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The study of size-grade of prehistoric settlement in the Circum-Songshan area based on SOFM network

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Abstract: Choosing site area, cultural layer thickness, significant relics and significant remains as the variables, we applied cluster analysis to the ancient settlements of four cultural periods, respectively, which were Peiligang, Yangshao, Longshan and Xiashang, in 9000–3000 a BP, around Songshan Mountain. Through application of the SOFM (self-organizing feature map) networks, every type of ancient settlements was classified into different size-grades. By this means, the Peiligang settlements were divided into two grades, Yangshao and Longshan settlements were divided into three grades, respectively, and Xiashang settlements were divided into four grades. The results suggested that the size-grade diversity of ancient settlements was not significant during the Peiligang period in this area. Around the middle–late Yangshao period (5000 a BP), the size-grade diversity of ancient settlements began to appear, a process that continued during the Longshan period and finally matured in the Xiashang period. Moreover, the results reflected the regional differences in cultural characteristics in a particular period, which were mainly represented in that there were three Peiligang cultural systems distributed in different areas. Such differences also existed in the spatial distributive characteristics between the Xia and Shang cultures. Based on the size-grade study of ancient settlements in the Circum-Songshan area, it was found that the SOFM networks method was very suitable for size-grade classification of ancient settlements, since, using this method, adjacent cells would compete and learn from each other, a benefit that reduced the effect on classification by the inaccuracy of site acreages.

Keywords: SOFM; Circum-Songshan area; prehistoric settlement; cluster analysis; size-grade

1 Introduction

The study area includes Zhengzhou, Luoyang, Xuchang, Pingdingshan and other places encircling the Songshan Mountain in Henan Province, China (Figure 1). It was the place from

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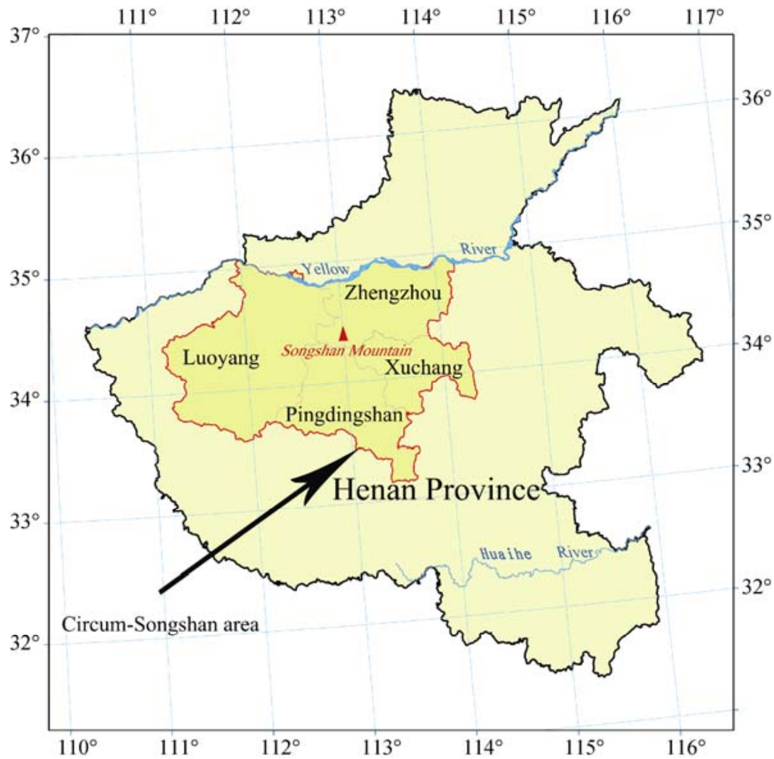

Figure 1 Location of the Circum-Songshan area in Henan Province, China

which the earliest country of China emerged and the key region for the origin of the Chinese civilization. There are over 1000 prehistoric settlements in this area (SACH, 1991). These are in consonance with the evolutionary sequence of Central China prehistoric cultures, which are Peiligang Culture (9000–7500 a BP), Yangshao Culture (7500–5000 a BP), Longshan Culture (5000–4000 a BP) and Xiashang Culture (4000–3000 a BP). Some important prehistoric sites, such as Wangchenggang, Erlitou, Zhengzhou Shang Dynasty City and Yanshi Shang Dynasty City, lie in this area. Moreover, the magnificent relics and important remains from these sites hint at the key role of the Circum-Songshan area in the evolution of Chinese civilization (Zhou *et al*., 2005).

Due to its close connection to many key questions of the origin of civilization, such as ancient social differentiation, the size-grade of prehistoric settlements has attracted researchers' attention for a long time (Trigger, 1967; Chang, 1972; Willey and Phillips, 1955). The traditional method of classification for the size-grade of prehistoric settlements mainly uses the site area that comes from the archaeological survey as the only parameter, while the number of grades and the size range of settlements of different grades are defined by the researchers' experience (Xu, 2001). However, the site area is normally determined on the basis of the distribution of the range of pottery pieces (Renfrew and Bahn, 2004). It often shows a large discrepancy with the actual values. Furthermore, although results that are drawn from the traditional method can reflect the actual size-grade situation of prehistoric settlements to some extent, there is great subjectivity in the application of the process, and it overly depends on the academic level and study experience of the researchers. Therefore, there is an urgent and important requirement to quickly design a more scientific and objective method to classify the size-grade of prehistoric settlements.

The self-organizing feature map (SOFM) is an unsupervised learning neural network (Kohonen, 1981). By using this network system, there is no need to preset classifying outputs or expectations relating to the input mode. Instead, the system self-adaptively develops different regions sensitive to signals of different properties through learning and competition between neighboring units in the neural network and then extracts characters and rules (Li and Zheng, 2003). Based on its ability to self-organize and carry out a self-adaptive study, SOFM has been applied to numerous fields, such as comprehensive physiographic regionalization, function classification of cities, evaluation of pollution, assessment of the fragility of ecosystems, spatio-temporal patterns of climatic change, soil classification, classification of plant communities and classification of remote sensing images (Huang *et al*., 2011; Liu and Song, 2005; Ma and Xu, 2010; Li *et al*., 2005; Fu *et al*., 2002; Zhang and Yang, 2007; Luo *et al*, 2008). But, the system has seldom been applied to the study of the size-grade of prehistoric settlements. As an unsupervised technique of pattern recognition, the application of SOFM to the study of size-grade of prehistoric settlements has three advantages. First, it is objective. SOFM can overcome strong subjectivity in the grade-dividing pattern imposed by the experience of experts and, instead, provide a scientific and universal method of prehistoric settlement grading to researchers at different academic levels. Secondly, the characteristic of competition and learning between neural units can partly reduce errors caused by data quality, a weakness which causes trouble from a method depending on a single index that divides the size-grade of prehistoric settlements, i.e., SOFM can reduce the impact of uncertain archaeological data based upon study results. Finally, relying on basic mathematics and the strong computing power of computers, SOFM can quickly extract the differential features by size-grade for prehistoric settlements. Because the system can greatly enhance the work efficiency, SOFM especially suits the work of size-grade dividing through prehistoric settlements on a macroscopic spatial scale, an activity that involves a great mass of data.

Choosing various factors that are closely related to the size-grade of prehistoric settlements as inputs, we applied clustering analysis to the Circum-Songshan prehistoric settlements (9000–3000 a BP) of the Peiligang, Yangshao, Longshan and Xiashang periods, respectively, using the SOFM network, and divided the settlements of each period into different size-grades. Then, the spatial distributive features of settlements in different grades were demonstrated on a map. The application not only provided proof and helped in a number of important fields closely related to the origin of civilization study, such as community division, settlement pattern evolvement and cultural transfer, but also created a more scientific and suitable method for size-grade division of prehistoric settlements and provided a reference for similar studies.

2 Principle and method

2.1 Clustering variables determined

According to the degrees of correlation between archaeological data and the size-grade of settlements, site area, cultural layer thickness, significant relics and significant remains were chosen as the clustering variables. Among these variables, site area reflects some factors, such as size scale, dweller capability and active territory of prehistoric settlements, all factors that impact the size-grade of settlements directly. Being a rough value, site area is still the most important criterion of the size-grade division of prehistoric settlements. The cultural layer is the horizon deposit containing cultural relics. Its thickness can reflect the time span, active intensity and frequency of human habitation. Some significant remains like bronze ware, jade articles and ceremonial vessels were often indications of social status in ancient communities, but could be acquired only with the monopolization of valuable resources. Therefore, such significant remains also can reflect the size-grade of settlements. In addition, some significant relics like city walls, palaces, great graves, sacred locations and areas of public activity can also reflect the size-grade of ancient settlements. In this way, these significant relics are key factors for the size-grade division of prehistoric settlements (Li, 2010; Chang, 1963; Childe, 1925).

Objectively speaking, the size-grade difference of prehistoric settlements can be reflected in all the factors chosen, including site area, cultural layer thickness, significant relics and significant remains. Because of the limitation imposed by the preserved conditions, ancient community development levels, archaeological investigation methods, site exposure extent and archaeological research evolvement, we are unable to fully understand the overall characteristics of all prehistoric settlement remains through current archaeology materials. There are also data incompleteness possibilities or loss in all four chosen variables. However, on the one hand, through the integrated application of the four variables, the high-grade level of some settlements can be confirmed. For example, the status of a settlement with a large area, thicker cultural layer thickness and more important relics and remains is undoubtedly higher than that of settlements with only a larger area. On the other hand, the integrated application of the four variables can revise the grade of some settlements that are small in area but more predominant in terms of other factors. Consequently, the grade level of these settlements can be raised. In view of the preceding, it can be seen that, site area, cultural layer thickness, significant relics and significant remains were chosen as the basis for size-grade division of prehistoric settlements in this paper. Among the four variables, site area and cultural layer thickness are quantitative variables, while significant relics and significant remains are type variables (Table 1).

Table 1 Variable description

Variables	Types	Units	Remarks
Site area	Quantitative variables	10,000 m^2	
Cultural layer thickness	Quantitative variables	m	
Significant relics	Type variables		If the relics include some important relics like city walls, palaces, great graves, sacred locations and public active areas, the value is 1. Otherwise, the value is 0.
Significant remains	Type variables		If the remains include some important remains like bronze ware, jade articles and ceremonial vessels, the value is 1. Otherwise, the value is 0.

2.2 The working principle of the SOFM network

The SOFM was developed by a Finish scholar, Teuvo Kohonen, in 1981. It is a simulation of the phenomenon called lateral inhibition, which exists in the human pallium. The working principle is an arithmetic operation similar to pallium competition (lateral inhibition) mentioned above. In this arithmetic of learning by competition, only one export unit can be activated either in each moment or in each group of export units. The export unit competes with others in order to be activated. Its natural inclination is to be activated and suppress other units from activating at the same time. The simplest winner is Winner Takes-All (WTA). After the input samples are accepted, the SOFM network begins to compete and learn. The input samples with the same function are close to one another. Meanwhile, those input samples with different functions are apart. So, some irregular input samples are arranged automatically. With a given learning arithmetic, the conjoined nodes are represented by type characteristic called characteristic mapping, which is different from the input samples. If the samples are enough, the distribution of weight can be similar to the probability density of input samples, and the export neural units can reflect this distribution. Namely, samples with a bigger probability centralize in a certain region of the export space. No matter how high the input sample dimension, all samples can be projected to a low-dimensional data space. The similar samples in the higher dimensional space are still similar after being projected to the lower dimensional space. The SOFM network is an unsupervised classification method when compared with the traditional classification method, the classifying center formed by SOFM can be reflected in a curved or flat surface that keeps the same topological structure.

The SOFM network learning process consists of the following steps. (1) Weight initialization. Every weight vector is given an initial value with a small random number. Each node weight should be different. (2) In the sample set, a sample x is chosen as a random input. (3) The best matching unit is chosen at t moment (competition process). In this step, the input vector x, which is the most similar to all weight vectors, is chosen as the winner unit. Using the Euclidean distance, it is represented as

$$\| x - w_c \| = \min \| x_i - w_i \| \quad (1)$$

where the subscript c stands for the winner unit. Then, the neighborhood size or neighborhood function is determined (cooperation process). NB_c stands for a group of subscripts around the winner unit c. Then, the weight of the winner unit and its neighborhood units are updated. (4) The weight value is revised:

$$\Delta w_i = \eta (x - w_i), i \in NB_c \quad (2)$$

where η is the positive learning rate. In order to achieve better convergence performance, learning rate and the neighborhood size should be gradually reduced. (5) New learning processes are carried on one by one until a meaningful perception map is formed. (6) If the neighborhood size of the winner unit is not defined, it can be replaced by a neighborhood function around a certain winner unit. The commonly used neighborhood function is a Gaussian function:

$$\Omega_c(i) = \exp\left(\frac{-\| p_i - p_c \|^2}{2\sigma^2} \right) \quad (3)$$

where p_i and p_c are the locations of export unit i and c, respectively, and σ is the width of the neighborhood function.

The SOFM network has a good clustering function for the input data. It can compress the data using the clustering center (the weight vector of each export node) to represent the original input. This compression is a good approximation to input data.

2.3 The size-grade division process of prehistoric settlements in the Circum-Songshan area

The size-grade division study of prehistoric settlements in the Circum-Songshan area processed and analyzed data according to the following steps. (1) The clustering data and spatial distribution data of prehistoric settlements in the Circum-Songshan area were collected and managed. (2) The SOFM network was programmed to operate in Matlab, then, the clustering analysis was applied respectively to the prehistoric settlement data of the four periods. (3) The spatial distributive characteristics of the clustering analysis results of the four-period prehistoric settlements were arranged in categories in ArcGIS. (4) The study results were analyzed.

3 Size-grade division

3.1 Data collection and management

The city and county boundaries were identified from 1:50,000 standard topographic maps selected as the work base map. The prehistoric settlements data mainly came from the *Cultural Relics Atlas of China* (*Henan Fascicule*), the third cultural relic census data and the newest archaeological investigation data. The settlement data were managed under categories of Peiligang, Yangshao, Longshan and Xiashang periods, respectively. The properties of each settlement collected included code, settlement name, geographical location (city, county, town and village), space coordinate, time, site area, cultural layer thickness, significant relics and significant remains. In addition, the site area, cultural layer thickness, significant relics and significant remains were calibrated according to the published archaeological excavation reports to assure the data precision. Some incomplete data were completed using average values. In total, 1931 prehistoric settlements were collected and managed, including 73 Peiligang, 563 Yangshao, 661 Longshan and 634 Xiashang settlements.

3.2 Clustering calculation

In the initialization of the SOFM for training purposes, the data needed to be normalized to ensure a unified competition standard for the neural units. However, in the size-grade division of prehistoric settlements, the four variables participating in clustering have different characteristics. The two variables of site area and cultural layer thickness are “quantitative” variables. Their normalized results are groups of numbers between 0 and 1. But, significant relics and significant remains are “type” variables. Normalized results of these remain unchanged. So, except for maxima, the normalized values of all other clustering data of site area and cultural layer thickness are less than 1. But, the normalized values of significant relics and significant remains include a lot of values of 1. This difference has an impact on weight distribution and adjustment and the final clustering result. Therefore, normalization is inapplicable in this study. From analyses of the distributive characteristics of prehistoric settlement data in the Circum-Songshan area, we found that there was a major difference between the category of site area and the category of significant relics and significant remains in the interval of 300,000–500,000 m^2 in terms of area. Significant relics and significant remains were often found in sites with an area over 500,000 m^2, and were rarely seen in sites with an area less than 300,000 m^2. The discovery of significant relics and significant remains were more random in sites with an area between 300,000 and 500,000 m^2. In order to highlight the competition ability of significant relics and significant remains in clustering, we selected the maximum 50 as the processing coefficient for significant relics and significant remains. Meanwhile, as the difference multiple between the average values of site area and cultural layer thickness, we selected 5 as the processing coefficient for cultural layer thickness. So, the final data that directly participated in clustering were the original site area, 5 times cultural layer thickness and 50 times significant relics and significant remains. Furthermore, as to the difference of settlement amount and the difference between each category of data among different periods, Peiligang settlements were divided into two grades, Yangshao and Longshan settlements into three, respectively and Xiashang settlements into four.

The clustering arithmetic of the SOFM network was programmed to operate in Matlab. The data of Peiligang, Yangshao, Longshan and Xiashang settlements were imported to implement the clustering operation. Through calculation, the Peiligang settlements were divided into two grades. The first grade included three settlements, namely, Tanghu, Wayaozui and Zhongshanzhai sites. The Yangshao settlements were divided into three grades. The first grade included nine settlements, namely, Tanxiaoguan, Gaopingzhai, Suyang, Shuidui, Ximazhuangxibei, Yanggou, Zhaiwannan, Taipu and Shuanghuaishu sites. The second grade included 83 settlements, among which were Dahecun, Qingtai, Xishan sites, etc. The Longshan settlements were divided into three grades. The first grade included 14 settlements, namely, Shenggang, Xinzhai, Guchengzhai, Wangchenggang, Shaochai, Boluoyao, Zhaiwannan, Ludi, Wadian, Taipu, Fanzhai, Yangzhuang, Wangwan and Shangzhuang sites. The second grade included 59 settlements, among which were Zhanmatun, Puchengdian, Huizui, Cuoli sites, etc. Xiashang settlements were divided into four grades. The first grade included two settlements, namely, Erlitou and Zhengzhou Shang Dynasty city sites. The second grade included 20 settlements (Figure 2), among which were Erligang, Xiaoshuangqiao, Xinzhai, Wangjinglou, Yanshi Shang Dynasty City, Madong sites, etc. The results of clustering analysis were loaded into ArcGIS to display the spatial characteristics of prehistoric settlements size-grade in the Circum-Songshan area (Figure 3).

As more attention has been paid to the key sites, the important prehistoric settlements in this region have normally been thoroughly studied by archaeologists. So to some extent, the data quality of these settlements is assured. Therefore, the high-grade settlements recognized by SOFM were basically consistent with those recognized by the archaeological studies. In the same way, on the lower grade settlements, the SOFM calibrated and supplemented the results of previous research. The size-grade of many small settlements was raised. The result showed that settlements of different grades at each period differed in size and that the structure of the number of different grade settlements were more and more reasonable. Moreover, the high-grade settlements basically covered the key sites on which the archaeological study focused. In particular, the settlements of the first grade at each period were always the most important sites in the area.

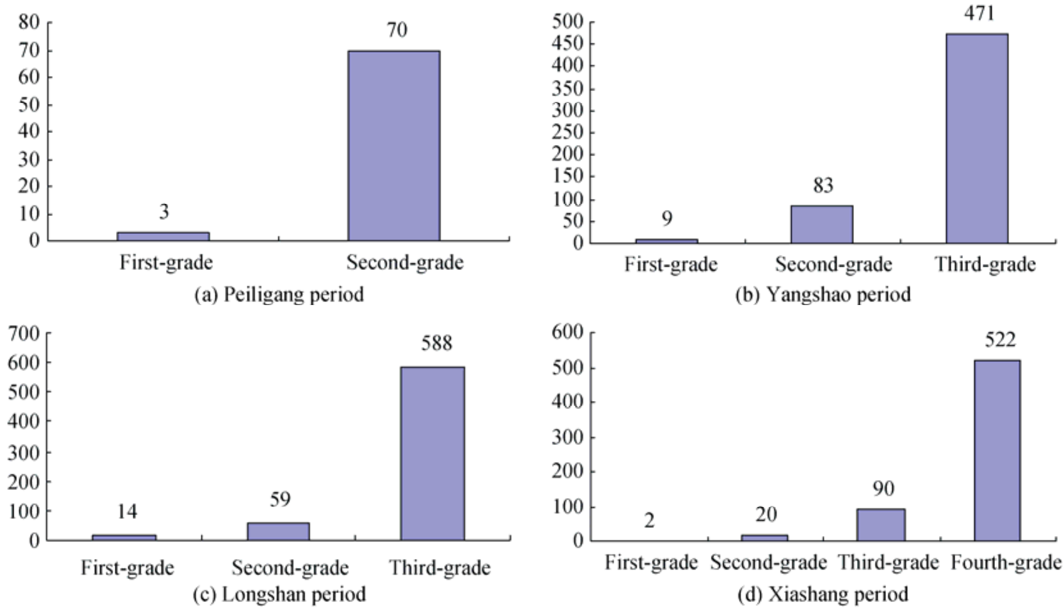

Figure 2 The size-grade number of prehistoric settlements in the Circum-Songshan area

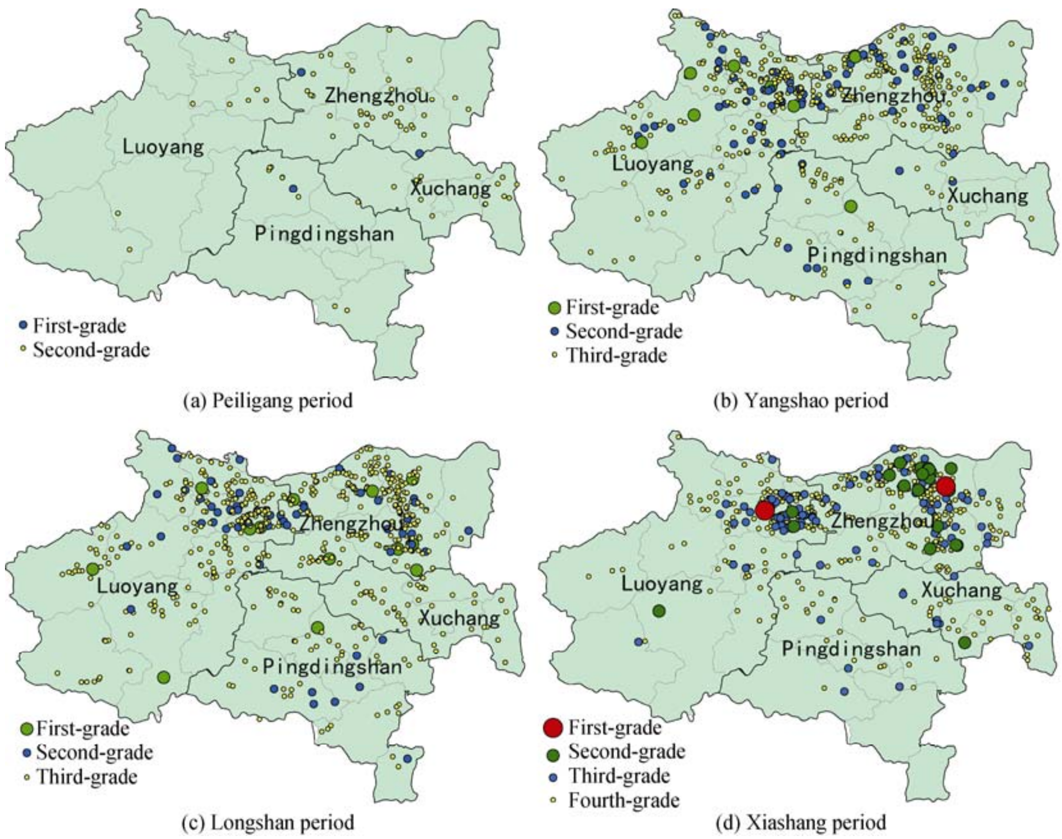

Figure 3 The size-grade map of prehistoric settlements in the Circum-Songshan area

3.3 Interpretation of result

The overall differentiation of Peiligang settlements in terms of size-grade was not obvious. On the whole, there was little difference among settlements in terms of site area and cultural layer thickness at this period. Up to this point, the significant relics and remains that could represent the high status of settlement, like city wall and valuable sacrificial vessel, were not found. In the Yangshao period, there were still no significant remains found and only one significant relic was found, which was the city wall in Xishan Site. The site area and cultural layer thickness of the different settlements demonstrated distinct differences during this period. For example, the largest area site, Shuanghuaishu Site, was 1,000,000 m^2, while the smallest site was only 1000 m^2. Considering the fact that most first-grade and second-grade settlements were in the middle–late Yangshao period (Zhao, 2001), it was concluded that the size-grade differentiation of prehistoric settlements began to appear 5000 a BP in the Circum-Songshan area. In the Longshan period, the size-grade differentiation of prehistoric settlements continued. Although the extent of the site area and cultural layer thickness among settlements during this period were generally similar to those in the Yangshao period, the appearance of ancient cities functioning as defense fortresses, including Wangchenggang (Fang, 2006), Xinzhai (Research Center for Ancient Civilization, Peking University and Zhengzhou Institute of Cultural Relics and Archaeology, 2004), Puchengdian (Henan Provincial Institute of Cultural Relics and Archaeology, Pingdingshan Municipal Bureau of Cultural Relics, 2008), Guchengzhai (Henan Provincial Institute of Cultural Relics and Archaeology, Xinmi Academy of the Yan-Huang History and Culture, 2002) and the lesser amount of first-grade and second-grade settlements may have reflected the current status and features of cultural integration in the Longshan period. The differentiation of prehistoric settlements in the Circum-Songshan area was completed in the Xiashang period. The amount of structure characteristics of settlements from different grades was more reasonable. Two great settlements with some characteristics of a capital city appeared in this period. These were the Erlitou and Zhengzhou Shang Dynasty City, which represented the Xia Culture and Shang Culture, respectively. The areas of these two sites were very extensive. In addition, the significant relics and significant remains such as palace city site, bronze vessel, kallaite dragon-shape ware in Erlitou Site (Xu *et al*., 2004) and city wall site, palace site great bronze sacrificial vessel in Zhengzhou Shang Dynasty City Site (Henan Provincial Institute of Cultural Relics and Archaeology, 2001), which could represent the status of settlements, were found in both sites.

The result of size-grade division of prehistoric settlements in the Circum-Songshan area could also reflect the cultural difference within each period. For example, three first-grade settlements in the Peiligang period, namely, Tanghu, Wayaozui and Zhongshanzhai sites, were distributed in the Yishuihe River Basin, Yiluohe River Basin and Ruhe River Basin, respectively. The archaeological research indicated that there were differences among the cultures in the three regions in the Peiligang period. So, it was inferred that the Peiligang Culture in the three regions could have belonged to different cultural systems (Zhao, 1987). Tanghu Site belonged to the Egou-Peiligang system, Wayaozui Site belonged to the Wuluoxipo system (Liao, 1994) and Zhongshanzhai Site belonged to the Zhongshanzhai system (The First Archaeological Team in Henan, IA, CASS, 1991). Moreover, similar information was found from the result of size-grade division of the Xiashang settlements. Two first grade settlements, namely the Erlitou Site and Zhengzhou Shang Dynasty City Site, respectively, could represent the distributive characteristics of the Xia and Shang cultures. Therefore, the result of size-grade division of prehistoric settlements could be considered as cultural type division at a certain time.

4 Discussion and conclusions

(1) Through learning and competing between neighborhood units, SOFM self-adaptively develop many sensitive regions relating to different kinds of signs, as well as gaining character and rule. They can reduce the impact of uncertainty of site area upon classifying result. In this way, they suits the size-grade division of prehistoric settlements.

(2) The result of size-grade division of prehistoric settlements in the Circum-Songshan area suggested that the size-grade difference of prehistoric settlements was not obvious in the Peiligang period. The differentiation began in the middle–late Yangshao period (5000 a BP) and continued into the Longshan period. It was finally concluded in the Xiashang period.

(3) The result of size-grade division of prehistoric settlements in the Circum-Songshan area could also reflect the regional difference of cultural types in certain periods. It was represented in different cultural systems in three regions during the Peiligang period and the different distribution characteristics of the Xia and Shang cultures. It could be construed as cultural types division at certain time.

Although the SOFM method was more scientific and reasoned in the size-grade division of prehistoric settlements in the Circum-Songshan area with a result that could reflect the regional cultural features and cultural evolution characteristics to some extent, it will be recognized that any method has its disadvantages. Only through comparison and reference between a variety of methods could the exact rule and character be achieved. Therefore, more advanced methods need to be introduced into the size-grade study of prehistoric settlements in the Circum-Songshan area and more in-depth studies carried out through comparison and reference between different methods.

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