Emergence, Evolution and Mutation: Interpretation of the Orderly Distribution of pre-modern Settlement in the Great Wall zone based on Complex Adaptive System theory

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The Great Wall zone represents the largest area of land-use and land-cover change in China in the past 300 years, when the borders of agricultural production and settlement continued to move northward, forming the pattern of settlements we see today, realizing its transition from wartime to peacetime. Instead of focusing on the development of individual urban, how can we understand the evolution essence of settlement system, located in the transition zone between agriculture and animal husbandry, from the perspective of complex system? In this article, the distribution pattern can be considered as a spatial projection of region social order. Then, the fractal dimension of settlement distribution is calculated by GIS, so as to demonstrate the complexity of pattern. And then, characteristics and mechanisms of the settlement system in the Great Wall area during Ming and Qing Dynasties is further analyzed from 7 basic points of Complex Adaptive System. Finally, the idea of attracting basin can be used to make a further description about the process of evolution, namely structural break and non-structural evolution.

Keywords: settlement system, the Great Wall zone, generation and evolution, complex adaptive system theory.

Introduction

The area, where the Great Wall is located, lies in the transitional zone between the humid and arid regions in Northern China. Seated in the transition between farming and stockbreeding areas, the Great Wall has always been the confronting surface of different cultures, and significantly influenced the trend of the ancient geopolitical layout in Northeast Asia. Besides, the Great Wall area represents the largest area of land-use and land-cover in China in the past 300 years, when the borders of agricultural production and settlement continued to move northward, forming the pattern of settlements we see today.

Once in quiet a long period, the Great Wall was simply known as “a wall built for the defense against Tartars”, mainly linked with military management system and how military installations were distributed and constructed along the way. Lattimore, an American sinologist, put forward the idea of “Great Wall transition zone”, regarding such a mixture of economy and culture as a result from the interaction between prairie area and farming area, which went beyond the traditional concept of “boundary line” and the inherent single viewing angle of agricultural civilization. During the field visit in the area of the Great Wall, Gaubatz sensed the military settlement along the line and its influence in this area, and then distinguished the developing pattern of “conversion from military defense to civil use” in border towns from that in inland, which made the research about the Great Wall extended from its frontier history to the history of the towns and the civil society in this area.

Ming Dynasty(1368-1644) and Qing Dynasty(1644-1912), the last two ancient dynasties in China, showed the two different situations of the Great Wall area respectively in times of war and peace. The entire Ming Dynasty was involved in the sharp confrontation between farming and animal husbandry from its very beginning, while Qing Dynasty realized the regional peace by placing them two in a unified state order. Therefore, with the historical progressing of Ming and Qing dynasties, the Great Wall area actually realized its order transition from wartime to peacetime, where farming and animal husbandry were accustomed well to each other, and also to some other conditions like nature, politics, economy and military matters. Settlements are the most straight and striking landscape that human activities add to the earth. The distribution pattern formed by different settlements turned in to a spatial projection of “order” which is abstract. Obviously, the order space in the Great Wall area can be considered as a spatial settlement-system pattern related to the Great Wall, which consequently became a start point for the “spatial turn” of research on systematic relation in the Great Wall area. What’s more, the spatial projection of the order in this area was named “the-Great-Wall order belt” because of the striped distribution of the settlements in the Great Wall area.

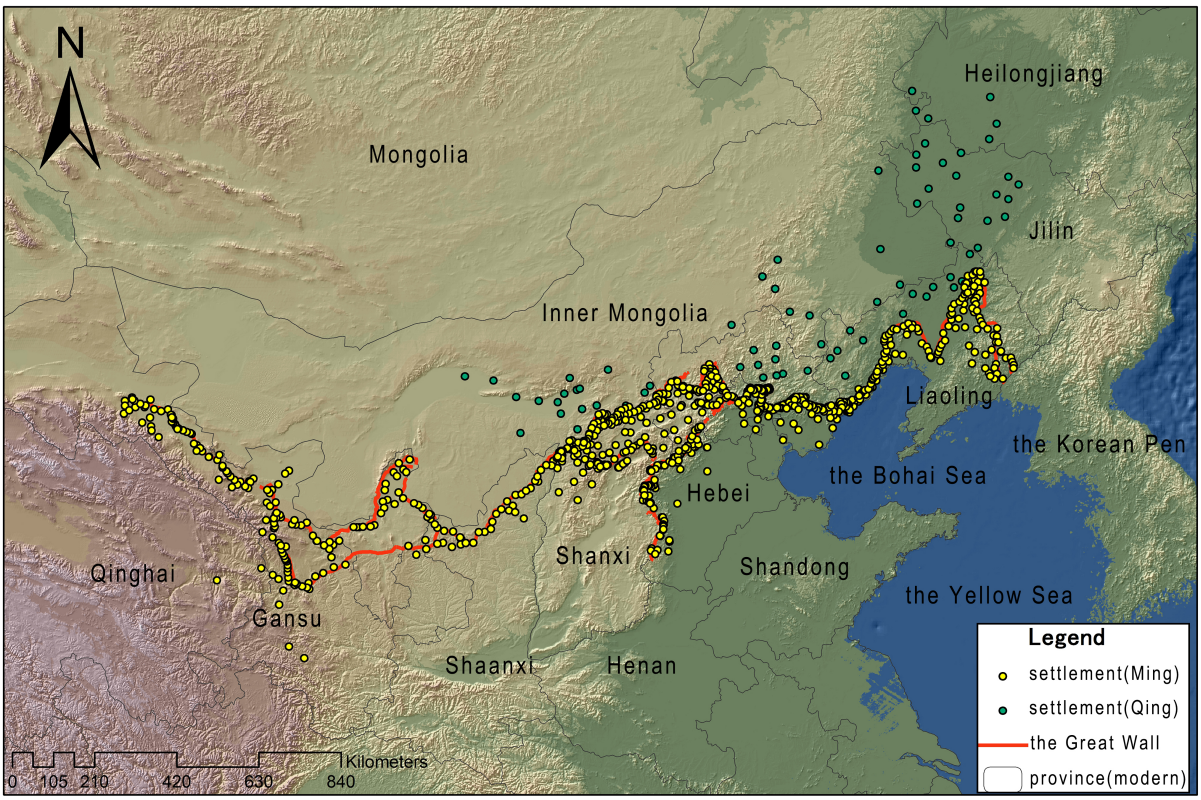

Figure 1: distribution of the Great Wall settlements in Ming and Qing Dynasties

1. Complex Adaptive System theory and the-Great-Wall order belt

1.1 Complex Adaptive System theory

Complex Adaptive Systems (CAS) was first mentioned by John H. Holland at the lecture held for the decennial of Santa Fe Institute and stated in the book named *Hidden Order* to explain the basic principle of the generation and operation mechanism of complexity. Its core concept is "adaptation builds complexity"[1]. According to Holland, CAS was described as "a system that is made up of some interactive agents restricted by rules".

Holland emphasized that adaptive agents were of active learning ability, constantly accumulating "experience" by reciprocal feedback with the outside world and accordingly adapting to external environment and other agents. An adaptive agent can pack the tested effective experience in modules and then generate the rule set (internal model) for its adaptation to the environment in the way of block stacking. A large number of agents gather according to "tags" and form the higher ranked agents (meta-agents) during interaction. Meta-agents are equipped with the specialty and structure—nonlinearity— that lower-leveled agents cannot achieve by simple addition. Also, meta-agents can continuously develop to another higher level— meta-meta-agents— by further aggregation.

1.2 The-Great-Wall order belt

The Great Wall order is the dynamic, balanced and stable state of the social organizations tied by the Great Wall, which appeared in the transitional zone between farming and animal husbandry under a specific historical circumstance, aiming to facilitate the regional structural transformation from "out of order" to "orderliness" and improve self-adaptive and self-developing abilities.

The-Great-Wall order belt spatially realized the order in the Great Wall area, reflecting on the means that the agent self-organizations took up the space. To be specific, the agent refers to the numerous individual persons. In Ming Dynasty, it meant the Ming defending warriors at the Great Wall and their family; In Qing Dynasty, it meant the Han immigrants in Mongolian land. With numerous agents gathering, settlements (meta-agent) and settlement systems (meta-meta-agent) started to emerge. Compared with agents (individuals), meta-agents (settlements) were easy to observe and analyze for the advantages of limited quantity, definite position and well-organized structure. Therefore, "the-Great-Wall order belt", as a spatial concept, can be regarded as the settlement group distribution in the limited space under rule constraint, which also be called the Great Wall settlement belt.

2. The spatial complexity of the -Great-Wall order belt

2.1 Method

Fractal theory, has been widely used in natural and social science fields to help understand the nonlinearity and complexity of objective things. Fractal dimensions are the parameters used to describe the irregular degree of fractals. Thereinto, grid fractal dimensions are used to describe the spatial distribution equilibrium of regional urban systems. The calculation is to cover point targets with the differently sized grids. While grid size r is varying regularly, the number N(r) of the grids used to cover point targets will also vary accordingly. If the targets present fractal features in a certain scale, then: $\lg N（r）= -D\lg r+A^2$

D refers to the grid dimension, A is a constant, r refers to the grid size and N(r) refers to the total amount of the grids whose side length is r and which are used to cover targets. The value of grid dimension is taken from 0 to 2: when D=0, it means towns gather together at one point; when D=1, it means linear distribution; when D=2, it means uniform distribution (Central Place Theory).

2.2 The fractal features of the-Great-Wall order belt

As the military settlement system in the Great Wall area during Ming presents the fractal characteristic in both spatial distribution and rank-size distribution[3], this paper mainly worked out the grid fractal dimension for the spatial distribution of the Qing Great Wall settlement system. By ArcGIS10.3, a rectangle-shaped covering target was generated in the range of 108° E～128° E and 39.5° N～48° N. Dividing each side into K section, the rectangular area is consist of K^2 girds, and r=1/K. First, the gird number N covered the points is counted, then the double logarithmic regression analysis of N and r is made. 1774, 1875, 1895 and 1911 are four nodes of immigration history in the Great Wall zone during Qing dynasty, so the grid fractal dimensions of settlement distribution corresponding to the 4 time is calculated respectively.

Table 1: Fitted Equation, R2and Grid Dimension of Grid Fractal of Global Towns during Each Time

	1774	1875	1895	1911
Fitter Equation	$\ln N_r=0.990\ln r+0.752$	$\ln N_r=1.018\ln r+0.689$	$\ln N_r=1.125\ln r+0.545$	$\ln N_r=1.429\ln r+0.217$
R^2	$R^2=0.949$	$R^2=0.977$	$R^2=0.980$	$R^2=0.994$
Grid Dimension	D=0.990	D=1.018	D=1.125	D=1.429

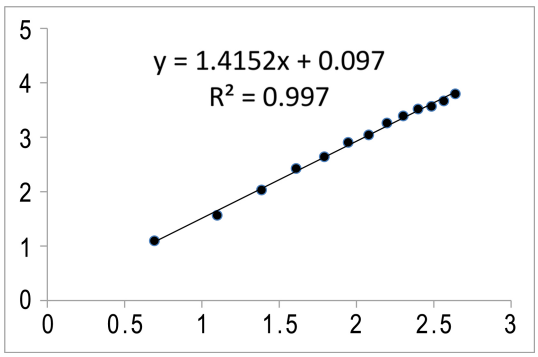

Figure 2: double logarithmic curve of grid dimension of the distribution of the Great Wall settlements in 1911

It is shown as Table 1, the spatial distribution of towns presented a simple fractal characteristic. From 1744 to 1911, D was constantly increasing from 0 to 2 and R2 was also rising, which reveals that the spatial structure was developing from integer dimension to fractal dimension through 3 major periods. ①Random period: In 1774, D=0.990. That shows settlements were randomly distributed with non-significant rank difference and low relative degree among them.

②Nurturing period: in 1774, D=0.990. In 1875, D=1.018 and D≈1, which shows the settlement in advantage of resources and location started to develop to greater towns and get the traffic lines between differentiation points.

③Developing period: In 1895, D=1.125, and in 1911, D=1.429. In this period, grid fractal dimension rose by leaps and bounds, having a good fitted degree. It indicates that the spatial structure of towns had taken its shape and started to get self-similarity.

3. The CAS-based cognitive framework of the-Great-Wall order belt

According to Holland, CAS has 7 basic characteristics: Aggregation, Tagging, Nonlinearity, Flows, Diversity, Internal Models and Building Blocks which are the necessary and sufficient conditions. Therefore, this paper made some further analysis on the characteristics and mechanisms of the Ming and Qing Great Wall settlement systems from these 7 points.

3.1 Stress reaction: spatial realization of the Ming Great Wall order

In Ming Dynasty (1368-1644), with Mongolians retreating to the prairie from central plains, the coexistence of mutually unrestrained multi-elements also got back to the transitional zone between agriculture and animal husbandry. One side is the northern prairie nomads represented by Mongol and Manchu, and the other side is southern agriculture-based regime of the Hans—the Ming Empire. Because of the absence of a higher ranked authority and mutual trust mechanism, the North and the South got involved in the violent competition for living resources. Compared with the self-sufficient agricultural economy, the animal husbandry economy which is single and unstable is determined to be more dependent on farm products. For that reason, the nomads seemed more proactive in such an imbalanced pursuit of mutual association. When looting replaced trading as the main means of association, it became urgent for Ming Government to build a boundary defending order, keeping the marginal agricultural region stable and reducing conflict possibility and expected loss.

For this purpose, Ming Government forcibly made the native inhabitant in the Great Wall area move out to the inland and a large number of armed forces and their families move in. Land was give away to these immigrants to make them feed themselves and guard for generations, artificially creating a buffer zone in the transitional area.

With the shared value and identity, these military immigrants formed differently sized military settlements by the rules of 5600, 1120, 112, 50 and 10 persons, and functioned respectively as guards, stationing, support and command according to their different locations and relative positions to the Great Wall. These settlements were distributed in radiate clusters approaching to the Great Wall: There were “Bao” fort, “Lu” fort and “Zhen” fort respectively at 3 different levels. The farther away from the Great Wall, the less the number and the higher the level.

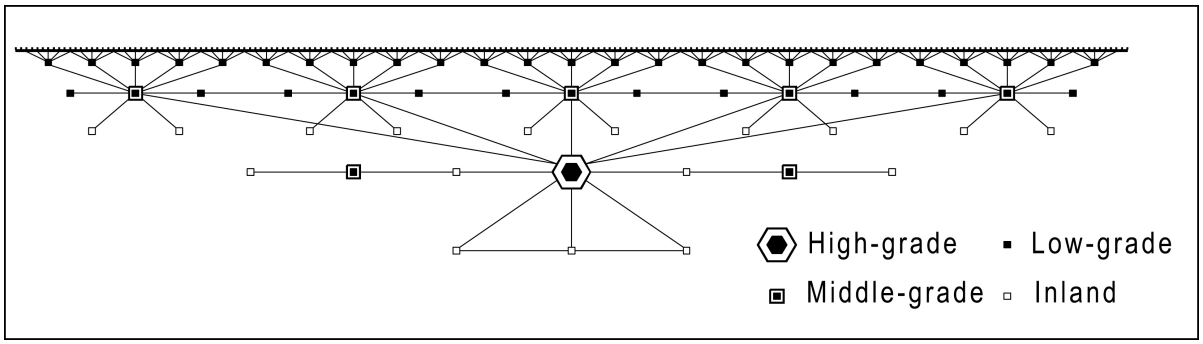

Figure 3: the distribution structure of the Ming Great Wall settlements

As shown in figure3, the low-grade “Bao” forts were arranged next to the south side of Great Wall Line in the largest number. Several middle-grade “Road ” forts were located at the medium level. The high-grade “Zen” fort in each defense areas (there were totally 11 Zen fotrs along the whole line.) was located most away from the Great Wall.

The game between farming and animal husbandry was the root cause for the existence and development of the Great Wall order in Ming Dynasty, but its spatial formation was the result of the constant adaptation of agents to the environment. In the face of the natural environment , the agents adaptively selected sites and built fortifications based on the terrain or brought in external energies to support the army. To adapt to the rival, it meant that the system had to solve the question how to make the most effective and cost-optimal response to highly mobile and uncertain invasions in a wide range. Tiny negligence was bound to result in the huge and expected consequence—looting and the periodic damage caused by the climatic fluctuation in prairie.

It can be seen that the Ming Great Wall settlement pattern was the very response to the above-mentioned restraints, using the cluster pattern to make random attacks changed into the ones in relatively predictable order and making local responses by pre-planned supporting strategies.

The layered structure made defending extended in depth. On the one hand, the rear commanding settlement gained enough time to deal with the information from a wider defensive range. On the other hand, it was more difficult for the invader to get information in back-land, and the consequent information asymmetry between the two parties resulted in the one-sided military transparency. The cluster structure optimized effective defensive range on the basis of equal strength and pre-planned the optimal pattern for troop concentration: when the

prearranged supporting plan was triggered, differently graded supporting forces would intercept the invader at the expected attack points and march lines along the "branch", so as to win the strength superiority over the invader. According to historical materials, such a military system, which seemed to be an achievement of Ming Dynasty, was actually a result of the trial-and-error process where agents "studied", "collected experience" and constantly performed optimization, rather than a process accomplished overnight.

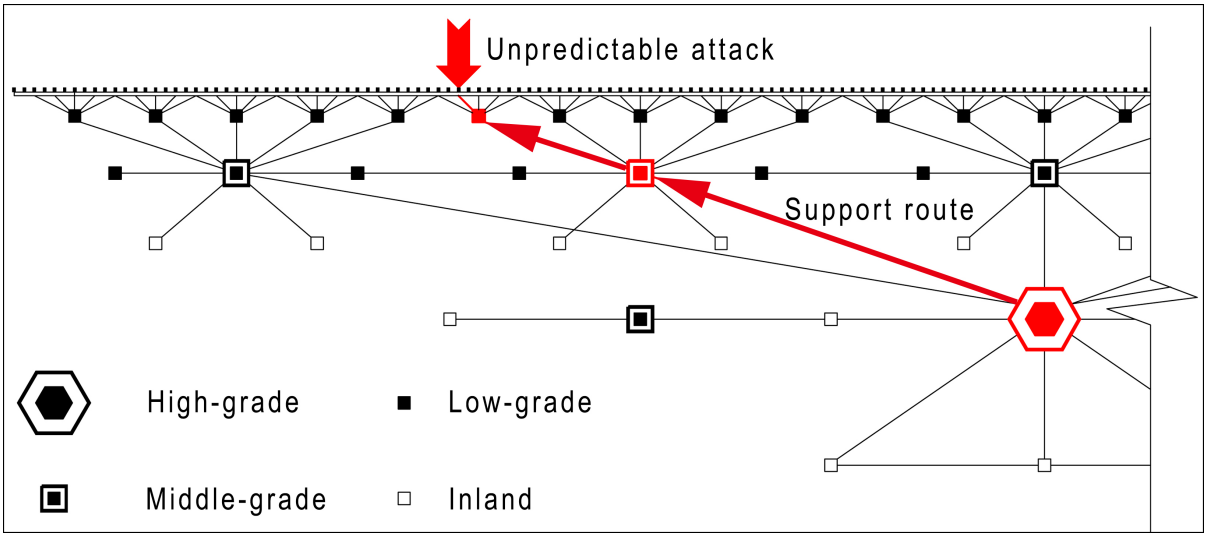

Figure 4: the stress response pattern of the Ming Great Wall settlement system

Table 2: the Characteristics of the Ming Great Wall Settlement Complex System

Number	Main Point	Key Word	Comment based on the Ming Great Wall Settlement System
1	aggregation	emergence	Because Ming warriors and their family were administratively forced to aggregate, the settlements of different sizes and functions emerged. Different settlements further aggregated and formed the defense systems in different defense area.
2	tagging	choice	Recognition of identity and subordination. Agents obediently gathered into settlements because of their identity as a military, and settlements were given different duties because of the different ranks of their commander, taking corresponding actions.
3	nonlinearity	Product effect	Spatial distribution and size-rank distribution were of fractal geometric feature. Settlement system can get a defending power more than the total number of people on its own side, for example, 3 settlements which had 1120 people in each one can successfully withdraw the attack of 3360.
4	flow	unidirectional passing	A transportation network was formed by settlement-post road, beacon tower-materials and information. The information about the enemy's situation was passed upwards by the fort closest to the Great Wall to higher graded settlements level by level, and then action directions would be passed down to relative settlements level by level. Provisions and warriors were also passed from high-leveled settlements to low-leveled ones in a unidirectional way.
5	diversity	cooperation	Settlements were different in shape, size and function. Even the settlements of the same level could have different functions and authority because of their different locations. The settlements assembled into differently functioned settlement systems according to the differences in quantity and grade.
6	internal	stress	Stress response mechanism. To resist against the uncertain attacks, the

	model		system would change from a regularly dispersed state to a regionally irregular state of aggregation.
7	blocks	fighting experience	The patterns that agents selected from plenty of practical experience were melted into the stress response mechanism, including the advantages, distribution and combinations of the settlements on different scale. For example, small fort were fit for guard; large fort were fit for dispatching; what's the proper distance for rescue; how much strength it was needed to withdraw the invasion of a certain scale; what are the possible lines for the enemy to advance or retreat.

3.2 Guide-balance: spatial realization of the Qing Great Wall order

In Qing Dynasty (1644-1912), Manchurian established a multi-ethnic country of Han, Manchu, Mongolian, Hui and Tibetan, creating favorable conditions for the development of the Great Wall area. With the realization of long-distance transportation of bulk commodities and the formation of trans-regional market, the Great Wall area turned into the transitional hinge communicating the goods from Chinese inland, Central Asia and Russia, rather than an economic marginal area, which highlighted the location advantage in this area. Therefore, in contrast to the settlement declination caused by "de-militarization" at the southern side of the Great Wall, the northern side kept on farming development and urbanization.

When the tripartite game emerged and the communication among nations was called for as an irresistible trend, it became necessary for Qing Government to construct a kind of management-and-control order in the transitional zone, so as to maintain the strength balance between them and the overwhelming superiority of Manchuria. As a result, the Great Wall, as a secret and disguised border, was playing its role of "isolation and controlling"[4]. On the one hand, the Great Wall was given full play as a hard border. Mongolia and Han were rigorously confined to the north and south of the Great Wall respectively, prohibited to cross. What's more, a depopulated zone was made out, extending dozens of kilometers wide along the Great Wall, where both farming and animal husbandry were forbidden to strengthen the isolation effect; on the other hand, the resources flowing into Mongolia were guided and managed by the controlled amount of issued passports and the appointed pass and route. As a result, although there was a thousands of miles boundary (the Great Wall) between the prairie and the inland, the elements on the two sides have to flow at an artificially higher cost.

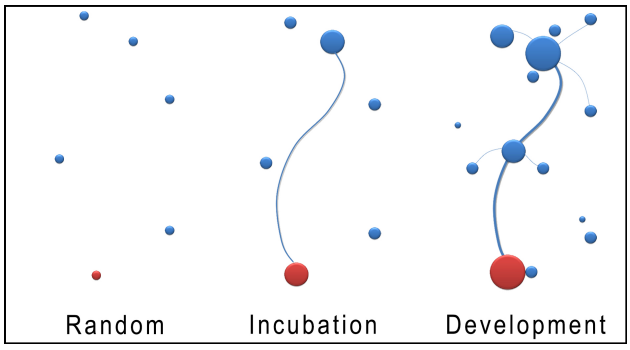

Figure 5: evolution model in point-axes way

At that time, The-Great-Wall order belt was confronted with a problem how to realize the balance between environmental carrying capacity and immigrant population by proper distribution on the condition of the designated area open to immigrant. Compared with the Ming Dynasty, the Qing Great-Wall order belt presented the spontaneity more clearly in its building process. Starting from the assigned pass, the Han immigrants spread along the post road from the south of the Great Wall, and thus formed settlement groups and energy transportation network. With new immigrants continuously moving in, the central intensity was constantly growing in the area with regional advantage, and the large transport corridor turned into the developing axis accelerating the further attachment of resources. While area polarization was coming to saturation, resources started their gradient transfer to the newly opened area, forming new aggregating point and extension line of connection. With that process repeating again and again, space would finally be filled in a "point-axes" way.

Table 3: the Characteristics of the Qing Great Wall Settlement Complex System

Number	Main Point	Key Word	Comment based on the Qing Great Wall Settlement System
1	aggregation	emergence	Because immigrants were induced by economic interest, settlements of different sizes emerged, such as villages, towns and cities. Different settlements further gathered into 3 different systems for politics, market and military matters.

2	tagging	choice	Immigrants aggregated at the destination because of their Han nationality and geographical relationship. Depending on whether there was a administrative governor or not and the rank of governor, different settlements were divided into central cities, prefectural cities, counties, towns and villages. The affiliation between different governors facilitated the generation of political settlement system. Besides, the different resource endowment promoted the formation of market network.
3	nonlinearity	power law distribution	The scale and spatial distribution of settlements followed the power law distribution.
4	flow	recycle	A transportation network of the system was formed by settlement-post road/ water way-personnel/information/materials. The exchange of personnel, capital, materials and information happened among the settlements within the system and also between the system and outside areas (inland and Mongolian land), which promoted the intake, conversion and metabolism of system elements and consequently advanced the formation and development of spatial aggregation.
5	diversity	plentiful	There was a variety of agent needs, settlement pattern and the settlement systems. The same settlement might have different functions in different system structures.
6	internal model	self-interest of rational individuals	Following the hypothesis of "economic man", agents took revenue maximization and cost minimization as the motivation of their actions. By figuring out the current relation between population and environmental capacity, settlements could make a prediction about the population state in the next period, aggregation or loss, and then made some relative countermeasures.
7	blocks	Survival experience	In the practice of environmental reconstruction, agents constantly collected the experience on, for example, the appropriate size for environmental capacity. In the residential areas endowed with different resources, the settlement of different sizes were grouped into differently leveled administrative network, market network and garrison network by the group elements of central cities, prefectural cities, counties, towns and villages.

4. Structural mutation: a new perspective on the evolution of the-Great-Wall order belt

The-Great-Wall order belt in Ming and Qing Dynasty was the aggregating state of agents adapting to the specific historical environment in the transitional zone between farming and animal husbandry. This system was always staying in dynamic variation along with the changes happened in the external environment. Throughout the Ming period, when prairie power rose alternately, the Great Wall system kept on its local adjustment and optimization all the time. For example, in the early and middle Ming Dynasty, new settlements backgrounded by the war between Ming Empire and Mongolia were mainly built in the middle and western part of the Great Wall (Zhang, 2016). Latterly, in order to resist the rise of northeast Manchuria, the eastern part of the Great Wall turned into the key area to defense. In Qing Dynasty, with a different immigrating policy and national situation, settlements constantly spread in the northern area of the Great Wall. Even so, the-Great-Wall order belt in Ming and Qing Dynasty still kept their own component elements and aggregating pattern. Only at the critical moment of the transition from Ming to Qing, did the system got its structural variation—phase change, which means military immigrants→immigrants and administrative enforcement→economical inducement and defensive settlements→ economical towns and cluster distribution→point-axis distribution.

Table 4: the Difference between the Great Wall Settlement System in Ming and Qing

	The Great Wall settlement system (Ming Dynasty)	The Great Wall settlement system (Qing Dynasty)

Order	War	Peace
Agent	Ming's soldiers and their family	Immigrant or refugee
Drive	Administrative force	Economic interest
Aggregation	Military immigrant→forts→defense system	Immigrant→towns→urban system
Function	Defense	Exploit
Mechanism	Stress response	Self-interest of rational individual
Distribution Pattern	Cluster	Point-axis

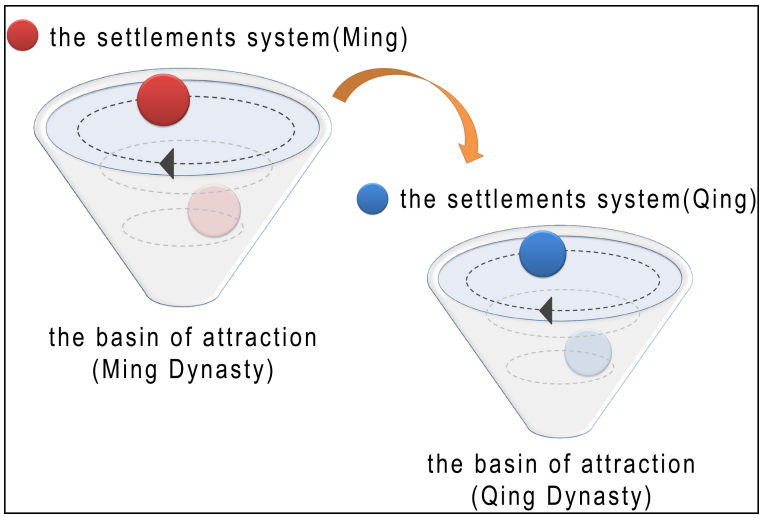

Figure 6: the evolution of settlements system in Great Wall zone in Ming and Qing Dynasties from the perspective of the attraction basin theroy

The idea of "attracting basin" can be used to make a further description about this phenomenon, taking all the influential factors of the natural and cultural environment in the transition zone between farming and husbandry as a basin-shaped set of points and the settlement pattern in the Great Wall area as a small ball in this basin. Each single position where the ball stayed represents a state of agent aggregation which was adaptable to the current natural, cultural and military factor sets. With the factor content varying, the ball keeps running in the basin. However, the political ecology in Qing Dynasty was so different from that in Ming Dynasty that the factor sets in Great Wall area structurally changed into two different attracting basins. And the structural change of the Great Wall settlement system from Ming to Qing can be regarded as the jump of the ball from the basin for Ming into the basin for Qing.

5 Conclusion

The spatial pattern of settlements across the Great Wall belt exhibited fractal geometry during pre-modern period. Especially in Qing Dynasty, with the increase of fractal dimension, the settlement system had experienced the process from random distribution to the overall self-similar, conforming to the theory and model of "Pole-Axis System".

The order in the Great Wall area and its spatial realization respectively in Ming and Qing Dynasty represents the two different typical social situations of the transition zone between farming and animal husbandry respectively in times of war and peace, fitting the description of complex adaptive system. In Ming, military immigrants was driven by administrative force to form settlements, that further aggregated and constituted the system rely on stress mechanism. In Qing, immigrants were induced by economic interest to form villages, towns and cities spontaneously. And the settlement system maintained a dynamic balance under the influence of environmental carrying capacity.

At the moment of transition from Ming to Qing, the phase change happens. It can be seen that the system drop from a high potential energy position to a low. The direction and trend of the process may be entropy production.

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Disclosure Statement

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