Network Analysis in Archaeology

New Approaches to Regional Interaction

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Grounding the Net: Social Networks, Material Culture and Geography in the Epipalaeolithic and Early Neolithic of the Near East (~21,000–6,000 cal BCE)

Fiona Coward

11.1 INTRODUCTION

The Epipalaeolithic and early Neolithic are often considered highly significant periods in the development of human culture. Traditionally, research into the period has focused on changing subsistence and economic strategies, including increasingly sedentary lifestyles and the adoption of new subsistence practices involving closer control of plant and animal species that ultimately resulted in the genetic changes now described as 'domestication'. However, more recently attention has shifted to the *social* implications of these developments (e.g. Kuijt 2000a). Changes in architecture and the use of space (Banning and Byrd 1989; Byrd 1994; Kuijt 2000b; Goring-Morris and Belfer-Cohen 2003, 2008), burial practices (Byrd and Monahan 1995; Goring-Morris 2000; Kuijt 2000c; Hayden 2004; although see also Belfer-Cohen 1995), art and symbolism (Bar-Yosef and Belfer-Cohen 1999; Cauvin 2000; Watkins 2004a), and material culture in general have all been hypothesized to indicate, and indeed to constitute, significant changes in social life (see e.g. Kuijt and Goring-Morris 2002 and chapters in Kuijt 2000a for discussion) at this time. Indeed, the shift to settled, agricultural village life is often held to represent the foundations of a way of life that still characterizes modern *Homo urbanus* (Runciman 2005: 29, 130–1; Watkins 2004a: 16; Cauvin 2000: 72), a majority urban-dwelling species (UNFPA 2007) living at extremely high densities in agglomerations frequently numbering millions of individuals.

However, criticisms of this neat origins myth of modern city life (e.g. Gamble 2007; Coward and Gamble 2008; Coward 2010a) have emphasized the need for these hypothesized changes in social structure over the course of the Epipalaeolithic and Early Neolithic to be demonstrated more robustly using large, empirical datasets. Research exploiting the potential of social network analysis to address these issues has indeed generally supported a model of social change at this time (Coward 2010a, b, in press), but has also identified the process as a much longer-term one than previously thought (e.g. Coward and Gamble 2008; Coward in preparation). In addition, it has highlighted some specific aspects of the process which require closer attention—in particular the role that material culture plays in the geographical scaling-up of social relations, and the significance of geography for the structure of social networks.

This chapter will focus on the latter of these issues. It will first briefly discuss the basis for empirically studying social change using SNA to analyse patterns of material culture distribution in order to infer social relations between and within groups in prehistory, then review previous work in this area before focusing on the significance of geography for the structure of social networks by examining the interaction between material and social networks over the course of the Epipalaeolithic and early Neolithic. In particular, I will focus on one significant aspect of the scaling-up of social systems that may have occurred over this period—that of the increasing supplementing of relationships based largely on geographical proximity with 'weak ties' that are largely, if not completely, a-spatial.

11.2 SOCIAL NETWORK ANALYSIS TECHNIQUES AND CHANGING SOCIAL NETWORKS OF THE EPIPALAEOLITHIC AND EARLY NEOLITHIC

11.2.1 Social Network Analysis

Sociological research among contemporary individuals and groups frequently uses social network analysis methodologies to investigate individual interactions and the ways in which these are embedded in, structured by, and indeed constitute, broader social structure.

At its heart, SNA relies on the insight that social entities (individuals, groups etc.) can be considered nodes in a wider network, each connected by potentially multiple relationships to other such entities/nodes. In more complex formulations such relationships can be directed if ties are not necessarily reciprocated, and relationships also can be valued according to self-report or by objective assessment of various criteria (number of interactions per unit time; time spent interacting etc.). In addition, multiple different types and/or contexts of interaction can be considered using multiple, 'layered' (known as *multi-modal* or *multiplex*) networks in which different types of relationship (family, friendships, work colleagues, etc.) between individuals, their context or mode of interaction (e.g. face-to-face, telephone, email), and intensity and/or duration of those interactions may be distinguished from one another. The ability of SNA techniques to handle the combinations of value and significance ascribed to individual relationships and the modes and contexts of the constituent interactions thus allows us to tease out the many different facets of our social lives (see e.g. Wasserman and Faust 1994; Hanneman and Riddle 2005 for further discussion).

Another significant property of SNA is that this very simple and intuitive way of thinking about relationships also allows us to access broader social structures. Social network structure is historical, in that the interactions any individual engages in today, or indeed tomorrow, are strongly influenced by past practice and pre-existing ties forged in earlier interactions. We do not have a completely free hand in our interactions, but the social structure that constrains us is also produced, reproduced, and altered by our own actions over greater timescales than those of discrete interactions. Furthermore, the networks described by these interactions and structure are multi-scalar. Nodes can represent individuals—however, they can also represent aggregate entities in broader systems, right up to the level of the corporate, national, and multinational conglomerate.

11.2.2 SNA in Prehistoric Contexts?

SNA methodologies are thus extremely useful for investigating social relations and broader structure and the interplay between these scales of analysis among contemporary group. However, in contemporary settings social relations can be observed or obtained from the participants themselves. In archaeological and especially prehistoric contexts, all interpretation, including that of the social interactions and structure of past societies, must be reconstructed via the material traces that such interactions may (but do not always) leave. Nevertheless, there are compelling reasons to suggest that SNA may also be applied to archaeological contexts. In SNA such techniques are routinely applied to a variety of different kinds of social entities, particularly at larger scales of analysis, where the relationships linking nodes together are often extrapolated from a variety of resources, frequently including the transfer and distribution of material resources such as money or trade volumes (Sangmoon and Hang 2002; Bhattacharya et al. 2008; Wang 2009; see also Wasserman and Faust 1994, chapter 2 for further discussion).

The reconstruction of material distribution patterns is of course something that archaeologists are already extremely familiar with; the study of trade and the dissemination and distribution of material culture in the archaeological record has long been a topic of considerable interest to archaeology in a wide variety of temporal and geographical contexts (Renfrew et al. 1968; Hodder 1974; Renfrew 1975; Plog 1976; Renfrew and Dixon 1976; Earle and Ericson 1977; Ericson and Earle 1982; Renfrew and Cherry 1986), and is routinely interpreted in terms of what it can tell us about wider social networks and relationships between social entities. Such interpretations hinge on the fact that material transmission and dissemination occur as part of a wider system of social relations. Diffusion of innovations and traits and the social practices involved in trade, exchange, and gifting is dependent on the intensity and duration of communication and interpersonal contact between individuals and groups (Hägerstrand 1952, cited McGlade and McGlade 1989; Collar 2007; Lu et al. 2009; Coward 2010a), to the extent that the spread of ideas and objects is often modelled in a similar way to epidemiological models of the spread of disease (see e.g. Granovetter 1973; Steele 1994; Barrat et al. 2004; Dodds and Watts 2005; see also Coward and Grove 2011: 117–18 for discussion).

Furthermore, there is a strong basis for believing that material culture is more than simply a passive reflection of, or archaeological proxy for, wider social relations, but that material objects instead constitute *part of* the process of negotiating and maintaining those relations (e.g. Appadurai 1986; Miller 2005; see also Buchli 2004 for review). New approaches in archaeology and beyond are increasingly emphasizing the significant role played by material culture in social interaction and even in memory (e.g. Connerton 1989; Watkins 2004b) and cognition (Hutchins 1995; Clark and Chalmers 1998; chapters in Malafouris and Renfrew 2010). For example, in theories of material engagement (e.g. chapters in DeMarrais et al. 2004), mutuality (Gosden 1994), and Actor-Network Theory (Latour 1996; Law 1999; Whatmore 2002, 2006), material culture (along with animals, plants, and all kinds of other entities) is often considered a fundamental part of the same social network as individual human persons and objects, which may acquire biographies and identities and in some circumstances be considered agents and persons in their own right (Strathern 1988; Hoskins 1998; Gosden and Marshall 1999).

Increasingly, such 'network' ways of thinking about the diffusion of innovations and/or material culture are challenging monolithic 'culture-history' approaches to the past, and traditional archaeological 'cultures' defined by material culture distributions are increasingly being viewed as the result of social interactions between individuals and groups selecting from broader oeuvres of material practice available to them according to local conditions, histories, traditions, and contexts of interaction (see e.g. Asouti 2006 for further discussion) as well as the properties and qualities of the material culture itself.

As a result of these theoretical developments, archaeology is increasingly embracing SNA methodologies, as the chapters in this volume attest. However, thus far many of the applications of SNA to archaeological datasets have been in historic contexts, drawing from textual records documenting trade or itineraries of travel (Graham 2006; Isaksen 2008), and, further, have mainly been applied to island or circum-marine groups of sites, particularly the Pacific Islands (Irwin 1983; Hage and Harary 1996), and the Mediterranean and Aegean archipelago (Broodbank 2000; Evans et al. 2008; Brughmans 2010), as well as in the Baltic (Sindbæk 2007). Furthermore, many of these applications of SNA in archaeology have focused on individual 'snapshot' pictures of social networks at a particular point in time. While these studies are certainly informative and interesting pieces of work, they rarely set out to investigate how these networks *change* over time—and those that do tend to model change using mathematical approaches rather than directly from the archaeological data (Broodbank 2000; Evans et al. 2009; although see e.g. chapters in Flannery 2009 [1976]). Such studies of course provide valuable models to which the archaeological record can be compared, and certainly avoid the perennial problem of the incomplete archaeological knowledge of regional settlement systems. However, such models also inevitably build in a number of assumptions regarding the likely trajectories of network change over time, rather than examining the changes reflected in the archaeological record itself.

11.2.3 Investigating Social Change in the Epipalaeolithic and Early Neolithic

Previous research has applied SNA techniques to the study of the ways in which the social and material networks reconstructed from the archaeological record changed over the course of the Epipalaeolithic and early Neolithic of the Near East (Coward 2010a, b; Coward in press). This research used a database of material culture from well-dated sites of these periods to establish indices of material culture similarity or closeness for each pair of sites (the nodes) dated to within the same 1,000-year 'timeslice'. This measure of similarity was interpreted as reflecting the strength of the social relationship between the sites, which is seen both as structured by and structuring the gifting, trade, and exchange of individual items and/or the dissemination of the skills of manufacture and the practices and contexts in which items were used. These pair-wise measures of material culture similarity were used as the basis for adjacency matrices from which a number of network properties could be calculated for each 1,000-year network, and the temporal trends in these measures ascertained (see Coward 2010a, b for more detailed discussion of how the analyses were conducted). Subsequent work exploited the multi-scalar capabilities of SNA in conducting complementary analyses at the intra-site level, using individual burial contexts as nodes, connected by shared material culture elements of mortuary practice and performance (details in Coward in press).

Results (Coward 2010a, Figs. 21.3, 21.4) suggested that, at the inter-site level, social networks became larger and more fragmented over the course of the Epipalaeolithic and early Neolithic. However, the average strength of relationships between sites ('degree'), and the overall density of the networks (the proportion of the maximum possible strength of ties that is actually realized) both increased. This was a surprising finding given that the time and energy costs of maintaining large numbers of relationships (Dunbar 2008; see also Roberts 2010 for further discussion and references) mean that there is usually an inverse relationship between network size and intensity or density of ties (see references and discussion in Wasserman and Faust 1994; Hanneman and Riddle 2005; Lehmann et al. 2010). However, it was clear that later networks sampled an increasing diversity of material culture, with many more different types of material culture contributing to adjacency matrices. For example, the thirteen sites dated to between 18 and 17kyrs BC shared a total of only seven different kinds of ground stone artefact, while the forty-one sites dated to 7–6kyrs BC yielded twenty-four. To correct for this, every cell of each matrix was divided by the total number of different kinds of material culture sampled in that timeslice to give a measure of the strength of relationship between each pair of sites relative to the maximum possible strength for that network. Thus normalized, average degree, density, and average network distance between pairs of sites in each network were shown to decline over the period, as might have been expected given the increasing numbers of sites making up the later networks (see Coward 2010a for a more detailed discussion of these results).

A slightly different pattern was seen at the intra-site level. As was the case in the inter-site analyses, average measures of material culture similarity (degree) between burial contexts increased over time—a pattern again related to the much larger oeuvres of material culture employed in later sites, as normalizing for this (as described above) removed this trend. However, measures of fragmentation did not change significantly over the period, and overall density in fact declines over time; early burial contexts are very similar in terms of the kinds of material culture and practice involved, but later burial contexts draw differently from a greater range of possible options, resulting in greater individualization of burial performances.

Coward argued that these patterns suggest a process in which the trade, exchange, and referencing of material culture within and between sites may have helped offset the increasing costs of larger social networks by allowing individuals and groups to maintain more links with others despite the increasing scale of the system (Coward 2010a; see also Coward and Gamble 2008). Nevertheless, the decline in density of intra-site social networks over time suggests that individuals' relationships with others in their increasingly large and permanently co-resident groups were coming under pressure, despite the increasing elaboration of material culture.

Such a picture accords well with ethnographic and sociological observations of social structure at different scales. Traditional hunter-gatherer societies are very open and ephemeral (humans are a classic 'fission-fusion'-organized social species; Aureli et al. 2008), and the major and perhaps only stable social 'units' are the lowest, 'intimate' level of the hierarchy of social groups, typically kin and close friends (see e.g. Gamble 1999: 58–62 for discussion and references), as is the case in the relatively low-degree but dense and tightly clustered early social networks documented here.

Increasing group size, documented by the many larger sites known from later periods of the Epipalaeolithic and early Neolithic in the Near East (e.g. Kuijt 2000b) is necessarily associated with an exponential increase in the cost of maintaining relationships with all other group members which rapidly becomes prohibitive. As a result, the expensive and highly-valued relationships characteristic of mobile hunter-gatherer groups must inevitably become increasingly supplemented with cheaper and less highly valued 'weak ties' (Granovetter 1973, 1983). This creates extra 'levels' in the hierarchy of social relationships which are added on top of the 'intimate' circle of approximately five kin relations and/or intimate friends; the 'sympathy group' of approximately fifteen wider family and friends; the approximately fifty individual-strong 'band' of wider associates and the approximately 150-strong strong 'active network' characteristic of traditional societies (Gamble 1999: 59–60). These groupings remain a significant building block for contemporary western humans (Dunbar 1993: 684–6, Tables 11.1 and 11.2; Zhou et al. 2005). However, the social networks of many modern humans incorporate much higher levels of this hierarchy, from the 'global network' level of approximately 400 (Gamble 1999: 59–60) to the tens of millions 'following' individual celebrities on social network sites. At each level, the number of nodes to which one is connected increases, but emotional engagement and personal input in each one decreases (Roberts et al. 2009), so that at higher levels, many individual relationships are simplified and highly contextual, confined to a relatively restricted part of an individual's broader network (Lofland 1973; Milgram 1977; Whitelaw 1991: 153; Kudo and Dunbar 2001).

It is the 'weak ties' characterizing these higher levels of individuals' social networks that are fundamental to linking up the densely connected and largely kin-defined intimate networks that are our primate heritage, biasing social systems from processes of fission—which keeps mobile and traditional societies small-scale—towards increasing fusion (Zhou et al. 2005; Onnela et al. 2011: 4). Thus the growth of social groups, ultimately resulting in larger-scale, sedentary, and urban societies, is not simply the result of increasing numbers but also involves structural changes in individuals' and groups' social networks as larger-scale, less dense networks are constructed which incorporate the smaller and more 'intimate' social groupings characteristic of small-scale societies.

Table 11.1. Matrix of great-circle distances in km between sites dated to 18–17kyr cal BC. Site codes: EGI3/4 = Ein Gev I level 3/4; H2 = Haon 2; HamIV = Hamifgash IV; KIVD = Kharaneh IV level D; Md = Mdamagh; NOTK = Nahal Oren Terrace XVII/IX (Noy); OII = Ohalo II; RC = Rakefet Cave XIII; UeR = Urkhan e-Rubb IIa; WH31 = Wadi Hammeh 31; Whs1065 = Wadi Hasa 1065 B-E; WJ6A = Wadi Jilat 6 Upper Phase A

	EGI3	EGI4	H2	HamIV	KIVD	Md	NOTK	OII	RC	UeR	WH31	Whs1065	WJ6A
EGI3	–	0.00	9.33	205.50	139.82	271.91	65.14	7.91	58.25	83.76	37.99	208.11	160.30
EGI4	0.00	–	9.33	205.50	139.82	271.91	65.14	7.91	58.25	83.76	37.99	208.11	160.30
H2	9.33	9.33	–	196.40	134.05	262.86	61.75	5.81	53.76	74.45	28.93	199.36	153.75
HamIV	205.50	205.50	196.40	–	187.62	124.85	173.86	198.43	169.37	126.70	171.50	114.22	177.40
KIVD	139.82	139.82	134.05	187.62	–	180.12	177.54	139.85	166.79	103.05	112.57	112.52	25.85
Md	271.91	271.91	262.86	124.85	180.12	–	266.66	267.11	258.68	190.16	233.94	68.81	156.73
NOTK	65.14	65.14	61.75	173.86	177.54	266.66	–	58.17	10.75	84.69	67.42	212.24	191.71
OII	7.91	7.91	5.81	198.43	139.85	267.11	58.17	–	50.82	78.01	33.48	204.05	159.46
RC	58.25	58.25	53.76	169.37	166.79	258.68	10.75	50.82	–	74.69	57.00	203.12	181.03
UeR	83.76	83.76	74.45	126.70	103.05	190.16	84.69	78.01	74.69	–	46.55	130.13	111.62
WH31	37.99	37.99	28.93	171.50	112.57	233.94	67.42	33.48	57.00	46.55	–	170.57	129.82
Whs1065	208.11	208.11	199.36	114.22	112.52	68.81	212.24	204.05	203.12	130.13	170.57	–	90.66
WJ6A	160.30	160.30	153.75	177.40	25.85	156.73	191.71	159.46	181.03	111.62	129.82	90.66	–

Table 11.2. Results of Shapiro-Wilks tests of distributions of the great-circle distance, GIS-derived cost of travel and material culture matrices. Low values of W indicate positive skew. * indicates result is significant at the 0.05 level; ** that it is significant at the 0.01 level

	Great-circle distance (GCD) matrix		GIS-derived cost of travel (GISCT) matrix		Material culture matrix	
Timeslice (kyr cal BC)	W	P	W	P	W	P
>21	0.73	0.021*	0.95	0.722	0.94	0.683
21–20	0.6	0.000**	0.85	0.161	0.99	0.995
20–19	0.65	0.002*	0.59	0.001**	0.83	0.131
19–18	0.58	0.000**	0.9	0.370	0.82	0.085
18–17	0.37	<0.0001**	0.8	0.006**	0.87	0.055
17–16	0.45	<0.0001**	0.64	<0.0001**	0.94	0.546
16–15	0.57	<0.0001**	0.63	<0.0001**	0.9	0.327
15–14	0.33	<0.0001**	0.04	<0.0001**	0.91	0.118
14–13	0.31	<0.0001**	0.52	<0.0001**	0.93	0.183
13–12	0.33	<0.0001**	0.65	<0.0001**	0.95	0.479
12–11	0.29	<0.0001**	0.8	0.001**	0.94	0.226
11–10	0.17	<0.0001**	0.78	<0.0001**	0.96	0.105
10–9	0.14	<0.0001**	0.83	<0.0001**	0.98	0.415
9–8	0.13	<0.0001**	0.88	<0.0001**	0.98	0.227
8–7	0.13	<0.0001**	0.84	<0.0001**	0.98	0.227
7–6	0.19	<0.0001**	0.89	0.002**	0.97	0.393

11.3 GROUNDING THE NET: THE GEOGRAPHICAL AND SOCIAL NETWORKS OF THE NEAR-EASTERN EPIPALAEOLITHIC AND EARLY NEOLITHIC

SNA thus provides an extremely useful framework for investigating social change archaeologically. However, the practicalities of applying SNA to archaeological data are still very much in the process of being thrashed out, and one particular aspect of concern is the rather abstracted nature of the networks discussed above from any kind of real-world geographic context. Network analysis in other disciplines has long recognized the significance of geography and spatial distance on connectivity. In spatial networks such as power grids, transport systems, and neural connectivity, the probability of a link between any two nodes is known to decrease proportionally to the geographic distance between them because of the higher costs associated with longer-range connections (see e.g. references in Backstrom et al. 2010: 62; Expert et al. 2010). Even in archaeology, the analysis of distance decay of raw material and material culture from its source (sometimes known as 'fall-off analysis') has been used to identify particular trade structures and institutions (see e.g. Renfrew et al. 1968; Hodder 1974; Renfrew and Dixon 1976 for further discussion).

However, the significance of geography in the establishment and evolution of networks has rarely been recognized in *social* network approaches, although there are strong intuitive reasons to believe it may be a significant factor. For example, in human social networks, increasing geographic distance between individuals necessarily means they are less likely to encounter one another and thereby establish or maintain a significant relationship. In modern contexts, geographic distance may perhaps be expected to be less of a constraint on the formation of a social relationship. Networks supported by the use of technologies such as landlines and, latterly, mobile phones and the internet, which significantly reduce the cost of communication over large geographic distances, might perhaps be expected to be less influenced by geographical factors. Nevertheless, declarations of the 'end of geography' (Graham 1998) or the 'death of distance' (Cairncross 2001) have more recently been challenged by a number of studies suggesting that geographical factors remain significant even in the formation of purely online social networks, such that the probability of any two nodes sharing a tie is inversely related to their geographic distance (with the rate of decay described by a power law of the form $P(d) \sim d^{-\alpha}$, the value of α ranging between 0.5 and 2; see references in Liben-Nowell et al. 2005; Lambiotte et al. 2008; Backstrom et al. 2010; Onnela et al. 2011; Scellato et al. 2011). In preliterate networks, where even ideas and concepts are necessarily transported in embodied or materialized form, geographical 'friction' can thus be expected to have a significant effect.

Indeed, the influence of geographical proximity on social network structure is of particular interest during the Epipalaeolithic and early Neolithic. In small-scale societies, social space is often largely coextensive with geographical space (Lofland 1973; Whitelaw 1991), as patterns of social interaction are organized primarily around kinship and close physical proximity (Wilson 1988; Whitelaw 1991). Such groups tend to be dense and tightly 'clustered' (i.e. with a high degree of 'transitive' relationships in which, if A is linked to B and C, there is a very high probability that B and C will also be linked; however, none of the three may be connected to any nodes outside these dense clusters). Tellingly, Watts has described this kind of network as a 'caveman' world (2003: 74–8). However, as noted above, the scaling-up of a social network necessarily requires increasing proportions of 'weak links'. While many relationships in larger societies are of course still based on kinship and/or geographical proximity (e.g. next-door neighbours, school or university friends, work colleagues at neighbouring desks), other forms of relationship may also be 'layered on' to these which may be almost completely *trans*-spatial (e.g. geographically remote colleagues working in the same field, people with shared interests, Liben-Nowell et al. 2005: 5). Just as weak links connect dense clusters into wider systems—the definition of a 'small-world' social system—geographically extended trans-spatial relationships connect dense local groups of individuals or sites into regional-scale social networks.

There is some independent evidence to suggest that such trans-spatial relationships may have become more significant during this period. Specialization of occupation—a major source of 'weak ties' in modern societies (Granovetter 1973, 1983)—seems to have formed an increasingly significant part of early Neolithic life. Specialization in activities such as the preparation of string or cord is inferred for Tell Abu Hureyra (Moore and Molleson 2000: 503; Molleson 2007: 193) while the specialized manufacture of jewellery is identified elsewhere in the Middle and Late PPNB (Mahasneh 2003; Wright and Garrard 2003: 272; Rollefson 2005; Gebel and Kinzel 2007), and perhaps even earlier (Kuijt and Mahasneh 1998; Reese 1991). The appearance of specialists in manufacture and trade may have been a significant mechanism by which more geographically distant connections were forged between individuals and groups.

The development of such long-range connections is likely to be hugely affected by spatial distance and the relative ease of travel through different kinds of terrain and habitat. Furthermore, ecological and environmental factors will necessarily impact on the time and energy available for engaging in different forms of social interaction (e.g. Lehmann et al. 2008), and on the ecological costs and benefits of large-scale versus local relations and trade between groups (Gamble 1983; Knappett et al. 2008: 1011). The Near East is characterized by considerable variation in terrain and habitat types, from the steppes and grasslands and scattered woodlands of the northerly, upland regions of the Taurus and Zagros and some parts of the Levant, to full desert over relatively short geographic distances (Ramankutty and Foley 1999; Chataigner and Barge 2007). Such geographical and ecological patterning can be expected to have had a significant impact on the development of regional-scale networks of distribution and dissemination of material culture and social practices.

Here I attempt to 'ground' the networks presented above by considering the interaction between materiality and geography at the regional scale for each 1,000-year timeslice throughout the Epipalaeolithic and early Neolithic. Networks derived using two different measures of geographic distance and ease of movement between sites/nodes are compared with those derived from material culture measures of interaction to try and tease out some preliminary details of the interplay between socio-material and geographic relations.

11.4 THE DATASETS

11.4.1 Distance-Derived Networks 1: 'As The Crow Flies' Great-Circle Distance

Matrices of the 'straight-line' geodesic great-circle distance (GCD; the shortest 'as the crow flies' spatial distance between any two points on the surface of a sphere) in km between each pair of sites in each 1,000-year timeslice were compiled (e.g. Table 11.1).

As expected, the distributions of these GCD matrices were highly positively skewed, demonstrating significant kurtosis or a 'fat-tailed' distribution in which most sites were relatively short geographic distances from most others, with increasingly fewer long-distance connections (though still significantly more than would be the case for a normal distribution). Shapiro-Wilks tests conducted on these matrices confirmed that, in contrast to those derived from material culture, distributions differed significantly from normal distributions (results are presented in Table 11.2). As the data are inherently positive, with values approaching zero, these matrices were $\log^{10}$ transformed to create normal distributions which could be statistically compared with those of the material culture networks (Shennan 1997: 94).

11.4.2 Distance-Derived Networks 2: GIS-Derived Cost of Travel

Straight-line, 'as the crow flies' distances provide a good preliminary guide to the costs of movement between sites. However, they remain a rather unsophisticated measure: the 423 km between M'lefaat and Ganj Dareh Tepe, involving considerable elevation changes, clearly presents a rather different set of challenges than the only slightly greater distance (548 km) between M'lefaat and Ali Kosh—a relatively gentle excursion along the Tigris, while the 1,145 km between Beidha and Ali Kosh, straight across the desert (Fig. 11.1), presents still different problems.

In order to address this, a GIS model of the region was constructed using the open-source GRASS GIS (<http://grass.fbk.eu/>). A digital elevation model (DEM) of elevation for the region was obtained from the Shuttle Radar Topography Mission (SRTM) dataset (<http://srtm.csi.cgiar.org/>), accurate to three arc-seconds (or ~90m at the Equator). Georeferenced maps of rivers and water bodies were downloaded from Natural Earth (<http://www.naturalearthdata.com/downloads/110m-physical-vectors/>) at a scale of 1:110 m and edited to remove such historical additions as the numerous dams and lakes along the course of the Euphrates in Turkey and Syria. These maps were then combined to provide a basic model of the region's (modern) geography (Fig. 11.1) which was then used as the basis for deriving a cost-surface at a resolution of six arc-minutes (~3.4 km^2 at the equator, in order to speed up processing time) specifying the ease or difficulty of traversing each 'cell' of data.

Costs of movement overland are solely predicated on the assumption of movement by foot, as there is no evidence of the use of domesticated animals for traction or transport during this period. The 'secondary products revolution' during which the use of animals for traction developed occurred later, during the 4th–3rd millennium (Sherratt 1981). The development of the wheel

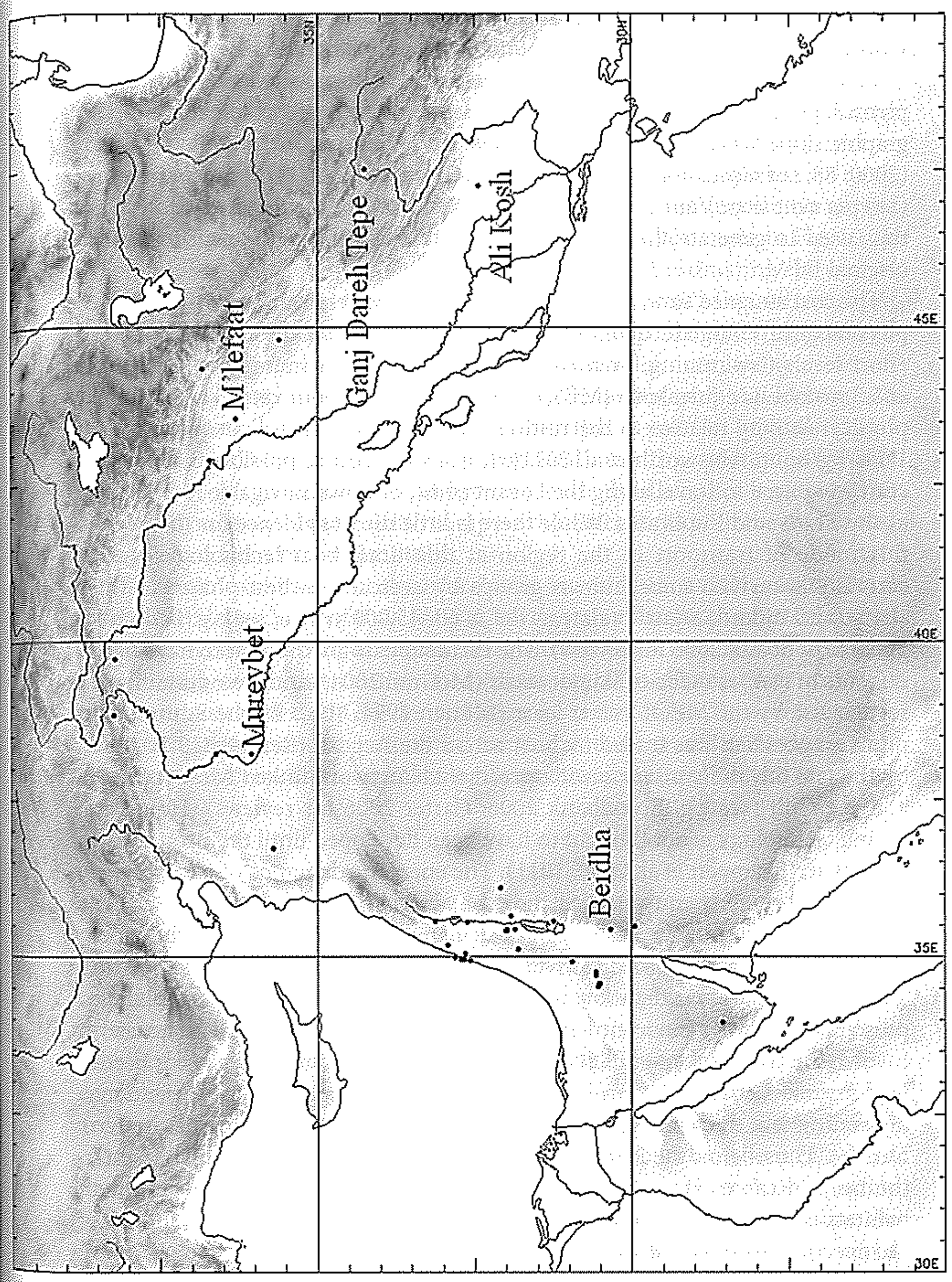

Fig. 11.1. DEM showing sites dating to 11–10 kyrs cal BC; darker colours indicate higher elevation. Only sites named in the text are labelled.

occurred after 4000 BCE (Anthony 2010: 65) and the domestication of horses is currently thought to have taken place in the Caucasus around 3500 BCE (e.g. Outram et al. 2009), well after the period under consideration here.

Calculation of the cost of movement overland is primarily derived from the physiological costs associated with movement over different gradients of topographic slope (Diez (cited by Leusen 1999: 217)) as modified by Bell and Lock (2000: 88; see discussion and references in Coward 2005: 221), such that cost = (*tan* per cent slope)/*tan* 1 (see e.g. Coward 2005: 221 for further discussion) was thus used to generate the cost surface from the slope layer derived from the original DEM.

The cost assigned to water bodies and the sea was determined by the relative physiological energetic demands of traversing water bodies. At 'moderate' effort levels ('swimming, breaststroke, recreational'), swimming is estimated at 5.3 metabolic equivalents (METs—the average metabolic rate of a particular physical activity relative to the resting metabolic rate, such that one MET = 1kcal/kg/hour; Ainsworth et al. 2011). It is also of course possible that watercraft were used to travel along the Levant coast, or down navigable rivers such as the Tigris and Euphrates. While there is little direct evidence for the use of this mode of transport in the region at this time, boat technologies were certainly known to some human groups by even the earliest phases of this study (and indeed, arguably date as far as 60–45,000 yrs BP; see e.g. Bednarik 2003; Broodbank 2006 for review). The earliest boats are thought to have been dugouts or canoes made of skin or reeds (McGrail 2004), and were certainly in regular use by the Mesolithic at least (Mithen 1994: 106). By the 8th millennium BC obsidian was traded by boat across the Aegean (Renfrew 1975), and by the late 6th millennium a widespread trade network linked Mesopotamia and the Gulf (see e.g. Broodbank 2006; Carter 2006 for reviews). However, sailing technology is not thought to have been developed until the Bronze Age *c* 2,000 BC (Knappett et al. 2008: 1011). The energetic demands of kayaking, at 5 MET, are roughly equivalent to those of swimming (Ainsworth et al. 2011), and a relative cost of 5× base cost as calculated from the DEM was therefore assigned to all cells assigned to rivers, water bodies, and the sea.

An additional consideration for travel within the region is the challenge presented by desert environments. Travel within these areas will necessarily involve the transport of sufficient water. An average human of ~87 kg needs to consume between 3.3 and 4.7 per cent body weight of water per day, depending on the climate (<http://www.csgnetwork.com/humanh2owater.html>). Thus, below the 250 mm isohyet (the ecological definition of a desert), the need to carry extra water over and above that normally carried in other habitats is equivalent to an increase in the weight being transported (and thus the energy consumed) of 1.4 per cent (the difference between the extra 3.3 per cent weight of water required in 'cool' or 'warm' conditions and the 4.7 per cent in 'extreme heat').

In order to incorporate this into the GIS, data on modern precipitation were downloaded (Hijmans et al. 2005, available from <http://www.worldclim.org>) and the region corresponding to <250 mm/yr rainfall (Fig. 11.2) extracted and assigned an additional 'friction' cost above the base cost derived from the DEM of 1.4 per cent (i.e. the elevation map was multiplied by 1.014). The resulting map was combined with the cost maps derived from elevation and the traversing of water to provide the final cost-surface used in these analyses.

The GRASS module r.cost was then used to calculate the cumulative cost of movement between each pair of sites in each timeslice (example in Fig. 10.3). The module r.walk provides a more accurate means of estimating the cost of human movement between two points; however, as r.walk takes into account the difference between ascending and descending slopes of differing gradient, this module outputs an anisotropic cost which is valid only in one direction (i.e. the cost of moving from A–B may differ from that of B–A). In contrast, r.cost outputs an isotropic cost figure, i.e. one that is valid in both directions (A–B *and* B–A). The choice of r.cost over r.walk was thus prompted by time constraints—as the cost of travel between each dyad of sites need only be computed once—and the need to compare these networks with the undirected ones derived from material culture.

The result was a raster 'cost-surface' map in which each cell was associated with a cumulative 'cost' of traversing it. Further maps of the cumulative cost of travel between each pair of sites were calculated from this, and the costs of movement between them determined (example in Table 11.3). Shapiro-Wilks tests demonstrated that GIS-derived costs of travel (GISCT) were not normally distributed, and therefore, as for the as-the-crow-flies distances discussed above, these data were also $\log^{10}$ transformed.

11.5 RESULTS

Pearson correlations between (logged) great-circle distance- (GCD) and GIS cost-derived (GISCT) matrices and the contemporary matrices derived from measures of material culture and material similarity were calculated for each timeslice using UCINET v6.31 (Borgatti et al. 2002). Since classic statistical tests cannot be used for social network analysis data (in which individual observations are typically not independent), association between networks is assessed using permutation. In this procedure after correlation coefficients have been calculated for each timeslice, the matrices are randomized (2,500 times in each of the below procedures) and coefficients recomputed for each permutation to determine the proportion of times the correlation between the observed and randomized geographic network exceeds that observed in the data. A low proportion of good correlations between the observed and randomized networks suggests

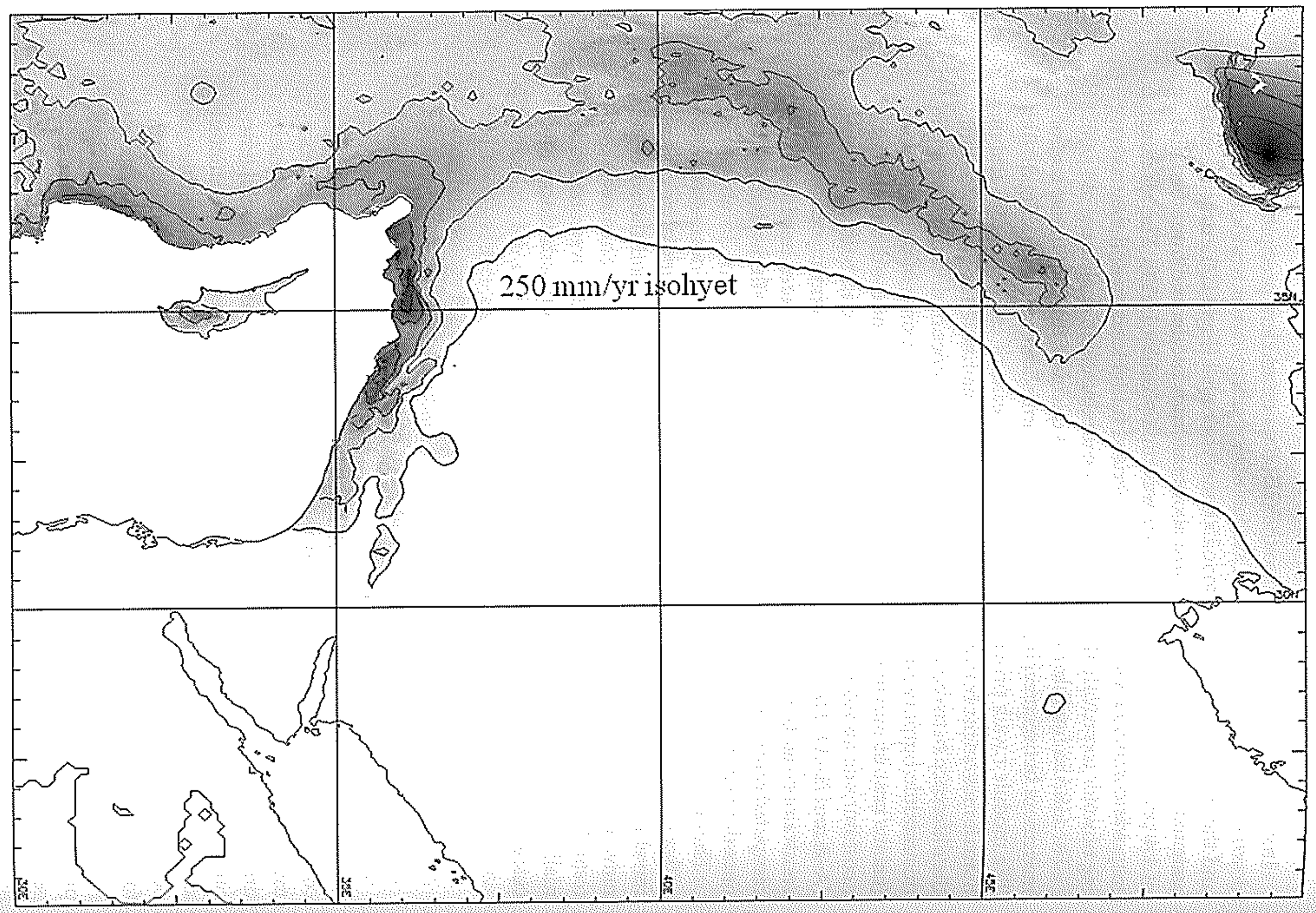

Fig. 11.2. Modern precipitation in the region, isohyets at 250 mm/yr intervals, 250 mm/yr isohyet labelled (source Hijmans et al. 2005).

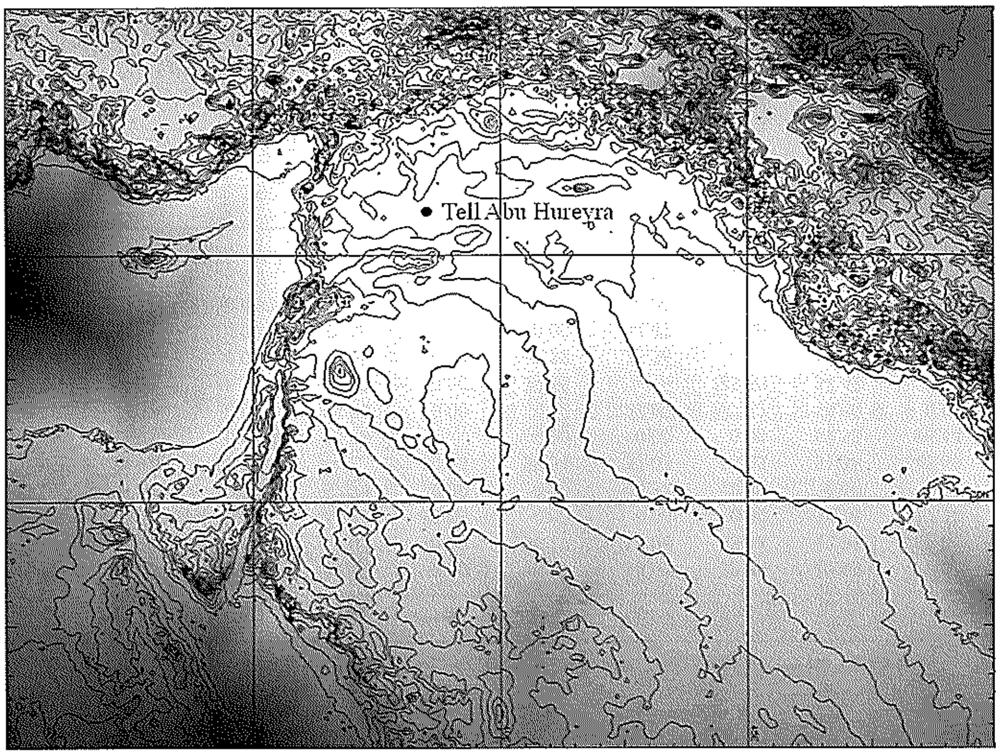

Fig. 11.3. Cost surface map of the region centred on Tell Abu Hureyra. Lighter areas in the immediate vicinity of the specified site indicate a low cumulative cost as they require less effort to reach from that site than areas at a distance, whose darker colour indicate higher cumulative costs.

Table 11.3. Matrix of GIS cost of travel between sites dated to 18–17kyr cal BC. Site codes are given in Table 11.4

	EGI3	EGI4	H2	HamIV	KIVD	Md	NOTK	OII	RC	UeR	WH31	Whs1065	WJ6A
EGI3	–	0.00	0.00	0.00	31.07	0.00	36.17	14.00	33.88	42.95	0.00	65.88	43.46
EGI4	0.00	–	0.00	39.01	31.07	0.00	36.17	14.00	33.88	42.95	0.00	65.88	43.46
H2	0.00	0.00	–	0.00	44.92	85.03	0.00	0.00	0.00	34.76	17.77	66.20	50.24
HamIV	0.00	39.01	0.00	–	67.74	0.00	0.00	45.37	0.00	0.00	0.00	58.02	0.00
KIVD	31.07	31.07	44.92	67.74	–	50.45	58.54	37.03	56.25	31.38	45.69	32.23	4.55
Md	0.00	0.00	85.03	0.00	50.45	–	0.00	0.00	0.00	69.53	96.14	47.21	44.02
NOTK	36.17	36.17	0.00	0.00	58.54	0.00	–	27.65	7.32	0.00	0.00	72.88	62.01
OII	14.00	14.00	0.00	45.37	37.03	0.00	27.65	–	25.36	34.42	0.00	76.53	49.46
RC	33.88	33.88	0.00	0.00	56.25	0.00	7.32	25.36	–	0.00	0.00	68.43	60.76
UeR	42.95	42.95	34.76	0.00	31.38	69.53	0.00	34.42	0.00	–	36.40	46.99	31.27
WH31	0.00	0.00	17.77	0.00	45.69	96.14	0.00	0.00	0.00	36.40	–	77.31	48.11
Whs1065	65.88	65.88	66.20	58.02	32.23	47.21	72.88	76.53	68.43	46.99	77.31	–	28.25
WJ6A	43.46	43.46	50.24	0.00	4.55	44.02	62.01	49.46	60.76	31.27	48.11	28.25	–

Table 11.4. Pearson correlations between material culture matrix and great-circle distance and GIS-derived travel cost matrices and significance based on 2,500 permutations using UCINET v6.31's QAP routine. Low p values suggest that the similarities between the observed and model network are unlikely to be solely due to chance, i.e. that there is no significant difference between the matrices. * indicates result is significant at the 0.05 level; ** that it is significant at the 0.01 level

	Great-circle distance (GCD) matrix		GIS-derived cost of travel (GISCT) matrix	
Timeslice	Pearson Correlation	p	Pearson Correlation	p
>21	−0.05	0.495	−0.508	0.118
21–20	0.15	0.289	−0.016	0.466
20–19	0.454	0.073	0.368	0.260
19–18	0.478	0.029*	0.228	0.230
18–17	−0.285	0.051	−0.353	0.016*
17–16	−0.261	0.045*	−0.289	0.034*
16–15	0.055	0.385	0.080	0.375
15–14	−0.104	0.182	−0.123	0.117
14–13	−0.131	0.105	−0.070	0.216
13–12	−0.254	0.012*	0.927	0.000**
12–11	−0.036	0.364	−0.067	0.291
11–10	−0.010	0.421	−0.125	0.042*
10–9	−0.076	0.112	−0.086	0.072
9–8	−0.106	0.023*	−0.117	0.017*
8–7	−0.124	0.007**	−0.142	0.013*
7–6	−0.057	0.213	−0.112	0.118

that the similarities between the observed and model network are unlikely to be solely due to chance (Hanneman and Riddle 2005). UCINET's Quadratic Assignment Procedure (QAP) computes Pearson's correlation coefficient between corresponding cells of an observed network (here, the adjacency matrix describing material culture similarities between pairs of sites) and an expected network (the GCD and GISCT networks). Results are presented in Table 11.4, and demonstrate that only a minority of material culture networks are significantly correlated with either measure of geographic distance. Furthermore, while most correlations are, as might be expected, negative (i.e. as geographic distance and/or cost of travel between sites increases, the material culture similarities between them decrease), this is not true in all cases. Indeed, two such positive correlations between high geographic distance and similarity in material culture inventories are significant—that between GCD and material culture matrices in the 19–18kyr cal BC timeslice, and between GIS and material culture matrices in the 13–12kyr cal BC timeslice. The strong correlation of the latter matrices (with a Pearson correlation of 0.927) is also strongly statistically significant (p=<0.000).

Table 11.5. Results of multiple regression using degree (material culture similarity) as the dependent variable and summed great-circle distance and summed GIS-derived travel cost as the independent variables

Timeslice (kyrs cal BC)	Correlation of GCD and GISCT	Colinearity of material culture similarity and GCD	Colinearity of material culture similarity and GISCT	r^2	p
>21	0.878	0.092	–0.395	0.997	0.411
21–20	0.904	0.182	0.161	0.033	0.876
20–19	0.995	0.41	0.381	0.235	0.89
19–18	0.887	0.757	0.529	0.666	0.325
18–17	0.837	–0.101	–0.182	0.042	0.772
17–16	0.972	–0.078	–0.148	0.099	0.676
16–15	0.991	0.039	–0.005	0.107	0.777
15–14	0.931	0.012	0.056	0.015	0.914
14–13	0.885	–0.027	–0.081	0.016	0.862
13–12	0.915	–0.060	–0.113	0.024	0.806
12–11	0.940	0.077	–0.015	0.034	0.689
11–10	0.862	0.203	0.000	0.159	0.099
10–9	0.662	–0.040	–0.101	0.012	0.718
9–8	0.688	–0.077	–0.143	0.021	0.550
8–7	0.747	–0.073	–0.110	0.012	0.663
7–6	1	–0.183	–0.256	0.071	0.284

These results suggest that geographic distance is not the sole determinant of material culture similarity in most cases, and indeed that in some cases the relationship may be completely at odds with the gravity models of fall-off with geographic distance usually posited as a priori assumptions in analyses of the relationship between geographic distance and material culture dissemination (e.g. Renfrew et al. 1968; Hodder 1974; Plog 1976; Renfrew and Dixon 1976; Pires-Ferreira 2009 [1976] and other sections in Flannery 2009 [1976]) or, indeed, any form of spatial distance relationship (Expert et al. 2010).

To investigate the relationship between geographic distance and material culture similarity within these networks, multiple regressions of the GCD and GISCT measures on material culture networks were performed, with material culture similarity (degree) as the dependent variable and GCD and GISCT as the independent variables. As before, significance was assessed by 2,500 random permutations. The sum of each site's GCD from every other was calculated and regressed on the sum of each site's GIS from every other and the degree centrality of that site (the summed values of each relationship that site has with all others; i.e. the summed number of material culture elements shared with all other sites). Results are presented in Table 11.5. As expected, correlation between the two geographic distance matrices is high throughout (although the two measures do diverge in some cases, particularly in some later timeslices), but correlation between either of these measures and the measure of material culture similarity (degree, in this case) is almost uniformly low. Again, while most of the measures of correlation are negative, indicating an inverse relationship between geographic distance and material culture similarity, this is not true in all cases. Low r^2 values suggest that geographic distances between sites—by either measure—are not closely related to material culture similarity. A very high r^2 value for the earliest timeslice is not significant, and is probably due to the small dataset. In short, it does not seem that the geographic relationship between sites, measured either by GCD or by GIS, has a significant relationship with the material culture relationship between sites.

Moran's *C* and Geary's *I* were also calculated to evaluate the autocorrelation between the network distance between actors and their material culture similarity. High measures of correlation in these statistical measures would indicate that nodes geographically closer to one another are also more likely to be those with more material culture similarities to other sites. Moran's *I* is similar to a regular correlation coefficient, evaluating the differences between each pair of sites/nodes values and the overall network mean and weighting the cross-products according to their geographic distance or the cost of travel from one another—a more 'global', network-level measure of difference. Geary's C, in contrast, focuses on the differences between each pair of nodes, weighted by their geographical closeness, and is thus usually considered more sensitive to local differences (Hanneman and Riddle 2005).

Table 11.6. Moran and Geary statistics for autocorrelation between degree (summed material culture similarity) and great-circle distance. Moran autocorrelation: –1 = a perfect negative correlation; +1 = a perfect positive correlation; 0 = no correlation. Geary autocorrelation: 1 = no association; < 1 = positive association; >1 = negative association. * indicates a result significant at the 0.05 level

Timeslice (kyrs cal BC)	Geary		Moran	
	Geary's *C*	p	Moran's *I*	p
> 21	0.974	0.470	–0.334	0.518
21–20	1.455	0.178	–0.5	0.129
20–19	1.504	0.075	–0.517	0.051
19–18	1.2	0.275	–0.246	0.441
18–17	0.732	0.179	–0.048	0.365
17–16	1.133	0.356	–0.135	0.4
16–15	1.051	0.354	–0.197	0.35
15–14	0.867	0.424	–0.037	0.426
14–13	0.729	0.406	–0.036	0.440
13–12	1.245	0.281	–0.117	0.176
12–11	1.155	0.195	–0.051	0.547
11–10	1.080	0.170	0.009	0.015*
10–9	0.981	0.4	–0.011	0.155
9–8	0.875	0.084	–0.009	0.126
8–7	0.903	0.124	–0.009	0.113
7–6	0.983	0.438	–0.016	0.144

Table 11.7. Moran and Geary statistics for autocorrelation between degree (summed material culture similarity) and GIS-derived cost travel. Moran autocorrelation: −1 = a perfect negative correlation; +1 = a perfect positive correlation; 0 = no correlation. Geary autocorrelation: 1 = no association; <1 = positive association; >1 = negative association. * indicates a result significant at the 0.05 level; ** significant at the 0.01 level

Timeslice (kyrs cal BC)	Geary		Moran	
	Geary's *C*	P	Moran's *I*	p
> 21	1.110	0.308	−0.338	0.513
21–20	1.157	0.389	−0.144	0.464
20–19	1.506	0.089	−0.503	0.094
19–18	1.245	0.279	−0.312	0.280
18–17	0.823	0.327	0.056	0.104
17–16	1.082	0.427	−0.107	0.454
16–15	1.094	0.333	−0.233	0.323
15–14	0.907	0.461	−0.063	0.490
14–13	0.763	0.402	−0.019	0.311
13–12	1.249	0.256	−0.099	0.230
12–11	1.269	0.048*	−0.073	0.213
11–10	0.990	0.454	−0.015	0.192
10–9	0.963	0.335	−0.021	0.45
9–8	0.959	0.309	−0.011	0.177
8–7	0.918	0.156	−0.010	0.139
7–6	0.957	0.333	−0.015	0.130

Results are presented in Tables 11.6 and 11.7. Low and overwhelmingly negative values of Moran's *I* (0 indicates no correlation, −1 a perfect negative correlation and +1 a perfect positive correlation) indicate that sites with high levels of material culture similarity to other sites do tend to be those closer to most other sites, but that this is a rather weak trend. Values of Geary's *C* (a value of 1 indicates no correlation, <1 a positive correlation, and >1 a negative correlation) also suggest only weak correlations, although here fully half the timeslices indicate a *positive* correlation between the two measures of geographic distance and similarity. In all cases, however, these correlations are weak. Only two results reach significance, and one of these in fact demonstrates an almost complete lack of correlation.

11.6 DISCUSSION

Results indicate that within each timeslice network, geographic distance, and the cost of travel between sites in fact have very little impact on the similarity of their material culture inventories. Only in a very few timeslices were material culture networks significantly correlated with either measure of geographic distance, and in most cases these correlations were very small. Furthermore, while in the majority of timeslices the geographic distance between sites had a negative impact on their material culture similarities, in a few cases sites further apart were actually on average *more* similar. Measures of the relationship between the overall material culture similarity of each site to the rest of the network (degree—the summed values of each site's ties to all other sites in the network) and the geographical relationships between those sites support these conclusions, with values of both Moran's *I* and Geary's *C* indicating only very weak and almost exclusively non-significant correlations. Again, most of these correlations were negative, but Geary's *C* indicated the presence of a limited number of dyads within some networks in which greater geographic distances between sites was related to greater similarity in material culture. Finally, regressions of the summed GCD and GISCT of each site from every other (as proxies for the geographical relatedness of each site to the rest of the network) on the summed values of material culture similarity between them found a generally—although by no means always—negative relationship between geographic distance and material culture, but this was not statistically significant.

These somewhat unexpected results are perhaps rather counter-intuitive and even contradictory at first sight, as numerous empirical studies, both in archaeological and contemporary contexts, have identified strong relationships between geographic distance and drop-off in trade and exchange between sites (see references on p. 254), and it will be necessary to refine these analyses in order to determine how robust these results are, as the datasets may in fact contain considerable variability at much finer scales than is apparent here.

11.6.1 Future Refinements

One possibility is that the size of the timeslices may hide finer-grained temporal variability. A millennium may sample anything between thirty and sixty-two generations, so there remains considerable uncertainty as to whether sites in the timeslice were occupied contemporaneously. As a result, it is of course possible that considerable temporal variation is contained within them.

Geographical patterning may also be disguised or conflated in these analyses because of the inclusion of a wide range of different types and kinds of material culture and sites in each network. Not all 'things' are the same, and different kinds of material culture are likely to circulate (or indeed, not circulate) as part of different social relationships and interactions and thus in rather different ways. For example, within these multiplex networks, some kinds of material culture may well demonstrate classic gravity-model fall-off patterns with geographic distance, while others—for example, valued or 'prestige' items—might be expected to exhibit more rapid fall-offs or, indeed, *increase* in frequency at greater geographic distances, for example if items are produced solely for trade. Further analysis of these datasets will thus focus on teasing individual networks apart to investigate potential differences in the patterns of distribution displayed by different forms of material culture and the contribution of this to network structure, for example by comparing the result of traditional fall-off analyses for the different forms of material culture incorporated in each network.

However, not all forms of social interaction are materialized, and therefore approaches based on material culture inventories will inevitably track only one aspect of the social relations that occurred between the sites in these networks. Nevertheless, the similarities in structure identified between materialized and non-materialized networks such as communication and internet networks discussed previously, and further below, suggest that while materially attested-to social relations may represent only one aspect of broader social relations, they are likely to represent impoverished versions of those wider interactions rather than being different in kind.

A more significant issue is that not only may different kinds of material culture be contributing differently to the network, but individual nodes/sites are also likely to differ. For example, more 'distant' sites are perhaps more likely to demonstrate reduced overall similarities in material culture inventories to others in the network, yet produce large quantities of another, different form of highly valued material culture which *is* traded widely throughout the network, thus at least partly compensating for its geographic distance. In tandem with the development of specialists—as discussed above—certain sites are likely to have increased in influence at the expense of others at this time ('central places'; Renfrew and Dixon 1976; Knappett et al. 2008; Flannery 2009 [1976]), thus contributing differently to overall network measure.

Further work will thus aim to incorporate independent measures of the significance of each node/site, as per traditional gravity models (Plog 1976; Knappett et al. 2008), in which the intensity of interaction between two nodes is considered to be proportional not only to the geographic distance between them but also to the 'importance' of the nodes—the assumption being that 'longer (and more expensive) ties will appear mainly between important entities, while a node will connect to an unimportant one only if they are close to one another' (Scellato et al. 2011: 8). This 'rich get richer' effect (described by Zipf's and Pareto's laws) has been noted in many social networks (Watts 2003: 105–6, 109–10).

Although 'sites' consisting solely of lithic scatters (presumably the result of ephemeral stopovers by mobile groups or more mobile components of sedentary populations) have been removed from these datasets (see Coward 2010a for discussion), no other attempt has been made to factor in differential significance of nodes in the analyses presented here. Further investigation of the variability of the distribution of tie strength are likely to yield some interesting results in this regard, including, for example, measures of network centralization (Hanneman and Riddle 2005: section 10), or indeed simply the coefficient of variation of each site or timeslice network. However, independent data on site significance are also available for at least some sites, and could potentially be incorporated into future analyses; for example in the form of estimates of spatial extent and/or inferred population or length of occupation (despite the many problems associated with estimating such measures). Alternative possibilities might also include ecological attributes of sites, such as net primary productivity or vegetation indices of the landscape within some specified geographic distance of the village (e.g. a day's walk; Vita-Finzi and Higgs 1970).

The population density of individual sites may also be a relevant aspect here which could perhaps be factored in to analyses. Work on contemporary social networks has identified the importance of population density to network connectivity, as more tightly 'packed' settlements or populations are inherently 'dense encounter sets' (Hillier and Hanson 1984: 27) where individuals are more likely to meet by chance. However, at the same time, at higher densities, nodes are less likely to be connected to nearby individuals (since there are so many of them), and more likely to be linked to more distant nodes (Backstrom et al. 2010). In addition, when investigating such internodal variability, Liben-Nowell et al. (2005: 9) have suggested that gross distance per se may be less significant than distance *rank*; i.e. that the relevant measure should be the number of nodes closer to *x* than *y* rather than the distance between them. Although Backstrom et al. (2010) found that such measures did not entirely factor out the effect of differing population densities, these findings do suggest that measures of straightforward degree of betweenness centrality, as used in these analyses, might be profitably supplemented by alternative measures such as eigenvector or Bonacich betweenness, both of which provide *relative* measures of nodes' 'centrality' to social (or distance-based) networks in terms of the 'global' or overall structure of the networks (Hanneman and Riddle 2005: section 10).

11.6.2 Socio-Spatial Networks: Neither Entirely Social, Nor Completely Geographic

Clearly further work remains to be done on these datasets. Nevertheless, the results presented here complement recent work on contemporary social networks which emphasizes the *interplay* between geographic and social factors in the structure of real-world social networks. Scellato et al.'s work on location-based social services, for example, identified clear structuring effects of *both* geographic distance and social topology, suggesting that real-world social networks 'can not be explained by taking into account only geographic factors or social mechanisms' (2011: 7). Similarly, Liben-Nowell et al.'s finding (2005) that while on average ~69 per cent of a user's ties were explained primarily by geography, the rest were explicable in terms of a constant baseline probability of any tie being *non*-geographic in origin (P[σ] among all pairs of users $u,v \approx 5.0\times10^{-6}$; Liben-Nowell et al. 2005: 6–7). Again, they conclude that personal social networks are influenced by 'two distinct processes, one comprising all geography-dependent mechanisms (like meeting in a shared workplace), and one comprising all nongeographical processes (like meeting online through a shared interest)' (Liben-Nowell et al. 2005: 5).

However, it is notable that many of these studies on mobile and online social networks have focused purely on the probability of a tie existing at all, and not on measures of that tie's *strength*. One exception is Onnela et al.'s work on the use of location-based online services, which found that while geography was strongly associated with the existence of a tie (with the decay rate well described by a power law), tie *strength* (measured as number of calls and/or texts between any two nodes) varied only weakly with geographic distance, and measures of network betweenness centrality and geographical centrality showed no correlation (Onnela et al. 2011: 2). Furthermore, Lambiotte et al. found that the average duration of mobile calls actually *increased* with geographic distance, although this reached a plateau at around 40 km (Lambiotte et al. 2008). These studies suggest that some forms of interaction in fact act to *compensate for* increasing geographic distance: Lambiotte et al. comment that calls between people living close by are short and functional, being intended primarily to coordinate face-to-face interactions, while at longer geographic distances phone calls are a major means of maintaining relationships between individuals (Lambiotte et al. 2008: 5319; see also Hill and Dunbar 2003). These compensatory forms of interaction may well explain the relatively frequent though small correlations between the remoteness of sites and their levels of material similarity with others in the wider network, as these more distant sites work harder to maintain relations with others in the region. The kind of relatively low-cost communication evaluated in these studies is clearly not a factor for the prehistoric networks discussed here. Nevertheless, such work does indicate that, as in the analyses presented here, the structure of networks does not always correlate in any straightforward way with geographic distance or even cost of travel. It would seem that some influences on the structure of socio-spatial networks remain to be fully identified, and that different modes of interaction such as material networks, online/phone networks, and face-to-face interactions need to be compared more explicitly in contemporary contexts to ascertain the differences in structure associated with the use of different kinds of resources and modes of interaction, and the interplay between them.

11.7 CONCLUSION

The analyses presented here aimed to investigate the relationships between material culture similarity—as a proxy for the strength of social relationships—between sites, and their geographical relationships over the course of a period of highly significant economic, cultural, and social change that occurred as groups became increasingly sedentary and resident in larger settlements and increasingly reliant on intensive subsistence on certain plant and animal species which ultimately became domesticated. Results suggest that within each network, the geographical relationships between sites are almost entirely unrelated to their similarity in material culture terms. In fact, while the relationship was very weakly negative in most cases, with more distant sites showing fewer similarities in material culture inventories, in some cases this pattern was in fact reversed.

These results suggest that geographic distance was not the major factor determining regional-scale relations between sites throughout this period, a finding which is very interesting in the light of the generally-held belief that in small-scale societies, the social worlds of individuals are coextensive with their spatial worlds, while in larger societies other, non-geographic forms of social relation may be layered on to these. In the analyses described here, however, there is no obvious indication that earlier, mobile hunter-and-gatherer networks are any more defined by geographical proximity than later, village-dwelling agriculturalists (although measures such as transitivity and clustering were not explicitly calculated and might prove illuminating in this regard). A number of refinements remain to be made to this model. Nevertheless, the analyses presented here do suggest that a more grounded form of social network analysis (both in contemporary and archaeological contexts) is an important step towards gaining a better understanding of the insights into social and geographical topologies of social interaction and the resources with which we construct our social networks.

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12

Evaluating Adaptive Network Strategies with Geochemical Sourcing Data: A Case Study from the Kuril Islands

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12.1 INTRODUCTION

In all parts of the world and throughout time, humans have developed strategies for dealing with the unpredictable nature of their environment, and for adapting to the conditions in their environment that change at varying scales. Optimization models derived from human behavioural ecology (HBE) propose that the behavioural decisions of low-density foragers regarding resource procurement and consumption activities are made with the ultimate goal of maintaining or increasing their fitness in an efficient manner. Establishing and maintaining inter- as well as intra-group social ties is one way that hunter-gatherer groups have adapted to living in the face of environmental unpredictability where assistance or outside resources may be required (Alexander 2000; Binford 2006; Grattan 2006; Hofman et al. 2007; Kirch 1988; Reycraft and Bawden 2000; Sheets and Grayson 1979; Torrence 1999, 2002; Whallon 1989, 2006; Wiessner 1982). The exchange of material and non-material resources provides a vehicle or mechanism for developing and maintaining these networks of social relationships.

Social network analysis (SNA) provides a body of theory and a set of techniques for visualizing and measuring sets of human relationships (such as exchange), and for evaluating the implications of those relationships (Wasserman and Faust 1994). By focusing on the relationships between social entities rather than just comparisons of entity attributes, patterns that are not immediately obvious in the data may become visible. In addition, SNA is a way to superimpose a measure of non-Cartesian social geography represented by human relationships on top of cartographic space to make comparisons between geographic and social space (Mackie 2001; Thomas 2001).