***УДК** 903'13(4-11)"636"*

*Vita Antiqua,
№ 10, 2018, p. 126-134*

***Aleksandr Diachenko**[1]*

Geographic determinism and Trypillia contact networks, c. 3600 – 3400 BC

This paper deals with the Trypillya sites in Western Volhyn, c. 3600 – 3400 BCE aiming to answer the question of the influence of geographic determinism on the formation of long-distance interactions. Simulation of networks, which correlates with the available empirical evidence, has shown the openness to innovations provided by the structure of Trypillya networks that shared the modified innovations in pottery styles from the entire region further to the east. The frontier between the Funnel Beaker culture and Trypillya complex, despite its peripheral location, therefore, may be viewed as the 'cultural incubator'. High intensity of interactions caused the hybridization of Trypillya traditions during a period of c. 100 years, while this 'cultural epidemics' is, probably, to a great extent caused by influences from the neighboring cultural units.

Key words: *network analysis, contact networks, 'cultural epidemics', Trypillya, Funnel Beaker culture, Western Volhyn*

Introduction

Geographic determinism causes the unequal informative potential of archaeological records. Preservation of artefacts made of different raw materials, especially organics, varies from region to region and from one time period to the other. Unlike wetland sites with their assemblages of archaeological data, ecofacts, detailed absolute chronologies, settlements belonging to numerous cultural units of prehistoric Europe are characterized by significant gaps in representation of the remote past in material remains preserved till nowadays. This requires the search for analytical tools filling such gaps. Geographic determinism, obviously, influenced not only the preservation of archaeological data, but also human behavior in prehistory causing the choices for settlement locations, subsistence strategies and framing the trans-regional interactions in the remote past. The related set of issues may be approached by the application of network analysis, which is widely applied in mathematics, physics, computer sciences, theoretical ecology, sociology, epidemiology and other fields of science. Graph theory and networks are not new in archaeology, but they have experienced a significant revival recently (e.g. Brughmans, 2010; 2013).

This paper deals with the Trypillya contact networks in Western Volhyn, c. 3600 – 3400 BCE, aiming to answer the question of the influence of unequal distribution of raw materials on the formation of Trypillya networks and 'cultural incubators' within them (the term is introduced in Crema and Lake, 2015). First, the paper introduces the theoretical and mathematical background of contact networks. Second, this study briefly overviews Trypillya complex and provides an insight into the case study. Third, trans-regional interactions of the Trypillya and Funnel Beaker culture (hereinafter – FBC) are discussed within a context of innovations flow through the Trypillya contact networks.

Contact networks

Graph theory, including the network analysis, is a field of discrete mathematics that deals with the properties of graphs. A graph consists of a series of vertices or nodes connected with the edges. Depending on the type of edges graphs could be directed, undirected or semi-directed, weighted or non-weighted. In directed graphs information, energy etc. flows from one node to the other only in certain direction, while in semi-directed graphs information between two nodes flows in both directions. In weighted graphs strength of tiers between the vertexes is additionally measured providing the weight of edges expressed in digits. One of the relatively recent topics in graph theory is the study of complex networks with non-trivial topological features, i.e. the features with patterns of connection between their elements that are neither purely regular, nor purely random (Albert and Barabasi, 2002). Different networks have different statistical properties. The most commonly used statistical parameters of networks are the degree centrality, the closeness centrality, and the betweenness centrality (Albert and Barabasi, 2002).

[1] Institute of Archaeology of the NASU

Degree centrality is equal to the number of edges that are linked to a node (in other words, the number of bonds that a node has). Closeness centrality is the number of other vertices divided by the sum of all distances between the vertex and all the others. Betweenness centrality is the proportion of all shortest paths between pairs of other vertices that include this vertex (de Nooy 2005, *et al.*: 127-131).

The concept of contact networks capturing the patterns of interactions that can lead to the transmission is being actively developed in epidemiology. Locations are translated into vertexes, and contacts among the locations are translated into edges. Disease or cultural transmission will propagate through the network where the Poisson distribution of contacts is replaced by the structure of the contact network (Meyers, 2007: 69-70). Analogy between the spread of an epidemic and the diffusion of innovations is striking (Doran, 1975; de Nooy *et al.*, 2005: 161-181). This similarity is based upon a number of variables – e.g. the total number of population, the number of individuals that are infected by a disease, the donors, the number and strength of the structural links between donors and recipients, and the degree of susceptibility to diseases, or, in our case, innovations (Anderson and May, 1980; 1991; Newman, 2002; Proulx *et al.*, 2005; Keeling and Eames, 2005; Shirley and Rushton, 2005; May and McLean, 2007).

The model proposed by Meyers (2007) developed in epidemiology have shown a good utility for the analysis of the archaeological contact networks when applied to Trypillya data (Diachenko and Menotti, 2015). The degree distribution of the networks (sites are considered to be the nodes) is always an assumption. The epidemic is possible only when the average transmissibility of a disease (T) is greater than critical transmissibility (T_c). The latter is defined as follows:

$$T_c = \frac{\langle k \rangle}{\langle k^2 \rangle - \langle k \rangle}, (1)$$

$$(\langle k \rangle = \sum_{k=1}^{\infty} k p_k)$$

where $\langle k \rangle$ and $\langle k^2 \rangle$ are, respectively, the mean degree and mean square degree of the network and p_k is the relative frequency of vertices of degree k in the network.

The basic reproductive rate of the disease or the number of secondary infections produced by a single infected host in an entirely susceptible population (R_0) equals to the average number of occupied edges emanating from a vertex:

$$R_0 = T\left(\frac{\langle k^2 \rangle - \langle k \rangle}{k}\right), (2)$$

If the transmissibility of a disease equals the epidemic threshold, then R_0=1. However, estimates of R_0 that assume a mass-action model may be invalid for populations with non-Poisson contact patterns (Meyers, 2007: 73-74). The probability for the individual vertex to be infected and the probability that an outbreak sparks an epidemic are explained in equations 3 and 4 respectively.

$$\varepsilon_k = 1 - (1 - T + T_u)^k, (3)$$

where ε_k is the probability for the individual vertex to be infected, and k is the degree of vertex. T_u is the probability that the disease is transmitted, but does not proceed into an advanced epidemics.

$$E = 1 - \left(\frac{\sum_{k=1}^{\infty} k p_k (1 - T + T_u)^{k-1}}{\sum_{k=1}^{\infty} k p_k}\right)^N, (4)$$

where E is the probability for an advanced epidemics, N is the size of the outbreak, and p_k is the relative frequency of vertices of degree k in the network (Meyers, 2007). In our case N represents the number of settlements that already accepted an innovation.

Considering the information, decease or innovations flow through the networks, simulations should also contain the parameter of time. It is possible to achieve by the inclusion of Newman's (2002) model into the analysis. The model is expressed as follows:

$$T = 1 - (1 - r)^t, (5)$$

where r is the average rate of disease-causing contacts between a pair of nodes and t is measured time steps.

Let start the analysis of the impact of geographic determinism on transregional networks of Trypillya populations with the brief overview of this cultural unit.

Trypillya contact networks: The case-study

The Cucuteni-Trypillya cultural complex formed at the north-eastern periphery of the Neolithic and Eneolithic cultural complexes of the Balkans and Danube region, and more precisely in the basins of Siret, Dniester and Prut. Over the course of two millennia its area expanded to become the largest cultural unit in Eastern Europe, occupying the territory from Carpathian Mountains to the eastern bank of the Dnieper, and from the forest zone of modern Ukraine to the north-western coast of the Black Sea (Fig. 1).

The Trypillya complex is divided into two cultures. Tsvek referred the settlements with ceramics mostly characterized by incised ornamentation as the sites of the Eastern Trypillya culture (ETC). For those settlements of the Trypillya complex, which are mostly characterized by painted ceramics, Ryzhov (2007; 2012) proposed the use of the term 'Western Trypillya culture' (WTC). The development of both the ETC and WTC may be described as the permanent colonization of peripheral areas to the North and the East.

 ISSN 2519-4542

Dergachev (1980) determined territorial and 'genetic' links between the sites. The 'genetic' links are the evolutionary chains of material culture development left by population groups at different time. The sites that have similar materials are usually clustered in space and are grouped into types. These types of sites compose the local groups, which form the genetic lines of development of the culture. The WTC and the ETC consisted of several genetic lines of development.

Network analysis is applied to the WTC settlement clusters of Korzhovka-Selisko 2 local group in the northern part of Western Volhyn. If the western part of the Eastern Volhyn was colonized by Trypillya populations relative early (Kruts and Ryzhov, 2000), these groups migrated to the northern part of Western Volhyn only c. 3500 BC (Kruts and Ryzhov, 2000; Diachenko and Kirilenko, 2016). Let us start the analysis specifying an important methodological issue.

The transmissions are depended not only on network structure, but also on strength of interactions (de Ruiter, 1995; McCann, 2000; May, 2006). The diversity of nodes has to be taken into account as well (Dunne et *al*., 2002; Berlow *et al*., 2004; de Nooy *et al*., 2005; May, 2006; Dale and Fortin, 2010; Fuller *et al*., 2010). The most appropriate way of considering both issues is the application of the gravity model as it was already proposed in theoretical ecology (Xia et *al*., 2004; Ferrari *et al*., 2006; Beaudry *et al*., 2008). This model is also well-known in spatial archaeology over the decades (see Nakoinz and Knitter, 2016 for the most recent overview), including the applications to Trypillya sites (Diachenko and Menotti, 2012; 2015). According to the gravity model, the strength of interactions (*I*) may be defined as follows:

$$I = \frac{P_x P_y}{D_{xy}^a}, (6)$$

Where p_x and p_y are the population values for the settlements x and y, and D_{xy}^a is the distance between them raised to a power of a. Our earlier study has shown that, at least, for the settlements of the WTC in the Southern Bug and Dnieper interfluve, exponent a is equal to 2 (Diachenko and Menotti, 2012; 2015).

Application of the gravity model to regions with distribution of resources, which is close to uniformed, shows appropriate results (Diachenko and Menotti, 2015). Meanwhile, the modelled values obtained for the settlements located in microregions that are rich in, for instance, high quality flint contradict the empirical evidence. This may be exemplified by the Trypillya BII settlement Bodaki in the southern part of Western Volhyn. This site is about 1.5 ha in size, meaning that the population estimates are comparatively low. Meanwhile, according to Tkachuk (personal comment), the percentage of imports found at this settlement reaches 17%. This value exceeds the number of imports that were found at the large settlements in the South Bug and Dnieper interfluve. Most probably, the attractiveness of Bodaki was caused by the specialization of its population in mining flint and producing long blades (Skakun *et al*., 2005). Let us consider the other area characterized by flint-mining in the case study.

Western Trypillya settlements of Korzvovka-Selisko 2 local group are located in both the western part of Eastern Volhyn and eastern part of the Western Volhyn (Kruts and Ryzhov, 2000; Diachenko and Kirilenko, 2016). In the latter region these sites are divided into two phases of development. Settlement Ostrog 1-4 belongs to the first phase of the local group, while settlements Ostrog-Zeman, Novomalin-Podobanka and Khorjev 1 and, probably, cemetery Ostrog-Zeman belong to the second phase (Fig. 2). Sites of both phases are dated in the range of 3500 – 3400 BC (Diachenko and Kirilenko, 2016).

Material complexes of these sites are characterized by significant influences of the Funnel Beaker culture (hereinafter – FBC) traditions (Fig. 3; Rybicka, 2016). The related mutual influences reached Kujawy region in north-western Poland were Trypillya traditions impacted the FBC pottery assemblages (e.g. Kośko, 1981; see Rybicka, 2015 for an overview). Hence, the flow of Trypillya and the FBC traditions through the contact networks of these two cultural units may be taken for the analogy of epidemics. Let us simulate the related possibilities.

Considering the FBC styles 'epidemics' that caused significant influence on Trypillya pottery and taking into account numerous finds of Volhynian flint in Poland (see Rybicka, 2015 for an overview), we could assume the chain of settlements of both cultures related to the flow of raw material or semi-fabricates, which is analogous to the networks of obsidian flow reconstructed by Renfrew and co-authors (1968). Since the actual number of edges for the sites is not known, the network of settlements with four to six edges per vertex with the dominance of six edges per vertex was simulated under the assumption of existence of sites that are not included into the sample. According to the equation 2, the mean degree and mean square degree of the network is estimated as, respectively, 5.25 and 11.56. The critical transmissibility is estimated as 0.45, while the average transmissibility fits the range from 0.55 to 1.

Figure 4 represents the probability of the expected 'cultural epidemics' with the average transmissibility of 0.6, 0.7, 0.8, 0.9 and 1 according to the equation 4. The achieved probabilities correspond to the range between 0.92 and 1. Hence, the simulated network shows extremely high potential to significant transformation of the material culture. Let us now consider the time period required for the 'cultural epidemics'.

Figure 5 represents the dependence of the average rate of disease-causing contacts between a pair of nodes on the number of phases of development according to the equation 5. Each phase lasted ca 50 years (Markevich, 1981; Kruts, 1989; also see: Diachenko and Menotti, 2015). Average transmissibility is equal to 0.6, 0.7, 0.8 and 0.9. The values of the average rate of disease-causing contacts fit the range from 0.6 to 0.9 ($t = 1$) or the range from 0.84 to 0.96 ($t = 2$). The obtained results under the assumption of $t = 2$ correspond to the available empirical evidence. After two phases of development of the Korzhovka-Selisko 2 group the latter is replaced by Khorzhev group highly impacted by the traditions of the FBC and Baden complex (Diachenko and Kirilenko, 2016). Meanwhile, the high average rate of disease-causing contacts requires additional explanation.

The modelled data fits the available empirical evidence well in its part dealing with Trypillya networks. Cultural influences of the FBC, as well as Baden traditions also noted in Western Vholyn are identified as far as at the Middle Dnieper region (e.g. Videiko, 2000; Pozikhovskij *et al*., 2013). Populations of the former region could not only incorporate traditions of their neighbours, but also transmitted them further to the east (Rybicka, 2015). Meanwhile, the FBC settlements in the analyzed micro-region in Western Volhyn are not known. Therefore, the assumption of the FBC and Trypillya settlements chain related to flow of Volhynian flint has to be rejected. The mechanics causing the intensive interactions between populations of the two cultural units may be explained in a different way.

The idea of settlement chain is initially based on hypothesis of the intensive exchange or even trade between the ancient populations, while power law function as a primary mathematical description of the expected pattern simply represents the decrease in relative frequencies of 'imports' with the increase in distance (Renfrew *et al*., 1968). As shown by significant studies in economy, the concept of 'economic man' proposed by Adam Smith is not sufficient for socio-economic relations in prehistory (Polanyi, 1944; Ostrom, 1990). Extraction of Volhynian flint and its further distribution among the FBC settlements in Poland is, most probably, related to special expeditions analogous to ochre and sandstone expeditions of Australian aborigines (Polanyi, 1944). This explanation does not contradict the empirical evidence, at the same time satisfying the model assumptions and outcomes. Because of the openness to innovations and high possibility of 'cultural epidemics' provided by the structure of Trypillya contact networks in Western Volhyn, even sporadic seasonal contacts between 'Tripillians' and the FBC groups could be resulted in significant transformations of material culture.

Conclusion and discussion

Thus, we analyzed the Trypillya contact networks in Western Volhyn. Trypillya settlements of this micro-region are characterized by significant influences from the neighboring cultures. Traditions of the Funnel Beaker culture are especially notable among these influences (Rybicka, 2015). The high intensity of interactions was caused by geographic determinism, or, more specifically, sources of high-quality flint in this area. Extraction of Volhynian flint and its further distribution among the FBC settlements in Poland, most probably, took the shape of special expeditions analogous to ochre and sandstone expeditions of Australian aborigines.

Simulation of Trypillya contact networks well-correlated with the available empirical evidence has shown the openness to innovations supported by the structure of Trypillya networks, which shared the modified innovations in pottery styles from Western Volhyn further to the east. The frontier between the FBC and Trypillya complex, even despite its peripheral location and dispersed populations living in small villages, therefore, may be viewed as the 'cultural incubator'. High intensity of interactions caused the hybridization of Trypillya traditions during a period of c. 100 years, while this 'cultural epidemics' seems to be a great extent caused by the influences from the outside.

Acknowledgements

This paper was made possible by a grant of the National Science Center of Poland awarded to Małgorzata Rybicka (OPUS 8/2014/15/B/HS3/02486). The author is one of the Co-PIs in this project.

References:

Albert R. and Barabasi A.-L., 2002, Statistical mechanics of complex networks, *Reviews of Modern Physics* **74(1)**: 47-97.

Anderson R. M. and May R. M., 1980, Infectious diseases and population cycles of forest insects, *Science, New Series* **210(4470)**: 658-61.

Anderson R. M. and May R. M., 1991, *Infectious Diseases of Humans*. Oxford.

Beaudry F., deMaynadier Ph. G. and Hunter Jr. M. L., 2008, Identifying road mortality threat at multiple scales for semi-aquatic turtles, *Biological Conservation* **141(10)**: 2550-63.

Berlow E. L., Neutel A.-M., Cohen J. E., de Ruiter P. C., Ebenman B., Emmerson M., Fox J. W., Jansen V. A. A., Jones J. I., Kokkoris G. D., Logofet D. O., McKane A. J., Montoya J. M. and Petchey O., 2004, Interaction strengths in food webs: Issues and opportunities, *Journal of Animal Ecology* **73(3)**: 585-98.

Brughmans T., 2010, Connecting the dots: Towards archaeological network analysis, *Oxford Journal of Archaeology* **29(3)**: 277-303.

Brughmans T., 2013, Thinking through networks: A review of formal network methods in archaeology, *Journal of archaeological method and theory* **20(4)**: 623-62.

Crema E. R. and Lake M. W., 2015, Cultural incubators and spread of innovation, *Human Biology Open Access Pre-Prints*: Paper 80.

Dale M. R. T. and Fortin M. J., 2010, From graphs to spatial graphs, *Annual Review of Ecology, Evolution, and Systematics* **41(1)**: 21-38.

de Nooy W., Mrvar A. and Batagelj V., 2005, *Exploratory Network Analysis with Pajek*. Cambridge.

Dergachev V. A., 1980, *Pamiatniki pozdnego Tripolja*. Kishinev. (In Russian)

de Ruiter P. C., Neutel A.-M. and Moore J. C., 1995, Energetics, patterns of interaction strength, and stability in real ecosystems, *Science* **269(5228)**: 1257-60.

Diachenko A. and Kyrylenko A., 2016, Pozdnee Tripolye Zapadnoj Volyni: sostojanie istochnikov i kratkij obzor khronologicheskih skhem, in A. Diachenko, D. Krol, A. Kyrylenko, M. Rybicka, D. Werteletski, *Nowomalin-Podobanka i Kurgany-Dubowa – Osiedla kultury trypolskiej na zachodnim Wolyniu*, 125-32. Rzeszow. (In Russian)

Diachenko A. and Menotti F., 2012, The gravity model: Monitoring the formation and development of the Tripolye culture giant-settlements in Ukraine, *Journal of Archaeological Science* **39(4)**: 2810-17.

Diachenko A. and Menotti F., 2015, Cucuteni-Tripolye contact networks: Cultural transmission and chronology, in A. Diachenko, F. Menotti, S. Ryzhov, K. Bunyatyan and S. Kadrow (eds.), *The Cucuteni-Trypillia Cultural Complex and Its Neighbours: Essays in Memory of Volodymyr Kruts*, 131-52. Lviv.

Doran J. E. and Hodson F. R., 1975, *Mathematics and Computers in Archaeology*. Edinburgh.

Dunne J. A., Williams R. J. and Martinez N. D., 2002, Food-web structure and network theory: The role of connectance and size, *Proceedings of the National Academy of Sciences of the USA* **99(20)**: 12917-22.

Ferrari M. J., Bjшrnstad O. N., Partain J. L., Antonovics J., 2006, A gravity model for the spread of a pollinator-borne plant pathogen, *The American Naturalist* **168(3)**: 294-303.

Fuller M. M., Wagner A. and Enquist B. J., 2008, Using network analysis to characterize forest structure, *Natural Resource Modelling* **21(2)**: 225-47.

Keeling M. J. and Eames K. T. D., 2005, Networks and epidemic models, *Interface* **2**: 295-307.

Kośko A., 1981, *Udział południowo-wschodnio-europejskich wzorców kulturowych w rozwoju niżowych społeczeństw kultury pucharów lejkowatych. Grupa mątewska*. Poznań.

Kruts V. and Ryzhov S., 2000, Tripolye culture in Volhynia (Gorodsk-Volhynian group), *Baltic-Pontic Studies* **9**: 86-110.

Markevich V. I., 1981, *Pozdnetripolskie plemena Severnoj Moldavii*. Kishinev. (In Russian)

May R. M., 2006, Network structure and the biology of populations, *TRENDS in Ecology and Evolution* **21(7)**: 394-99.

May R. M. and McLean A. (eds.), 2007, *Theoretical Ecology. Principles and Applications*. Oxford.

McCann K. S., 2000, The diversity-stability debate, *Nature* **405(6783)**: 228-33.

Meyers L. A., 2007, Contact network epidemiology: Bond percolation applied to infectious disease prediction and control, *Bulletin (New Series) of the American Mathematical Society* **44(1)**: 63-86.

Nakoinz O. and Knitter D., 2016, *Modelling Human Behavior in Landscapes: Basics Concepts and Modelling Elements*. New York.

Newman M. E. J., 2002, Spread of epidemic disease on networks, *Physical Review E* **66**: 016128.

Ostrom E., 1990, *Governing the Commons: the Evolution of Institutions for Collective Action*. Cambridge.

Polanyi K., 1944, *The Great Transformation. The Political and Economic Origins of Our Time*. Boston.

Pozikhovski A., Pasterkiewicz W., Rybicka M. and Verteletskyi D., 2013, Z badań nad problematyką oddziaływań kręgu badeńskiego na wschodnie rejony Wyżyny Wołyńskiej, in O. Pozikhovski, M. Rybicka and J. Rogoziński (eds.), *Pogranicze kultury trypolskiej i kultury pucharyw lejkowatych („Collectio Archaeologica Ressoviensis", t. XXVI)*, 55-74. Rzeszyw.

Proulx S. R., Promislow D. E. L. and Phillips P. C., 2005, Network thinking in ecology and evolution, *TRENDS in Ecology and Evolution* **20(6)**: 345-53.

Renfrew C., Dixon J. E. and Cann J. R., 1968, Further analysis of Near Eastern obsidian. *Proceedings of the Prehistoric Society* **34**: 319-31.

Rybicka M., 2015, Eastern peripheries of the Funnel Beaker culture, in A. Diachenko, F. Menotti, S. Ryzhov, K. Bunyatyan and S. Kadrow (eds.), *The Cucuteni-Trypillia Cultural Complex and Its Neighbours: Essays in Memory of Volodymyr Kruts*, 167-82. Lviv.

Rybicka M., 2016, Ceramika o zachodniej lub południowo-zachodniej afiliacji, in A. Diachenko, D. Krol, A. Kyrylenko, M. Rybicka, D. Werteletski, *Nowomalin-Podobanka i Kurgany-Dubowa – Osiedla kultury trypolskiej na zachodnim Wolyniu*, 125-32. Rzeszow.

Ryzhov S. M., 2007, Suchasnyj stan vyvchennia kulturno-istorychnoi spilnosti Cucuteni-Trypillya, in Yu Ya. Rassamakin and S.M. Ryzhov (eds.), *O. Olzhych. Archeologija*, 437-77. Kiev. (In Ukrainian)

Ryzhov S., 2012, Relative chronology of the giant-settlement period BII–CI, in F. Menotti and A. Korvin-Piotrovskiy (eds.), *The Giant-Settlements of the Tripolye Culture: Formation, Development and Decline*, 79-115. Oxford.

Skakun N. N., 2005, Bodaki – odin iz tsentrov kremneobrabatyvajushchego proizvodstva na Volyni, in N.N. Skakun, E.V. Tsvek, V.A. Kruts, B.I. Mateva, A.G. Korvin-Piotrovskiy, A. Samzun and L.M. Yakovleva, *Archeologicheskie issledovaniya tripolskogo poseleniya Bodaki v 2005 g*., 64-79. Kiev and Sankt-Petersburg.

Shirley M. D. F. and Rushton S. P., 2005, The impacts of network topology on disease spread, *Ecological Complexity* **2**: 287-99.

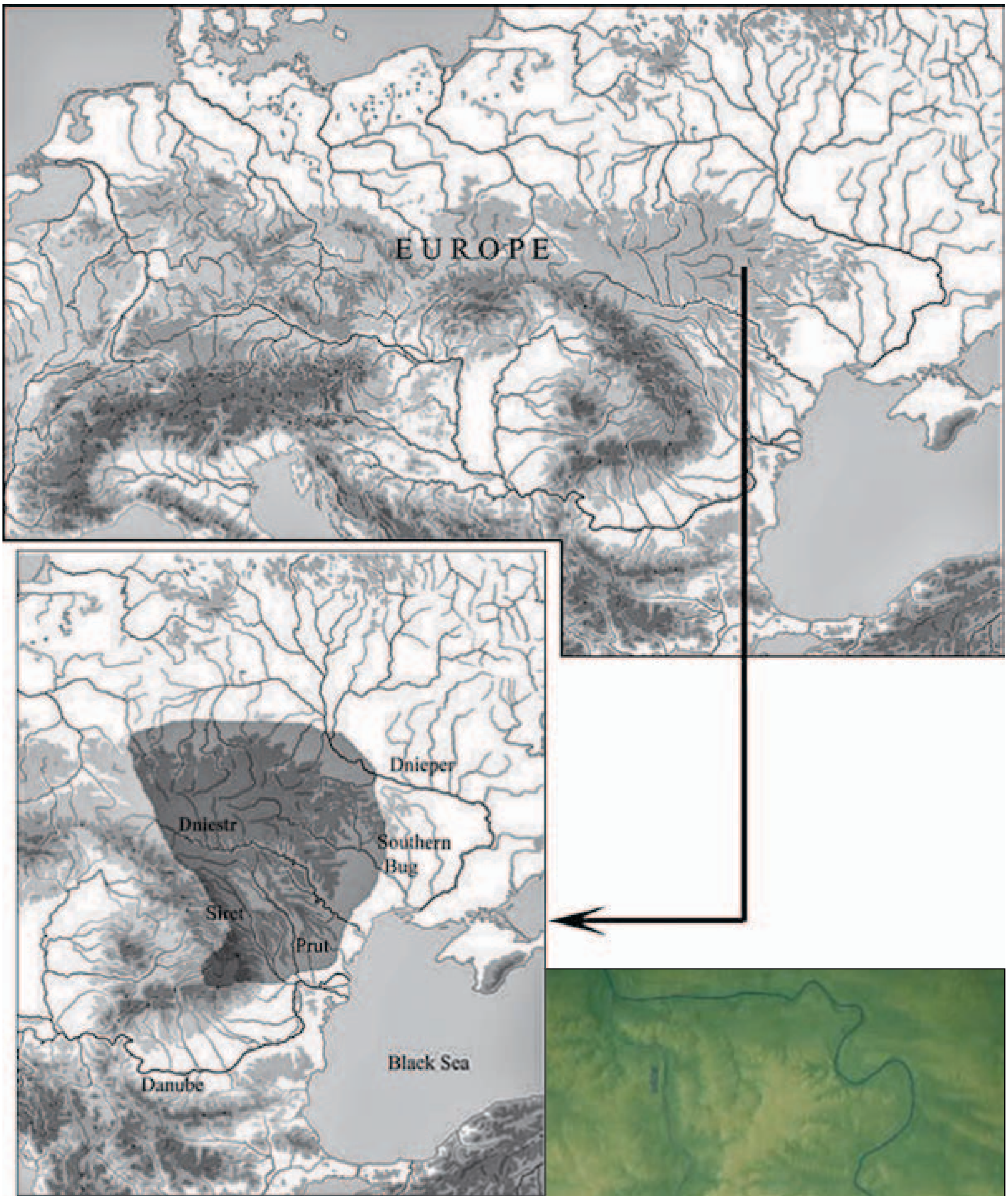
Xia Y., Bjшrnstad O. N. and Grenfell B. T., 2004, Measles metapopulation dynamics: A gravity model for epidemiological coupling and dynamics, *The American Naturalist* **164(2)**: 267-81.

Олександр Дяченко

Географічний детермінізм та трипільські контактні мережі (3600 – 3400 BC)

У статті розглядаються трипільські поселення Західної Волині, між 3600 – 3400 до н.е. з метою відповісти на питання про вплив географічного детермінізму на формування міжгалузевих взаємодій. Моделювання мереж, що співвідноситься з наявними емпіричними даними, показало відкритість до інновацій, що забезпечуються структурою трипільських мереж, які поділяли модифіковані інновації в стилі кераміки з усього регіону на схід. Таким чином, кордон між культурою лійчастого посуду та комплексом Трипілля, незважаючи на периферійне розташування, може розглядатися як "культурний інкубатор". Висока інтенсивність взаємодій спричинила гібридизацію трипільських традицій за період 100 років, а ця "культурна епідемія", ймовірно, значною мірою зумовлена впливами сусідніх культурних одиниць.

Ключові слова: *мережевий аналіз, контактні мережі, "культурна епідемія", Трипілля, Культура лійчастого посуду, Західна Волинь*



▲
Fig. 1. Cucuteni-Tripolye cultural complex.

Fig. 2. Settlements of the Korzhovka-Selisko 2 group in Western Volhyn. ▶

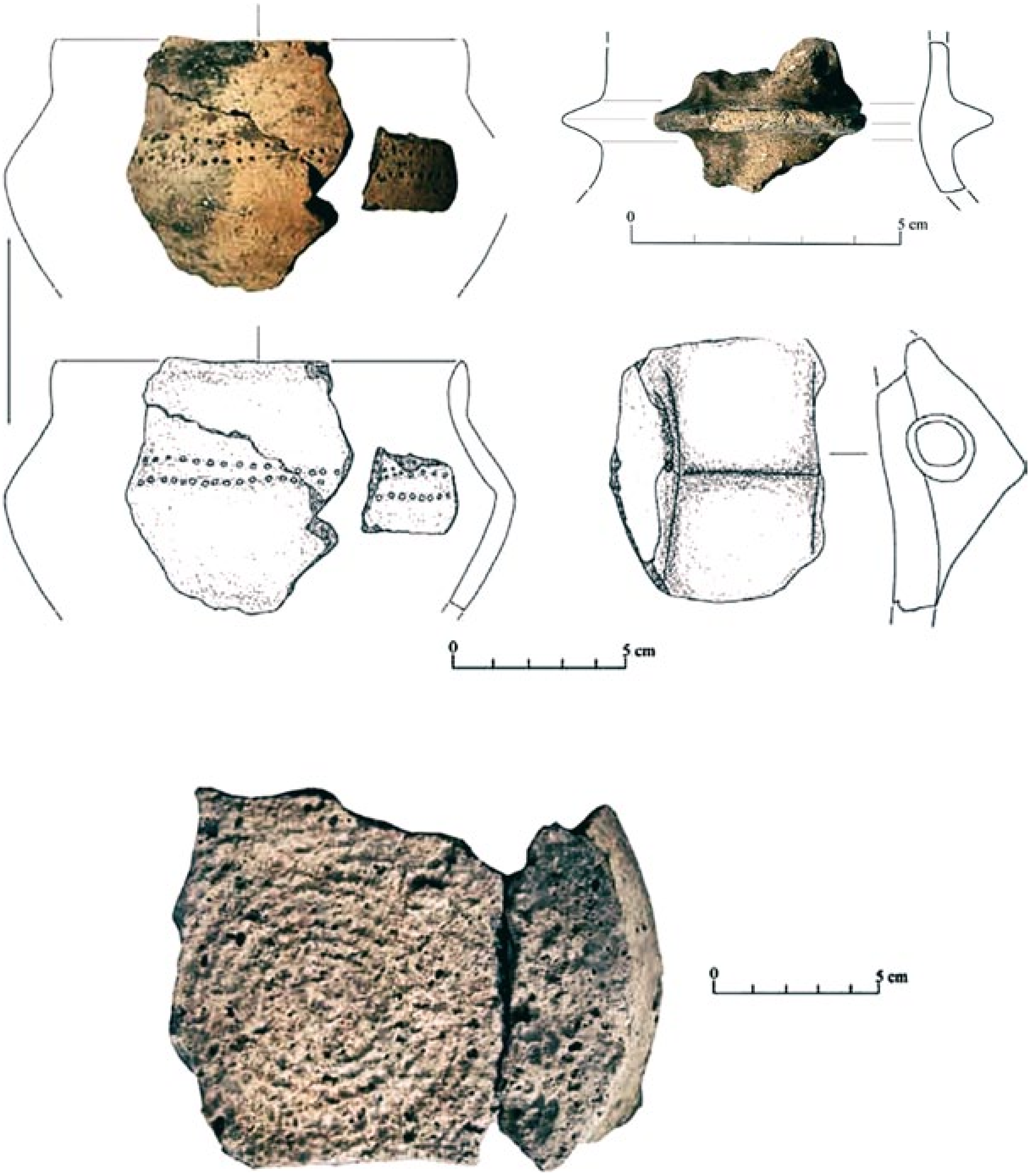


Fig. 3. Ceramics combining the FBC and Tripolye traditions (re-drawn from Rybicka 2016).

 ISSN 2519-4542

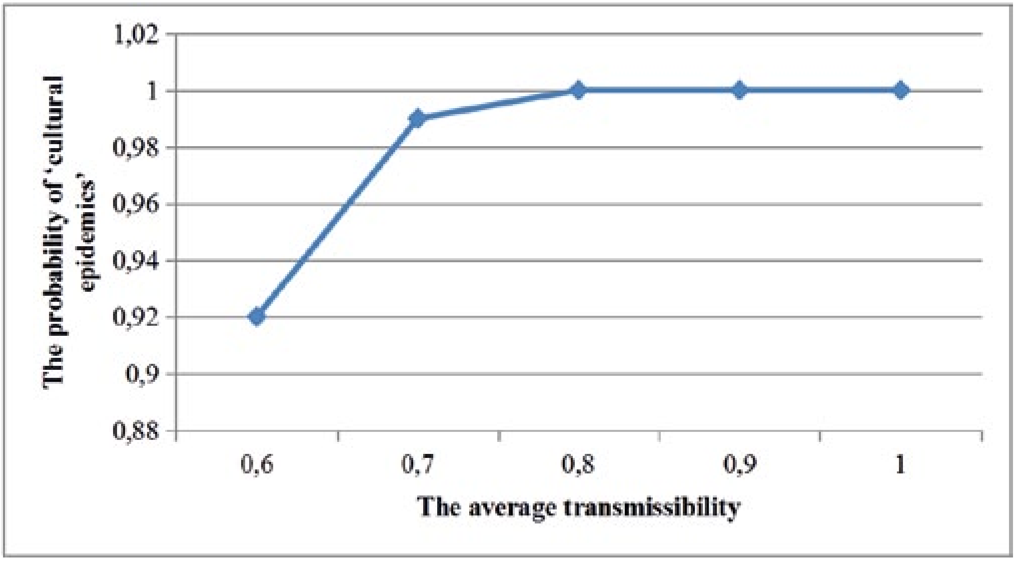
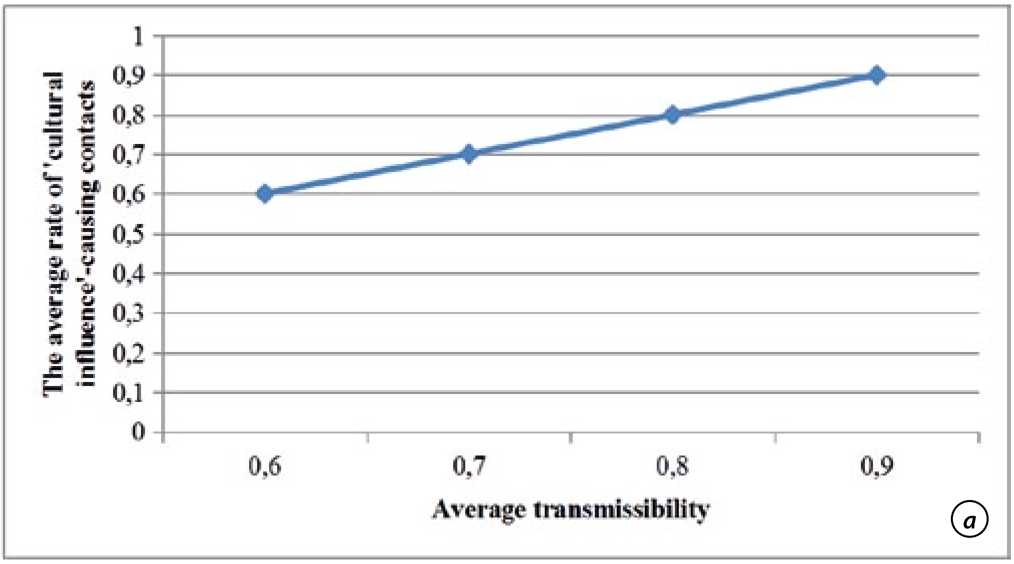


Fig. 4. The probability of 'cultural epidemics' according to the equation 4 (the average transmissibility is equal to 0.6, 0.7, 0.8, 0.9 and 1).



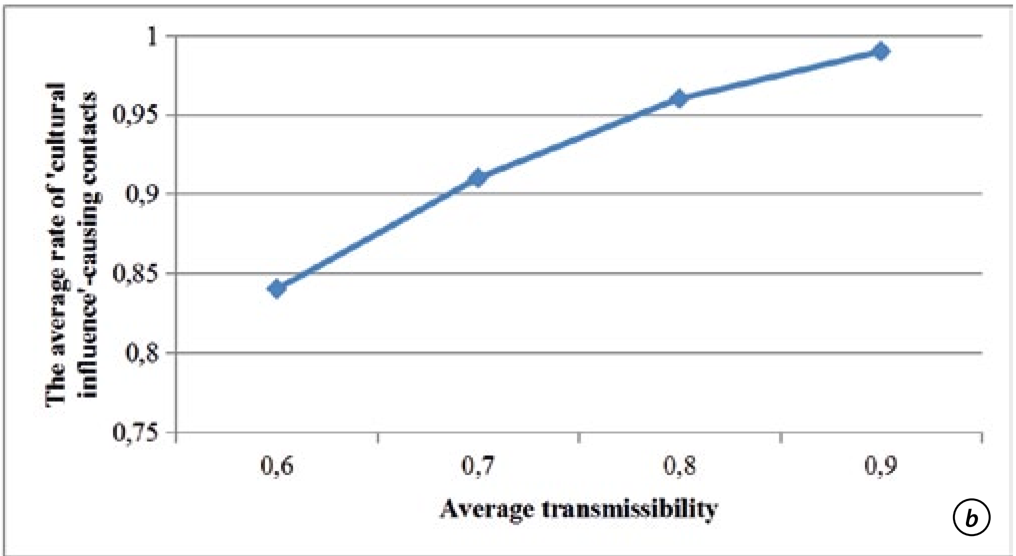


Fig. 5. The dependence of the average rate of 'cultural influence'-causing contacts between a pair of nodes on the number of phases of development according to the equation 5 (the average transmissibility is equal to 0.6, 0.7, 0.8, 0.9): *a* – after one time step; *b* – after two time steps.