Journal of Archaeological Science 40 (2013) 1866–1878

Contents lists available at SciVerse ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Environment and collapse: Eastern Anatolian obsidians at Urkesh (Tell Mozan, Syria) and the third-millennium Mesopotamian urban crisis

Ellery Frahm [a,*], Joshua M. Feinberg [b,c]

[a] Department of Archaeology, The University of Sheffield, Northgate House, West Street, Sheffield S1 4ET, United Kingdom
[b] Institute for Rock Magnetism, University of Minnesota, 310 Pillsbury Drive SE, Minneapolis, MN 55455, United States
[c] Department of Earth Sciences, University of Minnesota, 310 Pillsbury Drive SE, Minneapolis, MN 55455, United States

ARTICLE INFO

Article history:
Received 9 September 2012
Received in revised form
20 November 2012
Accepted 20 November 2012

Keywords:
Obsidian
Exchange
Bronze Age
Northern Mesopotamia
Third-millennium urban crisis
Deurbanisation
Climate change
Social networks

ABSTRACT

The Early to Middle Bronze Age transition in Northern Mesopotamia has received great attention for the apparent concurrence of aridification, deurbanisation, and the end of the Akkadian empire around 2200 BCE. Our understanding of the "crisis" has been almost exclusively shaped by ceramics, demography, and subsistence. Exchange and the associated social networks have been largely neglected. Here we report our sourcing results for 97 obsidian artefacts from Urkesh, a large urban settlement inhabited throughout the crisis. Before the crisis, six obsidian sources located in Eastern Anatolia are represented among the artefacts. Such a diversity of Eastern Anatolian obsidians at one site is hitherto unknown in Mesopotamia. It implies Urkesh was a cosmopolitan city with diverse visitors or visitors with diverse itineraries. During this crisis, however, obsidians came from only two of the closest sources. Two to three centuries passed before varied obsidians reappeared. Even when an obsidian source reappears, the raw material seems to have come from a different collection spot. We discuss the likely exchange mechanisms and related social networks responsible for the arrival of obsidians at Urkesh and how they might have changed in response to climatic perturbations and regional government collapse.
© 2012 Elsevier Ltd. All rights reserved.

1. Introduction

The transition from the Early Bronze Age (EBA) to Middle Bronze Age (MBA) in Northern Mesopotamia (2200–2000 BCE) has received considerable archaeological attention for the apparent concurrence of (1) aridification, (2) deurbanisation, and (3) the end of the Akkadian empire around 2200 BCE. Collectively, these phenomena are known as the late-third-millennium collapse (Weiss, 2000), aridity crisis (Fiorentino et al., 2008), or urban crisis (Akkermans and Schwartz, 2003) as well as the 4.2-ka event (Staubwasser and Weiss, 2006). The phenomena were first reported by Weiss et al. (1993) at Tell Leilan in Syria's Upper Khabur Basin (UKB; Figs. 1 and 2). The tenets of this "crisis" – aridity and urban decline in the late-third-millennium UKB – have withstood scrutiny, but the scale, timing, causality, and social effects remain unclear. It is no exaggeration when Ur (2010) states: "Almost all aspects of this transition are debated" (412). The topic has generated considerable debate (e.g., Dalfes et al., 1997; Weiss, 2000; Coombes and Barber, 2005; Kuzucuoğlu, 2007; Schwartz, 2007; Schwartz and Miller, 2007; Wossink, 2009; Yoffee, 2010; Butzer, 2012) and attention due to the current interest in climate change and the "collapse" of complex societies (e.g., McIntosh et al., 2000; deMenocal, 2001; Schwartz and Nichols, 2006; McAnany and Yoffee, 2009; Mainwaring et al., 2010; Diamond, 2011; Sheets and Cooper, 2012).

Data from numerous climate proxies have been amassed during the last two decades (see the review by Staubwasser and Weiss, 2006). Whether due to climate changes, regional weather patterns, and/or soil degradation after intensive agriculture, some degree of UKB aridification seems beyond a reasonable doubt. Simply documenting decreased rainfall, though, is insufficient because, as argued by McIntosh et al. (2000), "an environmental crisis is primarily a matter of the social realm... rather than a breakdown in the environment itself" (7).

Research into the social effects has largely focused on two approaches. First, archaeologists have examined material culture (dis)continuities (ceramic chronologies) and demography (inhabited area) (e.g., Weiss et al., 1993; Weiss and Courty, 1993; Courty and Weiss, 1997; Weiss, 2000; Ristvet and Weiss, 2005). This approach has led to criticisms that the "crisis" may be merely a contrivance of incomplete archaeological surveys and ceramic

* Corresponding author. Tel.: +44 74 0299 0202.
E-mail addresses: elleryfrahm@gmail.com, e.frahm@sheffield.ac.uk (E. Frahm), feinberg@umn.edu (J.M. Feinberg).

0305-4403/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jas.2012.11.026

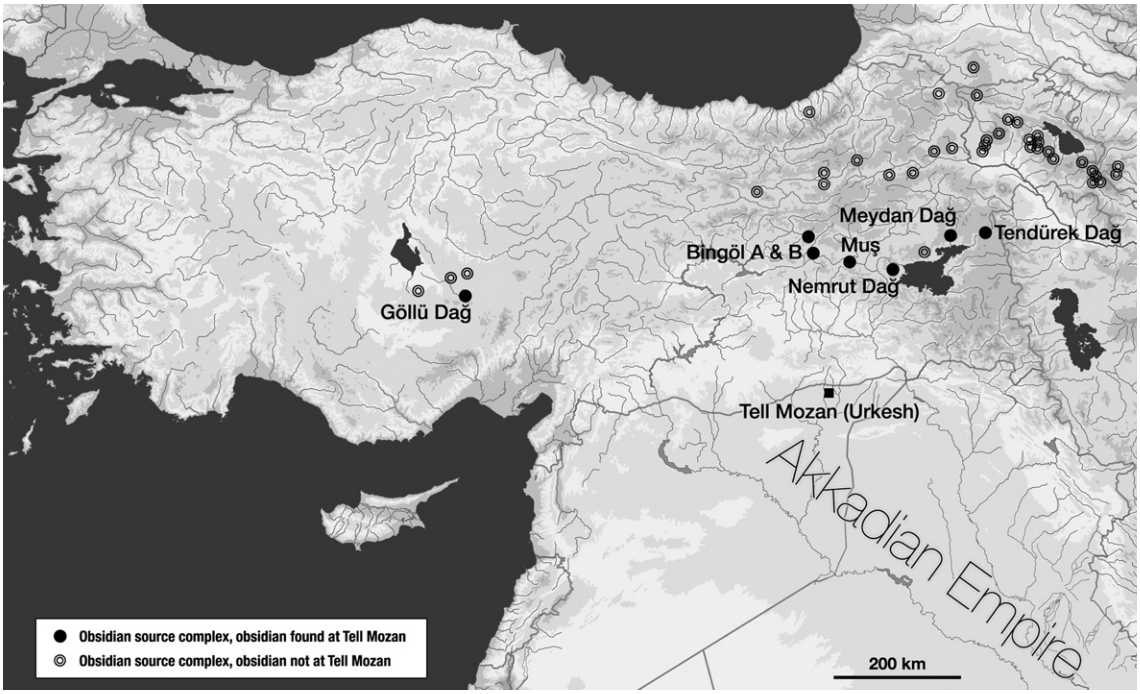

Fig. 1. Near Eastern obsidian sources and Tell Mozan (ancient Urkesh). Sources of the obsidian artefacts at Tell Mozan are marked by full black circles and labelled.

topology issues (e.g., Porter, 2007: 107). Second, various archaeobotanical and geoarchaeological proxies have shown agricultural changes, including differences in the crops and management practices (e.g., Deckers and Riehl, 2007; Riehl and Bryson, 2007; Riehl et al., 2008; Riehl, 2008, 2010). Thus, our understanding of this period has been largely informed by ceramic chronologies, demography, and farming practices.

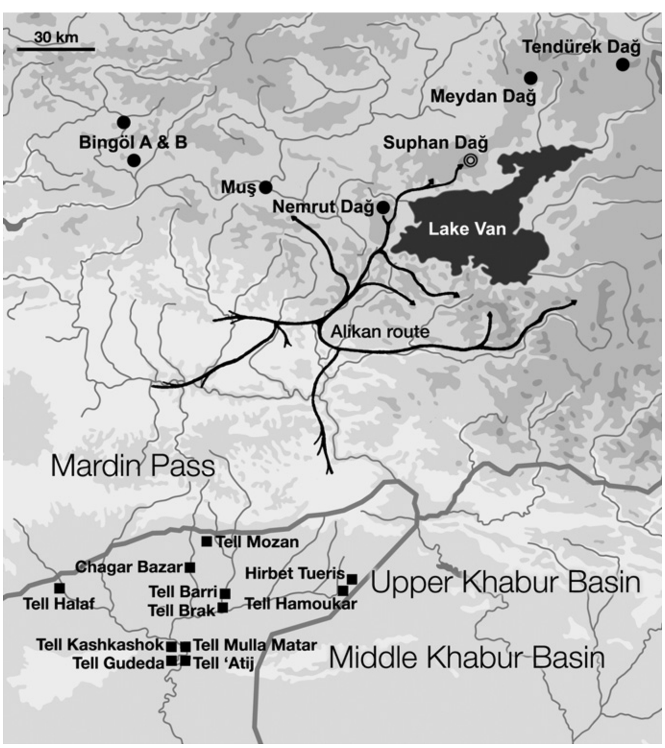

Fig. 2. Upper Khabur Basin (UKB) and Middle Khabur Basin (MKB) archaeological sites with prior obsidian sourcing results; see Table 1. The annual migration route of an Alikan nomadic group, as mapped by Beşikçi (1969) and redrawn in Cribb (1991), is also shown.

Here we discuss our sourcing results for 97 obsidian artefacts from Tell Mozan (Urkesh), an urban centre inhabited during the proposed UKB crisis. The artefacts were excavated from Bronze-Age strata before and after 2200 BCE, permitting a diachronic perspective. Our results reveal that, before 2200 BCE, six Eastern Anatolian obsidian sources are represented among the artefacts. Such a variety of Eastern Anatolian obsidians at one Mesopotamian site is hitherto unknown. This implies Urkesh was a cosmopolitan city with diverse visitors or visitors with diverse itineraries. After about 2200 BCE, obsidians came from two of the closest sources. The other four sources disappear. Two to three centuries passed before diverse obsidians reappeared at the city, consistent with the proposed crisis duration. Our results also indicate that, even when an obsidian source reappears at Urkesh, the raw material was likely collected from different quarries. Although this study alone cannot resolve the nature, causality, or severity of UKB aridification and deurbanisation, we discuss new evidence regarding concurrent shifts in exchange networks and quarrying practices.

2. Background: third-millennium Northern Mesopotamia

In Northern Mesopotamia, the middle of the third millennium, starting 2600–2500 BCE, was a period of increased urbanisation and societal complexity. This "urban revolution" is attributed, at least in part, to the production of agricultural surpluses that enabled labour mobilisation and craft specialisation. UKB urban centres grew markedly during this time. Tell Leilan and Tell Hamoukar expanded from 15 to 90 ha or more (Weiss and Courty, 1993; Ur, 2002). Wilkinson and colleagues devised a model encompassing population, subsistence, and environment to explain this process (e.g., Wilkinson, 1994, 1997, 2000; Wilkinson et al., 2007). The model predicts that, if a city drew on satellite agricultural settlements, its population could reach 12,000–14,000 across

70–110 ha. At such sizes, however, the model predicts that rain shortfalls would threaten sustainability.

The formation of the Akkadian empire soon followed. Centred in Southern Mesopotamia, it reached an apex circa 2300–2200 BCE after purported conquests in the north. Akkadian influence, at least in the south, apparently involved the imposition of an imperial administrative level above city-states' existing governments. Their influence and interests in Northern Mesopotamia remain unclear. Some researchers argue that the Akkadians subjugated UKB cities and controlled agriculture (Weiss and Courty, 1993), while others conclude that the empire instead exerted influence over trade routes (Nissen, 1988; Michalowski, 1993; Marcus, 1998; Van De Mieroop, 2004).

About 2200 BCE, many UKB settlements were abandoned or dwindled in population, and the Akkadian empire declined. Akkermans and Schwartz (2003) describe the situation:

> In the final centuries of the third millennium, the urban societies of Syria exhibit conspicuous evidence of stress or even collapse. In the Khabur region, numerous sites were abandoned at a point roughly synchronous or just subsequent to the period of the Akkadian presence in Syria. By c. 2200 BC, Leilan and the sites in its vicinity, Chuera, Beydar, Abu Hgaira, and all the excavated middle Khabur sites were deserted. Only Brak and Mozan survived. (282–283)

This idea of extreme regional depopulation has been moderated by subsequent discoveries of post-Akkadian habitation at some UKB sites (e.g., Chagar Bazar, McMahon and Quenet, 2007; Tell Barri, Orsi, 2008, 2010; Tell Hamoukar, Colantoni and Ur, 2011; Tell Leilan, Weiss, 2011; Tell Mohammed Diyab, Nicolle, 2006). Hence, while the "crisis" was widespread, the degree of deurbanisation was variable, and scattered settlements survived, albeit often reduced in size. Based on a survey of 1900 km^2, about three-fourths of sites were abandoned, and surviving sites shrank by two-thirds (Ristvet and Weiss, 2005:1). Ur (2010) notes that depopulation occurred "within the span of a single ceramic phase" and that, when a settlement reappears at a site, typically "it represents a clean break from the third millennium levels" (412). These effects were also uneven. It was three centuries before UKB states reformed, but only a century passed in the Middle Euphrates (Cooper, 2006a).

As noted in the Introduction, this period has been given various names, which highlight the uncertainties. Some authors argue that "collapse" implies failure rather than adaptation to changing circumstances (e.g., McAnany and Yoffee, 2009). Others contend that the terms "event" and "crisis" imply a singular cause or abrupt change. While we acknowledge the problems with these terms, we do not wish to devise yet another. When we use the term "crisis" here, we consider it shorthand for a thick description like "variable disintegration of urban-based societies."

Climate perturbations, particularly drought or aridification, are the most frequently proposed crisis trigger. Varied paleoclimatic proxies establish some kind of environmental change during this time, but the spatiotemporal scale is still debated. Some proxies suggest that it was a supra-regional trend with feedback loops that increased the severity in marginal regions like Northern Mesopotamia. Others suggest there were localised multi-year or -decade droughts and that the droughts debilitated agriculture. Regardless of the cause, archaeobotanical, stable isotopic, and soil micromorphological evidence attest to diminished water (Riehl et al., 2008; Riehl, 2009), suggesting rainfall decreased by as much as a third (Ristvet and Weiss, 2005). A related explanation ties deurbanisation to agricultural maximisation (e.g., Wilkinson, 1994, 1997). For cities, agricultural production reached sustainability limits and was prone to crisis during droughts. Centralised agriculture maximised food production in the short run, but it also increased the potential for crop failures or shortfalls.

Other researchers attribute the crisis to political and/or economic disruptions in the wake of the Akkadian regime. In this scenario, the Akkadians disrupted the regional authorities and power structures, leaving a void when their empire disintegrated. Such proposals are sometimes combined with climate or sustainability. Peltenburg (2000) claims that the Akkadians "ruined the indigenous political and economic infrastructure" and "created a political vacuum that left communities ill-equipped to deal with declining agricultural productivity and competition for reduced high-yield lands" (200). Hence, it could have been a regional government collapse combined with aridification that meant cities' food needs could not be met.

Reflecting social relations among groups, exchange would be expected to change under social stresses. One of the few researchers to focus on exchange networks during the crisis is Butzer (1997, 2012). Butzer views exchange as "energy flows" between nodes in a system and suggests Akkadian imperialisation was the prime mover of deurbanisation. Specifically, he claims there was "imperial unrest, which ended with disintegration of an internetworked world-economy, once extending from the Aegean to the Indus Valley" (2012: 1). The Akkadians' aim was interjecting themselves into this "world-economy," and their "relentless expansion... destroyed the entrepot role of Syria at the nexus of this economic system" (1). As evidence, Butzer cites his own network model of the Early Bronze Age "world-economy" (1997). His model, however, attributes more importance to sporadic contact between Iberia and Greece than the direct interactions between Northern Mesopotamia and Eastern Anatolia, which is absent from his proposed exchange network centred around Syria. Ultimately, if one finds Butzer's ideas compelling (e.g., Cooper, 2006b: 263), his heuristic model remains in need of additional archaeological data.

3. The people and site: Hurrians and Tell Mozan

Tell Mozan was inhabited by the Halaf period (6200–5300 BCE), grew to 130 ha in the mid-third millennium, and was abandoned about 1300 BCE. During the second and third millennia, the city was inhabited and ruled, primarily at least, by Hurrians, a minority in many Bronze-Age UKB settlements. Knowledge of third-millennium Hurrians was largely restricted to epigraphic sources and linguistic studies until 1995, when Tell Mozan was identified as Urkesh, known from texts as a Hurrian political and religious centre. Over the last three decades, excavations have uncovered a third-millennium palace (A in Fig. 3), a contemporaneous temple (B) on a 30-m-tall terrace linked to a plaza (J), and later third- and second-millennium habitation phases atop them.

The site lies near the terminus of the Mardin pass into the Taurus mountains' front range, the Tur Abdin. Akkermans and Schwartz (2003) suggest the location "may indicate control of the route to the copper mines of eastern Anatolia – and perhaps an entry point for Hurrian individuals" from the north (285). Mallowan (1947) wrote that, through this pass, "many a hillman must have set out on his way to the Khabur; warriors, traders, birds of passage, and settlers, all of them seeking their fortunes" (11). This may be reflected in a Hurrian myth about a young god, Silver, who lives in the mountains (Hoffner, 1990). His father is the god Kumarbi, the "father" of Urkesh, and Silver travels there in search of his father. This myth implies kinship with Hurrians in the highlands, concerns the arrival of mountain resources (i.e., silver), and raises the possibility of pilgrimages.

Tell Mozan has been a focus of ecological research due to its continued habitation during the EBA–MBA transition. Pfälzner (2010) summarises the environmental conditions at Tell Mozan

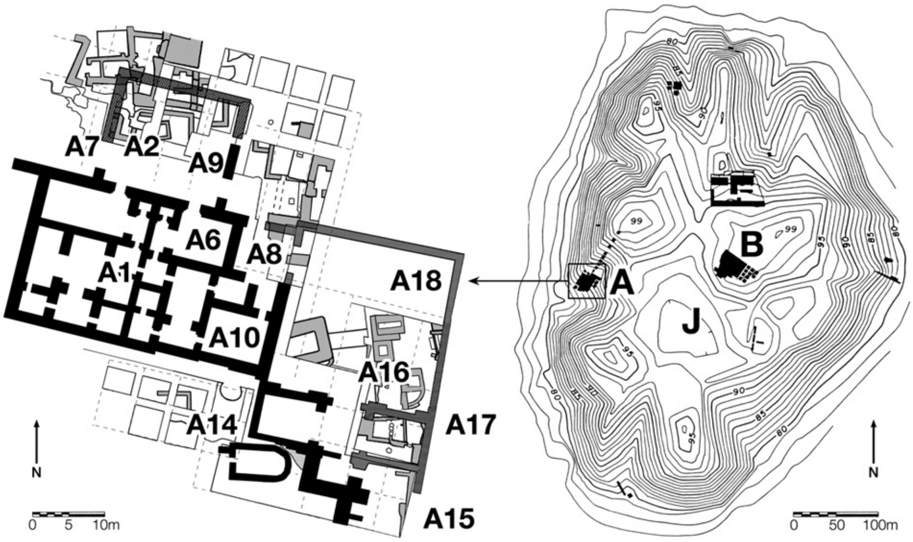

Fig. 3. Excavation units of sourced artefacts relative to the palace excavations (left) and Areas A, B, and J on the tell (right). Compiled and redrawn from various Urkesh expedition maps.

and in the UKB based on the studies of Riehl (2010), Deckers (2010a,b), and their colleagues. Deckers and Riehl (2007) propose that, after 2500 BCE, a nearby river slowed as a result of drier conditions or intensifying agriculture. Deckers and Pessin (2010) document vegetation changes using charcoal fragments from Tell Mozan. During 2200–2000 BCE, there was a decrease in woodland vegetation, indicating a shift towards steppe ecology or agricultural intensification. Riehl et al. (2008) conclude that the stable carbon isotopes of Tell Mozan archaeobotanical remains show increased water stress in the early MBA. During the EBA–MBA transition, Riehl (2009) found that, except at Tell Mozan and Tell Brak, emmer wheat nearly disappears from the UKB. Ultimately, Riehl (2012) argues the archaeobotanical remains attest to decreased rainfall circa 2200 BCE. Hence, we have highly local information that the Urkesh inhabitants experienced environmental changes.

From 1984 to 2010, this site was excavated by the International Institute for Mesopotamian Area Studies (IIMAS). Artefacts from the IIMAS excavations have the spatial contexts encoded in their labels. For example, the obsidian flake and blade core in Fig. 4a is A14 q566 f216 k14, so it came from Area A, Unit 14, Locus 14, Feature 216, Lot 566. Such information, when used with the Urkesh Global Record (UGR), an online excavation database, allows us to reconstruct contexts and explore chronological trends. This core, for instance, was found on a pisé floor with a grindstone, a hearth, and sherds dated to Phase 3b (2100 BCE). A bladelet (Fig. 4b) was lying on an adjacent floor with jar and cups sherds, grindstones, and a quern. Thus, we have a core on a working surface and a bladelet on a concurrent floor with grain-processing implements.

4. Methods and materials: artefacts and analyses

After a survey of the lithic assemblage at Tell Mozan, we compared 97 obsidian artefacts to hundreds of obsidian specimens using two geochemical techniques and rock magnetic analyses.

4.1. Obsidian assemblage and reference collection

This study focused on obsidian artefacts from the late EBA III to Late Bronze Age IIA (circa 2300–1300 BCE; Table 2). The IIMAS excavations have found over 820 obsidian artefacts from this period (32% of lithics by number and 6% by mass). Prismatic blades (Fig. 4c) and *ad hoc* flake tools dominate the assemblage. After an on-site

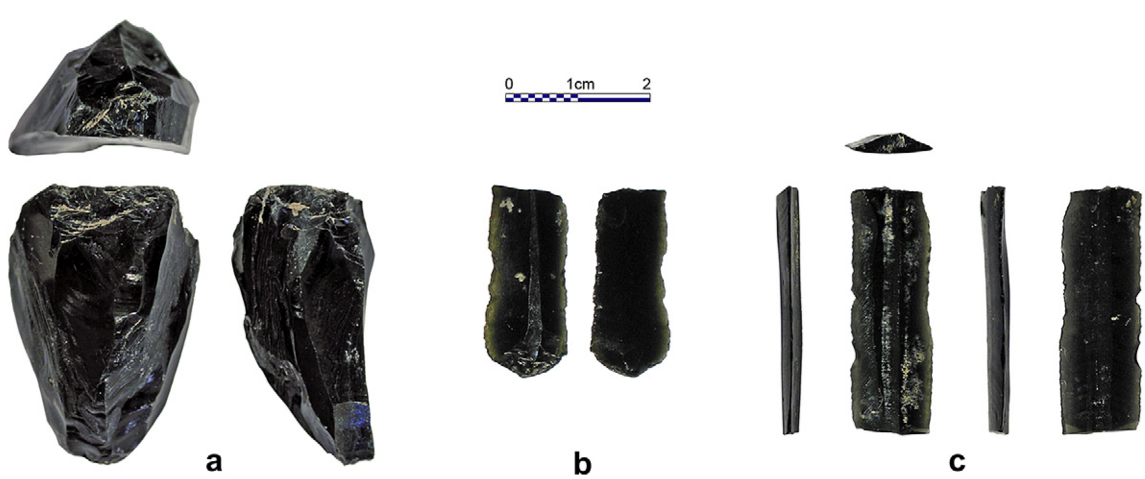

Fig. 4. Example obsidian artefacts from Tell Mozan. (a) Mixed blade and flake core, A14 q566 f216 k14. (b) Bladelet, A14 q712 f278 k4. (c) Prismatic blade, A12 q901 f382 k27.

Table 1
Published obsidian sourcing results for sites within the Upper Khabur Basin (UKB) and Middle Khabur Basin (MKB); see Fig. 2. Sourced obsidian artefacts from known Bronze-Age levels are highlighted.

Site (west to east)	Period (if known)	Reference	Artefacts	Source assignments	
			n	*n*	Source
Tell Halaf	Surface finds	Francaviglia and Palmieri, 1998	6	2	Bingöl A/Nemrut Dağ
				2	Meydan Dağ
				1	Bingöl B?
				1	Undetermined
Tell Kashkashok	Late Neolithic	Gratuze et al., 1993	8	4	Bingöl A/Nemrut Dağ
				4	Bingöl B
Tell Gudeda	**Early Bronze Age**	Chabot et al., 2001	**4**	**4**	**Bingöl A (?)**
Tell Mulla Matar	**Early Bronze Age**	Pernicka et al., 1997	**1**	**1**	**Nemrut Dağ**
Tell ʻAtij	**Early Bronze Age**	Chabot et al., 2001	**6**	**4**	**Bingöl A (?)**
				2	**Undetermined**
Chagar Bazar	Chalcolithic	Cann and Renfrew, 1964	1	1	Bingöl A/Nemrut Dağ
	Late Neolithic	Cann and Renfrew, 1964	1	1	Meydan Dağ?
Tell Brak	Surface finds	Francaviglia and Palmieri, 1998	5	4	Bingöl A/Nemrut Dağ
				1	Bingöl B?
	Late Chalcolithic	Khalidi et al., 2009	8	4	Bingöl A/Nemrut Dağ
				3	Bingöl B
				1	Meydan Dağ
	Records lost	Forster and Grave, 2012	4	4	Bingöl A/Nemrut Dağ
Tell Barri	Surface finds	Francaviglia and Palmieri, 1998	22	18	Bingöl A/Nemrut Dağ
				2	Meydan Dağ
				2	Bingöl B?
Tell Hamoukar	Surface finds	Hall and Shackley, 1994	10	9	Bingöl A/Nemrut Dağ
				1	Undetermined
	Surface finds	Francaviglia and Palmieri, 1998	16	16	Bingöl A/Nemrut Dağ
	Late Chalcolithic	Khalidi et al., 2009	32	27	Bingöl A/Nemrut Dağ
				2	Bingöl B
				2	Undetermined
				1	Meydan Dağ
Hirbet Tueris	Surface finds	Hall and Shackley, 1994	11	11	Bingöl A/Nemrut Dağ

lithics survey, 97 obsidian artefacts, all chip debris, were approved for export and non-destructive studies by Syria's Directorate General of Antiquities and Museums. Their spatiotemporal range reflects the IIMAS excavations: 81 artefacts from Area A, 3 from B, and 13 from J (Fig. 3). These artefacts are documented in Frahm (2010: 518–576), and the labels enable their contexts to be reconstructed using the UGR. The artefacts' compositions were compared to more than 900 geological specimens from 200 sampling loci in Anatolia and the Caucasus (Frahm, 2010: 257–269).

4.2. Geochemical analyses: source identification

These artefacts and geological specimens were geochemically analysed with two analytical techniques: electron microprobe analysis (EMPA) and portable X-ray fluorescence (pXRF). While not used as frequently as X-ray fluorescence (XRF) or neutron activation analysis (NAA), EMPA is an established technique for obsidian sourcing (e.g., Merrick and Brown, 1984; Weisler and Clague, 1998; Tykot, 1995; Tykot and Chia, 1997; Rosen et al., 2005; Le Bourdonnec et al., 2005, 2010; Wada et al., 2003; Wada, 2009; Sanna et al., 2010). Our calibration and analytical procedures are discussed in Frahm (2010: 302–364; 2012a). Evaluations of accuracy and precision (repeatability and reproducibility) were based on reference standards (e.g., VG-568), analytical "round robin" specimens, and XRF and NAA data from the University of Missouri's Research Reactor (MURR) for matched specimens (Frahm, 2010: 365–484, 2012a). Source attributions are based on three- to seven-dimensional Euclidean distance (ED) matrices of similarity coefficients (Frahm, 2010: 469–482, 2012a).

Handheld pXRF has recently become an established technique for obsidian sourcing around the world: the Near East (Frahm, 2007, 2013; Forster and Grave, 2012), East Asia (Jia et al., 2010), Mesoamerica (Nazaroff et al., 2010; Millhauser et al., 2011), South America (Craig et al., 2010), the North American Great Basin (Goodale et al., 2012), the Western Mediterranean (Tykot, 2010; Tykot et al., 2011), and Oceania (Burley et al., 2011; McCoy et al., 2011; Sheppard et al., 2011). Of the 97 artefacts, 52 were analysed using pXRF to corroborate artefacts' source identifications and evaluate its potential for future on-site analyses (Frahm, 2013). These measurements were calibrated using 18 Anatolian obsidian specimens analysed with NAA and XRF at MURR. Our source assignment procedures were identical to those for the EMPA data.

Table 2
Site phases linked to approximate dates and regional chronologies.

Phase	Approx dates	Bronze Age	Jezirah period	Mesopotamian period
2	2300–2200 BCE	EBA III	Early Jezirah IV	Early Akkadian
3	2200–2100 BCE	EBA IV	Early Jezirah IV	Late Akkadian
4	2100–2000 BCE	MBA I	Early Jezirah V	Ur III/Post-Akkadian
5	2000–1800 BCE	MBA IIA	Old Jezirah I–II	Old Babylonian
6	1800–1500 BCE	MBA IIB & IIC	Old Jezirah III	Middle Babylonian
7	1500–1300 BCE	LBA I & IIA	–	Mitannian/Middle Assyrian

4.3. Magnetic analyses: subsource identification

Different parts of an obsidian flow experience different temperature ranges, viscosities, and oxidation conditions as they cool. The morphologies, distributions, and chemistries of microscopic minerals in all obsidians reflect the localised cooling histories. The variations affect the obsidians' magnetic properties. McDougall (1978) first demonstrated the potential of obsidian sourcing using magnetic parameters, and additional magnetic studies followed but with mixed success (Frahm and Feinberg, 2013 and the references within). These studies sought to distinguish obsidian sources, but variability of the magnetic properties within individual flows complicated their efforts. In contrast, we use thermal-dependent (and thus spatial-dependent) magnetic properties of obsidian to identify different locations (i.e., quarrying sites, subsources) on a flow. Some of the variations that impede interflow differentiation are the same mechanisms that enable intraflow differentiation. Magnetic hysteresis parameters — saturation magnetisation (M_s), saturation remanence (M_{rs}), coercivity (H_c), and coercivity of remanence (H_{cr}) — have proven most useful for spatial information. A publication on our magnetic techniques is currently in preparation (Frahm and Feinberg, in preparation).

5. Results

Based on established models of Near East obsidian distribution (e.g., Cauvin and Chataigner, 1998; Chataigner, 1998; Chataigner et al., 1998), we anticipated that obsidians would have originated from the Eastern Anatolian sources. Indeed, 94 of the 97 artefacts came from these sources and are considered here. Three Phase 2b artefacts from Central Anatolia reflect a discrete phenomenon and are discussed elsewhere (Frahm and Feinberg, 2013).

5.1. Eastern Anatolian obsidians at Tell Mozan

Figs. 5 and 6 are scatterplots of the Eastern Anatolian artefacts and geological specimens analysed using EMPA and pXRF. Six Eastern Anatolian sources are identified among the artefacts (Fig. 2): Nemrut Dağ, Bingöl A, Bingöl B, Muş, Meydan Dağ, and Tendürek Dağ. EMPA results were the primary means of source identification, and the findings were corroborated with pXRF. In the case of Muş, pXRF resolved an ambiguous distinction between that source and Pasinler (i.e., six artefacts, using the EMPA data, plotted closest to Muş and also near Pasinler due to weathering, but the pXRF data were unaffected). Fig. 7 shows the distinction between Nemrut Dağ and Bingöl A obsidians. A supplementary table includes the relevant geochemical data (i.e., the eight elements used in the ED calculations) for the Eastern Anatolian artefacts and their sources (Table S1). The full dataset and ED similarity coefficients are available in Frahm (2010: 852–1019).

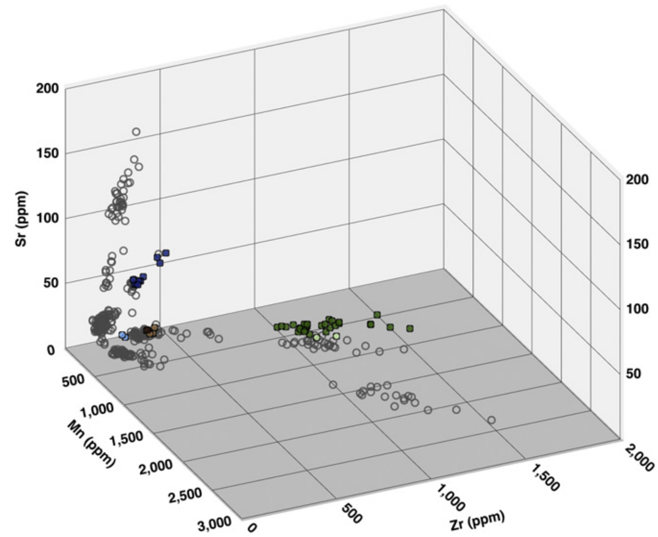

Fig. 6. Scatterplot of pXRF data of the artefacts (filled circles) and geological specimens (open grey circles); only the Eastern Anatolian obsidians are shown for clarity. Measurements are in parts per million (ppm). The pXRF data were calibrated using a set of 18 Anatolian obsidian specimens analysed using NAA and XRF at the University of Missouri's Research Reactor. Colour codes are consistent with Fig. 8. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Such a diversity of Eastern Anatolian sources is previously unknown in Mesopotamia. The majority of these 94 artefacts (85%) came from the three most prominent Eastern Anatolian sources: Nemrut Dağ, Bingöl A, and Bingöl B. The only other Eastern Anatolian source known in the UKB is Meydan Dağ (Table 1), where 2% of Tell Mozan artefacts originated. Use of Muş and Tendürek Dağ obsidians is, to our knowledge, previously unknown in Mesopotamia. Recently, Carter et al. (2013) report the first clear archaeological use of Muş obsidian: one artefact from Körtik Tepe in Turkey. The six artefacts from Tell Mozan corroborate that Muş must be considered an important source. It should be noted 3.5% of sourced Mesopotamian obsidian artefacts have unidentified sources, and in the UKB, this proportion rises to 4.5% (Frahm, 2010: 590–629).

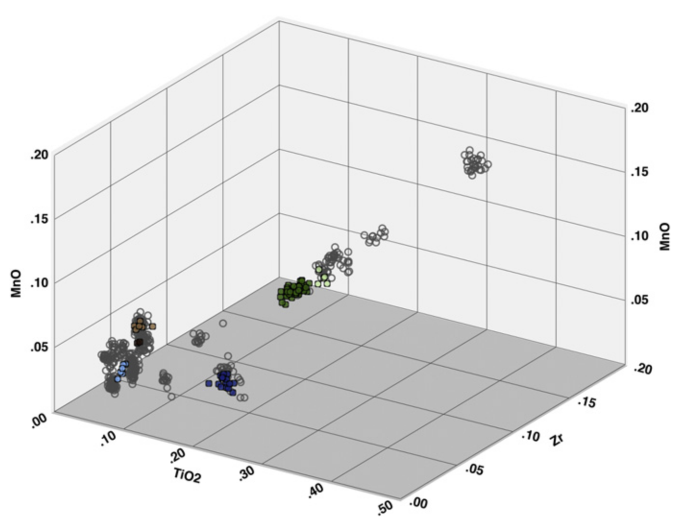

Fig. 5. Scatterplot of EMPA data for the artefacts (filled circles) and geological specimens (open grey circles); only the Eastern Anatolian obsidians are shown for clarity. Measurements are in weight percent (wt %). Colour codes are consistent with Fig. 8. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

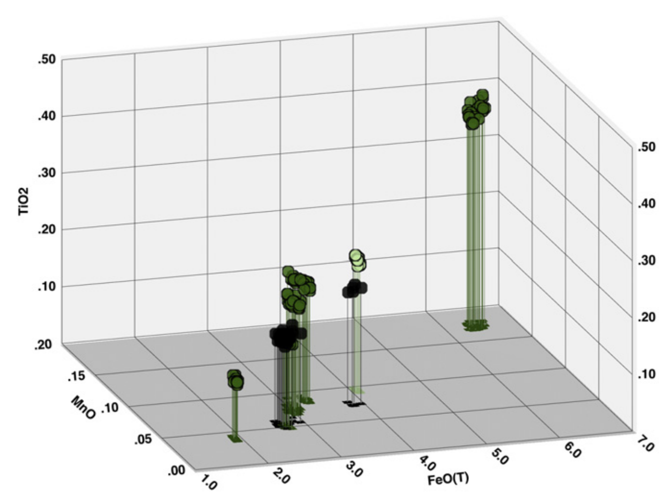

Fig. 7. Scatterplot of EMPA data for the peralkaline Tell Mozan obsidian artefacts (black circles) and the geological specimens from Nemrut Dağ (darker circles) and Bingöl A (lighter circles). Colour codes are consistent with Fig. 8. The artefacts from these sources fall into discrete populations, attesting to their different origins. The middle Nemrut Dağ cluster corresponds to what is commonly called "Nemrut Caldea" or "Nemrut I/II" in the literature. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

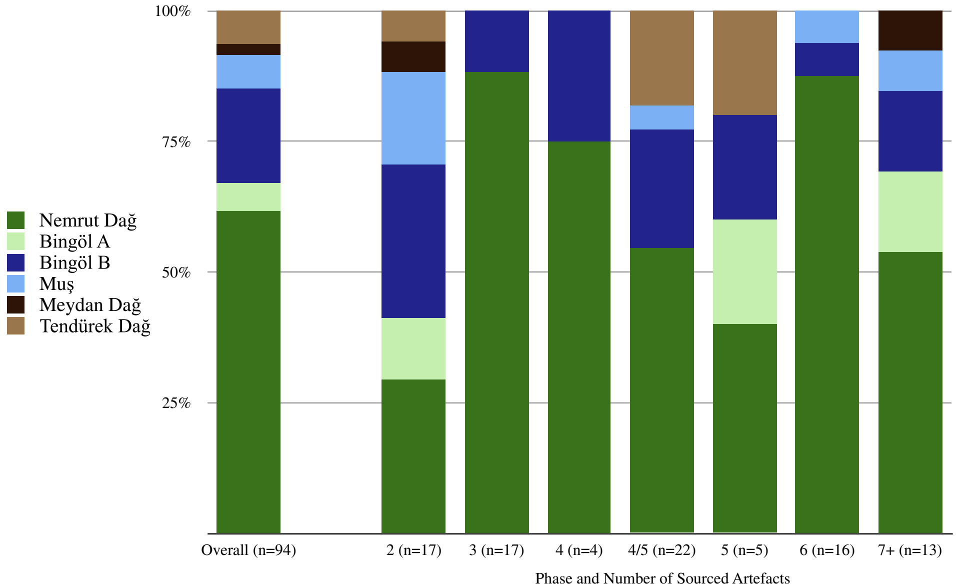

Fig. 8. Volcanic origins of the 94 artefacts from Eastern Anatolian obsidian sources (left) and a chronological breakdown (right). The site phases for Tell Mozan are described in Table 2. Of the Phase 2 artefacts, those most securely dated are ascribed only to Phase 2a. The remainder is ascribed to Phase 2 in general (i.e., none specifically to Phase 2b). The Phase 4/5 artefacts are thought to be principally, if not entirely, Phase 5; however, late Phase 4 attributions cannot be completely ruled out based on presently available chronostratigraphic data.

5.2. Geochemical inter-source chronology

Changes in obsidian use between Phases 2 and 3 are dramatic (Fig. 8 and Table 2). Phase 2 (2300–2200 BCE) obsidians are from six sources, and no source represents over 30%. In contrast, Phase 3 (2200–2100 BCE) obsidians came from only two of the closest sources: Nemrut Dağ (88%) and Bingöl B (12%). This trend apparently continues into Phase 4 (2100–2000 BCE): Nemrut Dağ (75%) and Bingöl B (25%). During Phase 5 (2000–1800 BCE), diverse obsidians reappear, but half of the artefacts (52%) are Nemrut Dağ obsidians (in Phases 4/5 and 5). Phases 6 (1800–1500 BCE) and 7 (1500–1300 BCE) might represent a second change between (1) the nearest three sources with a predominance of Nemrut Dağ obsidians and (2) followed by greater diversity.

5.3. Magnetic intra-source chronologies

Given that use of Muş and Tendürek Dağ obsidians is essentially unknown, the results of our magnetic analyses for these sources are especially interesting. Specifically, we found different parts of the sources were utilised over time. Consider Muş first. Obsidian outcrops from a lava dome on the Muş plains, and a secondary deposit lies downstream along the Murat River (Ercan et al., 1995; Bigazzi et al., 1997). The Muş artefacts and specimens comprise one chemical cluster, but magnetic analyses reveal discrete populations (Fig. 9). Obsidian from the west-central part of the dome matches the river-transported specimens. The artefacts most closely match these specimens. Thus, people may have collected obsidian from these outcrops or river deposits. One artefact is distinct from those in earlier and later phases, and it may have come from a different area, likely close to the southwestern edge of the dome. Thus, the initial reappearance of Muş obsidian at Tell Mozan might represent a distinct mode of raw-material acquisition at the source itself.

Obsidian occurs on the northern slopes of Tendürek Dağ and likely elsewhere on the volcano (Yılmaz et al., 1998). The Tendürek Dağ specimens and artefacts also fall into a single geochemical cluster, but magnetic analyses reveal discrete populations (Fig. 10). There are small differences among the four Tendürek Dağ sampling loci, and the Phase 5c matches these geological specimens. The only Phase 2a artefact is distinct, as are the four artefacts from intermediate phases. Like Muş, the Tendürek Dağ obsidian found at Tell Mozan was collected from distinct loci in different periods, indicating the acquisition mechanisms may have changed. These magnetic results also suggest that there are additional quarrying areas on the slopes of Tendürek Dağ.

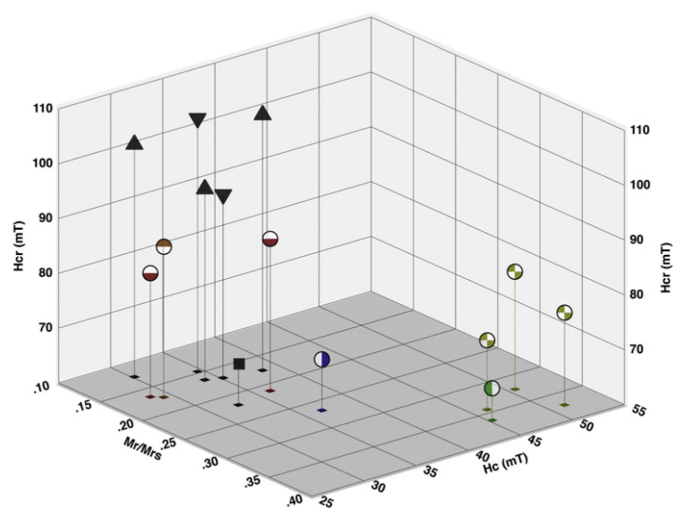

Fig. 9. Magnetic hysteresis parameters of Muş artefacts and specimens. Artefacts are the black shapes. Geological collection areas are represented by circles with different patterns/colours. Obsidian from the west-central part of the lava dome (facing the river; the top-shaded circle) matches the river-transported specimens (bottom-shaded circles). One artefact (square) has distinct magnetic properties than those from earlier and later phases (upward and downward triangles). This artefact may have been collected from a different location, most likely near the southwestern edge of the dome (right-shaded circle). The other circles (left- and quarter-shaded circles) represent other parts of the dome (east-centre and north-centre, respectively). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

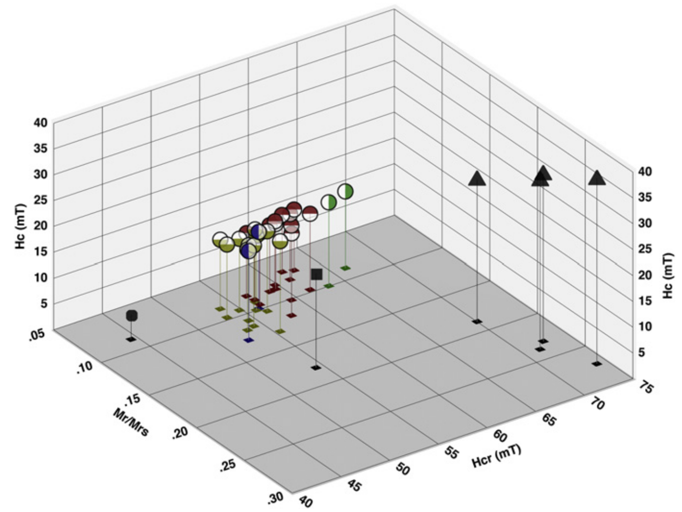

Fig. 10. Magnetic hysteresis parameters of Tendürek Dağ artefacts and specimens. Artefacts are the solid black shapes. Geological collection areas are represented by circles with different patterns/colours. Only the one Phase 5c artefact (square) matches specimens collected from the outcrops (half-shaded circles). A Phase 2a artefact (circle) is distinct from the geological sampling areas, as are the four artefacts from intermediate phases (triangles). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

5.4. Comparison to previous studies

Earlier obsidian sourcing studies provide little for comparison. To our knowledge, there are 135 sourced Eastern Anatolian obsidian artefacts from ten Khabur sites in published studies (Table 1). Over half ($n = 74$; 55%) have no spatiotemporal context. Just 11 artefacts (8%) were excavated from Bronze-Age strata at three sites. Tell Malla Matar, Tell Gudeda, and Tell 'Atij are small (1 ha) riverside villages within 4 km of one another in the Middle Khabur Basin (MKB; Fig. 2). These three EBA sites were abandoned roughly synchronous with EBA–MBA transition and, thus, cannot provide a diachronic perspective.

From Tell Mulla Matar, Pernicka et al. (1997) sourced only one artefact and attributed it to Nemrut Dağ rather than compositionally similar Bingöl A. Using their technique (Pernicka, 1992), Bingöl A was distinguished from the three major geochemical types of Nemrut Dağ obsidian, often called Nemrut Caldera, Nemrut Lake, and Nemrut South (e.g., Bressy et al., 2005) or Nemrut I/II, III, and IV (e.g., Blackman, 1984). Specifically, Pernicka et al. (1997) identified this artefact as "Nemrut Caldera" or "Nemrut I/II" obsidian. This is the same type of Nemrut Dağ obsidian found at Tell Mozan (Fig. 7) as well as numerous sites in the Euphrates Basin (e.g., Hassek Höyük, Pernicka, 1992; Dja'de, Halula, and Mureybet, Pernicka et al., 1997).

Just 10 obsidian artefacts were recovered at Tell Gudeda and 19 at Tell 'Atij (700 m apart on the Khabur River; Chabot et al., 2001). Collectively, the lithic assemblages are only 0.4% obsidian. To differentiate Nemrut Dağ and Bingöl A obsidians, Chabot et al. (2001) follow Poidevin's (1998) approach and use a geochemical plot (i.e., a CNK/A vs. NK/A from Shand, 1943). Poidevin (1998), though, knew only of the "Nemrut Lake" and "Nemrut South" obsidian types. Bressy et al. (2005) apparently first added "Nemrut Caldera" obsidian to such a graph, and this third obsidian type plots very near Bingöl A obsidian, casting prior identifications into doubt.

Chabot et al. (2001) determined that four artefacts from each site fell into the intermediate geochemical range between "Nemrut Lake" and "Nemrut South," so they attributed the artefacts to Bingöl A. Like Poidevin (1998), they were only aware of two Nemrut Dağ obsidian types, so these artefacts may be misattributed to Bingöl A. Instead, "Nemrut Caldera" obsidian, like that found at nearby Tell Mulla Matar, may be correct. Without geological specimens for comparison (*cf*., Fig. 7), the source remains uncertain. Their data, though, plot as one cluster, so it is unlikely that there is a mix of Nemrut Dağ and Bingöl A at the two MKB sites. Additionally, two other artefacts from Tell 'Atij had sources unidentified by Chabot et al. (2001).

Clearly there are considerable differences between the obsidians represented at a large UKB city and small riverside MKB villages in the EBA. Comparisons, however, are limited by the small sample sizes and uncertainties in source identification. Unfortunately, for Khabur sites with over 10 sourced obsidian artefacts (Fig. 11), the

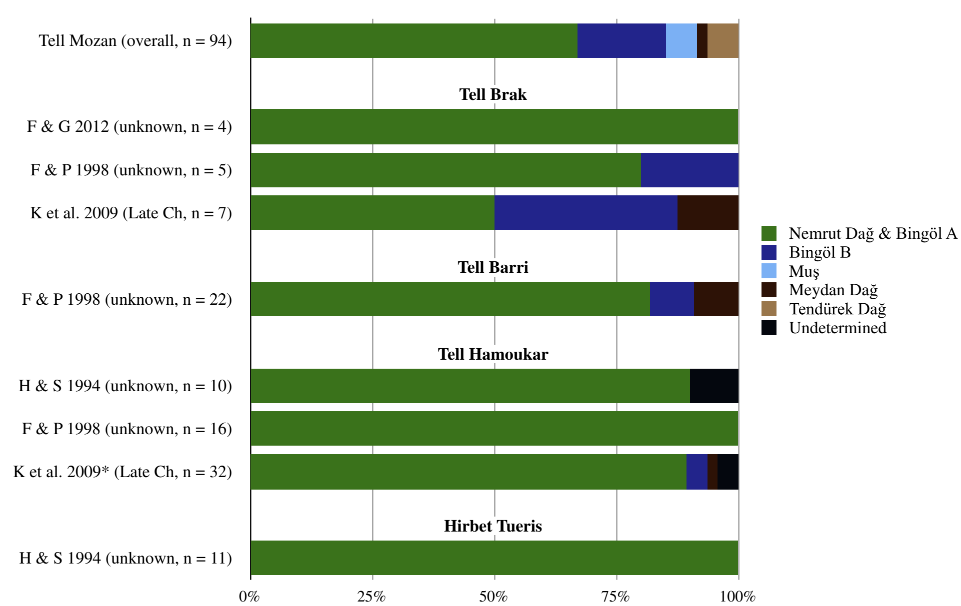

Fig. 11. Khabur archaeological sites with more than ten sourced obsidian artefacts. The asterisk denotes an adjustment of the source proportions based on statements by Khalidi et al. (2009) regarding their non-representative sample of sourced artefacts. Nemrut Dağ and Bingöl A are combined because the other studies could not distinguish these chemically similar sources.

artefacts are older or have no spatiotemporal context, and Bingöl A and Nemrut Dağ obsidians could not be discerned. These prior studies, however, establish the diversity (or lack thereof) of obsidians represented at other UKB sites.

6. Discussion

The transition between Phases 2 and 3 is roughly concurrent with the "crisis" onset. Phase 2 obsidians come from six Eastern Anatolian sources, but Phase 3 obsidians are from only two of the closest sources. Diverse obsidians seem to reappear during Phase 5, consistent with proposals that the effects lasted two to three centuries in the UKB. Determining the nature of the third-millennium crisis at Urkesh is, of course, a heavy burden to put on these 94 obsidian artefacts. This study alone cannot resolve the nature of the crisis. Our results, however, provide tangible evidence for changes in exchange at Urkesh and in quarrying at sources. Hence we consider potential mechanisms for obsidian artefacts' arrival and source-use changes in light of hypotheses regarding the crisis. We stress that the exchange of obsidian should not necessarily be conceptualised as obsidian-*driven*. It should be understood as a phenomenon in which obsidian was embedded in a primary or secondary role. The movement of obsidian may instead reflect the exchange of other goods (e.g., metals), the movement of people (e.g., migration, pilgrimages), or other phenomena.

6.1. Centripetal forces: Urkesh as a landmark

The Phase 2 obsidian *mélange* implies Urkesh residents did not practice direct procurement. Khalidi et al. (2009) claim that obsidian diversity in the Chalcolithic UKB is a metric of directness: one predominant source is an indicator of direct access while varied obsidians imply indirect access and procurement associated with other goods. We agree, in general, with this postulate, particularly in light of previous studies that identified highly diverse obsidians at a site. Consider Molyneaux's (2002) discovery of diverse obsidians at Devils Tower in Wyoming. He suggests that Devils Tower exhibited "a *centripetal* effect, as it drew — and continues to draw — travellers from all directions to its sides" (136) and that travellers simply carried varied obsidians. In Turkey, diverse obsidians are found at Göbekli Tepe during the Pre-Pottery Neolithic Period (Carter et al., 2012), and the variety is interpreted as evidence of pilgrimages by different groups. Thus, diverse obsidians at Devils Tower and Göbekli Tepe represent a convergence of travellers at a landmark.

Thus, diverse Phase 2 obsidians suggest that Urkesh was a cosmopolitan centre with diverse visitors or visitors with diverse itineraries. Urkesh was the largest city near the Mardin Pass, and its temple atop a 30-m-tall terrace, rivalling the Ziggurat of Ur, was a conspicuous landmark across the plains. There were likely pilgrimages or religious festivals attended by travellers. Crawford (1978) suggests obsidian trade occurred at bazaars, like those held outside Damascus, where "long-distance travellers... distribute the surplus of the goods thus acquired" to sedentary peoples (131). Wilkinson (2000) contends large UKB cities, like Urkesh, arose in locations suited to participation in exchange networks that incorporate sedentary, nomadic, and valuable goods.

Small MKB villages did not exhibit such centripetal effects. Low obsidian diversity, plus its scarcity, suggests fewer travellers reached the villages. The MKB pattern also implies the obsidians reaching Urkesh were not simply re-radiated throughout the basin. Perhaps their exchange involved distinct mechanisms. Nemrut Dağ and Bingöl B obsidians might have been moved via mechanisms that persisted and enabled them to reach Southern Mesopotamia (Fig. 12). Other obsidians may have reached the city via exchange mechanisms that did not continue, explaining their limited long-distance exchange. This mechanism may also have been "pulled" to Urkesh by a centripetal effect, which might have diminished in strength under societal and climatic stress.

6.2. Exchange, networks, and economy

To explain the differential occurrence of Central and Eastern Anatolian obsidians at Urkesh, we suggested two mechanisms for their arrival at the city (Frahm and Feinberg, 2013). We proposed Central Anatolian obsidian artefacts arrived via an established long-distance exchange network (the Anatolian Trade Network, 2500–2100 BCE, Şahoğlu, 2005), which linked Central Anatolian polities to the Aegean in the west and Middle Euphrates in the east. In contrast, drawing on ethnohistorical accounts from the region, we

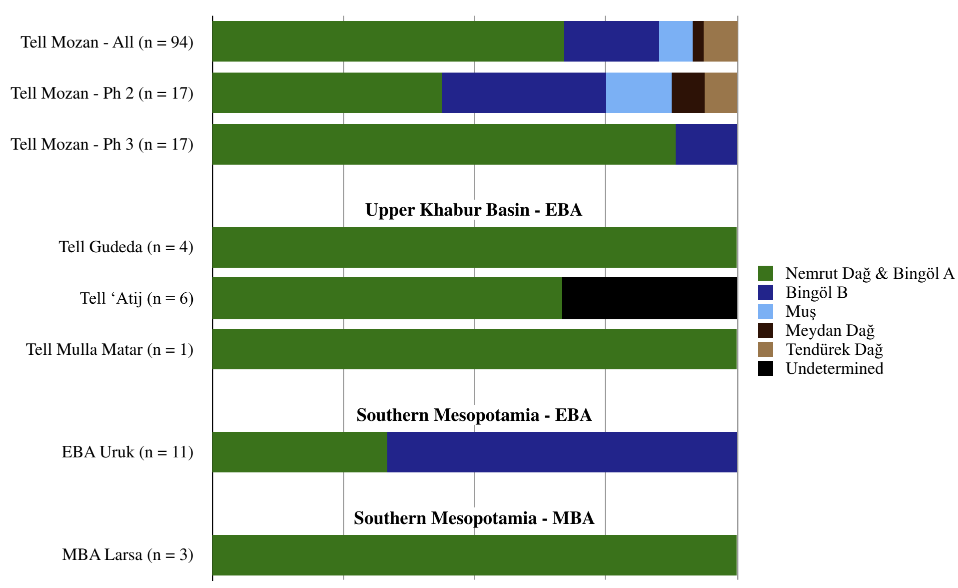

Fig. 12. Our results for Tell Mozan, the results for the three EBA MKB sites, and the published obsidian sourcing results for known EBA and MBA contexts at Southern Mesopotamian sites. Nemrut Dağ and Bingöl A are combined because the other studies (except for Pernicka et al., 1997) could not distinguish these chemically similar sources.

considered the possible roles of nomadic and semi-nomadic groups in distributing Eastern Anatolian obsidians. For example, Cribb (1991) documented the migrations of Alikan tribes across southeastern Turkey. The different groups' routes crossed, often at cities where goods could be traded, creating an intersecting *de facto* exchange network. Transhumance is perhaps the most discussed mechanism of obsidian distribution in Eastern Anatolia (e.g., Hole, 1968; Wright, 1969; Williams-Thorpe, 1995; Cauvin, 1996; Chataigner, 1998; Chataigner et al., 1998).

Shared material culture also attests to networks linking Northern Mesopotamia and Eastern Anatolia. Specifically, the Early Transcaucasian or Kura–Araxes complex (circa 3400–2000 BCE) spanned from the Caucasus to southeastern Anatolia. Obsidian, either as a raw material or finished tools, likely spread through the region via similar mechanisms as the material culture (e.g., the red-and-black burnished ware). At Urkesh, red-and-black burnished sherds occur in mid- and late-third-millennium levels of the palace and temple, roughly concurrent with the diverse Phase 2 obsidians. The disappearance of Early Transcaucasian sherds appears synchronous with the reduced diversity of obsidians. This is consistent with Edens' (1995) contention that the EBA–MBA transition in Eastern Anatolia and the Caucasus ended in "more fragmented regional cultures" (53). A disintegration of regional social networks may have ended the arrival of Early Transcaucasian ceramics (or peoples) and the diverse obsidians that disappeared from Urkesh. The causality of such a change, including any link to the "crisis" in Northern Mesopotamia, remains unknown.

Another possibility is that the diverse Phase 2 obsidian pattern reflects Akkadian influence at the city. Empires are known to extend their influence beyond regional borders to access a variety of resources (Barfield, 2001; Sinopoli, 2001). While most scholars hold that their influence in Northern Mesopotamia "fell decisively short of full imperial control" (Adams, 1966: 159), the Akkadians may have sought control over distribution routes for natural resources, especially highland resources like metals (Nissen, 1988; Michalowski, 1993; Marcus, 1998; Van De Mieroop, 2004). Additionally, trade under the Akkadians is thought to have been state-controlled, later becoming a private endeavour in the Old Assyrian system (1950–1750 BCE; Veenhof, 1997). Hence, it is possible that, either directly or indirectly, Akkadian influence altered the Urkesh economy in Phase 2. The local economy might have intensified its focus on resources from the north (and this could also have occurred for various reasons). For example, copper metallurgy, using ores from the north, could have increased due to demand from the south. With climatic shifts and the end of the empire, the Urkesh economy might then have refocused on local production and consumption in Phase 3.

Pastoral nomads' habitat-tracking perhaps also changed during this era, and migration shifts would also change the resulting network. Palynological, geochemical, and isotopic climate signals preserved in Lake Van sediments suggest environmental shifts in Eastern Anatolia as well. Lemcke and Sturm (1997) report "decreasing humidity (temperature) and a significant shift of precipitation" after 2190 BCE (673), and Wick et al. (2003) noted decreasing woodlands after 2100 BCE, replaced by an open landscape. Migration routes may have shifted, and if resource shortfalls occurred, there might have been changes in trade, territoriality, or other resource-control strategies. Not all groups would have to be affected because, as a network, shifts in the routes of only one group could affect how obsidians were distributed. Consequently, climate could have disrupted their *de facto* network and also effected the disappearance of four obsidians from Urkesh.

We should also consider the possibility that exchange embedded in complex networks might not be the mechanism to explain differential distribution of these obsidians. Perhaps a "simple" mechanism, such as multiple reciprocal exchange ("down-the-line" trade) among groups, could account for Nemrut Dağ and Bingöl B obsidians reaching crisis-era Urkesh as well as MKB villages and Southern Mesopotamian cities in small quantities.

Ultimately, much more data are needed to connect the patterns and processes. Tell Mozan is the only UKB site with sourced obsidian covering the EBA–MBA transition. One priority should be identifying similarities and differences in obsidian source-histories throughout the UKB. Different settlements might have reacted differently to climatic/societal stresses and had different approaches mitigating the effects. In prior studies of Khabur sites, more than half of the sourced artefacts have no context (Hall and Shackley, 1994; Francaviglia and Palmieri, 1998). It is no longer sufficient to source obsidian from a deeply stratified tell by collecting ten artefacts from the surface and ignore the ultimate spatiotemporal contexts of the analysed artefacts.

An important question is why Nemrut Dağ and Bingöl B obsidians might be different. Why would those specific obsidians not only persist through the crisis at Urkesh but also reach Southern Mesopotamia? One possible answer for Nemrut Dağ is proposed by Frahm (2012b): this volcano simultaneously exhibited a centripetal force, drawing in travellers from all around, and a centrifugal force, radiating obsidian outward across the Near East. Thus, we must also consider source-centric (i.e., centrifugal) mechanisms and interpretations for the observed shifts.

6.3. Centrifugal forces: sources, landscape, and environment

Our magnetic results suggest that past peoples collected obsidian at locations other than those sampled for the reference collection. Thus, at present, most of the artefacts cannot be "sourced" to a particular quarry. At this point, however, these results indicate changes in some aspect of human behaviour at the sources. Apparently there were shifts in quarry use for some reason. Perhaps, for example, changes in extraction techniques might have altered which quarries were considered "economically viable." Ethnographic and archaeological studies indicate that quarries can have cultural meanings that also affect their selection and use (Taçon, 1989, 1991; Saunders, 2001).

Given the apparent environment shifts (e.g., disappearing woodlands around Lake Van; Wick et al., 2003), one centrifugal (i.e., source-centric, materials radiating outward) perspective that must be considered is changing landscape and quarry accessibility. Obsidian forms only under particular conditions: when viscous lava oozes onto the surface and produces a lava dome (Fig. 7 in Frahm, 2012b). The inner shell of high-quality obsidian is deeply buried across most of the lava dome, and obsidian can be collected where this inner shell is exposed by slope processes, which are controlled by landscape-climate interactions. As a landscape shifts in response to climate, the locations where obsidian is accessible may also change. Some outcrops may be buried, whereas others are exposed. Consider, for example, how rain affects erosion and deposition. With high rainfall, streams can cut channels into a lava dome, exposing obsidian for people to collect. When rain decreases, sediment may accumulate in the channels and cover the obsidian, removing it from circulation and requiring people to seek new exposures. Thus, an accessibility signal *may* be preserved in obsidian artefacts. Models of changing mobility and exchange must, of course, be studied alongside those of changing accessibility because the stimulus (e.g., environmental change) could yield multiple responses (e.g., shifts in mobility or exchange networks) with potential equifinality.

At present, we can only state that the initial reappearance of Muş and Tendürek Dağ obsidians at Tell Mozan seems to involve different collection loci. Therefore, there were discontinuities at the sources, not just at Urkesh. Regardless of impetus, the changes are tangible, and magnetic analyses enable identification of quarry-scale changes in sources' use-histories.

7. Conclusions

The "crisis" in Northern Mesopotamia during the last centuries of the third millennium BCE is one of the most discussed and debated times of societal and climatic change. This shift was likely not an undifferentiated process explainable by a single *primum movens*. Instead, as Schwartz (2007) contends, "there were numerous crises in different regions at different chronological junctures from ca. 2300 to 1900 B.C., not a single catastrophic event" (62). Our study ultimately involves changes at only one UKB urban centre. Thus, our results are not poised to resolve what occurred throughout the region at this time. Instead, we report tangible evidence in the material culture of changes at this city and at some raw-material sources. We consider potential interpretations of these findings, all of which require further evidence and testing, in light of the proposed crisis.

To summarise, apparently concurrent with UKB aridification and deurbanisation as well as the decline of the Akkadian empire, there was a dramatic change in the obsidians arriving at Urkesh. Before this time, during Phase 2, six obsidian sources in Eastern Anatolia are represented among the artefacts. Such a variety of Eastern Anatolian obsidians at one Mesopotamian site is previously unknown. This finding implies that Urkesh was a cosmopolitan city and that its visitors carried diverse obsidians with them. During Phase 3, however, obsidians came from only two of the closest sources. The reduced diversity of obsidians is also synchronous with the disappearance of Early Transcaucasian ceramics at Urkesh. The reappearance of varied obsidians is roughly consistent with the proposed crisis duration in the UKB. Even when an obsidian source reappears, the raw material apparently came from different collection spots, implying discontinuities at the quarries, perhaps due to accessibility issues on a changing landscape. Although the precise mechanisms remain unclear, it may be that obsidians from different sources arrived at Urkesh via distinct networks and that one (or more) did not persist through the crisis.

Here we report evidence, geochemical and magnetic signals in obsidian artefacts discovered at Tell Mozan, for changes in exchange networks and quarrying practices concurrent with a time of societal and environmental stress. With a diachronic perspective on obsidian source-use from only one site, our findings are, at present, neutral regarding the degree of deurbanisation and whether the causes included climate shifts, unsustainable urban growth and subsistence practices, governmental collapse, economic forces, or societal fragmentation. The data do not yet support a particular model of the crisis, but our results suggest that it is not merely a contrivance of ceramic topology problems or incomplete surface surveys. As future work elucidates the changes in climate and society near the end of the third millennium BCE, there might be considerable implications regarding the roles that exchange and associated social networks play under societal and environmental stresses, how they change in response, and how they eventually recover or adapt.

Acknowledgements

Giorgio Buccellati and Marilyn Kelly-Buccellati are the directors of the Urkesh excavations under the auspices of the International Institute for Mesopotamian Area Studies (IIMAS). Export of the Tell Mozan artefacts was approved by the Directorate General of Antiquities and Museums, the Ministry of Culture, Syrian Arab Republic. EMPA was conducted with a JEOL 8900 SuperProbe in the Department of Earth Sciences' Electron Microprobe Laboratory at the University of Minnesota. Our magnetic analyses were conducted at the Institute for Rock Magnetism at the University of Minnesota, and we are grateful for the research assistance of Charissa Johnson (supported by the University of Minnesota's Undergraduate Research Opportunity Program and a Sigma Xi award) and Amy Hillis (supported by the National Science Foundation's Research Experience for Undergraduates program). Thermo Fisher is thanked for the loan of the NITON handheld pXRF instrument. Michael Glascock is thanked for NAA and XRF data that aided in accuracy assessment of the EMPA data and calibration of the pXRF data. Most of the Anatolian geological specimens were originally collected by George "Rip" Rapp, University of Minnesota and the late Tuncay Ercan, Directorate of Mineral Research and Exploration of Turkey. Additional specimens came from the collections of M. James Blackman, Robert L. Smith, and James F. Luhr. This research was supported by the Department of Archaeology of the University of Sheffield, the Departments of Earth Sciences and Anthropology of the University of Minnesota, and Marie Curie Network FP7-PEOPLE-2010-ITN: New Archaeological Research Network for Integrating Approaches to Ancient Material Studies (NARNIA). Two anonymous reviewers and the editor are thanked for their comments that improved the clarity of this paper.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2012.11.026.

References

Adams, R.McC., 1966. The Evolution of Urban Society. Aldine Transaction, Chicago.

Akkermans, P.M.M.G., Schwartz, G.M., 2003. The Archaeology of Syria: From Complex Hunter–Gatherers to Early Urban Societies (c.16,000–300 BC). Cambridge University Press, Cambridge.

Barfield, T., 2001. The shadow empires: imperial state formation along the Chinese-Nomad Frontier. In: Alcock, S.E., D'Altroy, T.N., Morrison, K.D., Sinopoli, C.M. (Eds.), Empires: Perspectives from Archaeology and History. Cambridge University Press, pp. 10–41.

Beşikçi, I., 1969. Gocebe Alikan Aşiret. Dogan Yayinevi, Ankara.

Bigazzi, G., Yeğingil, Z., Ercan, T., Oddone, M., Özdogan, M., 1997. Age determination of obsidian bearing volcanics in Eastern Anatolia using the fission track dating method. Geological Bulletin of Turkey 40 (2), 57–73.

Blackman, M., 1984. Provenance studies of middle eastern obsidian from sites in highland Iran. In: Lambert, J.B. (Ed.), Archaeological Chemistry III, pp. 19–50.

Bressy, C., Poupeau, G., Yener, K., 2005. Cultural interactions during the Ubaid and Halaf periods: Tell Kurdu (Amuq Valley, Turkey) obsidian sourcing. Journal of Archaeological Science 32, 1560–1565.

Burley, D., Sheppard, P., Simonin, M., 2011. Tongan and Samoan volcanic glass: pXRF analysis and implications for constructs of ancestral Polynesian society. Journal of Archaeological Science 38, 2625–2632.

Butzer, K., 1997. Sociopolitical discontinuity in the near east c. 2200 BCE: scenarios from Palestine and Egypt. In: Dalfes, H., Kukla, G., Weiss, H. (Eds.), Third Millennium BC Climate Change and Old World Collapse. Springer, Berlin, pp. 245–296.

Butzer, K., 2012. Collapse, environment, and society. PNAS 109, 3632–3639.

Cann, J.R., Renfrew, C., 1964. The characterization of obsidian and its application to the Mediterranean Region. Proceedings of the Prehistoric Society 30, 111–133.

Carter, T., Le Bourdonnec, F.-X., Poupeau, G., Schmidt, K., 2012. Towards an archaeology of pilgrimage: sourcing obsidian from the PPN temple complex of Göbekli Tepe. In: 7th International Conference on the Chipped and Ground Stone Industries of the Pre-pottery Neolithic. 14–17 February 2012. Centre d'Estudis i Recursos Culturals, Barcelona, Spain.

Carter, T., Grant, S., Kartal, M., Coşkun, A., Özkaya, V., 2013. Networks and Neolithisation: sourcing obsidian from Körtik Tepe (SE Anatolia). Journal of Archaeological Science 40, 556–569.

Cauvin, M.C., 1996. L'obsidienne dans le Proche-Orient prehistorique: etat des recherches en 1996. Anatolica 22, 1–31.

Cauvin, M.C., Chataigner, C., 1998. Distribution de l'obsidienne dans les sites archéologiques du Proche et du Moyen Orient (par phase chronologique). In: Cauvin, M.C., Gourgaud, A., Gratuze, B., Arnaud, N., Poupeau, G., Poidevin, J.L., Chataigner, C. (Eds.), L'obsidienne au Proche et Moyen-Orient: Du Volcan à l'Outil. BAR, Oxford, pp. 325–350.

Chabot, J., Poidevin, J.L., Chataigner, C., Fortin, M., 2001. Caracterisation et provenance des artefacts en obsidienne de Tell 'Atij et de Tell Gudeda (III millenaire, Syrie). Cahiers d'Acheologie du CELAT 10, 241–256.

Chataigner, C., 1998. Sources des artefacts du Proche Orient d'aprés leur caractérisation géochimique. In: Cauvin, M.C., Gourgaud, A., Gratuze, B., Arnaud, N., Poupeau, G., Poidevin, J.L., Chataigner, C. (Eds.), L'obsidienne au Proche et Moyen-Orient: Du Volcan à l'Outil. BAR, Oxford, pp. 273–324.

Chataigner, C., Poidevin, J.L., Arnaud, N.O., 1998. Turkish occurrences of obsidian and use by prehistoric peoples in the near east from 14,000 to 6000 BP. Journal of Volcanology and Geothermal Research 85, 517–537.

Colantoni, C., Ur, J., 2011. The architecture and pottery of a late third-millennium residential quarter at Tell Hamoukar, north-eastern Syria. Iraq 73, 21–69.

Coombes, P., Barber, K., 2005. Environmental determinism in Holocene research: causality or coincidence? Area 37.3, 303–311.

Cooper, L., 2006a. The demise and regeneration of Bronze Age urban centers in the Euphrates Valley of Syria. In: Schwartz, G.M., Nichols, J.J. (Eds.), After Collapse: the Regeneration of Complex Societies. University of Arizona Press, pp. 18–37.

Cooper, L., 2006b. Early Urbanism on the Syrian Euphrates. Routledge, London.

Courty, M.-A., Weiss, H., 1997. The scenario of environmental degradation in the Tell Leilan region during the late third millennium abrupt climate change. In: Dalfes, H., Kukla, G., Weiss, H. (Eds.), Third Millennium BC Climate Change and Old World Collapse, pp. 107–147. Berlin, Heidelberg.

Craig, N., Speakman, R., Popelka-Filcoff, R., Aldenderfer, M., Blanco, L., Vega, M., Glascock, M., Stanish, C., 2010. Macusani obsidian from southern Peru: a characterization of its elemental composition with a demonstration of its ancient use. Journal of Archaeological Science 37, 569–576.

Crawford, H., 1978. The mechanics of the obsidian trade: a suggestion. Antiquity 52, 129–132.

Cribb, R., 1991. Nomads in Archaeology. Cambridge University Press, Cambridge.

Dalfes, H., Kukla, G., Weiss, H. (Eds.), 1997. Third Millennium BC Climate Change and Old World Collapse. Springer, Berlin.

Deckers, K., 2010a. Anthracological research at the early to middle Bronze Age settlement of Tell Mozan. In: Deckers, K., Doll, M., Pfälzner, P., Riehl, S. (Eds.), The Development of the Environment, Subsistence, and Settlement of the City of Urkeš and Its Region. Harrassowitz, Wiesbaden, pp. 159–190.

Deckers, K., 2010b. Archaeological sites of the Upper Khabur Basin in their fluvial geomorphological context. In: Deckers, K., Doll, M., Pfälzner, P., Riehl, S. (Eds.), The Development of the Environment, Subsistence, and Settlement of the City of Urkeš and its Region. Harrassowitz, Wiesbaden, pp. 361–377.

Deckers, K., Pessin, H., 2010. Vegetation development in the Middle Euphrates and Upper Jazirah (Syria/Turkey) during the Bronze Age. Quaternary Research 74, 216–226.

Deckers, K., Riehl, S., 2007. Fluvial environmental contexts for archaeological sites in the Upper Khabur basin (northeastern Syria). Quaternary Research 67, 337–348.

deMenocal, P.B., 2001. Cultural responses to climate change during the late Holocene. Science 292, 667–673.

Diamond, J., 2011. Collapse: How Societies Choose to Fail or Survive: How Societies Choose to Fail or Succeed, revised ed. Penguin Books.

Edens, C., 1995. Transcaucasia at the end of the early Bronze Age. BASOR 299/300, 53–64.

Ercan, T., Şaroğlu, F., Kuşçu, İ., 1995. Features of obsidian beds formed by the activity of the volcanoes in Anatolia since 25 million years B.P. In: The Proceedings of the 29th International Symposium on Archaeometry, 1994 May 9–14, Ankara, Turkey, pp. 505–513.

Fiorentino, G., Caracuta, V., Calcagnile, L., D'Elia, M., Matthiae, P., Mavelli, F., Quarta, G., 2008. Third millennium B.C. climate change in Syria highlighted by carbon stable isotope analysis of ^{14}C-AMS dated plant remains from Ebla. Palaeogeography, Palaeoclimatology, Palaeoecology 266, 51–58.

Forster, N., Grave, P., 2012. Non-destructive PXRF analysis of museum-curated obsidian from the Near East. Journal of Archaeological Science 39, 728–736.

Frahm, E., 2007. An evaluation of portable X-ray fluorescence for artifact sourcing in the field: can a handheld device differentiate Anatolian obsidian sources?. In: Geological Society of America Annual Meeting, Denver, Colorado, 28–31 October 2007 Geological Society of America Abstracts with Programs, vol. 39, No. 6, p. 29.

Frahm, E., 2010. The Bronze-Age Obsidian Industry at Tell Mozan (Ancient Urkesh), Syria. Ph.D. dissertation, Department of Anthropology, University of Minnesota. Available online at University of Minnesota's Digital Conservancy. http://purl.umn.edu/99753.

Frahm, E., 2012a. Non-destructive sourcing of Bronze-Age near Eastern obsidian artefacts: redeveloping and reassessing electron microprobe analysis for obsidian sourcing. Archaeometry 54, 623–642.

Frahm, E., 2012b. Distinguishing Nemrut Dağ and Bingöl A obsidians: geochemical and landscape differences and the archaeological implications. Journal of Archaeological Science 39, 1435–1444.

Frahm, E., 2013. Validity of "off-the-shelf" handheld portable XRF for sourcing near eastern obsidian chip debris. Journal of Archaeological Science 40, 1080–1092.

Frahm, E., Feinberg, J.M., 2013. Empires and Resources: Central Anatolian Obsidian at Urkesh (Tell Mozan, Syria) during the Akkadian Period. Journal of Archaeological Science 40, 1122–1135.

Frahm, E., Feinberg, J., in preparation. From Flow to Quarry: Magnetic Properties of Obsidian and the Changing Scales of Archaeological Sourcing, in preparation.

Francaviglia, V., Palmieri, A., 1998. Analisi di ossidiane dell'area del Habur (Giazira Settentrionale). In: Pecorella, P.E. (Ed.), Tell Barri/Kahat 2: Relazione Sulle Campagne 1980–1993 a Tell Barri/Kahat, nel Bacino del Habur (Siria). Università degli studi di Firenze, pp. 335–344.

Goodale, N., Bailey, D., Jones, G., Prescott, C., Scholz, E., Stagliano, N., Lewis, C., 2012. pXRF: a study of inter-instrument performance. Journal of Archaeological Science 39, 875–883.

Gratuze, B., Barrandon, J., Al Isa, K., Cauvin, M.C., 1993. Non-destructive analysis of obsidian artefacts using nuclear techniques: investigation of provenance of Near Eastern artefacts. Archaeometry 35, 11–21.

Hall, M.E., Shackley, M.S., 1994. An energy dispersive x-ray fluorescence study of some Near Eastern Obsidians. Al-Rafidan 15, 25–32.

Hoffner, H., 1990. Hurrians Myths. Writings from the Ancient World 2. Scholars Press, Atlanta.

Hole, F., 1968. Evidence of social organization from western Iran. In: Binford, S., Binford, L. (Eds.), New Perspectives in Archaeology. Aldine, Chicago, pp. 245–265.

Jia, P., Doelman, T., Chen, C., Zhao, H., Lin, S., Torrence, R., Glascock, M., 2010. Moving sources: a preliminary study of volcanic glass artifact distributions in northeast China using PXRF. Journal of Archaeological Science 37, 1670–1677.

Khalidi, L., Gratuze, B., Boucetta, S., 2009. Provenance of obsidian excavated from Late Chalcolithic levels at the sites of Tell Hamoukar and Tell Brak, Syria. Archaeometry 51, 879–893.

Kuzucuoğlu, C., 2007. Climate and environmental trends during the third millennium B.C. in Upper Mesopotamia. In: Marro, C., Kuzucuoğlu, C. (Eds.), Sociétés humaines et changement climatique à la fin due troisième millénaire: Une crise a-t-elle eu lieu en Haute Mésopotamie? Actes du Colloque de Lyon, 5–8 décembre 2005. De Boccard, Paris, pp. 459–480.

Le Bourdonnec, F.-X., Lugliè, C., Dubernet, S., Bohn, M., Poupeau, G., 2005. Monte Arci (Sardinia) obsidians: new geochemical data from electron microprobe and ion beam analysis. In: Proceedings of the Third Meeting on the Monte Arci Obsidian in the Mediterranean, Pau, Italy, 25–26 September 2004, pp. 129–140.

Le Bourdonnec, F.-X., Poupeau, G., Lugliè, C., 2010. The Monte Arci (Sardinia, western Mediterranean) obsidians: characterization by multivariate analysis from SEM–EDS, EMP–WDS and PIXE elemental compositions. In: L'ossidiana del Monte Arci nel Mediterraneo, Pau, Italy, 27–29 June 2008, pp. 13–28.

Lemcke, G., Sturm, M., 1997. δ^{18}O and trace element measurements as proxy for the reconstruction of climate changes at Lake Van (Turkey): preliminary results. In: Dalfes, H., Kukla, G., Weiss, H. (Eds.), Third Millennium BC Climate Change and Old World Collapse. Springer, Berlin, pp. 653–678.

Mainwaring, A.B., Giegengack, R., Vita-Finzi, C., 2010. Climate Crises in Human History. American Philosophical Society, Philadelphia.

Mallowan, M.E.L., 1947. Excavations at Brak and Chagar Bazar. Iraq 9, 1–259.

Marcus, J., 1998. The peaks and valleys of ancient states. In: Feinman, G.M., Marcus, J. (Eds.), Archaic States. SARP, Santa Fe, pp. 59–94.

McAnany, P., Yoffee, N. (Eds.), 2009. Questioning Collapse: Human Resilience, Ecological Vulnerability, and the Aftermath of Empire. Cambridge University Press.

McCoy, M., Mills, P., Lundblad, S., Rieth, T., Kahn, J., Gard, R., 2011. A cost surface model of volcanic glass quarrying and exchange in Hawai'i. Journal of Archaeological Science 38, 2547–2560.

McDougall, J., 1978. An Analytical Study of Obsidian from Europe and the Near East by Examination of Magnetic Parameters. M.A. dissertation, Bradford University.

McIntosh, R.J., Tainter, J.A., McIntosh, S.K., 2000. The Way the Wind Blows: Climate Change, History, and Human Action. Columbia University Press.

McMahon, A., Quenet, P., 2007. A late third millennium BC pottery assemblage from Chagar Bazar (Area D, phase II). In: Tunca, Ö., McMahon, A., Baghdo, A.-M. (Eds.), Chagar Bazar (Syrie) II: Les vestiges 'post-akkadiens' du chantier D et etudes diverses. Peeters, Leuven, pp. 69–242.

Merrick, H., Brown, F., 1984. Rapid chemical characterization of obsidian artifacts by electron microprobe analysis. Archaeometry 26 (2), 230–236.

Michalowski, P., 1993. Memory and deed: historiography of the political expansion of the Akkad state. In: Liverani, M. (Ed.), Akkad: the First World Empire. Sargon, Padua, pp. 69–90.

Millhauser, J., Rodríguez-Alegría, E., Glascock, M., 2011. Testing the accuracy of portable X-ray fluorescence to study Aztec and Colonial obsidian supply at Xaltocan, Mexico. Journal of Archaeological Science 38, 3141–3152.

Molyneaux, B.L., 2002. Exploring the landscapes of long-distance exchange: evidence from obsidian Cliffs and Devils Tower, Wyoming. In: Glascock, M.D. (Ed.), Geochemical Evidence for Long-distance Exchange. Bergin and Garvey, Westport, Connecticut, pp. 133–152.

Nazaroff, A., Prufer, K., Drake, B., 2010. Assessing the applicability of portable X-ray fluorescence spectrometry for obsidian provenance research in the Maya lowlands. Journal of Archaeological Science 37, 885–895.

Nicolle, C., 2006. Tell Mohammed Diyab 3. Travaux de 1992–2000 sur les buttes A et B. Paris. In: Éditions Recherche sur les Civilisations.

Nissen, H.J., 1988. The Early History of the Ancient Near East: 9000–2000 B.C. University of Chicago Press, Chicago.

Orsi, V., 2008. Between continuity and transformation: the late 3rd millennium BC ceramic sequence from Tell Barri (Syria). In: Córdoba, J., Molist.,, M., Pérez, M.C., Rubio, I., Martínez, S., Sergio, I. (Eds.), Proceedings of the 5th International Congress on the Archaeology of the Ancient Near East, vol. 2. UAM Ediciones, Madrid, pp. 699–714.

Orsi, V., 2010. The passage from the early Bronze to the middle Bronze Age in Jezirah: a parallel between Tell Mozan and Tell Barri ceramic sequences. In: Matthiae, P., Pinnock, F., Nigro, L., Marchetti, N. (Eds.), Proceedings of the 6th International Congress on the Archaeology of the Ancient Near East, vol. 1. Harrassowitz Verlag, Wiesbaden, pp. 863–881.

Peltenburg, E., 2000. From nucleation to dispersal. Late third millennium BC settlement pattern transformation in the near east and Aegean. In: Rouault, O., Wäfler, M. (Eds.), La Djéziré et l'Euphrate syriens de la prehistoire à la fin du second millénaire av. J.-C. Tendances dans l'interpretation histori- que des donnes nouvelles, Subartu VII, Turnhout, Brepols, pp. 183–206.

Pernicka, E., 1992. Herkunftsbestimmung späturukzeitlicher obsidianfunde vom Hassek Höyük. Istanbuler Forschungen 38, 124–131.
Pernicka, E., Keller, J., Cauvin, M.C., 1997. Obsidian from Anatolian sources in the Neolithic of the Middle Euphrates region (Syria). Paléorient 23, 113–122.
Pfälzner, P., 2010. Introduction and synthesis: urban development and ecology at Tell Mozan. In: Deckers, K., Doll, M., Pfälzner, P., Riehl, S. (Eds.), The Development of the Environment, Subsistence, and Settlement of the City of Urkeš and Its Region. Harrassowitz, Wiesbaden, pp. 1–12.
Poidevin, J.-L., 1998. Les gisements d'obsidienne de Turquie et de Transcaucasie: géologie, géochimie et chronométrie. In: Cauvin, M.-C., Gourgaud, A., Gratuze, B., Arnaud, N., Poupeau, G., Poidevin, J.L., Chataigner, C. (Eds.), L'obsidienne au Proche et Moyen-Orient: Du Volcan à l'Outil. BAR International Series, pp. 105–167.
Porter, A., 2007. You say potato, I say…typology, chronology and the origin of the Amorites. In: Marro, C., Kuzucuoglu, C. (Eds.), Sociétés humaines et changement climatique à la fin du troisième millénaire: une crise a-t-elle eu lieu en Haute-Mésopotamie? De Boccard, Paris, pp. 69–115.
Riehl, S., 2008. Climate and agriculture in the ancient near east: a synthesis of the archaeobotanical and stable carbon isotope evidence. Vegetation History and Archaeobotany 17, 43–51.
Riehl, S., 2009. Archaeobotanical evidence for the interrelationship of agricultural decision-making and climate change in the ancient near east. Quaternary International 197, 93–114.
Riehl, S., 2010. Plant production in a changing environment – the archaeobotanical remains from Tell Mozan. In: Deckers, K., Doll, M., Pfälzner, P., Riehl, S. (Eds.), The Development of the Environment, Subsistence, and Settlement of the City of Urkeš and its Region. Harrassowitz, Wiesbaden, pp. 13–158.
Riehl, S., 2012. Variability in ancient Near Eastern environmental and agricultural development. Journal of Arid Environments 86, 113–121.
Riehl, S., Bryson, R.A., 2007. Variability in human adaptation to changing environmental conditions in Upper Mesopotamia during the Early to Middle Bronze Age transition. In: Marro, C., Kuzucuoglu, C. (Eds.), Sociétés humaines et changement climatique à la fin du troisième millénaire: une crise a-t-elle eu lieu en Haute-Mésopotamie? De Boccard, Paris, pp. 523–548.
Riehl, S., Pustovoytov, K.E., Hotchkiss, S., Bryson, R.A., 2008. Local Holocene environmental indicators in Upper Mesopotamia: pedogenic carbonate record vs. archaeobotanical data and archaeoclimatological models. Quaternary International 209, 154–163.
Ristvet, L., Weiss, H., 2005. The Hābūr region in the late third and early second millennium BC. In: Orthmann, W. (Ed.), The History and Archaeology of Syria. Verlag, Saarbrucken.
Rosen, S., Tykot, R., Gottesman, M., 2005. Long distance trinket trade: early Bronze Age obsidian from the Negev. Journal of Archaeological Science 32, 775–784.
Şahoğlu, V., 2005. The Anatolian trade network and the Izmir region during the early Bronze age. Oxford Journal of Archaeology 24, 339–361.
Sanna, I., Le Bourdonnec, F.-X., Poupeau, G., Luglie, C., 2010. Ossidiane non sarde in Sardegna. Analisi di un rinvenimento subacqueo nel Porto di Cagliari. In: L'ossidiana del Monte Arci nel Mediterraneo, Pau, Italy, 27–29 June 2008, pp. 99–119.
Saunders, N., 2001. A dark light: reflections on obsidian in Mesoamerica. World Archaeology 33, 220–236.
Schwartz, G.M., 2007. Taking the long view of collapse: a Syrian perspective. In: Marro, C., Kuzucuoğlu, C. (Eds.), Sociétés humaines et changement climatique à la fin due troisième millénaire: Une crise a-t-elle eu lieu en Haute Mésopotamie? Actes du Colloque de Lyon, 5–8 décembre 2005. De Boccard, Paris, pp. 45–67.
Schwartz, G.M., Miller, N.F., 2007. The "Crisis" of the late third millennium B.C.: ecofactual and artifactual evidence from Umm el-Marra and the Jabbul plain. In: Marro, C., Kuzucuoğlu, C. (Eds.), Sociétés humaines et changement climatique à la fin due troisième millénaire: Une crise a-t-elle eu lieu en Haute Mésopotamie? Actes du Colloque de Lyon, 5–8 décembre 2005. De Boccard, Paris, pp. 179–204.
Schwartz, G.M., Nichols, J.J., 2006. After Collapse: the Regeneration of Complex Societies. University of Arizona Press, Tucson.
Shand, S., 1943. The Eruptive Rocks, second ed. John Wiley, New York.
Sheets, P., Cooper, J. (Eds.), 2012. Surviving Sudden Environmental Change: Answers from Archaeology. University of Colorado Press.
Sheppard, P., Irwin, G., Lin, S., McCaffrey, C., 2011. Characterization of New Zealand obsidian using PXRF. Journal of Archaeological Science 38, 45–56.
Sinopoli, C., 2001. The shadow empires: imperial state formation along the Chinese-Nomad Frontier. In: Alcock, S.E., D'Altroy, T.N., Morrison, K.D., Sinopoli, C.M. (Eds.), Empires: Perspectives from Archaeology and History. Cambridge University Press, pp. 195–200.
Staubwasser, M., Weiss, H., 2006. Holocene climate and cultural evolution in late prehistoric-early historic West Asia. Quaternary Research 66 (3), 372–387.
Taçon, P.S.C., 1989. From Rainbow Snakes to 'X-Ray' Fish: the Nature of the Recent Rock Painting Tradition of Western Arnhem Land. Australian National University, Australia.
Taçon, P.S.C., 1991. The power of stone: symbolic aspects of stone use and tool development in western Arnhem Land, Australia. Antiquity 65, 192–207.
Tykot, R., 1995. Prehistoric Trade in the Western Mediterranean: the Sources and Distribution of Sardinian Obsidian. Ph.D. dissertation, Department of Anthropology, Harvard University.
Tykot, R., 2010. Sourcing of Sardinian obsidian collections in the Museo Preistorico-Etnografico "Luigi Pigorini" using non-destructive portable XRF. In: L'ossidiana del Monte Arci nel Mediterraneo, Pau, Italy, 27–29 June 2008, pp. 85–97.
Tykot, R., Chia, S., 1997. Long-distance obsidian trade in Indonesia. In: Vandiver, P., Druzik, J., Merkel, J., Stewart, J. (Eds.), Materials Issues in Art and Archaeology V. Materials Research Society, Pittsburgh, pp. 175–180.
Tykot, R., Lai, L., Tozzi, C., 2011. Intra-site obsidian subsource patterns at Contraguda, Sardinia (Italy). In: Turbanti-Memmi, I. (Ed.), Proceedings of the 37th International Symposium on Archaeometry. Springer-Verlag, Berlin, pp. 321–328.
Ur, J., 2002. Surface collection and offsite studies at Tell Hamoukar, 1999. Iraq 64, 15–43.
Ur, J., 2010. Cycles of civilization in Northern Mesopotamia, 4400–2000 BC. Journal of Archaeological Research 18, 387–431.
Van De Mieroop, M., 2004. A History of the Ancient Near East, ca. 3000–323 BC. Willey-Blackwell, New York.
Veenhof, K., 1997. "Modern" features in old Assyrian trade. Journal of the Economic and Social History of the Orient 40, 336–366.
Wada, K., 2009. Petrologic model of Shirataki obsidian, northern Hokkaido, Japan: its structure, composition and the origin. In: Geological Society of America Abstracts with Programs, vol. 41. Geological Society of America, Portland, Oregon, p. 553.
Wada, K., Mukai, M., Takeda, O., 2003. Chemical Compositions of Obsidian Glasses Determined by EPMA: the Origin of Obsidians from the Remains at the Mouth of Tokoro River, Eastern Hokkaido. Reports of Taisetsuzan Institute of Science, Hokkaido University of Education 37, pp. 59–70.
Weisler, M.I., Clague, D.A., 1998. Characterisation of archaeological volcanic glass from Oceania: the utility of three techniques. In: Shackley, M.S. (Ed.), Archaeological Obsidian Studies: Method and Theory. Society for Archaeological Sciences, pp. 103–128.
Weiss, H., 2000. Causality and chance: late third millennium collapse in Southwest Asia. In: Rouault, O., Wäfler, M. (Eds.), La Djéziré et l'Euphrate syriens de la protohistoire a la fin du IIe millenaire av. J.C. Tendances dans l'interprétation historique des données nouvelles. Brepols, Belgium, pp. 207–217.
Weiss, H., 2011. Altered trajectories: the intermediate Bronze Age in Syria and Lebanon 2200–1900 BCE. In: Killebrew, A.E., Steiner, M. (Eds.), Oxford Handbook of the Archaeology of the Levant. Oxford University Press.
Weiss, H., Courty, M.-A., 1993. The genesis and collapse of the Akkadian empire: the accidental refraction of historical law. In: Liverani, M. (Ed.), Akkad: the First World Empire. Sargon, Padua, pp. 131–155.
Weiss, H., Courty, M.-A., Wetterstrom, W., Guichard, F., Senior, L., Meadow, R., Curnow, A., 1993. The genesis and collapse of third millennium north Mesopotamian civilization. Science 261 (5124), 995–1004.
Wick, L., Lemcke, G., Sturm, M., 2003. Evidence of Lateglacial and Holocene climatic change and human impact in eastern Anatolia: high-resolution pollen, charcoal, isotopic and geochemical records from the laminated sediments of Lake Van, Turkey. The Holocene 13, 665–675.
Wilkinson, T.J., 1994. The structure and dynamics of dry-farming states in Upper Mesopotamia. Current Anthropology 35 (5), 483–520.
Wilkinson, T.J., 1997. Environmental fluctuations, agricultural production and collapse: a view from Bronze Age Upper Mesopotamia. In: Dalfes, H., Kukla, G., Weiss, H. (Eds.), Third Millennium BC Climate Change and Old World Collapse. Springer, Berlin, pp. 67–106.
Wilkinson, T.J., 2000. Regional approaches to Mesopotamian archaeology: the contribution of archaeological surveys. Journal of Archaeological Research 8, 219–267.
Wilkinson, T.J., Christiansen, J., Ur, J., Widell, M., Altaweel, M., 2007. Urbanization within a dynamic environment: modeling Bronze Age communities in Upper Mesopotamia. American Anthropologist 109, 52–68.
Williams-Thorpe, O., 1995. Obsidian in the Mediterranean and the near east: a provenancing success story. Archaeometry 37, 217–248.
Wossink, A., 2009. Challenging Climate Change: Competition and Cooperation Among Pastoralists. Sidestone Press.
Wright, G., 1969. Obsidian Analyses and Prehistoric Near Eastern Trade: 7500 to 3500 B.C. Anthropological Papers. Museum of Anthropology, University of Michigan.
Yoffee, N., 2010. Collapse in ancient Mesopotamia: what happened and what didn't. In: McAnany, P.A., Yoffee, N. (Eds.), Questioning Collapse. Human Resilience, Ecological Vulnerability, and the Aftermath of Empire. Cambridge University Press, Cambridge, pp. 176–206.
Yılmaz, Y., Güner, Y., Şaroğlu, F., 1998. Geology of the Quaternary volcanic centres of the east Anatolia. Journal of Volcanology and Geothermal Research 85 (1–4), 173–210.