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Science and Technology of Archaeological Research

Article

Exploring Late Bronze Age systems of bronzework production in Switzerland through Network Science

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Abstract Many hundreds of Bronze Age bronze artefacts are known from excavations in Switzerland, yet the interpretation of production networks from the object find locations remain problematic. It is proposed that the decorative elements used on items, such as ring-jewellery, can be used as elements to assist in the identification of artisanal traditions and 'schools', and also regional or community preference and selection of specific designs. Combining the analysis of over 1700 items of ring-jewellery from Switzerland with approaches from network science has facilitated the identification of regional clustering of design elements, comparable with cultural typologies in the area. It is also possible to identify potential instances of cultural differentiation through decoration within the broader regional cultural traditions. The study highlights important facets of bronzework production in the region of Switzerland, while also demonstrating future potential directions which could build upon the European wide dataset of prehistoric bronzework.

Key words Late Bronze Age; jewellery; decoration; production networks; Switzerland

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Introduction

The Bronze Age is so named because of the occurrence of objects in a new material – bronze – when compared to earlier periods, yet, despite the good preservation of these objects in the archaeological record, comparatively little is known regarding the processes of metalwork production. Archaeometallurgical analysis can provide technical details on the sources of metal ores, composition of bronze alloys, and bronze working techniques (Berger and Pernicka 2009; Mödlinger 2011; Rychner and Kläntschi 1995), but the social aspects of bronze smithing remain enigmatic. Even where conditions permit the excellent preservation of settlement plans, such as in the lake-settlements of the northern Alpine forelands, evidence which may shed light on the social and cultural practices of smithing is seldom encountered. Some of the many bronze objects recovered (e.g. axes, chisels, razors, sickles) are typically undecorated, but there are occasional decorated exceptions (examples in e.g. Jockenhövel 1971); absence of decoration may stem from their nature as primarily functional objects. Other items, such as arm- and leg-ring jewellery, jewellery pins, and knives, are predominantly decorated using a variety of techniques and designs (e.g. Bernatzky-Goetze 1987; Schmid-Sikimić 1996). Ornamentation of these objects may indicate their use as elements of identity construction and visual display, but other factors such as deposition context must also be considered (Fontijn 2002; Kaul 1998).

Ceramic studies from the same region have suggested that variations in decoration and shape were settlement and region specific (Eberschweiler, Riethmann, and Ruoff 2007; Gross 1986; Seifert 1996). It has also been suggested that specific elements of metalwork decoration – such as the number of lines used in specific elements – can be interpreted as the "handwriting" or "signature" of specific artisans due to the recurrent use of the same tools and style (Weidmann 1983). Following a scale falling between the macro analysis of object type and micro analysis of line numbers in specific elements may illuminate the networks of metalwork production and/or decoration, exchange systems, and specific decorative schemes favoured by certain settlements and/or artisans. Catalogue publication of many Bronze Age (BA) metalwork artefacts from Switzerland, and in particular Late Bronze Age (LBA) lake-dwellings, make this relatively small region an ideal case study to examine the potential for observing such networks of interaction.

In a discussion of Neolithic and Bronze Age pottery, Jones (2007) proposed the principles of "retention", "protention" and "citation" to discuss the development

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of artefact characteristics, properties, and embellishment over time and between different object groups. Considering these principles in association with theories of prehistoric bronze working, it is possible to envisage that artisanal 'schools' developed in different communities and locations. Such schools could have developed from the preferences of the 'master' for certain decorative schemes and working techniques being passed to the 'apprentices'. The categorisation of decorative elements and recording of occurrence across categories of artefacts offers the potential to identify such 'schools'. The application of network science methodologies facilitates the visualisation of these networks of co-occurrence (e.g. Sindbæk 2007). Identification of similar decorative elements at several sites may indicate that those communities were served by a single artisan or 'school', and also suggest a similarity in specific cultural attitudes and perceptions. In this manner the combination of network science techniques with a secondary source archaeological dataset will answer questions pertaining to Bronze Age smithing practices, social structure, and community affiliation.

Prehistoric bronze working

The occurrence of numerous casting moulds, in both clay and stone, for various objects at LBA lake-dwellings in Switzerland (e.g. Mörigen, see Bernatzky-Goetze 1987) indicates that these sites were certainly involved in the production of metalwork. Furthermore, the distribution of objects likely manufactured at those sites, such as *Corcelettes* type ring-jewellery, in wider central Europe suggests that they were also involved in the wider circulation and exchange of such objects (Jennings 2014b). There are no natural sources for copper or tin in the northern Alpine plateau, and so the lake-dwelling communities must have imported the raw materials for bronze production (Rychner and Kläntschi 1995). Regardless of the origin of copper (and tin) utilized by the bronzesmiths working in the lake-dwelling region, it is evident that they were producing a large number of objects.

Where the bronzesmiths were actually working within the lake-dwelling communities remains unclear. Many of the casting moulds have been recovered inside the settlements, suggesting that the moulds were at least stored within the site; few remains of casting have, however, been found, suggesting that actual metalwork production occurred outside the settlement (Bernatzky-Goetze 1987). Ethnographic evidence suggests that working equipment may not be left in their place of use, but moved to storage locations (Kent 1984). Thus, it is not possible to directly equate the find locations of moulds to smithing and casting locations. It is also unclear whether the smiths were resident at single sites, or itinerant artisans moving between settlements and serving a large territory. Bauer and Northover (2004) have written in support of the latter, but the number of stone moulds found at some sites may also hint at more permanent residence. Whether smiths would have moved with a collection of stone moulds is debatable, and it could be that (readily producible) clay moulds were favoured by traveling smiths. However, it is also possible that itinerant smiths would have had (semi-)permanent storage and residence places in numerous settlements, permitting the caching of moulds and raw materials between periods of occupancy. It is likely that both modes of production coexisted, with some smiths moving to serve the smaller settlements, such as Zug-Sumpf (Seifert 1996) and Greifensee-Böschen (Eberschweiler, Riethmann, and Ruoff 2007), while others undertook more permanent residence in the higher population centres, such as Mörigen (Bernatzky-Goetze 1987) and Grandson-Corcelettes (Fischer 2005). This essentially returns to a question repeatedly addressed since Michael Rowlands' (1971) ethnographic study of iron working: the role and status of metalworkers in prehistoric societies (see also Brück n.d.). Retreading such ground is not necessary here, but one aspect which requires discussion is the transfer of bronze working knowledge across generations.

Ethnographic studies have often assessed the role of 'apprenticeship' in generating and maintaining stylistic traditions across generations (e.g. Arnold 2012, 277; Gosselain 2011; Hosfield 2009; Rowlands 1971; Sinopoli 1991, 120). The development of skills in any form of production method is essentially based around the tutoring of novices by those more experienced in the techniques, resulting in the transfer of not only primary knowledge and skills, but also subliminal procedures, methods and styles across generations (Gosselain 2011; Sinopoli 1991). Thus, it is possible that the decorative preference of individual artisans and 'schools', within the confines of broader cultural schemes, become prominent or entrenched in specific communities, at a scale between the number of lines used in design elements and the typological classification of an object. The distribution of motifs may reflect varying modes of production: occurrence at single sites may be indicative of a more resident mode of production than those which occur over a wide area. However, a direct equation of design ubiquity to resident or itinerant modes of production precludes the obvious influence of trade and exchange practices on distribution: smiths were producing goods to be consumed, and, as seen in typological distribution maps (Jennings 2014b), those objects may have travelled widely from their place of production before deposition.

Networks of Objects

Decorative designs may not only indicate modes of production, but demonstrate conceptual connections between different groups of objects. Jones (2007) detailed the "citation", "retention", and "protention"

of object characteristics as a manner of presencing and evoking elements of other object classes and forms, past styles in the present, and guiding future possibilities of shape and decoration. By choosing to use decorative elements or features which typically occur on a specific object on a secondary object class, the producers (and users) could evoke associations with the past and/or social identities (e.g. Blanco-González 2015). Jones' discussion was built upon a study of Neolithic and Bronze Age material culture (primarily ceramics) from Orkney and the Western Isles (UK) consisting of a relatively limited range of designs and emblems, but those associations and evocations of designs and aspects linked the objects and their users with broader traditions and cultural memory (Jones 2007, 141–161).

The continued development of bronze metallurgy and accumulation of cultural knowledge and skills in metal working during the Bronze Age expanded the potential decorative schemes which could be applied to prestige items designed for public consumption and visibility. Considering the BA decorative schemes of objects, it is possible to see how design elements cross-fertilize amongst different object classes and how elements are retained over time; both between (e.g. similarities of designs on ceramics and bronze work) and within (e.g. within different forms of ring-jewellery) object classes. Accepting that individual bronzesmiths and schools may develop a penchant for specific decorative elements, it is possible that, within the confines of cultural requirements, they create similar combinations of decoration across different object classes – they will actively or passively cite similar motifs across multiple forms. Identification of recurrent modifications to decorative schemes, or the recurrent combination of niche motifs on various objects, may hint at the product of specific artisans or schools.

So far the decision to use specific styles of decoration and types of motif has been discussed in terms of the bronzesmiths' choices and preferences, but the decisions may also be symptomatic of broader community action and affiliation. The use of certain emblems within broader cultural traditions, for instance the regional flavours of the Urnfield culture (Rychner 1998b), may have been a method of creating community identity, symbolizing their 'similar-but-different' relationship to others. The expression of such local identities has previously been proposed for the LBA lake-dwelling communities, with large and spatially separated settlements utilizing different forms and decoration of ceramics (e.g. Gross 1986). Possibly due to the different scales of abundance and division of metalwork in to various *types* presenting an initial assumption of relative uniformity, such models have not been expanded to bronze objects beyond broad east : west Switzerland differentiation (Rychner 1979). The use of the citation-retention-protention principles may offer a theoretical basis through which to explore the creation of local community identities via the selective use of decorative elements from a broader stylistic tradition in recombination with more restricted designs and object classes.

Identifying decoration elements

Site and catalogue publications of bronze artefacts from the northern Alpine region, in this instance primarily Switzerland, provide a significant raw data resource with which to undertake an analysis of the decorative elements on Bronze Age metalwork. Some types of object, such as ring-jewellery and spearheads, have been addressed in catalogue publications (e.g. Pászthory 1985; Tarot 2000) while others, such as knives and jewellery pins have been studied on a site by site basis (e.g. Bauer 2002; Bernatzky-Goetze 1987). Data from these publications were collated and entered into a database, recording: site location, context, object typological classification, dating period, and the decoration elements (defined in a cumulative manner upon encounter). The classification of decoration (fully undertaken by the author using artefact images and descriptions over a short time period in order to address issues of consistency) was reduced to a basic level, moving away from 'rich decoration' and dividing to individual components (Figure 1, Table 2). To make the schemes applicable across various forms of object necessitated that no reference to the placement position of decoration elements on the object is mentioned, for instance 'socket' or 'neck', because these are not universally applicable locations. The removal of placement information does curtail the possibility that the same motif held or evoked different symbolism dependent upon its placement on an object. How such variable meanings of single motifs may occur remains problematic to comprehend, but the citation of motif associations between objects can be addressed through network science techniques.

Over 2600 objects have been recorded, of which over 1700 are items of arm- and leg-ring jewellery, with the remainder primarily jewellery pins and knives. These objects cover the entire Bronze Age (c. 2200 BC - 800 BC), but the majority relate to the Late Bronze Age (1350–800 BC), and particularly the Hallstatt A and B (1200–800 BC) phases in terms of the typological chronology (Rychner 1998a). The objects come from over 250 sites (ring-jewellery occurs at 194), many of which are lake-dwellings and wetland settlements of the LBA, accounting for the high representation of LBA objects, and resulting from the higher population and increased production of bronze objects when compared to earlier periods (Figure 2, Table 1). Due to the sheer dominance of the dataset by the ring-jewellery, the remainder of the discussion will focus on information gleaned from the decoration traits of these objects, but will draw upon information from the other object groups where applicable.

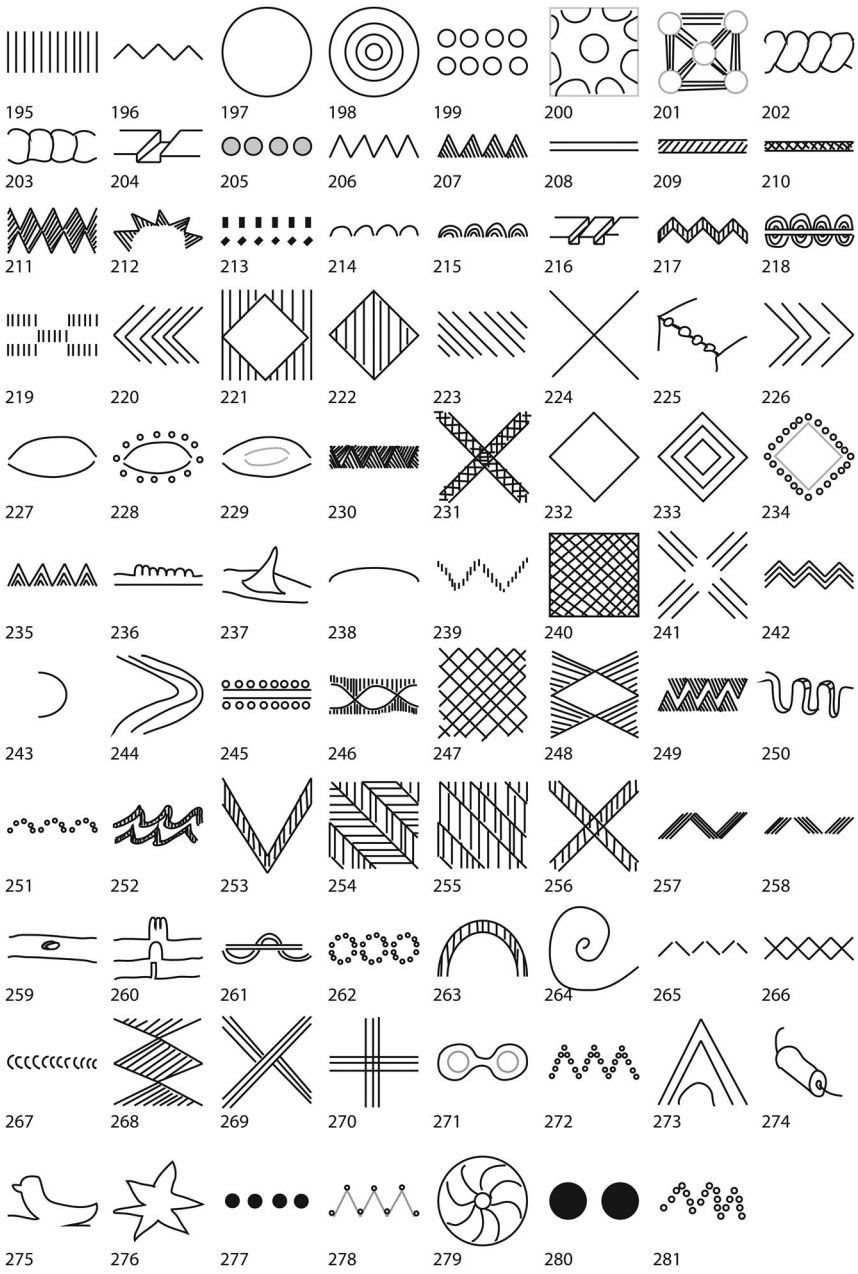

Figure 1 Decoration elements as defined for the study. Numbers correspond to descriptions in Table 2. Illustrations not to scale, and size of feature is not considered, apart from numbers 277 (small dot) and 280 (large dot).

Visualizing networks of decorative styles

Database collation of the decoration types enables interrogation of the dataset, but presents the information in a visually inaccessible and un-intuitive manner. In order to produce and interrogate visual representations of patterns and trends in the occurrence of decorative motifs, Social Network Analysis (SNA) software (Pajek, version 4.01) was used to create network graphs connecting sites and decorative elements. The application of network science techniques in archaeological research has developed rapidly in recent years, particularly with regard to the examination of exchange networks (e.g. Collar et al. 2015; Knappett 2013; Sindbæk 2007).

It is not the intention of this study to utilize the various statistical and mathematical functions exploited in Social Network Analysis (e.g. Scott and Carrington 2011), but to use the graph operations of Pajek to produce visual representations of the connections and structure within the data (Nooy, Mrvar, and Batagelj 2011). Where benefit may be found, SNA techniques, such as energizing the data to cluster vertices of similar strength and optimizing the arrangement of data for visual inspection, or statistical interrogation will be used (Krempel 2014, 560; Nooy, Mrvar, and Batagelj 2011, 20–21). Broadly, the visualization (and analysis) of networks use data category points (vertices) connected directly to each other (one-mode network), or connected indirectly through a second category (two-mode network). The primary two

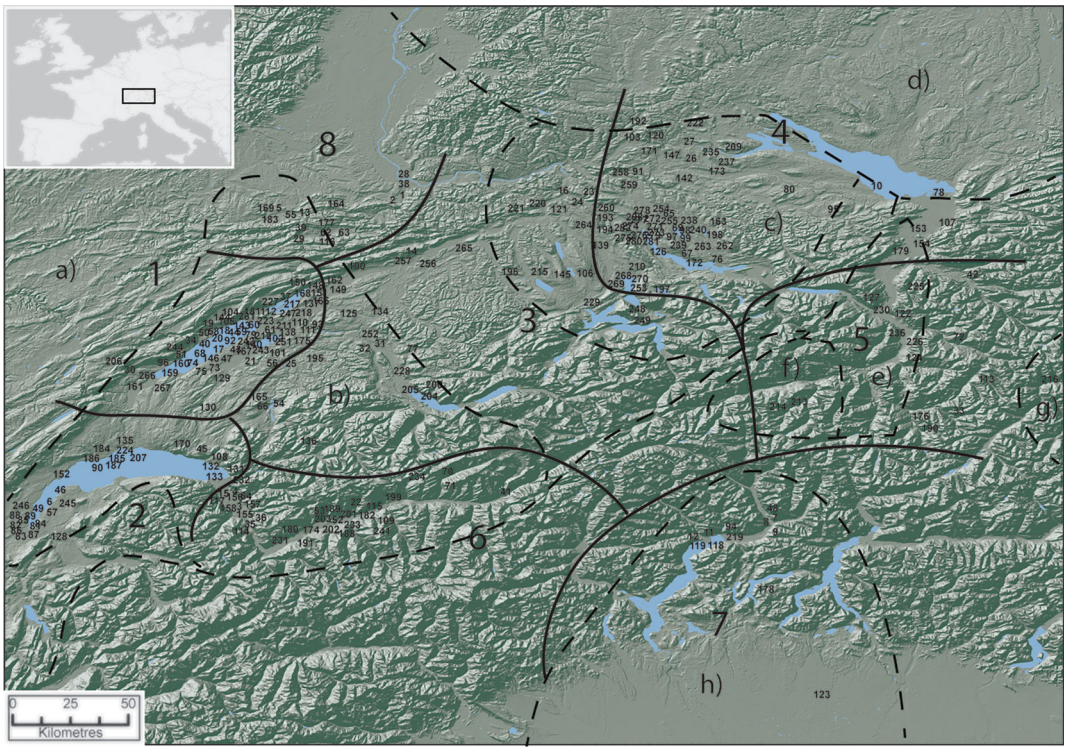

Figure 2 Location of sites with recorded artefacts. For site names see Table 1. Large numbers refer to regional divisions, as defined for Figures 6–12: 1) Lake Neuchâtel / Three Lakes; 2) Lake Geneva; 3) Central; 4) Lake Zurich & North East; 5) East; 6) Alpine Rhône Valley; 7) Southern; 8) North West. Late Bronze Age cultural regions identified by Rychner (1998b Fig. 39) marked with dashed line: a) Rhine-Swiss-East France Urnfield culture [RSFO]; b) RSFO – west Switzerland group; c) RSFO – east & central Switzerland group; d) Main-Swabian group [MS]; e) mixture of RSFO, and Laugen-Melauen culture; f) North Alpine zone with RSFO and MS influence; g) Laugen-Melauen culture; h) Proto-Golasecca culture.

categories of vertices used here are *site* and *decoration type*; sites can thus be related to others through co-occurrence of decoration types, and vice versa. Either category can be easily replaced with object group (e.g. ring-jewellery) or object type (typological classification within group, e.g. ring-jewellery: *Corcelettes*), so that decoration or site can be related by occurrence on/of the same classes of object.

The use of such binary network datasets – where connections between categories are depicted as either present or not present – has been exploited in archaeological projects (Mizoguchi 2009; Sindbæk 2007). Ascription of values (weight) to the occurrence of objects provides further interpretative options (Collar et al. 2015), but with binarized and valued forms of data management, it must be considered that the choices made in defining thresholds and filtering can have a substantial influence on the final network interpretations (Peeples and Roberts Jr 2013). Regardless of data management and selection issues, the basic principle behind the creation of such a network is the assumption that the greater the similarity between assemblages at different sites, then the greater likelihood that those sites (and populations therein) were in more frequent and/or intense interaction and contact than sites with less similar assemblages (Peeples and Roberts Jr 2013). In terms of the decoration element data, this could represent either direct production at numerous sites, effectively representing the customer territory of an artisan/school, or the post-production circulation of objects through exchange practices; these possibilities still fall within the *similar = more interaction, dissimilar = less interaction* scheme.

Visualization of all site : ring-jewellery is rather cluttered and difficult to comprehend with many lines obscuring the network structure and trends (Figure 3). Separation of the two categories (sites = inner circle : decoration = outer) demonstrates the range in connections and dominance of some vertices with many connections over the graph. With the vertices proportionally scaled (larger = more connections), it is clear that some decorations, such as 'vertical lines', are very well represented, while others, such as 'edge scallop' are connected to single sites. Energization of the complete network data (Figure 4) indicates that the larger vertices (those which have the most connections) are clustered in the centre – demonstrating their dominance and high connectivity in the network. As all of the connecting lines are unweighted (regardless of co-occurrence repetition a link between the same two vertices is counted once) the number of connections represents links between unique vertices: the same decoration at a single site many times does not equate to a high degree. The size of the vertices

Table 1 Site list for Figure 2. Sites from which objects in the database have been recorded. (N-A relates to objects which have no specific find location listed).

Site	No.	Region (Fig. 7)	Site	No.	Region (Fig. 7)
Aesch	1		Neftenbach	142	
Aesch-Kännelacker	2		Neuchatel	143	1
Aigle	3		Neuchâtel-Le Crêt	144	
Aigle-Grandchamps	4	6	Neudorf-Gormundermoos	145	
Alle-Noir Bois	5		Neuenburgersee	146	
Anières	6		Neuhausen am Rheinfall	147	
Arbedo-Castione	7	7	Nidau	148	1
Arbedo-Castione dal Marc	8		Nidau-Büren-Kanal	149	
Arbedo-Cerinasca	9	7	Nidau-Schlossmatte	150	
Arbon-Bleiche	10		Nidau-Steinberg	151	
Ascona	11		Nyon	152	2
Ascona-S. Materno	12		Oberriet-Felbenmadbüchel	153	
Asuel, Chételat	13		Oberriet-Montlingerberg	154	
Attiswil-Lindenrain	14		Ollon	155	6
Aus der Rhône	15		Ollon-Carrière du Lessus	156	6
Aus der Zihl bei Brügg	16		Ollon-Charpigny	157	6
Autavaux-La Crasaz	17		Ollon-St. Triphon	158	
Auvernier	18	1	Onnens	159	1
Auvernier-Brèna	19		Onnens-Gare	160	
Auvernier-Nord	20	1	Orbe	161	
Avenches-Eau Noire	21		Orpund	162	3
Ayent	22	6	Pfäffikon-Hittnauerstrasse	163	
Baden-Aus der Romerstrasse	23		Pleigne-Chateau de Löwenburg	164	
Baden-Baldegg	24		Pont-en-Ogoz	165	
Barberêche-Pensier	25		Port	166	
Basadingen-Gupfen	26		Portalban	167	
Basadingen-im Buchberg	27	4	Port-Zihlkanal	168	
Basel-Elisabethenschanze	28		Pruntrut	169	8
Bassecourt	29	8	Puidoux	170	
Baulmes-au Signal	30		Rheinau	171	
Belp-Aebnit	31		Richterswil	172	
Belp-Hohliebe	32		Rickenbach-Oberholz	173	
Bergün	33	5	Riddes	174	6
Bevaix	34	1	Ried-Guggemärli	175	
Bex	35	6	Riom-Parsonz Casti da Riom	176	
Bex-Lac de Luissel	36		Roc de Courroux	177	
Bielersee	37		Rovio	178	
Binningen	38		Ruggell	179	
Böecourt JU-Les Montoyes	39		Saillon	180	6
Boudry - Le Pervou	40		Saint Blaise	181	
Brigue	41	6	Saint Leonard	182	
Bürs-Schesa	42		Saint-Brais	183	
Chabrey	43	1	Saint-Prex	184	2
Chabrey-Montbec	44		Saint-Prex-Coulet	185	2
Chardonne-Signal	45		Saint-Prex-Coulet prés St Prex propriété Treuhardt	186	
Chens sur Leman, Touges	46		Saint-Prex-La Moraine	187	
Chevroux	47	1	Salins	188	
Claro	48	7	Savièse	189	
Collonge-Bellerive	49		Savognin-Padnal	190	
Colombier	50	1	Saxon	191	
Concise	51	1	Schleitheim	192	
Conthey	52	6	Schlieren	193	
Conthey-Sensine	53		Schlieren-Bundendal	194	
Corbières-Prévondavaux	54		Schmitten-Hohi Zelg	195	
Cornol, Mont Terri	55		Schötz	196	
Corsalettes	56		Schweiz	197	
Corsier-La Gabiule	57		Seegräben-Heidenburg	198	
Cortaillod	58	1	Sierre	199	
Cudrefin	59		Sigriswil-Ringoldiswil	200	
Cudrefin-Brolliet	60		Sion	201	6
Cudrefin-La Sauge	61		Sion-Maison Torrenté	202	
Delémont	62		Sion-Rue de Lausanne	203	
Delémont-La Communance	63		Spiez	204	
District Aigle	64		Spiez-Einigen, Holleeweg 3	205	
Dübendorf	65		St. Croix-Aiguilles de Baulmes	206	
Echarlens	66		St. Sulpice-Venoge	207	
Egg-Stirzental	67	4	Stampfenbach	208	
Estavayer-le-Lac	68	1	Stein am Rhein	209	4

(*Continued*)

Table 1 Continued.

Site	No.	Region (Fig. 7)	Site	No.	Region (Fig. 7)
Fällanden	69		Steinhausen-Sennweid	210	
Ferden	70		Sugiez	211	
Ferden-Goppenstein	71	6	Sugiez-Vully-le-Bas	212	
Fideris-Madinis	72		Surin	213	
Font	73	1	Surin-Crestaulta	214	
Font-La Pianta	74	1	Sursee-Zellmoos	215	3
Font-La Trabatiez	75		Susch-Chachlins	216	
Freienbach-Rapperswil	76		Sutz-Lattrigen	217	
Freimettingen-im Schlief	77	3	Täuffelen-Gerolfingen Oefeli	218	
Fussach-Rhein	78		Tenero-Contra	219	7
Gampelen-Witzwil	79		Thalheim-Brandbühl	220	3
Gärtensberg bei Wil	80		Thalheim-Gütighausen	221	
Geneve	81		Thayngen	222	
Geneve-Coulouvrenière	82		Thielle	223	
Geneve-Jonction	83		Tolochenaz-Le Boiron	224	2
Geneve-Les Eaux Vives	84	2	Triesenberg-Alp Sücka	225	
Geneve-L'Ile Maison Buttin	85		Trimmis-Dorfrüfe	226	
Geneve-Maison Buttin	86		Twann-St. Petersinsel	227	
Geneve-Paquis	87		Uetendorf-Limpachmösli	228	
Geneve-Petit Saconnex	88		vicinity Luzern	229	
Geneve-Sécheron	89		vicinity Mels	230	5
Genfersee	90		vicinity Saxon	231	
Glattfelden	91	4	vicinity Villeneuve	232	2
Gletterens	92		vicinity von Sion	233	6
Golaten-Kehrichtgrube	93		vicinity von Loéche-les-Bains	234	
Gordola	94		Unterstammheim	235	4
Gossau-Altenberg	95		Untervaz-Alp Salaz	236	
Grandson-Corcelettes	96	1	Ürshhausen-Horn	237	
Greifensee-Beim Schloss	97		Uster-Nänikon	238	
Greifensee-Böschen	98		Uster-Riedikon	239	
Greifensee-Station Wildsberg	99		Uster-Werriker Riet	240	
Grenchen-Breitenfeld	100		Valais	241	
Greng	101		Vallamand	242	
Guévaux	102	1	Vallamand-Des Ferrages	243	
Hallau-Wastetten	103		Vaumarcus-Forêt de Seyte	244	
Hauterive	104	1	Veigy	245	
Hauterive-Champréveyres	105	1	Versoix	246	
Hochdorf-Ronfeld	106		Vinelz-Ländti	247	
Hohenems	107		Vitznau-Grubisbalm	248	
Iongny	108	2	Vitznau-Müliflue	249	
Kanton Valais	109		Volders	250	
Kerzers-Grosses Moos	110		Vully-le-Bas	251	
Kerzers-Vormoos	111		Wabern	252	3
Lac Neuchatel, Bienne, Morat	112		Walchil-Chlimattli	253	
Landscahft Davos-Flülelapass	113		Wallisellen	254	4
Lavey	114	6	Wallisellen-Förrlibuck	255	
Lens-Chelin	115		Wangen an der Aare	256	
Les Esserts – Est	116		Wangen an der Aare – Galgenrain	257	3
Lit du Rhône	117	6	Weiach	258	
Locarno	118		Weiach-Hard	259	
Locarno-San Joiro	119	7	Weiningen	260	
Löhningen-Gehr	120		Westschweizerische Gewasser	261	1
Mägenwil-Stägler-Hau-Haberüti	121		Wetzikon-Oberkempten	262	
Maienfeld-Flur Bunte	122		Wetzikon-Robank	263	
Mailand-Casina Ranza	123		Wohlen	264	
Maladers-Tummihügel	124		Wynau-Aareufer	265	
Meikirch	125	3	Yverdon-Champittet	266	
Meilen-Schellen	126		Yverdon-les-Bains	267	
Mels-Heiligkreuz	127	5	Zug	268	
Monnetier-Mornex	128		Zug-Mänibach	269	
Montet	129	1	Zug-Sumpf	270	4
Montet-Glâne	130	1	Zurich-Alpenquai	271	4
Montreux	131	2	Zurich-Bauschanze	272	
Montreux-Terrasse de Rouvenaz	132		Zurich-Grosser-Hafner	273	
Montreux-Vernax dessous	133	2	Zurich-Kleiner-Hafner	274	
Moosseedorf	134		Zurich-Kolbenhoferegg	275	
Morges	135	2	Zurich-Rathaus	276	
Morges-Grand Cité	136		Zurich-Rathausbrucke	277	
Mörigen	137	1	Zurich-Schwamendingen	278	

(*Continued*)

Table 1 Continued.

Site	No.	Region (Fig. 7)	Site	No.	Region (Fig. 7)
Muntelier	138		Zurich-Storchen	279	
Muri-Lindenhof	139		Zurich-Wollishofen	280	4
Murtensee	140	1	Zurich-Wollishofen-Haumesser	281	
N-A	141		Zurich-Ziegelei Sihlfeld	282	

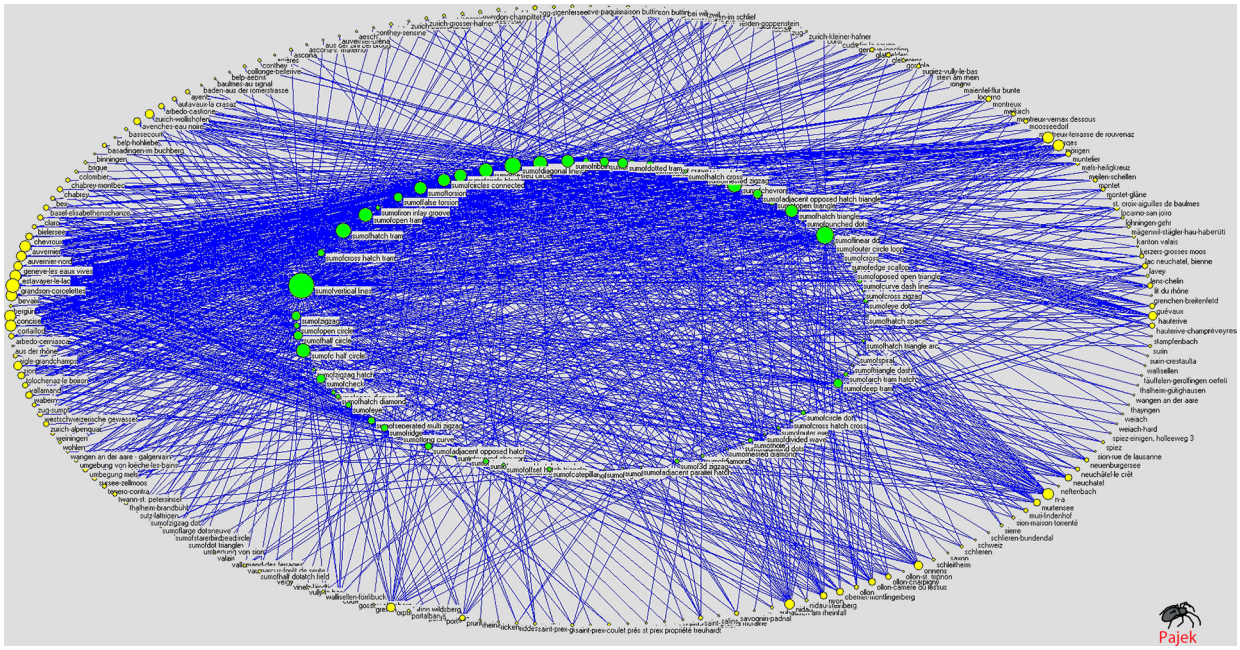

Figure 3 Two-mode network using the complete dataset of decoration types (inner circle) and sites (outer circle). Vertex point size is scaled according to the number of other vertices to which they are connected.

indicates that a) larger decoration vertices are those with wide dispersal, and b) larger site vertices have many different forms of decoration.

To begin addressing the selective use of specific elements by certain manufacturers and communities, it is desirable to remove the more ubiquitous decorative elements from the network. The occurrence of the same decoration type at many sites is one indication that it occurs on numerous objects (across a wide area). Comparison to a network linking decoration element to artefact typology indicates that they also occur across different types within the same object group. Removing the elements with high occurrence, while retaining the sites with high numbers of connections (but with values marginally reduced due to removal of some decorations), clears the situation and allows the identification of motifs which occur across a limited number of sites. However, motifs occurring at single sites or with very low total numbers are of little use when attempting to identify patterns of identity creation; these may, respectively, be one off experiments or rare instances of exchange.

Removal of both exceptionally recurrent and exceptionally limited decorative schemes in such a broad brush manner does not take account of time, and it may be that some of the repetitions of high frequency elements occur across both time and site. The influence of such temporal continuation – and tradition of decorative element – on the identification of specific community or 'school' use of elements is expected to be limited for the main discussion here due to the dominance of the dataset by LBA rings significantly outweighing the influence, representation and visualization of connections generated by earlier ring types (Pászthory 1985), but can be assessed by object type : decoration element network comparison and a consideration of site occupation phases.

Identifying workshops

The summed number of links (degree) between vertices of the two-mode network for ring-jewellery varies between 1 and 148 for both sites (across 194 vertices) and decoration types (across 87 vertices). The degree of sites and decoration type reflect two different situations: the former suggests the extent to which sites are (potentially) connected to a variety of decoration traditions, while the latter reflects the dispersal of decoration types. Due to these potentially varying representations, only the decoration degree is manipulated in order to study the dispersal of decorations: all decoration vertices with degree >17

Table 2 Number of vertices connected to each separate vertex (degree), for decoration type and site. Double line between 194 and 195 denotes transition from site vertices (<194) and decoration type (>195; see Figure 1). Average number of connections (degree) for decoration elements is 16.8, with a mean of 8.5, and mode of 1 (excluding 0 values). (N-A indicates no specific find location is available in the artefact record).

Vertex No.	Site	No. connected vertices (degree)	Vertex No.	Site / decoration type	No. connected vertices (degree)
1	Aesch	1	142	Sion	16
2	Aigle	3	143	Sion-maison torrenté	4
3	Aigle-grandchamps	6	144	Sion-rue de lausanne	2
4	Anières	1	145	Spiez	3
5	Arbedo-castione	9	146	Spiez-einigen, holleeweg 3	2
6	Arbedo-cerniasca	11	147	St. croix-aiguilles de baulmes	1
7	Ascona	3	148	Stampfenbach	2
8	Ascona-s. materno	1	149	Stein am rhein	4
9	Aus der rhône	1	150	Sugiez	5
10	Aus der zihl bei brügg	1	151	Sugiez-vully-le-bas	6
11	Autavaux-la crasaz	6	152	Surin	3
12	Auvernier	34	153	Surin-crestaulta	1
13	Auvernier-brèna	2	154	Sursee-zellmoos	8
14	Auvernier-nord	25	155	Sutz-lattrigen	4
15	Avenches-eau noire	12	156	Täuffelen-gerolfingen oefeli	1
16	Ayent	6	157	Tenero-contra	7
17	Baden-aus der romerstrasse	1	158	Thalheim-brandbühl	5
18	Basadingen-im buchberg	5	159	Thalheim-gütighausen	1
19	Basel-elisabethenschanze	10	160	Thayngen	2
20	Bassecourt	3	161	Tolochenaz-le boiron	14
21	Baulmes-au signal	1	162	Twann-st. petersinsel	6
22	Belp-aebnit	1	163	vicinity mels	8
23	Belp-hohliebe	2	164	vicinity saxon	3
24	Bergün	4	165	vicinity villeneuve	6
25	Bevaix	29	166	vicinity von sion	2
26	Bex	5	167	vicinity von loéche-les-bains	7
27	Bielersee	7	168	Unterstammheim	5
28	Binningen	1	169	Valais	1
29	Brigue	4	170	Vallamand	11
30	Chabrey	10	171	Vallamand-des ferrages	2
31	chabrey-montbec	6	172	Vaumarcus-forêt de seyte	4
32	Chevroux	15	173	Veigy	2
33	Claro	10	174	Versoix	4
34	collonge-bellerive	3	175	Vinelz-ländti	2
35	Colombier	4	176	Vully-le-bas	1
36	Concise	32	177	Wabern	12
37	Conthey	3	178	Wallisellen	1
38	Conthey-sensine	2	179	Wallisellen-förrlibuck	3
39	Corbières-prévondavaux	4	180	Wangen an der aare	2
40	Corsalettes	6	181	Wangen an der aare – galgenrain	4
41	Corsier-la gabiule	3	182	Weiach	2
42	Cortaillod	33	183	Weiach-hard	2
43	Cudrefin	7	184	Weiningen	7
44	Cudrefin-la sauge	2	185	Westschweizerische gewasser	10
45	Delémont	2	186	Wohlen	4
46	District aigle	4	187	Yverdon-champittet	4
47	Dübendorf	2	188	Zug	2
48	Egg-stirzental	6	189	Zug-sumpf	7
49	Estavayer-le-lac	30	190	Zurich-alpenquai	8
50	Fällanden	3	191	Zurich-bauschanze	2
51	Ferden-goppenstein	4	192	Zurich-grosser-hafner	4
52	Font	6	193	Zurich-kleiner-hafner	1
53	Font-la pianta	8	194	Zurich-wollishofen	21
54	Freimettingen-im schlief	6	195	Vertical lines	148
55	Gampelen-witzwil	7	196	Zigzag	18
56	Gärtensberg bei wil	3	197	Open circle	11
57	Geneve	6	198	Nested circle	43
58	Geneve-jonction	2	199	Circle row	13
59	Geneve-les eaux vives	18	200	Circle block	41
60	Geneve-l'ile maison buttin	2	201	Circles connected	35
61	Geneve-maison buttin	1	202	Torsion	41
62	Geneve-paquis	4	203	False torsion	20

(*Continued*)

Table 2 Continued.

Vertex No.	Site	No. connected vertices (degree)	Vertex No.	Site / decoration type	No. connected vertices (degree)
63	Genfersee	4	204	Iron inlay groove	5
64	Glattfelden	5	205	Punched dots	6
65	Gletterens	7	206	Open triangle	19
66	Gordola	3	207	Hatch triangle	35
67	Gossau-altenberg	1	208	Open tram	49
68	Grandson-corcelettes	48	209	Hatch tram	57
69	Greifensee-station wildsberg	1	210	Cross hatch tram	12
70	Grenchen-breitenfeld	1	211	Hatch space	2
71	Guévaux	10	212	Hatch triangle arc	3
72	Hauterive	21	213	Linear dd	73
73	Hauterive-champréveyres	10	214	Half circle	20
74	Iongny	2	215	C half circle	44
75	Kanton Valais	4	216	Deep tram	19
76	Kerzers-grosses moos	2	217	Zigzag hatch	3
77	Lac neuchatel, bienne, morat	5	218	Divided circle	9
78	Lavey	11	219	Check	17
79	Lens-chelin	3	220	Herring	47
80	Lit du rhône	10	221	Open diamond	5
81	Locarno	1	222	Hatch diamond	5
82	Locarno-san joiro	9	223	diagonal lines	65
83	Löhningen-gehr	4	224	X	29
84	Mägenwil-stägler-hau-haberüti	3	225	Edge scallop	1
85	Maienfel-flur bunte	1	226	Chevron	43
86	Meikirch	1	227	Eye	8
87	Meilen-schellen	2	228	Eye dot	7
88	Mels-heiligkreuz	8	229	Outer eye	4
89	Montet	5	230	Adjacent opposed hatch triangle	17
90	Montet-glâne	5	231	Cross hatch cross	2
91	Montreux	11	232	Diamond	3
92	Montreux-terrasse de rouvenaz	2	233	Nested diamond	2
93	Montreux-vernax dessous	5	234	Diamond dots	1
94	Moosseedorf	7	235	Nested triangle	10
95	Morges	28	236	Ribbing	41
96	Mörigen	28	237	Horn	1
97	Muntelier	10	238	Long curve	13
98	Muri-lindenhof	5	239	Zigzag dd	2
99	Murtensee	15	240	Cross hatch field	0
100	N-A	29	241	Diagonal block	16
101	Neftenbach	2	242	Nested zigzag	17
102	Neuchatel	12	243	Short curve	17
103	Neuchâtel-le crêt	5	244	Curved chevron	14
104	Neuenburgersee	6	245	Dotted tram	25
105	Neuhausen am rheinfall	3	246	Sinewave	2
106	Nidau	22	247	Cross hatch	1
107	Nidau-steinberg	4	248	Opposed hatch triangles	10
108	Nyon	15	249	Offset hatch triangle	4
109	Oberriet-montlingerberg	12	250	Catepillar	5
110	Ollon	7	251	Half dot	0
111	Ollon-carrière du lessus	15	252	Zigzag wave	1
112	Ollon-charpigny	8	253	Hatch v	1
113	Ollon-st. triphon	2	254	Adjacent opposed hatch	13
114	Onnens	17	255	Adjacent parallel hatch	1
115	Orpund	17	256	Hatch cross	3
116	Pont-en-ogoz	1	257	3d zigzag	6
117	Port	2	258	Seperated multi zigzag	13
118	Portalban	4	259	Hole	6
119	Pruntrut	9	260	Ridge	12
120	Rheinau	1	261	Divided wave	2
121	Rickenbach-oberholz	1	262	Circle dot	7
122	Riddes	4	263	Arch tram hatch	6
123	Ried-guggemärli	2	264	Spiral	1
124	Rovio	1	265	Triangle dash	2
125	Saillon	3	266	Cross zigzag	1
126	Saint blaise	1	267	Curve dash line	5
127	Saint leonard	2	268	Oposed open triangle	2
128	Saint-brais	2	269	Offset x	0

(*Continued*)

Table 2 Continued.

Vertex No.	Site	No. connected vertices (degree)	Vertex No.	Site / decoration type	No. connected vertices (degree)
129	Saint-prex	4	270	Cross	1
130	Saint-prex-coulet	2	271	Outer circle loop	2
131	Saint-prex-coulet prés st prex propriété treuhardt	4	272	Dot triangle	0
132	Saint-prex-la moraine	7	273	Triangle arch circle	0
133	Salins	1	274	Hanging bead	0
134	Savièse	1	275	Waterbird	0
135	Savognin-padnal	5	276	Star	0
136	Saxon	1	277	Small dot	0
137	Schleitheim	3	278	Point dots	0
138	Schlieren	4	279	Daisey	0
139	Schlieren-bundendal	1	280	Large dot	0
140	Schweiz	2	281	Zigzag dot	0
141	Sierre	3			
Mean	**16.8**				
Mode	**1**				
Median	**8.5**				

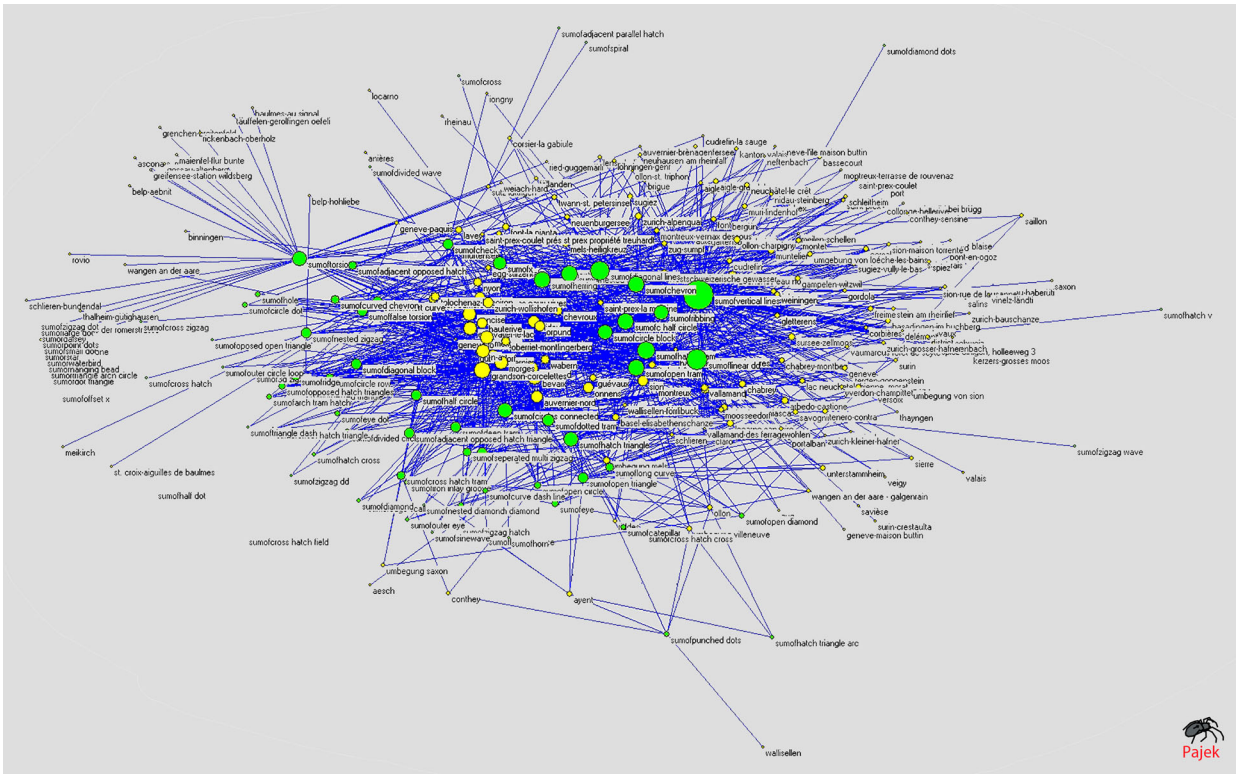

Figure 4 Complete data of decoration element (dark/green vertices) : sites (light/yellow vertices), energized with Kamada-Kawai function to arrange vertices by degree (number of connected vertices). Vertex point size is scaled according to the number of other vertices to which they are connected.

(mean degree is 16.8, Table 2), and connections (lines) with a weight or value <2 (equates to a single instance at a site) were removed, thereby significantly reducing the overall network display (Figure 5). These values were selected to exclude single instances of decorative motifs at a site, which could, for instance, have occurred through isolated trade and exchange or movement of individuals without reflecting a significant level of interaction, or represent failed experiments by workshops. Although the upper threshold was chosen based on the mean, it does include the vast majority of decorative elements, and only excludes those which obscure potential patterns due to their abundance; it is possible to argue for a lower upper threshold given that several high outliers push the mean significantly higher than the median (but this is not explored here). Thresholding data in such a manner is a common practice in network sciences (and other data-based disciplines) in order to reduce the volume of data interrogated at any one time.

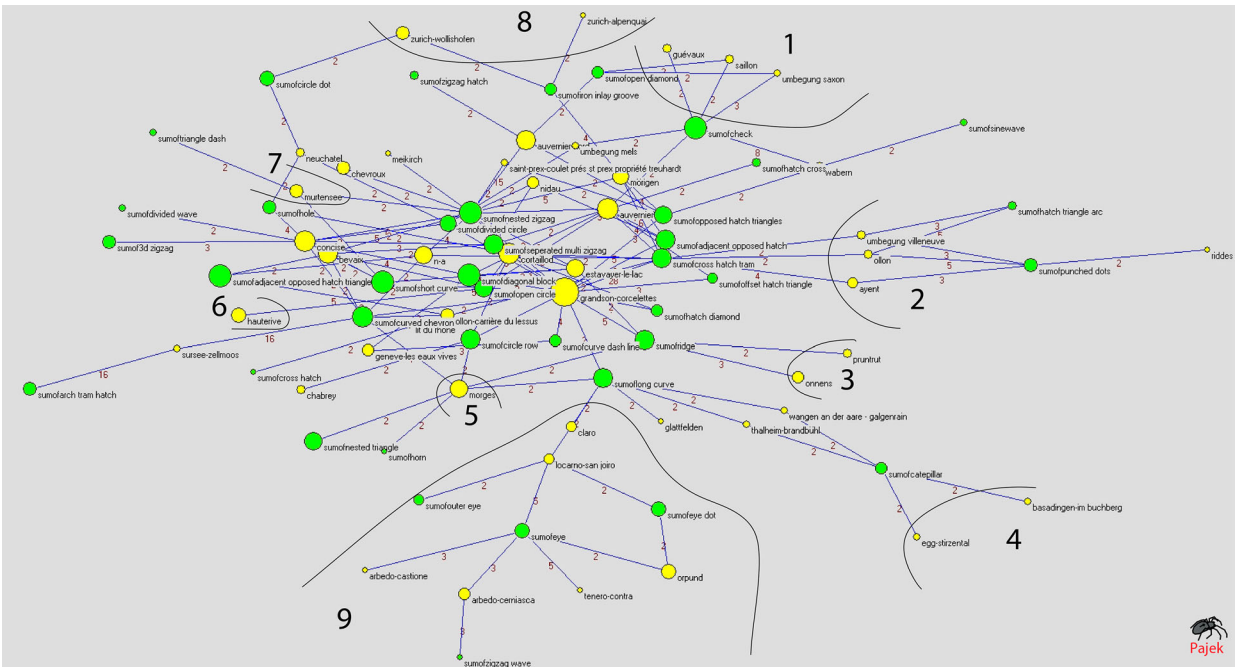

Figure 5 Visualization of reduced decoration element (dark/green vertices) : site (light/yellow vertices) network. Decorative elements connected to > 17 sites (degree greater than 17) removed as prominent elements; connections/lines of weight < 2 removed as rare or isolated occurrences. Vertex size relates to number of connected vertices, numbers adjacent to lines indicate total number of occurrences of that connection.

However, such actions can also influence the form of networks subsequently analysed through restricting the initial input data used to generate that network, effectively creating a cyclical effect (Peeples and Roberts Jr 2013). The focus here is to emphasise the low to medium value connections; removal of the higher value connections does not significantly impact upon the interpretation. The reduced network visualization highlights a number of factors regarding the occurrence of decorative elements at specific sites, particularly when the layout is energized (using Kamada-Kawai function in Pajek) (Nooy, Mrvar, and Batagelj 2011) to fix the vertex positions, with those vertices with more connections in the centre, and the less well connected at the outside (Figure 5).

Addressing those elements at the outer edge of the graph, it is apparent that some decorative forms occur at single sites, in low numbers, e.g. two 'Divided wave' at Concise, or higher quantities, e.g. the 16 'arch tram hatch' at Sursee-Zellmoos. In fact, the items at Sursee-Zellmoos are so similar, other than very slight variations in the decorative elements used, to other objects of the *Cortaillod* type that they have been classified as a sub-variant (Pászthory 1985). These elements of restricted circulation in multiple quantities may reflect the artistic preference or practices of specific manufacturers, or commissioners, in certain areas. Referring to the network including links of value 1, the 'arch tram hatch' motif is present at five further sites (Table 3), which are not spatially clustered. The spread of these sites across a broad area, and in both the eastern and western lake-dwelling regions, which are typically seen as having limited interaction

Table 3 All connections to decoration type 'Arch Tram Hatch', including those of single occurrences, which do not appear in Figure 5.

Site	Quantity	Site number (Figure 2)
Estavayer-le-Lac	1	68
Grandson-Corcelettes	1	96
Lavey	1	114
Orpund	1	162
Sursee-Zellmoos	16	215
Zurich-Wollishofen	1	280

and exchange of bronzework (Rychner 1979; Rychner and Kläntschi 1995), suggests they may have been produced by different artisans, and not the product of a sole itinerant craftsman (or school), or were included in low intensity trade.

In addressing factors of bronzework circulation and the development and maintenance of community and artisanal preferences for decorative elements, it is interesting to consider terminal sites and network branching. Terminal sites are those connected to a single decorative scheme (and thereby other sites, as indeed are all sites), but with the single connection marking the isolation of the site from other decorative traditions and communities. Conversely, gateway sites – those participating in the use of otherwise mutually exclusive decoration traditions – lead to branching of the network and the isolation of one decorative combination or tradition from another. Such branching and termination highlights the occurrence of decorative elements at isolated site clusters – sites which participate in the use of decorative combinations not seen

elsewhere in the network – thereby indicating cultural or community preference for specific emblems.

Network graph Figure 5 demonstrates several such terminal sites and branching (marked), for instance:

1) Guévaux, Saillon and vicinity Saxon, are terminal sites connected to 'check' decoration, and thereby to Auvernier, Wabern, vicinity Mels. Of the primary three sites, vicinity Saxon and Saillon are also connected to decoration scheme 'Open diamond' and thereby Auvernier-Nord.
2) Ayent, Ollon, and vicinity Villeneuve are connected to decoration schemes 'punched dots' and through 'Cross hatch tram' to Mörigen, Cortaillod, Grandson-Corcelettes and Ollon-Carrière du Lessus. Of the primary three sites Ollon and vicinity Villeneuve are also connected to terminal decoration 'Hatch triangle arc'.
3) Sites Pruntrut and Onnens are terminal sites connected to 'Ridge' decoration, and thereby to Estavayer-le-Lac, Grandson-Corcelettes, and Morges.
4) Egg-Stirzental and Basadingen-im-Buchberg have 'Catepillar' decoration, and are linked thereby to Wangen an der Aare-Galgenrain and Thalheim-Brandbühl, which are in turn connected to 'long curve' and thereby Grandson-Corcelettes, Morges, Claro, Glattfelden, and Locarno-San Joiro.
5) Morges is quite a significant site, with connections to five decorative schemes: 'Circle row', 'Curved chevron', 'Nested triangle', 'Horn', and 'Long Curve', and through these motifs to many other sites. Similarly significant sites are Bevaix and Concise, connected to numerous forms of decoration.
6) Hauterive has a relatively strong connection (five instances) to the scheme 'Open circle' but shows no other connections of greater than single weight.
7) Murtensee (objects from Lake Murten without specified find location) is connected to the 'Triangle dash', 'Nested zigzag' and 'Short curve' decorative scheme, and thereby to many terminal sites in western Switzerland.
8) Zurich-Alpenquai is connected to 'Iron inlay groove', and thereby to its immediate neighbour Zurich-Wollishofen, and, in western Switzerland, Mörigen. Zurich-Wollishofen also bridges to Neuchâtel (likely lake finds) via 'Circle dot'.
9) A distinct sub-branch of the network is visible on its lower edge, extending from the 'Long curve' scheme to Claro and Locarno-San Joiro, thereby to the 'Outer Eye', 'Eye dot' and 'Eye' schemes, to sites Arbedo-Castione, Arbedo-Cerinasca, Tenero-Contra, and ultimately to the motif 'Zigzag wave'.

Each of the decorative schemes represented in these clusters also has numerous connections of single strength to various other sites (Figure 6), but the stronger connections to certain sites may indicate the products of specific artisans or developments of stylistic schools. When considering the occurrence of decorative motifs in association with artefact typology, it is evident that variance in motif distribution is partly influenced by the occurrence of ring types which incorporate specific or unique motifs (see distribution maps in Jennings 2014b; Pászthory 1985; Rychner 1979). Some motifs occur on numerous ring types, demonstrating their continuance across stylistic development and citation of different forms. The occurrence of these elements at sites in low quantities may well be indicative of an itinerant model of production, with artisans producing low numbers of items at a relatively broad range of sites.

Combining network science and cultural geography

It is also possible to visualize the artefact decoration network in relation to the approximate geographic location of sites (Figure 7). Setting the graphic co-ordinates of the vertices on an ordinal scale against an actual map background positions them in their approximate relative real-world positions (Nooy, Mrvar, and Batagelj 2011), and converting the two-mode network to a single-mode network results in the direct connection of sites based upon the number of co-occurring decorations. Again, the full network data produces a rather clustered visualization; the removal of connections with value less than three (i.e. one or two different co-occurring motifs) results in a more readily discernible network (Figure 7). Three was selected as the lower threshold because many of the types of ring-jewellery found in burials (particularly in southern Switzerland and the Alpine Rhône valley), occur as matched paired items (Pászthory 1985) – this may result in a proliferation of low intensity connections between sites based on the occurrence of one or two objects in burials. While such items do provide indications of cultural connections between sites and areas, they may be the result of individual mobility or trade, not necessarily manufacture and production circles or cultural preferences for specific designs.

Considering specifically the network branch to the lower edge of the graph (Figure 5, point 9 above), it is clear that the majority of these sites are located in the southern Alpine region (Figure 7). Orpund stands out as a northerly site with the multiple representation of 'Eye' and 'Eye dot' designs, which also occur in singular values at Stein am Rhein, Lavey in the Alpine Rhône valley, in the Rhône valley near Geneva, and an unspecified location from a lake in western Switzerland (Lake Geneva, Neuchâtel, Murten or Biel). The southern associations are predominantly driven by the occurrence of several ring types, but only the occurrence of *Pourrières* type, mainly found in eastern France and with similarities to the north Italian *Zerba* type (Jennings 2014b, 124; Pászthory 1985; Rubat Borel 2009), drives

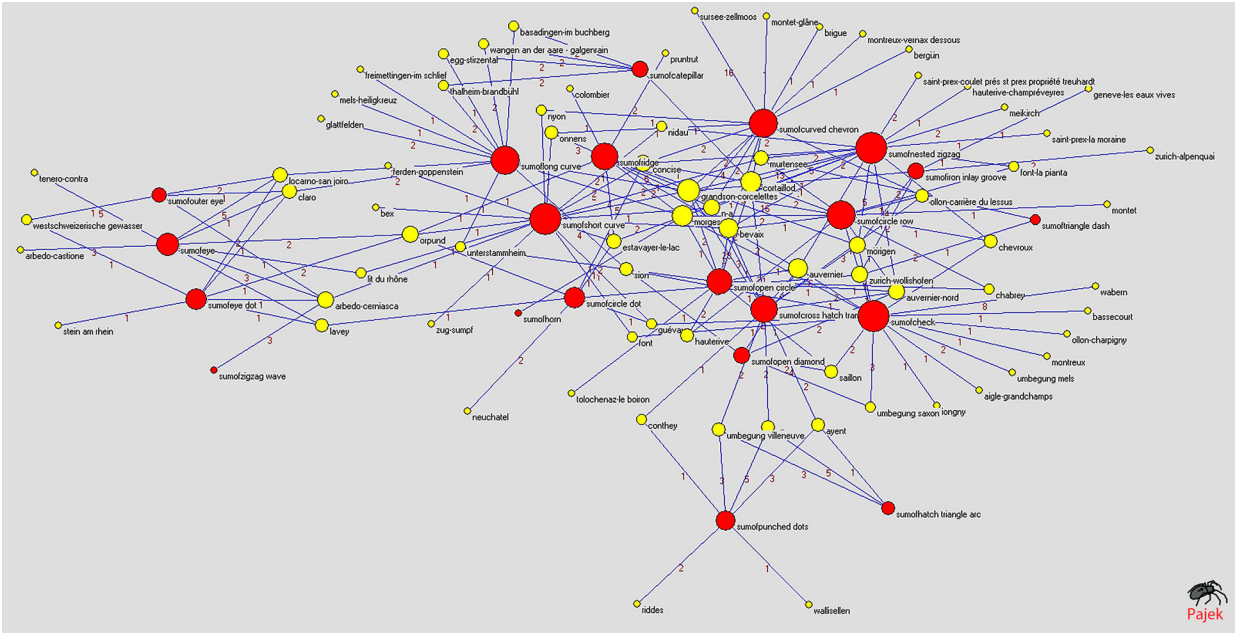

Figure 6 Network of all connections (including value 1) for the decoration element (dark/red vertices) : site (light/yellow vertices) identified in points 1–9. The branching of 'eye' decoration in the southern Alpine region is evident, as is the relative peripheral position of sites such as Zurich-Alpenquai and Zurich-Wollishofen, even though they represent a greater number of decoration types, these are only at low quantities. The site Sursee-Zellmoos now displays greater number of co-connected sites, through 'curved chevron'.

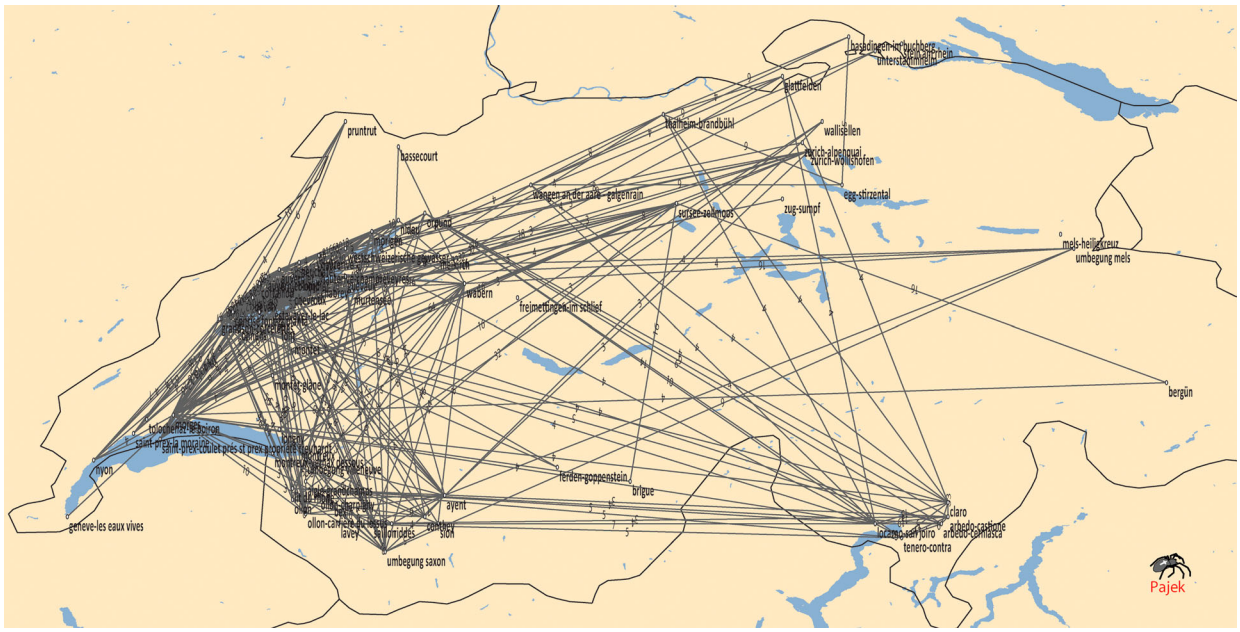

Figure 7 One-mode network of all sites connected to the decoration types listed in points 1–9. The decoration type vertices have been removed, directly connecting sites where the same emblems occur. The vertices are in their approximate geographic positions. It is evident that the sites around Lake Neuchatel (centre left) are particularly well connected through the co-occurrence of emblems, as are the sites in the southern Alps (bottom right), though they are well connected to the Alpine Rhine valley (lower centre). Interestingly there appears to be a stronger connection / similarity in design motifs to those in the Neuchatel region than other sites in eastern Switzerland (right).

the connection to Orpund. Thus, it is possible to suggest that the southern Alpine communities were exploiting different decorative elements as methods of social identity construction and affiliation compared to their northern Alpine counterparts. Some exchange of materials and concepts did however occur, as can be seen through the occurrence of designs along the Rhône valley (which may have been exploited as a trade and mobility route) towards Lake Geneva (Figure 7).

The occurrence of objects with 'Iron inlay groove', a category which is used to describe the use of small quantities of iron as decorative inlay on bronze objects, at two neighbouring sites in Zurich bay and at Mörigen in western Switzerland, represent one of the most restricted forms of decoration. Including single instances of this decoration from Geneva-Les Eaux Vives and Grandson-Corcelettes (both western Switzerland) raises the total to only 10 instances (of ring-jewellery), which are spread across a wide area. The use of a novel material (iron) as decorative inlay required the application of new working techniques, and may represent the use of a rare (in the LBA) material to provide indicators of status (Jennings 2014b, 163–164; cf. Snodgrass 1980). Such use of iron in the northern Alpine forelands is not confined to ring-jewellery, but is also recorded on swords, knives and needles (Bauer 2002; Berger 2011; Bernatzky-Goetze 1987), and so falls within a wider, but still limited in quantity, pattern of exploitation. Given the extra knowledge and skills required to produce objects with such decorative inlays, it may be possible to consider that these items (within Switzerland) were produced either by a single artisan/school, or by separate schools in the eastern (Lake Zurich) and western (Lake Neuchâtel) regions, with circulation though trade and exchange from those sites.

At the opposite end of the scale, some sites are particularly well represented both within single categories of decoration, and by the total number of decorative schemes, for instance Mörigen and Grandson-Corcelettes. These sites may be seen as production and/or market centres with more permanently resident metalwork producers (though not necessarily 100% specialized and producing metalwork continually), as also suggested by the quantities of casting moulds found at these settlements (Bernatzky-Goetze 1987; Jennings 2014b, 161–165). The strong dominance by Auvernier & Auvernier-Nord, Cortaillod, Estavayer-le-Lac, Grandson-Corcelettes and Mörigen of relatively disassociated motifs (Figures 5 & 6) demonstrates that even though these sites are within the same region, and broadly contemporaneous occupation, there are different preferences within the less prevalent decorative schemes. Thus, each site may have been served by different resident artisans, and the use of motifs may have been exploited to create a unique social identity. Moving to Lake Zurich, both Zurich-Wollishofen and – Alpenquai are rather separated from the Neuchâtel region sites, employing motifs not used by the above detailed production centres. Again, this may represent the occurrence of separate resident artisans in the Zurich area, and also a different social identity exploiting alternative motifs (which can also be seen in the preference for different ring-jewellery types, see Jennings 2014b, 124–144; Rychner 1979, and cultural typology, see Rychner 1998b and Figure 2).

One further point of interest is the apparent isolation of Egg-Stirzental (Figure 7, upper right) from other nearby sites. Connections instead link it to sites further north and west than its closer neighbours around Lake Zurich. This is a possible reflection of temporal differences, with Egg-Stirzental having late Middle Bronze Age (MBA) and early LBA (BzD) type ring-jewellery, while the lake-dwelling sites on Lake Zurich relate to the later LBA (HaA-HaB). Thus, the isolation of this site cannot be purely equated to differences in the selective use of decorative elements or ring types. Indeed, the exploration of temporal influences on the network of design motifs is one aspect requiring further investigation. The full influence is difficult to assess with the data used for analysis here, which consists primarily of Late Bronze Age ring-jewellery types. Expansion to include further forms of metalwork decoration, or comparison with a dataset based upon ceramic decorations would provide a complementary analysis and permit greater insight of the temporal variation in decoration tradition networks. However, it must be remembered that ceramic decoration forms, for instance, can cover vast time spans and draw influence from multiple sources (e.g. Blanco-González 2015).

Identifying site groupings by dissimilarity modelling

Exploiting network science techniques, it is possible to view the same data in the geographically arranged graph (Figure 7) in different formats. The production of a block model (Nooy, Mrvar, and Batagelj 2011), for instance, demonstrates the high co-occurrence of designs around Lake Neuchâtel, Lake Biel, and Lake Murten in western Switzerland (Figure 8). There is, however, somewhat of a separation between sites a) Guèvaux, Hauterive & Hauterive Champréveyres, Montet & Montet-Glâne, and b) Mörigen, Murtensee, Neuchâtel, Nidau, and Onnens. This could be a result of subtle differences in the occupation period of these sites. Moving to the Lake Geneva area, some separation is evident between sites located on the northern shore of the lake, those on the southern side (Geneva-Les Eaux Vives) and those of the western edge (Jongny and Montreux). This may be the result of cultural and stylistic affiliation, with Geneva isolated and looking towards eastern and southern France in cultural style, while the western sites show more connections to sites in central Switzerland and the Alpine Rhône valley (cf. Rychner 1998b). Sites in southern Switzerland are internally associated, and also show links to some sites in the Alpine Rhône valley, in addition to some further afield in central Switzerland and the Neuchâtel area, specifically to Grandson-Corcelettes. In fact, Grandson-Corcelettes clearly has the most connections from all of the listed sites, which would fit with its designation as a Late Bronze Age production and manufacturing centre (Jennings 2014b). In contrast, another large LBA site deemed to be a significant centre – Mörigen – does not appear to be so well connected. This could be a reflection of the general decline in prevalence of material culture and sites

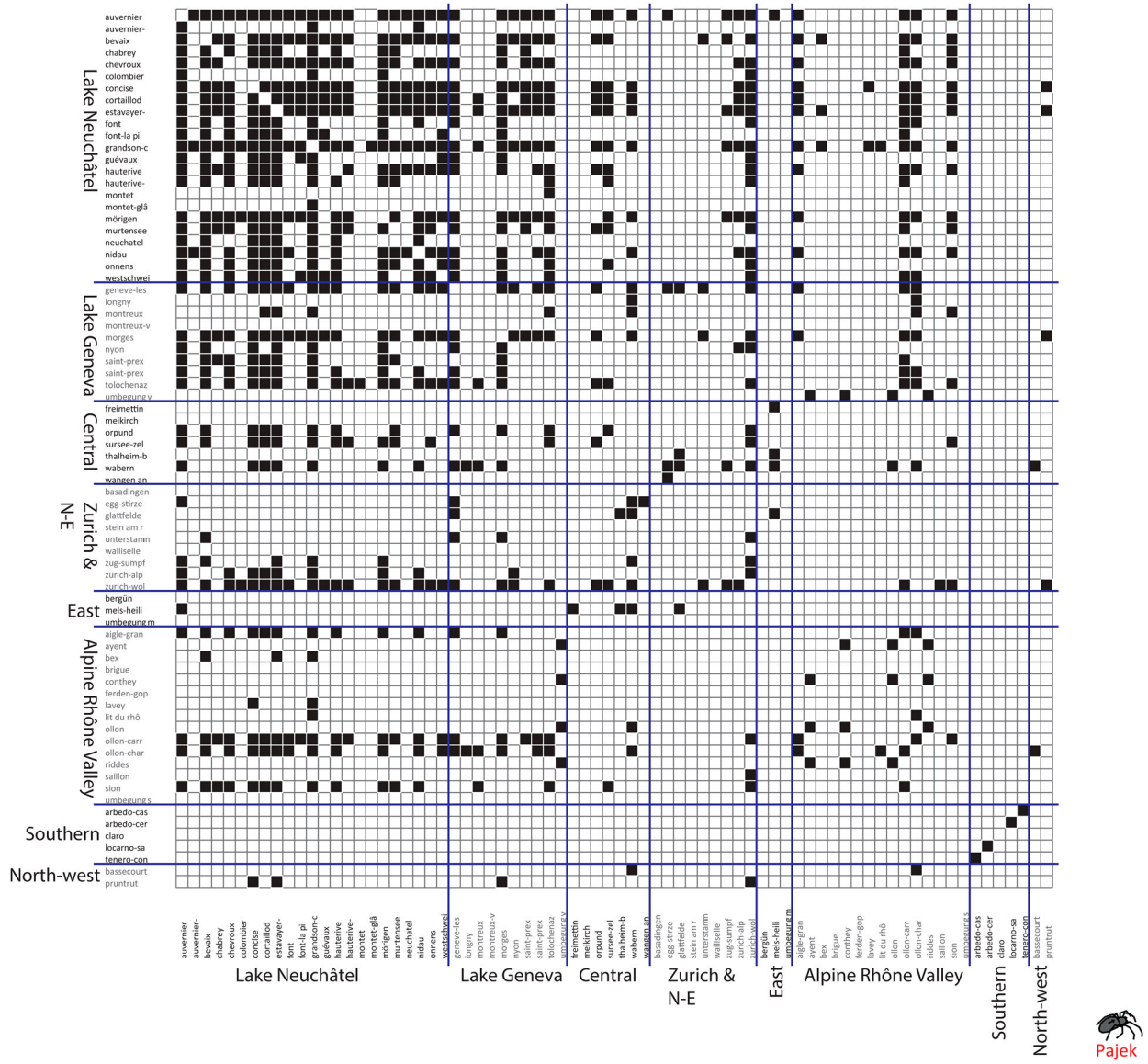

Figure 8 Block model of network illustrated in Figure 7. Squares represent a binary (black = present; open = absent) direct connection between sites – based on the co-occurrence of decoration types. Vertices are grouped based on their approximate geographic regions (labelled on axis), spatially defined by location clustering without reference to archaeological cultural and typological interpretation (see Figure 2, Rychner 1998b), while other regions are more disconnected. Sites in southern Switzerland are internally highly connected, with distinct affiliations to other sites in the Alpine Rhône valley, and isolated instances further afield in central Switzerland and the Neuchâtel region.

from the final stages of the LBA in Switzerland (Hochuli, Niffeler, and Rychner 1998), or an indication that it was not as significant as the former site. However, such binarization of the data does not reflect the true situation; a valued block matrix (Figure 9) shows that the connection between Grandson-Corcelettes and southern Switzerland is very weak when compared to those links occurring in the region of Lake Neuchâtel. The influence of cultural selection and artisan school on the co-occurrence of motif was greatest in the local neighbourhood of sites.

Dissimilarity / similarity hierarchies provide another method by which the sites can be grouped according to the (dis)similarity of their respective wider connectivity (Nooy, Mrvar, and Batagelj 2011). The hierarchy generated from the same data presented in Figures 8 and 9 (generated using Dissimilarity d1 in Pajek) suggest that 8 or 9 (depending on break level) distinct clusters can be observed (Figure 10), which are divided into two main branches. One of the clusters (labelled A in Figure 10) consists primarily of sites from the Neuchâtel region, indicating that they are more similar to each other than sites in different regions. Closely linked to this cluster is a second (B), again consisting of primarily sites from Neuchâtel. These two clusters form their own separate branch, and contain c. 50% (12 of 23) of all sites from the Neuchâtel region. The second branch contains the remainder of sites. Division into clusters identifies an isolated group (C) in which sites from southern Switzerland form the core component of a cluster also including some sites from central Switzerland and the Rhône valley. A

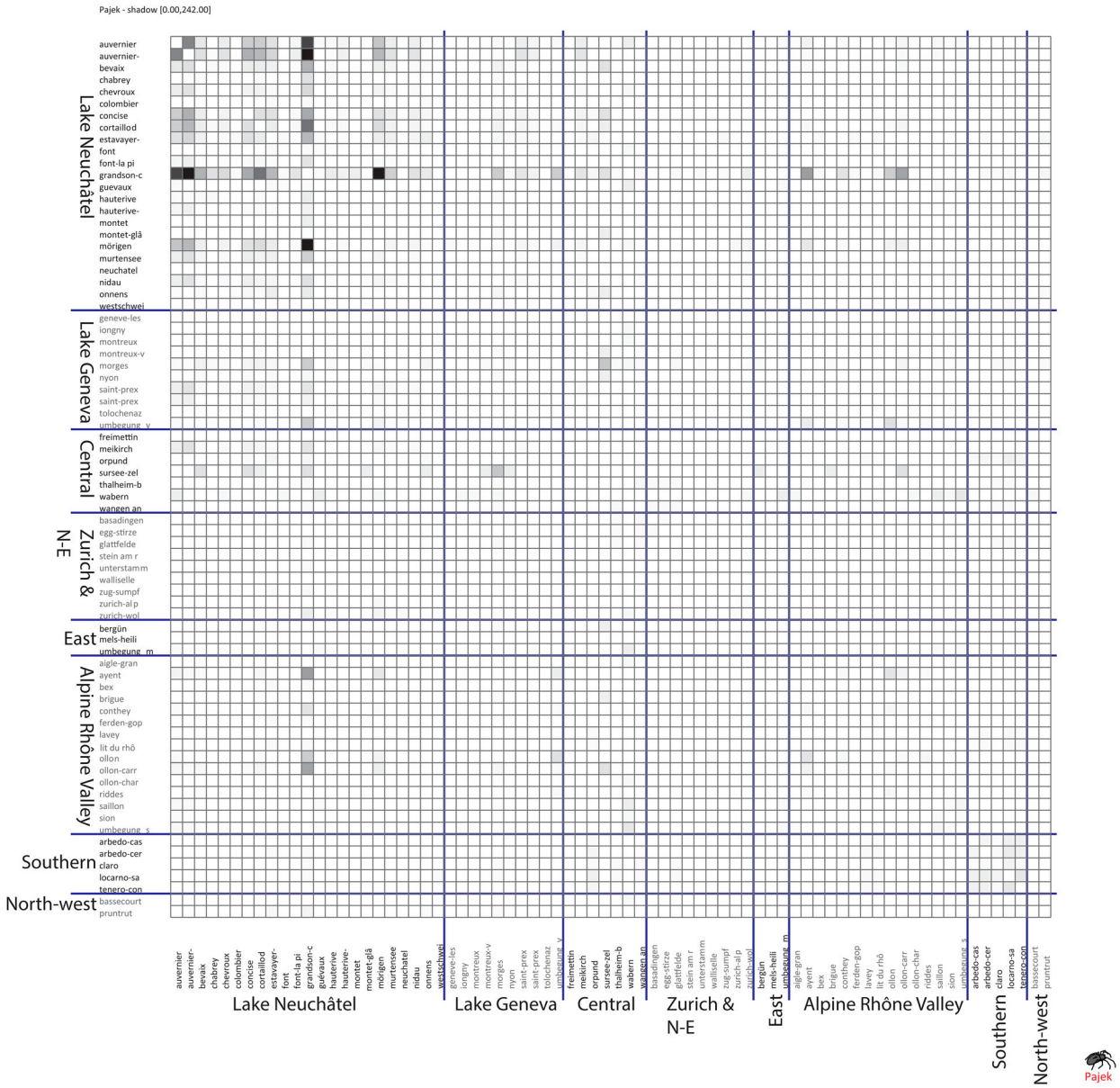

Figure 9 Graduated network block matrix, based on same data as Figure 8, but using valued connections to give graduated presence / absence of connection. Boxes greyscale shaded according to number of connections between site; greater numbers of connections result in darker shaded boxes. Clearly the most intensive co-occurrence occurs in the Lake Neuchâtel region.

larger sub-branch of the group contains a cluster of sites from the Rhône Valley (D), two large (E & F) and one small (G) cluster containing sites from a range of locations without clear domination by one region (but c. 40% of E is from the Neuchâtel region, accounting for 25% of total Neuchâtel region sites), a small cluster dominated by sites from Lake Zurich and north-east Switzerland (H), and one small subdivision consisting of one site from the Rhône valley and one site from central Switzerland (I). The overall insight given by the hierarchy is that the sites primarily divide into clusters based on their region, with sites being more similar to others in their vicinity than those at greater distances; clusters E and F are primary exceptions to this pattern. Returning to the consideration of the production networks, cultural preferences for specific styles, and artisan traditions, it is possible that the primary unique clusters include those sites which formed core areas and production centres, while the more mixed clusters consist of those sites which occurred towards the boundary of cultural and community zones, resulting in a combination of traditions and preferences under influence from varied cultural pressures and incorporation in multiple exchange and production communities. Referring back to the map of typological cultural regions in Switzerland (Figure 2), it is evident that different cultural traditions are recognizable in each of the main zones identified as clusters of (dis) similarity.

A dissimilarity hierarchy for the same sites based upon co-occurrence of ring types also identifies a number of clusters (Figure 11). The main factor illustrated by this hierarchy is, however, the distinct

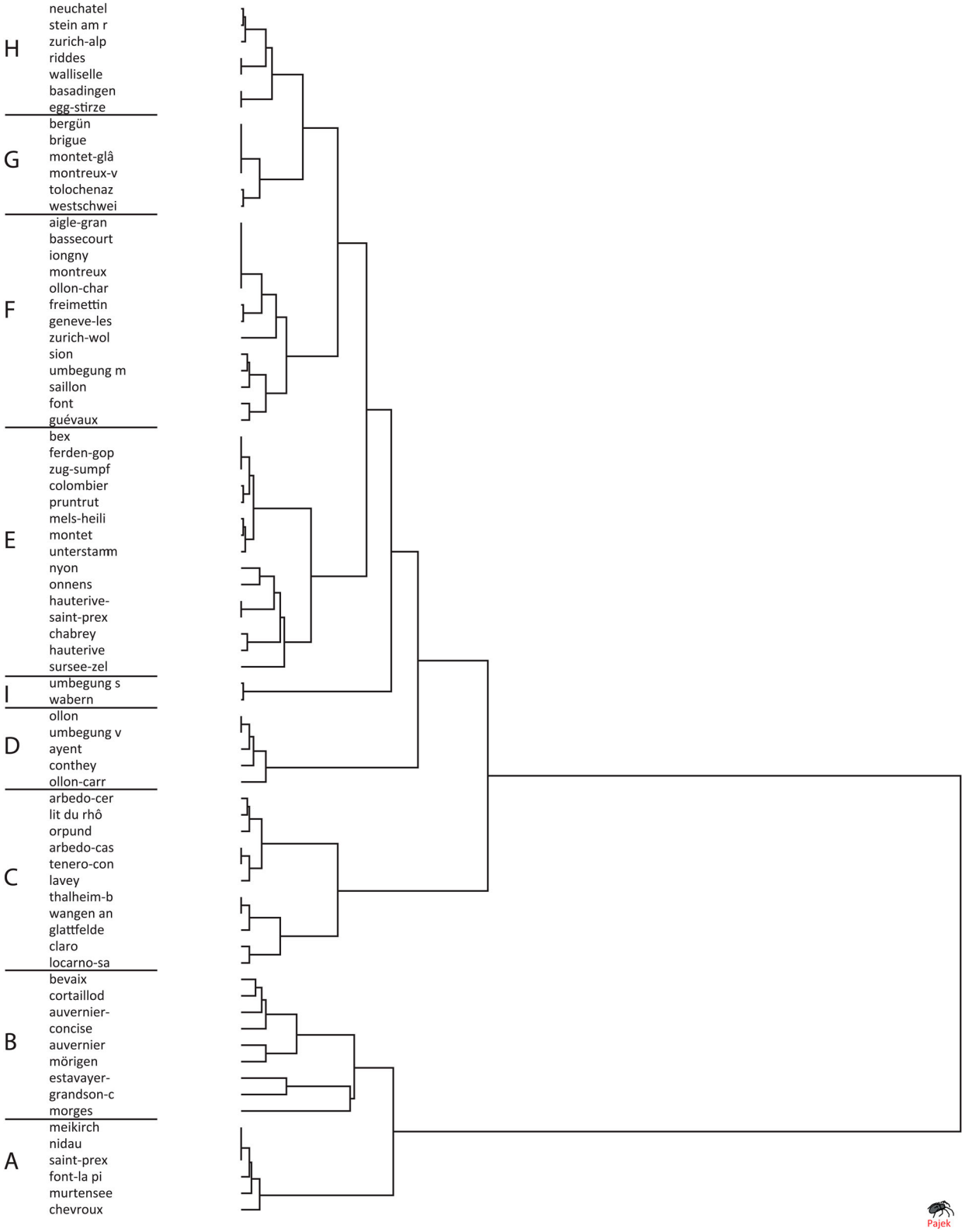

Figure 10 Hierarchy of dissimilarity of sites connected by co-occurrence of decorative elements, based on same one-mode network as Figure 8. In the dissimilarity hierarchy, sites (vertices) are ascribed relative values based on the similarity of their network structure – the similarity of their range of connections – to each site in the network. Sites are grouped according to the similarity of their profiles, and placed in a hierarchy with greater similarity identified by branching closer to the left side of the figure. The further towards the right branching occurs equates to greater dissimilarity between sites' connection profiles. The hierarchy demonstrates that regional clustering is well evidenced, with the co-occurrence of design elements occurring in nearby settlements, and increasing dissimilarity corresponding to increasing distance.

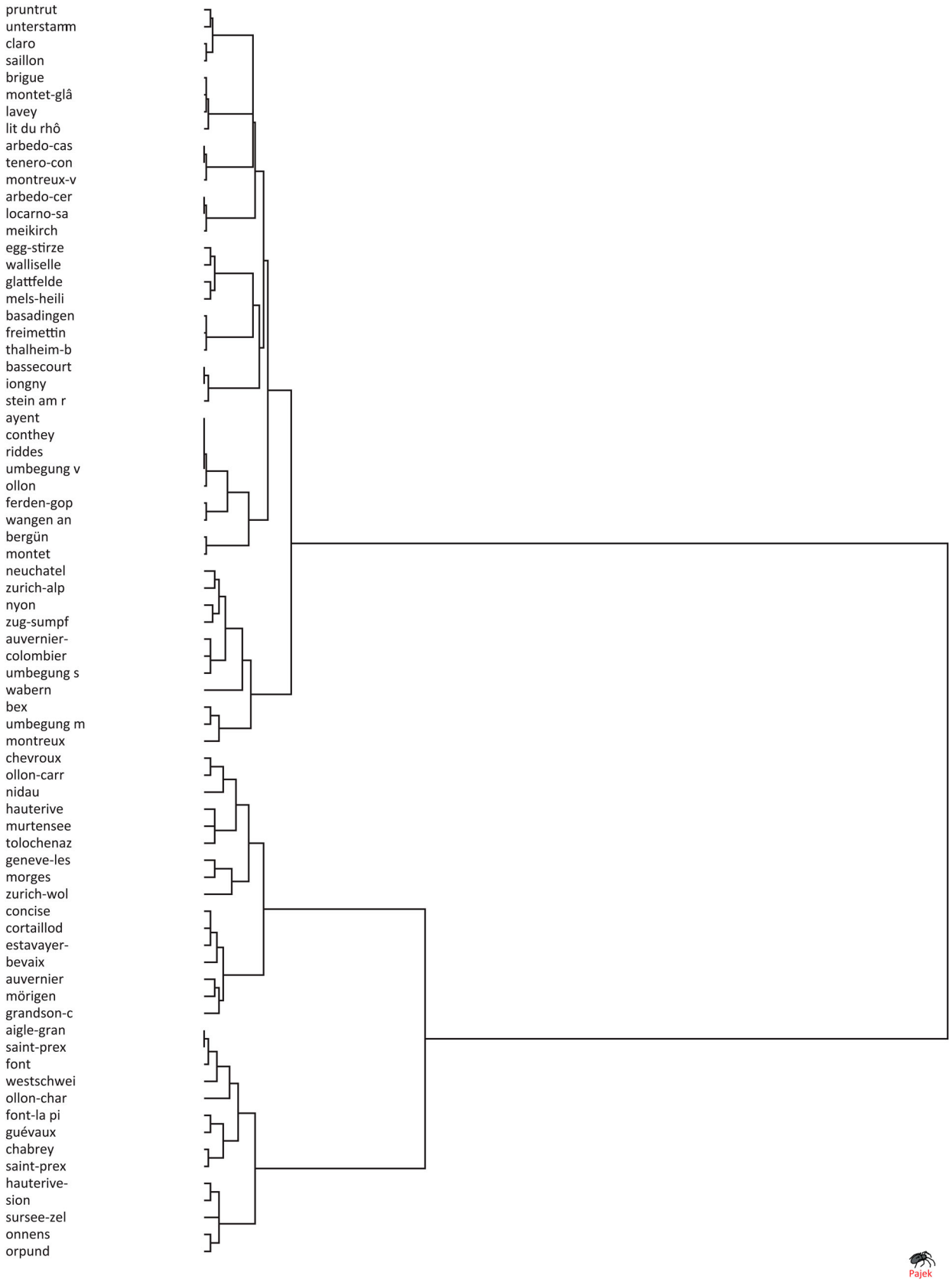

Figure 11 Dissimilarity hierarchy for one mode network of sites connected by co-occurrence of ring-jewellery type. A greater branching of the network is evidenced, but a broad regionalization and clustering of sites with those in proximity as opposed to greater distance is observable in the co-occurrence of jewellery types.

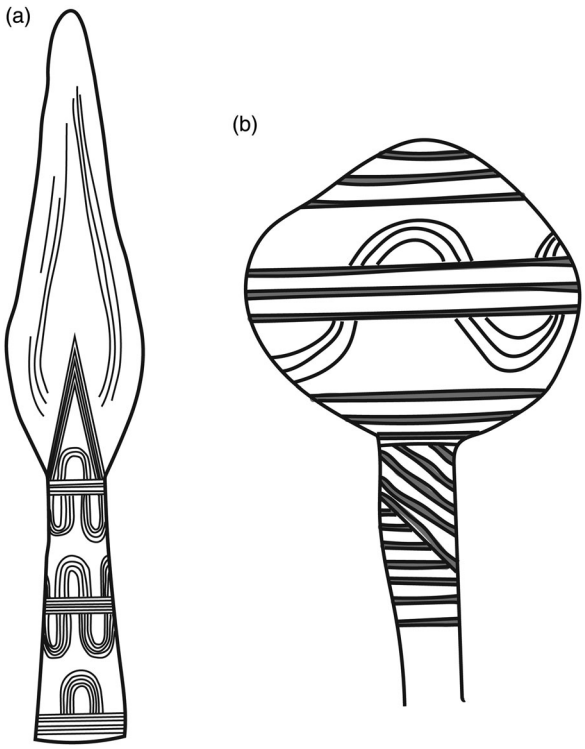

Figure 12 Examples of decorative citation. The 'divided wave' motif is more frequent on spearheads (a, from Cortaillod) than jewellery pins (b, from Zurich-Alpenquai) (images not to scale, and redrawn from Mäder 2001, plate 3.20; Tarot 2000, no. 112).

difference between sites located in the west of Switzerland (primarily Lake Neuchâtel, Lake Biel, Lake Murten, and Lake Geneva) compared to those in other regions of Switzerland. This phenomenon is evident in the material culture typology (Rychner 1979). Sub-clustering by locality is further recognizable in these two broad regions.

Conclusions: visualising production and stylistic networks

This paper began with the relatively broad aim of shedding light upon systems of metalwork production in Bronze Age, particularly Late Bronze Age, settlements of the northern Alpine forelands. Instead of focussing on metallurgical or typological analysis of objects, it was proposed that specific decorative elements may provide indications for the production of objects by individual artisans, or collective groups employing the same motifs ('schools'), and that the distributed occurrence of emblems may indicate whether production was conducted at centralized manufacturing centres or dispersed under an itinerant artisan model. Catalogue publication of many BA objects provides a significant data resource which can be utilized, but viewing such an array in tabular or database format, notwithstanding their ease of manipulation, can be problematic and is not necessarily conducive to clarity of comprehension. To visualise the relationships between occurrence of decorative elements, sites, and artefact typology, the graph production capabilities of Social Network Analysis software, in this instance Pajek (other applications are available, see Huisman and van Duijn 2005), were exploited. Reducing the quantity of vertices and links drawn on individual graphs (essentially the same as querying and filtering a database), aspects of motif : site : typology interaction, which may be not readily recognisable from tabular or catalogue data alone, become evident.

However, the production of a visual graph does not provide the interpretation itself, but only a means to identify data requiring the application of a theoretical model to make sense of the archaeologically obtained information. The network graphs, primarily addressing a relatively large dataset of arm- and leg-ring jewellery, and the geographical distribution of artefacts lend support to the principal that specific design elements were favoured or exploited by certain artisans/schools and stylistic traditions, and also that some of the large LBA lake-settlements formed production and manufacturing centres responsible for sustaining the metalwork consumption needs of surrounding sites. It is also possible that itinerant artisans were producing metalwork for a dispersed community. Furthermore, it is evident that practices of 'similar-but-different' were exploited by communities, and particularly evident during the LBA, when societies were symbolising a common broad cultural and artistic framework within the Urnfield 'culture', but modifying small elements of material culture to retain differences both within the broader region and within local

societies. Previous studies of Late Bronze Age ceramics (e.g. Bauer, Ruckstuhl, and Speck 2004; Gross 1986; Seifert 1996) have suggested that various lake-settlements were using assorted decorative designs and ceramic types as methods of local identification. Similar patterns can be observed in the broad ring-jewellery typologies, with certain types being abundant at some sites while rare at others (Jennings 2014b; Pászthory 1985; Rychner 1979). The influence of temporal spread, with the cyclical abandonment and rise to predominance of different settlements, cannot be entirely discounted as significant factor in such distribution patterns. The network analysis suggests similarities and the adoption of stylistic traditions at a broader scale than individual sites, but not fully in alignment with the proposed 'cultural affiliations' of the region (Figure 2). Further research on ceramic traditions and similar network analysis will contribute to enhancing the findings from the ring jewellery production network.

A briefly touched upon aspect which can be addressed through the same method is the occurrence of decorative elements across various object categories. This has been influenced by Andrew Jones' (2007) discussion of "citation", "retention" and "protention" – the transfer of decorative features and styles from one class of objects to another – and seeks to visualize how object categories are connected to each other through the co-occurrence of specific design elements. One of the best examples encountered in the preparation of the database for this study, but not directly discussed with in the network analysis due to a focus on ring-jewellery, is the use of the 'Divided wave' scheme (Figure 12), which is prominent on spearheads but a very rare occurrence on rings. Thus, it may be possible to interpret the cross-exploitation of emblems as the visual citation of spearhead symbolism on ring-jewellery, with the corresponding citation of social identity (possible 'warrior' identity) and cultural meaning by the jewellery wearer. The choice to incorporate unusual design elements on new objects – another term would be artistic skeuomorphism – is a dual action led by both the bronzesmiths and the consumers. On the one hand, producers follow the community traditions and stylistic preferences, while on the other hand the consumers drive the market for acceptance and incorporation of objects into meaning laden cultural symbolism. Without consumer acceptance some design transfers or evolutions may never be incorporated in to the wider material culture assemblage (cf. Miller 1982). Thus, the transfer of designs from one class of object to another not only reflects broader cultural affiliations and production traditions, but also the expression and recombination of social identities. In the same manner that fragmentation of objects was potentially used to presence past identities and times (e.g. Chapman 2000; Jennings 2014a), the citation of objects through design elements could have been used to evoke and recombine social identities and/or status strongly linked to the primary (original) medium and use of decoration. The task requiring greater consideration is the comprehension of those identities; equating, for example, swords or spears to a warrior status/identity is a simplistic interpretation which does not incorporate the multiple and diverse nature of prehistoric identity (Brück and Fontijn 2013). Unfortunately, the majority of artefacts used in this study are known from lake-dwelling excavations, with limited direct contextual information; comprehending the associations of objects and design elements necessitates close context information of the sort offered by burial assemblages. The network analysis here has provided some directions for future consideration, and focus on the burial assemblages of the region will begin to shed light on the potential identity associations of objects and design.

The dataset analysed herewith is primarily composed of arm- and leg-rings, but the nature of the database construction and Pajek software means that expansion is a relatively easy prospect. Indeed, the many catalogues of Bronze Age objects from across Europe, particularly under the *Prähistorische Bronzefunde* series, provide a significant and readily available dataset. The study highlights the benefits of applying network science methodologies to permit visualisation of connections and structure within a large dataset. It is with the ambition of creating a large dataset that the true potential of the method can be observed. To return to Jones' (2007) principles of "citation", "retention" and "protention", if a pan-European dataset, covering many decorated object classes and typologies, could be achieved, it may be possible to visualize European wide networks of decorative citation (e.g. the "folded ships" on Nordic spearheads and their transformation in central Europe, see Kaul 1998, 165–169), with the benefit of dating and chronological analysis to suggest which regions may have been origin areas for specific designs. Such a network of connections would provide myriad avenues to approach the creation of community identities and routes of interaction and exchange across Europe throughout prehistory, with the ability to focus on small regions or zoom out to the broader picture.

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Statement of Significance

Bronze Age research frequently discusses trade and exchange routes, production networks, and the existence of multiple social identities, but is frequently

hindered by the limited archaeological resource providing exceptionally brief windows on isolated aspects of past societies. The application of network science methodologies can provide insights to the structure of prehistoric interaction networks. Previous artefact studies have provided a rich catalogue of data concerning Bronze Age artefacts from across Europe, which can be utilized as a raw dataset for such network approaches. A macro-scale approach, focussing on the occurrence of decorative elements on Bronze Age ring-jewellery, highlights the potential for network analysis to illuminate prehistoric networks of production, cultural expression, and identity construction.

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