



## Analysis of Glass from Veshnaveh

James Lankton, Bernard Gratuze

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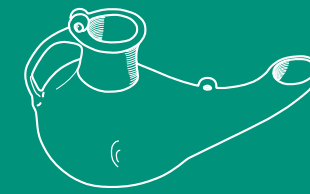
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Depositional Practices at the Natural  
Sanctuary of Veshnaveh, Central Iran

DER ANSCHNITT

BEIHEFT  
46

# Depositional Practices at the Natural Sanctuary of Veshnaveh, Central Iran



Jewellery and Watery Caves

Natascha Bagherpour Kashani



DER ANSCHNITT BEIHEFT 46

# Mining Archaeology in Iran 1

Research in Veshnaveh 1



# Depositional Practices at the Natural Sanctuary of Veshnaveh, Central Iran

## Jewellery and Watery Caves

Natascha Bagherpour Kashani

with a contribution on glass analysis by James Lankton and Bernard Gratuze

Mining Archaeology in Iran 1

Research in Veshnaveh 1



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#### Cover Image

View into Chale Ghar 1 (photo: K. Stange, AVttention).

#### Frontispiece

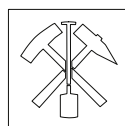
The donkey carries the equipment for the excavation at Chale Ghar (photo: M. Ecker).

The dissertation was submitted in May 2011 under the title "Studies of Ancient Depositional Practices and Related Jewellery Finds, Based on the Discoveries at Veshnaveh: a Source for the History of Religion in Iran" at the Faculty of History of the Ruhr-University Bochum, Germany, where it was published online in December 2014 and is available at: <https://nbn-resolving.org/urn:nbn:de:hbz:294-42741>. The present work is based on the research status of 2014 and supplemented with current literature until the preparation of the print manuscript.

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GEFÖRDERT VOM

Bundesministerium  
für Bildung  
und Forschung

*For my daughter Roya, who had accompanied this thesis  
since her first heartbeat.*





# Content

<b>Prefaces</b> .....	<b>9–10</b>
<b>1 Introduction and Background</b> .....	<b>11</b>
1.1 Veshnaveh: A Copper Mining Area .....	11
1.2 Aims, Questions and Methods .....	12
1.3 Previous Works on Arsacid and Sasanian Jewellery .....	13
1.4 Important Archaeological Sites for the Analysis of the Veshnaveh Material .....	15
1.5 Applied Techniques of glass and stone jewellery from Veshanveh .....	17
<b>2 Catalogue: Description and Interpretation of the Finds</b> .....	<b>25</b>
2.1 Coins .....	29
2.2 Beads .....	30
2.3 Pendants .....	127
2.4 Inlays and Gem .....	137
2.5 Finger rings .....	141
2.6 Earrings .....	159
2.7 Metal Sheets .....	165
2.8 Miscellaneous Objects .....	170
2.9 Summary: Content and Results of the Catalogue .....	184
<b>3 Excursus: Chemical Analyses</b> .....	<b>193</b>
3.1 Outline of Archaeometrical Analyses of Iranian Glass and Amber .....	193
3.2 Analysis of Glass from Veshnaveh .....	194
3.3 Analysis of Metal from Veshnaveh .....	206
3.4 Analysis of Amber from Veshnaveh .....	207
3.5 Conclusion .....	208
<b>4 Stratigraphy and Chronology of Chale Ghar 1 and 2</b> .....	<b>209</b>
4.1 Chronology of the Main Chamber of Chale Ghar 1 .....	209
4.2 Chronology of the Rear Chamber of Chale Ghar 1 .....	213
4.3 Chronology of the Entrance Area of Chale Ghar 1 .....	213
4.4 Chronology of Chale Ghar 2 .....	213
4.5 Conclusion .....	214
<b>5 Cultural and Religious Interpretation of Chale Ghar 1 and 2</b> .....	<b>217</b>
5.1 Considerations on the Exchange of Goods at Veshnaveh .....	217
5.2 Trade Routes in Iran – a Note .....	220
5.3 The Symbolic Meaning of the Jewellery Artefacts from Veshnaveh .....	222
5.4 Chale Ghar 1 and 2 – a Sanctuary .....	231
5.5 The Visitors of Chale Ghar 1 and 2 .....	235
5.6 Depositional Practices .....	237

<b>6 Summary.....</b>	<b>251</b>
6.1 The Discovery of the Sanctuary at Veshnaveh .....	251
6.2 The Examination of the Sanctuary at Veshnaveh .....	251
6.3 Perspective.....	255
 <b>Bibliography.....</b>	 <b>257</b>
<b>Maps .....</b>	<b>273</b>
<b>Plates .....</b>	<b>279</b>

## 3.2 Analysis of Glass from Veshnaveh

### 3.2.1 The Samples (Tab. 3.2.1)



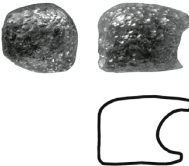

In 2010 it was possible to export eight fragments of glass beads from Iran for technical and chemical analysis at the UCL Institute of Archaeology in London, and at the IRAMAT, Institut de Recherche sur les Archéomatériaux, Centre Ernest Babelon, C.N.R.S., at Orléans in France (Lankton/Gratuze in this volume). James Lankton and Bernard Gratuze performed the analyses and obtained striking results. At this point the samples are described first, then J. Lankton and B. Gratuze present

their analyses, which are discussed in a final section by the author of this monography.

The eight glass samples were selected on account of their technical distinction and whenever one bead belonged to a group of beads that could be termed a type. Owing to Iranian regulations it was possible to export only a small number of fragmented beads, one complete spherical blue glass bead being an exception (no. 4419f).



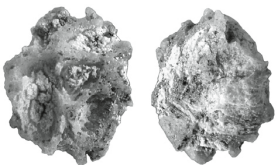

Three fragments of simple beads and one pendant were chosen for analysis (pl. 6, no. 1872h; nos. 4419f; pl. 8, no. 4582b; no. 4596d; pl. 23, no. 4189b). Another three fragments belonged to individual beads manufactured with noticeable techniques like the mosaic technique (nos. 1831a, 4416b; pl. 11, no. 4483).

Tab. 3.2.1: Eight glass samples from Veshnaveh that were chosen for analysis.

Find Number	Feature	Type <sup>60</sup>	Measurements	Illustration
1831a	10013	Not assigned to a special type	D. 1.24 cm, L. 1.2 cm	 <p>scale 1:1</p>
1872h	10013	Overlay bead	D. 0.5 cm, L. 0.45 cm	 <p>scale 2:1 (pl. 6)</p>
4189b	10012	Conical-shaped pendant	D. 0.43 cm, L. 0.55 cm	 <p>scale 2:1 (pl. 23)</p>
4416b	10012/5-6	Stripe-/trail-decorated bead	D. 2.04 cm, L. 1.26 cm	 <p>scale 1:1 (pl. 9)</p>

<sup>60</sup> The type here denotes the category under which the bead is described in this volume. Lankton and Gratuze technically specify in their table 3.2.2.4.1. For example, they categorise the powder bead as mosaic bead.

Tab. 3.2.1: Eight glass samples from Veshnaveh that were chosen for analysis.

Find Number	Feature	Type <sup>60</sup>	Measurements	Illustration
4419f	10012/5	Blue ring-shaped bead	D. 0.46 cm, L. 0.25 cm	 scale 2:1
4483	10012/6	Powder bead	D. 2.4 cm, L. 1.7 cm	 scale 1:1 (pl. 11)
4582b	10014	Greenish-yellowish bead fragment	D. 0.55 cm, L. 1.06 cm, W. 0.8 cm	 scale 2:1 (pl. 8)
4596d	10013	Wound bead of yellow, red, white and blue glass	D. 0.75 cm, L. 0.33 cm	 scale 2:1 (pl. 7)

No. 1872h is an overlay bead with a colourless translucent glass core and a blueish green cover (pl. 6; tab. 3.2.1). Nineteen more beads of this kind were excavated in Chale Ghar 1 and classified as so-called overlay beads.<sup>61</sup> The ring-shaped blue bead no. 4419f is one of fifteen similar dark blue glass beads that nonetheless vary slightly in size and appearance.<sup>62</sup> Very fragmented and corroded, but with three counterparts is the green-and-yellow piece of glass bead, no. 4582b (pl. 8; tab. 3.2.1).<sup>63</sup> It consists of layers or facets of green and very corroded yellow glass. One bead made of four different-coloured glasses that alternate in horizontal stripes or rings; this bead very clearly represents the group of twelve beads with concentric different-coloured rings (pl. 7, no. 4596d; tab. 3.2.1).<sup>64</sup>

The fragment of a conical pendant of translucent blue glass no. 4189b (pl. 23; tab. 3.2.1) was analysed as

being representative of three conical blue glass pendants that were found in Chale Ghar 1.<sup>65</sup>

Among the Veshnaveh beads one spherical bead made of opaque white, red and translucent green glass was not designated as belonging to a special type of bead (no. 1831a; tab. 3.2.1), but is interesting because of its technical features. The three differently coloured glasses seem to have been fused into each other without a comprehensible pattern.<sup>66</sup> By contrast, the fragment no. 4416b (pl. 9; tab. 3.2.1) was manufactured with clear vertical and horizontal stripes of black, white, green, yellow and red-brown glass.<sup>67</sup> No. 4483 has a red-and-yellow eye decoration against a blueish background. It is referred to in the chapter about the eye beads (pl. 11; tab. 3.2.1).<sup>68</sup>

<sup>61</sup> See paragraph about overlay beads.

<sup>62</sup> Dark blue ring-shaped beads made of translucent glass include: nos. 1716d, 1821e, 1825a, 4179a, 4407g, 4419h, 4457e, 4468c, 4578d, 4666c, 6264a6, 6347, 6841, 6961b1 (see paragraph about monochrome glass beads: blue ring-shaped beads).

<sup>63</sup> Counterparts are nos. 4496h, 4570b, 4579e. See chapter about beads with various forms of horizontal stripe decoration.

<sup>64</sup> See paragraph 2.2.3.

<sup>65</sup> See paragraph 2.3.1.1.

<sup>66</sup> In the first instance this bead was classified with the overlay beads: green/blue overlay beads with yellow or white cores, but a new classification needs to be considered.

<sup>67</sup> See paragraph 2.2.3.

<sup>68</sup> See paragraph 2.2.6.5.

### 3.2.2 Glass from the Chale Ghar 1 mine, Veshnaveh, Iran: Technological and chemical compositional analysis

by James Lankton and Bernard Gratuze

#### 3.2.2.1 Introduction

We analysed a total of eight different beads or bead fragments found in the ancient mine Chale Ghar 1, near the village of Veshnaveh in the central mountains of Iran. Seven of the samples were recovered through sieving of excavated material, while the eighth sample was found in situ. It was evident from the excavations that these glass objects had been deposited long after the active period of copper extraction from the mine, but not clear what the actual dating of the material might be, with associated ceramics from the Arsacid period and ornaments suggesting a Sasanian date. Radiocarbon dating, combined with the find of an Islamic coin, gave a broad date range from 800 BCE to the 8th century CE.

Important archaeological questions relating to the glass finds revolved around issues of dating, technology and provenance of the various beads or bead fragments. In particular:

1. How were the various beads made, and what are the implications for these technologies?
2. Does the chemical composition of the glass itself help us to understand the provenance of the finished objects, and, in particular, is there any evidence for centralized, or even localized, production?
3. Where does the glass evidence fit along the broad chronological continuum suggested for the site?

#### 3.2.2.2 Materials

One intact bead and fragments of seven others were presented for analysis (Fig. 3.2.2.2). Samples are listed in Table 1, along with brief descriptions including possible date, method of manufacture, colour, size and overall chemical compositional type.

#### 3.2.2.3 Methods

For manufacturing technology, the beads were examined with a binocular microscope at low to medium power. In order to determine the chemical composition of the glass, all samples were analysed by the authors at IRAMAT, Institut de Recherche sur les Archéomatériaux, Centre Ernest-Babelon (CNRS/Univ. Orleans), Orleans, France, using the technique of laser ablation-inductively coupled plasma-mass spectrometry (LA-ICPMS). LA-ICPMS provides 'virtually non-destructive' analysis, and is particularly useful for archaeological samples that cannot be destroyed, since the sampling mark left on the object

is invisible to the naked eye. The LA-ICPMS equipment consists of four parts: a Nd:YAG (Yttrium Aluminium Garnet) pulsed laser with wavelength 266 nm used to release a small amount of material from an area approximately 100 microns in diameter by 200 microns deep; an argon plasma torch to fully dissociate the glass into its component ions; a magnetic sector mass spectrometer to separate the various ions present and a three stage detector system: a conventional dual mode secondary electron multiplier combined with a single Faraday collector. The outer, weathered, glass present on all ancient samples is removed by a pre-ablation of 20 to 30 seconds, followed by an analytical time of 60 seconds. The precision and accuracy of the LA-ICPMS method for glass analysis may be determined by measurement of glass standards of known composition, and, in general, range from 5 to 20 relative percent for most elements. For archaeological glasses that are seldom entirely homogeneous in composition, precision will vary with the degree of heterogeneity and the actual spots sampled, and, while the measurement may be accurate for the particular area analysed, whether it is accurate for the entire object must be considered during the interpretation of the results. In all, we performed 27 individual analyses for the eight beads, since each colour was analysed separately. For a more complete explanation of the analytical procedures please see Gratuze (2013).

The raw chemical data, including trace elements, were compared to that of published and unpublished samples from our database, using the multivariate statistical tools Principal Component Analysis (PCA) and cluster analysis.

#### 3.2.2.4 Results

As stated above, the general chemical types of the glass samples, along with the forming technology where this could be determined, are indicated in Tab. 3.2.2.4.1. The complete compositional results are given in Tab. 3.2.2.4.2. From the eight original objects, we report a total of 22 analyses, reflecting separate analyses for each colour on the multi-colour beads. Major and a few minor elements are reported as weight percent (wt%), and most minor and trace elements as parts per million (ppm, where 1000 ppm equals 0.1 wt%). All areas sampled were soda-lime-silica glass with magnesia (MgO) values greater than 1.5%, suggesting the use of plant ashes as the source of alkali or flux for the glass. This glass type has been designated HMG (Sayre and Smith, 1961) because of the relatively high MgO levels. Metals and metal oxides used as colorants include copper ( $\text{Cu}^{2+}$ ) for greenish blue and green (particularly when in the presence of lead), precipitated metallic Cu for red, cobalt ( $\text{Co}^{2+}$ ) for dark or purplish blue, and tin-lead (Sn-Pb) oxide for yellow. Black areas are rather high in iron ( $\text{Fe}^{3+}$ ) and white glass is coloured and opacified with precipitated tin oxide ( $\text{SnO}_2$ ).



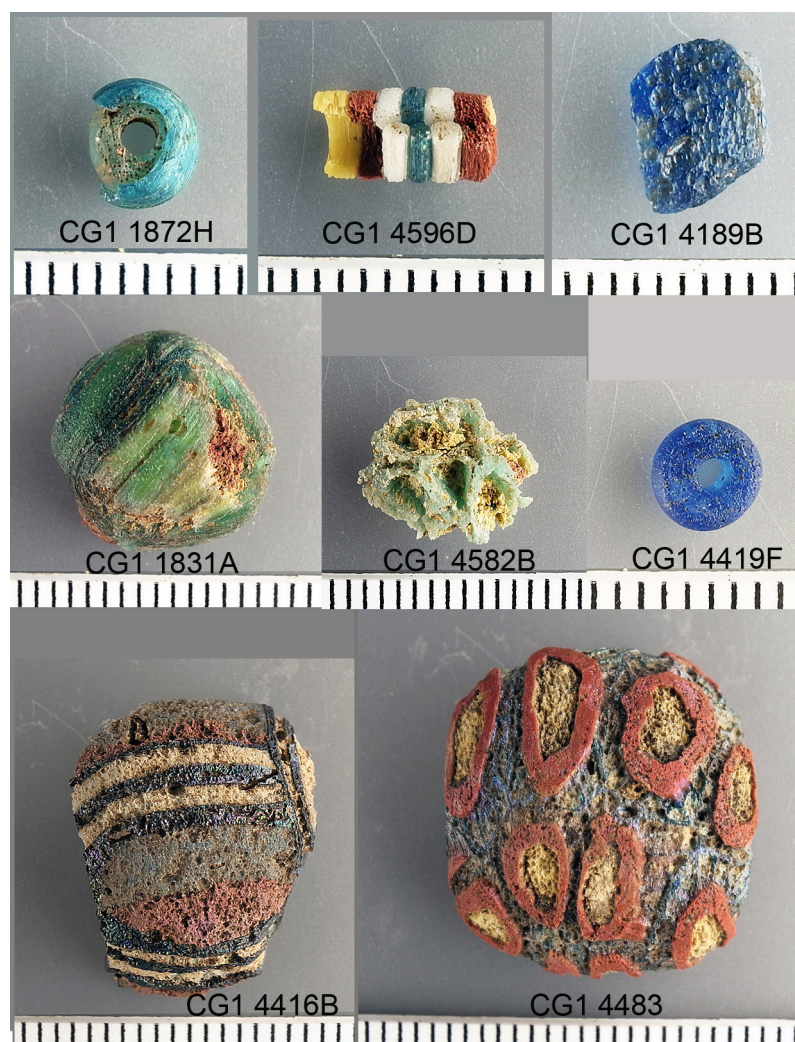


Fig. 3.2.2.2: Composite photograph of Chale Ghar 1 bead samples. Note that large and small beads are to different scales (in mm) (photos: J. Lankton).

Tab. 3.2.2.4.1: Sample list including suggested date, forming technology, colour, size and glass compositional type HMG (high-magnesia plant-ash glass).

number	date	technology	colour	size (mm) <sup>69</sup>	type
CG1 1831a	Early Islamic	pierced cane mosaic bead	green, red, yellow	20	HMG
CG1 1872h	Sasanian ?	wound layer over core	greenish blue, colourless	5	HMG
CG1 4189b	Early Islamic	bead fragment	cobalt blue	5	HMG
CG1 4416b	Sasanian	mosaic layer over core (?)	blue, green, red, white, black	20	HMG
CG1 4419f	Sasanian	drawn bead	cobalt blue	4	HMG
CG1 4483	Early Islamic	fused-cane millefiori mosaic bead	blue, red, yellow	20	HMG
CG1 4582b	Sasanian	fused-cane millefiori mosaic bead (?)	green, red, yellow	10	HMG
CG1 4596d black	Sasanian	rolled pad mosaic bead	black, red, white, yellow	7	HMG

<sup>69</sup> Due to different measuring methods, the values in table 3.2.1 differ, i.e. the diameter or the length of a bead can vary when using different methods. In principle, however, the largest length or diameter applies. Since the beads were returned to Ghom, Iran, we were unfortunately unable to subsequently check which measurement was correct.

Tab. 3.2.2.4.2: Chemical compositions in wt% (weight percent, major and some minor elements) and ppm (parts per million, trace elements).

	number	CG1 1831A green	CG1 1831A red	CG1 1831A yellow	CG1 1872H gr. blue	CG1 1872H colourless	CG1 4189B blue
SiO <sub>2</sub>		63.7%	59.4%	63.6%	66.8%	69.7%	62.3%
Na <sub>2</sub> O		16.3%	16.0%	15.5%	12.7%	13.8%	17.9%
K <sub>2</sub> O		2.3%	2.2%	2.4%	2.5%	2.3%	4.6%
MgO		3.8%	3.8%	4.1%	3.1%	2.4%	4.0%
CaO		8.6%	8.0%	8.9%	8.1%	7.9%	6.8%
Al <sub>2</sub> O <sub>3</sub>		1.2%	1.2%	1.1%	0.9%	1.3%	1.4%
Li		31	24	23	15	9	6
B		86	87	90	64	71	90
P <sub>2</sub> O <sub>5</sub>		0.2%	0.5%	0.2%	0.2%	0.3%	0.3%
Cl		9860	8922	9941	9427	8646	9043
Ti		320	405	318	330	471	457
V		14	25	16	13	21	16
Cr		12	22	12	26	84	44
MnO		0.23%	0.27%	0.36%	0.06%	0.03%	0.27%
Fe <sub>2</sub> O <sub>3</sub>		1.0%	2.7%	0.9%	0.8%	1.1%	0.9%
Co		3	6	3	3	3	258
Ni		24	113	20	42	33	106
CuO		0.9%	1.9%	1.0%	3.49%	0.0%	0.21%
Zn		87	95	85	130	54	74
As		74	241	76	30	3	3
Rb		40	28	36	10	14	9
Sr		618	586	660	492	511	341
Y		3	3	2	3	3	3
Zr		16	18	15	15	20	17
Nb		0.8	0.9	0.7	0.8	1.3	1.2
SnO <sub>2</sub>		0.1%	0.9%	0.1%	0.1%	0.0%	0.0%
Sb		67	368	79	12	3	3
Cs		4.9	2.1	4.7	0.4	0.6	0.1
Ba		97	219	190	110	56	69
La		2.6	3.0	2.6	2.8	3.7	3.0
Ce		5	6	5	7	7	5
Nd		2.5	2.8	2.5	3.5	3.8	2.6
Sm		0.7	0.8	0.6	0.5	0.8	0.6
Eu		0.2	0.2	0.2	0.1	0.2	0.1
Tb		0.1	0.1	0.1	0.1	0.1	0.1
Dy		0.6	0.6	0.5	0.5	0.6	0.5
Ho		0.1	0.1	0.1	0.1	0.1	0.1
Tm		0.0	0.0	0.0	0.0	0.0	0.0
Yb		0.3	0.3	0.3	0.3	0.4	0.3
Hf		0.4	0.5	0.5	0.4	0.6	0.5
Ta		0.2	0.1	0.0	0.1	0.1	0.1
Au		0.3	1.0	0.3	1.4	0.3	0.0
PbO		0.4%	1.9%	0.5%	0.1%	0.1%	0.1%
Bi		3	21	2	2	0	0
Th		0.7	0.9	0.7	0.8	1.0	0.8
U		0.4	0.5	0.4	0.5	0.7	0.3

Tab. 3.2.2.4.2: Chemical compositions in wt% (weight percent, major and some minor elements) and ppm (parts per million, trace elements).

	number	CG1 4416B blue	CG1 4416B black	CG1 4416B green	CG1 4416B red	CG1 4416B white	CG1 4419F blue
SiO <sub>2</sub>		62.7%	61.1%	59.8%	59.3%	58.5%	62.8%
Na <sub>2</sub> O		15.6%	17.1%	17.6%	16.1%	16.0%	15.9%
K <sub>2</sub> O		3.1%	3.3%	3.3%	3.0%	3.1%	4.1%
MgO		5.3%	4.3%	5.0%	4.8%	4.9%	3.7%
CaO		6.6%	6.7%	7.0%	7.2%	7.1%	6.7%
Al <sub>2</sub> O <sub>3</sub>		3.3%	3.8%	3.6%	4.1%	4.0%	2.2%
Li		11	10	12	10	10	12
B		128	134	132	131	124	98
P <sub>2</sub> O <sub>5</sub>		0.2%	0.3%	0.2%	0.3%	0.3%	0.5%
Cl		7219	11344	8981	10482	8526	8190
Ti		875	1377	1054	1259	1174	1436
V		19	20	20	19	21	30
Cr		142	241	172	167	230	99
MnO		0.05%	0.04%	0.05%	0.04%	0.04%	0.04%
Fe <sub>2</sub> O <sub>3</sub>		1.7%	1.1%	1.3%	1.2%	1.2%	1.9%
Co		858	5	544	17	4	627
Ni		64	29	67	44	29	25
CuO		0.25%	0.05%	0.20%	1.66%	0.09%	0.14%
Zn		75	105	59	60	40	1182
As		30	4	11	049	15	21
Rb		19	18	20	18	18	18
Sr		408	418	465	447	486	542
Y		5	5	5	5	5	6
Zr		71	117	78	87	90	311
Nb		2.2	2.9	2.2	2.9	2.4	3.0
SnO <sub>2</sub>		0.0%	0.5%	0.1%	0.1%	2.3%	0.0%
Sb		13	2	3	75	11	2
Cs		0.3	0.3	0.3	0.3	0.4	0.4
Ba		169	185	180	180	187	132
La		5.4	6.1	5.6	6.4	5.7	9.0
Ce		11	12	10	11	11	18
Nd		4.9	5.4	4.9	5.6	5.2	7.9
Sm		1.0	1.2	1.1	1.1	1.1	1.6
Eu		0.2	0.3	0.3	0.3	0.3	0.3
Tb		0.2	0.2	0.1	0.2	0.2	0.2
Dy		0.9	1.0	0.9	1.0	0.9	1.3
Ho		0.2	0.2	0.2	0.2	0.2	0.3
Tm		0.1	0.1	0.1	0.1	0.1	0.1
Yb		0.6	0.7	0.6	0.7	0.6	0.9
Hf		2.0	3.1	2.2	2.4	2.3	8.3
Ta		0.2	0.2	0.2	0.2	0.2	0.3
Au		1.6	0.8	2.8	1.4	0.7	0.1
PbO		0.2%	0.1%	0.2%	0.6%	1.2%	0.4%
Bi		1	1	1	3	1	0
Th		1.6	2.0	1.6	1.8	1.8	4.3
U		0.6	0.6	0.6	0.6	0.5	1.1



Tab. 3.2.2.4.2: Chemical compositions in wt% (weight percent, major and some minor elements) and ppm (parts per million, trace elements).

	number	CG1 4483 blue	CG1 4483 red	CG1 4483 yellow	CG1 4582B green	CG1 4582B red	CG1 4582B yellow
SiO <sub>2</sub>		59.1%	56.7%	53.5%	58.8%	55.1%	49.7%
Na <sub>2</sub> O		15.3%	14.2%	12.3%	15.1%	12.0%	8.7%
K <sub>2</sub> O		3.1%	2.4%	3.0%	2.4%	2.0%	1.5%
MgO		3.3%	3.7%	3.1%	5.8%	4.9%	3.5%
CaO		8.7%	9.4%	8.6%	6.6%	6.1%	4.9%
Al <sub>2</sub> O <sub>3</sub>		3.0%	3.6%	3.5%	2.9%	3.7%	5.3%
Li		13	12	10	19	16	9
B		83	98	81	64	52	36
P <sub>2</sub> O <sub>5</sub>		0.4%	0.4%	0.4%	0.5%	0.9%	0.6%
Cl		8138	6895	7701	5741	4541	3930
Ti		1012	1220	1235	831	1282	1057
V		26	32	46	39	99	45
Cr		96	102	110	166	274	257
MnO		0.29%	0.49%	0.66%	0.08%	0.06%	0.02%
Fe <sub>2</sub> O <sub>3</sub>		1.6%	3.0%	1.5%	1.2%	1.9%	1.5%
Co		8	12	4	3	3	2
Ni		66	73	26	33	31	19
CuO		2.61%	1.89%	0.15%	1.14%	1.50%	0.80%
Zn		74	120	73	224	148	34
As		47	49	22	47	61	25
Rb		19	19	18	15	12	10
Sr		577	547	647	516	514	523
Y		6	6	6	4	7	4
Zr		73	66	70	49	81	58
Nb		2.8	3.0	3.0	2.4	3.5	3.1
SnO <sub>2</sub>		0.3%	0.6%	1.9%	1.3%	3.3%	5.2%
Sb		17	24	44	40	58	19
Cs		0.8	1.3	0.9	0.3	0.2	0.4
Ba		152	175	178	112	190	219
La		7.6	7.9	8.0	5.0	7.1	4.8
Ce		18	16	17	10	17	10
Nd		7.0	7.0	6.5	4.4	7.6	4.6
Sm		1.3	1.5	1.4	1.0	1.5	0.8
Eu		0.3	0.3	0.3	0.1	0.4	0.1
Tb		0.2	0.2	0.2	0.1	0.2	0.1
Dy		1.1	1.2	1.1	0.8	1.3	0.8
Ho		0.2	0.3	0.2	0.2	0.3	0.2
Tm		0.1	0.1	0.1	0.1	0.1	0.1
Yb		0.7	0.7	0.6	0.5	0.8	0.5
Hf		2.0	1.8	2.0	1.4	2.2	1.5
Ta		0.2	0.2	0.2	0.2	0.3	0.2
Au		1.0	1.4	0.1	1.1	5.9	0.4
PbO		1.1%	2.6%	10.2%	3.4%	7.5%	17.6%
Bi		4	4	3	4	10	6
Th		2.1	2.2	2.2	1.7	2.5	1.9
U		0.8	0.8	0.7	0.7	1.6	0.4

*Tab. 3.2.2.4.2: Chemical compositions in wt% (weight percent, major and some minor elements) and ppm (parts per million, trace elements).*

	number	CG1 4596D black	CG1 4596D red	CG1 4596D white	CG1 4596D yellow
SiO <sub>2</sub>		66.5%	59.4%	60.3%	55.2%
Na <sub>2</sub> O		14.8%	14.9%	13.7%	12.6%
K <sub>2</sub> O		2.4%	2.4%	2.3%	2.1%
MgO		1.9%	1.8%	1.9%	1.6%
CaO		7.0%	6.3%	6.2%	5.9%
Al <sub>2</sub> O <sub>3</sub>		1.1%	1.3%	1.1%	1.0%
Li		15	15	13	13
B		60	58	60	50
P <sub>2</sub> O <sub>5</sub>		0.3%	0.3%	0.5%	0.2%
Cl		7765	9129	7951	6963
Ti		404	451	629	360
V		14	17	20	12
Cr		92	103	157	80
MnO		0.03%	0.03%	0.03%	0.02%
Fe <sub>2</sub> O <sub>3</sub>		0.8%	1.3%	1.3%	0.7%
Co		6	10	6	4
Ni		58	73	48	45
CuO		3.05%	3.06%	0.13%	0.37%
Zn		75	200	31	29
As		46	120	16	196
Rb		8	9	8	7
Sr		289	336	276	247
Y		3	4	3	2
Zr		18	21	23	17
Nb		1.1	1.4	1.4	1.0
SnO <sub>2</sub>		0.7%	1.0%	9.9%	2.9%
Sb		20	48	7	36
Cs		0.1	0.3	0.3	0.1
Ba		55	80	54	47
La		3.3	5.8	4.0	3.4
Ce		6	8	8	5
Nd		3.0	4.8	3.7	2.9
Sm		0.6	0.9	0.7	0.5
Eu		0.1	0.2	0.2	0.1
Tb		0.1	0.1	0.1	0.1
Dy		0.5	0.7	0.7	0.5
Ho		0.1	0.2	0.1	0.1
Tm		0.0	0.1	0.1	0.0
Yb		0.3	0.4	0.4	0.3
Hf		0.5	0.6	0.6	0.5
Ta		0.1	0.1	0.1	0.1
Au		1.4	1.6	0.7	0.6
PbO		0.4%	7.0%	1.4%	16.5%
Bi		2	7	1	3
Th		0.8	1.1	1.1	0.7
U		0.8	0.7	0.8	0.7

### 3.2.2.5 Discussion and interpretation

This discussion will follow the questions outlined in the Introduction.

#### 1. *How were the various beads made, and what are the implications for these technologies?*

Five of the eight beads were made using one of up to four different mosaic glass techniques. By this, we mean that coloured glasses arranged in a pre-prepared pattern were used in the construction or decoration of the beads. CG1 4483 provides perhaps the best example. In this case, slices of mosaic cane have been arranged to form both the decoration, a pattern of yellow and red 'eyes' in what was probably a blue and white ground, and the structure of the bead itself, since these mosaic canes go through to the perforation of the bead, indicating that the canes were fused together without a layer of underlying glass. Particularly when the mosaic canes are more complex, such mosaic beads are often termed 'millefiori' to refer to the repeating mosaic pattern on the surface. The very fragmentary CG1 4582b is probably the remnant of a similar millefiori bead. The earliest millefiori mosaic glass dates to the 2<sup>nd</sup> millennium BCE, and millefiori mosaic beads were probably made in one location or another from that time to the present.

On the other hand, CG1 4596d, although also formed from pre-patterned coloured glass, shows a very different technology. In this case, a 'ribbon' or pad of strips of coloured glass was prepared in advance. Small segments cut from this pad were then wrapped around an iron wire or mandrel, and the free ends were fused together. Such beads may be termed folded or rolled pad mosaic beads, and were most likely made over a very long period of time, particularly in western Asia and Egypt. Diagnostic for these beads is that the join of the two fused ends of the rolled pad usually shows a slight misalignment. Had the bead been made by winding the glass directly on the mandrel, each colour would be continuous around the circumference of the bead.

It is difficult to determine the exact forming technology for CG1 4416b because of the small size and poor condition of the remaining fragment. However, the regularity of the pattern of coloured glass suggests that a pre-fabricated section of striped glass was used for the decoration. It is not clear whether the circumferential stripes at the best preserved end were part of the original pattern or were added separately. On the interior of the bead, there seems to be a layer of cobalt-blue glass underlying the other colours, suggesting that the beadmaker may have made the original striped pad by laying stripes of contrasting colours over a thin layer of cobalt-blue, then wrapped this unit over what may have been a monochrome glass core.

CG1 1831a, although also in poor condition, probably represents a fourth mosaic glass technology, the pierced cane mosaic bead. The beadmaker started with

a prepared mosaic rod or cane; this original cane would have been striped in various shades of green or yellow. Once a section of the desired length was cut off, it would have been reheated enough so that an iron needle or mandrel could be pushed through the glass to make the perforation. Because the bead has broken in cross section, we can see that the perforation is much broader at one end than the other; the perforating iron would have been pushed into the broad end and come out on the narrow end. Pierced cane mosaic beads were most likely the easiest type to prepare, and, like the other three types mentioned above, were made over a long time from the earliest days of glassworking into the Islamic period.

Although these four types of mosaic beads are not specific for period or geography, they generally represent an Egyptian or West Asian, rather than East Asian, technology. During the Roman period, mosaic glassworking was perhaps more characteristic for Egypt than for the Levant, and this tradition may have continued into the Islamic period as well, with Fustat being a possible centre for mosaic glass beadmaking. On the other hand, there is no reason that mosaic glassworking, particularly for the simpler mosaic techniques, could not have been practiced in western Asia or Iran, even though actual production evidence so far is lacking.

Most small beads in the Roman and Islamic worlds were 'wound' beads, made by winding a small amount of glass around a wire or mandrel. On the other hand, the vast majority of small beads found in South and Southeast Asia were made by first drawing out a narrow tube of glass, then cutting this tube into small beads. In order to smooth the resulting sharp edges, these beads were subsequently reheated at a temperature lower than that required to actually melt the glass. This was the forming technology for so-called Indo-Pacific beads, produced in the millions in South and Southeast Asia. CG1 4419f is such a drawn bead, and, although there is little comparative material from Iran, its discovery at Veshnavah is something of a puzzle. Very similar beads, with similar although not identical chemical compositions, have been found in South and Southeast Asia, as well as Korea and Japan in northeast Asia, beginning around the 3<sup>rd</sup> to 4<sup>th</sup> century CE. Although the base glass for these beads is similar to Sasanian glass, the forming technology is more South or Southeast Asian, and we have wondered whether such beads were made in South or Southeast Asia using imported Sasanian raw glass or cullet (Lankton and Dussubieux, 2006). Increasing Sasanian control over sea trade on the Indian Ocean during this period seems consistent with such an hypothesis. Thus, the drawn bead CG1 4419f may have been made in South or Southeast Asia from Sasanian (Mesopotamian or Iranian) glass, then re-exported to Iran. If there are many such beads at Iranian sites, we may need to revise our thoughts on the places of manufacture.

The forming technology for CG1 4189b is not clear. The fragment itself seems to be broken from a toggle-shaped bead that was probably wound then pressed

into shape. Such beads are rare in South and Southeast Asia, and I would suspect a western Asian or Iranian manufacture.

CG1 1872h is perhaps the most unusual bead in the group. Here, there are two layers of glass, the underlying layer colourless and the outer layer blueish green due to copper. The colourless part of the bead seems to have been drawn, with the suggestion of longitudinal striations where the surface is exposed. On the other hand, the circumferential marks on the outer blue layer would have been produced by winding the blue glass around the colourless core. Whether this type is common in Iran would be very interesting to know.

We do not know the extent to which ancient bead-makers specialized in one or a few manufacturing methods, but, in general, it seems to be uncommon to see both wound and drawn beads made at the same sites. Making mosaic glass beads was a further specialization, and, even today, remains one of the most difficult techniques. Because the Chale Ghar 1 beads were made by up to seven different techniques, it seems very unlikely that they were all made by the same beadmakers, although we cannot rule out different groups of beadmakers, using different techniques, but located in the same general geographic area. There is good evidence that craftworkers, including beadmakers, were often itinerant, following markets and marketplaces, so that beadmakers from different technological traditions may have worked at the same sites.

## 2. Does the chemical composition of the glass itself help us to understand the provenance of the finished objects, and, in particular, is there any evidence for centralized, or even localized, production?

As stated in the Results section, all of the analysed glass areas were plant-ash soda glass, or HMG. However, there is great variability within this large group. The chemical compositions of plant-ash glasses combine elements from the plants that were burned to provide the ash/flux, and from the silica ( $\text{SiO}_2$ ) source, either relatively pure sand or ground quartz or a mixture of the two, to provide the structural backbone of the glass. The general theory is that the plant-ash derived elements will reflect the water taken up by the plants, thus reflecting the overall geology of the plant growing area, while heavy minerals, not usually taken up by plants, will reflect the source of the sand or quartz component of the glass. The interpretation of the chemical analyses of plant-ash glasses is made more complicated by the fact that while some elements, notably soda ( $\text{Na}_2\text{O}$ ), come mainly with the ash component, others, such as lime ( $\text{CaO}$ ), will have contributions from both the plant ash and the sand, if sand were used. In addition, we now know that not all plant species grown in the same region will have identical chemical compositions, and these differences may extend even to different parts of the same plant.

Mirti, et al. (2008; 2009) have studied the HMG glasses found at Sasanian Veh Ardašīr in Iraq, using the values for  $\text{MgO}$  (magnesia) and  $\text{K}_2\text{O}$  (potassia), plus the ratio of the two, along with  $\text{P}_2\text{O}_5$  (phosphate), to characterize the plant-ash flux, and heavy minerals such as REEs (rare-earth elements) to describe the sand sources as relatively pure (low in REEs) or impure (higher in REEs). They found, on this basis, that at least three types of plant-ash glass were used at Veh Ardašīr from the 3<sup>rd</sup> to the 7<sup>th</sup> century. Investigating the same glasses with the technique of strontium and neodymium isotope ratios analysis, Ganio, et al. (2013) have shown that the observed differences in chemical composition did not correlate well with differences in isotope ratios, suggesting that the different chemical compositional groups at Veh Ardašīr could simply be the result of using different materials from the same general area. On a more positive note, these authors did conclude that the isotope ratio patterns from Veh Ardašīr were sufficiently different from those of glasses produced along the Mediterranean coast to constitute a distinct and new group.

We can apply the same criteria used by Mirti, et al. (2008; 2009) to the plant-ash glasses from Chale Ghar 1, as illustrated in Fig. 3.2.2.5.1 comparing the  $\text{MgO}/\text{K}_2\text{O}$  ratios (the plant-ash component) to the values for hafnium ( $\text{HfO}_2$ , representing the heavy mineral content of the silica component). The Veh Ardašīr samples studied by Ganio, et al. (2013) are included for reference.

The eight Chale Ghar 1 beads fit into the general zones defined by Mirti, et al. (2008; 2009) for the Veh Ardašīr samples. While the base compositions for the various colours of a particular bead are generally quite similar, best illustrated by CG1 4596d, there is considerable difference between the beads, as, for example, between CG1 4596d and CG1 4582b. Following the reasoning of Mirti, et al. (2008; 2009) we would interpret beads 4596d, 4189b and 1872h as being made by combining very pure sand or even powdered quartz with plant ash rather low in  $\text{MgO}$ . In particular, CG1 4596d and CG1 4189b are similar in this regard, suggesting a possible similarity in the base glass, even though the technology for making these two beads was quite different. CG1 4419f stands out for its very high  $\text{HfO}_2$  content coupled with a low  $\text{MgO}/\text{K}_2\text{O}$  ratio because of the high  $\text{K}_2\text{O}$  value of 4.3 wt% (Tab. 3.2.2.4.2). This bead was also unique because it was made by the drawing technique, generally rare in western Asia and Iran. One point of caution is that while it is tempting to associate the Chale Ghar 1 beads with the corresponding Veh Ardašīr samples, if we were to include on this same plot some of the other 5<sup>th</sup> to 10<sup>th</sup> c. glasses from areas as diverse as the Levantine coast and Nishapur in Iran, we would find that these glasses also show similar patterns of more-or-less pure sand vs  $\text{MgO}$  and  $\text{K}_2\text{O}$  contents, so that the compositions identified for Veh Ardašīr are not unique to Veh Ardašīr, nor to the Chale Ghar 1 beads.

In sum, the wide variability of bead compositions and technologies makes it unlikely that all beads originate from

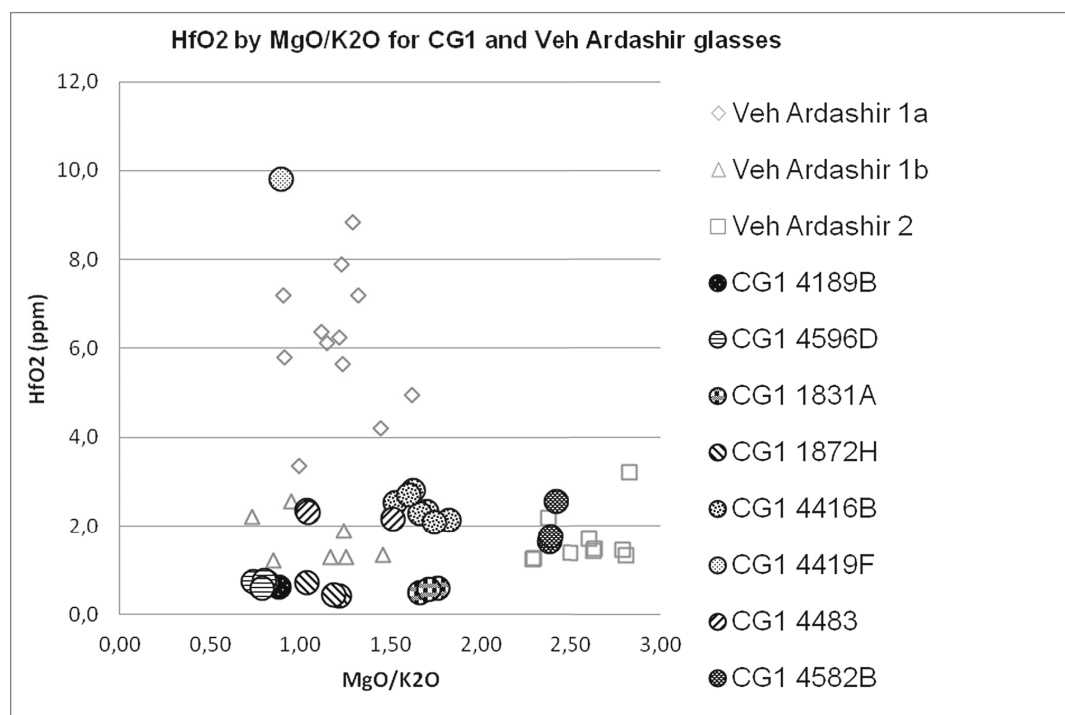


Fig. 3.2.2.5.1:  $MgO/K_2O$  by  $HfO_2$  for Chale Ghar 1 beads and Veh Ardashir vessels studied by Ganio, et al. (2013).

the same production centre. So far, the tentative evidence (see below) suggests greater compositional similarity of the CG1 glasses to samples from Iran and Iraq, rather than from glassworking sites in Egypt and the Levant, providing at least some backing for regional manufacture. Where in the Iran/Iraq region the beads might have been made remains uncertain, although there does seem to be greater compositional similarity with glasses from Nishapur and Hamadan than to those from either Ray or Qom. While we, in cooperation with R.H. Brill, formerly with the Corning Museum of Glass, have begun to develop a significant database of glass samples found in Iran, our ability to link these samples to documented production centers remains limited, and access to analytical samples with known archaeological provenance remains critical.

### 3. Where does the glass evidence fit along the broad chronological continuum suggested for the site?

In the absence of directly comparable material, it is difficult to be very specific about the chronology of the Chale Ghar 1 beads. As mentioned above, the earliest glasses in Mesopotamia and Egypt, dating to the 2<sup>nd</sup> millennium BCE, were plant-ash soda-lime glasses of the same general type as those found at Chale Ghar 1, and such compositions have probably continued in some areas until today. As a result, simply determining the overall compositional group, while essential, is generally not adequate by itself to answer detailed questions. Increasing access to excellent trace element data is certainly a big help, but even then the picture may be complicated by

the production of more than one type of glass at a single site, as at Veh Ardashir. In addition, the known exchange of glass and glassmaking materials from one area to another can complicate the interpretation of trace element data. An additional important factor is that most of the known chemical analyses were done on vessel glass, which may be quite different from deeply coloured glasses used for making beads.

Another way to compare glass compositions, particularly when many elements are involved, is to use such multivariate statistical techniques as PCA and cluster analysis. In Fig. 3.2.2.5.2 we've compared the Chale Ghar 1 glasses with a selection of samples representing colourless and coloured glass from Nishapur, dating from the 8<sup>th</sup> to 10<sup>th</sup> centuries, as well as Sasanian glass from Veh Ardashir. While the full mechanics of the PCA technique are beyond the scope of this article, in Fig. 3.2.2.5.2 we can see a general separation between the Islamic period glass from Nishapur and the Sasanian glass from Veh Ardashir. This separation, also found with cluster analysis (not shown), is surprisingly good, although the clusters that were predominantly Sasanian also contained about 10% Islamic glass, and vice versa. Of the Chale Ghar 1 samples, CG1 4596d, 4416b, 4419f and 4582b group closely with the Sasanian glasses, while CG1 4189b, 1831a and 4483 are much closer to the Islamic samples. CG1 1872h is intermediate between the Islamic and Sasanian groups by both PCA and cluster analysis. Based on this analysis, we would say that it is more likely that CG1 4596d, 4416b, 4419f and 4582b date to the Sasanian period, and are thus

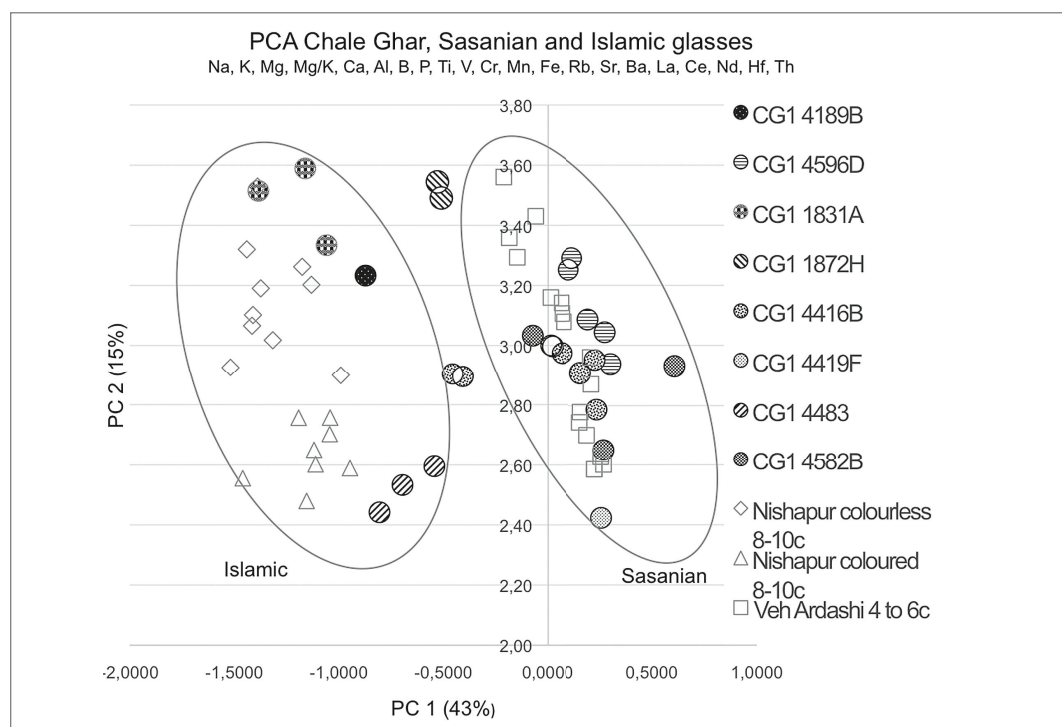


Fig. 3.2.2.5.2: PCA (Principal Component Analysis) for Chale Ghar 1, Sasanian (*Veh Ardashir*) and Islamic (Nishapur) glasses. Principal Components 1 and 2 account for 58% of the total variation.

earlier than CG1 4189b, 1831a and 4483, more likely to be Islamic in date. In addition, we have run similar PCA and cluster analyses for a large group of almost 700 glass samples found from Egypt to Central Asia. Preliminary results suggest that the Chale Ghar 1 glasses are more similar to samples found in Iran and Iraq than to glasses most likely made either in Egypt or along the Mediterranean coast.

Our best answer to Question 3, combining both the technological and compositional evidence, would be that the Chale Ghar 1 beads span the Sasanian and Early Islamic periods, roughly from the 4<sup>th</sup> to the 10<sup>th</sup> century. This interpretation is consistent with site formation and other artefacts found at Chale Ghar 1.

### 3.2.2.6 Conclusions

The Chale Ghar 1 samples submitted for analysis show considerable variability in both forming technology and chemical composition. While our conclusions are limited by the paucity of comparative material, it is still possible to see how the careful study of glass evidence may permit a more complete understanding of the archaeological context at Chale Ghar 1. Further analyses, including trace elements, of Iranian glass, particularly that associated with known production areas, would add considerably to our ability to compare, contrast and interpret the observed technological and chemical compositional data.

## 3.2.3 Discussion of Lankton and Gratuze's analysis and interpretation

Although Lankton and Gratuze could analyse only eight samples from Veshnaveh, they deduced important data about the chemical composition of Iranian bead glass and of their manufacturing techniques. Therefore their study is a first step towards the interpretation of Persian glass processing and its chronological development, as well as an approach of understanding how raw materials and goods were exchanged.

At this point the results and suggestions achieved through natural sciences will be compared with the archaeological analyses of this volume. This comparison shows how archaeological and natural scientific studies complement each other, but how they may also disagree in some points.

### 3.2.3.1 Technical Results

As already presented in the chapter of the overlay beads, bead no.1872h was made of a drawn colourless glass core and covered with greenish blue wound glass (pl. 6). This special technical attribute – the combination of drawing and winding in one bead – was confirmed by the examinations of Lankton and Gratuze. Due to a lack of references it remains uncertain whether this kind of bead is a specifically Iranian type or not.



The authors classify five beads belonging to the mosaic technique (Tab. 3.2.2.4.1) which in this study are placed in other categories:

- variously decorated (no. 1831a);
- stripe-/trail-decorated (nos. 4416b, 4582b, 4596d); and
- powder technique (no. 4483).

No. 1831a is considered to be a so-called pierced mosaic bead: It must be taken into consideration, that it is impossible to perforate hot glass – as described in Lankton and Gratuze's article – without the aid of a mould and without spoiling the decoration. Hence it can be assumed that this bead was made with the folding technique: a pre-manufactured stripe was folded around a conical rod. The latter would form the funnel shaped string hole, which is, according to the authors, linked to the perforation. The beads which are categorised as stripe- and trail-decorated beads are not real mosaic beads, although no. 4582b is probably made of overlaid mosaic canes. No. 4416b is decorated with horizontal and vertical stripes that do not extend to the perforation (pl. 9). Probably it was made of a basic bead and the decoration was applied on this core. The mosaic component was made of bundles of canes (Stern and Schlick-Nolte, 1994, p.54; Spaer, 2001, pp.48-49; Francis, 2001, p.94). Bead no. 4596d is obviously made of a pre-manufactured glass strip. Again, this method should not be described as a real mosaic technique and is instead in this study classified under the folding technique.

Lankton and Gratuze believe that the particular manufacturing technology found in bead no. 4483, where the mosaic canes penetrate the interior, was an Islamic one. In this case it is possible that the use of glass powder, in which the yellow and red canes were embedded, might have played a role.

### 3.2.3.2 Chemical Analysis of Glass

It might be possible to distinguish soda-lime glasses of different periods by analysing trace elements, as was done with the Veshnavah beads (page 203-204 in this volume).<sup>70</sup> So far Near Eastern glasses have hardly been examined for trace elements, and most glasses that have been analysed, consist of vessel glass, which is mostly not coloured like the glass used in beads. Therefore we are facing a lack of references and Lankton and Gratuze's study is of great importance for comparisons in future analyses.

<sup>70</sup> An additional and particularly useful method is the scientific examination of isotopes (Degryse, et al., 2009). Certainly, this method, even when combined with analysis of trace elements, is not a panacea, but, as P. Degryse and his colleagues write, 'The virtually unexplored field of vitreous materials can provide a unique, interesting and challenging perspective.' With the specific information provided by the techniques of isotopic investigation, the origins of the glass may become clearer. Based on this data the archaeologist may develop models of how the glass trade and the ancient economy generally operated' (Degryse, et al., 2009).

J. Lankton and B. Gratuze date the analysed beads from Veshnavah from the 4th to the 10th century AD. This is surprising, because most of the artefacts from Chale Ghar 1 have been dated by parallel finds and stratigraphic analysis to the Arsacid and Sasanian periods. In addition, only a few specimens seem to date to the early Islamic period at all, and probably not much later than the Umayyad era (661–750 AD), as is suggested by a coin dated to this period found in one of the upper layers in the mine. Most samples that were analysed in London and Orléans, on the contrary, were unearthed in different layers below the one containing the Islamic coin. Therefore, these date rather earlier than the Umayyad period. Probably the dating chosen by Lankton and Gratuze results from a lack of pre-Islamic references.

### 3.2.3.3 Conclusion

The chemical analyses of J. Lankton and B. Gratuze illustrates that the beads from Chale Ghar 1 show a similarity to samples from Iran and Iraq. This might be an indication that these beads were purchased from regional markets and do not originate as far as the Mediterranean coast or Egypt. The diverse techniques and different compounds suggest that the beads originate from different places within the Mesopotamian region, which is an important insight and confirms the results of the comparison studies in this work. However, in Chale Ghar 1 imports from farther locations are proved. There are e.g. the amber beads (see next section) or glass beads of special techniques (see previous studies in this volume)

In this context, the coherence of Indo-Pacific beads with one bead is very interesting (no. 4419f, from Chale Ghar 1). It remains unresolved whether Persian glass was exported to southern Asia and the beads reimported back to Persia or the other way around. Probably the glass bead making technique was imported to South Asia during Arsacid and Sasanian time since even Roman coins were imported there in the frame of an expanded, almost global, trade (compare McLaughlin, 2010 and Miller, 1998).

## 3.3 Analysis of Metal from Veshnavah

### 3.3.1 Introduction

In any archaeological excavation metal finds potentially have special meaning. The manufacturing technique used to make the objects can give details as to the chronology or the cultural background of the site (Moorey, 1988b, pp.23-32; Muscarella, 1988, pp.33-44; Schausensee, 1988, pp.45-62; Seidl, 1988, pp.169-76; Allan, 1979). Moreover, analysis of the metals and their comparison can bring further information about the location of prime deposits of metals: for example, the propor-