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From Network Connectivity to Human Mobility: Models for Minoanization

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Abstract

While network techniques are now used with some frequency in archaeology for tackling questions of connectivity and mobility at regional and inter-regional scales, they are still somewhat underexploited for more local scales. The considerable potential for multiscalar analysis has recently seen some progress, however, wedded to the idea of communities of practice. In this paper, I consider how this multiscalar approach could aid in the study of ancient globalizations, with the particular case of Minoanization from the Aegean Bronze Age. Although this specific problem has seen some network applications, they have mostly not been multiscalar in nature. I address some of the reasons for this state of affairs, using a distinction between "theory" and "data" models—and suggest some possible outcomes of a more explicitly multiscalar approach to Minoanization.

Keywords Mobility · Connectivity · Network · Data model · Theory model · Multiscalar · Material culture · Aegean · Bronze Age · Globalization · Minoanization

Introduction

While the past decade's flurry of activity in archaeological network analysis sees no sign of abating, a series of recent papers seek to characterize the different strands of analysis that have emerged and reflect on the future direction of such studies. Östborn and Gerding (2014) differentiate two approaches in network theory: network analysis and network modeling, though their review focuses only on the former. Rivers (2016) distinguishes between data and theory models, corresponding to analysis and modeling respectively in Östborn and Gerding's terms. A further distinction that follows along similar lines is that made by Mills (2017) between material and spatial networks. In a

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different register, Collar *et al*. (2015) wonder what stage network analysis has reached in the discipline: have we reached the "trough of disillusionment" after early expectations, or is the domain going from strength to strength? While we may recognize the different derivations of some of these approaches—with, for example, spatial networks and theory models taking their lead more from physics and geography, and material networks and data models inspired by sociology and social network analysis—there is nonetheless a good deal of common ground and 'ecumenicalism' (Mills 2017, p. 390). What Mills calls the "big tent" approach is surely what has enabled the uptake of network approaches across very diverse global and temporal contexts. And yet this diversity is underscored by a strong commonality, which is a frequent focus on regional and inter-regional scales of analysis (*e.g*., Knappett 2013). This focus perhaps reflects an implicit assumption that the local scale will consist of largely predictable triadic connections, while the regional scale and above has dyadic ties across longer distances that are harder to predict and thus more fruitful for network analysis. Not only has this assumption moved archaeological network studies away from the traditional strengths of network analysis in sociology (Kadushin 2012), it also breaks the intimate and necessary connection between the local and the regional. That said, the local scale is potentially quite accessible within the "material network" approaches that build from the bottom-up, and this potential for multiscalarity has indeed been realized of late (Pailes 2014; Blair 2015; Peeples 2018).

Despite their different starting points, material and spatial networks (or data and theory models) can be usefully compared. In this paper, I propose that a further way of exploring their complementarity is by using a distinction between *connectivity* on the one hand, and *mobility* on the other hand. This distinction comes from Mediterranean scholarship, and in particular the seminal work *The Corrupting Sea* by Horden and Purcell (2000), in which connectivity is deemed a property of the environment and mobility a property of people. In other words, connectivity is potential and mobility is actualization (Woolf 2016, p. 447). In these terms, then, it is connectivity that we can address using spatial networks and theory models, and mobility that is revealed in material networks and data models. We can do much in the heterogeneous environments of the Mediterranean to model connectivity using spatial interaction models. But these models do not say what happened historically in terms of actual mobility—they merely provide physical parameters. It is material networks/data models that can show us actual historical patterns of mobility. What we can then do by comparing theory with data models is evaluate the degree to which different historical patterns of mobility conform with or confound theoretical expectations for connectivity. A particular archipelagic environment, for example the Cyclades, might appear to lend itself to human mobility and exchange; but the historical evidence for mobility in this region is of course incredibly varied (Knappett and Nikolakopoulou 2014).

A set of processes throwing these issues of connectivity and mobility into high relief are the cultural phenomena we typically label as "-izations"—from Neolithization, to Hellenization, to Romanization. Archaeologists have recently begun to recognize that despite being in the distant past, these situations in which complex behaviors are transmitted over relatively long distances can be justifiably described as ancient globalizations (*e.g*., Jennings 2011). Jennings has argued that for an ancient scenario to be reckoned as a form of "globalization," the "complex connectivity" it engenders must involve intense interactions that form dense networks between different regions,

with the capacity to trigger social change (Jennings 2011, p. 2). One of the classic cases, as indicated above, is Romanization (Versluys 2014; Pitts and Versluys 2015), though Jennings also argues for Uruk, Cahokia, and Wari as ancient examples (and see also Hodos 2017 for wider discussion). Each of these phenomena raises questions about the "scaling up" or transmission of behaviors and ideas from one culture or region to another. Because these transmissions can be so varied and complex, archaeologists encounter many problems in understanding interactions beyond the local scale and how they are constituted.

We can take two recent developments that speak to these efforts to understand multiscalarity more effectively. The first concerns the increasing uptake of the idea of "communities of practice", which has been particularly effective in allowing archaeologists to bridge the level of individual agency with that of the community (*e.g.*, Roddick and Stahl 2016). It has been especially productive in work on craft production, as it enables a focus on the learning process whereby new actors are apprenticed into communities, through "legitimate peripheral participation" (Lave and Wenger 1991; Wenger 1998), and thereby a dynamic understanding of craft as a situated and communal practice that is generated from the bottom-up. However, communities of practice can be scaled up further still, as Wenger (1998) situated them within broader "constellations of practice". Barbara Mills in particular has recently developed these ideas of community and constellation and argued for their compatibility with multiscalar social network analysis (Mills 2016; see also Blair 2016).

A second development picks up on work in the "collective action" literature in sociology as a means to understand multiscalar processes. In archaeology more broadly this has become a live topic (*e.g.*, Carballo 2013; DeMarrais and Earle 2017), as well as being incorporated into network approaches (*e.g.*, Peeples 2018). In the sociological literature, we might point to the work of Ann Mische, for example (Mische 2008; see also Diani and McAdam 2003), and Elinor Ostrom's work on the commons (Ostrom 2010). We can usefully focus on one particular strand of this work to underline its utility for our current purposes, and this relates to the assumptions about the character of long-distance ties in work on inter-regional interactions. These ties are typically seen as weak relationally, even though the influential "strength of weak ties" hypothesis (Granovetter 1973) suggests that they may nevertheless be strong in terms of the overall network structure. Granovetter provided the example of job seeking, and how it is often a weak tie, perhaps an individual that one only connects with sporadically and who is not part of the close social circle, that can often be the most effective in such searches. The flipside of this is the assumption that local ties are relationally strong but structurally weak. In sociology, and notably in the collective action scholarship, these concepts have seen some revisions, notably with Centola and Macy (2007) arguing that Granovetter's ideas on the relative strength and weakness of distant *vs* local ties only really apply to certain situations of information transmission—those that are, to use an "epidemiological" model, "simple contagions," where all that is required is a single exposure for transmission to occur. As in an example given by Centola and Macy (2007, 706), you only need exposure to one person, your child, for example, to catch a cold—you do not need to be exposed to your spouse too. But there are other situations in which transmission does require "social affirmation or reinforcement from multiple sources" (Centola and Macy 2007, p. 707). These are what Centola and Macy call "complex contagions"—and some examples they give include the uptake of unproven

new technologies, or participation in risky migrations, for which one is likely to garner information from multiple sources before coming to a decision. These authors go on to suggest various social mechanisms that could explain the need for multiple "exposures" in certain circumstances (*e.g.*, legitimacy, credibility, strategic complementarity, emotional contagion). They show that long ties are actually quite weak when it comes to transmitting more complex behaviors; and what are actually needed are not weak ties, but wide bridges. A bridge in network terms connects together different parts of an "otherwise disconnected network"—and though generally a bridge need only consist of one tie, when it has more than one, its "width" increases (Centola and Macy 2007, p. 710). It is these "wide bridges" with multiple ties that are necessary for complex contagions to spread.

It is not only in sociology that the strength of weak ties has been questioned. In complexity science too, it has been argued that sometimes transmission, particularly of sensitive information, requires networks of strong rather than weak ties (Shi *et al.* 2007). This idea has made its way into archaeology in the work of Anna Collar on religious transmission in the Roman East (Collar 2013). Interestingly, in biblical studies, a similar topic has attracted network thinking (albeit drawing from Centola and Macy 2007, rather than Shi *et al.* 2007) with work on Paul's networks and the role therein of weak or strong ties (Duling 2013).

Some of the collective action scholarship, as the work of Centola and Macy shows, sets out to understand the conditions under which social action might scale up (see also Oliver and Marwell 1988; Macy 1990; Siegel 2009). In this it has some similarities to the work in communities and constellations of practice. The incorporation of each of these ways of thinking into archaeology of late shows the concern in the discipline with questions of the interrelationship between local and regional scales. What I think we can further show is the positive contribution that network approaches can make to multiscalarity. Now that we have briefly reviewed these two strains of thought and their relationship to network thinking, I would like to develop some of these ideas further in an archaeological setting, one that pertains to the "–ization" questions already raised (which are so pertinent to multiscalarity). The case study in question is drawn from the Aegean Bronze Age and allows us to explore how theory-driven approaches have had some effect, at different scales; how and why data-driven approaches are as yet largely unsystematized; and how with further work a systematic comparison of data and theory models could be productively mobilized toward a multiscalar understanding of transmission processes.

Minoanization as Multiscale Process

Minoanization describes the process whereby, following the establishment of "'Minoan culture" on the island of Crete, with deep sharing of all kinds of artefactual traditions right across this mini-continent, this culture then spreads off-island, touching much of the southern Aegean (Fig. 1), from the Peloponnese in the west to coastal Anatolia in the east, encompassing both the Cycladic and the Dodecanesian island groups (Broodbank 2004). This was initially seen, as some of the language used here already indicates (and which the very –ization term encourages), as diffusion from a terrestrial "core" to a maritime "periphery," arguably carried out by colonists from Crete, with the

Fig. 1 Map of the Aegean

periphery having relatively little say (Branigan 1981; Wiener 1984). Though revisions to this argument did assert that local communities may have had considerable agency and purpose in their decisions to emulate Minoan culture (Davis 1984), it was not for some time that the monolithic nature of Minoanization was more fully challenged by the recognition that Minoan features were adopted with considerable variation regionally and with differential uptake over time (Broodbank 2004; Knappett and Nikolakopoulou 2008). Moreover, this focus on variation and difference has generated an explicit emphasis on technological *practices*, which has fostered a greater concern with processes of adoption, transmission, and learning, often in explicit connection with the communities of practice literature and a concern for multiscalarity (*e.g.*, Hilditch 2009, Cutler 2011; Nikolakopoulou and Knappett 2016).

With multiscalarity key to Minoanization, we might also recognize the potential here for approaching the problem in terms of collective action, particularly *via* Centola and Macy's ideas on complex contagion, wide bridges, *etc.* There is a complexity to transmission in the case of Minoanization that clearly goes beyond simple contagion. If we accept the complex contagions involved, then we should also accept that these could only have been transmitted through wide bridges, not weak dyadic links. Moreover, it also seems likely that some degree of *transitivity* (*i.e.*, when all nodes in a triad are connected) would also have been useful in this process (see Centola and Macy 2007). What this then enables is an approach to Minoanization that seeks to articulate local and regional dynamics—or, in other words, local communities and regional constellations of practice.

Still, the work done to date in the Aegean on communities of practice has not seen much connection, unlike those examples cited earlier (*e.g.*, Blair 2015; Mills 2016), with

the kinds of network approach that might allow for a systematic analysis of connections across scales. This situation cannot be attributed to a lack of network analysis in the region because there have been network studies addressed to the problem of Minoanization (*e.g.*, Knappett *et al.* 2008, 2011). While these studies have helped to challenge some of the more basic "radial" core-periphery models, they have not as yet found close integration with emergent ideas on communities of practice (though see Knappett 2011 for a largely theoretical attempt to bring them closer). They have also tended to emphasize the structural strength of long-distance weak ties; it would certainly be interesting to introduce the idea of complex contagion, and think about the impact of wide bridges, presumably costly in some sense, on the stability of such networks. Nonetheless, network thinking has been typically inter-regional in its ambit.

To begin to treat Minoanization in a manner that works between the local and the global seamlessly, we need to make a series of adjustments in how we work with the data from Crete and the wider Aegean. First, the relatively recent initiative toward identifying communities of practice is very productive and promising—though it has tended to keep the archaeology of Crete somewhat separate from that of "Minoanized" areas (Hilditch 2009 and Cutler 2011 as notable exceptions). Second, network approaches have thus far been limited to spatial interaction models at regional/ inter-regional scales—they have not been integrated with the complexities of the data in any systematic way. We will now work through some of the factors contributing to this dual separation, discussing first how empirical and theoretical approaches to connectivity have been treated rather separately on Crete, before turning to the same data/theory separation for the wider Aegean. We will expand upon the distinction we briefly made above between data models and theory models, in order to explore how and why data models have largely failed to include network thinking, while theory models remain quite distant from our datasets. The aim is to identify some of the changes needed in order to properly harness the power of network analysis as a tool for investigating Minoanization as a multiscale process.

Cretan Theory Models

A theory model uses a set of theoretical expectations—"encoding in a formal way…our systems of belief about the world" (Rivers 2016, p. 124)—to model possible network outcomes given certain parameters. If we think that sites generally will choose to link to their nearest neighbors, then we might encode that in a model such as proximal point analysis, or a simple gravity model. Some models of this kind have been developed for Bronze Age Crete, and they can be generically classified as spatial interaction models (Rivers *et al.* 2013; Evans 2016). What these do is place sites in space and then use the parameters of the space to model which sites might be interacting, which sites might emerge as central, and where settlement hierarchies might form. Bevan and Wilson (2013), for example, have used entropy maximization methods to model the "flows" between sites, and the degree to which settlement locations and hierarchies might be reconstructed even when our evidence is quite incomplete (see also Bevan 2010). Their coarse-grained approach is suitable for the methodological issue with which they are primarily concerned. However, there are two refinements that can be introduced if we wish to think about some of the problems as historical ones too. First, a distinction

between the Proto- and Neopalatial periods could be very useful, as some scholars have argued for significant changes in settlement organization across this transition (*e.g.*, Haggis 2002). While in a general sense, society can in both periods be characterized as "palatial," with palaces at the heart of urban centers that act as the focal point for wider territories, there are significant geopolitical changes which seem to transform one center, Knosssos (for location, see Fig. 2), into the primary center for the entire island in the Neopalatial period. Second, they omit the smaller sites in the settlement hierarchy, which makes it impossible to look for those local social networks that might be more transitive in nature. These two features may be related, as Haggis (2002) argues that the geopolitical transformation that occurs between the Protopalatial and Neopalatial periods is a breaking up of a tight-knit local "lattice" settlement structure in the face of more coastal, long-distance links.

The argument Haggis puts forward is based on a relatively small sub-region of east Crete, studied in the Kavousi survey. A recent study attempts to test this proposition by investigating settlement patterns more broadly across east Crete, both including the smaller sites and attempting to differentiate between the Protopalatial and Neopalatial periods (Knappett and Ichim 2017). Using the technique of Bevan and Wilson to compensate for missing sites, this study uses survey results to establish likely site numbers and locales. What emerges is a very dense distribution in the Protopalatial period (Fig. 3). When we calculate likely patterns of centrality, we do see results that mimic what Haggis anticipates, with the more central sites located at the interior, rather than on the coast. With the distribution of sites in the Neopalatial period, however, the sites predicted to be most central are closer to the coast, again as Haggis observes with his data. In the Protopalatial scenario, we can imagine many closely knit communities with most of their links to neighboring sites, albeit with some sites having more centrality in regional communication links. It is possible to see here with this methodology how communities of practice and regional networks may coexist. With the Neopalatial period, there is perhaps a shift in balance more toward the regional networks, which presumably compromises local community structures, albeit perhaps only in a limited way. However, as we will see below, even though we do have some

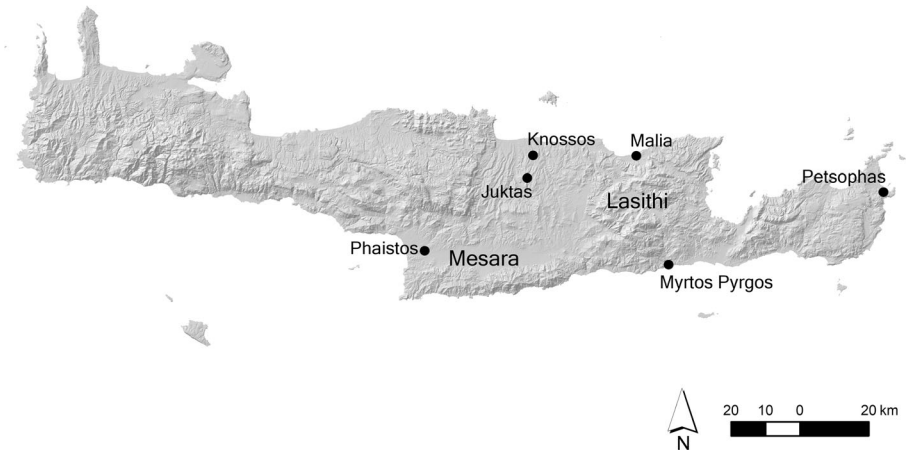

Fig. 2 Map of Crete, with sites mentioned in the text (courtesy of S. Déderix/ GeoSat ReSeArch Lab (FORTH))

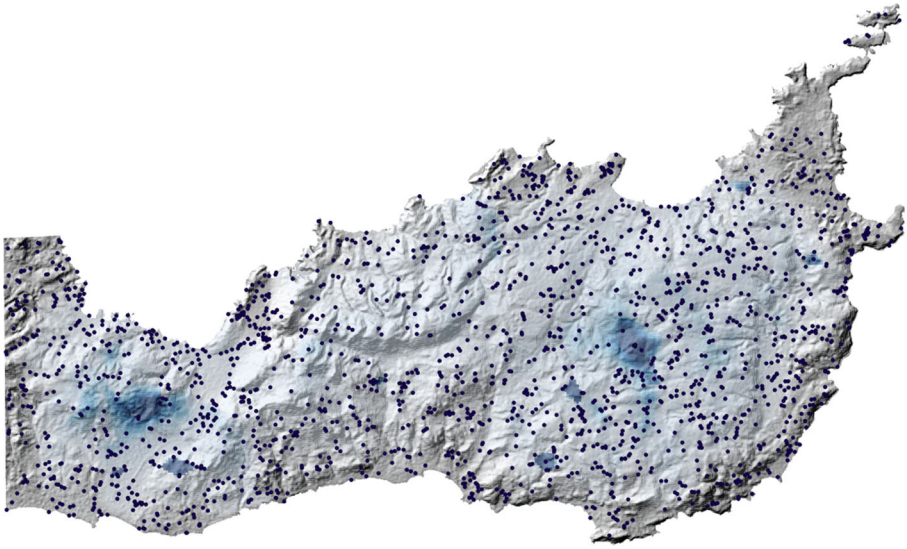

Fig. 3 Modeled distribution of sites in east Crete during Protopalatial period

evidence from material culture distributions that speaks to these changing patterns, it has not been put together in a way that would allow for systematic comparison against these theory models.

Cretan Data Models

Another approach is to develop "data models," which codify data, rather than our beliefs about the world (Rivers 2016, p. 124). These models use data to draw connections between sites, and they are "validated by their ability to describe the data" (Rivers 2016, p. 124). So, the patterns in the material culture we just mentioned would then be the basis for linking sites together. What we will now see though is that, although there is a lot of data, there has been hardly any work to create data models in the sense conveyed by Rivers, and as done successfully elsewhere, such as in the Southwest Social Networks Project (Mills *et al.* 2013; these are what Mills 2017 would call "material networks").

For Bronze Age Crete, well over a century of excavations has created an abundance of finds from many sites across the island. While initially the focus understandably fell on the larger and more conspicuous urban palatial sites, such as Knossos, Phaistos, and Malia (Fig. 2), over time a range of smaller village sites have also been explored. With the addition of survey data over the last few decades, we now possess a relatively full picture of the Cretan settlements in the Bronze Age, though of course many lacunae do still remain. What we also have is a reasonably good handle on the changes through time, from the beginning to the end of the Bronze Age, some two millennia. With the focus in this paper on the Proto- and Neopalatial periods, there are particular patterns we may highlight. The Protopalatial period (MM IB–IIB, c. 1925–1750 BC) sees the construction of palaces at the three main centers just mentioned—Knossos, Malia, and Phaistos—with other sites seemingly growing

in size and complexity too. While the architectural evidence is not all that good for this period, we can say that these palaces share a number of features, such as orientation, internal organization, and details of construction—to the extent that scholars usually imagine close connections between them, characterized by Cherry (1986) in terms of "peer polity interaction." That is to say, architecture emerged as a medium for competitive display among these centers. The strong connections between different centers are apparent in other areas too, such as pottery production. The introduction of the potter's wheel at the beginning of this period is quite thoroughly distributed between these centers, and indeed at many smaller sites too (Knappett 1999a; Jeffra 2013). Other close similarities are seen in the pottery forms themselves, with most types of drinking and pouring vessels, storage wares, and cooking pots quite similar in functional and morphological terms from one site to another (Betancourt 1985). One might also point out commonalities in other domains, such as the habit of using caves and peak sanctuaries for religious worship, seen across the island (although not in the far west); as well as figurines, burial customs, *etc*. In short, there is a very coherent "culture" that is surely the result of a series of communities of practice that are sustained by multiple local "triads" with dense connections (see Blake 2014 for an archaeological enquiry into local triads).

On the other hand, archaeologists do also recognize that the Protopalatial period is marked by quite pronounced regionalism. So, even though communities of practice seem to stretch across the island, some regions differentiate themselves through their material culture (and presumably other means that elude us archaeologically). Although in the drinking vessels, for example, pretty much all sites use carinated, hemispherical, and straight-sided cups, we observe pronounced differences in their stylistic details. For example, straight-sided cups in the Lasithi region (Fig. 2) may be decorated in the "tartan style" (Fig. 4), as identified at both Malia and Myrtos Pyrgos (Knappett 1999b; Poursat 2010; Cadogan 2013); yet if one were to find this style at Phaistos or Knossos, for example, it would stick out like a sore thumb.

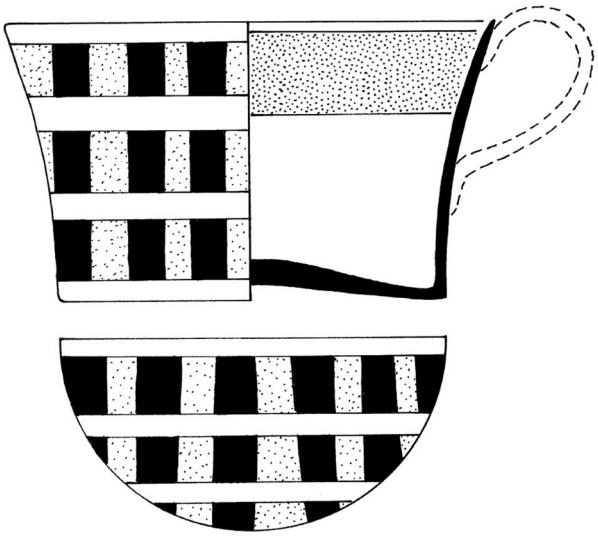

Fig. 4 a Minoan straight-sided cup with a distinctive decorative style from east Crete

Likewise, this Lasithi region sees many bridge-spouted jugs in their pouring vessels, whereas at Knossos, the preference is for bridge-spouted jars (*i.e.*, two handles rather than one). There is also regionalism in storage wares such as pithoi (Christakis 2005). Other categories of material culture display quite clear regional patterning too. Sealstones, for example, are quite different in east Crete and the Mesara (Anastasiadou 2016). Administrative scripts show regional differences too, with Linear A more common in central Crete and Cretan Hieroglyphic in the east (Olivier 1986; Schoep 1999). Both center and east have built tomb structures, but in the Mesara they are round (tholoi) and in the east they are square or rectangular (Legarra Herrero 2014). In terms of stone vase production, Morero notes that it is difficult to pin down clear-cut regionalisms, though there are certainly regional tendencies (Morero 2016, p. 31). The Protopalatial period also sees some regional variation in locales of religious devotion—though peak sanctuaries do seem to spread across much of the island, probably from an initial foundation at Juktas close to Knossos (Fig. 2), there are some areas of resistance or reluctance, such as at Malia, Phaistos, and in the far west (Nowicki 1994, p. 40). These differences do not detract from the idea of tight communities of practice in local clusters as, in order for these differences to work as clear indicators of identity, a high level of contact and communication must be sustained. All islanders seem, for example, to be making and/or using straight-sided cups in very similar ways—notwithstanding subtle variations as markers of identity.

This recognition of regional variation has also recently been matched by an acknowledgement of temporal variability. The Protopalatial period is not unchanging from beginning to end, and can be broken down into three phases, Middle Minoan IB, IIA, and IIB. The end of the Protopalatial does seem quite different from the beginning—hardly surprising given that it spans nearly two centuries. What we can now see with increasing clarity is that these regional distinctions are mostly visible in MM IIB, toward the end of the period, much more so than at the beginning (Knappett 2012). Perhaps, then, these changes are a response to shifting circumstances that anticipate what transpires in the Neopalatial period. Is it that the local clusters are already under threat from more far-flung connections, as the benefits to be gained from regional coastal trade become more apparent? Are more pronounced regional identities a response, by the palace at Malia, for example, as it sees its authority being gradually eroded by Knossos?

Whatever forces are at work through the course of MM IIB, the end of the period is marked by a series of site destructions, perhaps best exemplified by the Quartier Mu building complex at Malia (Poursat 2010). Although there is rebuilding at most sites that suffer, it seems that in the immediate aftermath the political landscape has been transformed. This is when Knossos really seems to come to the fore as a primary palatial center, with Phaistos and Malia receding somewhat in importance (Macdonald and Knappett 2013). The changes in material culture are quite striking too. A series of architectural innovations, such as the use of timber in conjunction with ashlar masonry and more articulated planning (Tsakanika-Theochari 2006; Letesson 2014), appear first at Knossos, before quickly spreading across much of the island in both palaces and "villas" (Hägg 1997). These impressive new buildings are also often now adorned with figurative scenes in fine painted plaster, again an innovation that seems to seed first at Knossos (Hood 2005). Particular forms of iconography are associated with this site, such as bulls and bull-leaping scenes (Hallager and Hallager 1995). This bull

iconography is not confined to wall painting but is also witnessed in seals and gold finger rings, another category of material culture transformed by this new figurative emphasis. Seals are still very much used for bureaucratic sealings in administration, though now there is only one script in use, Linear A having survived while Cretan Hieroglyphic disappears (Schoep 1999). Pottery shapes and styles now are shared more uniformly across the island, with one new type, the conical cup, becoming quite standardized and repetitive by LM IA (Wiener 2011; Knappett and Hilditch 2015). In decorative styles, tortoiseshell ripple is one innovation that does seem very widely shared, while others such as medallion spirals and reed patterns are also quite broadly distributed, in ways that were not seen in the Protopalatial period. At the same time, the thorough sharing of technological learning carries on as in the earlier phases, though now there is far less regionalism and more homogeneity across the island, as for example in stone vase production (Morero 2016, p. 32). As for burials, it is quite difficult tracking regionalism or lack thereof, as they suddenly become quite elusive in the Neopalatial period (Devolder 2010; Girella 2015). It is not entirely clear why the burial evidence now is so lacking. There also appear to be changes in religious expression: where previously there were multiple peak sanctuaries across central and east Crete, most of these go out of use, except for a select few, such as Juktas and Petsophas (Fig. 2). It also seems that female deities are now more readily rendered iconographically, where previously depictions of deities had been all but absent (Driessen 2015).

Basically, the degree of regionalism diminishes significantly in the Neopalatial period, and this change seems largely triggered by the unprecedented concentration of power at Knossos. But what were the conditions that enabled this kind of pan-Cretan communication, such that the island acted almost as a single large community? Surely, this would not have been entirely possible with a dominant network structure of local triads with high transitivity? We face some challenges in trying to identify what these changes might imply in network terms. The sharing of many cultural features island-wide in the Protopalatial period demonstrates that pan-Cretan communication was perfectly possible earlier. But did the structure of inter-site communication act as a barrier to the dominance of any one center? Was the growth of urban coastal communities in the Neopalatial period a move that helped a center like Knossos promulgate its ideology more thoroughly? Or would this have actually been perfectly possible in the Protopalatial period too?

Ideally, scholarship would have already identified the need for a quantitative approach to this problem, with data models developed to test the extent to which regionalism or pan-Cretanism is enabled or hindered by the structure of social networks. Some efforts have been made to at least map the distributions of different material culture traits, as Driessen did, many years ago now, for architectural styles in the Neopalatial period (Driessen 1989–1990). The argument that Haggis (2002) put forward for changes in settlement structure between the Proto- and Neopalatial periods evoked network structures in a very simple though effective manner, but this is more in line with a theory model than a data model, as his connections between sites are hypothetical rather than based on any analysis of material culture data. Thus, we are in a pretty poor state when it comes to data models for exploring the relative contribution of communities of practice and networks to the sociopolitical structure of Bronze Age Crete. We can speculate that the profound sharing of many forms of material culture

across the island in the Neopalatial period was encouraged by a Knossos-led hierarchy promulgating increased trade, facilitated by the proliferation of urban settlements in coastal locations (with maritime connectivity more cost effective than land transport). But we do not at present have anything even remotely resembling a data model, in which connections between sites might be drawn based on a quantification of their shared material culture. The theory models outlined above give us some possible hypotheses to explore, and they seem in line with what the data indicate, albeit only qualitatively at the moment.

Aegean Theory Models

Moving beyond Crete to the wider Aegean (Fig. 1), spatial interaction models have also been put into play at this scale in efforts to understand likely interactions between sites, given certain costs and benefits of entering into trade relations or not. The principal goal has been to establish why a site in a position like that of Knossos may become central in such networks, how sites in other regions may have connected with Crete, and what the overall network structure might have been (*e.g.*, Knappett *et al*. 2008, 2011). The basis for the spatial interaction models on Crete versus the wider Aegean are somewhat different (see Rivers *et al*. 2013; Evans 2016), but at a basic level they are still theory models—with connections between sites drawn on the basis of spatial distances and gravity assumptions, rather than similarity measures of finds data from the sites.

What these models for the Aegean have been principally concerned with is providing some explanatory network basis for Minoanization. During the Protopalatial period, various sites across the Aegean are certainly in contact—imports from Crete have been found on Cycladic islands, at sites in coastal Anatolia, and in the Dodecanese. These contacts seem to have relatively little impact on local cultural practices. However, the picture changes in the Neopalatial period, when Minoan cultural practices are now adopted across the southern Aegean, although by no means uniformly. If we think of these two scenarios in network terms, then we can perhaps imagine a small-world structure for the Protopalatial period—strong ties within clusters but a handful of weak ties between clusters that do enough to enable a relatively restricted trade between areas (Fig. 5). For the Neopalatial period though, with its complex contagion (*i.e.*, sharing of complex cultural practices), we must imagine different network dyads and topologies, as the weak ties of small worlds cannot sustain the transmission of complex behaviors (Centola and Macy 2007). This degree of sharing would have required wide bridges, which are anything but weak ties (weak, in relational, not structural, terms). However, using "ariadne"—a program devised by Tim Evans in conjunction with Ray Rivers and the author to model interactions between Bronze Age sites across the Aegean—we can suggest that on a regional scale networks with weak ties between clusters are relatively stable, while those with strong dyads are unstable—because these are connections that are costly to maintain (Knappett *et al*. 2011). Which raises the interesting possibility that the wide bridges over some distances that made Minoanization possible may also have created structurally weak networks. This feature would make them susceptible to perturbation, which arguably comes in the form of the Theran eruption, potentially increasing the costs of links still further (see Knappett *et al*. 2011).

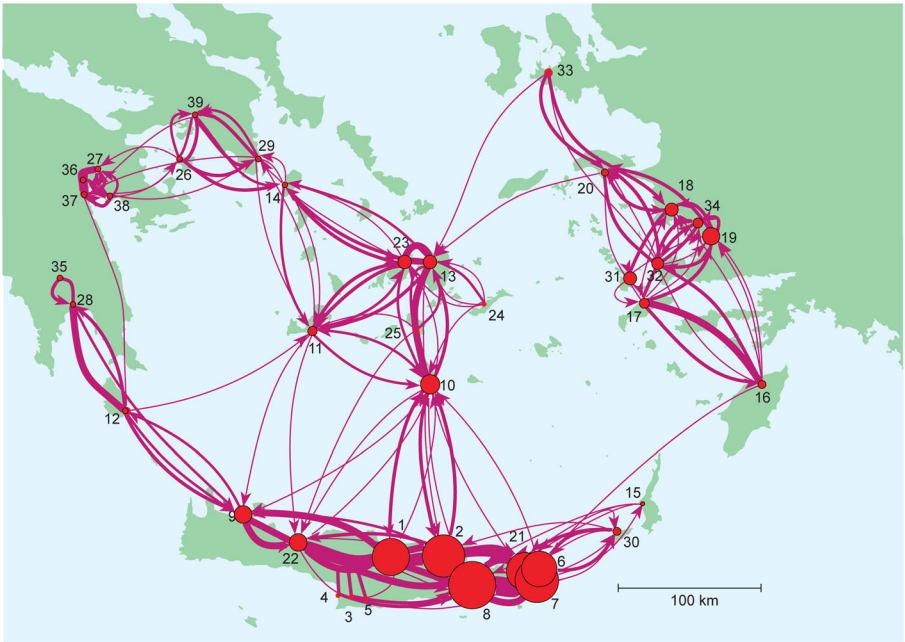

Fig. 5 Hypothetical small world network in the Aegean during Protopalatial period

Yet, testing of these models against the data in a systematic way is not at present possible. As we shall now see, the data have never been assembled in a format that would make them amenable to such testing.

Aegean Data Models

A number of relatively well explored, if incompletely published, sites are known from across the southern Aegean—Akrotiri on Thera, Phylakopi on Melos, Ayia Irini on Kea, Kastri on Kythera, Kolonna on Aegina, Trianda on Rhodes, Seraglio on Kos, and Miletus and Iasos in Asia Minor (see Fig. 1). To these we may add other less well-known sites, such as Tavşan Adası (Bertemes 2013), Çeşme – Bağlararası (Şahoğlu 2015), and Mikre Vigla on Naxos (Barber and Hadjianastasiou 1989). These sites may not rival the largest contemporary sites on Crete, or have palatial centers, but some are quite substantial, with Trianda on Rhodes estimated at 15 ha (Whitelaw 2001, p. 29), and Akrotiri on Thera at anything between 10 and 30 ha (Palyvou 2005, p. 27). During the early and middle part of the Middle Bronze Age (MBA), such sites do show signs of their interconnectedness, with modest ceramic imports (as mentioned above). Yet, they maintain their own regional cultural identities, with sites in the Cyclades, for instance, quite distinct in their material culture from other regions, as is the case for sites in the Dodecanese and Asia Minor. The only exception is Kythera (Fig. 1), which already from the Early Bronze Age is strongly connected to and influenced by Crete (Broodbank and Kiriatzi 2007). While, Kythera apart, we mostly only see quite low levels of trade connection among these various sites, there are some indications of a more thoroughgoing contact already in this period, with Ayia Irini on Kea showing in

phase IV (*i.e.*, equivalent to the Protopalatial period) signs of the use of the potter's wheel and the warp-weighted loom, suggesting the presence of some Cretan artisans, which is not to say that the whole community was "Minoanised" (Abell 2016, p. 76). Kolonna on Aegina too sees the use of the potter's wheel for Minoan-type pottery during phase I, which seems to overlap with MM II on Crete (Gorogianni *et al.* 2016, p. 200; Gauss and Kiriatzi 2011, p. 177). And at Mikro Vouni on Samothrace, in the northern Aegean, Minoan pottery shapes are imitated, Minoan-type loomweights are introduced, and there is even the use of Minoan administrative systems, with roundels and nodules (Girella and Pavúk 2016, p. 19).

However, in the latter part of the MBA, and into the early LBA, the picture changes significantly. Not only do the quantities of ceramic imports (especially from Crete) increase dramatically, but we begin to see more extensive cultural sharing, with the main pattern being the influence of Cretan practices across the wider area. This is true both in consumption and production practices. In terms of the former, the appearance of tripod cooking pots and "souvlaki stands" hints at the uptake of Minoan cooking practices, while various kinds of pouring and drinking vessels also suggest shared commensal customs, with the proliferation of conical cups particularly conspicuous (Wiener 1984; Knappett and Hilditch 2015). The decorative motifs employed on the fine wares increasingly draw from a Cretan repertoire, with tortoiseshell ripple being one decorative style that seems favored. This has implications for production too, as it is local potters who, in many cases, learn how to apply these new motifs. Tortoiseshell ripple is quite difficult to perfect as a decorative motif, as the blurring of the lines to create the ripple effect seems to be achieved by burnishing the painted surface while still slightly wet. At Akrotiri on Thera, for example, some potters seem to have pulled this off successfully, while others did not (Knappett and Nikolakopoulou 2008). So, this decorative style was not just a look that could be seen and then mimicked—it required some technical know-how. This was all the more so for more complex technical skills, not least the use of the potter's wheel, the adoption of which in the Cyclades at this time surely points to a deep connection with Cretan craftspeople. Cycladic potters were not using this technique at all in the MBA, but some potters on Thera do now start to adopt the technique for some wares, specifically those that mimic Cretan shapes (Knappett and Nikolakopoulou 2008). The wheel technique is not something that can be just seen and copied—it typically requires a long apprenticeship to learn. The adoption of this technique is a "complex contagion" that must have required a "wide bridge" for its transmission.

This is not the only Cretan technology that is transmitted beyond the island. Detailed analyses of loomweights from Minoanised sites across the southern Aegean have shown the adoption of the warp-weighted loom, a Minoan technique for making fine textiles (Cutler 2016). Administrative techniques are also taken up, with the Linear A script found in the Cyclades at Akrotiri, Phylakopi, and Ayia Irini (Karnava 2008), and in coastal Anatolia at Miletus (Niemeier 1996; Del Freo *et al.* 2015); while a cache of 70 sealings imported from Crete was also discovered at Akrotiri (Karnava in press), and nodules and roundels on Samothrace (Girella and Pavúk 2016). Furthermore, architectural innovations are adopted at various locales, such as at Akrotiri, where Xeste 3 has pier-and-door partitions and a lustral basin that are clearly of Cretan inspiration (Palyvou 2005), and at Ayia Irini on Kea, where both House A and the North-East Bastion are considered to have Minoan features (Fitzsimons and Gorogianni 2017).

The fine lime plaster used as the support for figurative wall paintings is also a Cretan innovation that spreads across the Aegean (Boulotis 2000; Nikolakopoulou and Knappett 2016), with frescoes most famously at Akrotiri of course (Doumas 1992), but also at Phylakopi, Ayia Irini, and Miletus (Morgan 1990; Niemeier 2005). Stone vase production is another technology that undergoes changes that are heavily influenced by Cretan techniques (Morero 2016, p. 229). All of these techniques—from methods of weaving, to writing script, to building, making lime plaster, and carving stone vases—require quite specific skills that would not have been easily learnt. Their successful learning and adoption would surely have required considerable technical and social support, of the kind that would surely only have been available through the extension of communities of practice beyond Crete.

Although we thus clearly have a plethora of new information on the complex contagions that constituted Minoanization, we have nothing approaching a data model. The closest we have are distribution plots where the data are reduced into a schematic form—while these are useful (see Fig. 6, after Niemeier 2005, fig. 23), they do not take us very far toward a quantifiable data model. Much of the information we have is incomplete, pending full publication; and with excavations conducted over many decades, to wildly differing standards, and in different languages too of course (Greek; German; Italian, English; French), the challenges for some kind of harmonizing of data ontologies are considerable. Currently, we are a very long way from being able to link up sites in a quantitative manner using data and then measure centrality, network topology, *etc*. At the moment, we have traditional debates between colonization and acculturation, but no real possibility for testing one hypothesis against another in terms of quantified data patterns.

Synthesis

There are many levels of synthesis required. First, we need to bring together theory models for Crete with those for the Aegean. Currently, they are largely separate. Second, it is essential that we align the Cretan data with the Aegean data. Scholars do intuitively compare the two when thinking about Minoanization, but the data should really be compiled in a way to allow for ready quantification in network data models. Third, and perhaps the greatest challenge, we might then attempt to compare and contrast the theory and data models across Crete and the Aegean (see Rivers 2016), which would allow us to more fully grasp the dynamics of *mobility* in relation to *connectivity*.

Why should we attempt these syntheses? As long as we think that the political geography of Crete on the one hand, and Minoanization on the other hand, are two separate problems, then perhaps there is no pressing need to align the data or theory models for the two areas. Yet, the changes on Crete in the Neopalatial period, with greater centralization of power at Knossos and enhanced coastal mobility between urban centers, do seem to coincide very closely with the expansion of communities of practice beyond Crete to the wider Aegean area—in the process becoming *constellations* of practice. If these phenomena are connected in some way, then we should probably be treating the data from both holistically.

However, while some progress has been made on the theory model front, the data models lag far behind. Their utility has been strongly demonstrated in other regions, not

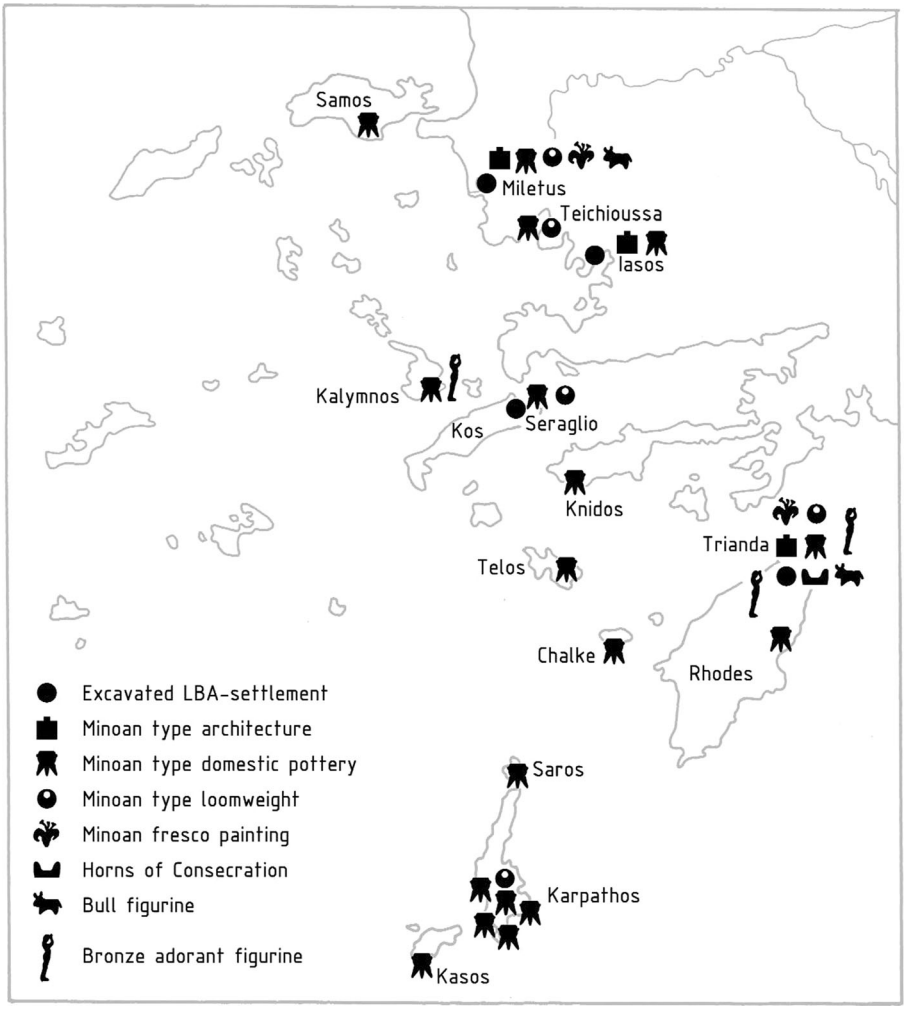

Fig. 6 Distribution of Minoanizing finds in Southeast Aegean (after Niemeier 2005, fig. 23).

least the US Southwest (Mills *et al.* 2013). But, theory models have not seen much testing against data models (though see Östborn and Gerding 2014; Crabtree 2015). If we could put the pieces in place and move toward such testing as a priority, then the Aegean Bronze Age would make an excellent case study for the investigation of the network dynamics of communities and constellations of practice (as would other ancient globalizations, such as Romanization). Then we would be able to move toward a position wherein networks are not artificially designated as a regional phenomenon, and communities of practice as solely local (see Mills 2016 on constellations of practice).

So, pending this kind of holistic study, what can we say currently about Minoanization in network terms? On the one hand, wide bridges were surely necessary for the kinds of complex contagion that characterize Minoanization. On the other hand, the distances involved are quite considerable, with some links presumably costly in terms of the investments required for travel across > 100 km of sea (and Samothrace is some 570 km from central Crete). If some degree of exchange was necessary across the

wider area for securing access to key resources (and information about their changing availability), then it might have been sufficient to maintain relatively weak links, which should not have been too costly. In small-world networks, it is these links that, despite their relational weakness, can be structurally strong (Granovetter 1973; Centola and Macy 2007). What, then, would possess communities to throw wide bridges across long distances when they are costly, and potentially contributory to network instability (Knappett *et al*. 2011)? Either the benefits must have appeared to far outweigh the costs, or perhaps the costs were much lower than we assume. What factors might have kept the costs of wide bridges down? One possibility lies in some special features of material culture that emerge at this time. We see the proliferation of symbols such as double axes, horns of consecration, and bulls that had iconic qualities facilitating their recognition and reproduction across time and space. These features form part of a wider "objectification" in Neopalatial material culture (Knappett 2011). Perhaps such symbols helped create a "koine" of sorts that served to limit communication costs over distance. And what if they were all tied up with Minoan religion? Could we then argue that it was the sharing of religious practices that had the effect of reducing distances between communities? The evidence from Miletus is especially suggestive, where the excavations uncovered a sanctuary complex with several fixed altar platforms and plaster offering tables from phases IIIb to IVa, *i.e*., the early Neopalatial period (Kaiser and Raymond 2015; Raymond *et al*. 2016, p. 60). The site of Ayia Irini on Kea also has a temple from the Late Minoan IB period with c.40 large female figurines, some life-size (Caskey 1986). As an interesting aside, Barbara Kowalzig argues that for later Greek colonization—with strong ties over wide areas—it is religion that provides the glue, enabling and encouraging otherwise risky/costly ties (Kowalzig 2018).

If we are to imagine Minoanization as at least in part a religious phenomenon, then should we rethink our theory models? Our underlying assumption in the ariadne theory model was that it was the search for metals that drove the network dynamics—*i.e*., a trade/exchange model. It has been criticized recently for not taking into account transitivity (Amati *et al*. 2017). But why should trade require transitivity? If, however, we think that the dynamics may have been in some part driven by other concerns, such as religious adoption, then we might have a justification for changing the terms of the model—if we think that religious transmission was more likely to require transitivity, which we very well might if we accept that when there are risks and costs in participation, then reinforcement is often necessary (Centola and Macy 2007, pp. 729–30). A further point we might then consider is a comparative one—if this "globalization" is some mix of trade and religion, then how do other globalizations compare (Hodos 2017; Knappett 2017)? Would we expect to see similar network structures in Mycenaeanization, Romanization, or Hellenization, if we think that they were potentially driven by some of the same network requirements? What are the effects on network stability over time? Are all such networks with dense ties somehow fragile, without some means to mitigate costs?

Finally, to reiterate, an approach combining theory and data models in the ways outlined enables us to think about the relative structural strength of southern Aegean connections *in the context of* local ties. It also puts us in a much better position to understand Minoanization as a decentered, multi-sited process emergent over time in which the connective potential of the southern Aegean is actualized in particular patterns of human mobility.

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