

# CHEMICAL AND MINERALOGICAL CHARACTERIZATION OF SASANIAN AND EARLY ISLAMIC GLAZED CERAMICS FROM THE DEH LURAN PLAIN, SOUTHWESTERN IRAN\*

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*One hundred and seventy-five glazed ceramics from Sasanian and Early Islamic period sites located on the Deh Luran Plain in southwestern Iran were examined by instrumental neutron activation analysis for characterizing differences in ceramic pastes and by laser-ablation inductively coupled plasma mass-spectrometry for identifying the constituents of the ceramic glazes. The results of the analysis reveal that alkaline-based glazed ceramics have paste compositions that are distinct from contemporary and later ceramics decorated with alkaline-low-lead and lead-based glazes.*

**KEYWORDS:** IRAN, IRAQ, DEH LURAN PLAIN, SASANIAN, EARLY ISLAMIC PERIOD, CERAMICS, GLAZES, LA-ICP-MS, INAA, TECHNOLOGICAL CHANGE

## INTRODUCTION

During the ninth century AD, profound changes took place in the glazed-pottery industries of the Near East. These changes came about primarily in response to the importation of glazed ceramics from China (Lane 1947, 11; Hallett 1999, 1). Many of the technological changes made in Near Eastern ceramics were attempts to simulate the appearance of contemporary Chinese ceramics, including the use of white-glazed backgrounds, the application of multiple colours to a vessel's surface, often in a semi-haphazard manner, and the application of glaze over a moulded surface (Fleming *et al.* 1992). The major technological change that crosscuts all of the new ceramic industries in the Near East is the shift from an alkaline-based glaze to a lead-based glaze (Tite *et al.* 1998). The new glazes were of the transparent high-lead type and contain 45–60% PbO (Mason and Tite 1997). By examining technological and decorative changes that occurred in the ceramic industries of the Near East, we hope to develop a better understanding of how innovation was incorporated into technological systems.

## INNOVATION IN CERAMIC TECHNOLOGICAL SYSTEMS

Change in material culture can be viewed as a consequence of local historical processes under social control (van der Leeuw and Torrence 1989; Sillar and Tite 2000; Lemonnier 2002). In short, technologies have histories that are socially contextualized. The following discussion

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will examine what a history of technology might look like by examining two different states that occur within the history of any given technology.

Innovation consists of the replacement or substitution of a material, device or process having some analogous relationship to a predecessor (Basalla 1988, 209). Innovation usually originates from experimentation by experienced crafts persons (von Hippel 1986, 328). Craft practitioners can be exposed to new technologies and materials through interaction with one another, or by borrowing from other technologies. Changes in the original technology may be required to adapt the new technology to locally available materials, technological knowledge or aesthetic preference (Smith 1981; essays in van der Leeuw and Torrence 1989; Lemonnier 2002).

Foster (1965) and Vandiver (1987, 1988) describe traditional pottery-making technologies as conservative. Technological conservatism results from the standardization of decisions made to produce consistent products. Hence, economic security lies in duplicating, to the best of the potter's ability, those materials and processes that are known from prior experience required to successfully produce a particular kind of pottery. Technology then becomes part of the motor vocabulary, and the reasons for making the original technological choices are lost (Vandiver 1988). At this point, what was once an innovative technology becomes a conservative technology.

Ceramic glazes in the Near East were produced with an alkaline-based flux composition from at least 1700 BCE into the Islamic period (Moorey 1994, 159; McCarthy *et al.* 1995, 58). These alkaline-based glazes contain metallic ions, most commonly copper, which provide a medium-to-light blue colour to the flux (Toll 1943, 2). Other, less common, glaze colorants include iron and manganese. Occasionally, the alkaline flux was used without an added colorant (Simpson 1997, 75). Consistency in glazed-pottery production spanning centuries represents the efforts of potters in dealing with trade-offs in the technology between access to raw materials, differential shrinkage rates between the glaze and ceramic body, and the maximum glaze maturation temperature. Once the technology for production of acceptable vessels using alkaline-based glazes was established, there was little room for additional technological innovation.

#### A DESCRIPTION OF THE CERAMIC SAMPLE AND THE METHOD OF INAA STUDY

Data for interpreting the course of technical change will be derived from analysis of glazed ceramic artefacts recovered from a series of settlements recorded by survey within the Deh Luran Plain (Hole *et al.* 1969; Neely 1969a,b, 1970, 1974; Neely and Wright 1994). The Sasanian and Early Islamic periods were a time of population increase on the Deh Luran Plain, the settlement occurring in small villages and in extensive towns (see Fig. 1). The economy of the Deh Luran Plain was based on intensive agricultural production. Agriculture was conducted using both dry farming and irrigation, the latter based on the extensive use of canals and *qanat*, underground channels that were apparently constructed during the Sasanian period. Intensive agriculture evidenced by the extensive irrigation network and possibly bitumen from several local oil seeps would have served to finance regional trade with nearby contemporary larger settlements such as Susa (Wenke 1987, 257). The continuous occupation of the Deh Luran Plain during the Sasanian and Early Islamic periods (*c.* 224–1250 CE) makes assemblages from the sites producing glazed ceramics ideal for the examination of change in the technology and sources of ceramics during the period under study. The strategy for collection of glazed ceramics from the Deh Luran Plain was variable. Ceramic collections from site locations represent either complete collections of glazed ceramics or smaller collections consisting of distinctive decorative styles and the rims from glazed ceramics (James Neely, pers. comm. 2002). The collections

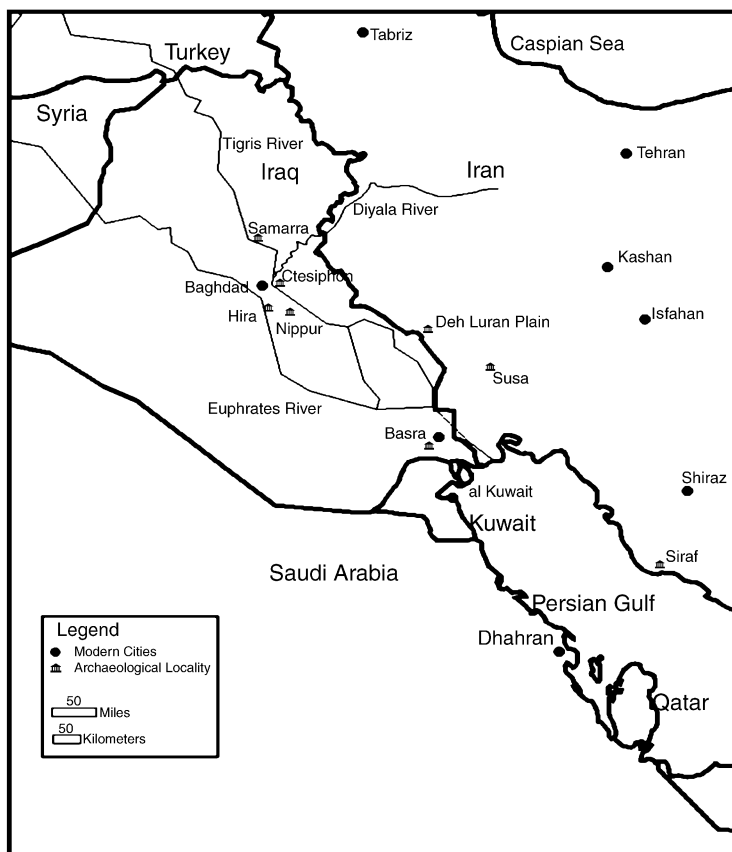


Figure 1 A map showing the location of the Deh Luran Plain in southwestern Iran. Archaeological sites and contemporary cities mentioned in the text are also present.

for the Deh Luran Plain are currently in curation at the Texas Archaeological Research Laboratory, located at the University of Texas at Austin. Occupation dates for the Deh Luran sites are based on ceramic typology and a series of optically stimulated luminescence (OSL) dates obtained from glazed rim sherds (Hill in preparation). A sample of glazed ceramics from the Parthian and Medieval Islamic periods were also included in the present study.

Instrumental neutron activation analysis (INAA) has been conducted on prehistoric and historical ceramics from Mesopotamia since the origin of the analytical technique (e.g., Brooks *et al.* 1974). Since this early study, extensive developments of INAA in terms of methods of analysis and statistical manipulation of the chemical data have occurred (Neff 2000). Regardless of these methodological advances, problems in distinguishing ceramics from some areas within Mesopotamia and Iran have been reported (Berman 1988, 109; Theusen and Heydorn 1990). With INAA, the ability to reliably distinguish between sources depends on the degree of difference between the sources. Under some conditions, alluvial clays may lack sufficient compositional differences to distinguish pottery produced at different sites within the same geomorphic setting.

Hallett (1999), Mynors (1983) and others have conducted successful INAA studies of ancient and historical ceramics from Mesopotamia. Mynors' study involved the analysis of

third millennium BCE ceramics from three widely dispersed locations in Iraq and two sites in the United Arab Emirates. Using the results from INAA, the pottery sample from each site was found to be compositionally unique. Petrographic analysis of a sample of sherds from the five sites found that the pottery from each site contained unique suites of mineral grains. When compared with a previous study of mineral suites present in the alluvial sediments from different areas of the Tigris–Euphrates Basin, the ceramics from Iraq were confirmed as having been produced near where the sherds were recovered (Phillips 1968; Mynors 1983).

Hallett's study of glazed ceramics from the Abbasid period also can be deemed successful. Her sample included ceramics that represented a wide range of contemporary decorative techniques, including polychrome splash glazes, lustrewares, and cobalt-painted and monochrome glazes. The ceramic sample was derived from sites in Egypt, Iran, Iraq, Syria and Thailand. Kiln wasters and rods from Basra were also included in this study. Kiln rods are placed in rows of holes constructed into kilns' walls and used to suspend vessels to keep the fluid glazed surfaces from touching one another during firing. A small sample of ceramics from known sources of contemporary pottery production was included in the study. Analysis of the compositional data found that, with the exception of the ceramics produced elsewhere, some of the monochrome glazes grouped with the kiln wasters and rods from Basra. Hallett interpreted the slight variations observed in the INAA data as indicating the use of more than one source of clay located near Basra (1999, 73). Hallett's research also illustrates that more than one type of decorated pottery was produced at the same locality, including white tin glaze ware, splash glazes and lustreware (Hallett 1999, 71).

Previous INAA studies conducted in Mesopotamia highlight some of the issues of compositional variation that occurs within and between clay sources. Clay sources in some geomorphic areas are so similar that one cannot discriminate between individual sources. However, the entire Tigris–Euphrates Basin is *not* compositionally homogeneous, as some archaeologists would argue (Mynors 1983; Hallett 1999, 73). In the case of Mynors' research, petrographic analysis and INAA independently supported the compositional differences of the ceramics from each of the five sites used in his study. INAA and petrographic analysis can be used in a complementary fashion to identify compositional differences among ceramics from different areas of Mesopotamia and Iran.

In addition to INAA, laser-ablation inductively-coupled-plasma mass-spectroscopy (LA-ICP-MS) was used to identify the composition of the glaze for each of the ceramics whose paste was characterized by INAA. LA-ICP-MS is a surface analysis technique with sensitivities similar to INAA, but it can also be used to generate data for elements that cannot possibly be measured by INAA (e.g., C, S, P and Pb). LA-ICP-MS analyses are conducted more quickly, with little time required for sample preparation and measurement. With its small spot size, LA-ICP-MS is also minimally invasive and one can avoid weathered areas of the glaze (Habicht-Mauche *et al.* 2002). By combining LA-ICP-MS and INAA chemical data, it should be possible to examine technological changes within the products of a single workshop or localized ceramic industry through time.

LA-ICP-MS is an appropriate analytical method for the characterization of ceramic glazes, given its rapid analytical time, low costs and sensitivity to a wide range of elements (Speakman *et al.* 2002; Speakman and Neff 2002, 2005; Neff 2003). By combining glaze composition data with INAA data, it is possible to compare the sources of the different glaze-producing industries. As potters tend to use clays located near their places of residence, continuity in the use of a single clay source though time would represent the stability of a single local industry (Arnold 1985). Thus, a study of regional clay compositional differences during

the Sasanian and Early Islamic periods is likely to be successful in discriminating vessels produced on the Tigris–Euphrates alluvial plain from vessels produced outside of Mesopotamia (Mynors 1983). Analysis of the ceramic sample using INAA provides information regarding the continuity or discontinuity of the productive sources of glazed ceramics over the time period under study.

#### INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS

One hundred and seventy-five samples from 35 sites, drawn from a total of 96 sites, recorded during the Deh Luran survey, that produced glazed ceramics dating to the Sasanian or Islamic periods, were examined using INAA (Table 1) at the University of Missouri Research Reactor

Table 1 *Descriptive information and group assignments for the Deh Luran analysed sample*

<i>I.D.</i>	<i>Site</i>	<i>Description</i>	<i>Time period</i>	<i>INAA</i>	<i>ICP-MS</i>
DVH-001	DL-49	Blue	Sasanian/Samarra	DL-2	MPB
DVH-002	DL-49	Blue	Sasanian/Samarra	Unas.	MPB
DVH-003	DL-49	Blue	Sasanian/Samarra	DL-2	HPB-1
DVH-004	DL-49	Blue	Sasanian/Samarra	DL-2	MPB
DVH-005	DL-62	Blue	Sasanian Medieval Islamic	DL-1	HPB-1
DVH-006	DL-62	Blue	Sasanian Medieval Islamic	Unas.	MPB
DVH-007	DL-62	Blue	Sasanian Medieval Islamic	DL-2	MPB
DVH-008	DL-62	Blue	Sasanian Medieval Islamic	unas.	MPB
DVH-009	DL-62	Blue	Sasanian Medieval Islamic	DL-2	MPB
DVH-010	DL-62	Blue	Sasanian Medieval Islamic	DL-2	MPB
DVH-011	DL-62	Blue	Sasanian Medieval Islamic	unas.	MPB
DVH-012	DL-62	Blue	Sasanian Medieval Islamic	DL-1	MPB
DVH-013	DL-62	Blue	Sasanian Medieval Islamic	DL-1	MPB
DVH-014	DL-62	Blue	Sasanian Medieval Islamic	DL-2	MPB
DVH-015	DL-62	Blue	Sasanian Medieval Islamic	DL-1	MPB
DVH-016	DL-62	Blue	Sasanian Medieval Islamic	DL-1	MPB
DVH-017	DL-62	Blue/mottled with black	Sasanian Medieval Islamic	DL-1	MPB
DVH-018	DL-62	Blue	Sasanian Medieval Islamic	DL-1	MPB
DVH-019	DL-62	Blue	Sasanian Medieval Islamic	DL-1	MPB
DVH-020	DL-62	Blue	Sasanian Medieval Islamic	DL-2	MPB
DVH-021	DL-62	Pea-green	Sasanian Medieval Islamic	DL-1	LPB
DVH-022	DL-62	Pea-green	Sasanian Medieval Islamic	DL-1	LPB
DVH-023	DL-62	Pea-green	Sasanian Medieval Islamic	DL-1	LPB
DVH-024	DL-62	Pea-green	Sasanian Medieval Islamic	DL-1	LPB
DVH-025	DL-62	Pea-green	Sasanian Medieval Islamic	Unas.	LPB
DVH-026	DL-62	Pea-green	Sasanian Medieval Islamic	DL-1	LPB
DVH-027	DL-62	Black	Sasanian Medieval Islamic	DL-1	LPB
DVH-028	DL-62	Black	Sasanian Medieval Islamic	DL-1	MPB
DVH-029	DL-62	Black	Sasanian Medieval Islamic	DL-1	LPB
DVH-030	DL-62	Black	Sasanian Medieval Islamic	DL-1	LPB
DVH-031	DL-62	Black	Sasanian Medieval Islamic	DL-1	LPB
DVH-032	DL-62	Black	Sasanian Medieval Islamic	DL-1	LPB
DVH-033	DL-62	Black	Sasanian Medieval Islamic	DL-1	LPB
DVH-034*	DL-62	Blue	Sasanian Medieval Islamic	DL-2	MPB
DVH-035	DL-62	Crow's foot	Sasanian Medieval Islamic	Unas.	n/a
DVH-036	DL-62	Islamic mottled brown	Sasanian Medieval Islamic	DL-2	HPB-2

Table 1 *Continued*

<i>I.D.</i>	<i>Site</i>	<i>Description</i>	<i>Time period</i>	<i>INAA</i>	<i>ICP-MS</i>
DVH-037	DL-5	Blue	Sasanian	DL-1	MPB
DVH-038	DL-5	Blue	Sasanian	DL-1	MPB
DVH-039	DL-5	Black	Sasanian	DL-1	LPB
DVH-040*	DL-5	Blue	Sasanian	DL-1	MPB
DVH-041	DL-5	Blue	Sasanian	DL-1	MPB
DVH-042	DL-2	Blue	Sasanian/Samarra	DL-2	HPB-1
DVH-043	DL-2	Green splash on white	Sasanian/Samarra	DL-2	HPB-1
DVH-044*	DL-17	Blue glaze exterior and interior	Sasanian Medieval Islamic	DL-2	MPB
DVH-045*	DL-49	Blue-glazed with barbotine decoration	Early Islamic	Unas.	HPB-1
DVH-046	DL-73	Green Sgraffiato	Early Islamic and Samarra	DL-3	HPB-1
DVH-047	DL-62	Black design on blue	Sasanian Medieval Islamic	Unas.	MPB
DVH-048*	DL-36E	Black design on blue	Sasanian Medieval Islamic	DL-1	MPB
DVH-049	DL-12	Blue interior and exterior	Sasanian	DL-2	MPB
DVH-050	DL-52	Blue-glazed with barbotine decoration	Early Islamic	DL-2	MPB
DVH-051	DL-242	Blue	Sasanian/Islamic	DL-2	MPB
DVH-052	DL-17	Pea-green	Sasanian Medieval Islamic	DL-2	LPB
DVH-053	DL-2	Blue with black splash interior	Sasanian/Samarra	DL-2	MPB
DVH-054*	DL-74	Blue	Medieval Islamic	Unas.	MPB
DVH-055*	DL-34	Blue	Parthian	DL-2	MPB
DVH-056	DL-38	Green splash on white base	Parthian/Early Islamic/Samarra	DL-2	HPB-1
DVH-057	DL-2	Blue-glazed with barbotine decoration	Sasanian/Samarra	DL-2	MPB
DVH-058	DL-12	Blue exterior, black interior	Sasanian	DL-2	MPB
DVH-059	DL-242	Blue exterior, black splash on blue interior	Sasanian/Islamic	DL-2	MPB
DVH-060	DL-49	Blue exterior, black splash on blue interior	Sasanian/Samarra	DL-2	MPB
DVH-061	DL-45	Blue exterior, black splash on blue interior	Sasanian	DL-2	MPB
DVH-062	DL-34	Blue exterior, black splash on blue interior	Parthian	DL-2	MPB
DVH-063*	DL-12	Blue exterior, light blue interior	Sasanian	Unas.	MPB
DVH-064	DL-12	Blue exterior, light blue interior	Sasanian	DL-2	MPB
DVH-065*	DL-2	Eroded exterior, blue-green and black on white	Sasanian/Samarra	Unas.	HPB-1
DVH-066*	DL-15	Dark green interior and exterior	Sasanian/Islamic	Unas.	HPB-1
DVH-067*	DL-34	Blue interior bowl	Parthian	DL-2	MPB
DVH-068	DL-252	Cobalt blue interior, eroded exterior	Sasanian/Islamic	DL-2	HNI
DVH-069*	DL-294	Pea-green	Sasanian/Samarra	DL-2	LPB
DVH-070*	DL-294	Pea-green	Sasanian/Samarra	DL-1	LPB
DVH-071	DL-34	Dark green	Parthian	DL-2	MPB
DVH-072*	DL-34	Mottled black/white/pea-green glaze	Parthian	DL-1	LPB
DVH-073	DL-2	Dark green interior and exterior	Sasanian/Samarra	Unas.	HPB-1
DVH-074	DL-111	Blue exterior, light blue interior	Sasanian/Samarra	DL-2	MPB
DVH-075	DL-2	Green splash on white	Sasanian/Samarra	DL-2	HPB-1
DVH-076	DL-294	Dark green interior, light yellow exterior	Sasanian/Samarra	DL-2	HPB-1
DVH-077	DL-40	Blue-glazed with barbotine decoration	Sasanian(?)/Samarra	DL-2	MPB
DVH-078	DL-17	Blue glaze interior, light blue with black spots interior	Sasanian Medieval Islamic	DL-2	NA
DVH-079*	DL-249	Blue exterior, black interior	Sasanian/Islamic	DL-2	MPB
DVH-080	DL-256	Blue glaze exterior, black glaze interior	Sasanian	DL-2	MPB
DVH-081	DL-239	Blue glaze exterior, mottled grey-brown interior	Sasanian/Islamic	DL-2	MPB
DVH-082*	DL-38	Dark green	Parthian/Early Islamic/Samarra	DL-2	HPB-1
DVH-083	DL-38	Brown splash on yellow	Parthian/Early Islamic/Samarra	DL-2	HPB-2
DVH-084*	DL-2	Dark green	Sasanian/Samarra	DL-2	HPB-1

Table 1 *Continued*

<i>I.D.</i>	<i>Site</i>	<i>Description</i>	<i>Time period</i>	<i>INAA</i>	<i>ICP-MS</i>
DVH-085	DL-2	Dark green press-moulded	Sasanian/Samarra	DL-2	HPB-1
DVH-086	DL-262	Pea-green	Sasanian	DL-2	LPB
DVH-087*	DL-74	Black-white mottled	Sasanian Medieval Islamic	DL-1	LPB
DVH-088*	DL-3	White with tan-painted Sgraffiato incisions and green splash	Samarra/Medieval Islamic	DL-3	LPB
DVH-089	DL-16	Blue exterior, black interior	Sasanian/Islamic	Unas.	MPB
DVH-090	DL-90	Blue-glazed with barbotine decoration	Sasanian/Islamic	DL-2	MPB
DVH-091	DL-20	Blue glaze exterior, black glaze interior	Samarra	DL-2	MPB
DVH-092	DL-2	Dark green	Sasanian/Samarra	DL-2	MPB
DVH-093	DL-36C	White-black mottled	Sasanian Medieval Islamic	DL-1	LPB
DVH-094	DL-2	Blue-glazed with barbotine decoration	Sasanian/Samarra	DL-2	MPB
DVH-095	DL-252	Blue-green jar	Sasanian/Islamic	DL-2	MPB
DVH-096	DL-74	Blue glaze with black design	Sasanian Medieval Islamic	DL-2	MPB
DVH-097	DL-74	Blue glaze with black design	Sasanian Medieval Islamic	DL-2	MPB
DVH-098*	DL-74	Green Sgraffiato	Sasanian Medieval Islamic	DL-3	HPB-1
DVH-099	DL-36w	Brown splash on yellow glaze	Sasanian Medieval Islamic	Unas.	HPB-2
DVH-100	DL-2	White majolica	Sasanian/Samarra	DL-2	HPB-2
DVH-101	DL-219	Blue exterior, black interior	Sasanian/Islamic	DL-2	MPB
DVH-102	DL-20	Incised blue exterior, black interior	Samarra	DL-2	MPB
DVH-103	DL-254	Brown lustre	Samarra	DL-2	HPB-2
DVH-104	DL-2	Green splash on white majolica	Sasanian/Samarra	DL-2	LPB
DVH-105	DL-2	Green splash on yellow	Sasanian/Samarra	DL-2	HPB-2
DVH-106	DL-2	Green splash on white majolica	Sasanian/Samarra	DL-2	HPB-1
DVH-107	DL-2	Blue-green splash on white majolica	Sasanian/Samarra	Unas.	HPB-2
DVH-108	DL-2	Green splash on yellow	Sasanian/Samarra	DL-2	HPB-2
DVH-109	DL-2	Green and yellow splash on white majolica	Sasanian/Samarra	DL-2	HPB-2
DVH-110	DL-2	Blue-green splash on white majolica	Sasanian/Samarra	DL-2	MPB
DVH-111	DL-2	Green splash on white majolica	Sasanian/Samarra	DL-2	HPB-1
DVH-112	DL-38	Green and yellow splash on Sgraffiato	Sasanian/Islamic	DL-2	HPB-1
DVH-113	DL-38	Green Sgraffiato with white exterior	Sasanian/Islamic	DL-3	HPB-1
DVH-114	DL-20	Mustard yellow glaze	Samarra	DL-1	LPB
DVH-115	DL-2	Green	Sasanian/Samarra	DL-2	HPB-1
DVH-116	DL-2	Dark green press-moulded	Sasanian/Samarra	DL-2	HPB-1
DVH-117	DL-222	Green Sgraffiato with white exterior	Sasanian/Samarra	DL-3	HPB-1
DVH-118	DL-2	Dark green press-moulded	Sasanian/Samarra	DL-2	HPB-1
DVH-119	DL-2	Dark green press-moulded	Sasanian/Samarra	DL-2	HPB-1
DVH-120	DL-2	Cobalt majolica	Sasanian/Samarra	DL-2	HNI
DVH-121	DL-2	Cobalt majolica	Sasanian/Samarra	DL-2	HNI
DVH-122	DL-2	Brown splash on mustard yellow glaze	Sasanian/Samarra	DL-2	HPB-2
DVH-123	DL-2	Black (Mn) mustard yellow and green splash on white majolica	Sasanian/Samarra	DL-2	HPB-1
DVH-124	DL-56	Green and yellow splash on Sgraffiato on white majolica	Sasanian/Islamic	DL-3	HPB-2
DVH-125	DL-63	Green and yellow splash on Sgraffiato	Sasanian/Samarra	DL-2	HPB-1
DVH-126	DL-36C	Green mottled with brown alkaline glaze	Sasanian Medieval Islamic	Unas.	LPB
DVH-127	DL-2	Cobalt majolica	Sasanian/Samarra	DL-2	HNI
DVH-128	DL-36C	Black glaze	Sasanian Medieval Islamic	DL-1	LPB
DVH-129	DL-36C	Blue-green splash on pea-green	Sasanian Medieval Islamic	DL-1	LPB
DVH-130	DL-36S	Mottled black/white/pea-green	Sasanian Medieval Islamic	DL-1	LPB
DVH-131*	DL-36S	Black	Sasanian Medieval Islamic	DL-1	LPB

Table 1 *Continued*

<i>I.D.</i>	<i>Site</i>	<i>Description</i>	<i>Time period</i>	<i>INAA</i>	<i>ICP-MS</i>
DVH-132*	DL-36S	Pea-green	Sasanian Medieval Islamic	DL-1	LPB
DVH-133	DL-36E	Blue	Sasanian Medieval Islamic	DL-1	MPB
DVH-134*	DL-63	Not glazed, incised zig-zag line	Sasanian/Samarra	DL-1	NA
DVH-135	DL-63	Blue	Sasanian/Samarra	DL-2	MPB
DVH-136	DL-20	White majolica	Samarra	DL-2	Unas.
DVH-137	DL-2	Blue-green splash on white majolica	Sasanian/Samarra	Unas.	MPB
DVH-138	DL-20	Mustard yellow with brown design	Samarra	Unas.	HPB-2
DVH-139	DL-20	Mustard yellow, green and black on white majolica	Samarra	DL-1	HPB-1
DVH-140	DL-73	Sgraffiato with green on white	Early Islamic/Samarra	Unas.	HPB-1
DVH-141	DL-36C	Black line on white	Sasanian/Islamic	DL-1	LPB
DVH-142	DL-24	Blue	Sasanian(?)/Islamic	Unas.	MPB
DVH-143	DL-24	Blue exterior, black splash on light blue interior	Sasanian(?)/Islamic	Unas.	MPB
DVH-144	DL-111	Weathered dark green interior	Sasanian/Samarra	DL-2	HPB-1
DVH-145	DL-2	Blue exterior, black splash on light blue glaze interior	Sasanian/Samarra	DL-2	MPB
DVH-146	DL-2	Dark green exterior, black interior	Sasanian/Samarra	DL-2	HPB-1
DVH-147*	DL-24	Blue glaze exterior, interior eroded	Sasanian(?)/Islamic	Unas.	MPB
DVH-148	DL-2	Blue exterior, light blue interior	Sasanian/Samarra	DL-2	MPB
DVH-149	DL-62	Blue	Sasanian Medieval Islamic	DL-2	MPB
DVH-150	DL-62	Blue	Sasanian Medieval Islamic	DL-1	MPB
DVH-151	DL-62	Blue mottle with black	Sasanian Medieval Islamic	DL-1	MPB
DVH-152*	DL-62	Blue	Sasanian Medieval Islamic	DL-1	MPB
DVH-153*	DL-62	Black glaze	Sasanian Medieval Islamic	DL-1	LPB
DVH-154	DL-62	Black	Sasanian Medieval Islamic	DL-1	LPB
DVH-155	DL-62	Black	Sasanian Medieval Islamic	DL-1	LPB
DVH-156	DL-62	Black	Sasanian Medieval Islamic	DL-1	LPB
DVH-157*	DL-62	Black glaze	Sasanian Medieval Islamic	DL-1	LPB
DVH-158	DL-62	Polychrome pea-green interior, blue spot on exterior	Sasanian Medieval Islamic	DL-1	LPB
DVH-159	DL-73	Blue exterior, black interior	Early Islamic/Samarra	DL-2	MPB
DVH-160	DL-62	Black interior, no glaze exterior	Sasanian Medieval Islamic	DL-1	MPB
DVH-161	DL-74	Mn splash on white	Sasanian Medieval Islamic	DL-1	LPB
DVH-162	DL-62	Dark greenish-brown	Sasanian Medieval Islamic	DL-1	LPB
DVH-163	DL-36	Black line on white slip	Sasanian Medieval Islamic	DL-1	LPB
DVH-164	DL-27	Dark green	Samarra	DL-2	HPB-1
DVH-165	DL-2	Blue	Sasanian/Samarra	DL-2	HPB-1
DVH-191	DL-12	Black splash on blue	Sasanian	DL-2	HPB-1
DVH-192	DL-2	Kufic(?) on white with green splash	Sasanian/Samarra	DL-2	HPB-2
DVH-193	DL-36	Dark blue	Sasanian Medieval Islamic	DL-1	LPB
DVH-194	DL-5	Blue underglaze-painted	Sasanian/Medieval Islamic	DL-1	MPB
DVH-195	DL-34	Dark green	Parthian	DL-2	MPB
DVH-196	DL-2	Cobalt and blue-green design on white	Sasanian/Samarra	DL-2	HNI
DVH-197	DL-62	Black mottled white	Sasanian Medieval Islamic	DL-1	LPB
DVH-198	DL-62	Dark green	Sasanian Medieval Islamic	DL-1	LPB
DVH-199	DL-62	Blue	Sasanian Medieval Islamic	DL-1	MPB
DVH-200	DL-62	Black	Sasanian Medieval Islamic	DL-1	LPB

\*Petrographic sample.



(MURR). A single non-glazed sherd decorated with a tooled zig-zag line and a possible 'crow's foot' were also examined as part of the sample. The single non-glazed sherd was included in the INAA sample for comparison with the results of the analysis of the glazed ceramics. The 'crow's foot' is a triangular object that was used to separate individual vessels during the firing process. The presence of small broken impressions in the glaze observed in the base of a few of the bowl sherds examined during the typological analysis indicates that such a piece of kiln furniture was used by Sasanian and Islamic potters. Crow's feet and the impressions that they leave on glazed vessels have been documented in other contemporary ceramic assemblages. Unfortunately, crow's feet are not temporally sensitive and can represent Iron Age to recent occupation (Simpson 1992, 270). The crow's foot may not be indicative of glazed ceramic production, as it may have remained attached to the bowls it was fired with and transported in that way prior to sale (Hallett 1999, 52). The crow's foot and a possible kiln waster from a large storage jar represent the only evidence of ceramic production recovered from the Deh Luran Plain. Given the very limited evidence for the production of glazed ceramics recovered from the Deh Luran Plain, it is likely that all of the ceramics examined during this study were produced outside of the survey area.

Each sample was first broken into two pieces, one for characterization of the ceramic paste by INAA and the other for LA-ICP-MS analysis of the glaze. The non-glazed sherd and the 'crow's foot' were sampled only for INAA. The samples for INAA were prepared by abrading the exterior surfaces with a tungsten-carbide drill to remove possible contamination from the glaze and other material adhering to the ceramics surface. The samples were then crushed in an agate mortar into a fine powder to homogenize the sample. An aliquot of each sample was weighed into high-purity quartz and polyvials.

As described by Glascock (1992), INAA of pottery at MURR consists of two irradiations and three gamma-ray counts on the quartz and polyvials. A short irradiation is carried out on the polyvials. The pneumatic tube system transports the samples to the reactor core, where they are exposed to a neutron flux of  $8 \times 10^{13} \text{ n cm}^{-2} \text{ s}^{-1}$  using 5-s irradiations. Following irradiation, the sample decays for 25 min before beginning a 12-min count with the HPGe detector to measure the short-lived elements Al, Ba, Dy, K, Mn, Na, Ti and V.

In order to measure elements with longer half-lives, an irradiation of 24 h is also carried out on the samples that were sealed in quartz vials, using a neutron flux of  $5 \times 10^{13} \text{ n cm}^{-2} \text{ s}^{-1}$ . Seven days after the end of irradiation, the samples were counted for 2000 s with an HPGe detector coupled to an automatic sample changer. The second count yields seven medium-lived elements: As, La, Lu, Nd, Sm, U and Yb. After an additional 3–4 week decay, a final count of 10 000 s was conducted to measure the long-lived elements: Ce, Co, Cr, Cs, Eu, Fe, Hf, Ni, Rb, Sb, Sc, Sr, Ta, Tb, Th, Zn and Zr.

The resulting data were analysed using a battery of multivariate statistical procedures. The underlying objective of the use of multivariate statistical techniques to INAA data is to facilitate identification of compositional groups. The first step in the analysis was to transform the abundance data into base-10 logarithms. Initially, the data were subjected to an average link cluster analysis (CA) to identify preliminary groups. The groups identified through CA were then tested using principal components analysis (PCA)—a pattern-recognition procedure used to give an idea of the subgroup structure of chemical compositional data. PCA calculates the orientations and lengths of axes of greatest variance in the data; these are found by eigenvector extraction. The corresponding eigenvalues indicate the length of each eigenvector. The axes are organized in terms of decreasing variance; thus the first principal components express the greatest amount of variance. Employing PCA as a simultaneous RQ-mode technique allows

the simultaneous plotting of elements and samples that contribute to group separation. The R-mode loadings give the co-ordinates of the original elemental concentrations and the Q-mode loadings give the co-ordinates of the objects. To evaluate the coherence of each group, the Mahalanobis distances were used to calculate multivariate probabilities of group membership. Specimens whose Mahalanobis distance lay outside the 1% probability cut-off relative to all groups were left unclassified.

#### THE RESULTS OF THE INAA STUDY

PCA of the INAA ceramic paste data resulted in the identification of three distinct compositional groups and a small group of unassigned sherds. As shown in Figures 2–4 and Table 2, samples assigned to the Deh Luran-1 group form a tight cluster comprised of monochrome ceramics that are primarily attributable to the Sasanian, Early and Medieval Islamic period occupations of the Deh Luran Plain. A single Parthian sherd was also included in this group. Several sherds attributable to the post AD 1250 occupation of the Deh Luran Plain were also assigned to Deh Luran-1, including two blue underglaze-painted examples, one of which produced an OSL date of AD 1750  $\pm$  100 (OxL 1348). This latter sherd is an isolated find and cannot be attributed to a specific site. Two OSL-dated monochrome-glazed sherds from different sites were dated to AD 1230  $\pm$  330 (OxL1353) and 1290  $\pm$  150 (OxL 1351). The incised non-glazed sherd was also a member of Group 1.

Deh Luran-2 consists of a more compositionally and technically variable group. Glazed ceramics members of this group include Sasanian and Early Islamic blue and green coloured monochrome glazes. Five of the six Parthian sherds analysed—one of which was dated by OSL to AD 490  $\pm$  180 (OxL-1350)—were assigned to this group. Also assigned to Deh Luran-2

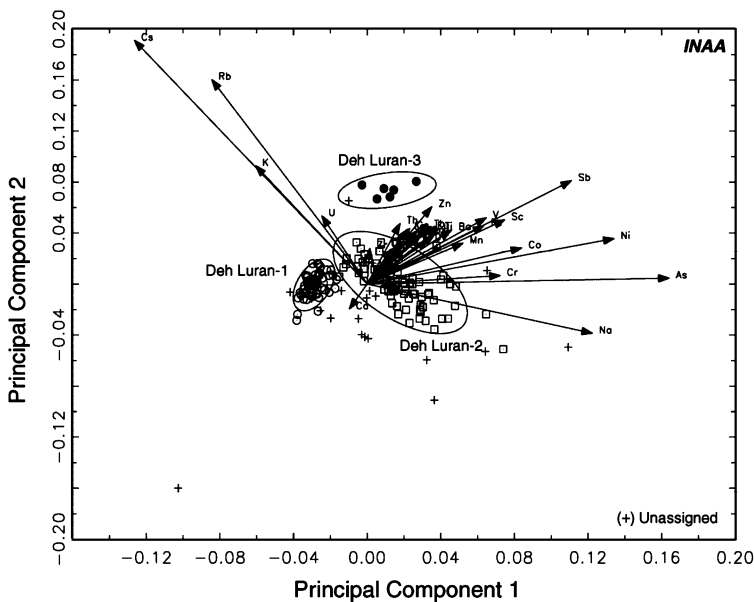


Figure 2 A variance-covariance matrix biplot of principal components 1 and 2, showing the separation of the Deh Luran INAA ceramic paste groups. Ellipses represent 90% confidence intervals for group membership.

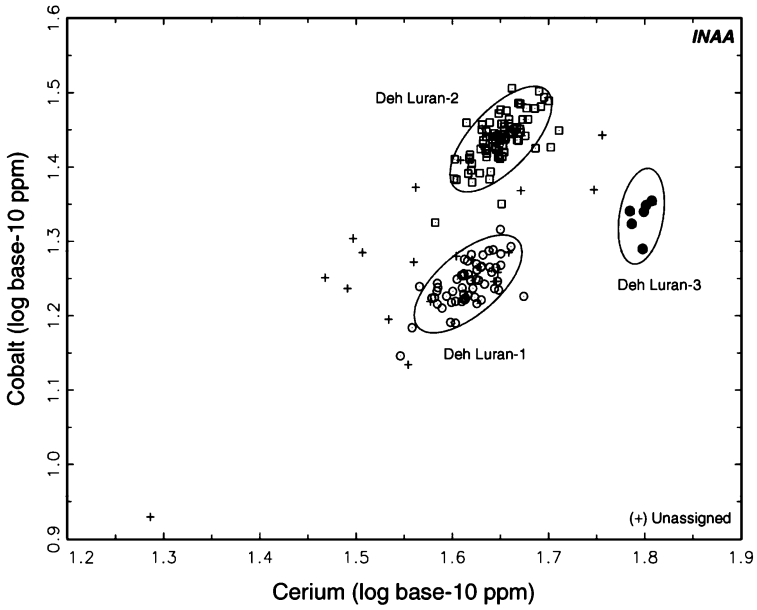


Figure 3 A bivariate plot of cerium and cobalt base-10 logged concentrations, showing separation of the Deh Luran INAA ceramic paste groups. Ellipses represent 90% confidence intervals for group membership.

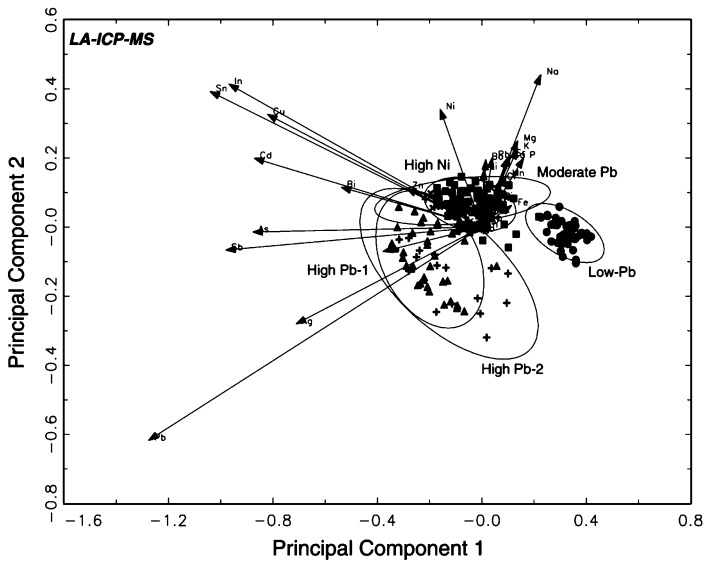


Figure 4 A variance-covariance matrix biplot of principal components 1 and 2 derived from LA-ICP-MS analysis of the Deh Luran glazes. Ellipses represent 90% confidence intervals for group membership.

Table 2 *INAA Paste Group compositions*

<i>Element</i>	<i>Deh Luran-1</i>	<i>Deh Luran-2</i>	<i>Deh Luran-3</i>
As	7.84 ± 1.26	13.75 ± 8.28	21.72 ± 9.62
La	20.42 ± 1.09	22.06 ± 1.17	31.19 ± 0.74
Lu	0.28 ± 0.02	0.31 ± 0.03	0.4 ± 0.01
Nd	18.12 ± 1.51	19.74 ± 1.74	26.21 ± 1.28
Sm	3.88 ± 0.17	4.26 ± 0.22	5.62 ± 0.11
U	2.05 ± 0.41	1.81 ± 0.29	3.14 ± 0.38
Yb	1.83 ± 0.12	2.06 ± 0.14	2.67 ± 0.14
Ce	41.44 ± 2.35	44.74 ± 2.46	62.58 ± 1.16
Co	17.55 ± 1.17	27.36 ± 2.17	21.6 ± 1.05
Cr	229.69 ± 28.11	315.95 ± 74	158.13 ± 4.98
Cs	3.62 ± 0.71	2.68 ± 1.05	7.05 ± 0.51
Eu	0.89 ± 0.04	1.01 ± 0.05	1.23 ± 0.03
Fe (%)	3.41 ± 0.21	4.6 ± 0.28	4.60 ± 0.16
Hf	3.35 ± 0.18	3.39 ± 0.32	4.06 ± 0.1
Ni	116.86 ± 20.46	234.47 ± 34.27	117.77 ± 17.89
Rb	59.1 ± 7.52	46.75 ± 22.15	104.93 ± 6.65
Sb	0.7 ± 0.07	0.96 ± 0.6	4.1 ± 0.38
Sc	12.06 ± 0.79	17.32 ± 0.99	16.92 ± 0.5
Sr	493.59 ± 123.7	496.69 ± 112.83	487.25 ± 152.96
Ta	0.72 ± 0.04	0.81 ± 0.05	1.06 ± 0.04
Tb	0.55 ± 0.06	0.63 ± 0.08	0.85 ± 0.11
Th	6.01 ± 0.39	6.44 ± 0.38	10.43 ± 0.28
Zn	73.77 ± 6.37	87.79 ± 8.44	127.01 ± 8.2
Zr	92.67 ± 16.21	83.71 ± 16.1	119.5 ± 17.24
Al (%)	5.39 ± 0.25	6.34 ± 0.40	7.99 ± 0.25
Ba	368.42 ± 164.45	466.49 ± 288.46	694.03 ± 286
Ca (%)	1.12 ± 0.11	1.16 ± 1.16	5.84 ± 0.37
Dy	3.02 ± 0.27	3.45 ± 0.36	4.39 ± 0.17
K (%)	1.67 ± 0.26	1.27 ± 0.30	2.99 ± 0.12
Mn	764.88 ± 58.3	960.34 ± 70.65	881.5 ± 110.4
Na (%)	0.72 ± 0.10	1.17 ± 0.39	0.93 ± 0.05
Ti (%)	0.33 ± 0.03	0.37 ± 0.04	0.40 ± 0.04
V	81.13 ± 7.46	113.94 ± 15.2	108.89 ± 5.54

are a wide variety of Samarra Horizon glaze types, including splash glazes, Sgraffiato, lustreware, tin-glazed whiteware and press-moulded ceramics. No ceramics that could be stylistically attributed to the post AD 1250 period occur in the Deh Luran-2 group.

Six splash-glazed Sgraffiato sherds comprise the Deh Luran-3 group. Twenty-two glazed ceramics could not be attributed to a single group and were classified as unassigned. Examination of this group of sherds indicates that they represent individual ceramics from non-group-related sources. The 'crow's foot' could not be attributed to a compositional group.

#### PETROGRAPHIC ANALYSIS OF THE DEH LURAN INAA COMPOSITION GROUPS

Petrographic analysis was conducted on a sample of sherds from each of the INAA paste composition groups. The petrographic study was conducted for the purpose of comparing the

current INAA analysis to previous petrographic studies of Early Islamic ceramics. Analysis was conducted using a Nikon Optiphot-2 petrographic microscope.

Eleven sherds assigned to the Deh Luran INAA Paste Composition Group 1 were examined through petrographic analysis. Ceramics in the sample included glaze pottery from the Sasanian and Early Islamic periods. A distinctive characteristic of these sherds was the presence of 5% or less 0.065–0.5 mm rounded calcareous inclusions. The calcareous inclusions have a micritic texture and occasionally contain isolated rounded grains of quartz or untwinned alkali feldspar. It is assumed that these rounded calcareous inclusions represent weathered and possibly redeposited soil carbonate, and as such represent a natural inclusion in the paste of the Compositional Group 1 ceramics, just like the mineral grains and rock fragments described below.

The paste of INAA Paste Composition Group 1 ranges from a medium to a dark reddish-brown colour and contains 1–5% 0.01–0.5 mm sub-angular grains of quartz, untwinned alkali feldspar and brown biotite. Trace amounts of plagioclase, reddish-brown volcanic tuff of aphanitic texture with or without secondary chalcedony, andesine plagioclase in a reddish aphanitic groundmass and biotite schist are also present in the paste of Composition Group 1 ceramics. Individual grains of augite, chert and basalt were observed in one or more of the sherds, but were not universal to the total sample.

A previous petrographic study of Islamic ceramics reports a similar set of inclusions, including 5% quartz, 2% each of biotite, felsic volcanics and biotite schist, 1% untwinned alkali feldspar, plagioclase and trace amounts of plagioclase, amphibole, muscovite, clinopyroxene and opaque inclusions, designated the 'Siraf 4' Petrofabric (Mason 1994, 48). However, the calcareous inclusions observed in the current study were apparently not present in Mason's Islamic material from Siraf or Basra. Carbonate has been recognized in a small sample of Islamic material thought to originate in Hira. However, the rest of the mineral suite recorded for the Hira ceramics differs considerably from that observed in the Paste Composition Group 1 pottery. Consequently, INAA Paste Composition Group 1 represents a new source of ceramic production, one with considerable time-depth.

The single study of the sources of sediment in the Tigris–Euphrates Basin can be used to suggest potential source areas for the production of INAA Paste Group 1 ceramics (Phillips 1968). The Tigris River in its upper reaches receives the majority of its water and sediment from the Greater and Lesser Zab Rivers. These rivers drain the Nappe Zone, a region composed of highly folded and faulted igneous and metamorphic rocks that would have served as sources for water-transported sediments (Dunnington 1958). The presence of both igneous and metamorphic rock fragments in Composition Group 1 indicates a source of the ceramics above Baghdad, where most of the sediments transported by the Tigris drop out as it becomes a meandering stream. Given that many of Composition Group 1 ceramics are of Sasanian age, it is possible that Composition Group 1 glazed ceramics were produced at Ctesiphon or elsewhere in central Iraq.

A sample of 10 sherds from the Deh Luran INAA Paste Composition Group 2 were examined through petrographic analysis. The glazed ceramics examined include Parthian, Sasanian and Early Islamic period pottery. The sherds belonging to INAA Composition Group 2 are characterized by a light yellow or grey, very fine, featureless paste. The paste contains 3% or less silt-sized rounded grains of quartz, with trace amounts of brown biotite and untwinned alkali feldspar. Trace amounts of medium- to coarse-sized rounded grains of quartz and untwinned alkali feldspar are also present in INAA Compositional Group 2 ceramics.

The results of the petrographic study of INAA Paste Composition Group 2 accord well with the description of the 'Basra Petrofabric' (Mason and Keall 1988; Mason 1994, 45). The Basra

Petrofabric was identified in an extensive sample of Early Islamic ceramics and kiln furniture from Basra. Some of the kiln furniture examined by Mason formed a part of Hallett's INAA study. The Basra Petrofabric as identified in ceramics and kiln furniture is characterized by a featureless groundmass containing 2–3% angular quartz, with trace amounts of amphibole and biotite, all under 0.05 mm in size (Mason 1994, 46). Mason also reports a smaller population of 0.25–1.0 mm of trace to 10% quartz, trace to 3% weathered untwinned alkali feldspar, and trace to 1% clear plagioclase (Mason 1994, 46). Given the similarity of the petrographic data between the analysis of the Deh Luran INAA Paste Composition Group 2, previously published descriptions of the Basra Petrofabric and Hallett's previous INAA study of Early Islamic period glazed ceramics, it is likely that these three studies are examining the same source of ceramic raw materials. It is proposed that the resource zone used by Islamic potters living in the vicinity of Basra represents continuity in the use of this source of clay since at least the Parthian period.

Given the small number of sherds that make up the Deh Luran Paste Composition Group 3, only two sherds were examined. The paste of these two sherds is a dark reddish-brown colour. The two sherds contain roughly equal proportions of quartz, untwinned alkali feldspar and brown biotite, which account for 5% of the ceramic paste. These mineral grains range in size from 0.065 to 0.5 mm. Single fragments of moderately well sorted arkose characterized by a reddish-brown cement are present in both sherds. Splash-glazed Sgraffiato sherds with the above paste composition have not been previously identified, so no possible source can be assigned for the ceramics that make up Deh Luran Paste Composition Group 3.

In summary, on the basis of their paste characteristics, the Parthian, Sasanian and Islamic ceramics that make up Deh Luran Paste Composition Group 1 cannot be attributed to a previously identified source. On the basis of Mason's research, which suggests that the mix of volcanic and metamorphic rocks originated in the Taurus Mountains (Mason, 1994), it is possible that these sherds originated in Iraq. The Parthian, Sasanian and Islamic ceramics that comprise Deh Luran Paste Composition Group 2 are likely to have been produced in the vicinity of Basra or elsewhere in the lower Tigris–Euphrates delta, indicating a long history of glazed ceramic production in this region. The origin of the splash-glazed Sgraffiato sherds that make up Deh Luran Paste Composition Group 3 is also unknown.

#### LASER-ABLATION INDUCTIVELY COUPLED PLASMA MASS-SPECTROMETRY

During the past few years, researchers have begun to use LA–ICP–MS to address archaeological questions (e.g., Pollard and Heron 1996; Gratuze 1999; Watling 1999; Devos *et al.* 2000; Gratuze *et al.* 2001; Junk 2001; Speakman and Neff 2002, 2005; Speakman *et al.* 2002; Neff 2003). LA–ICP–MS offers several advantages over other analytical methods, such as high accuracy and precision, low detection limits, rapid analytic time, low cost per sample and high sample throughput, and LA–ICP–MS is minimally destructive to the artefact. One of the more exciting applications of LA–ICP–MS is the *in situ* analysis of pigments and glazes used to decorate pottery.

A major advantage of LA–ICP–MS as a microprobe analytical technique is the ability to obtain data for virtually any element in the periodic table, except oxygen and nitrogen. LA–ICP–MS also can be used to determine elements that are present in the low parts per million (ppm) to parts per trillion (ppt) range. In contrast, other surface techniques, such as SEM, XRF and PIXE, are limited by the number of elements that are detectable and have higher detection limits than ICP–MS.

In LA-ICP-MS, the sample is placed inside a sample holder or laser cell, where ablation takes place. The ablated area varies in size depending on the sample matrix, but is usually smaller than  $1000 \times 1000$  m and less than  $30 \mu\text{m}$  deep. The ablated material is flushed from the laser cell using a  $1.1\text{--}1.3 \text{ l min}^{-1}$  flow of argon or an argon/helium-mixed carrier gas through Tygon tubing, and introduced into the ICP-MS torch, where an argon gas plasma capable of sustaining electron temperatures between 8000 K and 10 000 K is used to ionize the injected sample. The resulting ions are then passed through a two-stage interface designed to enable the transition of the ions from atmospheric pressure to the vacuum chamber of the ICP-MS system. Once inside the mass spectrometer, the ions are accelerated by high voltage and pass through a series of focusing lenses, an electrostatic analyser and finally a magnet. By varying the strength of the magnet, ions are separated according to mass/charge ratio and passed through a slit into the detector, which records only a very small atomic mass range at a given time. By varying the instrument settings, the entire mass range can be scanned within a short period of time.

The instrument used in the studies reported here is a VG Axiom magnetic-sector inductively coupled plasma mass spectrometer, capable of resolving atomic masses as close as 0.001 atomic mass units apart, thus eliminating many interferences caused by molecular ions that pose problems for quadrupole ICP-MS instruments. The ICP-MS is coupled to a Merchantek Nd:YAG 213-nanometer wavelength laser-ablation unit. The laser can be targeted on spots as small as 5 m in diameter. The small spot size and the high sensitivity of magnetic-sector ICP-MS to a wide range of major, minor and trace elements make LA-ICP-MS a very powerful microprobe. Moreover, laser ablation is virtually non-destructive to most samples, considering that the ablated areas are often indistinguishable to the naked eye.

Prior to data acquisition, samples were pre-ablated using the laser to remove possible surface contamination. The power settings for the laser were adjusted to prevent the laser from burning through the glaze during analysis, thus ensuring that the material introduced to the ICP-MS was actually glaze and not the underlying clay matrix. NIST SRM 610 and 612 (glass wafers spiked with ~60 elements), Ohio Red clay and Glass Buttes obsidian were used as standards to calibrate data.

Blank-subtracted, isotopic abundance-corrected counts were calibrated using the Gratuze Method (Gratuze 1999; Gratuze *et al.* 2001; Neff 2003) to produce oxide concentrations for the elements analysed in each sample. The basic assumption of the Gratuze approach is that the elements being measured represent essentially all of the material, other than oxygen, that is ablated from the sample. Oxygen is then taken into consideration by converting the elemental signals to signals of their oxides. Some error may be introduced at this point for elements that occur in more than one oxidation state—particularly iron, which may be present as FeO as well as  $\text{Fe}_2\text{O}_3$ . Additionally, any water in the material is unaccounted for in the summation to 100%, as are some elements, such as chlorine, which may be present but are not measured. These missing measurements may contribute to a slight overestimation of the various measured oxides.

#### THE RESULTS OF THE LA-ICP-MS ANALYSES

Five compositional groups were identified using a combination of PCA and through inspection of bivariate plots (Table 3). Group 1 (low-lead) and Group 2 (moderate-lead) are composed of soda/lime/silica glazes. Group 2 ceramics contain only trace amounts of lead in a soda/lime/silica glaze. The limited amount of lead in the Parthian glazes is thought to result from the

Table 3 LA-ICP-MS Glaze Group compositions

Element	Low Pb (n = 42)	Moderate Pb (n = 77)	High Pb-1 (n = 31)	High Pb-2 (n = 13)	High Ni (n = 5)
Li <sub>2</sub> O	138.11 ± 71.54	210.11 ± 85.76	119.7 ± 72.49	147.77 ± 73.44	200.32 ± 51.97
Na <sub>2</sub> O (%)	9.17 ± 3.05	8.38 ± 2.06	2.32 ± 2.46	1.93 ± 2.02	6.05 ± 0.71
MgO (%)	3.01 ± 1.02	2.79 ± 1.13	1.02 ± 0.66	1.27 ± 1.01	2.45 ± 0.45
Al <sub>2</sub> O <sub>3</sub> (%)	2.72 ± 1.14	328.56 ± 1.14	2.26 ± 1.66	3.21 ± 0.58	2.49 ± 0.59
SiO <sub>2</sub> (%)	70.1 ± 6.4	68.7 ± 4.2	43.1 ± 12.3	42.9 ± 11.3	60.3 ± 8.3
P <sub>2</sub> O <sub>5</sub>	8053.59 ± 2985.26	6220.82 ± 2297.11	2484.45 ± 1783.3	2942.7 ± 2263.8	4739.54 ± 1767.54
SO <sub>3</sub>	85.7 ± 18	88.32 ± 19.36	61.05 ± 10.15	60.48 ± 12.72	74.26 ± 7.76
K <sub>2</sub> O (%)	4.20 ± 0.78	4.04 ± 0.98	1.85 ± 1.58	2.55 ± 2.01	4.54 ± 1.16
CaO (%)	6.89 ± 2.21	7.19 ± 1.94	3.21 ± 1.71	2.74 ± 1.45	5.14 ± 1.08
Sc <sub>2</sub> O <sub>3</sub>	4.6 ± 2.08	4.75 ± 2.21	3.62 ± 2.04	5.07 ± 8.21	3.82 ± 0.55
TiO <sub>2</sub>	1274.13 ± 670.61	1288.27 ± 704.76	1400.45 ± 1138.38	1041.92 ± 680.88	1579.07 ± 436.1
V <sub>2</sub> O <sub>5</sub>	41.77 ± 21.64	49.01 ± 20.3	34.58 ± 17.51	129.34 ± 317.66	42.14 ± 13.55
Cr <sub>2</sub> O <sub>3</sub>	85.39 ± 110.64	162.5 ± 670.06	44.77 ± 52.45	25.17 ± 13.83	45.16 ± 32.49
Fe <sub>2</sub> O <sub>3</sub> (%)	2.63 ± 1.95	1.34 ± 0.62	0.92 ± 0.69	2.26 ± 1.85	3.45 ± 0.92
Mn <sub>2</sub> O <sub>3</sub>	800.06 ± 386.33	922.11 ± 3124.29	719.16 ± 2388.79	2343.12 ± 3931.42	2308.25 ± 2809.55
CoO	82.34 ± 59.64	70.21 ± 27.8	64.33 ± 44.59	69.18 ± 53.18	136.44 ± 20.33
NiO	7.39 ± 4.18	59.49 ± 93.17	15.27 ± 22.83	9.89 ± 7.71	5401.44 ± 2023.17
CuO (%)	0.13 ± 0.73	2.50 ± 1.12	2.49 ± 1.23	0.08 ± 0.05	0.71 ± 0.30
ZnO	195.56 ± 154.38	1417.33 ± 1960.95	2875.82 ± 3762.82	191.05 ± 101.33	4299.83 ± 3342.55
As <sub>2</sub> O <sub>3</sub>	3.28 ± 2.36	341.6 ± 484.35	1223.18 ± 1466.05	1339.54 ± 1473.23	242.32 ± 230.8
Rb <sub>2</sub> O	58.8 ± 28.9	85.57 ± 32.3	48.24 ± 46	78.08 ± 71.51	114.75 ± 39.64
SrO	493.63 ± 180.31	499.97 ± 162.96	213.09 ± 141.12	214.68 ± 145.84	430.81 ± 91.95
Y <sub>2</sub> O <sub>3</sub>	7.43 ± 3.05	10.02 ± 5.38	9.2 ± 6.27	22.42 ± 54.63	9.66 ± 0.9
ZrO <sub>2</sub>	47.09 ± 23.76	71.19 ± 74.33	145.48 ± 188.97	116.08 ± 126.63	220.65 ± 157.83
Nb <sub>2</sub> O <sub>5</sub>	3.97 ± 2.54	4.34 ± 1.38	4.36 ± 2.11	4.37 ± 3.52	4.89 ± 1.00
Ag <sub>2</sub> O	0.36 ± 0.56	4.14 ± 5.3	28.51 ± 19.09	23.69 ± 29.05	3 ± 3.69
CdO	2.34 ± 10.79	51.3 ± 71.31	253.88 ± 490.86	692.85 ± 1271.59	73.6 ± 77.85
InO	0.17 ± 0.88	5.91 ± 5.6	20.89 ± 41.62	58.66 ± 104.93	16.68 ± 13.99
SnO <sub>2</sub>	47.73 ± 274.98	1256.07 ± 1653.7	4829.63 ± 9658.25	12770.49 ± 22746.32	1827.96 ± 1950.25
Sb <sub>2</sub> O <sub>3</sub>	0.97 ± 3.12	92.38 ± 109.82	253.08 ± 339.34	294.44 ± 454.79	41.42 ± 25.41
Cs <sub>2</sub> O	0.65 ± 0.44	0.74 ± 0.49	0.64 ± 0.69	1.24 ± 1.29	1.28 ± 0.33
BaO	185.07 ± 78.70	359.19 ± 179.81	168.56 ± 138.39	149.6 ± 93.13	183.05 ± 69.6
La <sub>2</sub> O <sub>3</sub>	8.12 ± 5.05	10.11 ± 3.12	7.51 ± 4.68	7.67 ± 7.47	9.39 ± 2.02
Ce <sub>2</sub> O <sub>3</sub>	14.64 ± 8.11	16.99 ± 5.07	14.21 ± 11.1	12.94 ± 12.31	16.85 ± 3.29
Nd <sub>2</sub> O <sub>3</sub>	7.74 ± 4.42	8.93 ± 2.68	7.1 ± 4.66	6.83 ± 6.49	9.04 ± 1.92
Sm <sub>2</sub> O <sub>3</sub>	1.41 ± 0.64	1.69 ± 0.7	1.39 ± 0.91	1.99 ± 3.19	1.85 ± 0.67
Eu <sub>2</sub> O <sub>3</sub>	0.35 ± 0.16	0.41 ± 0.21	0.26 ± 0.14	0.26 ± 0.24	0.43 ± 0.17
Tb <sub>2</sub> O <sub>3</sub>	0.22 ± 0.1	0.24 ± 0.11	0.21 ± 0.15	0.52 ± 1.2	0.28 ± 0.1
Dy <sub>2</sub> O <sub>3</sub>	1.09 ± 0.57	1.29 ± 0.48	1.17 ± 0.94	2.73 ± 6.36	1.47 ± 0.36
Yb <sub>2</sub> O <sub>3</sub>	0.69 ± 0.36	0.84 ± 0.32	0.83 ± 0.64	1.59 ± 3.32	1.02 ± 0.24
Lu <sub>2</sub> O <sub>3</sub>	0.09 ± 0.06	0.12 ± 0.05	0.12 ± 0.08	0.23 ± 0.48	0.16 ± 0.04
HfO <sub>2</sub>	1.2 ± 0.78	2.08 ± 4.13	3.69 ± 6.01	3.46 ± 3.98	6.03 ± 2.41
Ta <sub>2</sub> O <sub>5</sub>	0.19 ± 0.13	0.25 ± 0.18	0.27 ± 0.23	0.29 ± 0.36	0.29 ± 0.07
WO <sub>2</sub>	0.22 ± 0.2	0.39 ± 0.27	0.4 ± 0.27	0.4 ± 0.14	0.25 ± 0.06
AuO	0.03 ± 0.04	0.41 ± 1.96	0.34 ± 0.29	0.16 ± 0.09	0.08 ± 0.06
HgO	39.9 ± 32.29	75.4 ± 126.08	67.12 ± 102.75	47.72 ± 16.82	58.9 ± 23.73
PbO (%)	0.007 ± 0.008	0.48 ± 0.45	41.27 ± 18.3	40.77 ± 18.81	12.61 ± 10.89
Bi <sub>2</sub> O <sub>3</sub>	0.27 ± 0.29	4.59 ± 4.72	44.02 ± 204.54	2.13 ± 2.43	3.06 ± 4.17
ThO <sub>2</sub>	2.29 ± 1.49	2.55 ± 0.82	2.5 ± 1.83	3.46 ± 4.9	2.75 ± 0.3
U <sub>3</sub> O <sub>8</sub>	1.07 ± 1.18	0.99 ± 0.53	0.77 ± 0.33	0.92 ± 0.69	1.3 ± 0.16



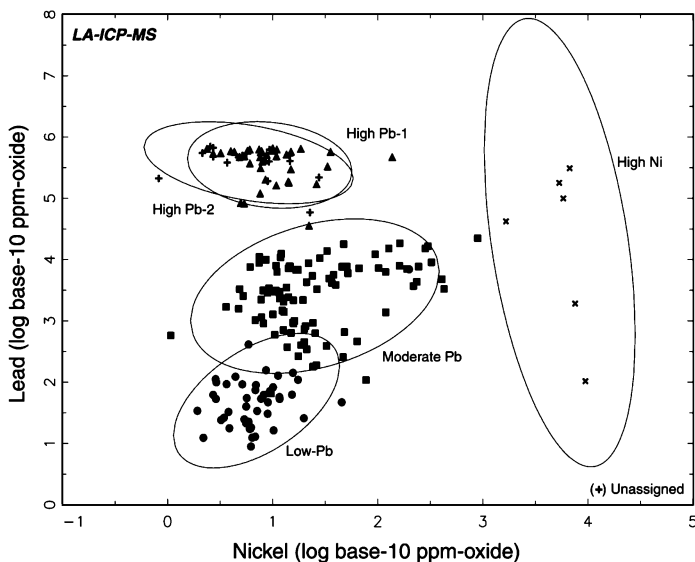


Figure 5 A bivariate plot of nickel and lead base-10 logged concentrations for the Deh Luran glazes. Ellipses represent 90% confidence intervals for group membership.

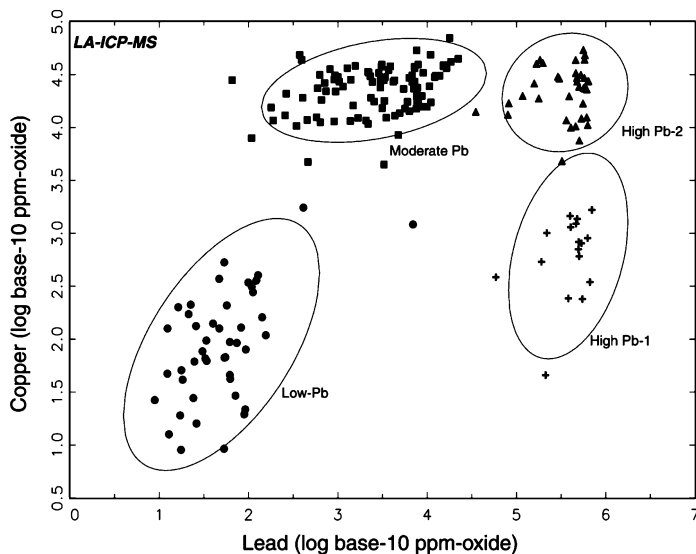


Figure 6 A bivariate plot of copper and lead base-10 logged concentrations for the Deh Luran glazes. Ellipses represent 90% confidence intervals for group membership.

recycling of mixed metal scale during the glaze production process (Wulff 1966, 162). Ceramic glazes that incorporate a soda/lime/silica composition persisted in West Asia for more than 1500 years, before being augmented by a low-lead/alkali/silica glaze (c. 0.5–2% Pb) during the Parthian era of the first century BCE (Hedges and Moorey 1975; McCarthy 1996, 58).

Groups 3 (high-lead 1) and 4 (high-lead 2) glazes are lead-based. The major discriminating element between these two groups is the presence of copper that was used as a colorant. Group 3 high-lead/high-copper ceramics are either blue or green monochrome, press-moulded sherds, with green glazes or green areas of splash glazes. Group 4 includes non-decorated tin-glazed, lustreware and yellow-brown lead stannate coloured glazes.

Group 5 glazes are characterized by high nickel. These sherds were decorated using cobalt as a colorant, and it seems likely that the presence of nickel is indicative of the use of the similar ores for the cobalt. Previous research has suggested that the cobalt used for glaze decoration was from an ore source with a high nickel content (Kleinmann 1991). Deposits of high-purity cobalt–nickel ores are present in shallow deposits in the Anarak mining district in central Iran, which could have served as a possible source of the cobalt used for glaze decoration (Tarkiam *et al.* 1983, 112).

#### A COMPARISON OF CERAMIC PASTE AND GLAZE COMPOSITIONS

All of the soda/lime/silica glazed decorated ceramics are assigned to the Deh Luran-1 and -2 compositional groups. Furthermore, pottery assigned to the Deh Luran-1 paste group includes all of the Group 1 glazes (soda/lime/silica)—the group with the lowest levels of lead. Only three Group-1 sherds, all decorated using a pea-green coloured glaze, were assigned to Deh Luran-2.

In general, soda/lime/silica/low-lead and lead-glazed ceramics (glaze groups 3, 4 and 5) were only associated with the Deh Luran-2 paste group. Only two sherds, a monochrome blue glaze and a mustard-yellow lead stannate glaze with green and black splash, have lead-based glazes and Deh Luran Group 1 ceramic pastes. If the Deh Luran-2 composition represents the products of the Basra ceramic industry, the city's location on the Euphrates and as a seaport might have facilitated easier access to lead ores, which could have originated in Turkey, on the Iranian Plateau or in the Arabian Peninsula. The presence of slightly elevated levels of lead in the glazes of the five Parthian sherds with Deh Luran-2 pastes indicates that potters in Lower Mesopotamia may have gained familiarity with the properties of lead first as an accidental inclusion from the use of recycled metals used for the production of glaze colorants. Experimentation with lead by potters who were already familiar with its properties in glaze colorants may have led to increased usage. However, without isotopic analysis of the lead found in the Parthian sherds and in lead-glazed ceramics, continuity in the source of glazing materials cannot be assumed. Lead isotope ratios collected using LA-ICP-MS are not as accurate or precise as other techniques (Habicht-Mauche *et al.* 2002). Future studies of lead isotope ratios for the low- and high-lead glazes are planned to address the origins and variations in the sources of lead observed in the ceramic glazes during the course of this study.

#### CONCLUSIONS

By combining analysis of the compositions of ceramic pastes and glazes from a series of ceramics whose production spans the development of lead glazes, it is possible to reconstruct a history of this technology. Analysis of the ceramic sample from the Deh Luran Plain has identified two contemporary glaze-making traditions in Mesopotamia. One tradition consists of the production of soda/lime/silica-based glazes. The origin of ceramics representing this tradition is unknown, but possibly lies in the Tigris River above modern-day Baghdad. The use

of soda/lime/silica-based glazes by potters represents a conservative technology. Soda/lime/silica-based glazes continue to be produced contemporarily with lead-based glazes during the Early Islamic period.

A second glaze-producing tradition is present in Lower Mesopotamia. While potters in this area also produced soda/lime/silica based glazes, glazes containing lead appear in Lower Mesopotamia during at least the Parthian period. The presence of small amounts of lead in glazes may be due to the use of recycled metals or possibly copper–lead alloys as a source for glaze colorants. It was this prior experience with lead as an accidental glaze component that probably encouraged its use, possibly to increase the wetting properties of the glaze, which encouraged some potters in Lower Mesopotamia to experiment with the intentional addition of lead to glaze recipes and led to the eventual development of lead-based glazes during the late eight or early ninth centuries CE in Basra.

A third ceramic centre produced exclusively splash-glazed Sgraffiato. The location of this source is unknown.

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#### REFERENCES

- Arnold, D. E., 1985, *Ceramic theory and cultural process*, Cambridge University Press, London.
- Basalla, G., 1988, *The evolution of technology*, Cambridge University Press, New York.
- Berman, J. C., 1988, Ceramic production and the development of complex societies in late prehistoric southwestern Iran, *Ph.D. thesis*, City University of New York.
- Brooks, D., Bieber A. M. Jr., Harbottle, G., and Sayre, E. V., 1974, Biblical studies through activation analysis of ancient pottery, in *Archaeological chemistry* (ed. C. W. Beck), 48–80, Advances in Chemistry Series 138, American Chemical Society, Washington, DC.
- Dunnington, H. V., 1958, Generation, migration, accumulation, and dissipation of oil, in *Habitat of oil* (ed. I. G. Weeks), 1194–251, American Association of Petroleum Geologists, Tulsa, Oklahoma.
- Devos, W., Senn-Luder, M., Moor, C., and Salter, C., 2000, Laser ablation inductively coupled plasma spectrometry (LA–ICP–MS) for spatially resolved trace analysis of early-medieval archaeological iron finds, *Fresenius Journal of Analytic Chemistry*, **366**, 873–80.
- Fleming, S. J., Hancock, R. G. V., Mason, R. B., and Scott, R. E., 1992, Tang polychrome wares: an interaction with the Islamic West, in *Science and technology of ancient ceramics 2, Proceedings of the International Symposium* (eds. L. Jiazhi and C. Xianquo), 211–22, Shanghai Research Society of Science and Technology of Ancient Ceramics, Shanghai, China.
- Foster, G. F., 1965, The sociology of pottery: questions and hypotheses arising from contemporary Mexican work, in *Ceramics and man* (ed. F. R. Matson), 43–61, Viking Fund Publications in Anthropology No. 41, Wenner–Gren Foundation for Anthropological Research, New York.
- Glascock, M. D., 1992, Characterization of archaeological ceramics at MURR by neutron activation analysis and multivariate statistics, in *Chemical characterization of ceramic pastes in archaeology* (ed. H. Neff), 11–26, Prehistory Press, Madison, Wisconsin.
- Gratze, B., 1999, Obsidian characterization by LA–ICP–MS and its application to prehistoric trade in the Mediterranean and the Near East: sources and distribution of obsidian within the Aegean and Anatolia, *Journal of Archaeological Science*, **26**, 869–81.
- Gratze, B., Blet-Lemarquand, M., and Barrandon, J. N., 2001, Mass spectrometry with laser sampling: a new tool to characterize archaeological materials, *Journal of Radioanalytical and Nuclear Chemistry*, **247**, 645–56.

- Habicht-Mauche, J. A., Glenn, S. T., Schmidt, M. P., Franks, R., Milford, H., and Flagal, A. R., 2002, Stable lead isotope analysis of Rio Grande glaze paints and ores using ICP-MS: a comparison of acid dissolution and laser ablation techniques, *Journal of Archaeological Science*, **29**, 1043–53.
- Hallett, J., 1999, *Trade and innovation: the rise of the pottery industry in Abbasid Basra*. Ph.D. thesis, University of Oxford.
- Hedges, R. E. M., and Moorey, P. R. S., 1975, Pre-Islamic ceramic glazes at Kish and Nineveh in Iraq, *Archaeometry*, **17**, 25–43.
- Hill, D. V., in preparation, *Change and continuity in the technology of Sasanian and Islamic glazed ceramic production*, Ph.D. thesis, Department of Anthropology, University of Texas at Austin.
- Hole, F., Flannery, K. V., and Neely, J. A., 1969, *Prehistory and human ecology of the Deh Luran Plain*, University of Michigan Memoirs of the Museum of Anthropology No. 1, University of Michigan, Ann Arbor.
- Junk, S. A., 2001, Ancient artefacts and modern analytical techniques—usefulness of laser ablation ICP-MS demonstrated with ancient gold coins, *Nuclear Instruments and Methods in Physics Research B*, **181**, 723–7.
- Kleinmann, B., 1991, Cobalt pigments in the early blue Islamic glazes and the reconstruction of the way of their manufacture, in *Archaeometry '90: Proceedings of the 27th International Archaeometry Symposium* (eds. E. Pernika and G. A. Wagner), 327–36, Birkhauser, Basel.
- Lane, A., 1947, *Early Islamic pottery*, Faber and Faber, London.
- Lemonnier, P., 2002, Introduction, in *Technological choices: transformation in material culture since the Neolithic* (ed. P. Lemonnier), 1–35, Routledge, London.
- Mason, R. B., 1994, *Islamic glazed pottery: 700–1250*, Ph.D. thesis, University of Oxford.
- Mason, R. B., and Keall, E. J., 1988, Islamic ceramics: petrography and provenience, in *Proceedings of the 26th International Archaeometry Symposium*: (eds. R. M. Farquhar, R. G. V. Hancock and L. A. Pavlish), 184–7, Royal Ontario Museum, Toronto.
- Mason, R. B., and Tite, M. S., 1997, The beginnings of tin-opacification of pottery glazes, *Archaeometry*, **39**, 41–58.
- McCarthy, B. E., 1996, *Microstructure and compositional studies of the technology and durability of ceramic glazes from Nippur, Iraq, c. 250 B.C.–1450 A.D.*, Ph.D. thesis, Department of Conservation, The Johns Hopkins University, Baltimore, Maryland.
- Moorey, P. R. S., 1994, *Ancient Mesopotamian materials and industries: the archaeological evidence*, Eisenbrauns, Winona Lake, Indiana.
- Mynors, H. S., 1983, An examination of Mesopotamian ceramics using petrographic and neutron activation analysis, in *The Proceedings of the 22nd Symposium on Archaeometry, University of Bradford* (eds. A. Aspinall and S. E. Warren), 377–87, University of Bradford.
- Neely, J., 1969a, Field notes, 1968–1969, Archaeological Survey of the Deh Luran Plain, Kauzistan, Southwestern Iran, Notes in possession of J. A. Neely, Department of Anthropology, University of Texas, Austin.
- Neely, J., 1969b, Preliminary report on the Archaeological Survey of the Deh Luran Region, 1968–1969, in *Preliminary reports of the Rice University Project in Iran* (ed. F. Hole), 1–8, Rice University, Houston, Texas.
- Neely, J., 1970, An archaeological reconnaissance of the Deh Luran Plain, 1968–1969, *Iran*, **8**, 202–3.
- Neely, J., 1974, Sasanian and Early Islamic water-control and irrigation system on the Deh Luran Plain, Iran, in *Irrigation's impact on society* (eds. T. E. Downing and M. Gibson), 21–44, Anthropological Papers No. 25, University of Arizona Press, Tucson, Arizona.
- Neely, J. A., and Wright, H. T., 1994, *Early settlement and irrigation on the Deh Luran Plain: village and early state societies in southwestern Iran*, University of Michigan Museum of Anthropology Technical Reports No. 26, The University of Michigan, Ann Arbor.
- Neff, H., 2000, Neutron activation analysis for provenience determination in archaeology, in *Modern analytical methods in art and archaeology* (eds. E. Ciliberto and G. Spoto), 81–134, Chemical Analysis Series, vol. 155, John Wiley, New York.
- Neff, H., 2003, Analysis of plumbate pottery surfaces by laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS), *Journal of Archaeological Science*, **30**, 21–35.
- Pollard, A. M., and Heron, C., 1996, *Archaeological chemistry*, The Royal Society of Chemistry, London.
- Phillips, G., 1968, Mineralogy of recent sediments of Tigris and Euphrates Rivers and some of the detrital deposits, *Journal of Sedimentary Petrology*, **38**, 35–44.
- Sillar, B., and Tite, M., 2000, The challenge of 'technological choices' for materials science approaches in archaeology, *Archaeometry*, **42**, 2–20.
- Simpson, St. John, 1992, *Aspects of archaeology of the Sasanian period in Mesopotamia*, Ph.D. thesis, University of Oxford.

- Simpson, St. John, 1997, Partho-Sasanian ceramic industries in Mesopotamia, in *Pottery in the making: world ceramic traditions* (eds. I. Freestone and D. Gaimster), 74–9, British Museum Press, London.
- Smith, C. S., 1981, *A search for structure: selected essays on science, art, and history*, The MIT Press, Cambridge, Massachusetts.
- Speakman, R. J., and Neff, H., 2002, Evaluation of painted pottery from the Mesa Verde Region using laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS), *American Antiquity*, **66**, 137–44.
- Speakman, R. J., Neff, H., Glascock, M. D., and Higgins, B., 2002, Characterization of archaeological materials by LA-ICP-MS, in *Archaeological chemistry: materials, methods, and meaning* (ed. K. Jakes), 48–63, ACS Symposium Series 831, American Chemical Society, Washington, DC.
- Speakman, R. J., and Neff, H., 2005, *Laser ablation ICP-MS: a new frontier in archaeological characterization studies*, University of New Mexico Press, Albuquerque (in press).
- Tarkiam, W., Bock, D., and Newmann, M., 1983, Geology and mineralogy of the Cu–Ni–Co–U ore deposits at Talmessi and Meskani, central Iran, *Tschermaks Mineralogische und Petrographische Mitteilungen*, **32**, 111–33, Springer-Verlag, Berlin.
- Tite, M. S., Freestone, I., Mason, R., Molera, J., Vendrell-Saz, M., and Wood, N., 1998, Lead glazes in antiquity—methods of production and reasons for use, *Archaeometry*, **40**, 241–60.
- Toll, N., 1943, The green glazed pottery, in *The excavations at Dura-Europos*, vol. IV, Part I (eds. M. I. Rostovtzeff, A. R. Bellinger, F. E. Brown and C. B. Wells), 1–95, Yale University Press, New Haven.
- Thuesen, I., and Heydorn, K., 1990, Instrumental neutron activation analysis of ED I–II pottery from the Diyala Region and Farukhabad, in *Uch Tepe II: technical reports* (ed. M. Gibson), 65–89, Oriental Institute of Chicago, Chicago and Copenhagen.
- van der Leeuw, S. E., and Torrence, R., eds., 1989, *What's new? A closer look at the process of innovation*, Unwin Hyman, London.
- Vandiver, P. B., 1987, Sequential slab construction; a conservative Southwest Asiatic ceramic tradition, ca. 7000–3000 B.C. *Paleorient*, **13**, 9–35.
- Vandiver, P. B., 1988, The implications of variation in ceramic technology: the forming of Neolithic storage vessels in China and the Near East, *Archaeomaterials*, **2**, 139–74.
- von Hippel, E., 1986, Tools for thinking about the sources of innovation in ceramic materials and processes, in *High-technology ceramics: past, present, and future* (ed. W. D. Kingery), 325–33, The American Ceramic Society, Inc., Westerville, Ohio.
- Watling, R. J., 1999, Novel applications of laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) in the field of forensic science and forensic archaeology, *Spectroscopy*, **14**(6), 16–34.
- Wenke, R. J., 1987, Western Iran in the Partho-Sasanian period: the imperial transformation, in *The archaeology of western Iran* (ed. F. Hole), 251–72, Smithsonian Institution Press, Washington, DC.
- Wulff, H. E., 1966, *The traditional crafts of Persia*, The MIT Press, Boston.