.05	<2	<5	3.6	210	43.4	15	100	5	6	<1	<5
79	KHQ4525	4	4.06	0.32	<0.01	<0.05	<2	<5	6.0	<50	46.6	11	120	4	5	<1	<5
80	KHQ 4533	9	4.41	0.41	<0.01	0.06	<2	<5	9.0	760	17.6	15	162	<1	6	<1	<5
81	KHQ 4584	9	4.84	0.72	<0.01	0.07	<2	<5	5.0	230	44.3	15	180	2	9	<1	<5
82	KHQ4590	<1	5.53	0.50	<0.01	<0.05	5	<5	4.5	470	23.5	26	191	2	15	<1	<5
83	KHQ 4605	<1	5.43	0.67	<0.01	<0.05	5	<5	5.8	<50	22.6	27	165	3	14	<1	<5
84	KHQ 4608	12	4.24	0.79	<0.01	<0.05	<2	<5	6.1	<50	56.1	12	160	<1	7	<1	<5
85	KHQ 4645	5	3.47	0.81	<0.01	<0.05	<2	<5	5.3	<50	77.2	11	100	3	5	<1	<5
86	KHQ4647	<1	5.41	0.54	<0.01	<0.05	<2	<5	6.6	290	22.0	25	160	3	17	<1	<5
87	KHQ4649	5	3.70	0.72	<0.01	<0.05	<2	<5	5.0	130	67.6	10	99	4	4	<1	<5
88	KHQ 4671	11	2.77	0.59	<0.01	<0.05	<2	<5	6.9	110	94.7	17	66	3	3	<1	<5
89	KHQ 4797	13	3.42	0.76	<0.01	<0.05	<2	<5	7.5	120	32.2	13	84	2	3	<1	<5
90	KHQ 4870	4	4.76	0.27	<0.01	<0.05	<2	<5	11.8	230	15.0	25	175	8	4	<1	<5
91	KHQ 4880	16	3.41	0.69	<0.01	<0.05	<2	<5	6.0	280	56.9	15	174	3	3	<1	<5
92	KHQ4881	6	3.75	0.42	<0.01	<0.05	<2	<5	7.3	180	34.5	12	120	5	5	<1	<5
93	KHQ4889	16	4.37	0.52	<0.01	<0.05	<2	<5	8.5	330	56.3	19	108	4	4	<1	<5
94	KHQ5146	4	3.65	0.51	<0.01	<0.05	<2	<5	5.4	130	16.9	12	89	3	4	<1	<5
95	GQ3-8/1	5	5.18	0.34	<0.02	<0.05	<5	<5	14.7	<140	17.7	30	175	12	4	<1	<5
96	GQ8-11/1	8	5.41	0.82	<0.02	<0.05	6	<5	5.6	520	49.5	19	162	6	5	<1	<5
97	GQ8-45/1	6	4.48	0.45	<0.01	<0.05	<2	<5	8.8	<50	52.2	23	127	8	3	<1	<5
98	GQ8-57/1	7	5.13	0.60	<0.04	<0.05	<2	<5	10.6	<110	64.2	27	148	8	5	<1	<5
99	GQ8-81/1	5	4.85	0.42	<0.01	<0.05	8	<5	8.5	<79	29.8	22	113	8	4	<1	<5
100	GQ8-82/1	6	4.88	0.50	<0.02	<0.05	<2	<5	6.2	<50	16.5	21	135	8	5	<1	<5
101	GQ8-84	5	4.29	0.71	<0.01	<0.05	<2	<5	7.4	<50	58.8	20	110	6	3	<1	<5
102	GQ8-84/1	6	4.59	0.74	<0.02	<0.05	<2	<5	10.1	<50	64.8	22	110	7	4	<1	<5
103	GQ8-86/1	9	5.03	0.74	<0.02	<0.05	<2	<5	7.3	430	74.0	15	153	6	4	<1	<5
104	GQ8-88/1	6	4.74	0.54	<0.01	<0.05	<2	<5	7.3	<50	32.5	20	127	9	4	<1	<5
105	GQ8-90	5	4.47	2.34	<0.01	<0.05	6	<5	10.1	210	86.6	20	109	5	4	<1	<5
106	GR7-5/1	12	3.91	0.67	<0.02	<0.05	7	<5	8.6	<50	38.7	14	127	6	4	<1	<5
107	GR8 Q15	9	4.70	0.80	<0.01	<0.05	32	<5	11.1	200	35.7	15	140	3	8	<1	<5
108	GR8 QB	8	3.42	0.32	<0.01	<0.05	<2	<5	5.4	<50	35.1	11	100	4	4	<1	<5
109	GR8 QA	5	4.37	0.50	<0.01	<0.05	<2	<5	7.4	<50	49.5	18	110	5	4	<1	<5
110	GQ12-9/1	10	4.02	0.57	<0.02	<0.05	<2	<5	10.6	290	50.6	18	136	6	5	<1	<5
111	GQ28-3/1	10	4.88	0.81	<0.02	<0.05	<2	<5	8.7	370	35.3	22	194	5	5	<1	<5
112	GQ28C/1	6	4.75	0.44	<0.02	0.06	<2	<5	2.8	400	20.1	20	157	8	4	<1	<5
113	GQ29-8/1	8	4.17	0.96	<0.02	<0.05	<2	<5	7.9	780	294	29	150	7	4	<1	<5

table 18 continued

Lab no.	Mo	Ni	Rb	Sb	Sc	Se	Ta	Th	U	W	Zn	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
54	7	<71	54	0.8	14.9	<3	<0.5	8.1	2.7	12	180	38.3	80	38	6.7	1.7	<0.5	3.3	0.49
55	11	<59	96	<0.1	15.9	<3	2.2	6.8	3.6	20	<50	28.5	53	26	5.9	1.2	1.0	2.7	0.41
56	9	<72	48	<0.1	13.9	<3	<0.5	6.5	4.0	8	<50	22.6	50	25	4.3	1.1	<0.5	2.4	0.36
57	8	<52	53	0.6	15.0	<3	<0.5	6.6	2.9	8	147	23.5	50	24	5.6	1.3	0.7	2.5	0.38
58	13	<54	<15	0.8	19.2	<3	2.8	13.5	2.5	11	139	57.1	113	51	11.0	2.5	1.4	5.1	0.76
59	<1	450	56	0.8	17.5	<3	<0.5	10.9	2.8	7	120	45.8	102	36	7.8	2.1	0.8	4.3	0.66
60	8	<73	52	1.0	16.5	<3	2.0	11.3	3.2	7	110	47.8	102	48	8.0	2.3	<0.5	4.2	0.64
61	11	<73	55	<0.1	16.2	<3	<0.5	9.8	3.9	7	<50	44.2	97	47	7.5	2.0	<0.5	4.2	0.65
62	18	<45	62	1.2	13.5	<3	<0.5	7.4	5.6	14	156	37.3	69	29	7.5	1.5	1.1	3.4	0.52
63	18	<79	<15	0.9	16.4	<3	<0.5	9.1	2.9	17	120	42.0	85	29	8.6	1.9	1.2	3.8	0.56
64	17	<47	68	1.1	16.9	<3	2.1	11.3	2.7	16	121	43.4	95	43	8.5	2.1	1.2	5.0	0.75
65	9	<82	57	0.7	16.5	3	2.0	9.9	3.0	<1	150	46.6	107	44	7.9	2.0	1.8	4.1	0.62
66	9	250	120	1.2	12.9	<3	0.9	13.4	3.1	11	<50	41.5	90	36	6.6	1.7	<0.5	2.6	0.40
67	5	<81	71	0.5	19.9	4	<0.5	7.2	2.2	10	72	29.7	68	28	5.7	1.7	<0.5	3.3	0.49
68	9	<51	71	0.8	18.6	<3	0.9	8.9	4.4	<1	180	41.9	90	32	7.1	1.8	<0.5	3.6	0.54
69	11	<58	<15	0.9	11.4	<3	<0.5	7.0	4.9	10	150	31.0	56	22	5.5	1.3	1.6	2.6	0.40
70	19	<68	<15	0.6	17.8	<3	<0.5	8.7	4.8	23	120	30.2	64	35	7.1	1.5	<0.5	3.4	0.53
71	13	<52	80	0.8	15.2	<3	<0.5	8.4	3.7	12	121	41.4	79	36	8.1	1.8	1.1	3.5	0.54
72	19	<75	57	<0.1	15.3	<3	<0.5	6.4	2.9	8	130	27.7	58	26	5.3	1.3	<0.5	2.8	0.42
73	12	<67	78	<0.1	15.4	<3	<0.5	6.3	3.5	6	98	24.0	52	21	4.4	1.0	<0.5	2.3	0.34
74	7	<77	120	0.4	19.8	<3	<0.5	9.3	4.8	8	130	33.0	69	31	5.5	1.4	1.1	2.7	0.41
75	10	<51	56	1.0	14.6	<3	<0.5	7.6	5.1	6	157	38.0	70	32	7.5	1.7	0.9	3.4	0.52
76	19	<70	57	0.6	18.2	<3	<0.5	7.5	4.5	<1	140	29.2	70	32	5.4	1.4	<0.5	2.8	0.42
77	9	<50	<15	0.8	14.8	<3	1.7	7.6	4.7	1	135	35.0	67	27	7.0	1.5	1.0	3.4	0.52
78	3	<72	110	<0.1	16.0	4	1.7	8.1	2.8	8	<50	27.8	62	24	4.7	1.1	<0.5	2.4	0.37
79	11	<76	77	0.5	15.5	<3	<0.5	7.4	4.0	14	76	24.5	53	26	4.8	1.1	<0.5	2.4	0.36
80	14	<54	42	0.7	12.9	<3	<0.5	8.1	3.0	13	176	33.6	65	31	6.2	1.5	<0.5	3.1	0.47
81	16	<76	<15	0.5	14.8	<3	<0.5	8.0	3.6	8	170	37.9	77	28	6.6	1.6	<0.5	3.2	0.48
82	17	<64	48	0.7	17.4	<3	<0.5	11.6	2.8	19	135	48.5	93	46	9.0	2.2	<0.5	4.8	0.74
83	13	70	69	0.5	17.6	3	2.2	11.0	3.0	11	82	47.2	109	46	7.5	2.3	1.1	4.1	0.61
84	14	<69	71	0.8	12.0	<3	<0.5	6.8	3.2	9	160	31.7	66	30	5.8	1.6	<0.5	3.0	0.45
85	5	<54	61	0.2	14.8	4	0.5	5.8	2.4	<1	110	24.3	53	22	4.5	1.3	<0.5	2.5	0.37
86	12	<73	50	0.8	16.1	<3	<0.5	10.8	2.8	9	<50	46.1	104	43	8.0	2.3	1.3	4.5	0.70
87	9	<65	81	0.3	14.3	<3	<0.5	5.9	2.2	6	63	23.2	47	22	4.3	1.0	<0.5	2.1	0.36
88	5	<50	26	0.4	12.1	<3	<0.5	4.5	2.8	<1	100	18.8	42	18	3.5	1.0	<0.5	1.6	0.24
89	3	<56	63	0.5	14.2	<3	1.2	5.0	3.2	<1	120	22.9	48	25	4.1	1.0	1.0	2.0	0.30
90	12	<57	74	0.5	22.8	<3	<0.5	8.8	4.0	17	92	34.6	67	34	7.5	1.8	<0.5	3.9	0.60
91	11	<50	46	0.8	15.8	<3	<0.5	7.6	3.3	8	140	33.9	54	25	6.5	1.4	<0.5	2.8	0.42
92	9	<71	64	0.5	15.4	<3	<0.5	6.3	2.6	8	<50	24.0	52	24	4.4	1.1	<0.5	2.2	0.34
93	7	<71	76	0.7	17.9	<3	<0.5	7.4	2.7	<1	90	25.9	60	24	5.0	1.2	<0.5	2.4	0.36
94	6	<57	49	0.2	16.0	<3	<0.5	6.3	2.7	<1	<50	25.4	55	23	4.5	1.1	<0.5	2.3	0.35
95	15	<187	118	<0.2	22.2	<3	<0.5	11.5	5.6	23	<50	37.2	63	31	7.1	1.6	<0.5	2.7	0.42
96	22	<117	83	<0.1	20.4	<3	<0.5	9.6	<0.5	13	<50	36.2	62	28	7.4	1.8	1.5	3.0	0.49
97	<1	<87	89	<0.1	19.3	<3	1.7	9.0	3.7	12	100	28.9	65	25	6.3	1.5	<0.5	2.8	0.43
98	<3	<182	132	<0.2	20.8	<3	<0.5	9.5	<0.5	<1	<50	35.8	64	54	7.3	1.2	<0.5	3.0	0.45
99	11	<138	139	0.6	20.3	<3	<0.5	9.1	2.8	5	235	28.3	51	23	6.7	1.6	<0.5	2.9	0.44
100	<1	<76	110	<0.1	19.0	<3	1.4	8.2	3.5	3	<50	32.2	63	24	6.2	1.6	<0.5	2.7	0.40
101	2	<51	110	0.5	19.0	<3	<0.5	7.8	2.7	<1	92	30.0	52	21	5.2	1.3	<0.5	2.5	0.38
102	5	<84	91	0.9	20.0	<3	<0.5	8.4	1.9	<1	<50	32.2	61	19	5.8	1.3	<0.5	2.6	0.40
103	<1	<100	112	0.8	19.3	<3	<0.5	9.3	2.4	6	210	35.2	60	31	7.2	1.5	<0.5	3.6	0.52
104	7	<57	130	0.6	20.5	<3	1.0	8.6	3.1	<1	98	31.0	67	20	5.9	1.5	<0.5	2.7	0.40
105	<1	<66	98	0.7	18.5	<3	<0.5	8.0	2.1	<1	<50	29.7	53	22	5.2	1.2	<0.5	2.6	0.39
106	<1	<88	82	0.4	16.6	<3	<0.5	8.2	4.8	11	<50	26.7	42	23	5.3	1.2	0.6	2.5	0.38
107	<1	<70	51	0.8	13.6	<3	<0.5	7.8	4.0	5	150	35.2	74	32	6.2	1.7	1.1	3.3	0.50
108	7	<59	68	0.5	13.5	<3	<0.5	5.2	4.5	7	<50	21.2	40	19	3.8	1.0	<0.5	2.1	0.30
109	16	<75	87	0.5	17.0	<3	1.6	7.6	3.1	2	<50	27.6	56	24	5.0	1.2	<0.5	2.5	0.38
110	6	<78	90	0.8	14.5	<3	1.8	7.0	4.6	<1	87	31.3	58	24	5.6	1.4	<0.5	3.0	0.45
111	21	<160	100	0.8	18.2	<3	<0.5	9.7	3.3	<1	<50	34.5	71	25	7.2	1.1	<0.5	3.3	0.51
112	7	<76	93	0.5	19.2	<3	<0.5	9.0	4.6	10	115	33.8	62	22	6.4	1.3	<0.5	3.0	0.45
113	<3	<207	110	<0.2	19.7	<3	<0.5	6.7	<0.8	15	<50	31.0	58	28	5.4	1.4	<0.5	2.7	0.42

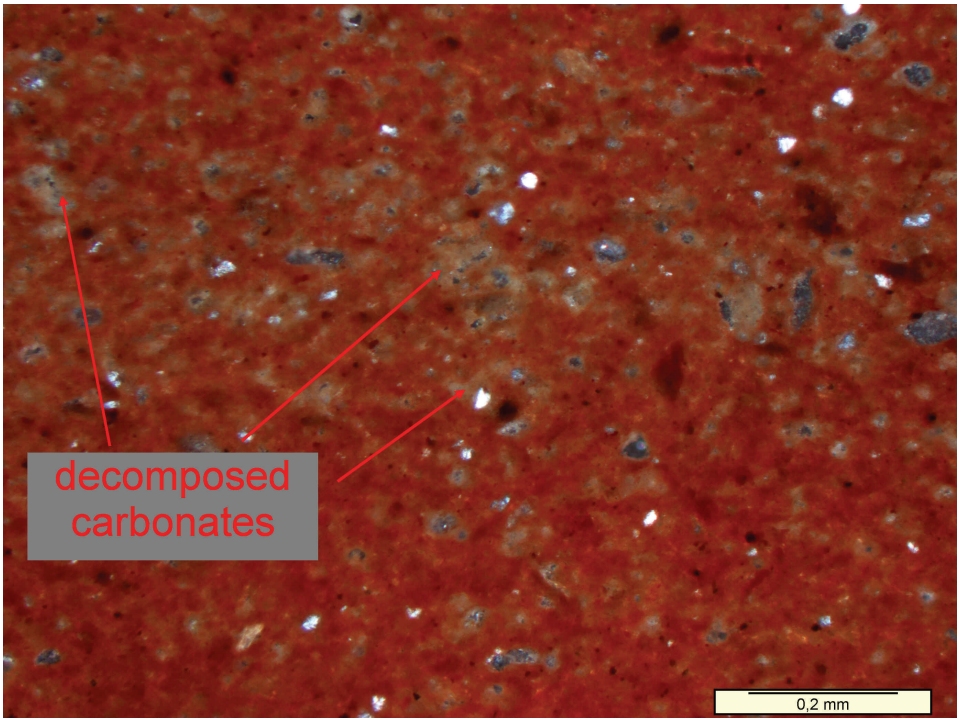

Fig. 42. Qumran, compella KhQ4870 (specimen 90), loc. 19, level 4. Polarising microscope, crossed nicols.

The calculations were made according to the same procedure and on the basis of the same elements as those employed in the study of the ceramics from Jericho.

A projection of the objects from an 18-dimensional space onto the plane of the first two principal components PC1 and PC2 represents the total of 71.96% of actual distances and angles between the objects (Fig. 43). The fidelity of the mapping into the space of all the three principal components equals 71.47% (Table 19, Fig. 44).

The first principal component PC1 is mainly determined by the variation of rare earths, Th, Fe, Hf and Cr; the second component, PC2, is determined by the variation of Cs, Rb and Sc; and the third, PC3, is principally determined by the variation of As and Ca (Table 20).

In both diagrams (Figs 43, 44) the individual petrographic groups form three clusters. Exceptions are sample 54 (loc. 89) with a petrography of the terra rossa soil, chemically close to the foraminiferous Petrographic Group I, and sample 70 with the features of vessels making up the rich clay – quartz sand group (Petrographic Group III), chemically also similar to those of the foraminiferous group. Also sample 103, a 'scroll jar', is chemically close to the quartz sand group, even though it contains foraminifer shells.

Table 19. Results of principal components analysis based on the correlation matrix of the chemical composition of the Qumran pottery.

Principal component number	Eigenvalue	Percentage of variance explained	Cumulative % of total variance
1	9.9661	56.31	56.31
2	2.6829	15.16	71.47
3	1.2180	6.88	78.35
4	0.9067	5.12	83.47
5	0.8092	4.57	88.04
6	0.5269	2.98	91.02
7	0.3682	2.08	93.10
8	0.2918	1.65	94.75
9	0.1984	1.12	95.87
10	0.1808	1.02	96.89
11	0.1556	0.88	97.77
12	0.1467	0.83	98.60
13	0.0775	0.44	99.04
14	0.0720	0.41	99.45
15	0.0492	0.28	99.73
16	0.0254	0.14	99.87
17	0.0203	0.11	99.98
18	0.0045	0.02	100.00

Table 20. PCA of the Qumran pottery. Determination coefficient R^2 x 100%.

Element	PC1	PC2	PC3
As	11.32	0.25	39.77
Ca	41.36	0.14	34.47
Co	48.09	19.41	0.11
Cr	59.13	1.22	15.00
Cs	1.96	74.93	0.92
Fe	84.47	5.89	0.00
Hf	66.54	14.01	11.07
Rb	3.07	53.29	5.53
Sc	11.32	70.94	0.75
Th	74.70	7.91	0.14
U	0.24	19.17	6.07
La	92.41	0.12	0.23
Ce	86.72	1.67	2.00
Nd	73.64	1.04	1.93
Sm	87.48	0.13	5.27
Eu	86.29	0.74	0.01
Yb	92.17	1.11	0.36
Lu	92.59	0.88	0.25

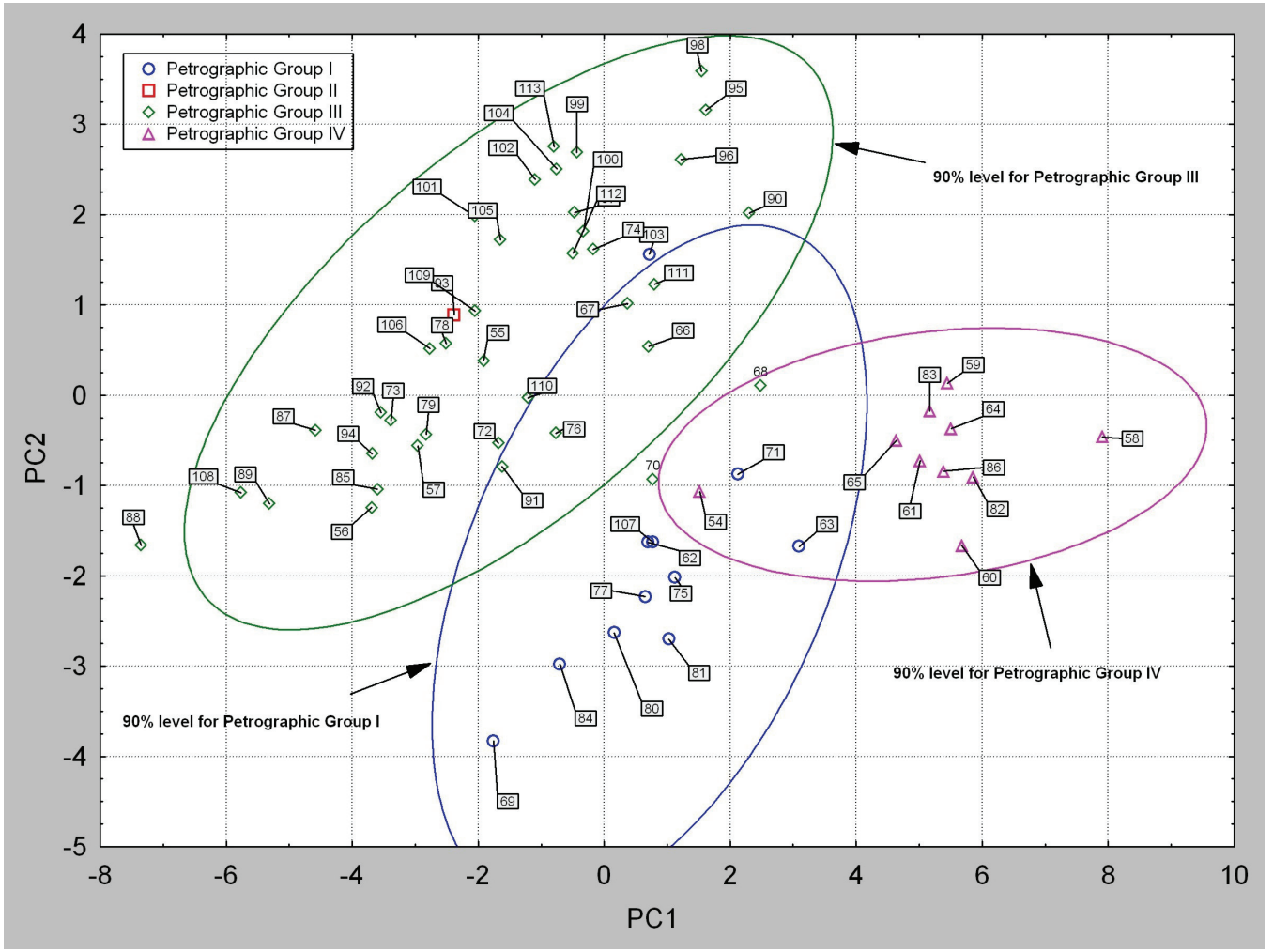

Fig. 43. Principal components analysis: a set of the Qumran ceramics projected onto a plane of the principal components PC1-PC2.

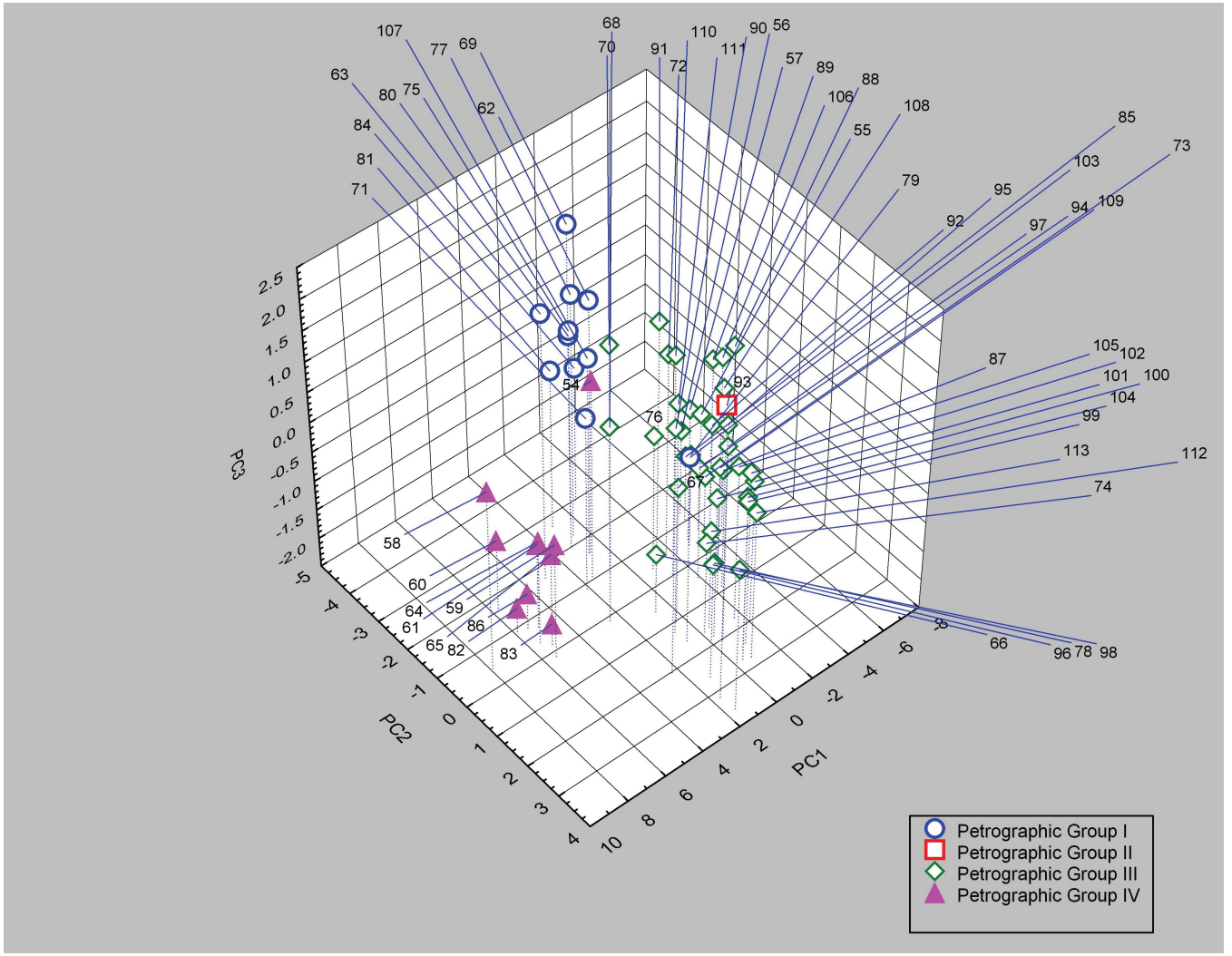

Fig. 44. Result of projection onto the space of the three principal components PC1-PC2-PC3; 78.35% of total variance is explained.

The values of the nearest Euclidean distances among the specimens studied are presented in Table 21.

Table 21. Values of the shortest Euclidean distances between the successively closest points representing samples of the Qumran ceramics in the 18-dimensional space of the elements analysed. Significant differences are marked with an asterisk.

Pairs	Distance	Pairs (ct.)	Distance
54 - 107	1.47	57 - 85	1.85
107 - 62	2.12	85 - 56	1.88
62 - 75	1.36	85 - 87	1.76
75 - 71	1.85	87 - 108	2.32
71 - 68	2.46	108 - 89	2.56
68 - 65	**3.35***	89 - 88	**3.48***
65 - 61	1.61	85 - 94	1.42
61 - 59	1.73	94 - 73	2.01
59 - 58	**3.78****	55 - 91	2.90
61 - 60	2.27	55 - 106	2.06
65 - 86	1.56	55 - 109	1.94
86 - 64	1.72	109 - 93	1.81
86 - 82	1.88	109 - 101	1.40
86 - 83	1.31	101 - 105	1.41
68 - 90	2.96	105 - 102	1.39
90 - 95	**3.06***	102 - 104	1.94
75 - 77	2.68	104 - 97	1.67
77 - 63	2.91	104 - 99	1.72
77 - 70	2.35	104 - 100	1.31
77 - 81	2.31	100 - 67	2.36
75 - 80	2.48	67 - 103	2.64
80 - 69	3.39*	103 - 111	2.60
80 - 84	2.05	100 - 74	1.94
107 - 66	**4.75****	74 - 112	2.31
107 - 110	2.94	102 - 113	**3.23***
110 - 55	2.17	113 - 96	**3.70***
55 - 79	2.19	113 - 98	**3.88****
79 - 78	2.53	110 - 72	2.06
79 - 92	1.74	72 - 76	2.49
92 - 57	1.76		

M = 2.28
(σ) = 0.73
* M + σ = 3.01
** M + 2 σ = 3.74

Those distances provided a basis for constructing a spanning tree (Fig. 45).

The structure of the dendrite (Fig. 45) largely confirms the results of principal components analysis.

The mean (M) of all the shortest distances between points equalled 2.28, while the standard deviation (δ) = 0.73. If we set the criterion of a division into subgroups at M + 2σ = 3.75, which corresponds to a 95.5% probability

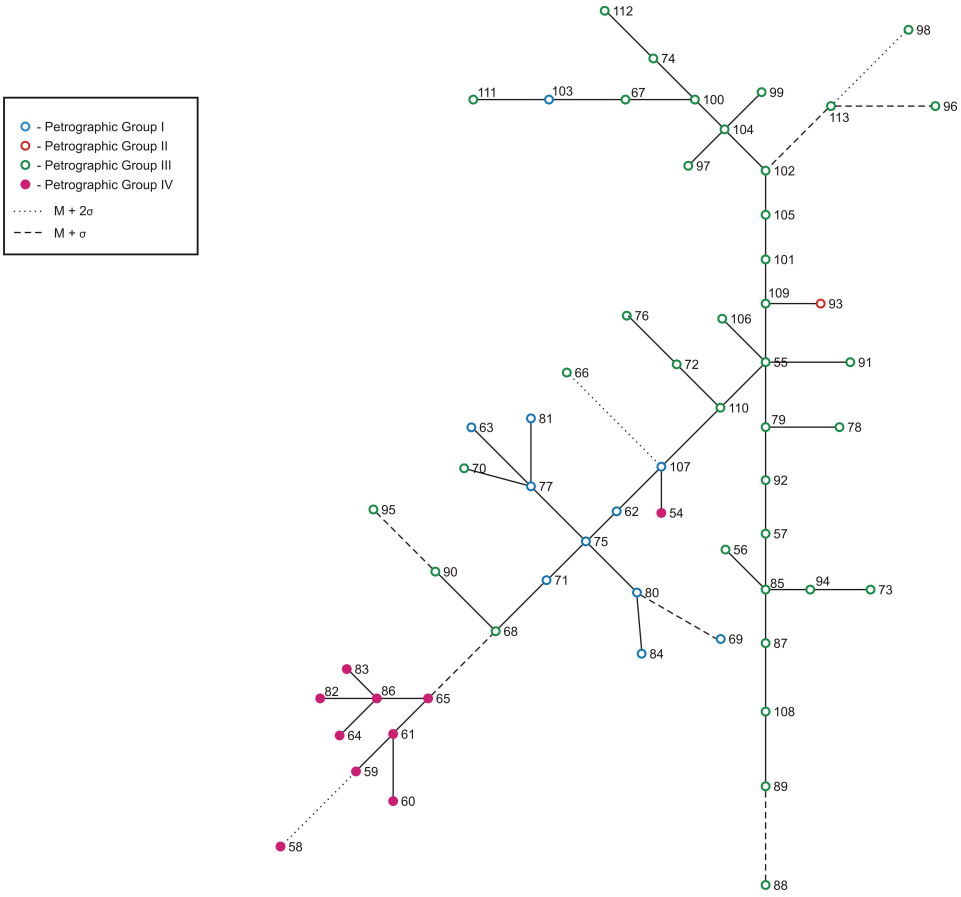

Fig. 45. Spanning tree presenting the greatest similarity (closeness) among the ceramics from Qumran.

that the specimens separated in this way are actually different, then the only vessels significantly different statistically are specimens no. 58, 66 and 98. With a probability of 68% (M + σ) = 3.01, also different will be most of the ceramics assigned to Petrographic Group IV (59, 60, 61, 64, 65, 82, 83, 86) as well as specimens 69, 88, 90, 95, 96 and 113.

When mapping onto the dendrite the division resulting from petrographic similarity, we can find that the pairing of samples 107 and 110 with a value of 2.94 is the boundary between the group of vessels of Petrographic Group III containing a quartz sand temper and Petrographic Group I made of foraminiferous clay. Assumed as a limiting value, it also separates the ceramics of the entire set into groups corresponding to the petrographic classification. We then obtain the following division:

- a group embracing most of the samples made of foraminiferous clay, including four samples (68, 70, 90, 95) assigned to Petrographic Group III and sample 54 petrographically similar to Petrographic Group IV;
- a group composed of the majority of samples made of rich clay mixed with quartz sand temper assigned to Petrographic Group III chemically distinct are only samples 88, 66, 90, 95 and 98); and
- a group of specimens with the petrographic properties of the terra rossa soil (Petrographic Group IV).

4.4. Chemical similarities and differences between the Qumran and Jericho ceramics

Let us now determine the degree of similarity between the vessels from Jericho and Qumran by calculating principal components and plotting a dendrite on the basis of the levels of the same 18 elements we have employed to correlate the ceramics coming from the individual sites. Then let us turn to the causes of the observed inter-group variability.

With the help of the first two principal components, we can account for 70.7% of the actual variability of the chemical composition of the Qumran and Jericho ceramics (cf. Table 22, Fig. 46).

Table 22. Results of principal components analysis based on the correlation matrix of the chemical composition of the Qumran and Jericho pottery.

Principal component number	Eigenvalue	Percentage of variance explained	Cumulative % of total variance
1	9.8934	55.45	55.45
2	2.7251	15.27	70.72
3	1.1926	6.68	77.40
4	0.9016	5.05	82.45
5	0.7536	4.22	86.67
6	0.5467	3.06	89.73
7	0.4178	2.34	92.07
8	0.3338	1.87	93.94
9	0.2519	1.41	95.35
10	0.1873	1.05	96.40
11	0.1774	0.99	97.39
12	0.1469	0.82	98.21
13	0.1066	0.60	98.81
14	0.0779	0.44	99.25
15	0.0601	0.34	99.59
16	0.0395	0.22	99.81
17	0.0245	0.14	99.95
18	0.0039	0.02	99.97

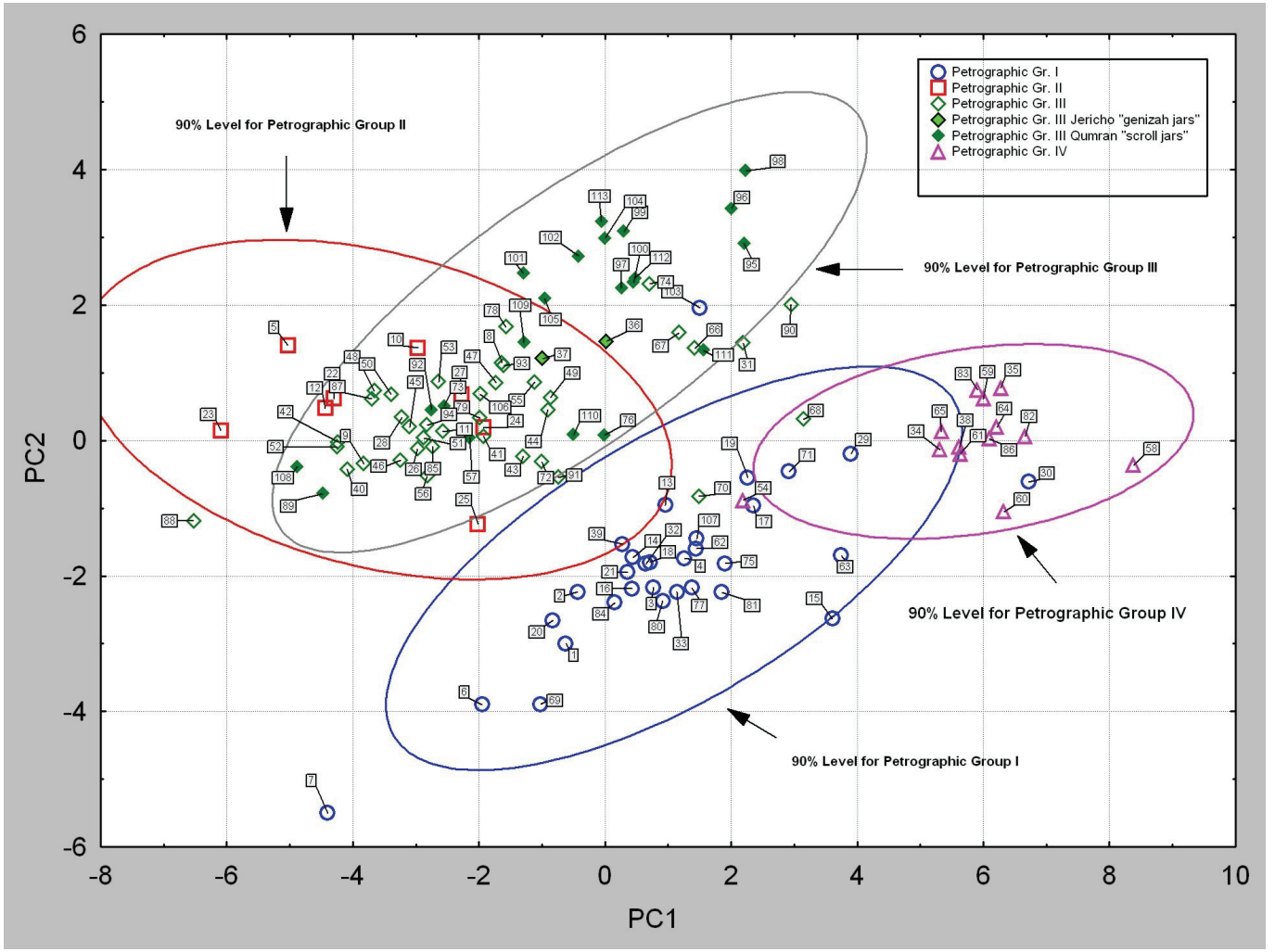

Fig. 46. Petrographic groups of the ceramics from Qumran and Jericho in the PC1-PC2 co-ordinate system. Note the separateness of the 'scroll jars' from the other wares made of fine clay tempered with quartz-carbonate sand.

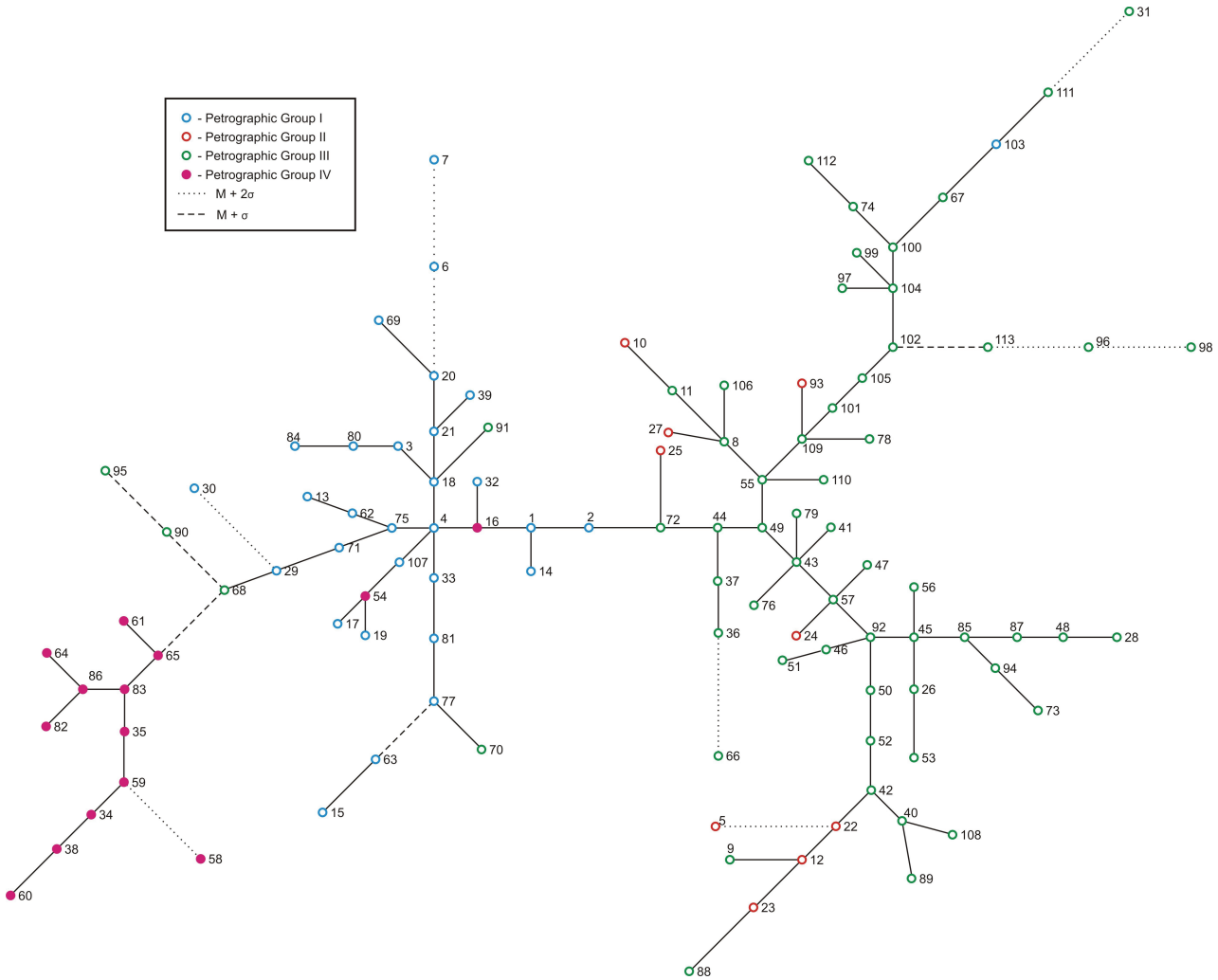

Fig. 47. Spanning tree of the data set presenting the greatest similarity (closeness) between the ceramic specimens from Jericho and Qumran.

As expected, the relations among the individual petrographic groups do not change, and this is also corroborated by the structure of the dendrite plotted (Table 23, Fig 47).

Table 23. Values of the shortest Euclidean distances between the successively closest points representing samples of the Qumran ceramics in the 18-dimensional space of the elements analysed. Significant differences are marked with an asterisk.

Pairs	Distance	Pairs (c.t.)	Distance
1 - 2	1.96	100 - 67	2.49
2 - 72	2.49	67 - 103	2.64
72 - 25	2.69	103 - 111	2.57
72 - 44	1.89	111 - 31	**4.18****
44 - 37	1.76	100 - 74	1.90
37 - 36	1.70	74 - 112	2.19
36 - 66	4.47	102 - 113	**3.41***
44 - 49	1.44	113 - 96	**3.65****
49 - 43	1.60	96 - 98	**3.71****
43 - 41	1.61	55 - 110	2.08
43 - 57	1.76	1 - 16	1.84
57 - 24	1.72	16 - 4	1.41
57 - 47	1.59	4 - 18	1.48
57 - 92	1.77	18 - 3	1.68
92 - 45	1.44	3 - 80	1.45
45 - 26	1.73	80 - 84	1.99
26 - 53	2.37	18 - 21	1.66
45 - 56	1.64	21 - 20	1.87
45 - 85	1.68	20 - 6	**3.96***
85 - 87	1.75	6 - 7	**3.87***
87 - 48	1.51	20 - 69	2.77
48 - 28	1.80	21 - 39	1.71
85 - 94	1.42	18 - 91	2.71
94 - 73	2.05	4 - 33	1.65
92 - 46	1.50	33 - 81	2.06
46 - 51	1.39	81 - 77	2.15
92 - 50	1.77	77 - 63	2.92*
50 - 52	1.67	63 - 15	2.63
52 - 42	1.62	77 - 70	2.36
42 - 22	1.68	4 - 75	1.29
22 - 5	**4.40****	75 - 62	1.35
22 - 12	1.56	62 - 13	1.58
12 - 9	2.53	75 - 71	1.90
12 - 23	2.36	71 - 29	2.31
23 - 88	3.24	29 - 30	**4.26****
42 - 40	1.39	29 - 68	1.87
40 - 89	2.02	68 - 65	**3.34***
40 - 108	1.74	65 - 61	1.60

Pairs	Distance	Pairs (c.t.)	Distance
43 - 76	2.07	65 - 83	1.57
43 - 79	1.60	83 - 35	1.35
49 - 55	1.57	35 - 59	1.66
55 - 8	1.79	59 - 34	1.49
8 - 11	2.55	34 - 38	1.61
11 - 10	2.33	38 - 60	2.26
8 - 27	1.80	59 - 58	3.93
8 - 106	1.91	83 - 86	1.33
55 - 109	1.93	86 - 64	1.72
109 - 78	2.34	86 - 82	1.76
109 - 93	1.88	68 - 90	**2.92***
109 - 101	1.41	90 - 95	**3.11***
101 - 105	1.36	4 - 107	1.60
105 - 102	1.40	107 - 54	1.56
102 - 104	2.00	54 - 17	1.24
104 - 97	1.69	54 - 19	1.27
104 - 99	1.69	16 - 14	1.40
104 - 100	1.29	16 - 32	1.48
MEAN (M) = 2,06 STD. DEV (σ) = 0,75 * M + σ = 2,81 ** M + 2σ = 3,57			

Assuming a distance equal to M + 2σ to be the criterion of the division of this set, only samples 5, 6, 7, 30, 31, 58, 66, 96 and 98 are different and can be regarded as outliers (Table 23).

As in the earlier calculations, the group of vessels assigned to Petrographic Group IV with features of a terra rossa soil is the most outstanding one. Clearly distinct are also vessels of group I made of foraminiferous clay. In turn, the most similar are groups II and III, made of pure clay tempered with quartz-calcareous or pure calcareous sand.

4.5. Genesis of the chemical variability of the Qumran and Jericho ceramics

Fe, Th, Hf and Cr, as well as Cs, Sc, Rb and Ca are the chief source of differences among the vessels under study, as shown by the determination coefficients R^2 obtained in PCA analysis (Table 24). These are the same elements that determined the principal components calculated in the analyses of the ceramics from Jericho and then from Qumran (cf. Tables 14, 20). The mean

levels of the elements in the particular petrographic groups are listed in Table 25.

Table 24. Comparison of the Qumran and Jericho ceramics. Determination coefficient R^2 x 100% for the first three principal components PC1, PC2 and PC3.

Element	PC1	PC2	PC3
As	1.8	9.5	42.5
Ca	29.3	7.5	27.8
Co	48.5	10.8	4.2
Cr	59.7	3.3	6.8
Cs	3.1	71.3	0.8
Fe	82.0	5.9	1.4
Hf	64.6	8.4	15.7
Rb	1.3	54.8	0.9
Sc	13.1	66.3	3.4
Th	75.9	7.7	0.8
U	0.1	24.4	11.0
La	92.9	0.5	0.4
Ce	88.9	0.4	0.8
Nd	78.2	1.6	0.7
Sm	90.0	0.0	2.6
Eu	85.6	0.2	0.0
Yb	91.3	1.4	0.2
Lu	92.0	1.0	0.3

One can readily note the separateness of Petrographic Group IV, which involves a high content of iron and an insubstantial proportion of calcium (Fig. 48). Let us remember that the fabric of those vessels is characterised by a great amount of very well sorted silt, mostly quartzitic, and by a dark-red colour. Both these features can be indicative of terra rossa[2] as the raw material (cf. Fig. 41).

Iron is a major element in the soil. It is present mostly as Fe^{+2} in ferromagnesian silicates (olivine, pyroxene, amphibole and biotite) and as Fe^{+3} in iron oxides and hydroxides produced by weathering. Precipitation of Fe^{+3} hydrous oxides often leads to co-precipitation of such metals as Mn, Ti, V,

[2] Terra rossa develops when fairly heavy precipitation enables moderately strong hydrolytic weathering of silicate minerals (which give rise to clay minerals) and the dissolution of calcareous rocks (which leads to the leaching of clay minerals). Iron compounds released from the weathered minerals are precipitated as ferrihydrites or hematite (Yaalon 1997: 160). The deposit developing in this way is further influenced by an addition of the eolian dust from the Saharan-Arabian deserts (Durn et al. 1999; Frumkin, Mordechai 2004).

Table 25. Average levels of selected elements from the Jericho and Qumran pottery assigned to the four petrographic groups.

Element	Petrographic Group										
	Jr I		Qm I		**Jr+Qm I**		Jr II		Qm II	**Jr+Qm II**	
	n=20		n=11		**n=31**		n=8		n=1	**n=9**	
	M	σ	M	σ	**M**	σ	M	σ		**M**	σ
Ca (wt %)	10.85	2.13	9.64	1.75	**10.41**	2.06	9.38	2.13	16.00	**10.11**	2.97
Fe (wt %)	4.41	0.95	4.54	0.43	**4.46**	0.80	3.83	0.45	4.37	**3.89**	0.46
As (ppm)	11.89	8.59	8.30	1.87	**10.61**	7.14	10.24	5.39	8.50	**10.04**	5.07
Co (ppm)	15.40	4.30	15.64	1.91	**15.48**	3.60	15.38	3.42	19.00	**15.78**	3.42
Cr (ppm)	166.90	28.45	174.27	23.12	**169.51**	26.53	110.00	22.37	108.00	**109.77**	20.93
Cs (ppm)	<1.80	1.32	<2.00	2.19	**<1.87**	1.65	4.38	1.51	4.00	**4.33**	1.41
Hf (ppm)	<6.70	1.03	6.73	1.56	**6.71**	1.22	2.88	0.99	4.00	**2.78**	1.56
Mo (ppm)	<7.90	6.26	<11.40	5.90	**<9.00**	6.46	6.63	4.50	7.00	**6.44**	4.59
Rb (ppm)	49.00	18.56	<48.54	45.44	**<48.83**	23.70	66.63	24.53	76.00	**67.67**	23.16
Sc (ppm)	13.81	2.63	14.41	2.18	**14.02**	2.46	15.73	1.36	17.90	**15.97**	1.47
Th (ppm)	7.56	1.30	7.92	0.78	**7.69**	1.15	6.59	0.73	7.40	**6.68**	0.74
U (ppm)	4.28	1.05	3.92	1.03	**4.16**	1.04	3.68	0.96	2.70	**3.57**	0.96
La (ppm)	34.73	5.93	36.21	3.54	**35.25**	5.20	22.16	2.71	25.90	**22.58**	2.83
Ce (ppm)	67.50	10.25	69.82	8.47	**68.32**	9.58	47.00	6.76	60.00	**48.44**	7.67
Nd (ppm)	31.75	7.31	29.73	3.52	**31.03**	6.25	19.38	3.46	24.00	**19.89**	3.58
Sm (ppm)	6.33	1.25	6.93	0.97	**6.54**	1.18	4.46	0.57	5.00	**4.52**	0.56
Eu (ppm)	1.56	0.33	1.60	0.17	**1.57**	0.28	1.11	0.22	1.20	**1.12**	0.21
Yb (ppm)	3.19	0.49	3.30	0.32	**3.22**	0.43	2.13	0.35	2.40	**2.16**	0.34
Lu (ppm)	0.47	0.07	0.50	0.05	**0.48**	0.06	0.32	0.05	0.36	**0.32**	0.05

n = number of samples, M = mean, σ = standard deviation.
* The mean abundance given for Cr ignores the outstanding sample no. 31.

Sc, Cu and Co in the limonitic or hematitic (Fe_2O_3) phases. Hence an elevated level of Fe is usually accompanied by elevated concentrations of the mentioned elements (De Vos, Tarvainen 2006: 163-168). A correlation between Fe and Co can only be found in vessels of group IV (Fig. 49).

In turn, a strong correlation can be found between Fe and Cr (Fig. 50) in Petrographic Groups I, II and III.

Chromium is an element forming several minerals, including chromite $FeCrO_4$; it is also present in amphiboles, micas, pyroxenes and garnets, and its elevated values are indicative of mafic rocks. During weathering the behaviour of Cr^{+3} resembles that of Fe^{+3}, leading to a widespread accumulation in secondary oxides and clays. Cr behaviour depends on the pH, Eh and organic matter (De Vos, Tarvainen 2006:127-131). The strong correlation of those two elements indicates that they have been adsorbed by clay together; moreover, chromium could have substituted for Fe^{+3} also in a later period.

table 25 continued

Element	Petrographic Group											
	Jr III		Qm III		**Jr+Qm III**		Jr IV		Qm IV		**Qm+Jr IV**	
	n=22		n=38		**n=60**		n=3		n=10		**n=13**	
	M	σ	M	σ	**M**	σ	M	σ	M	σ	**M**	σ
Ca (wt %)	<6.68	2.73	6.50	2.82	**6.56**	2.76	1.00	0.00	<2.00	2.49	**1.77**	2.20
Fe (wt %)	3.73	0.37	4.23	0.61	**4.05**	0.58	5.65	0.11	5.67	0.56	**5.66**	0.48
As (ppm)	7.44	3.61	7.65	2.50	**7.57**	2.93	9.13	1.45	9.04	3.22	**9.06**	2.85
Co (ppm)	12.23	2.33	17.50	5.16	**15.57**	5.01	27.67	3.21	25.50	3.81	**26.00**	3.67
Cr (ppm)	117.6*	45.81*	127.32	29.54	**123.88***	25.22	174.33	7.51	170.10	13.98	**171.08**	12.63
Cs (ppm)	<4.70	1.12	5.68	2.22	**5.33**	1.94	2.67	0.58	2.80	0.79	**2.77**	0.73
Hf (ppm)	4.68	0.84	4.58	1.08	**4.61**	0.99	15.00	1.00	14.00	2.54	**14.23**	2.28
Mo (ppm)	<9.40	4.62	<8.20	5.93	**8.58**	5.99	<9.70	6.11	<10.80	4.83	**10.38**	5.24
Rb (ppm)	74.50	20.22	<82.60	31.33	**80.01**	26.37	59.33	21.94	<49.40	23.67	**54.00**	15.97
Sc (ppm)	15.65	1.38	17.32	2.72	**16.71**	2.44	16.43	0.15	16.88	1.15	**16.78**	1.10
Th (ppm)	6.76	1.59	7.80	1.76	**7.42**	1.76	11.57	1.04	10.82	1.40	**10.99**	1.26
U (ppm)	3.19	0.48	3.18	1.32	**3.18**	1.09	2.87	0.25	2.94	0.39	**2.92**	0.40
La (ppm)	24.76	4.62	29.44	5.37	**27.73**	5.55	44.03	0.50	46.50	4.73	**45.93**	4.57
Ce (ppm)	52.82	10.98	58.82	10.93	**56.62**	11.24	102.00	4.22	100.20	9.46	**100.61**	8.74
Nd (ppm)	22.95	3.09	26.08	6.43	**24.93**	5.62	37.00	7.21	44.20	4.52	**42.53**	5.14
Sm (ppm)	4.87	0.51	5.62	1.10	**5.35**	0.99	7.63	2.65	8.19	1.16	**8.06**	1.04
Eu (ppm)	1.17	0.19	1.33	0.24	**1.27**	0.24	1.97	0.31	2.15	0.22	**2.10**	0.24
Yb (ppm)	2.47	0.29	2.68	0.45	**2.60**	0.41	4.27	0.31	4.36	0.53	**4.33**	0.46
Lu (ppm)	0.38	0.04	0.41	0.07	**0.40**	0.06	0.65	0.06	0.66	0.08	**0.66**	0.07

Another feature that differentiates the Dead Sea pottery under study in a significant way is the proportion of its scandium relative to Fe, Th and the rare earths.

Scandium displays a dispersed lithophile behaviour and often substitutes for Al and Fe^{+3} in rocks. This element is generally associated with siderophile elements like Fe, Cr and Co, although its co-associations may vary depending on the surficial environment. During weathering the Th/Sc proportion remains fairly constant, reflecting the chemistry of the parent rock (Condie et al. 1995). Most of the Sc in the lithosphere is held in ferromagnesian minerals, especially Fe-rich pyroxenes. Higher Sc levels in sedimentary rocks are observed in argillaceous rocks, especially in laterites. It is worth noting that phosphatic shales tend to be enriched with Sc, probably because of the low solubility of $ScPO_4$ (De Vos, Tarvainen 2006: 327).

The different proportions of Sc relative to Fe, Th and REEs differentiate vessels of Petrographic Groups II and III from those of groups I and IV (Figs 51, 52, 53): in the former the Sc content with respect to Fe, Th and REEs is high, while in the latter it is low.

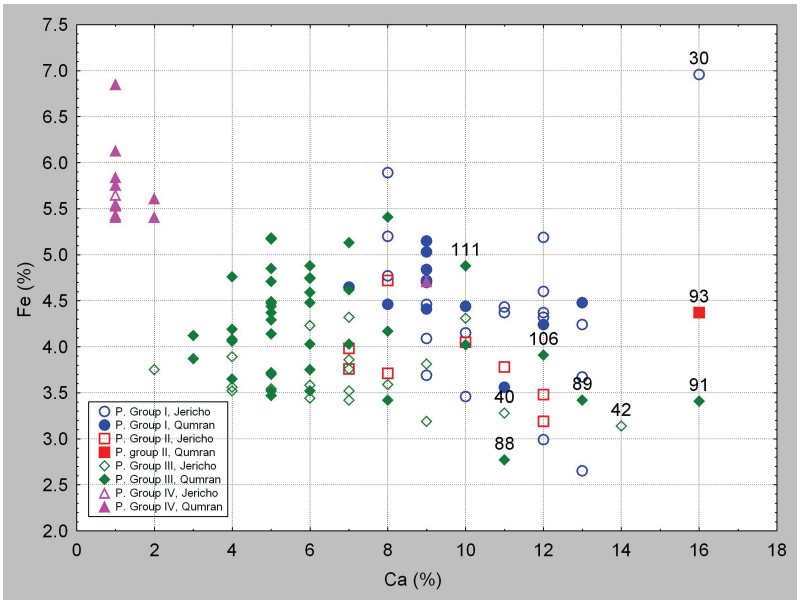

Fig. 48. Bivariate Fe/Ca plot of the Qumran and Jericho pottery. Clearly distinct are pots made of a raw material resembling terra rossa. The Ca content in vessels of Petrographic Groups I and II is slightly higher than in most of those of Petrographic Group III. The correlation of Ca with Fe is weak and negative.

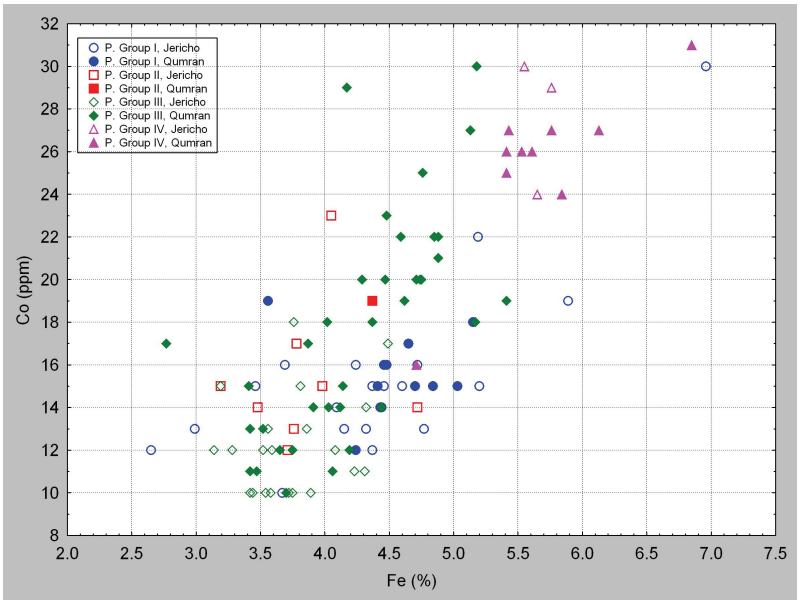

Fig. 49. Bivariate Co/Fe plot. Note the elevated Co values in Petrographic Group IV and no correlation between the two elements in the remaining petrographic groups.

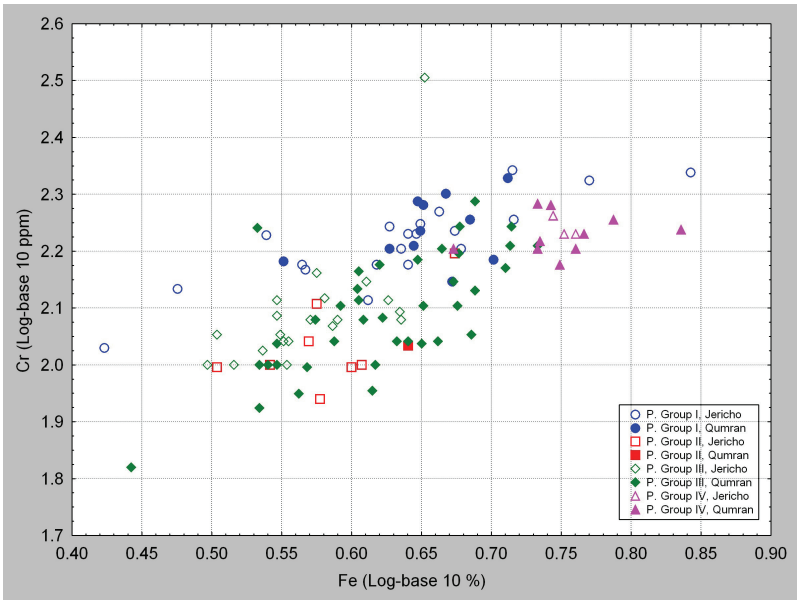

Fig. 50. Bivariate Cr/Fe plot. Notable is the correlation of Fe with Cr in the samples of Petrographic Groups I, II and III, and the outlying position of Petrographic Group IV caused by a disproportionate increase in the iron content.

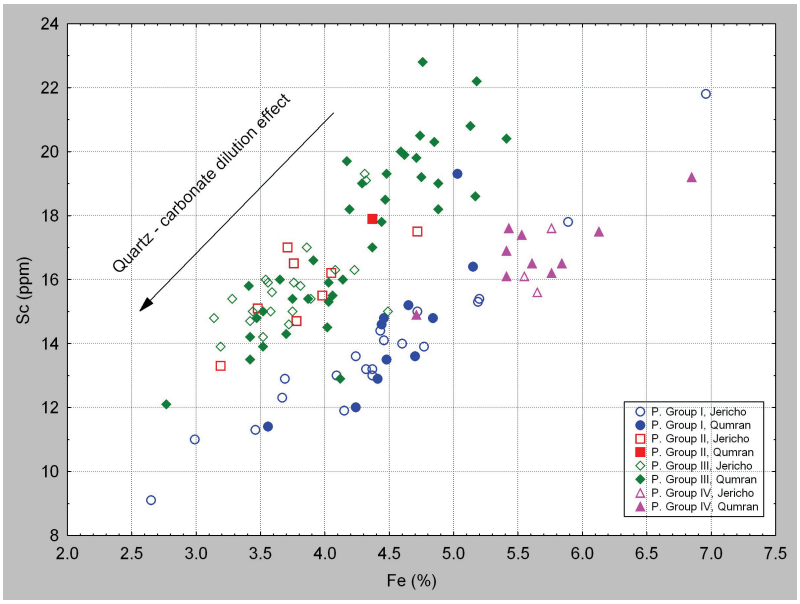

Fig. 51. Bivariate Fe/Sc plot. Notable is the strong correlation between the two elements, while the Fe/Sc proportion differentiates Petrographic Groups I and IV from II and III. In groups II and III the Sc content relative to that of Fe is higher than in groups I and IV.

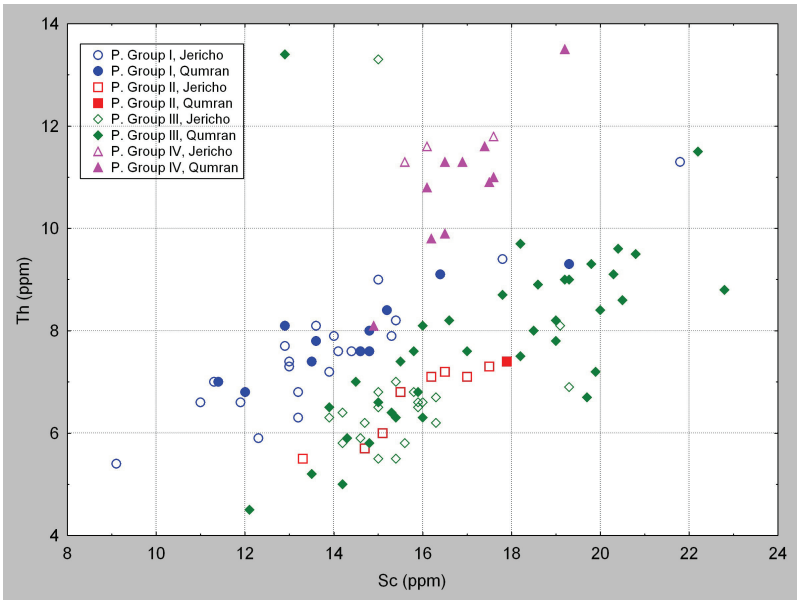

Fig. 52. Bivariate Th/Sc plot of the Jericho and Qumran pottery. As in the case of the Fe/Sc and La/Sc rates, the same difference in the proportion can be observed between Petrographic Groups I and IV on the one hand, and II and III on the other.

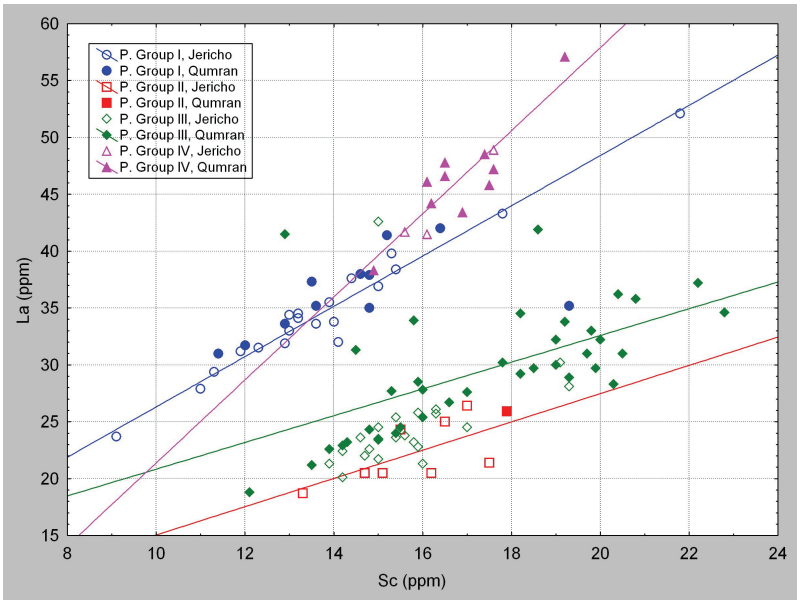

Fig. 53. Bivariate Sc/La plot. Note the strong correlation within Petrographic Group IV and an almost identical correlation in the other groups. Clearly distinct are the different Sc/La proportions in groups I and IV vs. groups II and III.

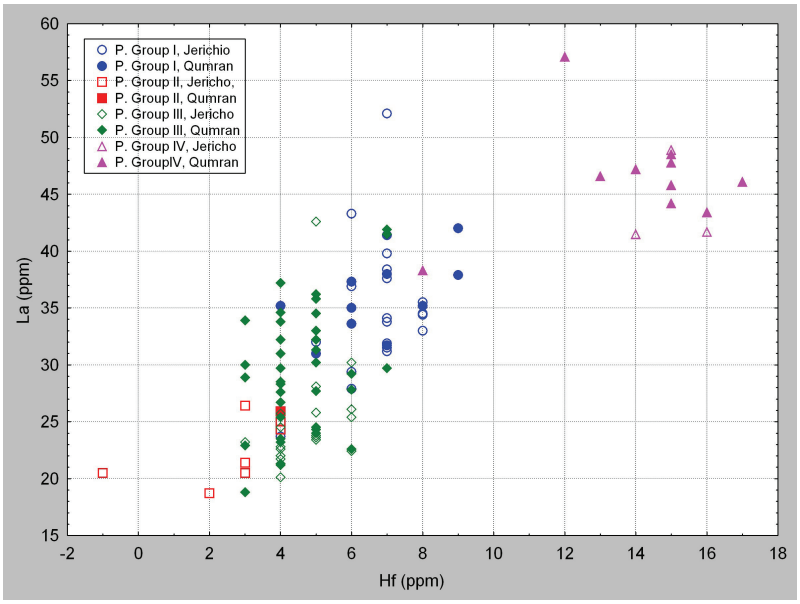

Fig. 54. Bivariate Hf/La plot. Note the proportional increase in hafnium and lanthanum in groups I, II and III, and a jump in the Hf level in group IV.

The correlation of Sc with Th and REEs is positive in all the petrographic groups, being especially strong in group IV (Fig. 53).

Also hafnium is an element whose presence offers an insight into the chemical differences among the Dead Sea ceramics. Hafnium substitutes for zirconium in all its minerals, especially in zircon crystals (Zr, Hf)SiO_4. It belongs to the group of heavy minerals and is extremely resistant to weathering. Hence elevated concentrations of zircon and other heavy minerals are typical of residual deposits produced by advanced weathering processes. Apart from Hf, zircons contain substantial amounts of REEs (except Eu), Y, Nb, Ta and Ti. Hafnium shows a weak correlation with Eu, Th, Ag and Ba (De Vos, Tarvainen 2006: 187-191).

In both the vessels from Jericho and Qumran, the smallest content of Hf, and hence of heavy minerals, can be found in the samples of Petrographic Groups II and III. The ceramics of Petrographic Group I are somewhat richer in this element, while its content jumps in those of group IV (Fig. 54). This group is also characterised by an elevated level of thorium.

The elevated levels of Fe compounds and heavy minerals (as indicated by the Hf content) in the samples of vessels from Petrographic Group IV imply elevated concentrations of elements usually present in them. This holds especially for Cr, which can substitute for Fe and the rare-earth elements present in zircons (Fig. 55).

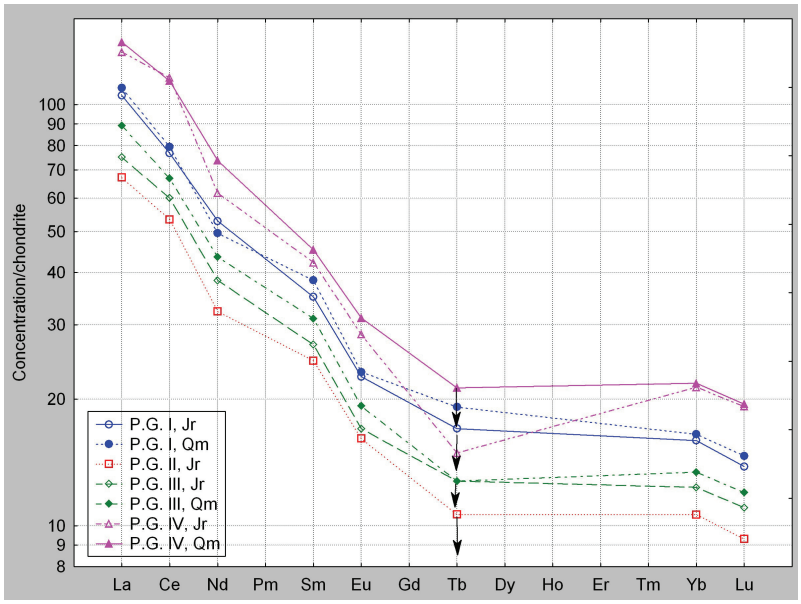

Fig. 55. Concentration of rare-earth elements in the specimens of Jericho and Qumran pottery, normalised to chondritic values (Haskin et al. 1968). Arrows indicate that during the analysis the Tb content in some of the samples proved to be below detection limit.

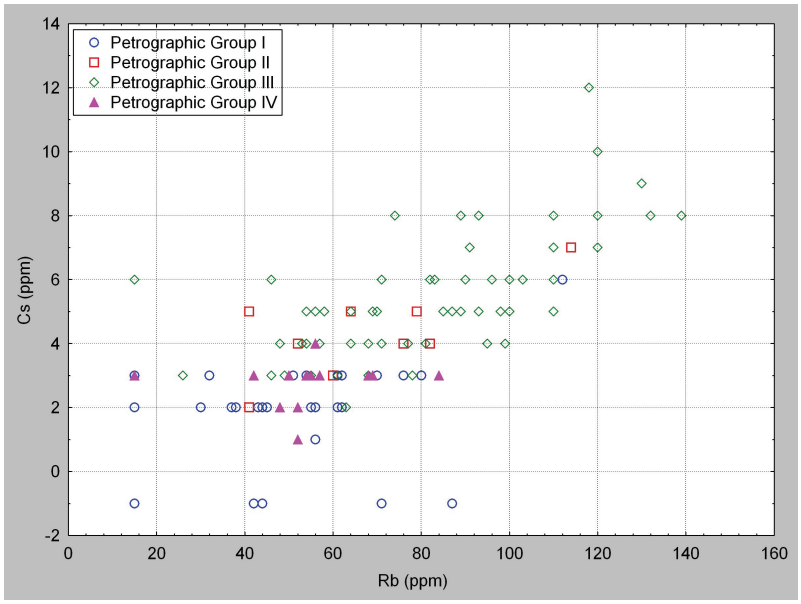

Fig. 56. Bivariate Cs/Rb plot. Note the high content of both elements in the ceramic samples of Petrographic Groups II and III.

It can be stated, therefore, that it is Fe compounds and heavy minerals which determine the distinctness of this group most strongly. They are also a confirmation of the residual nature of the raw material employed – in all probability it was terra rossa.

Also notable are elevated levels of rubidium and caesium in the specimens of Petrographic Groups II and III (Fig. 56). In sedimentary rocks Rb and Cs are present mainly in K-feldspar, muscovite and clay minerals. It is assumed that the two elements map the geochemistry of sediments derived from felsic rocks, granitoids and shales (De Vos, Tarvainen 2006: 133-136, 299).

4.6. Summing up

The three varieties of raw material used to make the vessels discovered in Jericho were also employed in the production of those in Qumran. The fabrics of the vessels differ in petrographic terms, which makes it possible to divide them into four petrographic groups.

The ceramics of Petrographic Group I were made from foraminiferous clay with an elevated amount of quartz-feldspar silt and a variable number of small fragments of limestone. The ceramics of Petrographic Group II were made from rich clay containing pure calcareous sand. Those of Petrographic Group III were also made from rich clay, but tempered with quartz or quartz-carbonate sand, while those of Petrographic Group IV were made of a terra rossa soil.

In terms of the chemical composition, Petrographic Group II is similar to group III, while the remaining two groups, I and IV, differ from each other as well as from groups II and III. This chemical distinctness of the individual groups is determined by:

(1) different proportions of Hf and REEs reflecting different concentrations of heavy minerals in the raw material used;

(2) different Cr and Fe levels reflecting the concentrations of iron compounds;

(3) different proportions of scandium relative to Fe, Th and REEs, probably reflecting differences in the origin of the deposit; and

(4) different Rb and Cs levels reflecting the content and genesis of the clay minerals forming the raw material.

In chemical terms, Petrographic Group IV stands out most distinctly. It is marked by the highest content of iron and hafnium, the latter being an indicator of the presence of heavy minerals (Fig. 57). In turn, the presence of those minerals implies elevated concentrations of the rare-earth elements.

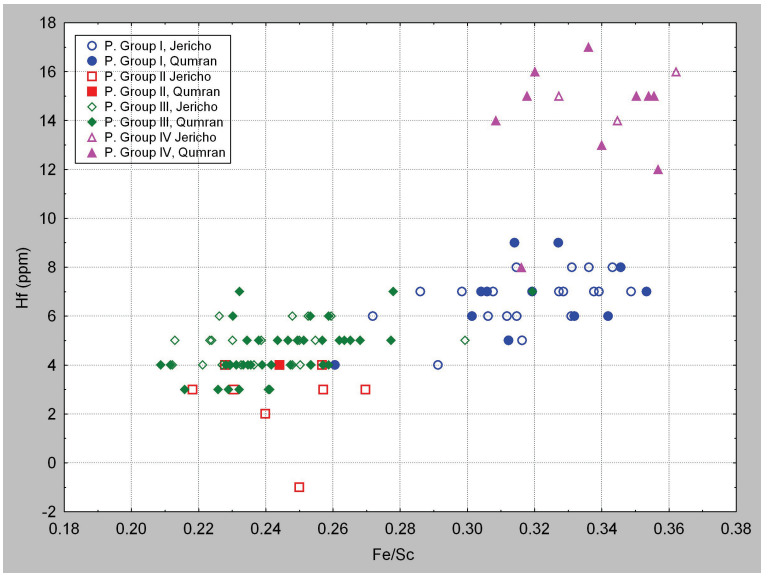

Fig. 57. Bivariate plot of hafnium vs. the Fe/Sc ratio in the Jericho and Qumran ceramics. Note the clear separateness of groups I and II, and the similarity of groups II and III.

Petrographic Group I is characterised by Sc/Fe and Sc/La proportions similar to those in group IV. What makes group I distinct from group IV and most of the samples of the other two groups is an elevated Ca content. It also displays mean Fe and Hf levels lower than group IV.

The highest degree of chemical affinity can be observed between groups II and III. The basic dissimilarity between them is a somewhat different Ca content connected with the different tempers employed. Both groups have a higher proportion of Sc with respect to iron and the lowest levels of Hf and REEs.

Readily apparent is the intra-group diversification of the vessels assigned to Petrographic Group III (the rich clay – quartz sand group). On the diagrams of geochemical correlation, the common wares of this group are partly separated from most of the 'scroll jars', among which we also find the two 'genizah' (?) jars from Jericho (Fig. 46).

The ceramics are indistinguishable by site (Fig. 58), i.e. in both Qumran and Jericho we find the same varieties of raw material used. Hence there are no grounds for distinguishing vessels produced in Jericho from those made in Qumran, as suggested by Gunneweg and Balla (2003). For this reason, any comparison of the chemical composition of vessels of unknown provenance (especially in the absence of petrographic studies) with the so-called 'reference group' local to Jericho or local to Qumran (or Jerusalem, etc.) is a gross misunderstanding!

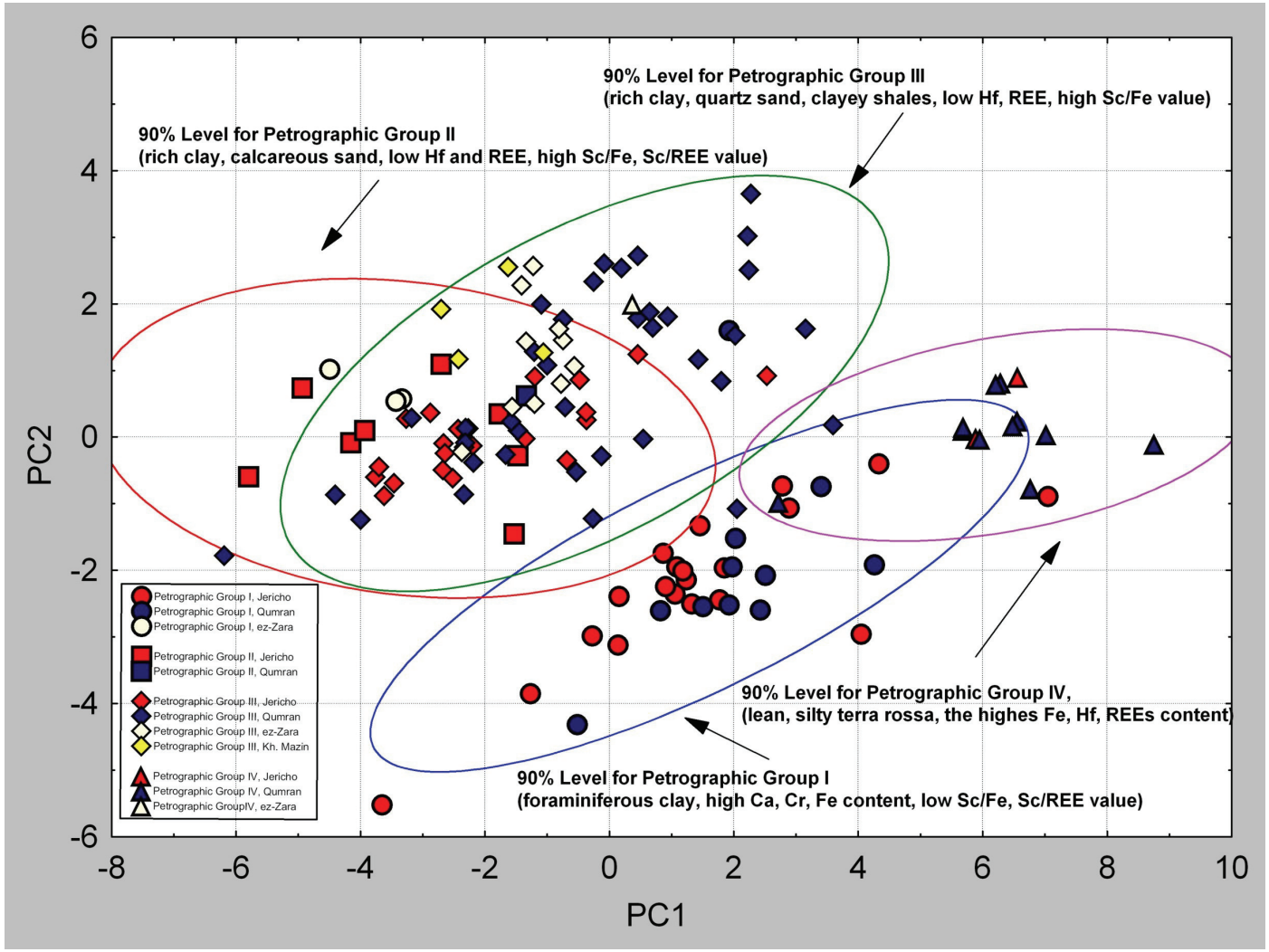

Fig. 58. PCA correlation of the Jericho, Qumran, ez-Zara and Khirbet Mazin pottery by petrographic group assignment and site.

5. CERAMICS FROM QUMRAN AND JERICHO AS COMPARED WITH EZ-ZARA AND KHIRBET MAZIN POTTERY AND CLAYS SAMPLED IN THE FIELD

This chapter discusses the similarities of the Jericho and Qumran pottery to 14 fragments of storage jars from ez-Zara/Callirrhoe[1] and to a few pieces of Roman jars collected by the author in situ at Khirbet Mazin. Clay samples of the Moza Formation, terra rossa soil and deposits of Wadi Qumran (Qum 2001) were also used in the investigations (cf. Tables 3, 26).

5.1. Petrographic investigations

The petrographic features of the Jericho and Qumran ceramics were presented in the previous chapters. The characteristics of the jars from ez-Zara and Khirbet Mazin are presented in Table 27.

5.1.1. The jars from ez-Zara

13 out of the 14 investigated samples of jars from ez-Zara were made of rich clay (<2% of quartz silt) containing variable amounts of the tempering admixture. The petrography of this jars is similar to Petrographic Group III.

Coarse inclusions are composed mainly of well-rounded grains of monocrystalline, subrounded quartz and micrite limestones. Some quartzes have rings of calcite, there are also sparse grains of fine sandstone built of monocrystalline quartz embedded in calcium carbonate (Fig. 59).

Micromass is almost totally devoid of quartz silt. Depending on the conditions of firing, it has assumed a light red or grey colour; under crossed polars, upon rotation, it reveals partially preserved shale fragments.

What distinguishes the three jars 122, 123 and 124 is the presence of very numerous, evenly distributed fine foraminifer shells (Fig. 60). Owing to the

[1] Samples of the ez-Zara ceramics were provided by Christa Clamer (École Biblique).

high temperature of firing, the shells embedded in samples 122 and 123 have undergone advanced disintegration making their micropaleontological identification impossible.

Table 26. Descriptive information and group assignment of the analysed samples of jars from ez-Zara/Callirrhoe, Khirbet Mazin and clays sampled in the field for comparative purposes.

Lab. no.	Registration no.	Stratigraphic level	Petrographic group
ez-Zara			
114	Ez401/217	Roman	3
115	Ez128/815	Roman	3
116	Ez243/68z	Roman	3
117	Ez339-a/498	Roman	3
118	Ez342/499	not stratified	3
119	Ez 334/454	Roman	3
120	Ez401b/218	Roman	3
121	Ez401-b/217	Roman	3
122	Ez401-c/224	Roman	3 (?)
123	Ez213/635	erosion level	3 (?)
124	Ez302-b/58	Roman	3 (?)
125	Ez401-a/219	Roman	3
126	Ez300/17	?	4
127	Ez338/486	Roman	3
Kh. Mazin			
128	M1	unstratified	3
129	M2	unstratified	3
130	M3	unstratified	3
131	M5	unstratified	3
clays			
132	H1A	Moza Fm	
133	H1A/1	Moza Fm	
134	HFPO	Moza Fm	
135	HFPO/2	Moza Fm	
136	HFP1	Moza Fm	
137	H2A/1	terra rosa	
138	H2A/2	terra rosa	
139	H2C/1	Moza Fm	
140	H2D	Moza Fm	
141	H2D/1	Moza Fm	
142	H2F	Moza Fm	
143	H2F/1	Moza Fm	
144	H2J/1	Moza Fm	
145	HEB/2001	Moza Fm	
146	HEB/2001/A	Moza Fm	
147	HEB/2001/B	Moza Fm	
148	P4/2/2002	Moza Fm	
149	P4/2/2002/A	Moza Fm	
150	QUM2001	Wadi Qumran	
151	QUM2001/A	Wadi Qumran	

Table 27. Petrographic features of the ez-Zara and Khirbet Mazin ceramics.

Lab. no.	Registration no.	Munsell colour		Sandy admixture			Quartz silt frequency (%)	Fine dolomites*	Foraminifers**	White stains	Rhomb-shape grits
				Frequency (%)	Quartz (%)	Carbonates (%)					
114	Ez401/217	10R 5/8	red	10-15	30	70	<1	1!	?	1	1
115	Ez128/815	10R 5/8 – 10R 4/1	red/ dark reddish gray	20-25	50	50	<2	0	0	0	0
116	Ez243/68z	2,5YR 6/8 – 2,5YR 6/2	light red / pale red	10-15	60	40	<2	1	0	1	0
117	Ez339-a/498	10R 5/8 – 10R 5/1	red/ dark reddish gray	10-15	60	40	<2	0	0	1	0
118	Ez342/499	10R 5/8 – 10R 5/2	red/ weak red	10-15	60	40	<2	1	0	1	0
119	Ez 334/454	2,5YR 5/8 – 2,5YR4/1 core	red/ dark reddish gray	<10	80	20	<2	1	0	0	0
120	Ez401b/218	10R 5/8 – 10R 5/1	red/reddish gray	<5	50	50	<1	0	0	1	0
121	Ez401-b/217	10R 5/8 – 10R 5/2	red/reddish gray	<5	50	50	<2	0	0	1	0
122	Ez401-c/224	7,5YR 5/2	brown	<10	80	20	<1	?	1!	1!	0
123	Ez213/635	10R 6/8 – 10R 5/1	light red / reddish gray	<5	80	20	<1	?	1!	1	0
124	Ez302-b/58	10R6/8 – 5YR 5/1	light red/gray	<2	100	0	<1	0	1!	0	0
125	Ez401-a/219	5YR 5/6 – 10R 5/1	yellowish red / reddish gray	10-15	60	40	<2	1	0	1	0
126	Ez300/17	10R 5/8 – 10R 5/1	red / reddish gray	<5	0	100	25-30	0	0	1	0
127	Ez338/486	10R 6/8 – - 10R 5/1	light red / reddish gray	10	80	20	<2	1	0	1	0
128	M1	2,5YR 5/8	red	25	100	0	<1	1	0	1	0
129	M2	2,5YR 7/6 – 2,5YR 5/2	light red / weak red	20	100	0	<1	0	0	0	0
130	M3	5YR 8/4 – 5YR 6/4 : 5/1	pink, light reddish brown - gray	0	0	0	0	0	1	1	0
000	M4	5YR 6/6	reddish yellow	10	0	100	<1	0	0	0	0
131	M5	2,5YR 5/8 – 2,5YR 4/1	red/ dark reddish gray	10	50	50	<1	0	0	1	0
								0 - absent 1 - present	0 - absent 1 - present 1! - commmon	0 - absent 1 - present 1! - commmon	0 - absent 1 - present

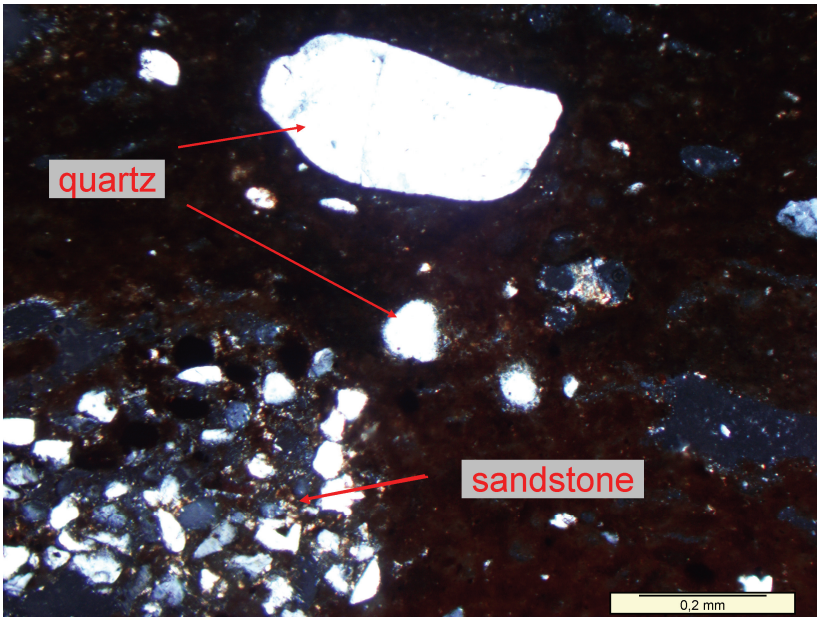

Fig. 59. Petrographic Group III. Ez-Zara Roman jar Ez339-a/498 (specimen 117). Polarising microscope, crossed nicols.

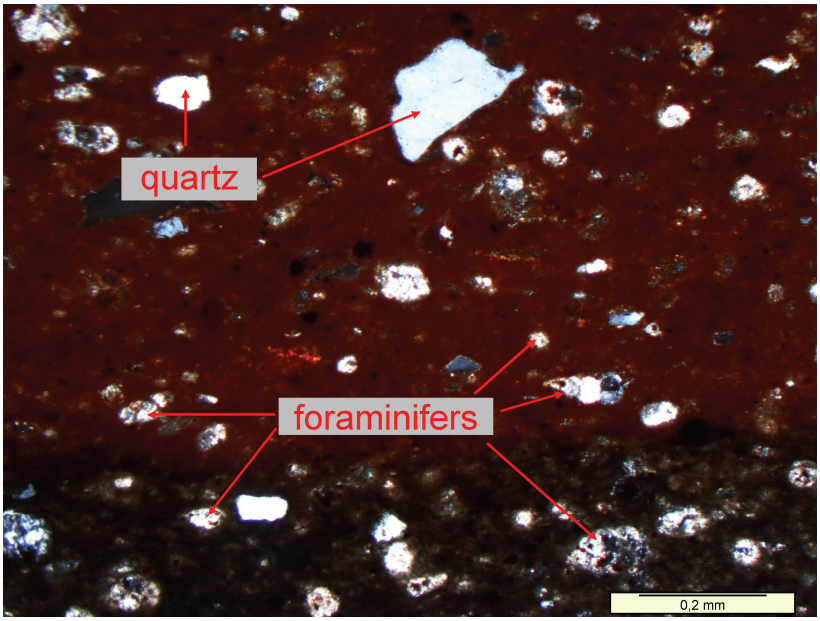

Fig. 60. Petrographic Group III. Ez-Zara Roman jar Ez302-b/58 (specimen 124). Note the presence of numerous foraminifers (crossed nicols).

The foraminifers from sample 124, fired at a slightly lower temperature, are representatives of the taxa *Heterohelix aff. reussi* (Cushman) and *Hedbergella* sp., which indicates that it is made of an Upper Cretaceous (Middle Turonian-Maastrichtian) raw material.

Standing out among the rest is sample 126 (Fig. 61) containing 25-30% angular quartz silt. Petrographically, it is similar to the silty terra rossa soil (Petrographic Group IV).

In sum, the raw material of all the examined vessels from ez-Zara is highly similar in petrographic terms to that of which the pottery from Qumran and Jericho is made.

5.1.2. The Khirbet Mazin specimens

The analysis embraced a mere 5 sherds (M1-M5). Macroscopically, the samples differ in colour, their core is usually dark grey or dark brown. Two samples, M1 and M2 (Fig. 62), are tempered with quartz sand, one, M5, with quartz-calcareous sand (Fig. 63), while sample M3 is devoid of any admixture. Petrographically, this is the same raw material of which the vessels from ez-Zara are made.

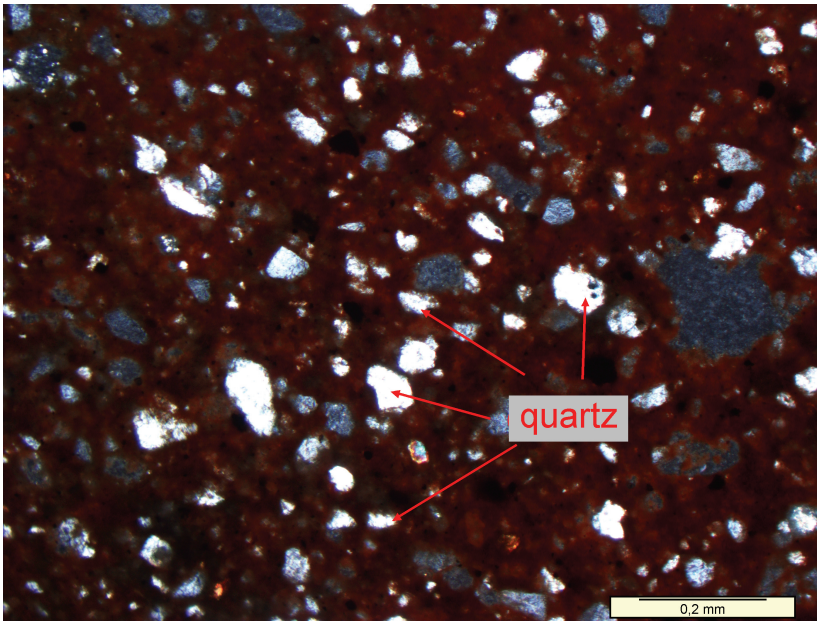

Fig. 61. Petrographic Group IV. Ez-Zara jar Ez300/17 (without stratigraphy), specimen 126. Note the high content of quartz silt (crossed nicols).

Table 28. Concentrations of 35 elements in the ez-Zara and Khirbet Mazin pottery and the potential raw material sampled in the field: results of the INAA analyses.

Lab. No.	Registration no.	Element															
		Ca	Fe	Na	Sn	Sr	Au	Ag	As	Ba	Br	Co	Cr	Cs	Hf	Hg	Ir
		wt %	wt %	wt %	wt %	wt %	ppb	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppb
114	Ez4<b/217	3	4.02	0.29	<0.01	<0.05	3	<5	4.3	<50	6.4	19	94	10	4	<1	<5
115	Ez128/815	4	3.57	0.45	<0.01	<0.05	<2	<5	4.1	270	81.4	12	99	4	5	<1	<5
116	Ez243/68z	10	3.63	0.37	<0.01	<0.05	<2	<5	4.8	470	19.4	12	93	5	5	<1	<5
117	Ez339<a/498	6	3.98	0.52	<0.01	<0.05	<2	<5	5.1	<50	57.7	12	101	5	4	<1	<5
118	Ez342/499	6	3.98	0.49	<0.01	<0.05	3	<5	5.1	140	30.1	17	98	5	4	<1	<5
119	Ez334/454	5	3.81	0.44	<0.01	<0.05	<2	<5	4.5	320	25.8	12	100	5	5	<1	<5
120	Ez401<b/218	8	3.87	0.26	<0.02	<0.05	<2	<5	4.9	<50	11.0	13	98	6	4	<1	<5
121	Ez401<c/217	4	3.99	0.29	<0.01	<0.05	<2	<5	3.9	290	8.0	19	91	9	4	<1	<5
122	Ez401<c/224	8	3.94	0.38	<0.01	0.07	10	<5	5.0	360	5.5	19	115	9	4	<1	<5
123	Ez213/635	11	4.11	0.55	<0.01	0.10	<2	<5	8.9	690	146.0	20	120	6	4	<1	<5
124	Ez302<b/58	13	4.44	0.32	<0.01	0.05	<2	<5	9.5	<50	34.0	22	126	6	4	<1	<5
125	Ez401<a/219	6	4.29	0.29	<0.01	<0.05	<2	<5	3.7	290	4.8	12	100	7	4	<1	<5
126	Ez300/17	3	4.34	0.32	<0.01	<0.05	<2	<5	6.0	260	24.3	17	119	7	7	<1	<5
127	Ez338/486	10	3.68	0.27	<0.01	<0.05	<2	<5	3.3	370	7.0	12	110	4	5	<1	<5
128	M1	3	3.63	0.30	<0.01	<0.05	<2	<5	7.9	<50	15.4	120	81	5	<1	<1	<5
129	M2	3	3.74	0.14	<0.01	<0.05	<2	<5	10.5	<50	18.5	150	93	4	2	<1	<5
130	M3	6	4.02	0.22	<0.01	<0.05	<2	<5	9.7	290	13.7	100	113	7	2	<1	<5
xx	M4	6	5.23	0.60	<0.01	<0.05	<2	<5	12.4	240	13.3	87	1100	3	2	<1	<5
131	M5	4	3.88	0.29	<0.01	<0.05	<2	<5	10.6	340	17.1	83	99	5	3	<1	<5
132	H1A	13	3.06	0.05	<0.01	<0.05	<2	<5	8.3	120	4.8	11	97	6	4	<1	<5
133	H1A/1	14	3.29	0.05	<0.01	<0.05	2	<5	11.1	200	3.0	12	94	5	4	<1	<5
134	HFPO	3	4.50	0.07	<0.01	<0.05	<2	<5	9.1	120	2.7	11	110	7	3	<1	<5
135	HFPO/2	2	4.45	0.08	<0.01	<0.05	<2	<5	8.5	210	<0.5	11	120	8	4	<1	<5
136	HFP1	8	2.95	0.95	<0.01	<0.05	<2	<5	8.7	<50	7.6	75	87	3	5	<1	<5
137	H2A/1	3	5.52	0.38	<0.01	<0.05	<2	<5	7.4	400	5.5	32	140	3	11	<1	<5
138	H2A/2	2	5.46	0.38	<0.01	<0.05	<2	<5	9.2	420	5.1	32	140	3	11	<1	<5
139	H2C/1	11	4.40	0.06	<0.01	<0.05	<2	<5	15.1	<50	3.0	18	86	4	2	<1	<5
140	H2D	5	4.72	0.09	<0.01	<0.05	<2	<5	12.8	430	2.9	13	120	9	5	<1	<5
141	H2D/1	4	4.62	0.08	<0.01	<0.05	<2	<5	11.7	370	1.9	14	110	8	4	<1	<5
142	H2F	1	5.72	0.06	<0.01	<0.05	5	<5	30.3	<50	2.8	14	140	9	5	<1	<5
143	H2F/1	1	5.74	0.06	<0.01	<0.05	<2	<5	31.6	<50	<0.5	15	130	9	5	<1	<5
144	H2J/1	<1	6.15	0.08	<0.01	<0.05	<2	<5	38.6	260	2.3	20	151	7	5	<1	<5
145	HEB/2001	13	3.66	0.06	<0.01	<0.05	<2	<5	4.4	130	1.9	9	104	6	3	<1	<5
146	HEB/2001/A	13	3.40	0.05	<0.01	<0.05	4	<5	7.3	<50	2.8	9	100	5	2	<1	<5
147	HEB/2001/B	11	3.63	0.05	<0.01	<0.05	<2	<5	6.9	<50	2.0	9	111	7	3	<1	<5
148	P4/2/2002	19	2.74	0.03	<0.01	<0.05	3	<5	5.7	<50	2.0	10	62	4	3	<1	<5
149	P4/2/2002/A	22	2.77	0.03	<0.01	<0.05	<2	<5	4.9	<50	2.5	11	67	4	3	<1	<5
150	QUM2001	31	2.99	0.14	<0.01	0.11	<2	<5	14.7	340	14.7	14	255	2	2	<1	<5
151	QUM2001/A	28	2.92	0.15	<0.01	<0.05	<2	<5	15.1	390	15.1	13	272	2	3	<1	<5
xx	QUM96/1*	20	2.13	0.55	<0.01	<0.05	7	<5	10	270	13.0	10	200	1	2	<1	<5
xx	QUM96/2*	21	2.18	0.10	<0.01	0.06	<2	<5	9.7	210	9.2	10	210	2	2	<1	<5
xx	QUM97/1*	27	3.00	0.20	<0.01	0.11	<2	<5	14.3	300	18.0	12	252	3	3	<1	<5
xx	QUM97/2*	26	2.90	0.20	<0.01	0.09	<2	<5	15.4	330	17.0	13	262	3	3	<1	<5
xx	QUM/98*	26	3.00	0.20	<0.01	0.07	<2	<5	15.4	400	20.4	14	249	2	3	<1	<5

table 28 continued

Lab. No.	Element																		
	Mo	Ni	Rb	Sb	Sc	Se	Ta	Th	U	W	Zn	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
114	2	<56	119	0.5	17.9	<3	1.4	8.0	2.9	<1	61	26.0	53	21	5.7	1.2	0.8	2.6	0.40
115	3	<50	67	0.4	15.7	<3	<0.5	6.5	2.2	<1	61	24.1	56	24	4.9	1.3	0.8	2.6	0.40
116	4	<64	70	<0.1	15.1	<3	0.9	7.6	1.9	<1	82	27.0	57	28	6.2	1.2	<0.5	2.5	0.38
117	6	<55	94	0.6	17.7	<3	<0.5	8.1	2.3	<1	<50	26.2	53	19	5.7	1.2	1.0	2.7	0.40
118	4	<54	86	0.4	17.7	<3	<0.5	7.6	2.0	4	88	26.7	56	29	5.8	1.3	<0.5	2.6	0.40
119	2	<50	80	0.4	16.7	<3	<0.5	7.0	2.7	3	100	26.0	60	25	5.2	1.6	0.6	2.7	0.41
120	7	<80	72	<0.1	17.3	<3	<0.5	8.3	2.5	<1	163	26.5	61	24	5.6	1.4	<0.5	3.0	0.44
121	<1	<59	110	0.4	18.0	<3	<0.5	7.5	2.9	<1	<50	25.9	52	23	5.8	1.1	<0.5	2.6	0.40
122	4	<59	69	0.4	17.4	<3	<0.5	5.9	4.6	<1	142	19.8	43	18	3.7	0.8	<0.5	1.8	0.27
123	5	<68	75	0.4	17.0	<3	<0.5	7.0	4.5	<1	<50	21.9	41	15	4.3	1.0	<0.5	2.1	0.32
124	12	<64	61	0.7	19.3	<3	<0.5	6.5	5.2	<1	153	21.3	43	17	3.8	0.8	<0.5	2.1	0.33
125	<1	<56	100	0.4	18.5	<3	<0.5	7.8	3.5	<1	79	26.7	52	24	6.3	1.3	<0.5	2.7	0.42
126	4	<62	82	0.5	21.7	<3	<0.5	10.1	4.0	<1	87	29.1	54	21	5.2	1.2	<0.5	3.1	0.46
127	11	<65	62	<0.1	13.9	<3	<0.5	6.1	2.2	6	100	23.4	53	25	4.6	1.5	<0.5	2.1	0.32
128	7	<52	76	0.7	14.5	<3	<0.5	6.4	2.0	1050	130	22.9	61	20	4.4	1.1	<0.5	2.4	0.36
129	6	<52	62	0.4	14.8	<3	0.9	7.3	3.2	1150	100	22.5	47	19	4.5	1.0	<0.5	2.3	0.35
130	7	<52	110	0.5	18.6	<3	<0.5	7.6	2.7	520	120	25.5	59	22	4.8	1.2	0.9	2.2	0.33
xx	5	680	68	0.8	17.7	<3	<0.5	5.8	2.2	218	200	18.8	41	15	3.4	0.8	0.8	1.6	0.25
131	8	<51	70	0.5	16.1	<3	<0.5	6.5	2.6	551	140	26.0	59	22	4.9	1.4	1.0	2.5	0.39
132	4	<50	54	0.4	16.5	<3	0.9	6.4	2.7	<1	<50	24.4	51	26	4.7	1.2	1.0	2.4	0.36
133	<1	<50	72	0.4	17.0	<3	<0.5	6.6	2.3	7	64	26.0	61	30	4.8	1.3	1.0	2.5	0.38
134	13	<56	92	0.4	21.4	<3	<0.5	7.2	1.9	15	110	22.6	52	20	4.7	1.1	<0.5	2.3	0.34
135	2	<53	87	0.5	21.9	<3	<0.5	7.7	2.9	16	79	23.3	55	25	4.8	1.2	<0.5	2.2	0.34
136	2	<50	51	0.3	13.2	<3	<0.5	6.6	2.8	597	75	26.0	55	37	4.5	1.1	1.5	2.4	0.36
137	<1	<52	74	0.8	16.9	<3	<0.5	10.1	2.6	65	120	43.7	97	38	7.4	2.3	1.3	4.4	0.66
138	8	<53	52	0.6	17.0	<3	1.9	10.5	2.7	64	130	44.7	102	40	7.4	2.4	<0.5	4.2	0.62
139	6	<51	79	0.4	14.9	<3	<0.5	5.3	2.7	5	180	24.5	48	21	4.2	1.2	<0.5	2.0	0.31
140	7	<56	110	0.5	20.5	<3	<0.5	7.8	3.0	11	130	24.4	56	27	4.5	1.4	0.8	2.3	0.36
141	5	<52	83	0.6	20.5	<3	<0.5	7.7	3.3	11	97	23.2	50	22	4.3	1.4	0.8	2.2	0.34
142	2	<58	85	0.8	21.1	<3	<0.5	8.8	2.2	14	82	28.1	67	28	6.0	1.6	<0.5	3.1	0.47
143	<1	<55	76	0.8	20.9	<3	1.4	8.2	2.8	15	140	28.6	65	34	5.6	1.7	0.9	2.8	0.42
144	3	240	92	0.6	22.1	<3	<0.5	8.9	2.4	10	110	30.2	70	40	5.6	1.7	<0.5	2.9	0.44
145	3	<55	101	0.5	19.2	<3	<0.5	7.5	2.3	<1	<50	27.0	59	21	5.0	1.5	<0.5	2.5	0.40
146	3	<61	76	0.4	18.6	<3	<0.5	6.7	2.7	<1	<50	26.0	53	23	4.8	1.3	<0.5	2.5	0.48
147	<1	<62	85	<0.1	19.1	<3	<0.5	7.8	1.7	<1	<50	27.0	56	20	4.7	1.3	<0.5	2.5	0.37
148	<1	<47	86	<0.1	11.5	<3	<0.5	5.2	1.8	<1	55	19.3	40	15	3.7	1.1	<0.5	2.0	0.32
149	<1	<48	62	0.2	12.1	<3	<0.5	5.5	2.3	1	<50	20.6	43	19	3.9	0.9	0.6	1.9	0.31
150	24	<55	54	1.6	10.7	3	<0.5	5.4	14.6	<1	314	30.7	55	25	4.9	1.2	<0.5	2.8	0.41
151	21	228	<15	2.0	11.5	<3	1.0	5.6	15.9	<1	300	31.6	53	25	4.8	1.3	0.6	3.2	0.49
xx	11	<29	33	1.3	7.7	<3	<0.5	3.9	10.0	<1	210	21.2	39	17	3.4	0.8	0.6	1.9	0.32
xx	10	110	16	1.2	7.9	<3	<0.5	3.8	12.0	<1	220	21.9	41	18	3.3	0.9	0.6	2.0	0.34
xx	15	134	32	1.4	10.7	<3	1.3	5.0	15.4	<1	286	26.8	45	21	4.4	1.2	0.7	2.5	0.40
xx	15	<33	34	1.9	10.4	<3	<0.5	5.2	16.6	<1	300	28.3	54	26	4.6	1.3	0.6	2.7	0.40
xx	10	<36	40	1.8	10.8	<3	<0.5	5.7	16.9	<1	277	26.3	56	21	4.6	1.5	0.7	2.8	0.40

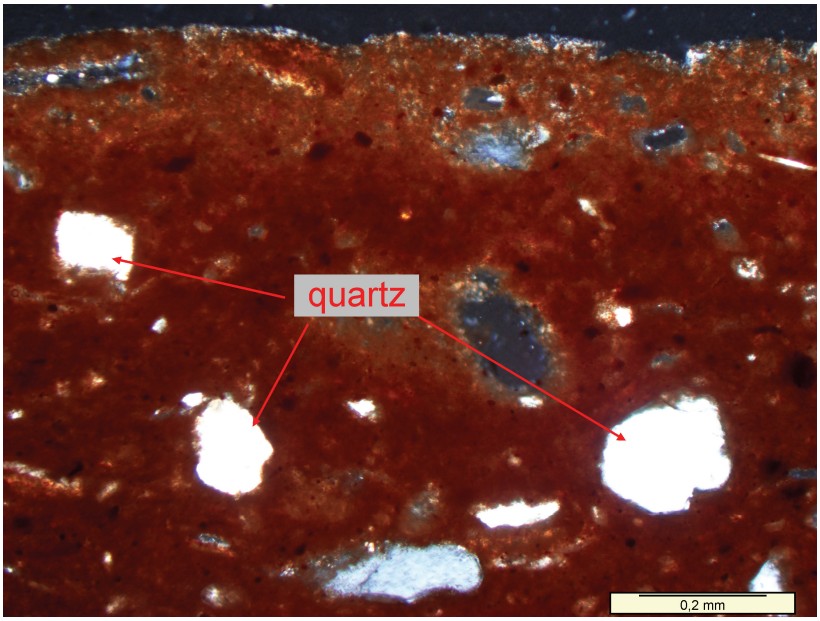

Fig. 62. Petrographic Group III. Khirbet Mazin Roman jar M2 (specimen 129). Polarising microscope, crossed nicols.

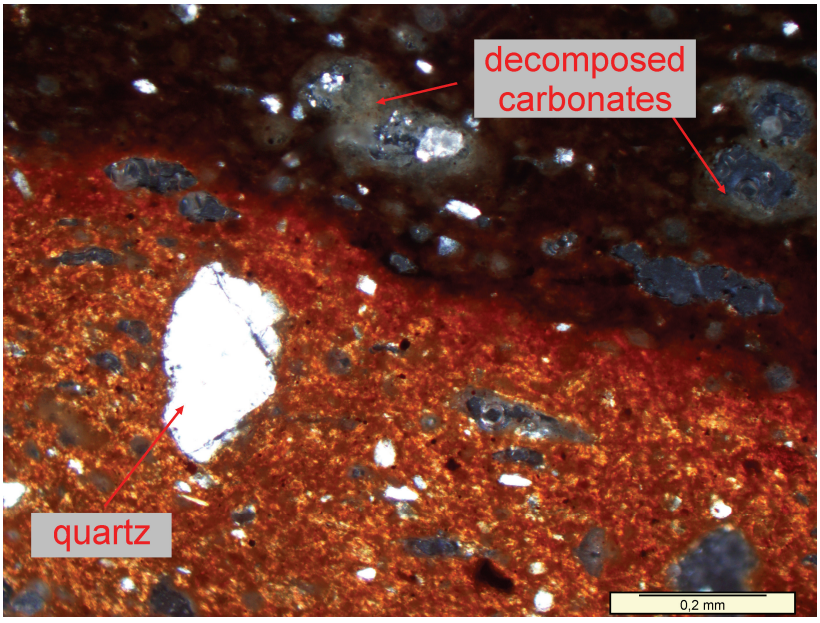

Fig. 63. Petrographic Group III. Khirbet Mazin Roman jar M5 (specimen 131). Polarising microscope, crossed nicols.

The sample that turned out to be totally distinct is M4 containing orange crystals (an effect of high-temperature firing) of altered olivines. It is tempered with 10% carbonate sand. The presence of olivine indicates that the raw material probably contained an admixture of pyroclastic material (volcanic ash). Owing to the significant chemical dissimilarity of this vessel due to a high Cr content, it was omitted from the mathematical analysis.

5.2. Comparative chemical analysis

The chemical data concerning the Jericho and Qumran ceramics were presented in the previous chapters (cf. Chapter III, Table 12, and Chapter IV, Table 18). The chemical data of the ceramics from ez-Zara, Khirbet Mazin (Qasr el-Yahud) and the clays sampled in the field as potential raw material are presented in Table 28. The results of principal components analysis are presented in Figs 64, 65, cf. Table 29.

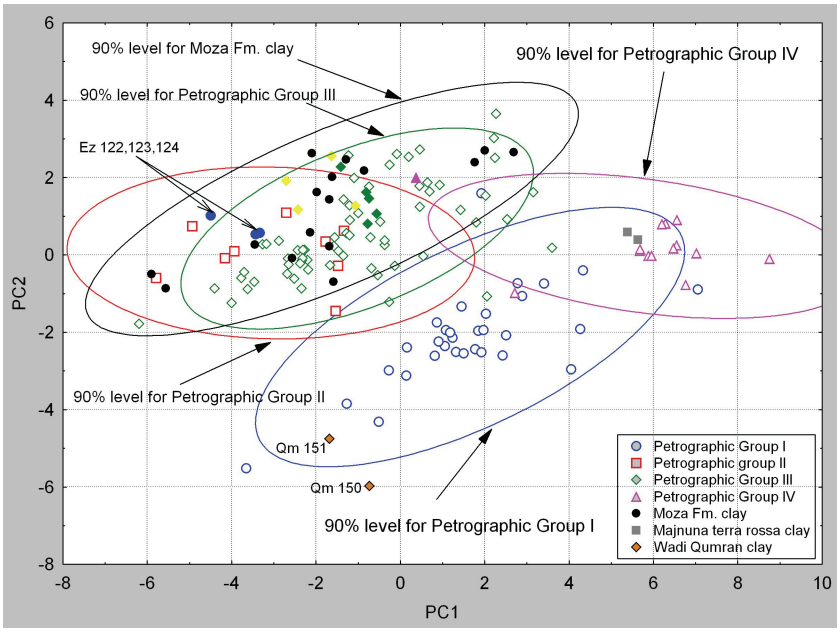

Fig. 64. Principal components analysis: a set of the Jericho, Qumran, ez-Zara and Khirbet Mazin pottery, and the clays sampled in the field, projected onto a plane of the principal components PC1-PC2. The mapping of actual relations of similarity between the samples reaches 68% (Table 29). Yellow symbols mark the Khirbet Mazin ceramics, and solid green marks the ez-Zara ceramics belonging to Petrographic Group III. Three blue points represent the ez-Zara ceramics of Petrographic Group III containing substantial amounts of Cretaceous foraminifers.

An extension of the set of data analysed so far to include the samples of ceramics from ez-Zara and Khirbet Mazin as well as clay has not changed the basic geometric relations among the particular petrographic groups: the same elements still determine their distribution (Table 30).

Table 29. Results of principal components analysis based on the correlation matrix of the total data set.

Principal component number	Eigenvalue	Percentage of variance explained	Cumulative % of total variance
1	9.2155	51.54	51.5
2	2.9450	16.47	68.0
3	1.2058	6.74	74.8
4	1.0129	5.66	80.4
5	0.7541	4.22	84.6
6	0.6556	3.67	88.3
7	0.4771	2.67	91.0
8	0.3015	1.69	92.7
9	0.2057	1.51	94.2
10	0.2230	1.25	95.4
11	0.2139	1.20	96.6
12	0.1782	1.00	97.6
13	0.1588	0.89	98.5
14	0.1010	0.57	99.1
15	0.0776	0.43	99.5
16	0.0538	0.30	99.8
17	0.0284	0.16	100.0
18	0.0079	0.04	100.0

Table 30. PCA of the total data set. Determination coefficient R^2 x 100%.

Element	PC1	PC2	PC3
As	3.2	2.8	62.1
Ca	27.3	21.1	0.4
Co	11.8	6.7	18.5
Cr	52.5	9.6	4.8
Cs	5.9	68.8	0.8
Fe	71.4	10.9	2.2
Hf	63.0	3.7	12.3
Rb	2.6	56.0	0.0
Sc	7.4	68.7	2.1
Th	72.0	11.7	0.2
U	0.0	32.3	15.5
La	91.8	1.1	0.0
Ce	89.1	0.0	0.4
Nd	76.9	0.9	0.4
Sm	87.9	0.0	0.0
Eu	83.3	0.0	0.3
Yb	91.0	1.2	0.5
Lu	90.2	0.9	0.7

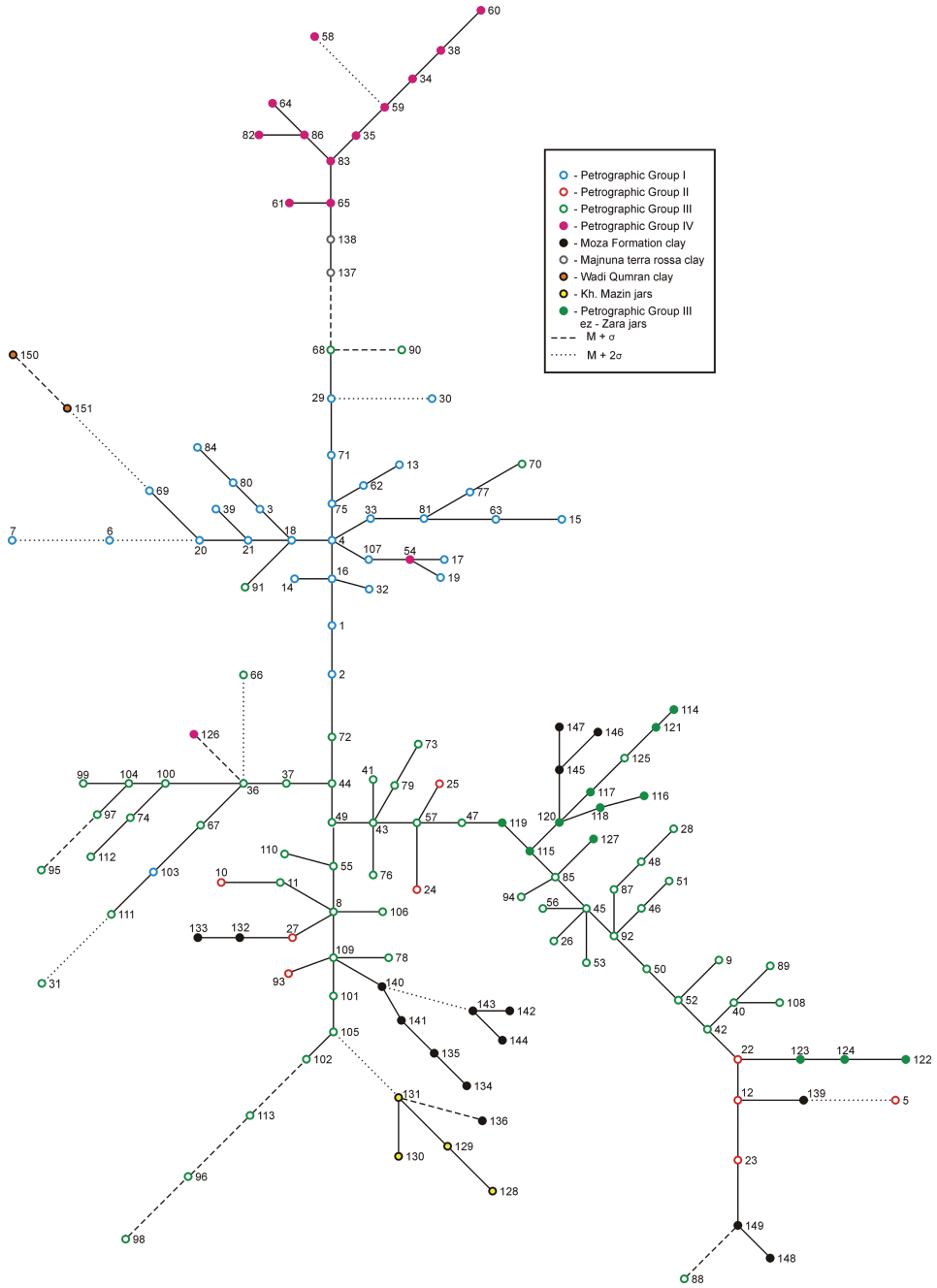

Fig. 65. Spanning tree of the full data set presenting the greatest similarity (closeness) between the ceramic specimens from Jericho, Qumran, ez-Zara and Khirbet Mazin, and the clays sampled in the field.

In diagram 64, samples of the ez-Zara ceramics (markers filled with green colour) are placed among the Qumran and Jericho vessels assigned to Petrographic Group III. Worth noting is the fact that most of the ez-Zara samples are situated in the nearest vicinity of one another, forming a sort of a subgroup.

Similarity to Petrographic Group III also holds for three samples from ez-Zara (122, 123, 124) containing abundant shells of Upper Cretaceous foraminifers, and sample Ez-126 with petrographic features typical of the silty terra rossa soil (cf. Tables 27, 31).

In diagram 64, the present-day samples of clays of the Moza Formation are scattered among the ceramics of groups II and III. In turn, the samples of terra rossa collected near the settlement of Majnuna are chemically very similar to the samples of pots making up Petrographic Group IV. The REE pattern, both in the pottery and the terra rossa clay, is very similar. Those samples display higher concentrations of total REEs than the other sediments and ceramics (Fig. 66).

Table 31. Mean chemical composition of samples of the ez-Zara and Khirbet Mazin ceramics as well as clays collected in the field. For comparison, the mean chemical composition of the pottery from Petrographic Groups III and IV is included. The chemical composition of the Wadi Qumran clays is a mean of 9 samples collected in the years 1997, 1998 and 2002, including two, numbered 150 and 151, analysed with the ceramics.

Element	ez-Zara P.Group III		ez-Zara P.Group III (?)		Jr+Qm P.Group III		Kh. Mazin jars		Moza Fm. Clay		Terra rossa		Jr+Qm P.Group IV		Wadi Qumran clay	
	n=10		n=3		n=13		n=4		n=16		n=2		n=13		n=9	
	M	σ	M	σ	M	σ	M	σ	M	σ	M	σ	M	σ	M	σ
Ca (wt %)	**6.20**	2.44	**10.67**	2.52	**6.56**	2.76	**4.00**	1.41	**8.81**	6.68	**2.50**	0.71	**1.77**	2.2	**26.44**	3.84
Fe (wt %)	**3.88**	0.22	**4.16**	0.25	**4.05**	0.58	**3.82**	0.17	**4.11**	1.10	**5.49**	0.04	**5.66**	0.48	**2.78**	0.36
As (ppm)	**4.37**	0.62	**7.80**	2.44	**7.57**	2.93	**9.68**	1.25	**13.44**	10.48	**8.30**	1.27	**9.06**	2.85	**13.82**	2.28
Co (ppm)	**14.00**	3.06	**20.33**	1.53	**15.57**	5.01	**113.25**	28.79	**16.38**	15.95	**32.00**	0.00	**26.00**	3.67	**12.56**	1.59
Cr (ppm)	**103.50**	17.82	**120.33**	5.51	**123.88***	25.22	**96.50**	13.30	**105.56**	24.06	**140.00**	0.00	**171.08**	12.63	**247.44**	25.52
Cs (ppm)	**6.00**	2.05	**7.00**	1.73	**5.33**	1.94	**5.25**	1.26	**6.31**	1.99	**3.00**	0.00	**2.77**	0.73	**2.11**	0.60
Hf (ppm)	**4.40**	0.52	**4.00**	0.00	**4.61**	0.99	**2.00**	0.82	**3.75**	1.06	**11.00**	0.00	**14.23**	2.28	**2.56**	0.53
Mo (ppm)	**4.10**	3.14	**7.00**	4.36	**8.58**	5.99	**7.00**	0.82	**<3.43**	>3.16	**4.50**	4.95	**10.38**	5.24	**16.78**	5.83
Rb (ppm)	**86.00**	19.29	**68.33**	7.02	**80.01**	26.37	**79.50**	21.13	**87.44**	35.61	**63.00**	15.56	**54.00**	15.97	**32.56**	15.28
Sc (ppm)	**16.85**	1.49	**17.90**	1.23	**16.71**	2.44	**16.00**	1.87	**18.16**	3.56	**16.95**	0.07	**16.78**	1.1	**10.21**	1.42
Th (ppm)	**7.45**	0.71	**6.47**	0.55	**7.42**	1.76	**6.95**	0.59	**7.12**	1.15	**10.30**	0.28	**10.99**	1.26	**5.07**	0.72
U (ppm)	**2.51**	0.49	**4.77**	0.38	**3.18**	1.09	**2.63**	0.49	**2.49**	0.45	**2.65**	0.07	**2.92**	0.4	**14.66**	2.27
La (ppm)	**25.85**	1.17	**21.00**	1.08	**27.73**	5.55	**24.23**	1.78	**25.08**	2.89	**44.20**	0.71	**45.93**	4.57	**27.68**	3.99
Ce (ppm)	**55.30**	3.27	**42.33**	1.15	**56.62**	11.24	**56.50**	6.40	**55.06**	8.14	**99.50**	3.54	**100.61**	8.74	**50.11**	6.58
Nd (ppm)	**24.20**	2.94	**16.67**	1.53	**24.93**	5.62	**20.75**	1.50	**25.50**	6.91	**39.00**	1.41	**42.53**	5.14	**22.56**	3.40
Sm (ppm)	**5.58**	0.54	**3.93**	0.32	**5.35**	0.99	**4.65**	0.24	**4.74**	0.61	**7.40**	0.00	**8.06**	1.04	**4.41**	0.62
Eu (ppm)	**1.31**	0.15	**0.87**	0.12	**1.27**	0.24	**1.18**	0.17	**1.31**	0.23	**2.35**	0.07	**2.10**	0.24	**1.19**	0.21
Yb (ppm)	**2.61**	0.22	**2.00**	0.17	**2.60**	0.41	**2.35**	0.13	**2.41**	0.33	**4.30**	0.14	**4.33**	0.46	**2.66**	0.46
Lu (ppm)	**0.40**	0.03	**0.31**	0.03	**0.40**	0.06	**0.36**	0.03	**0.38**	0.05	**0.64**	0.03	**0.66**	0.07	**0.41**	0.06

Table 32. Values of the successive shortest Euclidean distances among all the specimens studied.

Element	ez-Zara P.Group III		ez-Zara P.Group III (?)		Jr+Qm P.Group III		Kh. Mazin jars		Moza Fm. Clay		Terra rossa		Jr+Qm P.Group IV		Wadi Qumran clay	
	n=10		n=3		n=13		n=4		n=16		n=2		n=13		n=9	
	M	σ	M	σ	M	σ	M	σ	M	σ	M	σ	M	σ	M	σ
Ca (wt %)	**6.20**	2.44	**10.67**	2.52	**6.56**	2.76	**4.00**	1.41	**8.81**	6.68	**2.50**	0.71	**1.77**	2.20	**26.44**	3.84
Fe (wt %)	**3.88**	0.22	**4.16**	0.25	**4.05**	0.58	**3.82**	0.17	**4.11**	1.10	**5.49**	0.04	**5.66**	0.48	**2.78**	0.36
As (ppm)	**4.37**	0.62	**7.80**	2.44	**7.57**	2.93	**9.68**	1.25	**13.44**	10.48	**8.30**	1.27	**9.06**	2.85	**13.82**	2.28
Co (ppm)	**14.00**	3.06	**20.33**	1.53	**15.57**	5.01	**113.25**	28.79	**16.38**	15.95	**32.00**	0.00	**26.00**	3.67	**12.56**	1.59
Cr (ppm)	**103.50**	17.82	**120.33**	5.51	**123.88***	25.22	**96.50**	13.30	**105.56**	24.06	**140.00**	0.00	**171.08**	12.63	**247.44**	25.52
Cs (ppm)	**6.00**	2.05	**7.00**	1.73	**5.33**	1.94	**5.25**	1.26	**6.31**	1.99	**3.00**	0.00	**2.77**	0.73	**2.11**	0.60
Hf (ppm)	**4.40**	0.52	**4.00**	0.00	**4.61**	0.99	**2.00**	0.82	**3.75**	1.06	**11.00**	0.00	**14.23**	2.28	**2.56**	0.53
Mo (ppm)	**4.10**	3.14	**7.00**	4.36	**8.58**	5.99	**7.00**	0.82	**<3.43**	>3.16	**4.50**	4.95	**10.38**	5.24	**16.78**	5.83
Rb (ppm)	**86.00**	19.29	**68.33**	7.02	**80.01**	26.37	**79.50**	21.13	**87.44**	35.61	**63.00**	15.56	**54.00**	15.97	**32.56**	15.28
Sc (ppm)	**16.85**	1.49	**17.90**	1.23	**16.71**	2.44	**16.00**	1.87	**18.16**	3.56	**16.95**	0.07	**16.78**	1.10	**10.21**	1.42
Th (ppm)	**7.45**	0.71	**6.47**	0.55	**7.42**	1.76	**6.95**	0.59	**7.12**	1.15	**10.30**	0.28	**10.99**	1.26	**5.07**	0.72
U (ppm)	**2.51**	0.49	**4.77**	0.38	**3.18**	1.09	**2.63**	0.49	**2.49**	0.45	**2.65**	0.07	**2.92**	0.40	**14.66**	2.27
La (ppm)	**25.85**	1.17	**21.00**	1.08	**27.73**	5.55	**24.23**	1.78	**25.08**	2.89	**44.20**	0.71	**45.93**	4.57	**27.68**	3.99
Ce (ppm)	**55.30**	3.27	**42.33**	1.15	**56.62**	11.24	**56.50**	6.40	**55.06**	8.14	**99.50**	3.54	**100.61**	8.74	**50.11**	6.58
Nd (ppm)	**24.20**	2.94	**16.67**	1.53	**24.93**	5.62	**20.75**	1.50	**25.50**	6.91	**39.00**	1.41	**42.53**	5.14	**22.56**	3.40
Sm (ppm)	**5.58**	0.54	**3.93**	0.32	**5.35**	0.99	**4.65**	0.24	**4.74**	0.61	**7.40**	0.00	**8.06**	1.04	**4.41**	0.62
Eu (ppm)	**1.31**	0.15	**0.87**	0.12	**1.27**	0.24	**1.18**	0.17	**1.31**	0.23	**2.35**	0.07	**2.10**	0.24	**1.19**	0.21
Yb (ppm)	**2.61**	0.22	**2.00**	0.17	**2.60**	0.41	**2.35**	0.13	**2.41**	0.33	**4.30**	0.14	**4.33**	0.46	**2.66**	0.46
Lu (ppm)	**0.40**	0.03	**0.31**	0.03	**0.40**	0.06	**0.36**	0.03	**0.38**	0.05	**0.64**	0.03	**0.66**	0.07	**0.41**	0.06

Samples of clays from Wadi Qumran are located near the margins of diagram 64, closer to the points representing the ceramics of Petrographic Group I (Fig. 66).

The pattern of similarity of all the samples of ceramics and clays under study, plotted in the form of a dendrite, is close to that obtained on the plane produced by the first two principal components PC1-PC2. The samples lying closest to one another (i.e. displaying the greatest similarity) include in particular (cf. Fig. 65):

(1) vessels assigned to Petrographic Group IV (largely cooking pots), petrographically and chemically similar to samples of the silty terra rossa soil (specimens H2A);

(2) bowls, jugs, jars and kraters made of foraminiferous clay assigned to Petrographic Group I;

(3) vessels made of rich clay tempered with quartz or carbonate sand (Petrographic Groups and II and III), among which the storage jars from ez-Zara form a relatively compact subgroup. Similar to the vessels of this group are the clays of the Moza Formation coming from the Hebron and Majnuna regions.

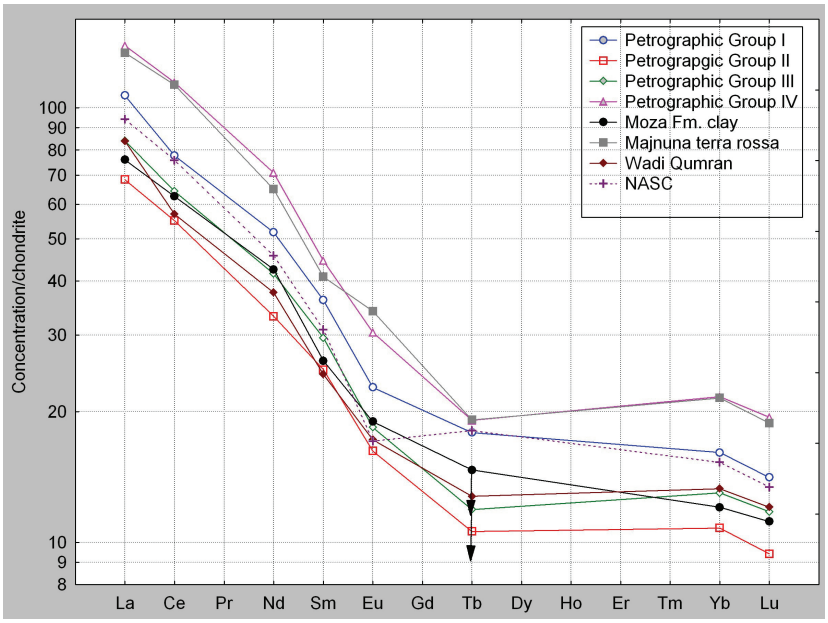

Fig. 66. Rare-earth element concentrations normalised to chondritic meteorite values, plotted against REE atomic numbers for mean values of the petrographic groups, Moza Fm. clay, terra rossa, and Wadi Qumran clay. As a measure of the degree of REE fractionation with the changing REE content, a curve was included presenting the REE abundances in the North American Shale Composite (NASC) (Gromet et al. 1984, fide Rollinson 1993: 136).

Assuming M + 2(σ) = 3.51 to be the criterion of statistical separateness, the samples that stand out are primarily:

(1) Wadi Qumran clays (150, 151);

(2) Khirbet Mazin jars M1-M5 (in diagram 64 those jars are denoted yellow, they are distinct among the remaining samples of Petrographic Groups II and III, and give the impression of forming a set of their own);

(3) Moza Adoraim – Moza Formation clays and single samples of vessels: 6 and 8 (Petrographic Group I), 5 (Petrographic Group II), 3, 66, 88, 95, and 98 (Petrographic Group III), and 58 (Petrographic Group IV).

The distinctness of the clays sampled near the locality of Moza Adoraim consists largely in their high Ca content which results from an abundance of small dolomite crystals in those samples (cf. the table with the chemical composition of the samples in Michniewicz, Krzyśko 2003: 64, photo 2). The analyses of the individual Moza Formation clay samples show considerable variations in the levels of trace elements in those rocks, as reflected in the high standard deviation figures (cf. Table 31).

Diagram 65 reveals the uniqueness of clays coming from the upper part of Wadi Qumran. In comparison with the remaining samples of clays and ceramics, they contain much higher amounts of Ca and especially of chromium and uranium, while being much lower in Fe, Hf, and Sc (cf. Table 31).

A solution to such a considerable chemical dissimilarity of those rocks can be sought in the presence of the preserved rocks of the Hatrurim Formation containing an abundance of trace elements, especially Cr, which cover at places the underlying rocks of the Mount Scopus group. Rocks of this formation are exposed in the desert, directly above Wadi Qumran, and are drained by the waters of intermittent streams that empty directly into this wadi.

5.3. Interpretation of the results

When searching for potential similarities or differences between the ceramics from Qumran and those from Jericho, it should be emphasised that the Qumran vessels under study represent the Herodian period and come primarily from levels 3a and 3c, while those from Jericho were made in a much broader time interval, from the Hasmonean periods 1 and 2 through Herodian 1 and 2 to Herodian 3.

The obtained results prove that the Hasmonean and then Herodian ceramics from Jericho as well as the Herodian ceramics from Qumran were made alternatively of one of the three kinds of raw material:

(1) slightly silty foraminiferous clay (pottery assigned to Petrographic Group I),

(2) rich clay tempered with quartz-carbonate sand or carbonate sand (pottery assigned to Petrographic Groups II and III), and

(3) silty, ferruginous terra rossa soil (pottery assigned to Petrographic Group IV).

These three types of raw material differ, both petrographically and in terms of their chemical composition.

The slightly silty foraminiferous clay of Petrographic Group I was used in the manufacture of bowls, storage jars, lamps, jugs, and sometimes even 'scroll jars'. The substantial number of vessels produced from this raw material indicates that it was as widely used as rich clay, hence it had to be readily available (cf. Arnold 2000). On the diagrams of geochemical correlation the vessels of this group form a separate cluster.

This raw material is a marly clay with variable amounts of fine limestone grains, containing about 10% of very fine angular quartz silt and 2-3% of fresh silty feldspars. Indirectly, on the basis of the hafnium content, numer-

ous heavy metal particles can also be assumed to be present. The total content of rare-earth elements is higher than in Petrographic Groups II and III, Moza Formation clay, and Wadi Qumran clay. Depending on the oxidation-reduction conditions during firing, the ceramics made of these clays have assumed a colour from red to light brown. Their distinctive features primarily include:

(1) the presence of Cretaceous foraminifers *Hedbergella, Heterohelix, Globigerinelloides*, and *Gümbelitria cenomana* (Keller); and

(2) chemical separateness because of the highest content of Ca; high levels of Fe and Cr (in relation to Petrographic Groups II and III); and high Fe/Sc, Cr/Sc and REE/Sc ratios whose values in many samples are similar to those observed in the samples of Petrographic Group IV. This group also displays a high content of Hf and REEs (Fig. 66).

The preserved genera and species of foraminifers show that the raw material employed was clays of the Upper Cretaceous or the Lower and Upper Cretaceous (Albian/Cenomanian) boundary. It certainly could not be the Paleogene clays of the Taqiye Formation or Triassic clays. However, one cannot rule out a pedogenic origin of this raw material, which could have developed on a substratum of rocks of Cretaceous age. Indirect evidence may be its chaotic, homogeneous structure, the presence of a pelitic admixture, and elevated levels of heavy minerals. The elevated levels of iron compounds and their accessory metals, mainly Cr, would result from their precipitation from pore water.

The rich, variably marly clay of Petrographic Groups II and III was used to make most of the 'scroll jars', bowls, juglets, kraters, pitchers, and goblets. Storage jars made of this clay have been found in Qumran, Jericho, Khirbet Mazin as well as ez-Zara/Callirrhoe. The features petrographically distinguishing the raw material of this group include:

– the presence of dispersed shale fragments slreili with a residual parallel optical orientation, usually different from that of the clayey background;

– a very low content of quartz silt, not exceeding 5% and often even under 2%;

– a sporadic presence of grains of quartz sandstones bound by carbonate cement; and

– single calcitic pseudomorphs after fine rhombus-shaped dolomite crystals.[2]

Chemically, the distinctive features of the ceramics of this group are:

– low Fe/Sc and Cr/Sc ratios,

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[2] A large number of rhombohedral dolomites would be a diagnostic feature of Cenomanian clays of the Moza Formation (Porat 1989, Goren 1995).

– high Rb and Cs content,
– calcium content lower than in Petrographic Group I, and
– the lowest mean content of hafnium and the rare earths among all the groups.

The pottery made of this type of clay usually does not contain organic fossils that would allow the identification of the age of the raw material. Still, in some samples foraminifer shells have been preserved which represent the Upper Cretaceous or its lower boundary (Albian/Cenomanian), as in the case of Petrographic Group I. Though some of the shells could have been added with the tempering admixture, the presence of at least some of them is undoubtedly of an autogenic nature. This concerns especially the three jars from ez-Zara (122, 123 and 124).

Rich-clay outcrops closest to Qumran and Jericho can be found in the Judean Mountains between Hebron and Ramallah.[3] These are Cenomanian clays of the Moza Formation. In the eastern part of the Dead Sea basin they correlate with the Fuheis (Naur?) Formation exposed above Zarga Main.[4] The more compact parts of this formation show bedding-plane fissility, which would corroborate their association with the ceramics under study. Those clays do not contain quartz sand, let alone sandstone grains. One might think, therefore, that if they actually were the material of which some of the vessels were made, the quartz grains, limestones and sometimes sandstones that appear in them are an artificial admixture.

The chemical composition of the Moza Formation clays is usually not homogeneous and varies with the colour of the samples collected, which may be indicative of variable oxidation-reduction conditions accompanying the sedimentation of those deposits. Besides, those rocks show a variable content of carbonates, especially dolomite. This fact greatly hinders a comparison of their composition with that of the ceramics under analysis.[5] Still, it should be emphasised that, chemically, the samples of those clays are most similar to the vessels of Petrographic Group III.

An alternative source of the pure rich clay can be sought in the Lower Cretaceous (Albian) shales of the Kurnub Group. Those clays outcrop in Trans-Jordan, especially between the northern Dead Sea and Zarga and

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[3] The En Yorge'am member of the Hazera Formation, correlative with the Moza Formation in the northern part of the Dead Sea basin, is usually covered by a talus and consists of limestone, chalk and some marl. South of Qumran, En Yorge'am rocks occur in Wadi Darga. En Yorge'am samples taken by the author in En Gedi are not suitable for the production of ceramics because of their high content of $CaCO_3$.

[4] The ceramics produced experimentally from this raw material is of good quality.

[5] The content of thorium, one of the least mobile elements, remains constant, thus being an indicator of the common geotectonic origin of those samples.

Eastern Samaria i.e. the north eastern part of the West Bank e.g. in Wadi Far'ah, Wadi el Malikh (Goren 1995, Goren, Zuckermann 2000: 170). According to Goren (1995), however, the diagnostic features of those rocks are a substantial proportion of silt and the presence of limonitic ooliths. The vessels assigned to Petrographic Groups II and III have neither of those characteristics. On the other hand, what speaks for a relation between the vessels and the clays of this formation are the preserved shale fragments and the presence of coarse quartz grains and fine clasts of sandstone, which would be a natural admixture in this case.

One cannot also exclude the possibility that the raw material used was clays of the Nezer Formation covering laterally the top of the Shivta Formation.

The silty, ferruginous terra rossa soil (Petrographic Group IV) was used primarily for the production of cooking pots. Its high content of fine quartz together with the low levels of carbonates and elevated levels of iron compounds ensured them resistance to changes in temperature and low porosity, and hence low absorbability.

In chemical terms, the diagnostic feature of this group of vessels is the highest content of Fe and Hf, and a very low one of Ca. It also displays the highest concentrations of Th and rare earths. Petrographic Group IV is closer to Group I than to the other two groups. What emphasises its separateness from Petrographic Group I is an increased content of heavy minerals.

5.4. Are the Qumran ceramics made of Wadi Qumran deposits?

The results of the petrographic observations of the vessels from Qumran, especially those revealing their internal structure, seem to be especially significant in the context of the discussion about the function of the settlement in the Herodian period and the scale of the ceramic production carried out there. Did the settlement's kilns supply with pottery only its own residents, or were they an element of an intensive manufacturing process intended to meet the demand of the entire region from Jericho to En Boqeq? Did the water facilities provide Qumran with the clay raw material in quantities making it possible to produce vessels at a scale suggested by Magen and Peleg (2006, 2007)?

What would corroborate this hypothesis would be the homogeneity of the Dead Sea ceramics, specifically the intra-group similarity of its structure and the mineral and chemical compositions, combined with a similarity to the deposits of Wadi Qumran coming from its upper part, i.e. one overlying the Dead Sea Group sediments.[6] The clay suspension transported to sedi-

[6] The aqueduct ran over the deposits of the Dead Sea Group, including the Lissan Formation.

mentary basins via the aqueduct should have a homogeneous structure, certainly with no features typical of shales; moreover, it should contain a microfossil assemblage similar to those found in the ceramics.

The vessels coming closest to fulfilling the above criteria are those made of foraminiferous clay assigned to Petrographic Group I. Still, the wadi deposit is more marly and displays a different content of trace elements (high abundances of Cr, U, low abundances of Fe, Rb and Cs). Besides, in the opinion of Barbara Olszewska, the microfossils that it contains, viz. *Dorothia bulleta* Cushman, *Stensioeina cf. exculpta* (Reuss), *Contusotruncana fornicata* (Plummer), *Globigerinelloides escheri* (Kaufman), *Hedbergella bornholmensis* (Douglas & Rankin), *Hedbergella monmouthensis* (Olsson), and *Heterohelix globulosa* (Ehrenberg), may indicate it to be of younger age (the higher part of the Upper Cretaceous) than the raw material of the vessels, in which foraminifers are rather indicative of the lower part of the Upper Cretaceous or the Albian/Cenomanian boundary.[7]

Undoubtedly, most of the Qumran pottery, including the majority of 'scroll jars', was made of the pure clay (the ceramic paste assigned to Petrographic Groups II and III), displaying a residual parallel orientation of clay minerals and containing abundant coarse fragments of shales. Their presence, the absence of microfossils typical of the Wadi Qumran deposit as well as a quite different chemical composition are evidence that the vessels were not made of Wadi Qumran clay deposited in the form of suspension.[8]

There is no doubt that the vessels from Qumran were made of at least three clays of different provenance, hence only one of them could derive from the Wadi Qumran installation. Even assuming, after Magen and Peleg, that the Wadi Qumran deposit was indeed used for pottery making, it should be stressed that this is not a raw material dominating among the Qumran vessels; in the case of jars discovered there, it even accounts for a negligible proportion of them. The jars, including most of the 'scroll jars', were made of pure clay containing fragments of shales. This type of raw material does not occur in the vicinity of the Qumran site.

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[7] In her expert's report Barbara Olszewska states: "When compared with the assemblage obtained in the process of wet-sieving of the Wadi Qumran clays, the assemblages from thin sections seem to be older (the boundary of the Lower and Upper Cretaceous), as indicated by the presence of the species *Gümbelitria cenomana* (Keller). Also, there are no large forms that are present in the wet-sieved sample. It should be kept in mind, however, that wet-sieving a sample tends to enrich the fossil assemblage artificially, while a thin section contains few organic remains, usually representing the smallest forms. In this material these are representatives of the genera *Hedbergella, Heterohelix* and *Globigerinelloides*, hence its Upper Cretaceous character is highly probable."

[8] They could not be transported by the aqueduct owing to their size and the associated weight.

5.5. Conclusions

The above results show that four groups of fabric can be identified among the Jericho and Qumran pottery. They are characterised by different sets of petrographic features and different chemical compositions. The basic petrographic features differentiating them include:

(1) the presence of Cretaceous foraminifers in a clayey background whose high abundance is typical of Petrographic Group I;

(2) great, moderate or negligible amounts of quartz-feldspar grains of the pelitic fraction. Their great amount is typical of Petrographic Group IV; moderate, of Petrographic Group II, and negligible, of Petrographic Groups II and III;

(3) the presence of a natural or artificial sand-fraction admixture: carbonate, typical of Petrographic Group II, or quartz /quartz-carbonate, typical of Petrographic Group III; and

(4) the presence of preserved shale fragments and fine-grained sandstones typical of Petrographic Group III.

The petrographic differences among those vessels are reflected in their different chemical compositions, especially in different proportions of three elements: Hf, Fe and Sc (cf. Fig. 57), but also Ca, Rb and Cs (Figs 48, 56).

Petrographic Groups II and III are chemically similar to each other and radically different from Petrographic Group IV. Petrographic Group I displays an intermediate composition; with its elevated levels of Fe and Cr compounds as well as Hf and REEs, it seems petrographically closer to group IV. What makes Petrographic Groups II and III chemically dissimilar to the two remaining groups is mainly their higher proportions of scandium with respect to iron, chromium and REEs, and higher levels of rubidium and cesium. The presence of the two latter elements is indicative of a relatively high content of potassium in those rocks, and shows their genesis to be connected with the weathering of broadly understood acidic crystalline rocks.

Among the clays collected in the field, samples of the Cenomanian Moza Formation are chemically similar to the ceramics of Petrographic Groups II and III.

It is certain that the clays of the upper part of Wadi Qumran were not the raw material of which the examined ceramics were made. Their samples are radically different from both, the samples of the vessels and from the remaining clay samples. What distinguishes them is a very high chromium content while their levels of iron are low, of uranium high, and of hafnium and the rare-earth elements low. The high Cr and U content in those deposits probably results from the close vicinity of an outcrop of rocks of the Hatrurim Formation (Chapter 1.1): they are exposed in the desert, immediately over Wadi Qumran.

Two samples of terra rossa developed among the caverns of the Cenomanian Amminadav Formation are very similar, petrographically and chemically, to the samples of Petrographic Group IV.

The results obtained do not offer an unequivocal answer to the question of where the ceramics discovered in Qumran and Jericho were made. They were certainly produced from several varieties of raw material. It was Cretaceous material extracted in at least three different places. Because of the lateral arrangement of rock layers in the Dead Sea basin, a closer determination of its provenance does not seem to be possible.

It is highly probable that the rich clays of the ceramics assigned to Petrographic Groups II and III represent either the Cenomanian Moza Formation or the top part of the Lower Cretaceous Kurnub Group outcropping on the eastern side of the Jordan, and in Eastern Samaria.

Elevated concentrations of trace elements, especially hafnium and rare earths, in the paste of the vessels of Petrographic Group I and the documented Cretaceous age of its foraminifers may indicate that the raw material employed may be pedogenic weathered material which has developed on the substratum of calcareous rock of Cretaceous age that had undergone only weak diagenesis, and which has been enriched with iron compounds and iron-related metals, chiefly Cr. It could also have been deposited in the channel of a wadi emptying into the Dead Sea.

If we reject the possibility of the ceramics of group I being associated with soil processes or deposits of intermittent stream channels, then an alternative explanation of their chemical dissimilarity to those of groups II and III, could be the location of mines of even-aged clay deposits on the opposite sides of the Dead Sea transform fault. Those clays, though coeval, would be deposited in the sea basin separated by a distance of at least 100 km[9], hence perhaps in somewhat different conditions of sedimentation and the later diagenesis, and this, in turn, might have been reflected in their trace-element composition.

The results obtained also provide an answer to more detailed questions:

1. In the group of Jericho pottery, no petrographic features were found that would differentiate the Hasmonean from the Herodian ceramics.

2. The 'scroll jars' discovered in the caves were made of the same material as the jars coming from the site, but owing to the widespread use of this raw material in the Herodian period, this fact cannot be taken as evidence of a direct connection of the manuscripts with the settlement.

3. Most of the 'scroll jars' examined, as well as other types of common wares from Qumran, were made of pure rich clay which certainly does not derive from Wadi Qumran.

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[9] 100 km is the range of the parallel displacement of Sinai relative to the Arabian Peninsula.

6. The Qumran lamps from locus 130 were made of the same raw materials that were used to produce the other vessels. No features were found that might attest to their alien origin.

7. The two jars that, according to Bar-Nathan, could perform the function of 'genizah' were made of a similar raw material as the slim Qumran 'scroll jars'. However, as in the case of the ceramics from the caves, this similarity should be placed in the context of the widespread use of this raw material in that period.

8. There are no clues that would allow even a part of the vessels to be ascribed to a workshop in Jericho or Qumran.

Future studies should not only embrace a much wider variety of vessels from Qumran and Jericho; they should also be extended to include a detailed field research, because the provenance of the Dead Sea ceramics is impossible to establish with any precision without a thorough examination of the clay rock outcrops on both sides of the Dead Sea. Unfortunately, in the conditions of the Middle Eastern conflict, this is a project unlikely to be put into effect at present.

The author hopes that the results of the chemical and petrographic analyses presented here will be useful to archeologists, and that they will enable both, a discussion of the suggestions made here and their different interpretation.

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CERAMIKA Z QUMRAN I JERYCHO – BADANIA PETROGRAFICZNO-CHEMICZNE NAD JEJ POCHODZENIEM

Streszczenie

1. Wstęp

W latach czterdziestych, nieopodal kamiennych ruin (arab. „khirbeh") zwanych Qumran, odkryto słynne rękopisy zawierające zarówno księgi Starego Testamentu jak też teksty pozabiblijne. Kwestie genezy zwojów, ich związku z mieszkańcami Qumran, kto i z jakiego powodu zasiedlał tę osadę i jaką ona pełniła funkcję – modlitewną, produkcyjną czy też posiadłości letniej – nie zostały w sposób jednoznaczny i przekonywający rozstrzygnięte. Wraz z nowymi odkryciami formułowane są coraz to bardziej przeciwstawne poglądy.

Do niedawna powszechnie akceptowana była hipoteza o monastycznym charakterze Qumran, które miało być związane z żydowskim ugrupowaniem esseńczyków. Jej twórcą był odkrywca Qumran, Roland De Vaux (1953a, b, 1954, 1955, 1959, 1973). De Vaux był przekonany, iż odnalezione w pobliskich grotach manuskrypty zostały stworzone przez mieszkańców Qumran.

Pierwszą istotną reinterpretacją tej hipotezy była publikacja Karla Rengstorfa (1960) sugerująca, iż zwoje mogą pochodzić ze świątyni w Jerozolimie[1]. Teorię tę rozwinął ostatecznie Norman Golb (1980), całkowicie odrzucając religijny charakter osady. W roku 1994 Pauline Donceel-Voûte także odrzuciła esseńską genezę Qumran, uznając jednocześnie Qumran za luksusową posiadłość wiejską.

W tym samym roku (1994) J.B. Humbert[2] określił Qumran jako rezydencję hasmonejską (por. Humbert 1994: 166, 169, 174; Humbert 2003: 421-423, 432-436) zasiedloną przez esseńczyków dopiero po jej zniszczeniu, które mogło nastąpić bądź na skutek najazdu Gabiniusza w roku 56, ataku Partów w roku 40, lub podboju dokonanego przez Heroda Wielkiego w roku 31 p.n.e. Według Humberta, Qumran mogło pełnić funkcję regional-

[1] Por. opinię de Vaux na temat tej hipotezy (1973: 105)

[2] J.B. Humbert jest następcą de Vaux, odpowiedzialnym za prowadzenie badań archeologicznych przez francuską Ecole Biblique et Archeologique.

nego centrum modlitwy, otwartego dla społeczności zamieszkującej basen Morza Martwego (por. tabela 1).

Odmienną wizję Qumran przedstawili ostatnio izraelscy archeolodzy Magen i Pelleg (2006, 2007), którzy po 10 sezonach badań na terenie osady uznali Qumran za husmonejską fortecę, zamienioną w okresie okupacji rzymskiej na centrum produkcji ceramicznej. Wybudowane nowe baseny na terenie osady miałyby stanowić rezerwuar iłu dostarczanego w formie zawiesiny przez akwedukt. Według tych autorów ilość gromadzonej gliny była wystarczająca dla produkcji tysięcy naczyń. W okresach intensywnych opadów glina gromadziła się w basenach w nadmiarze, przez co mogła być przekazywana np. do Jerozolimy lub Jerycho. Cylindryczne dzbany zostały mylnie określone jako „scroll jars" (dzbany do przechowywania zwojów), podczas gdy w rzeczywistości służyły do przechowywania daktyli i miodu (Magen i Pelleg 2006: 109-113).

W kontekście zazwyczaj sprzecznych ze sobą teorii dotyczących funkcji Qumran i roli, jaką pełniła ta osada, istotnym argumentem weryfikującym przynajmniej niektóre z zaprezentowanych powyżej hipotez mogą być wyniki badań nad zmiennością składu mineralnego i chemicznego naczyń ceramicznych w stosunku do ich kształtu, pozycji stratygraficznej i miejsca odkrycia.

– Czy naczynia o tym samym kształcie odkryte w Qumran, Jerycho, Khirbet Mazin, a także na przeciwległym brzegu Morza Martwego w ez-Zara/Callirrhoe wykonano z tego samego surowca?

– Czy możemy wykazać zespół cech petrograficznych lub chemicznych ceramiki, które pozwalałyby przybliżyć jej wiek?

– Czy możemy wskazać miejsce produkcji ceramiki z Qumran i Jerycho, a przynajmniej skąd pochodzi wykorzystany surowiec?

– Czy petrografia ceramiki z osady oraz z grot potwierdza lub zaprzecza związkowi manuskryptów z mieszkańcami Qumran?

– Czy ił pochodzący z Wadi Qumran mógł być podstawą działalności produkcyjnej na terenie osady?

Istnieją także zagadnienia bardziej szczegółowe:

– Z jakiego surowca wykonano lampy pochodzące z Qumran locus 130, których kształt, wg Humberta (2003: 435), nie jest nigdzie spotykany na obszarze Palestyny; czy mogą one pochodzić z importu?

– Czy dzbany z Jerycho datowane na okres hasmonejski wykonano z innego surowca niż dzbany powstałe w okresie herodiańskim?

– Czy surowiec dzbanów odkrytych w Jerycho o kształcie sugerującym, iż służyły do przechowania zwojów jest podobny do surowca, z którego wykonano dzbany na zwoje odkryte w Qumran?

Odpowiedź na wspomniane kwestie jest celem prezentowanej pracy. 62 próbki ceramiki z Qumran, w większości reprezentujące okres rzymski (wg de Vaux II i III okres rozwoju osady), zostały porównane z 46 fragmentami ceramiki z Jerycho, której wiek został precyzyjnie określony podczas prac archeologicznych prowadzonych na terenie hasmonejsko-herodiańskich pałaców w Jerycho (Netzer 2001, Bar-Nathan 2002). Ponadto badaniami objęto niewielką ilość fragmentów dzbanów reprezentujących okres rzymski, zebranych wśród ruin Khirbet Mazin (portu położonego w pobliżu Qumran) a także fragmenty dzbanów z herodiańskich term ez-Zara/Callirrhoe[3] (por. Clamer 1989, 1997).

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[3] Jest to miejsce ostatnich prób leczenia Heroda Wielkiego, gdzie przebywał tuż przed swoją śmiercią.

1.1. Zastosowana metoda badawcza

Podstawą pracy są wyniki petrograficznej analizy porównawczej powiązane z wynikami analiz chemicznych.

Z każdego fragmentu ceramiki wykonano preparat petrograficzny. W badaniach mikroskopowych zwracano szczególną uwagę na udział i skład mineralny domieszek schudzających oraz strukturę i skład masy podstawowej. Identyfikację zawartych w części próbek otwornic przeprowadziła prof. Barbara Olszewska z Instytutu Nauk Geologicznych PAN w Krakowie.

Ułamane fragmenty próbek utarto w moździerzu agatowym a następnie przesłano do laboratorium, gdzie określono ich skład chemiczny.

Skład chemiczny lampek oliwnych, z uwagi na małą wielkość próbek, określono metodą spektralnej analizy plazmowej ICP MS w kanadyjskim laboratorium ACME. Badania składu chemicznego pozostałych naczyń zostały wykonane za pomocą neutronowej analizy aktywacyjnej w kanadyjskim laboratorium „ACTLABS". Próbki te zostały naświetlone w reaktorze uniwersyteckim McMaster 5MW wiązką neutronów $7x10^{12}$ n cm^{-2} s^{-1}.

Wyniki analiz składu chemicznego interpretowano stosując metodę składowych głównych w połączeniu z taksonomią wrocławską (Florek i in. 1951).

Do obliczeń wykorzystano programy Statistica 6.0 oraz „Principal Components Analysis" (Maćkiewicz, Ratajczak 1992).

1.2. Potencjalny surowiec ilasty

Do potencjalnych złóż skał ilastych, które mogły być wykorzystane do wykonania ceramiki odkrytej zarówno w Qumran jak też Jerycho należą przede wszystkim:

1) iły cenomańskiej formacji Moza, których liczne wychodnie spotykamy po zachodniej stronie Morza Martwego. Ich odpowiednikiem po stronie wschodniej (jordańskiej) wydają się być iły formacji Fuheis (por. Arkin et al. 1965, Begin 1975, Porat 1989; Eisenberg 1993; Zorn et al. 1994; Gunneweg et al. 1994, Goren 1995; Schulze et al. 2003: 648);

2) dolnokredowe (górny Alb) łupki ilaste grupy Kurnub, szeroko odsłoniętej w górnej części doliny Jordanu, np. wschodniej Samarii (Wadi Far'ah, Wadi el Malikh) oraz po wschodniej stronie rzeki Jordan, w odległości 2 km od drogi łączącej miejscowości Arda – Karama (por. Porat 1989: 28; Goren 1995: 302; Greenberg, Porat 1996: 5-26); Amireh 1997; Amireh, Abed 1999; Goren, Zuckermann 2000: 170; Khoury 2002: 20-27);

3) iły formacji Taqiye (dan – paleocen) charakteryzujące się obecnością otwornic *Loxostomoides applinae* (Plumer), *Truncorotalia angulata* (White), oraz *Bulimina midwayensis* (Cushman and Parker) (Bentor 1966: 72-73; Flexer 1968: 106; Goren 1995: 302);

4) plejstoceńskie lessy spotykane w północnej części pustyni Negew (zawartość iłu dochodzi w nich do 38%);

5) szeroko rozprzestrzenione gleby typu rendzina i terra rossa;

6) aluwia rzek okresowych (Yaalon 1959; bentor 1966, Dan et al. 1972, Porat 1989);

7) margle turońskiej formacji Nezer, pokrywające strop formacji Shivta.

2. Badania lampek oliwnych

Analizie porównawczej poddano 18 lampek oliwnych z Qumran oraz 4 lampki z pałaców zimowych w Jerycho. Zbiór ten uzupełniono próbkami iłów formacji Moza oraz próbkami trzech dzbanów z Khirbet Mazin.

Obserwacje mikroskopowe pozwoliły wyróżnić 3 grupy lampek:

1) grupę lampek wykonanych z iłu zawierającego otwornice wieku kredowego, 5-10% kwarcu o frakcji mułowej, nieliczne ziarna drobnego kwarcowego lub kwarcowo-węglanowego piasku;

2) grupę lampek wykonaną z tłustej, w różnym stopniu marglistej gliny, zawierającej domieszkę romboedrycznych węglanów o frakcji piaszczystej;

3) grupę lampek wykonanych z tłustego iłu schudzonego piaskiem kwarcowym.

Chemicznie największą odrębność wykazują lampki wykonane z surowca zawierającego otwornice (petrograficzna grupa I). Pozostałe lampki są chemicznie do siebie podobne. Brak chemicznej odrębności lampek przypisanej do petrograficznej grupy II oraz grupy III sugeruje, że różnica pomiędzy nimi jest odzwierciedleniem odrębnych praktyk garncarskich, a więc odrębności warsztatów czerpiących podobny (ten sam?) surowiec.

W świetle uzyskanych wyników można sądzić, iż lampki z Qumran oraz Jerycho zostały wykonane w warsztatach stosujących te same – przynajmniej dwie – odmiany surowca ilastego.

Przebadane lampki o nietypowym kształcie, określane jako „Qumran loc. 130", wykonano z tego samego surowca co pozostałe lampki, tzn. gliny zawierającej otwornice (petrograficzna grupa I) oraz tłustej gliny schudzonej piaskiem kwarcowym (petrograficzna grupa III).

3. Ceramika użytkowa z Jerycho

Badaniami objęto 37 dzbanów i 9 miseczek (tabela 10). Naczynia te reprezentują pięć poziomów stratygraficznych odpowiadających etapom architektonicznej rozbudowy pałaców zimowych w Jerycho (por. Netzer 2001: 1-10; Bar-Nathan 2002: 4-5). Wiek naczyń, nawiązujący do wspomnianych poziomów, oznaczono następującymi symbolami:

HS1 – okres hasmonejski 1 (100 – 95/85 p.n.e.),
HS2 – okres hasmonejski 2 (85/75 – 31 p.n.e.),
HR1 – okres herodiański 1 (31 – 15 p.n.e.),
HR2 – okres herodiański 2 (15 p.n.e. – 6 n.e.),
HR3 – okres herodiański 3 (6 – 48 n.e.).

Stosując petrograficzne kryterium podobieństwa, możemy wyróżnić cztery odmiany masy ceramicznej nazwane grupami petrograficznymi. Uzyskany w ten sposób podział został przedstawiony w tabeli 10. Bardziej szczegółowa charakterystyka petrograficzna tych naczyń została zawarta w tabeli 11.

Zróżnicowanie petrograficzne ceramiki z Jerycho dotyczy głównie zawartości domieszki schudzającej, jej składu mineralnego, zawartości mułu kwarcowego, a także barwy.

Petrograficzną grupę I tworzą naczynia wykonane z marglistego iłu zawierającego muszelki kredowych otwornic oraz 5-10% kwarcu frakcji mułowej.

Petrograficzną grupę II tworzą naczynia wykonane z tłustego iłu zawierającego romboedry węglanów o frakcji piaszczystej.

Petrograficzną grupę III stanowią naczynia wykonane z tłustego iłu zawierającego 10-20% piasku kwarcowego lub kwarcowo-węglanowego.

Petrograficzną grupę IV utworzyły 3 garnki do gotowania wykonane z chudej gliny wykazującej cechy rezydualnego osadu typu terra rossa.

4. Ceramika użytkowa z Qumran i jej porównanie z ceramiką z Jerycho

Badania objęły 40 fragmentów ceramiki użytkowej oraz 22 fragmenty dzbanów służących do przechowywania zwojów „scroll jars" (tabela 15).

Tak jak w przypadku lampek oliwnych oraz ceramiki z Jerycho, naczynia te wykonano z podobnych odmian surowca. Zostały one przypisane do czterech grup petrograficznych (cechy petrograficzne grupy II posiada tylko jedna próbka, nr 93).

Na dalszym etapie badań określono stopień podobieństwa chemicznego pomiędzy ceramiką z Jerycho i Qumran. Na podstawie zawartości tych samych 18 pierwiastków wykonano ponownie obliczenia składowych głównych, a także kreśląc rozkład ich podobieństwa w postaci dendrytu (ryc. 47). Stwierdzono, iż naczynia z Qumran wykonywano z tych samych surowców co naczynia z Jerycho, a relacje między poszczególnymi grupami petrograficznymi nie uległy zmianie.

Średnie zawartości analizowanych pierwiastków poszczególnych grup petrograficznych przedstawia tabela 25.

Stwierdzono, że odrębność chemiczna tych grup jest głównie determinowana poprzez:

1) odmienną proporcję Hf i ziem rzadkich odzwierciedlającą odmienną koncentrację minerałów ciężkich w użytym surowcu,

2) odmienną zawartość Cr i Fe,

3) odmienną proporcję skandu względem Fe, Th i ziem rzadkich nawiązującą zapewne do odmiennej genezy osadu,

4) odmienną zawartość Rb i Cs, pierwiastków odzwierciedlających udział i genezę minerałów ilastych tworzących surowiec.

Szczególnie odrębna chemicznie jest petrograficzna grupa IV, którą wyróżnia najwyższa zawartość żelaza i hafnu. Hafn jest wskaźnikiem obecności minerałów ciężkich w osadzie, których obecność implikuje z kolei zwiększoną koncentrację pierwiastków ziem rzadkich.

Petrograficzną grupę I charakteryzuje podobna jak w grupie IV proporcja Sc/Fe, a także Sc/ La. Odrębność grupy I w stosunku do grupy IV, a także w stosunku do większej części próbek należących do dwóch pozostałych grup, polega na zwiększonej zawartości Ca. Jednocześnie grupa ta wykazuje niższą od grupy IV średnią zawartość Fe oraz Hf (por. ryc. 57).

Największy stopień pokrewieństwa chemicznego obserwujemy pomiędzy grupami II i III. Podstawowa różnica pomiędzy nimi polega na nieco odmiennej zawartości Ca, związanej z odmiennym charakterem domieszki schudzającej. Obie grupy charakteryzuje wyższa proporcja Sc względem żelaza oraz najniższa zawartość Hf oraz pierwiastków ziem rzadkich.

Stwierdzono, że nie istnieją przesłanki, które pozwalałyby odróżniać naczynia produkowane w Jerycho od naczyń produkowanych w Qumran, co sugerują Gunneweg i Balla (2003).

5. Porównanie ceramiki z Jerycho i Qumran z ceramiką z ez-Zara i Khirbet Mazin, a także z próbkami glin pobranych w terenie

Ceramikę z Jerycho i Qumran porównano z 14 fragmentami naczyń pochodzącymi z ez-Zara, położonej na wschodnim brzegu Morza Martwego, z 5 próbkami dzbanów pochodzącymi z portu Khirbet Mazin, oraz z próbkami glin zebranych w terenie. Gliny te re-

prezentują przede wszystkim cenomańską formację Moza. Do porównania wykorzystano także dwie próbki terra rossy.

Badania petrograficzne dzbanów z ez-Zara wykazały, że 10 próbek zostało wykonanych z tłustego iłu zawierającego piaszczyste ziarna monokrystalicznego kwarcu oraz pojedyncze ziarna piaskowców. Są to cechy ceramiki z Qumran i Jerycho przypisanej do petrograficznej grupy III. Trzy próbki o podobnych cechach petrograficznych wyróżnia znaczna zawartość drobnych, zdysocjowanych podczas wypału muszelek otwornic, co czyni problematycznym ich związek z petrograficzną grupą III. Jedna z próbek została wykonana z surowca o cechach przypominających terra rossę (petrograficzna grupa IV).

Z kolei spośród 5 dzbanów z Khirbet Mazin, 2 reprezentują petrograficzną grupę III, jeden grupę II, jedna z próbek została wykonana z iłu pozbawionego wszelkiej domieszki, zaś jedna zawierała zmienione kryształki oliwinu.

Spośród glin pobranych w terenie, skład chemiczny większości próbek iłów formacji Moza jest bardzo podobny do składu ceramiki przypisanej do petrograficznej grupy II i III. Z kolei całkowicie odrębnymi okazały się próbki iłów Wadi Qumran. Próbki terra rossy są bardzo podobne do próbek garnków tworzących petrograficzną grupę IV.

6. Interpretacja wyników

Poszukując ewentualnych podobieństw lub różnic pomiędzy ceramiką z Qumran a ceramiką z Jerycho należy podkreślić fakt, iż przekazane do badań próbki ceramiki z Qumran reprezentują okres herodiański (stratygraficzny poziom 3A oraz 3C), podczas gdy przebadana ceramika z Jerycho została wykonana w znacznie szerszym przedziale czasowym od okresu hasmonejskiego aż po koniec okresu herodiańskiego. Uzyskane wyniki dowodzą, że hasmonejską, a następnie herodiańską ceramikę z Jerycho, jak też herodiańską ceramikę z Qumran wykonywano stosując alternatywnie jeden z trzech rodzajów surowca, tzn.:

1) zmiennie marglisty ił, charakteryzujący się obecnością kredowych otwornic oraz 5-10% udziałem kwarcu frakcji mułowej **(petrograficzna grupa I)**;

2) tłusty ił, zawierający domieszkę piasku węglanowego **(petrograficzna grupa II)**, kwarcowego, lub kwarcowo-węglanowego **(petrograficzna grupa III)**;

3) żelazistą, raczej chudą glinę o cechach przypominających terra rossę **(petrograficzna grupa IV)**.

Te trzy odmiany surowca różnią się tak pod względem petrograficznym jak i składu chemicznego. Wykonaną z nich ceramikę podzielono na cztery grupy petrograficzne.

Glinę **petrograficznej grupy I** stosowano do produkcji miseczek, dzbanów zasobowych, lampek oliwnych, dzbanków, a niekiedy nawet dzbanów na zwoje. Znaczna liczba naczyń wykonanych z tego surowca wskazuje, że podobnie jak w przypadku gliny tłustej był on powszechnie stosowany, musiał być zatem łatwo dostępny (por. Arnold 2000). Na diagramach korelacji chemicznej naczynia tej grupy tworzą oddzielne skupienie. W zależności od warunków oksydacyjno-redukcyjnych panujących podczas wypału, wykonana z tych glin ceramika uzyskała barwę od czerwonej po jasnobrązową. Surowiec ten wyróżniają przede wszystkim dwie cechy:

– obecność kredowych otwornic *Hedbergella, Heterohelix, Globigerinelloides, Gűmbelitria cenomana* (Keller);

– najwyższa zawartość Ca, wysoka (w stosunku do petrograficznej grupy II i III) zawartość Fe i Cr, oraz wysoka wartość proporcji żelaza, chromu i pierwiastków ziem

rzadkich w stosunku do skandu. Wartość tej proporcji w wielu próbkach podobna jest do tej, jaką obserwujemy w próbkach petrograficznej grupy IV. Grupę tę charakteryzuje również wysoka zawartość hafnu oraz pierwiastków ziem rzadkich (ryc. 55, 57).

Tłustą, zmiennie marglistą glinę **petrograficznej grupy II i III** stosowano do wykonania większości „scroll jars", miseczek, dzbanów, dzbanków oraz kielichów. Dzbany zasobowe wykonane z tego surowca spotykamy w Qumran, Jerycho, Khirbet Mazin, a także ez-Zara/Callirrhoe. Petrograficznie surowiec tej grupy wyróżniają następujące cechy:

– obecność rozproszonych fragmentów łupków ilastych o równoległej orientacji optycznej, zazwyczaj odmiennej w stosunku do ilastego tła,

– bardzo mała zawartość pyłu i mułu kwarcowego, nie przekraczająca 5%, a niejednokrotnie mniejsza nawet od 2%,

– sporadyczna obecność ziaren piaskowców kwarcowych spojonych cementem węglanowym,

– pojedyncze kalcytowe pseudomorfozy po kryształkach dolomitu.

Chemicznie ceramikę tej grupy charakteryzuje:

– wysoka, w stosunku do pozostałych grup petrograficznych, zawartość Sc względem Fe i Cr,

– wysoka zawartość Rb i Cs,

– niższa w stosunku do grupy II zawartość Ca,

– najniższa zawartość Hf oraz pierwiastków ziem rzadkich.

Ceramika wykonana z tej odmiany gliny zazwyczaj nie zawiera szczątków organicznych, które pozwalałyby zidentyfikować wiek surowca. W niektórych próbkach muszelki otwornic są jednak zachowane i podobnie jak w przypadku petrograficznej grupy I, reprezentują kredę górną lub jej dolne pogranicze (alb/cenoman). Choć część tych muszli mogła być dodana wraz z domieszką schudzającą, to przynajmniej obecność niektórych z nich ma niewątpliwie charakter autogeniczny. Dotyczy to zwłaszcza trzech dzbanów z ez-Zara (122, 123, 124).

Najbliższe Qumran jak też Jerycho wychodnie tłustej gliny występują na obszarze Gór Judzkich pomiędzy Hebronem i Rammallah. Są to cenomańskie iły formacji Moza. Po wschodniej stronie basenu Morza Martwego ich odpowiednikiem jest formacja Fuheis, odsłaniająca się ponad Zarga Main[4]. Fragmentarycznie iły tej formacji wykazują budowę łupkową, co potwierdzałoby ich związek z badaną ceramiką. Iły te nie zawierają piasku kwarcowego, tym bardziej ziaren piaskowców. Można więc sądzić, iż jeśli rzeczywiście to z nich wykonano część naczyń, zawarta w ceramice domieszka ziaren kwarcu, skał wapiennych oraz pojawiających się niekiedy piaskowców ma charakter sztucznej domieszki.

Skład chemiczny iłów formacji Moza w dużej mierze nie jest jednorodny i zmienia się wraz ze zmianą barwy zebranych próbek. Może to wskazywać na zmienny charakter warunków utleniająco-redukcyjnych towarzyszących sedymentacji tegoż osadu. Ponadto wykazują one zmienną zawartość węglanów, szczególnie dolomitu. Fakt ten znacznie utrudnia porównanie składu glin tej formacji ze składem badanej ceramiki[5]. Tym niemniej należy podkreślić, że chemicznie próbki tych glin są najbardziej podobne właśnie do naczyń petrograficznej grupy III.

Jako alternatywne źródło surowca o podobnych cechach należy rozważyć dolnokredowe (alb) łupki ilaste grupy Kurnub. Gliny te odsłaniają się w wielu miejscach Transjor-

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[4] Ceramika uzyskana eksperymentalnie z tego surowca jest dobrej jakości.

[5] Zawartość Th będącego jednym z najmniej mobilnych pierwiastków pozostaje stała będąc wskaźnikiem wspólnej proweniencji geotektonicznej tych próbek.

danii, szczególnie pomiędzy północnym wybrzeżem Morza Martwego a Wadi Zarga, a także we wschodniej Samarii. Jednak według Gorena (1995), cechą diagnostyczną tych skał jest znaczna zawartość mułu jak też obecność limonitowych konkrecji. Żadnej z tych cech naczynia przypisane do grupy II i III nie posiadają. Z drugiej strony, za związkiem przebadanej ceramiki z iłami tej formacji przemawiać mogą zachowane ślady struktury łupkowej, a także obecność ziaren kwarcu oraz piaskowców, które w tym wypadku stanowią domieszkę naturalną. Nie można także wykluczyć, iż wykorzystanym surowcem były iły formacji Nezer przykrywające lateralnie strop formacji Shivta.

Chudą i zarazem żelazistą terra rossę (**petrograficzna grupa IV**) wykorzystywano przede wszystkim do wytwarzania garnków do gotowania. Duża zawartość drobnego kwarcu, przy jednoczesnej małej zawartości węglanów oraz podwyższonej zawartości związków żelaza, zapewniały uzyskiwanej ceramice odporność na zmiany temperatury oraz małą porowatość, a tym samym małą nasiąkliwość.

Pod względem chemicznym cechą diagnostyczną tej grupy naczyń jest najwyższa zawartość Fe i Hf przy bardzo małej zawartości Ca. Grupę tę charakteryzują ponadto największe koncentracje Th oraz pierwiastków ziem rzadkich. Grupa IV jest bliższa grupie I niż pozostałym dwóm grupom. Jej odrębność chemiczna w stosunku do grupy I prawdopodobnie jest następstwem zwiększonej zawartości minerałów ciężkich.

7. Czy ceramikę z Qumran wykonano z osadów Wadi Qumran?

Wyniki obserwacji petrograficznych naczyń z Qumran, zwłaszcza te ujawniające ich budowę wewnętrzną, wydają się być szczególnie istotne w kontekście dyskusji nad funkcją osady w okresie herodiańskim oraz skali prowadzonej tam produkcji ceramicznej. Czy funkcjonujące na terenie osady piece zaopatrywały w ceramikę tylko jej mieszkańców, czy też miała tam miejsce intensywna działalność produkcyjna, pokrywające zapotrzebowanie w całym regionie, od Jerycho po En Boqeq? Czy rzeczywiście instalacje wodne dostarczały do Qumran surowiec ilasty w ilości umożliwiającej produkcję naczyń na tak wielką skalę, jak to sugerują Magen i Peleg?

Potwierdzeniem tej hipotezy byłaby jednorodność ceramiki znad Morza Martwego, przede wszystkim wzajemne podobieństwo jej struktury, składu mineralnego i chemicznego przy równoczesnym podobieństwie do osadów Wadi Qumran pochodzących z górnych jego partii, tzn. osadów zdeponowanych ponad węglanową sekwencją osadów należących do grupy Morza Martwego.[6]

Doprowadzana do basenów sedymentacyjnych za pomocą akweduktu zawiesina ilasta powinna mieć homogeniczną strukturę, z pewnością pozbawioną cech typowych dla łupków ilastych, powinna ponadto zawierać zespół mikroszczątków podobnych do tych stwierdzonych w ceramice.

Najbliższe spełnienia tych postulatów są naczynia wykonane z iłu otwornicowego (petrograficzna grupa I). Osad Wadi Qumran wykazuje jednak odmienny skład chemiczny. Jest on znacznie bardziej marglisty, a przede wszystkim wyróżnia go bardzo duża zawartość chromu i uranu przy niskiej zawartości żelaza, rubidu i cezu. Ponadto zawarte w nim mikroszczątki: *Dorothia bulleta* Cushman, *Stensioeina por. exculpta* (Reuss), *Contusotruncana fornicata* (Plummer), *Globigerinelloides escheri* (Kaufman), *Hedbergella bornholmen-*

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[6] Akwedukt był przeprowadzony ponad osadami grupy Morza Martwego, w tym formacji Lissan.

sis Douglas & Rankin, *Hedbergella monmouthensis* (Olsson), oraz *Heterohelix globulosa* (Ehrenberg), w opinii Barbary Olszewskiej mogą (czyli nie muszą) wskazywać na jego młodszy wiek (wyższa część kredy górnej), podczas gdy otwornice zachowane w czerepie naczyń wskazują raczej na niższą część kredy górnej, względnie pogranicze alb/ cenoman[7].

Niewątpliwie większość naczyń z Qumran, w tym przeważająca liczba „scroll jars", została wykonana z tłustej gliny (grupy II i III), ujawniającej pozostałości struktury łupkowej zawierającej także liczne fragmenty łupków ilastych. Ich obecność, brak mikroszczątków typowych dla osadów Wadi Qumran, a przede wszystkim odrębny skład chemiczny dowodzą, iż naczynia te nie zostały wykonane z iłu Wadi Qumran deponowanego w formie zawiesiny[8].

Na pewno naczynia z Qumran wytwarzano przynajmniej z trzech glin o odmiennej proweniencji, w związku z tym zaledwie tylko jedna z nich mogłaby pochodzić z instalacji Wadi Qumran. Nawet jeśli zgodnie z hipotezą Magena i Pelega przyjmiemy, iż rzeczywiście osad Wadi Qumran był wykorzystywany dla celów garncarskich, to należy równocześnie podkreślić fakt, iż nie jest to surowiec dominujący wśród naczyń z Qumran, a wśród odkrytych tam dzbanów stanowi znikomy procent. Dzbany, w tym „scroll jars", wykonano bowiem z czystego iłu zawierającego fragmenty łupków ilastych. Surowiec ten nie występuje w pobliżu Qumran.

8. Wnioski

Przedstawione rezultaty wykazały obecność przynajmniej czterech petrograficznych grup naczyń odkrytych w Jerycho i Qumran. Grupy te charakteryzuje odrębny zespół cech petrograficznych oraz odmienny skład chemiczny.

Do podstawowych cech petrograficznych, różnicujących ceramikę znad morza Martwego należą:

1) zawartość kredowych otwornic w ilastym tle, których duża liczebność jest cechą typową dla petrograficznej grupy I;

2) obecność dużej, umiarkowanej lub nikłej ilości kwarcowo-skaleniowych ziarenek frakcji pelitycznej. Ich duża ilość jest cechą typową dla petrograficznej grupy IV, średnia ilość dla petrograficznej grupy II, a nikła dla petrograficznej grupy II i III;

3) obecność sztucznej lub naturalnej domieszki frakcji piaszczystej: węglanowej – typowej dla petrograficznej grupy II, lub kwarcowej/ kwarcowo-węglanowej, typowej dla petrograficznej grupy III;

4) obecność zachowanych fragmentów łupków ilastych oraz drobnoziarnistych piaskowców, typowej dla petrograficznej grupy III.

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[7] W swojej ekspertyzie Barbara Olszewska pisze: W stosunku do zespołu uzyskanego w procesie przepłukania iłów Wadi Qumran, zespoły ze szlifów wydają się być starsze (pogranicze kredy dolnej i górnej) na co może wskazywać obecność gatunku *Gümbelitria cenomana* (Keller). Brak jest również dużych form obecnych w próbce płukanej. Należy jednak pamiętać, że płukanie próbki sztucznie wzbogaca zespół skamieniałości, natomiast szlif zawiera niewiele szczątków organicznych, zwykle reprezentujących najdrobniejsze formy. W tym materiale są to przedstawiciele rodzajów *Hedbergella, Heterohelix, Globigerinelloides*, stąd jego górnokredowy charakter jest bardzo prawdopodobny.

[8] Nie mogłyby być one transportowane przez wadę akweduktem z uwagi na swą masę.

Zróżnicowanie petrograficzne znajduje odzwierciedlenie w odmiennym składzie chemicznym, szczególnie poprzez odmienną proporcję trzech pierwiastków: Hf, Fe oraz Sc. Odmienny jest także udział ziem rzadkich, Ca, Rb i Cs.

Petrograficzna grupa II oraz grupa III są chemicznie do siebie podobne, a zarazem skrajnie odmienne od grupy IV.

Petrograficzna grupa I wykazuje skład pośredni, ze względu na zwiększony udział związków Fe i Cr, a także Hf i ziem rzadkich, wydaje się być bliższa petrograficznej grupie IV.

Odrębność chemiczna petrograficznej grupy II i III od dwóch pozostałych grup polega głównie na wysokiej proporcji skandu względem żelaza, chromu i ziem rzadkich oraz na podwyższonej względem pozostałych grup zawartości rubidu i cezu. Obecność tych dwóch pierwiastków wskazuje na względnie dużą zawartość potasu w tych skałach, oraz na ich genezę związaną z wietrzeniem szeroko rozumianych kwaśnych skał krystalicznych.

Spośród glin pobranych w terenie, próbki iłów cenomańskiej formacji Moza są chemicznie podobne do składu próbek ceramiki petrograficznej grupy II i III.

Iły górnych partii Wadi Qumran, z pewnością nie były surowcem, z którego wykonano przebadaną ceramikę. Ich próbki są skrajnie odmienne zarówno od próbek badanej ceramiki jak też od pozostałych próbek glin. Odróżnia je bardzo duża zawartość Cr przy niskiej zawartości Fe, wysoka zawartość U, niska zawartości Hf i pierwiastków ziem rzadkich. Wysoką zawartość Cr oraz U w tych osadach najprawdopodobniej jest następstwem bliskiej obecności wychodni skał formacji Hartrurim. Skały tej formacji są bowiem odsłonięte na pustyni, bezpośrednio nad Wadi Qumran.

Dwie próbki terra rossy powstałej wśród kawern cenomańskiej formacji Amminadav są bardzo podobne petrograficznie oraz chemicznie do próbek petrograficznej grupy IV.

Uzyskane wyniki nie przynoszą jednoznacznej odpowiedzi na kwestię, gdzie wykonywano ceramikę odkrytą w Qumran i Jerycho. Bez wątpienia ceramika ta została wykonana z kilku odmian surowca. Był to surowiec kredowy, czerpany przynajmniej w trzech różnych miejscach. Z uwagi na lateralny układ warstw skalnych na obszarze basenu Morza Martwego, bliższe określenie proweniencji tego surowca nie wydaje się możliwe.

Jest wielce prawdopodobne, że tłuste gliny ceramiki przypisanej do petrograficznej grupy II i III reprezentują bądź cenomańską formację Moza, bądź stropową część dolnokredowej grupy Kurnub.

Podwyższone koncentracje Hf oraz ziem rzadkich wśród naczyń petrograficznej grupy I i jednocześnie udokumentowany kredowy wiek otwornic mogą wskazywać, iż użyty surowiec może mieć charakter pedogenicznej zwietrzeliny rozwiniętej na podłożu słabo zdiagenezowanych skał wapiennych wieku kredowego, która została wzbogacona w związki żelaza oraz spokrewnione z nim metale, głównie Cr. Mógł on być także deponowany na dnie jednego z wadi uchodzącego do basenu Morza Martwego.

Jeśli odrzucimy możliwość związku ceramiki grupy I z osadami koryt rzek okresowych, to alternatywnym wytłumaczeniem jej odmienności chemicznej w stosunku do ceramiki grup II i III, także wykonanej z surowca górnokredowego, mogłaby być lokalizacja wychodni jednowiekowych iłów po przeciwległych stronach uskoku transformacyjnego Morza Martwego. W tym wypadku gliny te, choć jednowiekowe, byłyby deponowane w zbiorniku morskim w odległości co najmniej 100 km[9], a więc być może poddane nieco

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[9] 100 km odpowiada skali równoległego przesunięcia Synaju względem Półwyspu Arabskiego.

odmiennym warunkom sedymentacji oraz późniejszej diagenezy, a to z kolei mogłoby zostać odzwierciedlone w składzie zawartych w nich pierwiastków śladowych.

Uzyskane wyniki dają także odpowiedź na kwestie bardziej szczegółowe:

1. W ceramice z Jerycho nie stwierdzono cech petrograficznych, które pozwalałyby odróżnić ceramikę hasmonejską od herodiańskiej.

2. Dzbany na zwoje odkryte w obrębie grot zostały wykonane z tego samego materiału, co dzbany pochodzące z zabudowań Qumran, jednakże z uwagi na powszechne wykorzystanie tego surowca w okresie herodiańskim fakt ten nie może stanowić dowodu na bezpośredni związek manuskryptów z osadą.

3. Większość przebadanych „scroll jars", a także innych typów naczyń użytkowych z Qumran została wykonana z tłustej gliny, która z pewnością nie pochodzi z Wadi Qumran.

6. Lampki typu „Qumran loc. 130" zostały wykonane z tych samych surowców, z których wykonane są pozostałe przebadane naczynia. Nie stwierdzono żadnych cech, które mogłyby świadczyć o ich obcym pochodzeniu.

7. Dwa dzbany mogące wg Bar-Nathan pełnić funkcję przechowywania zwojów zostały wykonane z podobnego surowca, co wysmukłe „scroll jars" z Qumran, podobnie jednak jak w przypadku ceramiki z grot, podobieństwo to należy postrzegać w kontekście powszechnego w tamtym okresie stosowania tego samego surowca.

Przyszłe badania powinny z jednej strony objąć swym zasięgiem znacznie większy asortyment naczyń z Qumran i Jerycho, a z drugiej strony zostać rozszerzone o szczegółowe badania terenowe, gdyż bliższa odpowiedź na temat proweniencji ceramiki znad Morza Martwego nie będzie możliwa bez szczegółowego rozpoznania wychodni skał ilastych po obu stronach Morza Martwego. Niestety, obecnie w warunkach konfliktu bliskowschodniego ten postulat nie jest możliwy do spełnienia.