CHAÎNE OPÉRATOIRE, TECHNOLOGICAL NETWORKS AND SOCIOLOGICAL INTERPRETATIONS

Cadena Operativa, redes tecnológicas e interpretaciones sociológicas

VALENTINE ROUX *

ABSTRACT In this paper, I first argue that technological analysis of archaeological assemblages in terms of *chaînes opératoires* is a privileged qualitative approach to reconstruct technological networks, namely networks of socially linked object-makers. This is a first step before explaining dynamic phenomena such as diffusion of techniques or emergence of shared norms at the population level. The second step is to call upon sociological regularities since archaeology alone cannot provide a fine-grained temporal resolution to evaluate how micro-level interactions might have scaled up in changes. In the second part of the paper, I give archaeological examples and illustrate how to use sociological regularities for explaining past dynamics.

Keywords: Technological Networks, *Chaîne opératoire*, Regularities, Diffusion Dynamics, Emergence of Shared Norms, Potter's Wheel.

RESUMEN En este documento, sostengo en primer lugar que el análisis tecnológico de las cerámicas arqueológicas en términos de *Cadenas Operativas* es un enfoque cualitativo privilegiado para reconstruir las redes tecnológicas, es decir, las redes de productores de objetos socialmente vinculados. Se trata de un primer paso antes de explicar fenómenos dinámicos como la difusión de técnicas o la aparición de normas compartidas a nivel de la población. El segundo paso consiste en recurrir a regularidades sociológicas, ya que la Arqueología por sí sola no puede proporcionar una resolución temporal ajustada para evaluar cómo las interacciones a nivel microeconómico podrían haber incrementado en los cambios. En la segunda parte del documento, doy ejemplos arqueológicos e ilustro cómo utilizar las regularidades sociológicas para explicar la dinámica del pasado.

Palabras clave: Redes tecnológicas, Cadena Operativa, Regularidades, Dinámica de difusión, Aparición de normas compartidas, Torno de alfarero.

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* Maison de l'archéologie et de l'ethnologie (MAE), Laboratoire Préhistoire et technologie, CNRS / Université Paris Nanterre, Nanterre.

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INTRODUCTION

In ceramic studies, the *chaîne opératoire* approach is used to reconstruct multiscalar networks linking either the different steps of the manufacturing tasks (provenience studies linking sources of clay material/temper/pigments and vessels), producers (linking those who collect clay material/temper/pigment and those who manufacture the vessels —if distinct—, those who are responsible for one stage of the manufacturing process and others —if distinct—, and/or those who use the same manufacturing techniques), producers and distributors (linking producers and distributors —if distinct—), producers and users (linking producers and users —if distinct—), and users (linking those using the same type of vessels)[1]. However, these technological studies that provide network analyses rarely use formal models, even though the power of social network models for interpreting dynamic social processes is well established (Brughmans *et al.*, 2016; Peeples, 2019).

In this paper, in line with Knappett (2018), I argue that both approaches are desirable, starting with data networks and qualitative network analysis, and pursuing with either network modeling or the use of sociological regularities. The goal is to take benefit from Social Networks Analysis (SNA) to investigate past social processes through the structure of relations among social entities knowing that SNA has convincingly shown its role in the forms of change (Mills, 2017). In typical formal networks, social entities are the nodes and the relations are the edges linking the nodes (Collar *et al.*, 2015). These relations or ties may be different "ranging from economic transactions to shared identities and other affiliations" (Mills, 2017:380). In material network studies, one problem often mentioned is that ties linking nodes are inferred from similarity between objects across, or within, archaeological sites. The underlying principle is that shared similar artefacts express interactions between sites or within sites and, therefore, social relationships (Coward, 2013; Borck *et al.,* 2015; Mills *et al.*, 2013; Östborn and Gerding, 2014). The limitation with this approach is that while, theoretically, any shared trait can indicate cultural interactions, only some traits can help to distinguish different types of connections and to assess the relational structure of social groups (Knappett, 2018). Exchange networks are the most problematic for defining the type of social relations between sites because the presence of a same type of object on different sites does not necessarily indicate how the sites interacted (directly *versus* indirectly) and through which actors (ex. consumers with consumers and/or brokers and/or producers), knowing moreover that the objects themselves may have played a role in the emergence of these exchange networks which can be a result of varied sorts of interactions rather than the expression of

1. It would be difficult to quote all the relevant works on these topics; let us simply cite a recent example of archaeological data from South-East Asia showing how the *chaîne opératoire* approach can be applied to different raw materials (ceramics, stone, glass) in macro-regions to highlight multiscalar networks (Bellina, 2017; Dussubieux and Bellina, 2018; Favereau and Bellina, 2016).

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recurrent directed social interactions (as in the case with boundary objects; on this topic see Mills (2018). Distribution and/or consumption networks, both often conflated under the label of provenance-based networks, is a type of exchange network with sites linked by similar objects whose route of circulation is traced through raw material provenance (Mills 2017:387). They raise the same questions about the type of relationships between sites.

I will focus here on the significant ceramic traits of social affiliation, i.e. traits that indicate that the vessel producers (the nodes) are linked by shared social identity (the edges). As we shall see, these significant traits are technical traits that can testify that the vessels were manufactured by producers belonging to the same social group. They will enable us to draw technological networks, here defined as networks of socially linked object-makers. They answer the basic questions on the nodes and links, what they are and how they structure networks, that is to say the relational and social boundary issue of social network analyses (Knappett, 2013; Mills, 2017; Knappett, 2018). Technological networks could also be called "affiliation networks", but not in the sense given by Knappett, who defines these networks on the basis of "joint participation in daily practices" (Knappett, 2011:105), thus mixing technical and consumer practices. Technological networks include only those producers whose shared know-how signals social links between them.

In the first part of the paper, I recall the principles of the technological approach and its relevance to draw technological networks and carry out multiscalar network analyses. Once the technological networks are reconstituted, past dynamic phenomena can be understood using different approaches. Network modeling is one approach (Peeples, 2019). The analogical approach using the regularities highlighted by Social Network Analysis is another one. In the second part of this paper, I will show how to carry out analogical reasoning and use sociological regularities to explain past social phenomena. Two phenomena are examined: the diffusion of the potter's wheel in north Lebanon and the emergence of common norms among the Late Chalcolithic population in the southern Levant.

THE *CHAÎNE OPÉRATOIRE*: A SIGNIFICANT VARIABLE OF SOCIAL AFFILIATION

A *chaîne opératoire* is a series of actions that transform raw material into finished product (Cresswell, 1976:13). It characterizes technical traditions, defined as "patterned ways of doing things that exist in identifiable form over extended periods of time" (O'Brien *et al.*, 2010:3797). In ceramics, the steps organizing the *chaîne opératoire* range from collecting the raw material to firing the pots. Each of them is likely to be significant of shared social identity. This has been well documented by anthropological and ethnoarchaeological studies (examples in Lemonnier, 1993; Roddick and Stahl, 2016).

Technical traditions equal social groups

Two main rules can explain that technical traditions express shared social identity and therefore equal social groups. The first rule is based on the studies on craft learning in the domain of experimental psychology and movement sciences (influenced by the ecological psychology school and social learning theories which take social interactions into account, i.e. Mezirow, 2009). These studies demonstrate that we always learn only one way of doing things and that way is the tutor's one (i.e. Bril, 2015). More precisely, technical skills are always acquired following a model although learning cannot be reduced to imitation since it involves progressively controlling the mechanical constraints of the technical task through specific, culturally "selected", working postures and movements which are long to master. The tutor who provides the model educates the learner's attention and directs his/her exploratory activities towards the development of efficient skills (Bril, 2002, 2015, 2019, 2018). As a consequence of this social guidance and necessary repeated human interactions, the developed culturally situated skills are in line with the tutor's ones (Bril, 1986, 2018; Ingold, 2001), contributing thus to the reproduction of the tutor's way of doing. The second rule articulates the individual to the group. As we saw, learning to master technical tasks implies to follow a tutor's model. When the craft is carried out at the domestic scale (specialised or not), the tutors are usually selected within one's social group which makes that, "mechanically", the social group (also called "collective") has the same way of doing things and that technical boundaries are superposed to social boundaries whatever the type of transmission, vertical, horizontal or oblique (examples in Roux *et al.*, 2017). Social groups practicing in the same way at the domestic scale may be of different nature (in archaeology, to be determined with the help of archaeological contextual data); however, they necessarily include individuals who are socially affiliated and whose ties are more or less tight (family *versus* non family ties). When the craft is carried out within workshop context, individuals can come from different social backgrounds, but form a professional group, socially identified, who contributes to the formation of technical traditions through transmission of the craft over generations (example of the guilds). This process by which traditions are created explains why they equal social groups, i.e. groups in which a certain way of doing things has been handed down from generation to generation through tutors belonging to the same social group.

Social groups sharing technical traditions are also called "communities of practice" (Lave and Wenger, 1991; Knappett, 2011; Knappett and Kiriatzi, 2016:12; Roddick and Stahl, 2016). The concept of "communities of practice" describes how group identity is created or reified through common practice and regular interactions (Wenger, 2000). In Lave's word: "participation as members of a community of practice shapes newcomers' identities and in the process gives structure and meaning to knowledgeable skill" (Lave, 1991:74). In other words, this concept of "community of practice" literally mean communities of individuals who practice together and whose common practice makes them a community (Lave and Wenger, 1991). In this regard, such a concept is a mechanism, a process that generates the regularity linking ways of doing and community identity. In archaeology, epistemological studies underline that validatable interpretation of archaeological data calls upon regularities and not the mechanisms that generate and explain them (Gallay, 2011). Hence the choice to interpret ancient ceramic traditions in terms of social groups/ collectives rather than “communities of practice” even though, from the archaeologist’ view point, it is a convenient expression conflating the mechanism and the regularity (communities defined by their common practice across time).

Forming technique matters

Let us first recall that ways of forming vessels are to be described in terms of techniques, methods and tools if one wants to capture its cultural dimension (Roux, 2019a). Techniques are the physical modalities according to which raw material is transformed. Method is the way techniques are carried out during the process of transforming the raw material. It is an ordered sequence of functional operations carried out by a set of elementary gestures for which different techniques can be used. The same intention (for example to obtain pots with thin walls from base to top) and the same object (a jug) can be obtained with different techniques (handmade *versus* wheel made) and different methods (ex. wheel throwing in one *versus* two stages). Techniques are in limited number and can be the object of convergence. On the contrary, methods are theoretically infinite and more likely to be specific. The combination of techniques and methods reveals cultural solutions to universal physical constraints, distinguishing between traditions linked through the transmission of information, and convergent solutions to specific situations (Shennan, 2002:73). These cultural solutions are distributed across time and space. They are at the heart of technical traditions which can include different ways of making pots depending on their shapes. They can be identified on ancient ceramics by conducting macro-, meso- and micro-observations (Roux, 2019a).

Now, each step of the *chaîne opératoire* can be perpetuated or modified independently of each other (Gosselain, 2008). Among them, the way of forming vessels is the most stable. Its temporal stability is well attested in archaeology (examples of stability expressed through phylogenetic links between forming traditions over more than 2000 years in the Sahel (Mayor, 2010), in the southern Levant (Roux, 2019) or in Taïwan (Wu, 2012). This can be explained by three factors: a) they are not subject to evolution through copy and error (even though motor skills are subject to copy-and-error as expressed by the morphometric variability of vessels within the same technical tradition (Gandon *et al.*, 2014); b) their mastery requires long repeated direct interactions (Bril, 2015) within one’s own social group (Roux *et al.*, 2017); as a result, the motor and cognitive skills are embodied and not likely to change through mere contacts with other traditions (Gosselain, 2000); c) at last, they are not subject to be modified at the request of consumers who play a major role in the evolution of ceramic production, but mainly in that of visible features (shapes, color, decoration of finished products). This temporal stability of the forming traditions makes them a privileged variable for assessing producers' social affiliation.

In contrast, the other steps of the *chaîne opératoire*, although they may be significant of social affiliation, especially when combined with each other, are less relevant variables if considered independently of the forming techniques. Indeed, they are less constrained by the learning and transmission mechanisms and therefore more likely to change through direct and/or indirect interactions, adaptation to changing environment and consumer's demand. Thus, operations such as clay preparation or decoration, once mastered, are easier to change than forming techniques because they do not entail to learn (or de-learn) new motor skills. Moreover, they are more exposed to change through direct transmission (they can be carried out outside one's own social group (examples in Gosselain, 2008) and/or indirect transmission through brokers or circulating pots (example in Roux, 2015). Even though they can be significant of social affiliation (examples of clay recipes which follow the same pattern than forming techniques across place and time indicating social boundaries), their interpretation in terms of social ties may therefore not be straightforward and will depend on contextual data. In other words, linking socially two pots made with the same clay material or with the same decoration will require further arguments, unlike forming technology (when described in terms of techniques and methods) that univocally indicates potters' social affiliation across space and time.

Chaînes opératoires and social networks

Let's now consider three situations. In the first situation, technical traditions are distinguished from each other on the basis of all stages of the manufacturing process. In this case, similar technical traditions distributed at the local, regional and/or macro-regional scale signal actors (object makers) who are socially related, because of the learning and transmission rules discussed previously. Conversely, dissimilar technical traditions at the local, regional and/or macro-regional scale signal actors who are not socially related. Accordingly, the ties linking the nodes can be qualified as strong or weak: strong ties represent "marked or close relationships such as marriage, descent, or close friends, and/or membership in the same subgroup" (Mills, 2017:388). "Weak ties describe infrequently accessed connections (acquaintances)" (Collar *et al.*, 2015:23). Ties can also be long- or short-distance, depending on their spatial distribution. Combining relational (strong or weak ties) and geographical distances (short or long) allows to acknowledge a wide range of possibilities: strong short-distance ties draw the boundary of a clustered social group; weak short-distance ties link distinct social groups co-existing spatially or living close-by. Conversely strong long-distance ties describing similar technical traditions practiced in distant places, link socially individuals/groups living in remote places. They testify to the move of artisans at a certain period of time. Indeed, on the one hand, a whole *chaîne opératoire* cannot be adopted through indirect contacts —learning necessitates direct interactions while finished products do not provide *per se* information on forming technology—; on the other hand actors may adopt exogenous techniques through direct contacts, but never the whole *chaîne opératoire* except in very rare cases attesting to the adoption of a new technical system in order to change status (Gosselain, 2011). Weak long-distance ties link distinct social groups living far away and having infrequent relationships.

The second situation describes the use of a same *chaîne opératoire* for different types of finished products (different shapes/decors) depending on places. It expresses different intentions of the artisan which may vary depending on the consumers' demand. Indeed, finished products refers to the consumers' sphere and not to the producers' one. It follows that new shapes or new decorations can be adopted given new demands or new consumers. Thus, when producers belonging to the same social group live far from each other, the respective consumers may require different types of finished products, which will, however, be made with the same *chaîne opératoire*. In this case, the similarity of the ways of doing testifies to the social relationship of the artisans. The frequency of interactions is potentially visible in the similarity of the shapes, and the links between producers can be weighted accordingly. In other words, in the case of strong long-distance ties, suggesting that producers are socially related, the frequency of interactions may vary and can be measured against the morphological and stylistic traits of the vessels; the edges linking the nodes can be weighed accordingly.

In a third situation, only forming technology may distinguish between technical traditions. Indeed, *chaînes opératoires* are not "closed package" as outlined by Gosselain who insists that they are made of components which can be modified through encounters with other practitioners (Gosselain, 2011:219). This explains that one does not always come across contrasted technical traditions. There are "hybrid" cases as exemplified by one case often met: only some stages of the *chaînes opératoires* are similar; for example, the preparation of the clay material and/or the surface treatments and/or the firing technique may differ, while the forming technique and method may be the same. Here, a major statement is that any technical tradition evolves in the course of time. In order to analyze the type of ties linking "hybrid" *chaînes opératoires*, a diachronic perspective is required and their evolution described or modeled through approaches like the cladistic one (Manem, 2020). This approach amounts to reconstruct technological lineages through phylogenetic trees across time and space. Ancestral and derived traits are highlighted. In the domain of ceramics, the forming techniques and methods are potential ancestral traits whose stability on the longue durée is well attested given the favourable conditions mentioned above. In contrast, operations such as clay paste preparation or surface treatments which are likely to evolve more rapidly are the derived traits. On the basis of these phylogenetic trees, "hybrid" *chaînes opératoires* can be socially linked through the transmission of shared ancestral traits (forming techniques and methods), indicating descendants from a same social group (ancestral kin ties) while, at the same time, derived traits indicate differential evolution process across time and space. The main outcome is that when studying "hybrid" *chaînes opératoires*, the links between the nodes (potters' ceramic tradition) can be assessed in terms of social affiliation and weighed with time parameters.

A last point is that, in social network analysis, assessing connections between producers implies not only to assess similarity between their way of doing and qualify ties as strong or weak, but also to examine the embeddedness of the network ("the degree to which a node or subgroup is tied to other nodes or subgroups in the network", Mills, 2017:389). A qualitative approach to embeddedness is the complexity of archaeological assemblages at the macro-regional scale: they can be homogeneous *versus* heterogeneous depending on the number of *chaînes opératoires* involved (clay provenience is here a major variable). This complexity depends on the function of the sites (ex.: settlement *versus* shrines *versus* gathering sites) and accordingly testify to movements of individuals between sites and social interactions (Roux, 2019a). In a macro-region where sites are recognized as epicenters of interactions, these sites indicate strong network embeddedness.

In sum, technical traits, namely the whole *chaîne opératoire* or salient traits like the forming techniques, alone or combined with other traits such as the clay preparation and/or decoration, are robust qualitative variables to infer and draw technological networks and their boundaries with nodes corresponding to object-makers (potters' technical tradition) and edges to social affiliation ties (strong *versus* weak ties combined with short- *versus* long-distance ties). These links can be drawn independently of a fine time synchronization because two objects made the same way indicate, whatever the time slice, that the same technology has been transmitted through generations within the same social group (since as a rule learning takes place within one's social group). Technical traits are also robust variables for evaluating interactions among object makers and therefore their degree of embeddedness (quantification of interactions between actors, Borck *et al*. 2015:37). At last, the direction of interactions can also be specified, either in the case of centrality of sites, or movements of object-makers or influence between actors linked by weak or strong ties.

As said in the introduction, reconstruction of technological network and network analysis are only a first step. The second step aims at explaining evolutionary phenomena such as diffusion of cultural traits or emergence of shared new norms. However, archaeology alone cannot provide a fine-grained temporal resolution to evaluate how micro-level interactions might have scaled up in changes (Roux and Manzo, 2018). In contrast, the scope of SNA is to assess through quantitative/computational studies how changes are generated depending on network properties (how individual interactions generate change depending on the structure of the network into which these interactions take place). The results obtained provide regularities, also called invariants, stating the conditions for the actualization of change. As we shall see, when applied back to archaeological data through analogical reasoning, these regularities succeed in explaining evolutionary phenomena in terms of social facts.

EXPLAINING ANCIENT EVOLUTIONARY PHENOMENA BY REFERENCE TO SOCIOLOGICAL REGULARITIES

Epistemological analyses have well shown that archaeological interpretation inevitably consists in drawing an analogy between archaeological data and referential data, and then transferring the attributes of the referential data, namely the regularities, to the former (Gardin, 1980; Gallay, 2011). Regularities (also called models) are recurrent attributes linking objects and meaning. Their context of validity corresponds to the conditions of their occurrence. In the domain of technology, these regularities link diagnostic traits and *chaînes opératoires*, techniques and technical skills, technical operations and quantitative data (ex. duration of work), technical traditions and social groups, and dynamic phenomena with social network structures.

Within the framework of this paper, I will use three sociological regularities stating that initial borrowing of techniques requires weak ties and expertise, diffusion of techniques requires strong ties and inventor's consistent behavior, and emergence of shared norms without large-scale coordination requires homogeneous mixing population. The mechanisms generating them have been tested, simulated and verified against empirical data by SNA studies. In particular, these studies have used simulations to test the different conditions into which micro-level interactions have scaled up in changes; some of them have tested the relevance of the results obtained against empirical data (Manzo *et al.*, 2018). Future studies can modify the results obtained but one expects the conditions for generating the regularities to be completed rather than to be demonstrated as wrong (Gallay and Gardin, 2009). In this regard, they can be considered as "provisional" regularities. Meanwhile, their use in archaeology enable us to explain the evolution of material culture patterns. As a first step, ancient network properties (ex., weak *versus* strong ties, homogeneously mixing population *versus* heterogeneous population) have to be highlighted; it involves a qualitative technological analysis of the archaeological material for drawing qualitative data networks. As a second step, the sociological regularities linking network properties and dynamic phenomena can be used if analogous situations are observed. They help us to explain why specific networks have favored the evolutionary phenomena seen in the material culture patterns, here the diffusion of the potter's wheel in the central Levant, and the emergence of shared norms among Late Chalcolithic heterarchical societies in the southern Levant.

Diffusion of the potter's wheel in the Akkar plain, central Levant

Ceramic assemblages from the third millennium BC from the Tell Arqa site in the Akkar plain in northern Lebanon have been studied using the *chaîne opératoire* approach (Thalmann, 2006; Roux and Thalmann, 2016). Results obtained show that a same technical tradition was practiced at Tell Arqa throughout the third millennium BC and, from 2500 BC onwards, throughout the entire Akkar plain, where settlements began to spread. The temporal continuity and spatial similarity in the technological way of making ceramics such as revealed by the *chaîne opératoire* approach led us to suggest that a same tradition had been transmitted through generations and across places testifying to strong ties between individuals, of the order of kinship. In a network format, the nodes would be the sites with ceramics made the same way; the links connecting the nodes would be strong ties describing relationships of social affiliation (whatever the time slice). The potter's wheel, a major technical breakthrough, started to be used in the first half of the 3rd millennium BC. The type of wheel is Palestinian, used by the Bronze Age inhabitants of the southern Levant (Roux and Miroschedji, 2009). In the second half of the 3rd millennium BC, another type of tournette was used, of Mesopotamian origin, comparable to those found northwards.

What was the dynamic behind the adoption and diffusion of the potter's wheel? As we shall see, sociological regularities will help us in interpreting firstly the initial adoption stage which describes the adoption of new techniques at the individual scale, and secondly the diffusion stage which describes the diffusion of the technique once it has penetrated the group. These two stages are below analyzed successively for explaining how the potter's wheel penetrated Arqa and became predominant in the Akkar plain.

Initial adoption of the potter's wheel

Sociologists have highlighted the importance of weak ties in the diffusion process of cultural traits (Granovetter, 1973). Weak ties are supposed to be far more likely to be bridges than are strong ties, linking otherwise unconnected different small groups (Granovetter, 1983:208). The argument is that weak ties are necessary for new information to spread within closely knit social structures that are otherwise deprived of information coming from distant parts of the social system. Without weak ties, new ideas would spread very slowly. However, as elaborated by Granovetter, all weak ties do not act as bridges. In this regard, what is important is not their numbers, but their likelihood of being bridges, and promote technical diffusion. In this perspective, a study has been carried out recently to test the hypothesis that, as for diffusion of techniques, expertise is necessary for weak ties to act as bridges and new techniques penetrate cohesive social groups (Roux *et al.*, 2018). Experiments have been conducted in the Jodhpur region (India) where potters have adopted gradually the kiln, resulting in a potter population made up of early, late, and/or non-adopters. Numerous variables (finished products, action, and product dynamics) were analyzed in order to assess potters' expertise and assess whether it correlates with potters' adoption behaviours. Experimental results show that early adopters have better results than late adopters, adapting more effectively to new situations. This adaptation reflects a better understanding of the properties of the techniques: individuals assess technical tasks not in light of their cultural representations, but in light of a cost-benefit analysis leading them to perceive their advantages. Because this mechanism generating potters' behavior respond to cognitive universals, we concluded that expertise is a necessary, albeit not sufficient, condition for weak ties to act as bridges and thereby, new techniques to spread.

How to use this regularity to interpret the modalities of adoption of the potter's wheel at Tell Arqa? According to Thalmann (Thalmann, 2009, 2010, 2016), the ceramic types from the first half of the third millennium testify to cultural affinities or contacts with the Early Bronze II-III southern Levant. However, no other craft bear witness to relationships between these two regions. In this regard, the ties between Tell Arqa and the southern Levant can be qualified as "weak" (infrequently accessed connections) by opposition to "strong" (close relationships). At the same period, contacts with the north were limited "to the occurrence of pattern-combed jars on the coast as far north as Ras Shamra (…), suggesting a mainly "southern" orientation of the EBA culture of the Akkar before the middle of the third millennium" (Thalmann 2009:10). A shift in contacts, now privileging the north and inland Syria, started by the middle of the third millennium BC (Thalmann, 2009, 2010). These contacts are signaled by some limited comparisons with Hama J and Amuq I and J, by a few local imitations of "Hama beakers" and other "caliciform" shapes, and by some actual imports from central Syria. Apart from pottery, contacts with the north are signaled by metal (copper pins) and lithic (large Canannean blades made of imported flint) objects. However, these are limited contacts as shown by the strongly local character of mid-third millennium BC pottery, suggesting kind of autarkic entity (Thalmann, 2009:12) and therefore weak ties rather than strong ties with the north and inland Syria. By the early second millennium BC, the Akkar settlements kept looking northwards (Thalmann, 2010).

In network terms, the archaeological data suggest that the borrowing of the tournettes took place through weak ties, in the course of infrequent contacts. Indeed, the Palestinian type tournette was adopted by the early third millennium BC when Tell Arqa had a few contacts with southern populations. The Mesopotamian type tournette was adopted later, by the end of the third millennium BC or early second millennium BC, when Tell Arqa developed rare contacts with the northern populations (as detailed above). Now, sociological studies have shown that weak ties and expertise are favourable conditions for the initial borrowing of techniques. This regularity can be used given similar social conditions (weak ties). It can be then transferred to the archaeological data in order to explain that infrequent contacts with remote populations represented favourable conditions for the adoption of the potter's wheel. It also completes the account of this adoption since it includes as a necessary condition, expertise: during visits to the South or the North, the experts were able to recognize the advantages offered by the instrument and brought it back to Tell Arqa (fig. 1). The archaeological interpretation obtained can be validated with regard to the validity of the regularity (Gallay, 2011).

Diffusion of the tournette and the wheel coiling technique

Recently, sociologists have debated Granovetter's hypothesis about weak ties, arguing that this is the structure of strong ties that really matters to sustain rapid

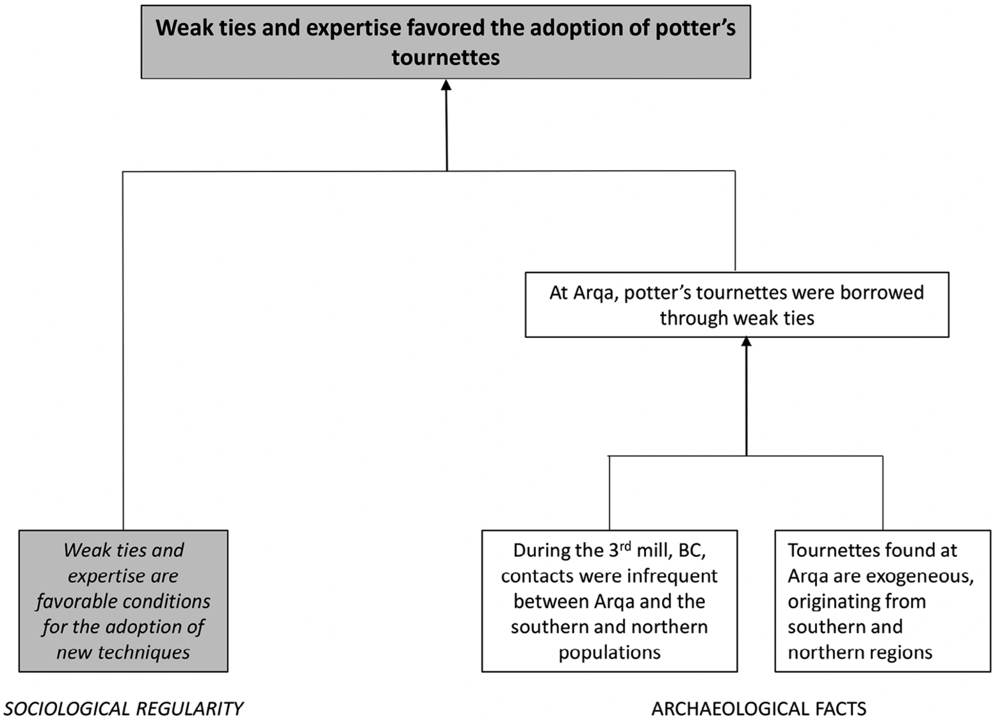

Fig. 1.—Logicist diagram (Gardin, 1980) illustrating the use of a sociological regularity to interpret the initial adoption of the potter's tournettes at Tell Arqa. The sociological regularity is transferred to the archaeological data given the analogy of social network properties (weak ties).

wide diffusion. A unique study combining ethnographic data (collected in North West India and Central Kenya), social network analysis and computational models has been conducted to test this hypothesis (Manzo *et al.*, 2018). The results obtained show that clustered strong ties are one condition for fast diffusion. Indeed, weak ties are crucial to initiate the probability that some actors (the experts) will borrow a new technique. However strong ties are essential to sustain the diffusion process once the innovation penetrated the community. The higher the number of connections between strong-tie related actors (that is to say the number of times an actor is exposed to the new technique, a measure of local redundancy in complex contagion studies), the more rapid the diffusion of a technique. Nonetheless, strong ties were found to be insufficient in some cases. Diffusion process appeared to be also determined by the potter's behavior who initiated the new technique depending on whether he/she consistently provided others with a coherent signal (consistently standing by the new technique; see a detailed example in Roux and Gabbriellini, 2019). The general conclusion, after testing and modeling the conditions favourable to diffusion, is that both local redundancy of within-group strong ties and initiator's behavior are important in the diffusion process, acting as diffusion facilitators (Manzo *et al.*, 2018).

Towards the middle of the third millennium BC, settlements expanded in the Akkar plain (Thalmann, 2000:1622). Tell Arqa, Tell Kazel and Tell Jamous (two sites north of the Nahr el-Kebir) probably functioned as small regional urban centers (Thalman 2009:5). At the same time, the potter's wheel spread instantly, as can be seen in the ceramic assemblages which, from this period onwards, include exclusively vessels made with the wheel coiling technique. Now, let us recall that the analysis of the *chaînes opératoires* involved in the manufacturing of the third millennium ceramics show that at Tell Arqa a same tradition was transmitted over more than a millennium (Roux and Thalmann, 2016). This indicates its transmission within a same social group. The use of rotary instruments testifies to the development of specialised skills, and therefore suggests that the craft was specialised since the beginning of the third millennium BC. Its resilience suggests that it was practiced within households (specialised families), knowing that family structure resists better to social and/or political changes than structures depending on specific institutions (ex.: attached specialists). Hence the hypothesis that, at Tell Arqa, the potters' households were linked by kinship ties. The presence of the same tradition in the Akkar plain suggests that the potter families spread at the same time as the development of the settlements. The consequence was a social network of potters linked by kinship ties and in this regard, the existence of a local redundancy of within-group strong ties.

This social structure is analogous to that favourable to the rapid spread of techniques. Hence the possibility of transferring the related sociological regularity to the archaeological data to explain how the ancient social network of potters in the Akkar plain led to the rapid spread of the wheel coiling technique and the related instrument, the Mesopotamian tournette: the high rate of diffusion was favored by the strong kinship ties linking the potters living in the Akkar plain. It can be further specified, by reference to the sociological regularity, that the potter's behavior who initiated the wheel coiling technique had been consistent (fig. 2).

Emergence of shared norms in heterarchical societies

The second example aims at showing how technological networks are also powerful tools for understanding phenomenon such as the emergence of shared norms at the population level in heterarchical societies (Roux, 2019b). The latter describe societies whose components are "either unranked relative to other elements or possesses the *potential* for being ranked in a number of different ways" (Crumley, 1987:157). This definition applies to ancient societies where the production of prestige objects by craft specialist co-exist with an absence of hierarchical features (visible usually in architecture or graves). Such is the case of the southern Levant Late Chalcolithic societies (4500-3900 BC). They have been interpreted either as egalitarian (Gilead, 1988) or hierarchized (Levy, 1995). The debate is still vivid as more evidence of so-called prestige objects points toward complex networks of production and distribution and interconnected ties between communities sharing

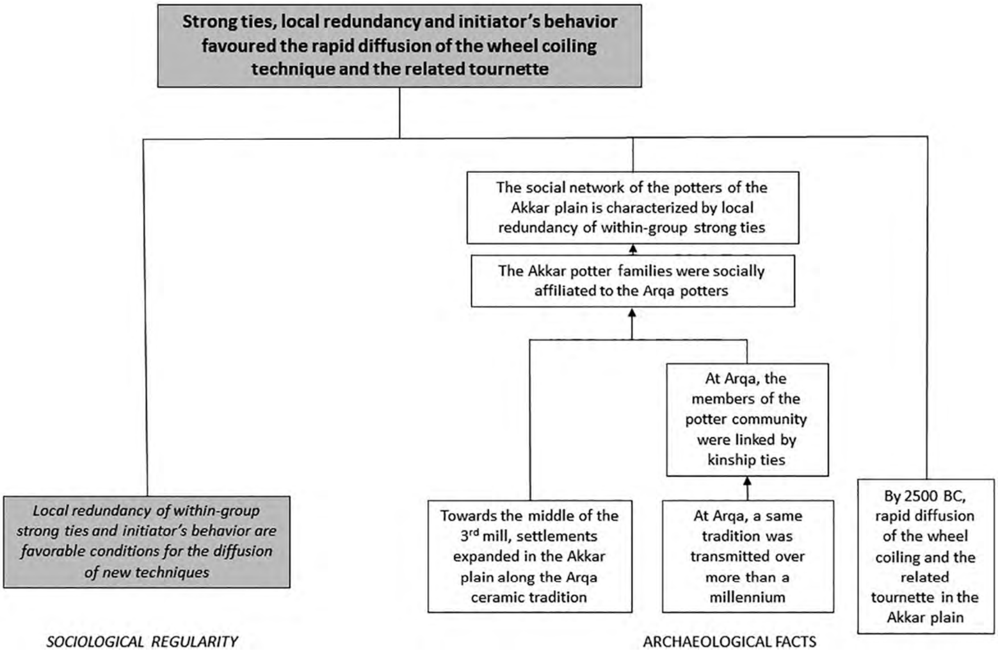

Fig. 2.—Logicist diagram (Gardin, 1980) illustrating the use of a sociological regularity to interpret the diffusion of the potter's tournette in the Akkar plain. The sociological regularity is transferred to the archaeological data given the analogy of social network properties (local redundancy of within-group strong ties).

similar symbolic norms despite limited evidence for hierarchical formation and centralized political power (Rowan and Golden, 2009). Here, the question is to understand how similar symbolic norms as expressed by the common use of ceremonial objects[2] could have been shared by geographically dispersed communities. Was it encouraged by a hierarchy or by the social structure itself?

In order to answer this question, I conducted a technological analysis of numerous ceramic assemblages dated from 4500-3900 BC and distributed across the southern Levant. The goal was to assess the links between the communities/sites as well as their embeddedness. The main result obtained is that a same *chaîne opératoire* was carried out by all the Ghassulian[3] communities of the southern Levant (Roux, 2019c). It suggests that the Ghassulian communities (a site corresponding to a community) were socially affiliated because shared practice requires learning

2. These objects include mainly wheel shaped bowls, basalt bowls, violin figurines, ivory and copper items.

3. The Ghassulian culture is defined as a "coherent culture" by its artifacts and whose spatial delineation covers present-day Israel and Jordan (except broadly for the regions located south of the southern tip of the Dead sea).

with socially related tutors as seen previously. Moreover, our technological analysis highlighted that the communities were connected at the population level at a given point in time as shown by the ceramic assemblage of the site of Abu Hamid, located in the Middle Jordan Valley. This assemblage is in effect made of vessels coming from all the regions of the southern Levant testifying to the visit of the site by all the Ghassulian communities (Roux and Courty, 2007). This suggests, in return, that the Ghassulian population was a homogeneously mixing population (each individual had the opportunity to interact with one another through gathering sites such as Abu Hamid) within a tight embedded social network (ceramic practices testify to social links between all the sites).

Now, given these social conditions, one can question whether they could have promoted shared norms without large-scale coordination. Recent researches by sociologists (Centola and Baronchelli, 2015) have shown that the network structure that promotes the emergence of shared norms is one with the higher connectivity between individuals, namely a society where individuals can interact with all the individuals of the community. This result is based on experiments on the web with players who had to agree on the name to give to someone and who were tested in three situations: interactions between actors close spatially, random interactions and interactions with all the individuals. More studies are probably required to demonstrate that homogeneously mixing populations (interactions with all the individuals) is a necessary and/or sufficient condition for shared norms to emerge. Meanwhile, it can be considered as a “provisional” regularity whose generating mechanism has been tested.

The Ghassulian archaeological data indicate a social network (homogeneously mixing populations) analogous with the social network structure favourable to the emergence of shared norms without coordinated leadership. The related regularity can be therefore transferred to the archaeological data and explain why this social network structure was conducive to this dynamic process (fig. 3).

CONCLUSION

In this paper, I have first argued that the *chaîne opératoire* approach (i.e. the technological analyses of archaeological assemblages) is a powerful tool to reconstruct technological networks (i.e. networks of socially affiliated object-makers). Then, I have proposed that, once technological networks are reconstructed, social networks’ regularities (invariants) can be used to formulate explanatory hypotheses about past dynamics (diffusion of technical traits, emergence of shared norms). The condition for using these sociological regularities is that the ancient technological network properties are analogous to those that have been shown to be favourable to evolutionary social phenomena such as the diffusion of techniques or the emergence of new norms.

In archaeology, because of time resolution which prevents us to evaluate how micro-level interactions might have scaled up in changes, we cannot explain macro-

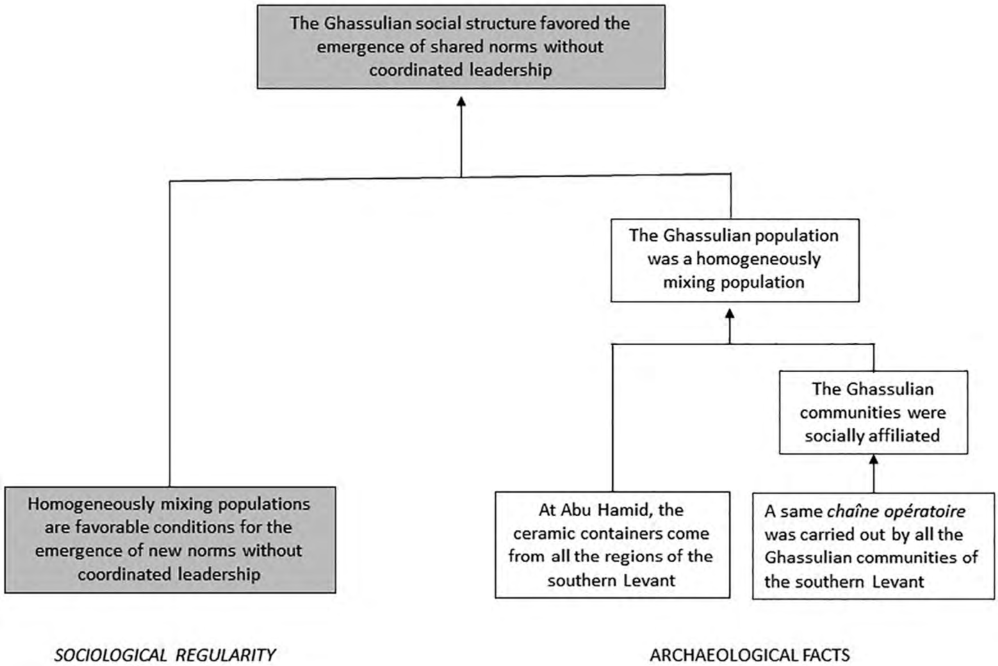

Fig. 3.—Logicist diagram (Gardin, 1980) illustrating the use of a sociological regularity to interpret the emergence of shared norms within the Ghassulian society. The sociological regularity is transferred to the archaeological data given the analogy of social network properties (homogeneously mixing population).

evolutionary changes. Hence the necessary use of sociological regularities to explain why specific network properties represent favourable conditions to changes when facing particular "historical" situations (particular factors proper to social group's history). Testing the mechanisms that generate sociological regularities enables SNA studies to assess their validity (invariance of the conditions for their occurrence) and, therefore, the related archaeological interpretation. They participate directly to highlight evolutionary "laws" explained by social facts.

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