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Genetic Information Coding and Mapping of Traditional Settlement Landscapes in Northern Shaanxi

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ABSTRACT: Traditional settlements represent typical rural landscapes that have emerged from specific historical and cultural backgrounds. They are also important spatial carriers for the transmission of regional cultural heritage. As the historical source of traditional Chinese culture, traditional settlements exhibit stable and harmonious development, with unique features. The Loess Plateau in China nurtures the unique cave dwelling culture of northern Shaanxi. It is characterised by distinct architectural features such as traditional cave dwellings. However, the cave settlements in northern Shaanxi, which exhibit Chinese culture, face a habitat crisis due to rapid urbanisation. Based on the kernel density distribution of traditional settlements in Shaanxi Province, one of the core distribution zones centred at Suide County and Mizhi County appear in the Southeast region of Yulin City and the eastern region of Yan'an City. It is a major distribution zone involving cave settlements and their characteristic landscapes. Settlements mainly extend along river valleys and gullies, accompanied by water and soil loss as well as harsh ecological environment. However, it is marked by a severe shortage of construction land and narrow space for development. Over the years, the hills and gullies of the Loess Plateau in northern Shaanxi constrained the development of settlements in the region. Therefore, the traditional settlements in the Loess hills and gullies of northern Shaanxi were selected for further investigation. Landscape genetics and construction mapping were studied by combining with local settlement status. Appropriate protection and inheritance mechanisms of traditional settlements in Shaanxi Province were analysed.

Based on the theory of landscape genetics, 46 national traditional settlements in northern Shaanxi were selected. First, the typology of traditional settlement was used to establish landscape gene information codes in northern Shaanxi. The numerical codes of "Shaanxi E-M1/2-XXXX" were acquired using the combination of "area code + gene category code + Class-1 element + Class-2 element + Class-3 element + landscape gene element". Second, further analysis revealed that the traditional settlements in northern Shaanxi were mainly based on family inheritance and small-scale peasant economy, and depicted in terms of location layout, clansman and residential buildings. Hence, the genetic pedigree of traditional settlements in the region can be built by combining internal and external environmental elements, information associated with traditional residential and subjective public buildings as well as landscape genes with similar cultural significance, that is, the "A+ B+ C+ D" mode. Third, this study presents the material landscape map of cave settlements in northern Shaanxi symbolically and provides a two- and three-dimensional graphical expression of landscape elements including site selection pattern, spatial layout, street layout and architectural form of cave settlements in northern Shaanxi. The abstract symbols have been extracted based on morphological features and cultural connotation of elements, and abstract internal connotations based on graphical expression. Finally, a landscape gene map of 15 typical settlements in northern Shaanxi was built by combining with landscape gene code structure and extraction of landscape gene prototype.

Based on the results of landscape genetic analysis of traditional settlements in northern Shaanxi, this study explored the landscape gene code and established a landscape gene map. Results have practical implications for sustainable development of different types of traditional settlement and

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ecological restoration of traditional dwellings. Although the landscape genetic map of traditional settlements provides a practical basis for their historical and cultural transmission, genetic "mutations" and functional transformations within the settlements as well as new demands of local residents for modern living space after development over a long period have been identified. The hierarchy of regional characteristics and the delineation of settlement zones in the landscapes provides further direction for subsequent research. The findings provide a comprehensive insight into the natural and human characteristics of traditional settlements in a particular landscape and the construction of a regional landscape map eventually. This system provides a layer-by-layer analysis of specific areas using a set of maps. The hierarchical regional map corresponds to large areas, sub-areas, sub-sub-areas and even individual settlements in the traditional landscape systems. It not only facilitates a comprehensive, scientific and accurate understanding and representation of the unique characteristics of traditional settlement landscapes from a macroscopic to a microscopic perspective, but also enhances the analysis of traditional settlement landscapes in China.

KEY WORDS: northern Shaanxi; traditional settlement; landscape gene; genetic code; mapping

Introduction

As the historical source of the traditional culture of the Chinese nation, traditional settlements have maintained a stable and harmonious state of development, preserving their unique features. In China, the Loess Plateau has nurtured the unique cave-dwelling culture of northern Shaanxi. Traditional cave dwellings are the most distinctive architectural type on the Loess Plateau. However, amid rapid urbanization, the cave-dwelling settlements in northern Shaanxi, which embody Chinese culture, are facing a habitat crisis. Therefore, how to scientifically and effectively tap into the landscape genes of traditional settlements and ensure their inheritance and continuation has always been an essential topic of research at home and abroad.

Foreign scholars' research on traditional settlements has shifted from the development of settlement resources to the restoration and protection of settlement cultural landscapes [1]. The research content focuses on the inherent cultural genes of landscape features and has been applied to the study of specific spatial areas [2]. Domestic research results on the genetic information coding and mapping of traditional settlement landscapes are becoming increasingly abundant. From the perspective of specific research content, they can be divided into two levels: material and non-material. At the level of material landscape gene research, Liu Peilin, Hu Zui, and other scholars first divided the landscape system of traditional settlements from a national perspective, and further analyzed the practical significance of the genome mapping of traditional settlement landscapes [3]. Existing studies have conducted in-depth research on material landscape elements such as settlement environmental factors [4] and architectural

factors [5], used field research [6], GIS spatial analysis [7], and other research methods, and combined interdisciplinary theories such as typology and geography to construct a traditional settlement landscape genome map [8]. At the level of non-material landscape gene research, traditional culture is the core element rooted in traditional settlements, and the customs, dialects, clans, and belief features [9] within the settlements are essential components of the settlement landscape features.

In summary, scholars at home and abroad generally agree that traditional settlement landscape genes share features with biological genes, both of which exhibit stable inheritance and individual variation. They have successively researched landscape gene identification and extraction, map construction, and the regional division of traditional settlements. However, current research on the internal structure among various elements of landscape genes is not systematic enough. In view of this, this study took 46 national traditional settlements in Yulin and Yan'an in northern Shaanxi as the research objects, took the theory of landscape genetics as the research perspective, and the landscape genetic information coding as the framework, combined with the results of the construction of landscape gene prototypes and landscape gene maps, to clarify the relationship between the various elements of traditional settlement landscapes in northern Shaanxi and provide new paths for its protection and development [10].

1 Areas in this research and data sources

1.1 Overview of the areas in this research

Administratively, northern Shaanxi includes Yulin City and Yan'an City, as well as 21 county-level regions, accounting

for approximately 39% of the total area of Shaanxi Province. Except for Jingbian County, Dingbian County, Hengshan District of Yulin City on the southern edge of the Mu Us Desert, and Luochuan County on the border of the Loess Plateau, the remaining 17 counties are all located in the loess gully landform area. The total area is 43,578 km², accounting for 22.2% of the province's total area, and comprises 230 townships and 5,570 administrative villages.

Based on the kernel density distribution of traditional settlements in Shaanxi Province (Figure 1), a core distribution zone centred at Suide County and Mizhi County appear in the Southeast region of Yulin City and the eastern region of Yan'an City. It is a major distribution zone of cave settlements and a typical region of cave settlement landscapes. The development of these settlements primarily extends along river valleys and gullies, areas that are simultaneously characterized by severe water and soil loss. The ecological environment is harsh, marked by a severe shortage of construction land and narrow space for development [11]. Over the years, the unique loess hilly and gully landform in northern Shaanxi has become the most significant impediment to settlement development in the region. Therefore, this paper selects traditional settlements in the loess hilly and gully area of northern Shaanxi as the research objects, conducts relevant research on landscape genetic information coding and mapping based on the current status of local settlements, and explores the direction of protecting and inheriting traditional settlements in this area.

1.2 Data source

The research samples in this paper mainly come from the 46 existing national traditional settlements in northern Shaanxi (Figure 2). These settlements have well-preserved historical features, which more completely reflect the production and living styles of the settlement residents and the regional spatial features; or they have unique spatial layouts and rich traditional residential buildings, which possess high protection and research value. This is of universal significance for the study of traditional settlements in northern Shaanxi [12]. These settlements have been successively included in the list of traditional villages, and their research value has been recognized. The historical and cultural customs of the villages are relatively complete, making it easier to conduct research.

The primary data sources of this study include literature materials and field surveys. The literature materials include Shaanxi Provincial Chronicles, traditional village atlases, traditional village planning texts, traditional village-related survey registration forms, and other research results related to Shaanxi's traditional settlements. In addition, the basic data for the northern Shaanxi region are sourced from the National Geomatics Center and the Geospatial Data Cloud. Remote sensing image data and contour terrain data are collected using software such as Google Earth, 91 satellite images, and Global Mapper. The graphs are drawn collaboratively using software such as AutoCAD, Photoshop, and Arc GIS.

2 Basis and process of constructing traditional settlement landscape gene maps

2.1 Traditional settlement landscape gene identification indicator system

Identifying the landscape genes of traditional settlements involves examining their essential features at the micro level. The article adopts the feature deconstruction extraction method proposed by Hu Zui [13], which divides the landscape of traditional settlements into two categories: material landscape genes (including environmental and architectural features) and non-material landscape genes (including custom, clan, dialect, and belief features), which are then further divided into six categories including 17 indicators (Figure 3).

2.2 Genetic information encoding of traditional settlement landscapes

To obtain a map of the traditional settlement landscape genes in a specific area, it is necessary to sort and encode the identified landscape genes, which involves arranging them in a logical order and constructing a landscape gene information coding structure. In the process of encoding landscape genes, the article applied typological principles and adopted coding techniques based on the *Chinese Library Classification* and the *Classification and Codes for Fundamental Geographic Information Feature*, and used the N-level coding theory to encode the landscape genetic information of traditional settlements in northern Shaanxi [14].

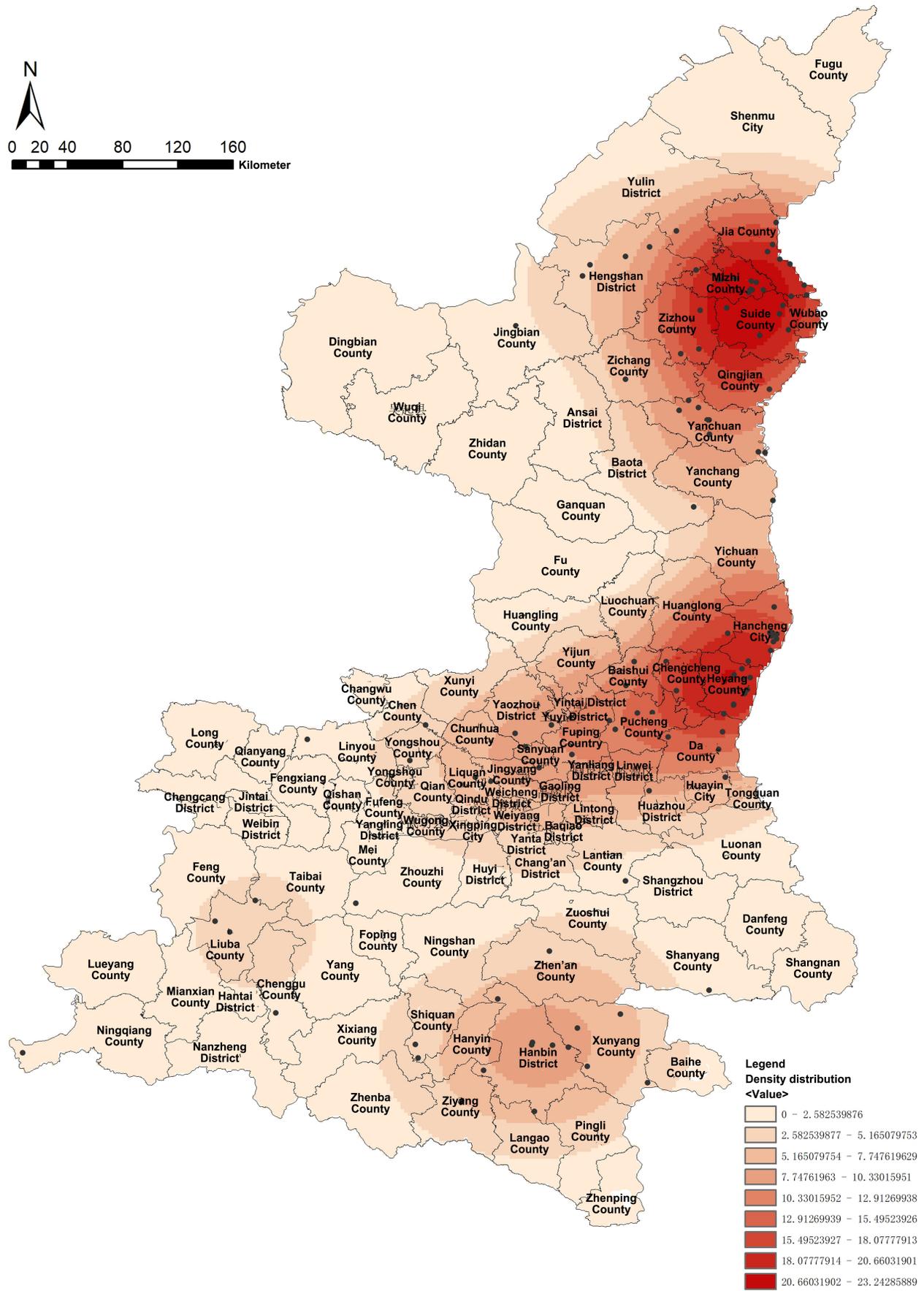


Figure 1 Distribution map of traditional villagekernel density in Shaanxi Province

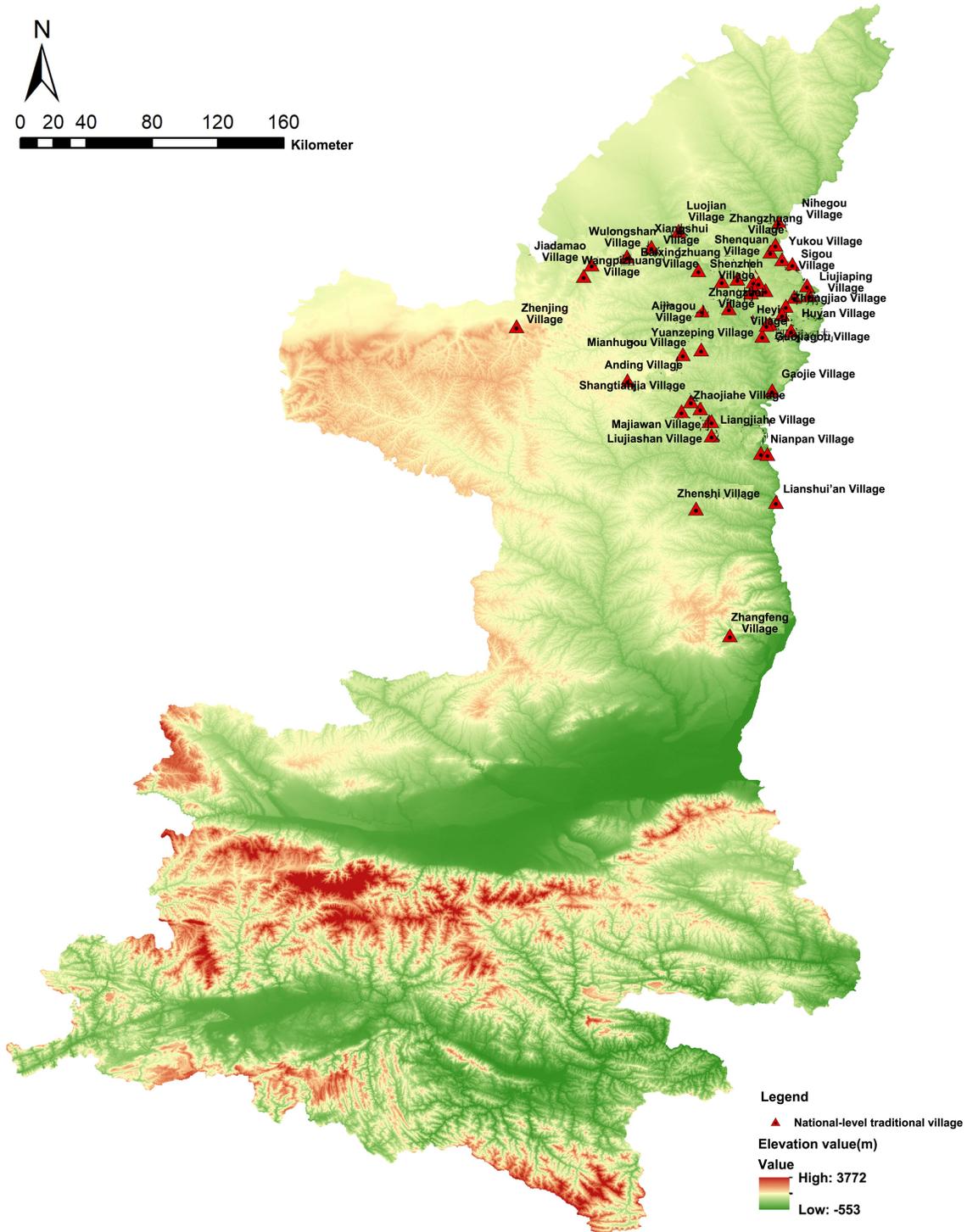


Figure 2 Spatial distribution of national-level traditional villages in northern Shaanxi

Taking northern Shaanxi as an example, the coding structure of landscape genes is divided into "area code + category code + feature code": ①Area code: Northern Shaanxi is set to Shaanxi-E, where Shaanxi represents the Shaanxi region and E represents North; ②Category code: According to the "Meme" proposed by Dawkins, M is used to describe landscape genes,

and according to the landscape gene identification index system, it is divided into M1 (material landscape genes) and M2 (non-material landscape genes); ③Feature code: The subordinate relationship of the landscape genes of cave settlements in northern Shaanxi is divided into four levels: "class-1 element, class-2 element, class-3 element, and

landscape gene element". Each level is represented by a single digit and encoded using Arabic numerals (Figure 4). Through landscape coding, not only can the encoded tradi-

tional settlement landscape genes be identified, but also the classification and affinity between numerous landscape genes can be accurately determined.

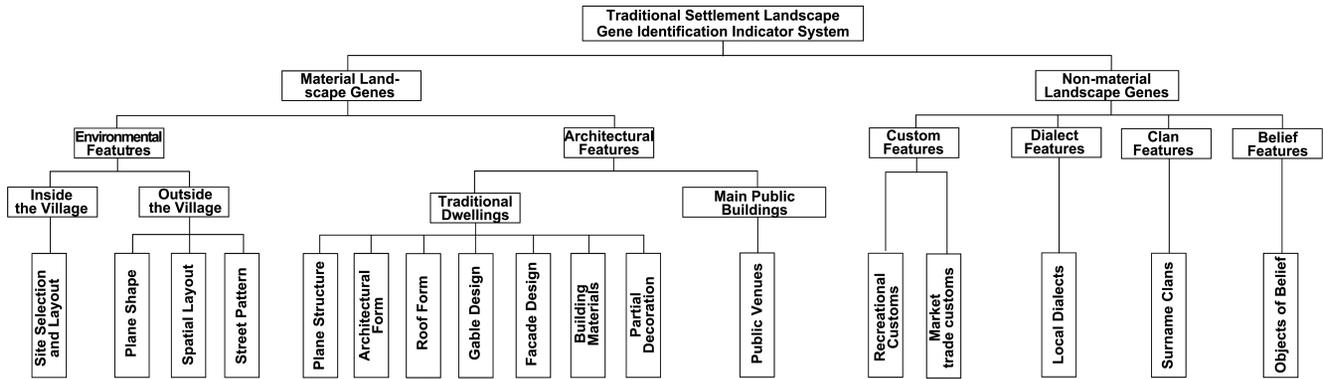


Figure 3 Traditional settlement landscape gene identification indicator system

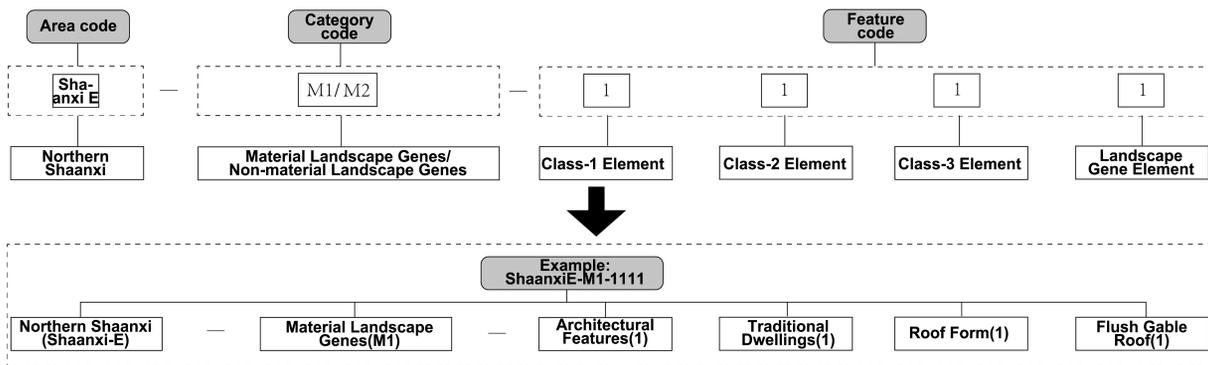


Figure 4 Genetic information encoding of traditional settlement landscapes

2.3 Construction of traditional settlement landscape gene maps

The construction of landscape gene maps involves using graphic language to comprehensively express and analyze the research object across temporal and spatial dimensions, thereby interpreting, classifying, and identifying it by disassembling and refining graphics or patterns [15]. The application paths of the mapping construction method mainly include landscape gene feature identification, landscape gene coding structure, and landscape map screening and reconstruction. The construction of traditional settlement landscape gene maps employs methods of abstraction, conceptualization, and typification. This method employs graphic language to explore, organize, classify, select, extract, and reorganize the fundamental features of traditional settlement landscapes, and then to interpret and express these features.

3 Genetic information coding structure of traditional settlement landscapes in northern Shaanxi

3.1 Genetic information coding of traditional settlement landscapes in northern Shaanxi

Through literature and field investigations, the traditional settlement typology is used to construct the genetic information coding of traditional settlement landscapes in northern Shaanxi. The specific structure of the digital code is "Shaanxi E-M1/2-XXXX" (Figure 5), which follows the format of "area code + gene category code + class-1 element + class-2 element + class-3 element + landscape gene element." According to the landscape genetic information coding structure diagram of traditional settlements in northern Shaanxi, its landscape genes are divided into two major categories: material landscape genes (M1) and non-material landscape genes (M2).

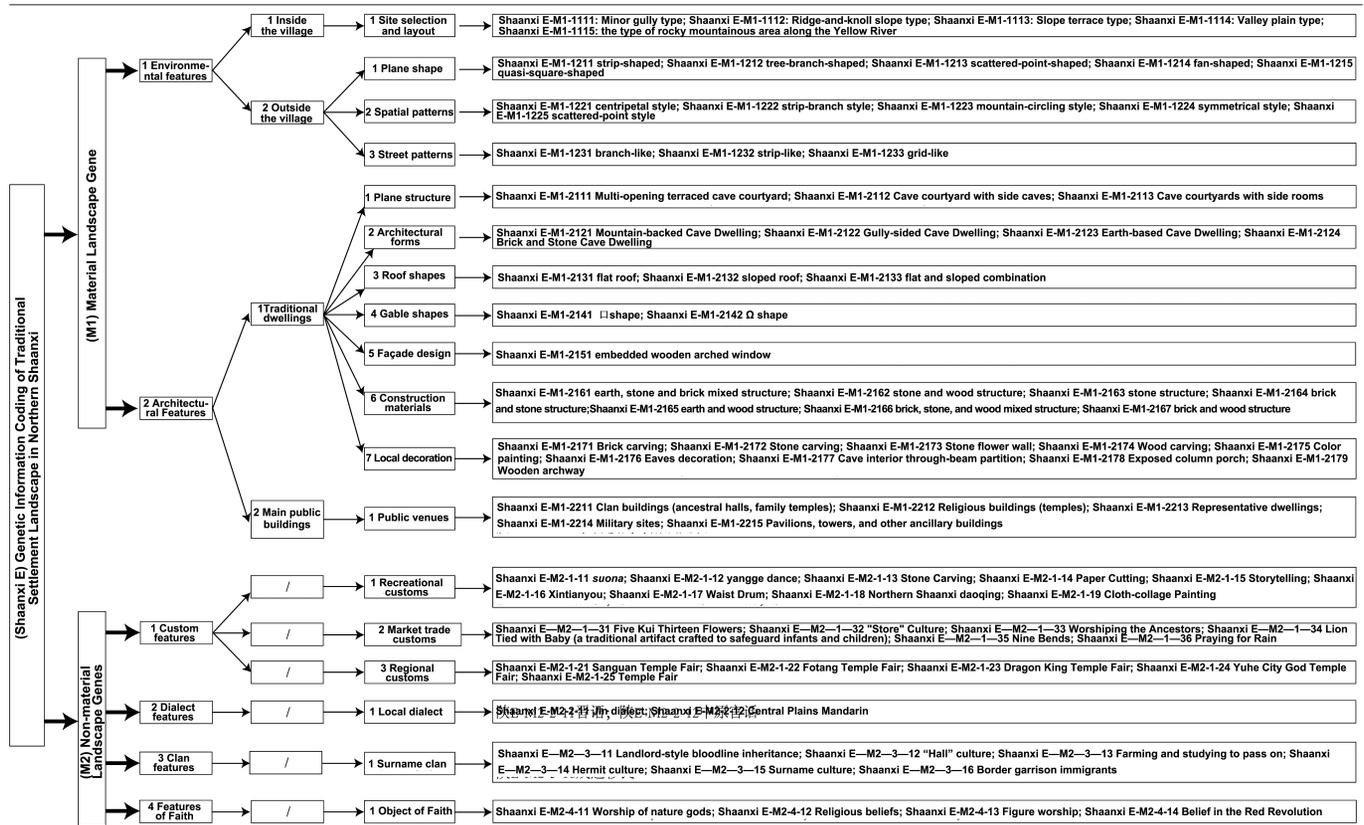


Figure 5 Genetic information coding of traditional settlement landscapes in northern Shaanxi

Among these, material landscape genes are divided into two categories: environmental and architectural features. (1) In terms of environmental features, cave settlements in northern Shaanxi are mainly located in the hilly and gully areas of the Loess Plateau and the rocky mountainous areas along the Yellow River. The plane forms of the settlements are mainly strip-shaped, tree-branch-shaped, scattered-point-shaped, fan-shaped, and quasi-square-shaped. The street patterns are mainly tree-shaped, strip-shaped, and grid-shaped. (2) In terms of architectural features, ① traditional dwellings are mainly divided into seven categories based on their plane structures, building forms, roof and gable shapes, façade design, local decoration, and building materials. ② Main public buildings are primarily divided into five types: clan and religious buildings, representative dwellings, military sites, pavilions, towers, and other ancillary buildings.

The non-material traditional settlement landscape genes in northern Shaanxi are categorized into four distinct features: custom, clan, dialect, and belief features. (1) In terms of custom features, ① entertainment customs in-

clude suona (traditional Chinese trumpet), yangge dance, stone carving, paper-cutting, storytelling, Xintianyou folk songs, waist drum performances, Northern Shaanxi daoqing (a local ballad form), and cloth-collage painting. ② Market trade customs are mainly temple fairs, including the Sanguan Temple Fair, the Fotang Temple Fair, the Dragon King Temple Fair, and the Yuhe City God Temple Fair. (2) Dialect features include the Jin dialect and Central Plains Mandarin. (3) Clan features are divided into landlord-style blood inheritance, "hall" culture, and surname culture. (4) Belief features are divided into nature god worship, religious belief, historical figure worship, and red revolutionary belief according to different belief objects.

3.2 Generation of the genetic pedigree of traditional settlement landscapes in northern Shaanxi

Through the previous analysis of the landscape genes of traditional settlements in northern Shaanxi and the construction of the landscape genetic information coding structure, it can be concluded that most of the traditional settlements in northern Shaanxi are based on family inheritance and small-scale peasant economy, which is reflected in the location layout, clan, and

residential architecture. Therefore, by combining the internal and external environmental genes of the settlement, the genes of traditional dwellings and main public buildings, and the

landscape genes with the same cultural significance, we can construct the traditional settlement landscape genetic pedigree in the region, namely the "A+ B+ C+ D" mode (Figure 6).

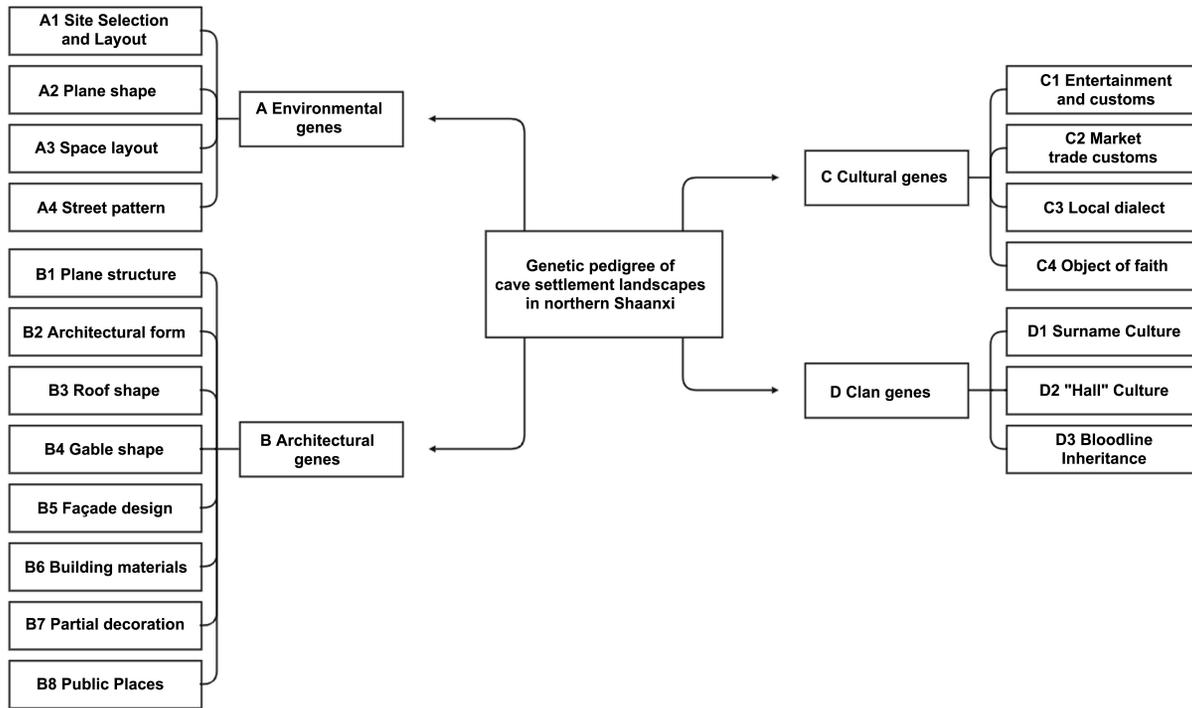


Figure 6 Genetic pedigree of traditional settlement landscapes in northern Shaanxi

4 Genetic prototype extraction and mapping of traditional settlement landscapes in northern Shaanxi

4.1 Genetic prototype extraction of traditional settlement landscapes in northern Shaanxi

The extraction of landscape gene prototype is the process of abstractly extracting and restoring the layout and architectural forms of traditional settlements, including their internal structure and formation principles, mainly achieved through methods such as graphic extraction, element extraction, and meaning extraction [13]. Because the existence and development of material landscapes have their own laws and clear representational forms, and non-material cultural landscapes are "living" landscapes that are transferred and flow based on human consciousness, and have collided and integrated with the cultures of various regions many times in the course of historical development, expressing human activity forms and spiritual and cultural emotions, this article mainly attempts to symbolically express the material landscape gene map of cave settlements in northern Shaanxi. The land-

scape elements of the cave settlements in northern Shaanxi, including site selection patterns, spatial layouts, street patterns, and architectural forms, are visually represented through two-dimensional and three-dimensional graphics. Abstract symbols are extracted based on the morphological features and cultural connotations of each element, and their inherent meanings are abstracted through graphical expression [16].

4.1.1 Prototype extraction of environmental genes from traditional settlements in northern Shaanxi

Combined with landscape gene identification results, the graph extraction method was used to derive prototypes for site selection, pattern, plane form, spatial pattern, and street pattern in traditional settlements of northern Shaanxi (Figure 7).

(1) The location and pattern of traditional settlements in northern Shaanxi can be divided into five types: minor gully type, ridge-and-knoll slope type, slope terrace type, river valley plain type, and the type of rocky mountainous area along the Yellow River. ① Among them, influenced by the topography, the minor gully type settlements are the

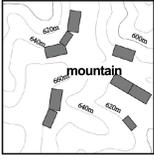
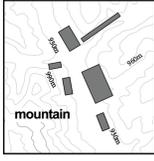
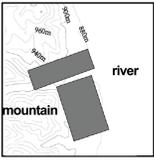
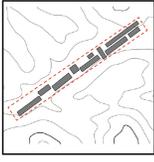
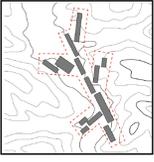
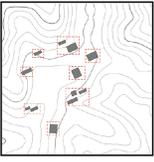
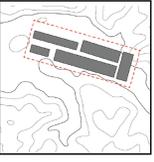
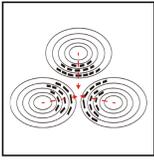
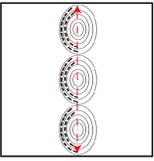
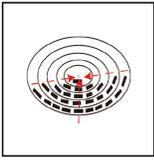
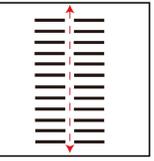
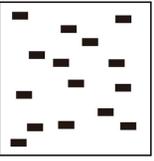
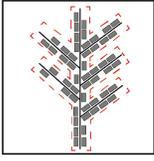
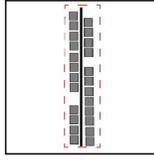
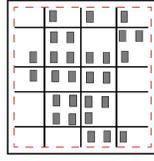
Site selection and layout Related description	Minor gully type	Ridge-and-knoll slope type	Slope terrace type	River valley plain type	the type of rocky mountainous area along the Yellow River
Genetic coding	Shaanxi E-M1-1111	Shaanxi E-M1-1112	Shaanxi E-M1-1113	Shaanxi E-M1-1114	Shaanxi E-M1-1115
Graph form					
Main features	Settlements developed along the mountainside on both sides. Their external boundaries were irregular, their scale was small, there was little arable land, and transportation was inconvenient.	The terrain is high, and the settlements are distributed in linear clusters along the mountain contours. The external boundaries are vague, the scale is small, and the cultivated land is close to the settlements.	The terrain has elevation differences and suitable slopes. The settlements extend vertically along the mountain, forming a scattered layout.	Most settlements are located in the middle reaches of the river. They are large in scale, with clear external boundaries, and are distributed in clusters along the river.	The terrain is relatively flat, the settlements are small, with clear external boundaries, are highly concentrated, and are distributed along the river.
Plane shape Related description	Strip-shaped	Tree-branch-shaped	Scattered-point-shaped	Fan-shaped	Quasi-square-shaped
Genetic coding	Shaanxi E-M1-1211	Shaanxi E-M1-1212	Shaanxi E-M1-1213	Shaanxi E-M1-1214	Shaanxi E-M1-1215
Graph form					
Key features	Influenced by the mountains on both sides, the settlement extends horizontally along the contour lines, built against the mountains, with its buildings facing the ravines.	The settlement is situated in an area where numerous gullies intersect, with the main gully serving as the development center and multiple development directions radiating out from it.	Each cluster is composed of multiple small building complexes, which are connected by streets and alleys, forming a point-linked spatial relationship.	Settlements are typically situated in winding channels, and their layout is circular along the contour lines, with the spatial axis aligned with the direction of the mountains on both sides.	The external form of the settlement is relatively regular, with a compact layout of main features, a clear internal structure, and an axis consistent with the direction of the mountain or river.
Spatial pattern Related description	Centripetal style	Strip-branch style	Mountain Circling style	Symmetrical style	Scattered-point style
Genetic coding	Shaanxi E-M1-1221	Shaanxi E-M1-1222	Shaanxi E-M1-1223	Shaanxi E-M1-1224	Shaanxi E-M1-1225
Graph form					
Key features	Settlements are distributed centripetally around the intersection of gullies, with the intersection often serving as the layout's center.	They are primarily distributed in gullies between loess ridges and ridges, and between ridges and gullies, and mainly extend in east-west or north-south belts.	The settlements are typically gathered on a hilltop and are often fan-shaped.	It is mostly distributed in river valley plains, and is less common in loess gully areas due to the complex terrain.	There is no connection between the settlements, and they are arranged in a free scattered manner.
Street pattern Related description	Branch-like		Strip-like	Grid-like	
Genetic coding	Shaanxi E-M1-1221		Shaanxi E-M1-1222	Shaanxi E-M1-1223	
Graph form					
Key features	It typically occurs in landforms with numerous gully intersections, with the main gully serving as the development center and extending in multiple directions on both sides.		It extends horizontally along a main gully or main road, shows apparent directionality, and emphasizes horizontal structure.	Typically, the site is chosen on flat, open terrain, featuring a grid combined with a ring road network. The primary and secondary are in order, and the surrounding transportation is convenient. It is close to the county town or city.	

Figure 7 Environmental gene prototype of the traditional settlements in northern Shaanxi

most numerous. They develop along the mountain lines on both sides. The external boundaries of the settlements are irregular, the scale is small, there is little cultivated land, and transportation is inconvenient, as seen in Aijiagou Village and Changjiagou Village. ② Ridge-and-knoll slope type settlements are distributed in higher areas. The settle-

ments are distributed in linear clusters along the contours of the mountain. The external boundaries are vague, the scale is small, and the cultivated land is located near settlements, such as Liangjiagou Village and Huling Village. ③ Slope terrace type settlements are distributed in areas with large elevation differences and suitable slopes. The

settlements extend vertically along the mountain, forming a scattered layout, as seen in Yuanzeping Village and Gaojie Village. ④ River valley plain type settlements are mostly distributed in the middle reaches of rivers. They are large in scale, with clear external boundaries, and are distributed in clusters along the river, such as Zhangzhai Village and Nihegou Village. ⑤ The rocky mountainous settlements along the Yellow River have relatively flat terrain, small settlement scale, clear external boundaries, and a high concentration, distributed along the river, such as Liujiaping Village and Mutouyu Village.

(2) The plane forms of traditional settlements in northern Shaanxi are strip-shaped, tree-branch-shaped, scattered-point-shaped, fan-shaped, and quasi-square-shaped. ① Strip-shaped settlements are primarily based on the surrounding water systems and transportation, with streets and alleys used as extension units of traditional dwellings, thus presenting a linear extension trend. Influenced by the mountains on both sides, settlements extend horizontally along the contour lines, built against the mountains, with buildings facing the gullies, such as Zhongjiao Village and Zhangfeng Village. ② Tree-branch-shaped settlements are located in a terrain where multiple gullies intersect, with the main gully as the development center and multiple development directions extending around it. In the time of primitive society, the settlements were located in deep gullies. Due to the obstruction of roads and transportation, they could avoid war and reproduce in a relatively comfortable environment. For example: Heyi Village, Taozhen Village. ③ Scattered-point-shaped settlements are usually located at the top of ridge-and-knoll slopes. The settlement morphology consists of several clusters connected by a network of streets and alleys. There is no obvious center for the development of residential architecture. Terraces are typically cultivated on the surrounding ridges and knolls to increase the area of arable land, reflecting the ecological thinking of the primitive residents. Each cluster is composed of multiple small building groups, connected by streets and alleys, forming a point-linked spatial relationship, as in Heiyita Village and Liujiashan Village. ④ Fan-shaped settlements are usually located in winding gully channels. The settlement layout is

circular along the contour lines, with the spatial axis aligned with the direction of the mountain or river, as seen in Jiadamao Village and Zhenjiawan Village. ⑤ The quasi-square-shaped settlements have a relatively regular external shape, a compact layout, a clear internal structure, and a spatial axis that is consistent with the direction of the mountains on both sides, such as Anding Village and Luoyan Village.

(3) The spatial pattern of traditional settlements in northern Shaanxi presents five types of forms: centripetal style, strip-branch style, mountain-circling style, symmetrical style, and scattered-point style. The spatial pattern of settlements shows a clear correspondence with their plane forms. Settlements with strip-shaped plane forms usually present a strip-branch style pattern, while settlements with tree-branch-shaped plane forms mostly have a centripetal style spatial pattern. ① Settlements with a centripetal style pattern are often distributed centripetally along intersecting gullies, with the intersection often being the center of the layout, such as Liujiamao Village and Yuejiacha Village. ② Settlements with a strip-branch style pattern are mostly distributed in gully channels between loess ridges and ridges, and between ridges and gullies, and mainly develop in an east-west or north-south belt, such as Nianpan Village and Zhaojiahe Village. ③ Mountain-circling style settlements are usually clustered on a hilltop and are usually fan-shaped, such as Liangshui'an Village and Jiadamao Village. ④ Settlements with symmetrical style layout are mostly distributed in river valley plains. They are less common in loess gully areas due to the complex terrain, such as Mutouyu Village. ⑤ Settlements with a scattered-point style layout are usually unrelated to each other and present a free scattered layout, such as Huling Village and Heiyita Village.

(4) The street patterns of traditional settlements in northern Shaanxi present three forms: branch-like, strip-like, and grid-like. ① The branch-like pattern usually appears in landforms with many gullies intersecting. This pattern is most common in traditional settlements in northern Shaanxi. It develops from the main gully as the center and extends in multiple directions on both sides, such as Mianhugou Village and Baixingzhuang Village. ② The

strip-like pattern often appears in settlements located in tributary gullies or slope terraces. When the mountains on both sides are steep and the slope is limited, making it difficult to build residential houses vertically, the settlement will expand parallel to the contour lines. In this case, the streets and alleys connecting the settlements will develop in a strip-like form, extending horizontally along a main gully or main road. This has a clear directionality and emphasizes a horizontal structure, as seen in Yuejiacha Village and Shapingshang Village. ③The grid-like pattern is typically situated in flat and open terrain, primarily distributed within river valley plains and settlements with minimal elevation difference and relatively level ground. The pattern within such settlements is usually regular and orthogonal. However, in areas with slight topographic variations, the village street network adopts a more freely intersecting form. A hierarchical order is maintained between the grid and ring road systems, with the grid pattern dominant and the ring roads secondary. Surrounding transportation is convenient and close to county towns or cities, such as Zhenziwan Village and Zhenjing Village.

4.1.2 Prototype extraction of architectural genes from traditional settlements in northern Shaanxi

Combined with the identification results of landscape genes, the element extraction method was used to extract prototypes of traditional dwellings and main public buildings in traditional settlements in northern Shaanxi (Figure 8).

(1) The plane structures of traditional residential buildings in northern Shaanxi are of three different forms: multi-opening terraced cave courtyards, cave courtyards with side caves, and cave courtyards with side rooms. ① Multi-opening terraced cave courtyards are the most common in cave settlements of northern Shaanxi, and there are also a small number of landlords' manors, such as the Dang family manor in Heyi Village, which use this courtyard model. ② The cave courtyard with side caves is the most typical model of cave dwellings in northern Shaanxi. The courtyard is oriented south-to-north, with a cave dwelling serving as the main room, often featuring five openings. Four hidden caves are symmetrically distributed on either side of the main cave, and six side caves are distributed on the east and west sides. The courtyard's interi-

or follows the ethical and functional layout of "main cave as the most important, side rooms as the second, and miscellaneous rooms as the auxiliary", which provides good privacy and functionality. Examples include Ma's Manor in Yangjiagou Village, Jiang's Manor in Liujiamao Village, and Chang's Manor in Gaomiaoshan Village. ③ Cave courtyards with side rooms are mainly distributed in the northern part of the Weibei area. They are only found in Zhangfeng Village in northern Shaanxi. The settlement features a coexistence of both the cave courtyards with side rooms and the narrow courtyards typical in the Guanzhong area, demonstrating distinct transitional and divergent characteristics.

(2) Traditional dwellings in northern Shaanxi are mainly cave dwellings. From the perspective of architectural form, they are divided into mountain-backed cave dwellings and independent cave dwellings. Among them, mountain-backed cave dwellings are further divided into mountain-backed and gully-sided cave dwellings based on their architectural form. ① The mountain-backed cave dwelling is against the cliff, with an open plain in front. The layout is significantly influenced by the terrain and is often parallel to the contour lines, featuring a curved or broken line layout. ② The gully-sided cave dwellings are cave dwellings dug inward on the cliffs on either side of the gully. This type of cave dwelling typically features a complex and varied layout. Because it is located near the gully, it can effectively shield against wind and sand, thereby regulating the regional microclimate. Its ecological environment is good, making it an ideal place to live. ③ Independent cave dwellings are divided into brick and stone cave dwellings and earth-based cave dwellings. Since the Wuding River Basin is rich in stone and quarrying is convenient, residents use local materials—soil, stone, and wood—to construct cave buildings that are closely integrated with nature.

4.2 Genetic mapping of typical settlement landscapes in northern Shaanxi

The landscape gene map of traditional settlements is a comprehensive expression of their landscape genes, including architecture, layout, and culture. It can clearly present the landscape genes of the settlements, including lay-

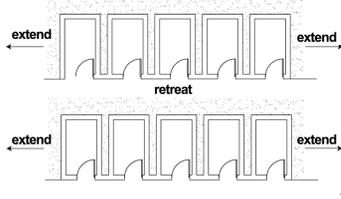
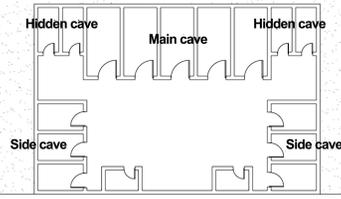
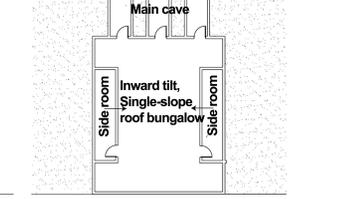
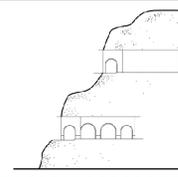
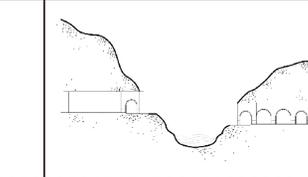
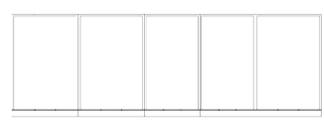
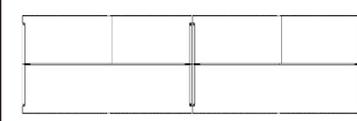
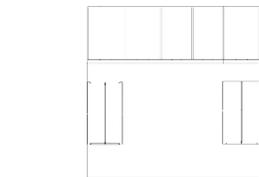
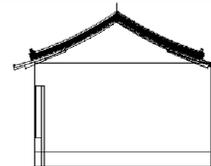
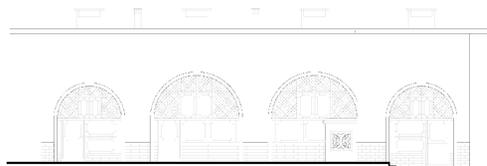
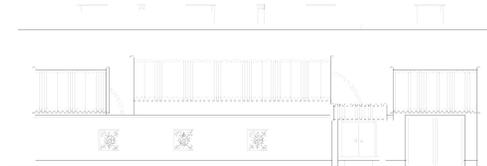
Plane structure Related description	Multi-opening terraced cave courtyard	Cave courtyard with side caves		Cave courtyards with side rooms
Genetic coding	Shaanxi E-M1-2111	Shaanxi E-M1-2112		Shaanxi E-M1-2113
Graph form				
Architectural form Related description	Mountain-backed cave dwelling	Gully-sided Cave dwellings	Earth-based cave dwellings	Brick and stone cave dwellings
Genetic coding	Shaanxi E-M1-2121	Shaanxi E-M1-2122	Shaanxi E-M1-2123	Shaanxi E-M1-2124
Graph form				
Roof shape Related description	Flat roof	Sloping roof		Flat and slope combination
Genetic coding	Shaanxi E-M1-2131	Shaanxi E-M1-2132		Shaanxi E-M1-2133
Graph form				
Gable shape Related description	□ shape		Ω shape	
Genetic coding	Shaanxi E-M1-2141		Shaanxi E-M1-2142	
Graph form				
Facade design Related description	Embedded wood-carved arched windows			
Genetic coding	Shaanxi E-M1-2151			
Graph form				

Figure 8 Architectural gene prototype of the traditional settlements in northern Shaanxi

out, architecture, beliefs, and folk customs, and explain the inherent laws of the traditional settlement landscape genes. It also reflects the logic and orderliness of the settlement landscape genes. Combining the traditional settlement

landscape gene coding structure in northern Shaanxi and the landscape gene prototype extraction results, this article constructed a landscape gene map of 15 typical settlement cases in northern Shaanxi (Table 1).

Table 1 Construction of the landscape gene map of typical settlements in northern Shaanxi

	Heyi Village	Aijiagou Village	Changjiagou Village	Guojiagou Village	Huyan Village	Liangjia Village	Zhongjiao Village	
Building genes	Plane structure	Shaanxi E-M1-2111 Multi-opening terraced cave courtyard	Shaanxi E-M1-2112 Cave courtyard with side caves	Shaanxi E-M1-2111 Multi-opening terraced cave courtyard	Shaanxi E-M1-2112 Cave courtyard with side caves	Shaanxi E-M1-2111 Multi-opening terraced cave courtyard	Shaanxi E-M1-2112 Cave courtyard with side caves	Shaanxi E-M1-2112 Cave courtyard with side caves
	Architectural form	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2123 Earth-based cave dwellings	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2123 Earth-based cave dwellings	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2123 Earth-based cave dwellings	Shaanxi E-M1-2122 Gully-sided cave dwelling Shaanxi E-M1-2124 Brick and stone cave dwellings	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2124 Brick and stone cave dwellings	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2124 Brick and stone cave dwellings	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2124 Brick and stone cave dwellings
	Roof shape							
	Gable shape	Shaanxi E-M1-2141 □ shape	Shaanxi E-M1-2141 Ω shape	Shaanxi E-M1-2141 □ shape	Shaanxi E-M1-2141 □ shape	Shaanxi E-M1-2141 □ shape Shaanxi E-M1-2142 Ω shape	Shaanxi E-M1-2141 □ shape	Shaanxi E-M1-2141 □ shape
	Facade design							
	Building materials	Shaanxi E-M1-2161 Earth-stone-brick mixed structure	Shaanxi E-M1-2161 Earth-stone-brick mixed structure	Shaanxi E-M1-2162 Stone-wood structure	Shaanxi E-M1-2162 Stone-wood structure	Shaanxi E-M1-2163 Stone structure	Shaanxi E-M1-2164 Brick-stone structure	Shaanxi E-M1-2165 Earth-wood structures
	Local decoration							
	public space	Shaanxi E-M1-2213 Representative dwellings (Dang Family Manor)	Shaanxi E-M1-2212 Religious buildings (Guandi Temple, Zhenwu Patriarch Temple)	Shaanxi E-M1-2212 Religious buildings (Monkey King Temple, Dragon King Temple, Buddhist Temple)	Shaanxi E-M1-2212 Religious buildings (Qingliang Temple, Sanguan Temple)	Shaanxi E-M1-2212 Religious buildings (Temple of the God of Wealth)	Shaanxi E-M1-2211 Clan building (ancestral hall) Shaanxi E-M1-2212 Religious buildings (ancestral temples, Dragon King Temple)	Shaanxi E-M1-2214 Military ruins (ancient road ruins)

(Continued)

	Heyi Village	Aijiagou Village	Changjiagou Village	Guojiagou Village	Huyan Village	Liangjia Village	Zhongjiao Village	
Cultural genes	Recreational customs	Shaanxi E-M2-1-11suona Shaanxi E-M2-1-12 yangge dance Shaanxi E-M2-1-13 stone carving	Shaanxi E-M2-1-12yangge dance (water-moving boat)	Shaanxi E-M2-1-12yangge dance Shaanxi E-M2-1-13 Stone Sculpture	Shaanxi E-M2-1-12yangge Shaanxi E-M2-1-14 Paper Cutting Shaanxi E-M2-1-15 Storytelling	Shaanxi E-M2-1-11suona Shaanxi E-M2-1-12 yangge dance	Shaanxi E-M2-1-13 stone carving	Shaanxi E-M2-1-11Suona Shaanxi E-M2-1-12 yangge dance
	Regional customs	/	Shaanxi E-M2-1-31 Five Kui Thirteen Flowers (Wedding Customs)	/	/	Shaanxi E-M2-1-33 "Store" culture	Shaanxi E-M2-1-33 Worship the ancestors	Shaanxi E-M2-1-34 Lion Tied with Baby (traditional artifacts crafted to safeguard infants and children)
	Object of Faith	Shaanxi E-M2-4-12 Religious beliefs (Buddhism)	Shaanxi E-M2-4-12 Religious beliefs (Buddhism, Taoism)	Shaanxi E-M2-4-13 Character Worship (Legend of Chang Yuchun's Descendants)	Shaanxi E-M2-4-11 Nature Worship (Legend of the Hongtong Big Locust Tree Immigrants)	Shaanxi E-M2-4-13 Character worship (the legend of "Li Guang shooting a tiger")	/	/
clan genes	Shaanxi E-M2-3-11 Landlord-style bloodline inheritance	Shaanxi E-M2-3-13 Farming and studying to pass on	Shaanxi E-M2-3-14 Hermit Culture	/	/	Shaanxi E-M2-3-15 Surname Culture (Ma Family)	Shaanxi E-M2-3-13 Farming and studying to pass on	
Building genes	Plane structure	Shaanxi E-M1-2111 Cave courtyard with side caves	Shaanxi E-M1-2112 Cave courtyard with side caves	Shaanxi E-M1-2111 Multi-opening terraced cave courtyard	Shaanxi E-M1-2111 Multi-opening terraced cave courtyard	Shaanxi E-M1-2111 Multi-opening terraced cave courtyard	Shaanxi E-M1-2111 Multi-opening terraced cave courtyard	Shaanxi E-M1-2112 Cave courtyard with side caves
	Architectural form	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2124 Brick and stone cave dwellings	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2124 Brick and stone cave dwellings	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2124 Brick and stone cave dwellings	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2124 Brick and stone cave dwellings	Shaanxi E-M1-2123 Earth-based cave dwellings Shaanxi E-M1-2124 Brick and stone cave dwellings	Shaanxi E-M1-2122 Gully-sided cave dwelling Shaanxi E-M1-2124 Brick and stone cave dwellings	Shaanxi E-M1-2121 Mountain-backed cave dwelling Shaanxi E-M1-2124 Brick and stone cave dwellings
	Roof shape							
	Gable shape	Shaanxi E-M1-2141 □ shape	Shaanxi E-M1-2141 □ shape Shaanxi E-M1-2142 Ω shape	Shaanxi E-M1-2141 □ shape	Shaanxi E-M1-2141 □ shape	Shaanxi E-M1-2141 □ shape	Shaanxi E-M1-2141 □ shape	Shaanxi E-M1-2141 □ shape Shaanxi E-M1-2142 Ω shape

(Continued)

		Heyi Village	Aijiagou Village	Changjiagou Village	Guojiagou Village	Huyan Village	Liangjia Village	Zhongjiao Village
Building genes	Facade design							
	Architecture Materials	Shaanxi E-M1-2166 Brick, stone, and wood mixed structure	Shaanxi E-M1-2166 Brick, stone, and wood mixed structure	Shaanxi E-M1-2164 Brick and stone structure	Shaanxi E-M1-2167 Brick and wood structure	Shaanxi E-M1-2164 Brick and stone structure	Shaanxi E-M1-2166 Brick, stone, and wood mixed structure	Shaanxi E-M1-2166 Brick, stone, and wood mixed structure
	Local decoration							
	Public space	Shaanxi E-M1-2212 Religious building (Ma's Ancestral Hall), Shaanxi E-M1-2213 Representative dwellings (Chairman Mao's former residence)	Shaanxi E-M1-2212 Religious buildings (Buddhist temples, Laoye temples) Shaanxi E-M1-2213 Representative dwellings (Chang Family Manor) Shaanxi E-M1-2215 Pavilions, towers, and other ancillary buildings (theater)	Shaanxi E-M1-2212 Religious buildings (Buddha temples, Guangong temples)	Shaanxi E-M1-2212 Religious building (Niangniang Temple), Shaanxi E-M1-2213 Representative dwellings (Guo Hongtao's former residence) Shaanxi E-M1-2214 Military Site (Former Site of the CPC Midong County Committee)	Shaanxi E-M1-2212 Religious buildings (Temple of Zhenwu Emperor) Shaanxi E-M1-2213 Representative dwellings (Ma Mingfang's former residence)	Shaanxi E-M1-2212 Religious buildings (Mawangye Temple, Sangong Palace) Shaanxi E-M1-2213 Representative dwellings (Bai's stone cliff cave dwelling)	Shaanxi E-M1-2212 Religious buildings (Dragon King Temple, Fajia Temple) Shaanxi E-M1-2213 Representative dwellings (Jiang's Manor)
Cultural genes	Entertainment customs	Shaanxi E-M2-1-11 suona Shaanxi E-M2-1-14 Paper Cutting	Shaanxi E-M2-1-14 Paper Cutting	Shaanxi E-M2-1-12 yangge dance	Shaanxi E-M2-1-12 yangge dance	Shaanxi E-M2-1-12 yangge dance	/	Shaanxi E-M2-1-12 yangge dance
	Regional customs	Shaanxi E-M2-1-35 Nine Bends Shaanxi E-M2-1-36 Pray for rain	Shaanxi E-M2-1-36 Pray for rain	/	/	/	/	/
	Object of Faith	Shaanxi E-M2-4-12 Religious belief (Buddhism) Shaanxi E-M2-4-14 Red Revolutionary Belief	Shaanxi E-M2-4-12 Religious beliefs (Buddhism)	Shaanxi E-M2-4-13 Character Worship (Li Dingming's "Streamlining Administration" Theory)	Shaanxi E-M2-4-12 Religious beliefs (Buddhism)	Shaanxi E-M2-4-11 Worship of Nature Gods (Legend of the Hongtong Big Locust Tree Immigrants)	Shaanxi E-M2-4-11 Worship of nature gods (fengshui prosperity theory)	Shaanxi E-M2-4-13 Character Worship (The Legend of Jiang Yaozu's Rise to Wealth)

(Continued)

	Heyi Village	Aijiagou Village	Changjiagou Village	Guojiagou Village	Huyan Village	Liangjia Village	Zhongjiao Village
clan genes	Shaanxi E-M2-3-13 Farming and studying to pass on Shaanxi E-M2-3-12 "Hall" Culture Shaanxi E-M2-3-15 Surname Culture (Ma Family)	Shaanxi E-M2-3-11 Landlord-style bloodline inher- itance	Shaanxi E-M2-3-11 Landlord Blood- line Inheritance (Bloodline of the "the Sixth of Old Li Clan")	Shaanxi E-M2-3-15 Surname Culture (Guo Family Revolutionary Tradition)	Shaanxi E-M2-3-16 Border Guard Immigrants	Shaanxi E-M2-3-13 Farming and studying to pass on	Shaanxi E-M2-3-11 Landlord blood- line inheritance

5 Conclusion and discussion

5.1 Conclusion

(1) The genetic information coding structure of traditional settlement landscapes in northern Shaanxi has been initially formed. By adopting the structural mode of "area code+ gene category code+class-1 element+class-2 element+class-3 element+landscape gene element", and analyzing the settlement landscape genes, the main characteristics and internal composition laws of the settlement can be clarified, thereby realizing the recognition of the overall and regional landscape features.

(2) Extract and analyze the genetic prototypes of traditional settlement landscapes in northern Shaanxi. The prototypes of the material landscape environmental genes, and architectural genes in northern Shaanxi were extracted using graphic extraction and element extraction methods, respectively, and it was concluded that the minor gully type settlements and multi-opening terraced cave settlements are the main cave types and courtyard patterns in northern Shaanxi.

(3) Construct a landscape gene map of typical cave settlements in northern Shaanxi. Fifteen typical settlements were selected, and a landscape map was constructed using graphical expression. The obtained landscape gene map can serve as an important data and information source for traditional settlement protection planning, providing theoretical support for the restoration of the historical memory of traditional settlement landscapes in northern Shaanxi, the establishment of regional identity, and landscape protection planning.

5.2 Discussion

(1) Based on the results of landscape genetic analysis

of traditional settlements in northern Shaanxi, this study explored the landscape gene code and established a landscape gene map. Results have practical implications for the sustainable development of different types of traditional settlements and the ecological restoration of traditional dwellings. Although the landscape genetic map of traditional settlements provides a practical basis for their historical and cultural transmission, genetic "mutations" and functional transformations within the settlements, as well as new demands from local residents for modern living space after long-term development, have been identified.

(2) The hierarchy of regional characteristics and the delineation of settlement zones in the landscapes provide further direction for subsequent research. The findings offer comprehensive insight into the natural and human characteristics of traditional settlements in a particular landscape and, eventually, into the construction of a regional landscape map. This system provides a layer-by-layer analysis of specific areas using a set of maps. The hierarchical regional map corresponds to large areas, sub-areas, sub-sub-areas and even individual settlements in the traditional landscape systems. It not only facilitates a comprehensive, scientific, and accurate understanding and representation of the unique characteristics of traditional settlement landscapes from a macroscopic to a microscopic perspective, but also enhances the analysis of traditional settlement landscapes in China.

Sources of Figures and Tables

All figures and tables in this article are drawn by the author.

References

- [1] SUN Q J, MALIKI N Z, ZHANG R X. Inherit and Reconstruction of Chinese Rural Landscape Culture-On the Development of Chinese Rural Settlements under the Background of Fast Urbanization [C]// Applied Mechanics and Materials. Trans Tech Publications Ltd, 2013, 357: 2126-2130.
- [2] VERDINI G, FRASSOLDATI F, NOLF C. Reframing China's Heritage Conservation Discourse. Learning by Testing Civic Engagement Tools in a Historic Rural Village[J]. International Journal of Heritage Studies, 2017, 23(4): 317-334.
- [3] HU Zui, LIU Peilin. Genome Mapping Characteristics of Traditional Chinese Settlement Landscapes[J]. Journal of Geography, 2015, 70(10): 1595-1605.
- [4] QI Jianqing. Research on the Geography of Traditional Residential Houses in Shaanxi[D]. Shaanxi Normal University, 2017.
- [5] QI Jianqing, DENG Yunyuan, ZHENG Wenwu, et al. Identification of Genes and their Variation in the Landscape of Kiln Architecture [J]. Arid Zone Resources and Environment, 2019, 33(6): 84-89.
- [6] WEN Jing. Principles of Cultural Landscape Gene Mapping and Tourism Display of Heritage Sites Based on the Perspective of "Landscape Gene Information Chain"[D]. Xi'an: Northwestern University, 2017.
- [7] LIN Runze, YANG Fan, ZHANG Dan, et al. Extraction of Landscape Features and Zoning of Traditional Villages in Minjiang River Basin[J]. Southern Architecture, 2022(4): 54-60.
- [8] LIU Peilin, ZENG Can, LIU Ruirui. Environmental Adaptation of Traditional Chinese Settlement patterns and its Landscape Gene Mapping[J]. Habitat International, 2023(135): 102808.
- [9] CAO Shuaiqiang. GIS-based Landscape Genetic Conservation Value of Intangible Cultural Heritage: Taking Hunan Province as an Example[J]. Journal of Hengyang Normal College, 2017, 38(3): 1-7.
- [10] XIANG Yuanlin, CAO Mingming, ZHAI Zhouyan, et al. Landscape Genome Mapping and Characterization of Traditional Rural Settlements in Shaanxi Kiln Caves[J]. Human Geography, 2019, 34(6): 82-90.
- [11] XIANG Yuanlin. Research on the Genetic Variation Mechanism of Traditional Rural Settlement Landscape and its Restoration in Shaanxi[D]. Xi'an: Northwestern University, 2020.
- [12] ZHANG Wenfang. Study on the Spatial Form of Traditional Villages in the Lower Wuding River in Northern Shaanxi[D]. Xi'an: Xi'an University of Architecture and Technology, 2020.
- [13] HU Zui, LIU Peilin, DENG Yunyuan, et al. Research on the Identification and Extraction Methods of Traditional Settlement Landscape Genes[J]. Geoscience, 2015, 35(12): 1518-1524.
- [14] WANG Yinxia. Research on the Construction of Cultural Gene Map of Traditional Villages in Southern Fujian[D]. Fuzhou: Fujian Agriculture and Forestry University, 2020.
- [15] LI Ling. The Construction of Landscape Feature Mapping of Traditional Settlements in Multicultural Intermingled Areas—an Example from Southern Shaanxi[J]. Geographical Research and Development, 2020, 39(5): 175-180.
- [16] ZHANG Gejuan, XU Ya, HAN Yi. Gene analysis and Expression Study of Ancient Town Landscape in Southern Shaanxi under Transitional Geography[J]. Journal of Northwestern University (Natural Science Edition), 2014, 44(4): 661-666.