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# Integrated RS, GIS and GPS approaches to archaeological prospecting in the Hexi Corridor, NW China: a case study of the royal road to ancient Dunhuang

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ABSTRACT

According to historic records, the wasteland northeast of modern Dunhuang oasis contains remarkable, undiscovered monuments of medieval courier stations. In this study, statistical analysis of historic records and census data, image processing and interpretation of satellite remote sensing images, GIS analysis, and field surveys were carried out to contribute to the discovery of courier stations and the reconstruction of the medieval royal road system from Guazhou to Shazhou. Firstly, in order to obtain the existence regions of courier stations, historic records and census data were abstracted and digitized, for generating preliminary regions of interest by using GIS tools. Secondly, dried river channels and traces of the Great Wall were extracted from the remote sensing images, and GIS buffer and overlay analyses were applied to the creation of prospective sub-areas. Thirdly, prospective sub-areas were mapped from very high resolution WorldView-2 images, and suspected sites were found based on the human-computer interactive interpretation. Fourthly, suspected sites were investigated on the GPS-based archaeological survey, and were confirmed as two courier stations based on the remains of Han-Tang period observed at sites' surface. Lastly, the royal road to ancient Dunhuang, one of the most important sections of the royal road system in the Hexi Corridor, was discussed and reconstructed with the combined application of remote sensing imagery and ground-truthing.



## 1. Introduction

With the rapid development of science and technology, especially combined applications in the natural sciences and the humanities and social sciences, archaeology has developed into several new subfields, such as environmental archaeology, historical archaeology, remote sensing archaeology, and other multidisciplinary approaches. Both the horizontal scale and vertical depth have been extending in archaeological prospection with the rise of Earth observation technology and computer science since the 1950s. Earth observation technology mainly based on remote sensing (RS), GIS, and global positioning system (GPS), collectively called 3S (Deng et al., 2010; Nie and Yang, 2009; Luo et al., 2012), has become an important tool helping archaeologists to prospect and understand archaeological sites, to discover hidden sites, and to resolve real archaeological problems.

Remote sensing as a non-destructive tool to uncover remains of ancient human occupation and past landscapes has been used for archaeological applications since the 1970s when it started to be available for civil purposes (Noviello, 2013). Archaeologists have used a variety of ever-more sophisticated techniques to identify, extract, delineate and analyze archaeological sites and their surroundings (Clark et al., 1998; Brivio et al., 2000; Ur, 2003; De Laet et al., 2007; Masini and Lasaponara, 2007; Beck et al., 2007; Wisemann and Baz, 2007; Lasaponara and Masini, 2007, 2011, 2012, 2014; Parcak, 2007, 2009; Alexakis et al., 2011; Morehart, 2012; D'Orazio et al., 2012).

GIS has over the last 10 years become an important tool in archaeology. The three main applications of GIS in archaeology are visualization, spatial analysis and modeling (Church et al., 2000; Brandt et al., 1992; Van Dalen, 1999; Woodman, 2000), and Conolly and Lake (2006: 33–50) note that four typical applications

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of GIS in archaeology are management of archaeological resources, excavation, landscape archaeology (or field-working) and the spatial modeling of past human behavior. GIS-based archaeology is now paid more and more attention all over the world and there have been many successful cases which are mostly engaged in cultural resource management and academic research (Espa et al., 2006; Evans et al., 2007; Siart et al., 2008; Alexakis et al., 2011; Sadr and Rodier, 2012).

GPS is a satellite navigation system used to provide precise locations to receivers on the Earth surface. GPS units can record site, feature, and survey information with accuracy within a few centimeters. Archaeological surveying and field work have been enriched and become more effective through the use of GPS, such as the use of GPS units to plot survey transects and archaeological sites and features (Maktav et al., 2009; Chapman and Noort, 2001; Luo et al., 2012). At present, hand-held GPS units are widely employed to identify specific points by archaeologist.

Archaeological predictive modeling (APM) is one of the most common methodologies in quantitative archaeology (Wheatley and Gillings, 2002: 79). There have been some inductive GIS-based APM methods proposed (Warren, 1990; Brandt et al., 1992; Vaughn and Crawford, 2009; Konstantinos and Athanasios, 2011; Carrer, 2013; Stirn, 2014), but none have been very successful in discovering the new sites. Because of most of them are built to mapping archaeological potential based on the specific characteristics of the known sites, including topographical, hydrological and humanistic characteristics. In this study, derived from historic records, APM that integrate RS and GIS techniques can expedite and realize the process of site discovery by identifying prospective sub-areas of high archaeological potential for subsequent GPS-based field investigation.

The aim of this study is to present a case study to demonstrate how RS, GIS and GPS technologies have been able to contribute to the discovery, interpretation and documentation of medieval courier stations on the royal road system in Dunhuang.

## 2. Study area

The Silk Road was opened up for communication between ancient China and the Western world in the 2nd century B.C. This is of great significance for archeological prospection, with a huge number of archaeological monuments distributed along Silk Road routes, especially in the Hexi Corridor. Hexi Corridor, part of the ancient Silk Road running northwest from the Yellow River (Fig. 1a, b), was the most important route from East China to the Tarim Basin and Central Asia for traders and soldiers.

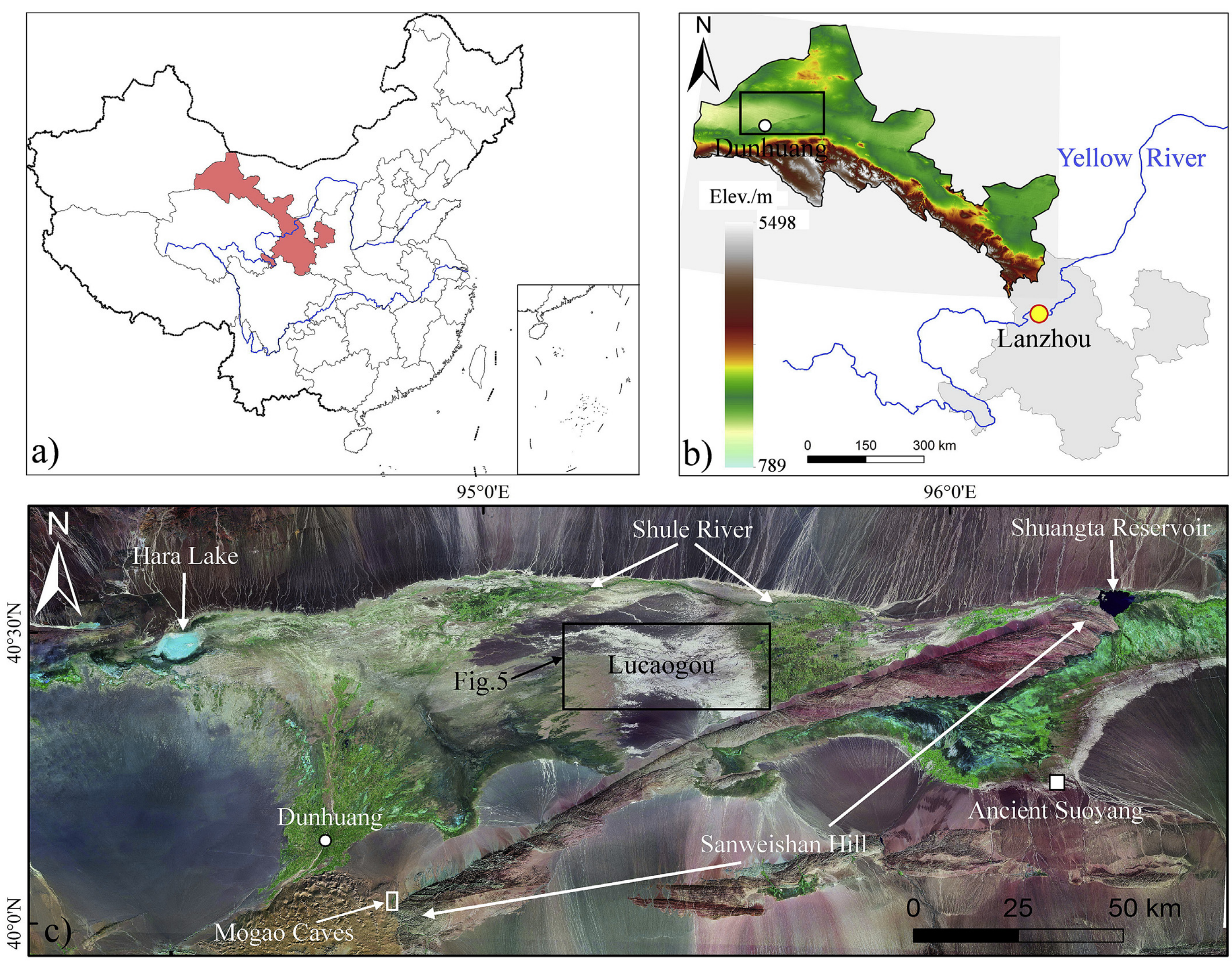


Fig. 1. Location of the study area. a) Hexi Corridor in NW China; b) DEM map of the Hexi Corridor; c) Landsat ETM + data (R (7) G (4) B (1) compositions) from the box in (b).

In this study, research was performed for a well-documented historic site called Lucaogou located close to the modern city of Dunhuang, in the northwestern Hexi Corridor. Lucaogou is part of the ancient Dunhuang oasis near the confluence of the ancient Shule River (Fig. 1c), now characterized by the wind-eroded yardang landforms and sand dunes. The strategic location of Lucaogou favored continuous human activity from the Paleolithic to present, especially in the period from the Han (202 B.C. to 220 A.D.) to early Tang (618 A.D. to 907 A.D.) dynasties, as testified by archaeological remains (Stein, 1921; Yan, 1953; Xia, 1955; Li B C, 1995; Li Z Y, 1995) and historic records (Stein, 1921; Ban, 1961; Li, 2008).

With regard to the Han-Tang period, documentary sources state the existence of a Great Wall defense system of the Han Dynasty (Stein, 1921; Yan, 1953; Li B C, 1995; Li Z Y, 1995, 2008) and a royal road system of the early Tang Dynasty (Xia, 1955; Li B C, 1994, 1996; Li Z Y, 2008) in the ancient Lucaogou oasis. The Lucaogou oasis achieved its maximum expansion between the second century B.C. and eighth century A.D. and was thoroughly abandoned in the beginning of the Yuan Empire (1271 A.D. to 1368 A.D.) (Li, 1994), whereas the ancient earthen royal road system was partially used until the foundation of new China in 1949 (Li B C, 1994, Li Z Y, 2008).

Today, the only preserved remnants are paleochannels, wind-eroded landforms, and sand dunes. It is very difficult to discover archaeological remains and settlement sites by traditional archaeological methods in this untraversed region. Historic records and previous work constitute key sources of data in this study. However, the precise spatial location, actual shape of the documented archaeological sites and the structure of the Han Great Wall defense system and royal road system were still not well known prior to this research. In order to reveal answers to these mysteries, a combined application of GIS, RS and GPS approaches were used to prospect and analyze the archeological monuments in Lucaogou. Only the royal road system of the Tang Dynasty is the object of this study.

## 3. Data and methods

### 3.1. Data

#### 3.1.1. Historic records and census data

The ancient Chinese composed and preserved a large number of historic records on the Northwest Frontier from the Han to Qing dynasties. These materials are a major resource for academic studies in a wide variety of fields including history, religious studies, linguistics, and manuscript studies. Dunhuang Manuscripts P.2005 and P.5034 are two Tang-period historical-geographical manuscripts concerning medieval Shazhou (modern Dunhuang) and Guazhou discovered in the Mogao Caves of Dunhuang in 1900, and are now collected in the National Library of France. In this study, Dunhuang Manuscript P.2005 and P.5034 constitute key sources of data for archaeological prospection of Lucaogou and provide rough spatial information of courier station sites along the royal road system (Li B C, 1996; Li Z Y, 2008).

China's 3rd National Cultural Relic Census was conducted from April 2007 to December 2011. The census data around the study area provide knowledge of archaeological sites in relation to Lucaogou, such as precise spatial location, size and structure, function and significance. All of these as indirect information are useful for discovering new sites. For instance, the ruin of the ancient city of Liugong, listed in the 3rd National Cultural Relic Census database, is located in southeastern Lucaogou. Ancient Liugong was the metropolis of ancient Changle, which was a county of ancient Dunhuang Prefecture, and a courier station named Changleyi was founded in Ancient Liugong during the Tang Dynasty. The spatial relationships between the Changleyi courier station and others have a short record in the Dunhuang Manuscript P.2005 and P.5034.

#### 3.1.2. Remote sensing data

Satellite remote sensing data, including Landsat 7 ETM+, ZY-3 and WorldView-2, were employed and analyzed together with Google Earth data, having different areal coverages and resolutions.

*3.1.2.1. Landsat data.* Landsat 7 ETM + data were acquired from the Institute of Remote Sensing and Digital Earth of the Chinese Academy of Sciences (http://ids.ceode.ac.cn/). This imagery is composed of seven bands from the visible to the mid-infrared parts of the spectrum. Each band has a spatial resolution of 30 m. These data also include a panchromatic (PAN) image with a spatial resolution of 15 m. Landsat images provided the basis for mapping dried river channels in the Lucaogou region, where the morphological aspects of the dried channels can be observed exceptionally well due to their spectral signature and texture characteristics.

*3.1.2.2. ZY-3 data.* ZY-3 (Ziyuan-3 or Resources-3) is China's first civil high-resolution mapping satellite. Launched in the spring of 2012, it provides 2.1 m resolution PAN and 5.8 m resolution multispectral (MS) image products for implementing topographical mapping and observation of land resources. The ZY-3 PAN image, acquired from the China Centre for Resources Satellite Data and Application (http://www.cresda.com) has a good view of linear features, especially the Han Great Wall in the Lucaogou region, though some traces are less obvious.

*3.1.2.3. WorldView-2 data.* Archaeologists interested in detecting archaeological features are increasingly employing very high resolution (VHR) commercial satellite imagery. The Ikonos VHR images and QuickBird VHR images have been widely used in previous studies (De Laet et al., 2007; Lasaponara and Masini, 2007, 2011, 2014; Parcak, 2007, 2009), and will continue to play a constructive role in the identification of archaeological features in the future. Image-based archaeological studies using VHR presently concentrate on the Ikonos VHR images and QuickBird VHR images, lacking applications of the latest WorldView-2 (WV-2) satellite's VHR data. WV-2 provides data from two imaging sensors: the PAN, with a spatial resolution of 0.46 m, and the MS sensor that acquires data in eight spectral bands from 0.4 μm to 1.04 μm, with a spatial resolution of 1.84 m. Hence for this study, WV-2 VHR images were purchased from DigitalGlobe to identify and map archaeological monuments.

*3.1.2.4. Google Earth data.* Google Earth, a ‘virtual globe’ map and geographical information program released in 2005, is now widely used in the field of geoarchaeology (Myers, 2010a, 2010b; Sheppard and Cizek, 2008; Thomas et al., 2008; Sadr and Rodier, 2012). VHR images provided by Google Earth were used as a supplement in the reconstruction of royal road system to ancient Dunhuang.

### 3.2. Methods

#### 3.2.1. Satellite images preprocessing

Since the Landsat ETM+, ZY-3 and WV-2 images are products with systematic geometric corrections; no such corrections were applied in the pre-processing. Image-to-image co-registration between ZY-3 and Landsat images was undertaken for the study area. We used a Landsat 7 ETM + image as a reference to implement the image-to-image geometric corrections. A manual geometric correction was performed with a root mean square error (RMSE) of less than 0.4 pixels. The co-registration between Landsat and VHR images (WV-2 and Google Earth) at the study area was already highly accurate and hence there was no need for manual co-registration.

Pan-sharpening was the latter operation executed in order to combine both the very high spatial resolution of PAN images and the high spectral resolution of MS images. Pan-sharpening can be considered a suitable operation to improve the visibility of archaeological features on satellite data both on small and large scales (Noviello et al., 2013). Several studies present results of applying these methods for a better identification of buried structures (Beck et al., 2007; De Laet et al., 2007; Lasaponara and Masini, 2007, 2012; Traviglia and Cottica, 2011; Noviello et al., 2013). All satellite images were enhanced by Gram Schmidt pan-sharpening (Lasaponara and Masini, 2012) in this study, except for ZY-3 data and Google Earth VHR images.

#### 3.2.2. Abstract and digitize the historic records and census data

The courier stations on the royal road to ancient Dunhuang were documented in Dunhuang Manuscripts (P.2005 and P.5034) in Chinese, especially the Dunhuang Manuscripts P.2005. The P.2005 described the courier stations as follows: "New royal road system with ten courier stations, from Guazhou to Shazhou, was founded north of Sanweishan Hill in 691 A.D., and seven of the stations, Changleyi (CLY), Jietingyi (JTY), Gancaoyi (GCY), Changtingyi (CTY), Baitingyi (BTY), Hengjianyi (HJY), and Qingquanyi (QQY) from the east to the west, were newly founded by the Empress Wu", and "QQY was located forty Chinese li northeast of Ancient Shazhou and twenty Chinese li south of HJY; HJY was located sixty Chinese li northeast of Ancient Shazhou and twenty Chinese li south of BTY; BTY was located eighty Chinese li northeast of Ancient Shazhou and forty Chinese li southwest of CTY; CTY was located one hundred and twenty Chinese li northeast of Ancient Shazhou and twenty five Chinese li northwest of GCY; GCY was located one hundred and forty five Chinese li northeast of Ancient Shazhou and twenty five Chinese li northwest of JTY; JTY was located one hundred and seventy Chinese li northeast of Ancient Shazhou and thirty Chinese li northwest of CLY; All of the stations were founded south of the Han Great Wall". One Chinese li is equal to 540 m in the period of the Tang Dynasty (Li, 1994; Schinz, 1996; Wu, 2006).

In medieval China, the distance, from one courier station to the other, is not the straight line, but the distance traveled. This study proposes that the distance traveled was a journey along the river channels and the edge of the desert, and takes full consideration of landforms and geomorphology in Lucaogou. This paper uses $(x, y)$ to abstract and digitize the written records of distance and direction based on Dunhuang Manuscript P.2005, where $x$ represent distance traveled and $y$ represent direction. The value of $y$ has eight choices, where $0$ represents no movement, $+1$,$+2$,$+3$ and $+4$ represent north, northeast, east, and southeast, respectively, and $-1$,$-2$,$-3$ and $-4$ represent south, southwest, west, and northwest, respectively. A skew-symmetric matrix shows the distance and direction relationship among the stations in Table 1. For example, $(30, -4)$ indicates that the JTY station is located thirty Chinese li northwest of the CLY station. Both distance and direction values were bolded in Table 1.

Eight of the courier stations on the new royal road have been studied from the previous researches: five of them, Shazhou, JTY, CLY, XQB, Guazhou, have been discovered and confirmed (Li B C, 1996; Li Z Y, 2008); three of the courier stations, QQY, HJY, and BTY, located on the margin of modern Dunhuang oasis, have been roughly positioned by some studies and investigations (Yan, 1953; Li B C, 1994, 1996; Li Z Y, 2008). The GCY and CTY stations are still-missing. Details will be discussed in the section 5. Fig. 2 sketches the distribution of the courier stations on the newly royal road system to ancient Dunhuang based on above analysis.

In this paper, JTY station and Han Great Wall were used as control and reference features to positioning and mapping the existence regions of the still-missing courier stations. JTY station suffered wind-erosion for nearly a thousand years, leaving only the remains of a beacon tower in the northwest (Li B C, 1994, 1996; Li Z Y, 2008). Fig. 3a shows the ruin of Jietingyi and surrounding areas. The Han Great Wall can be seen in the high resolution ZY-3 PAN image with unique linear characteristics (Fig. 3b), and could be easily extracted from a ZY-3 PAN image.

#### 3.2.3. Prospective sub-areas creation

The facilities and cities were mostly built along the river in ancient China, especially on the north side. The Great Wall was a defensive system against invasions from the north, and the fortifications and human settlement sites were generally constructed south of the Great Wall. Thus, we focus on the regions which were near the dried river channels and located south of the Great Wall in this study. Here, the creation process of prospective sub-areas to GCY station was showed as a demonstration (Fig. 4).

The majority of the dried paleochannels in Lucaogou were more promptly recognized using optical images. Hence, these features could be easily observed and extracted on Landsat images, particularly using the R (7) G (4) B (1) composition (Fig. 4a). The linear traces of Great Wall were early detected from the density slicing ZY-3 PAN image (Figs. 3b and 4b). A three-ring channels' buffer-layer was built by using the multiple-ring buffer tool under the ESRI ArcInfo software, the buffer distances far from the channels are 500 m, 1000 m and 1500 m, respectively (Fig. 4c). The Great Wall's buffer layer, one-sided layer, is corresponding to the area which located south of the Great Wall (Fig. 4d).

Dunhuang Manuscript P.2005 recorded that "GCY was located 25 Chinese li northwest of JTY". These words indicate that the GCY was 13.5 km (distance traveled) northwest from JTY, and the crow-fly distance was less than 13.5 km. The shortest crow-fly distance was determined to 10.8 km after many simulation experiments on the GoogleEarth. JTY station was represented and mapped with point feature in GIS based on census data, and then the point was used as a center, and distance traveled and shortest crow-fly distance, as radiuses to draw circles, respectively. The northwest part of the area, between JTY's two concentric circles, was the

**Table 1**
Distance traveled and direction matrix of the CSs (unit: Chinese li).

| | CLY | JTY | GCY | CTY | BTY | HJY | QQY | Shazhou |
|---|---|---|---|---|---|---|---|---|
| CLY | (0, 0) | (30, +4) | (55, +4) | (80, +4) | (120, +4) | (140, +3) | (160, +2) | (200, +2) |
| JTY | **(30, −4)** | (0, 0) | (25, +4) | (50, +4) | (90, +4) | (110, +3) | (130, +2) | (170, +2) |
| GCY | (55, −4) | (25, −4) | (0, 0) | (25, +4) | (65, +4) | (85, +2) | (105, +2) | (145, +2) |
| CTY | (80, −4) | (50, −4) | (25, −4) | (0, 0) | (40, +3) | (60, +2) | (80, +2) | (120, +2) |
| BTY | (120, −4) | (90, −4) | (65, −4) | (40, −3) | (0, 0) | (20, +1) | (40, +2) | (80, +2) |
| HJY | (140, −3) | (110, −3) | (85, −2) | (60, −2) | (20, −1) | (0, 0) | (20, +2) | (60, +2) |
| QQY | (160, −2) | (130, −2) | (105, −2) | (80, −2) | (40, −2) | (20, −2) | (0, 0) | (40, +2) |
| Shazhou | (200, −2) | (170, −2) | (145, −2) | (120, −2) | (80, −2) | (60, −2) | (40, −2) | (0, 0) |

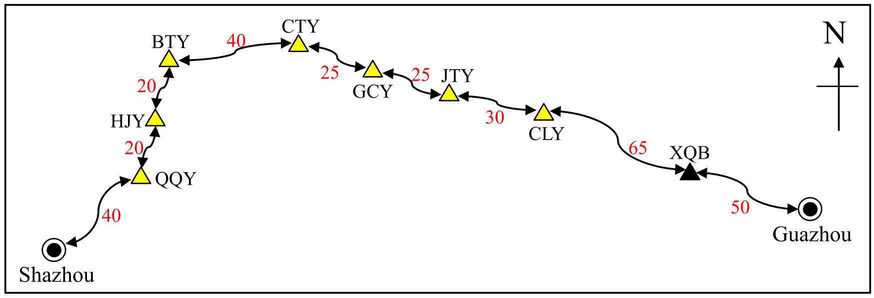


**Fig. 2.** Distribution of courier stations from Guazhou to Shazhou. Red marks around the double-headed arrows indicate the distance traveled between one station and its neighbor based on Dunhuang Manuscript P.2005 (unit: Chinese li).

preliminary regions of interest of the GCY (Fig. 4e). Preliminary ROIs, produced from the Dunhuang Manuscripts, were used to narrowing the search scope for the still-missing courier stations. The hierarchical intersections, overlaid by preliminary ROIs, Great Wall buffer, and dried river channels' buffer in GIS, are the prospective sub-areas of the GCY station (Fig. 4 f, g).

We produced two prospective sub-areas corresponding to the undiscovered courier stations: GCY and CTY, and marked them on the Landsat images with red boxes (Fig. 5). WV-2 VHR Pan-sharpening images, correspond to prospective sub-areas, were human-computer interactive interpreted by using the RS image processing software ENVI4.8. The regular geometric shapes were

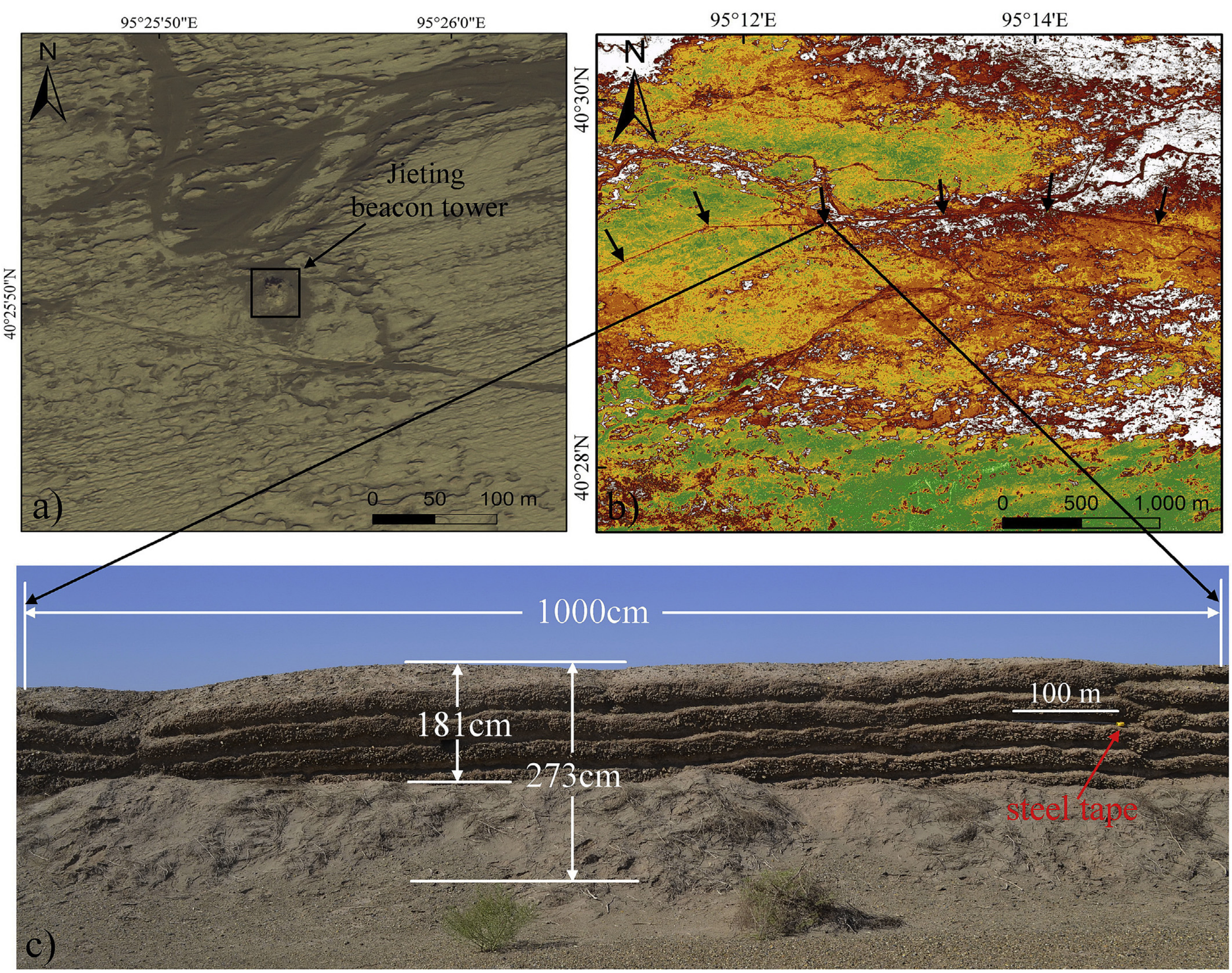


**Fig. 3.** a) WV-2 VHR image of JTY; b) color mapping of high-resolution ZY-3 PAN image by using density slice, the black arrows indicate the Han Great Wall; c) field photo of the Han Great Wall.

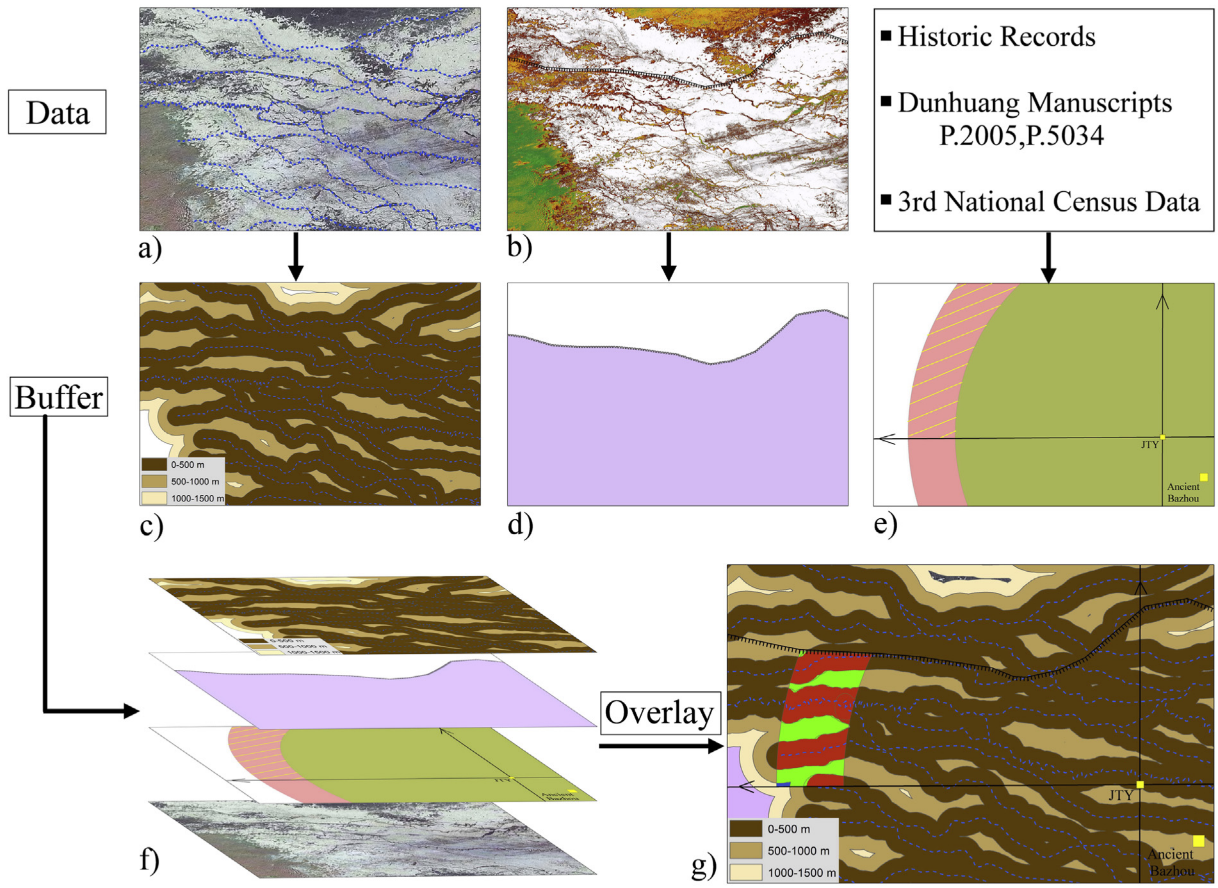


**Fig. 4.** The creation process of prospective sub-areas to GCY station. a) dried river channels (blue dotted line) based on Landsat composite image; b) Han Great Wall traces extract from density slicing ZY-3 PAN image; c) 3-ring channels' buffer; d) Great Wall's buffer; e) the preliminary ROIs of GCY (yellow-shaded region), the light pink and light green circles indicate the distance traveled and the shortest crow-fly distance, respectively; f) diagram of GIS Overlay-analysis; g) the prospective sub-areas to GCY, red and green areas represent the high and low archaeological potential, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

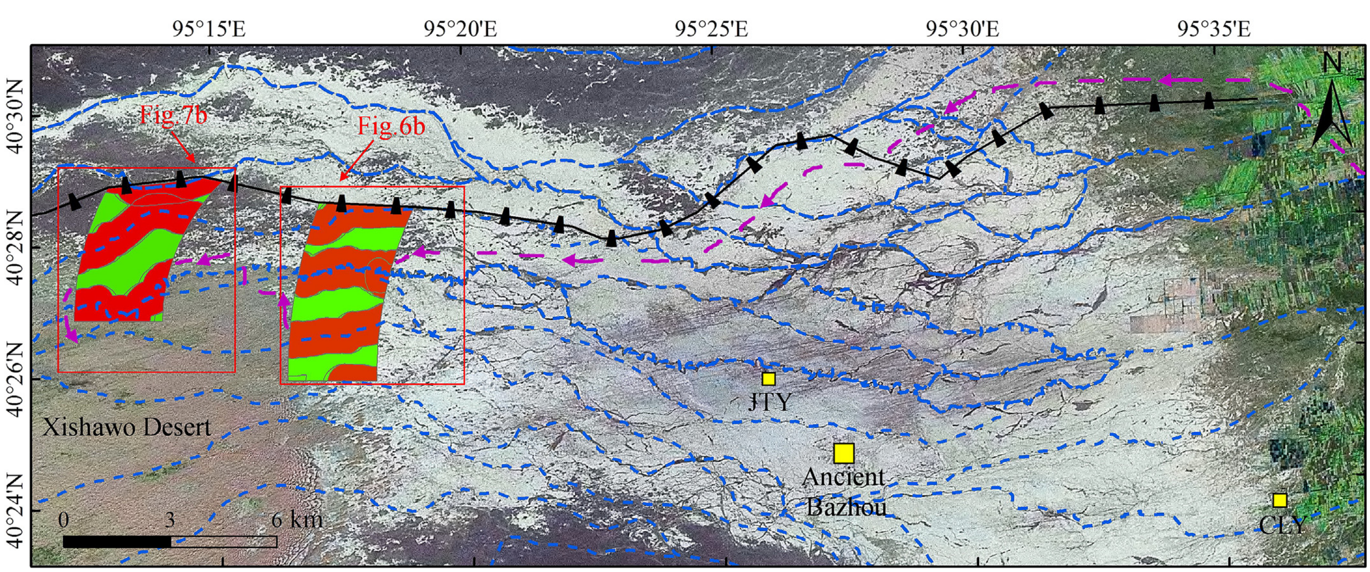


**Fig. 5.** Prospective sub-areas to GCY and CTY on the Landsat image. Blue dotted lines indicate dried and buried channels; the black line indicates the Han Great Wall; the route of field investigation is lined out in magenta on the map, and arrows indicate the march direction. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

focuses, especially the rectangle- and square-shaped figures. This paper found three suspected spots after the semiautomatic interpretation. The shapes of the spots are completely different from the direction of the extending sand dunes and the yardang landform distribution that are apparently controlled by wind. Thus, these were suspected to be archaeological monuments. Based on the preliminary analysis of the prospective sub-areas, the expedition route was determined. With the use of GPS and these recorded geographical coordinates extracted from the corrected Landsat ETM+ and WV-2 VHR images of the sub-areas, a field investigation was conducted in August and October 2013 in Lucaogou.

## 4. Discoveries

In August and October 2013, the senior authors of this article took part in two expeditions to the Lucaogou region and searched suspected sites from the prospective sub-areas for ground-truthing. The integrated scientific investigation conducted in October 2013 led to the discovery of three ancient sites, located to the south of the Han Great Wall. The exploring team was going straight to the suspected sites, which were seen so obvious on the satellite imagery, but we took full advantage of the ancient road and the dried rivers' channel during the marches.

### 4.1. Newly discovered site no. 1

Located on the eastern margin of the Xishawo Desert, about 14.2 km northwest of the Ancient Bazhou ruins in Lucaogou. This site (40°26′46.38″N, 95°17′51.50″E, altitude 1105 m) is approximately 3.2 km from the Han Great Wall. From the WV-2 VHR image of the prospective sub-area, a square-shaped mark can be seen northwest of Bazhou, situated north of a paleochannel (Fig. 6a). Each side of the suspected spot was measured at ~43 m long.

On October 15, 2013, the exploring team arrived at a site about 1.7 km north from the first suspected spot (square-shaped mark), and turned to south across the dried out river. When the exploration crew trekked through the yardang and reached a flat place outside the spot, a broken wall into view, which was later confirmed as the north wall. Across the broken north wall, many pottery and brick fragments were found (Fig. 6c–e). The suspected site has no complete walls, but the remains of three wall piers were investigated. There are northwestern, northeastern, and southeastern piers 2.12 m (Fig. 6c), 2.25 m, and 1.93 m high, respectively. The northern and eastern walls are exposed, with a width of 2–3 m. Pottery and brick fragments are scattered among the walls and their surroundings. No obvious wall in the south and west were found due to the coverage of the gravel layer. Thus, we confirmed that this suspected site is a courier station ruin based on a number of ancient remains observed at this site and its surrounding area. This study proposes a name for this site, “Site 1 of Lucaogou”.

### 4.2. Newly discovered site no. 2

Located on the northern margin of the Xishawo Desert, about 20.1 km northwest of the Ancient Bazhou ruins. This northwestern city site (40°27′13″N, 95°13′33″E, altitude 1098 m) is ~6.3 km from Site 1 of Lucaogou. From the WV-2 VHR image of the prospective sub-area, an incomplete rectangular-shaped mark can be seen approximately 3 km south of the Han Great Wall, situated north of a paleochannel (Fig. 7a).

On October 16, 2013, the exploring team arrived at “Site 1 of Lucaogou”, and turned to west through the Xishawo desert. The route of this march is the channel of the dried out river. When the suspected site was reached, an uplift beam was encountered first, with an average height of 80 cm and width of 6–7 m. This beam, extending to the southern end, was confirmed as the eastern wall of the city after the field work (Fig. 7a). No ancient remains were found inside because of the site was buried by the sand dune. The northern and western walls also have parts of beams formed and exposed, with a height of 50–90 cm. No wall was found in the south due to both fluvial erosion and wind erosion in the past. The eastern wall is ~139 m long, the northern wall is ~132 m, and the western wall is ~173 m. The walls were found to be made of mud and Chinese tamarisk (Fig. 7c), showing the same architectural material and style as in the Great Wall of the Han Dynasty (Fig. 7d). Thus, we confirmed that this suspected site was a city during the Han Dynasty with the remains of three walls. This study proposes the name “Site 2 of Lucaogou” for this site.

### 4.3. Newly discovered site no. 3

Located on the northern margin of the Xishawo Desert, about 21.2 km northwest of Ancient Bazhou ruins. The site of this northwestern city (40°27′47″N , 95°12′57″E, altitude 1093 m) is ~1.3 km from “Site 2 of Lucaogou”. From the WV-2 VHR image of the prospective sub-area, an incomplete rhombic-shaped mark can be seen approximately 2 km south of the Han Great Wall (Fig. 8a). After we had finished the fieldwork of “Site 2 of Lucaogou”, we investigated the third sites.

On arrival at the suspected spot, a gravel beam was encountered first (Fig. 8b) with an average height of 25 cm and width of 1.5 m. The beam was later confirmed as the western wall-base of the newly discovered site. Reddish, burnt soils of a few square meters (Fig. 8c), several pottery fragments (Fig. 8d), and one broken “Qidaowubai” coin (Fig. 8e) were found along the inner western beams. “Qidaowubai” (Fig. 8f), knife-shaped currency, was founded and used during the period of the Xin Dynasty (9 A.D. to 23 A.D.), which followed the Western Han Dynasty and preceded the Eastern Han Dynasty (Yan, 1953; Ban, 1961). The base of the southern wall was not found due to coverage by sand dunes. The other three exposed wall-bases were each ~90 m long. Both northern and eastern wall-bases also had parts of beams formed and exposed. Thus, based on ancient remains observed at this site and its surrounding area, we confirmed that this suspected rhombic-shaped site is a city ruin with the remains of three 90-m walls. This study refers to this site as “Site 3 of Lucaogou”.

The three newly discovered sites were found in the autumn of 2013 by the author using GIS from historic records and remote sensing imagery, and were eventually confirmed during the GPS-supported ground-truthing. The strategic locations of newly discovered sites raised many speculations on what these sites were in the past. Being integrated our discoveries and Dunhuang Manuscripts with GIS and remote sensing imagery, this paper attempts to address the spatio-temporal distribution of the archaeological sites and reconstruct the medieval royal road system in the section 5.

## 5. Reconstruction of the royal road system to medieval Dunhuang

The courier stations and royal road system to medieval Dunhuang were studied and discussed here to integrate our discoveries with previous researches and historic records. The purpose of this section is to draw a comparison between the discoveries and the documented sites of courier stations, and reconstruct the royal road system.

Dunhuang Manuscript P.2005 states that “Ten courier stations, from Guazhou to Shazhou, were founded north of Sanweishan Hill in 691 A.D.” Presently, five of these courier stations have been discovered and confirmed: Guazhou station in Ancient Suoyang

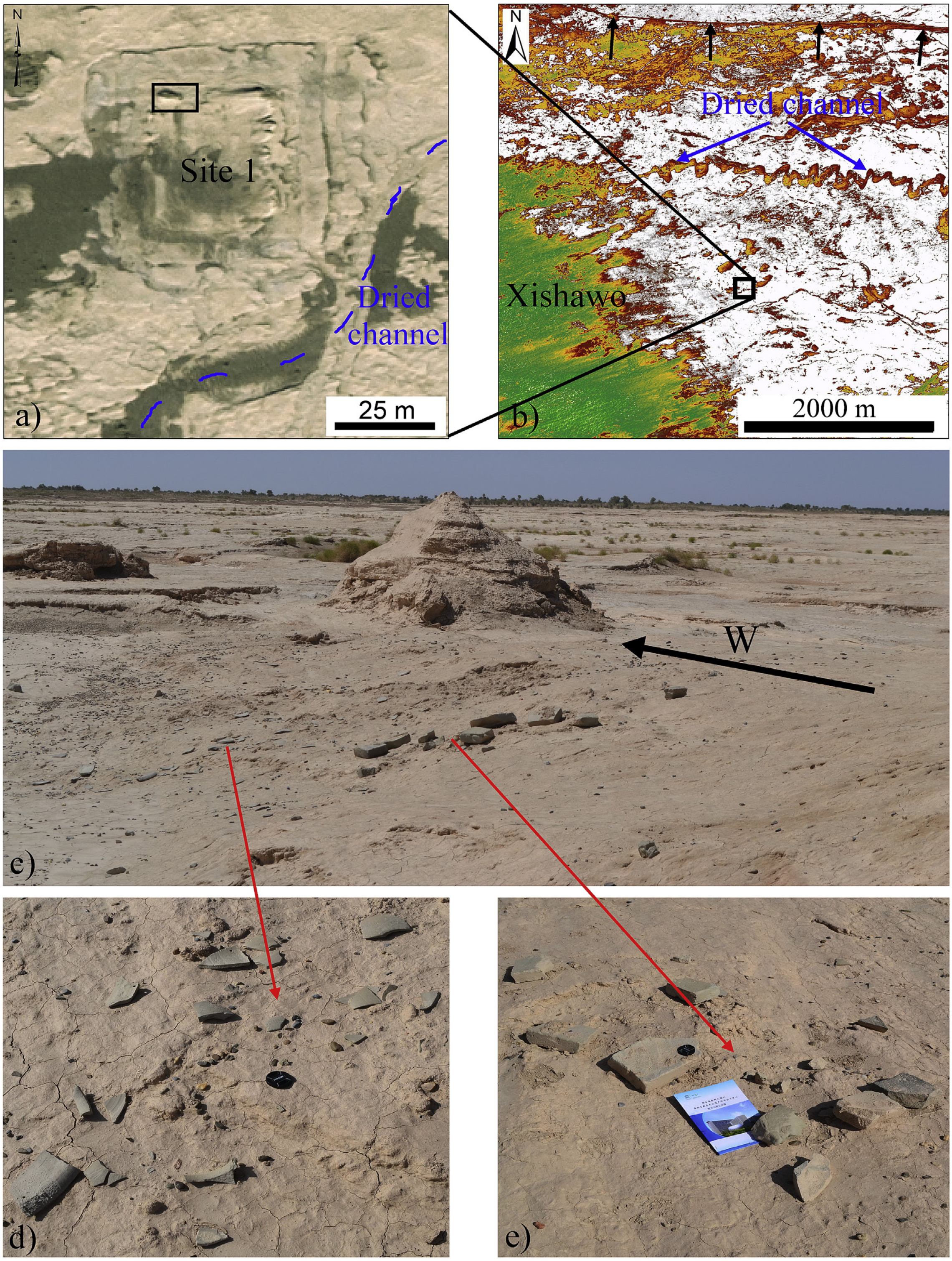


**Fig. 6.** Site 1 of Lucaogou. a) WV-2 VHR image of Site 1; b) spatial location of the site based on a ZY-3 density-sliced PAN image (the black arrows indicate the Han Great Wall); c) photo of the northwestern wall pier from the box in (a); d) pottery fragments; e) brick fragments.

(Fig. 9a); XQB station in Ancient Pochengzi (Fig. 9b); CLY station in Ancient Liugong (Fig. 9c); JTY station in the eastern Lucaogou (Fig. 4a); and Shazhou station in ancient Dunhuang (Fig. 9d) (Li B C, 1996; Li Z Y, 2008). Three courier stations, QQY, HJY, and BTY, have been researched by some studies and investigations (Yan, 1953; Li B C, 1994, 1996; Li Z Y, 2008). But very little information about GCY and CTY stations has been obtained from previous studies and archaeological prospection because they are away from modern urban area and field expeditions are difficult performed. Until now, the only sign of existence of these two courier stations has been some text in Dunhuang Manuscripts.

According to the records of archaeological investigations in the 1950s, there remained medieval city ruins correspond to the QQY station (Li B C, 1996). Because of the sites on the margin of modern

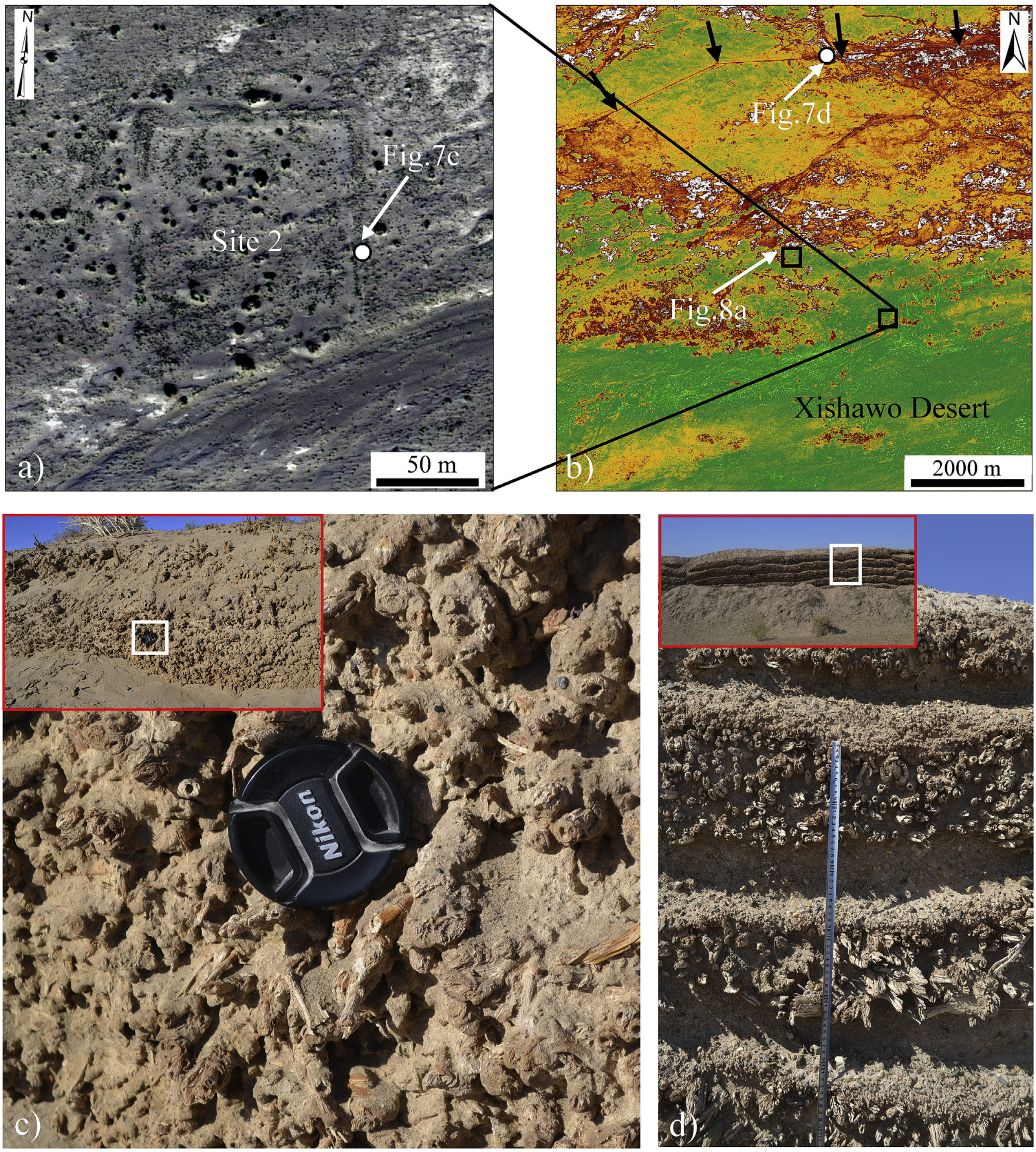


**Fig. 7.** a) WV-2 VHR image of Site 2; b) spatial location of Site 2 based on a ZY-3 density-sliced PAN image (the black arrows indicate the Han Great Wall); c) eastern wall made of mud and Chinese tamarisk, showing the same architectural material and style as in the Great Wall of the Han Dynasty in d).

Dunhuang Oasis, they were destroyed and transformed into the farmlands in the China's campaign to "Learn from Tazhai in agriculture" in 1963 (Li B C, 1996; Li Z Y, 2008). Due to excessive reclamation together with the lack of water, the farmlands became barren and were abandoned after the special campaign. Only saline-alkaline lands and dead reeds leap to the eyes during our field work.

The rough locations of HJY and BTY stations, the spatial position relation to the Han Great Wall and the paleoriver, have been provided by Li (2008) based on the Dunhuang Manuscripts and their expeditions in the 1980s. To some extent, the sites of BTY and HJY stations are looming, not missing. The prospective regions of BTY and HJY stations have been searched carefully based on both the WV-2 VHR images and GoogleEarth. But no suspected spots were found, not only because of the complicated terrain and landforms, but also cause by our not perfect model. This paper proposes that the sites of BTY and HJY stations were hid in the wind-eroded yardang landforms or buried by sand dunes. For the

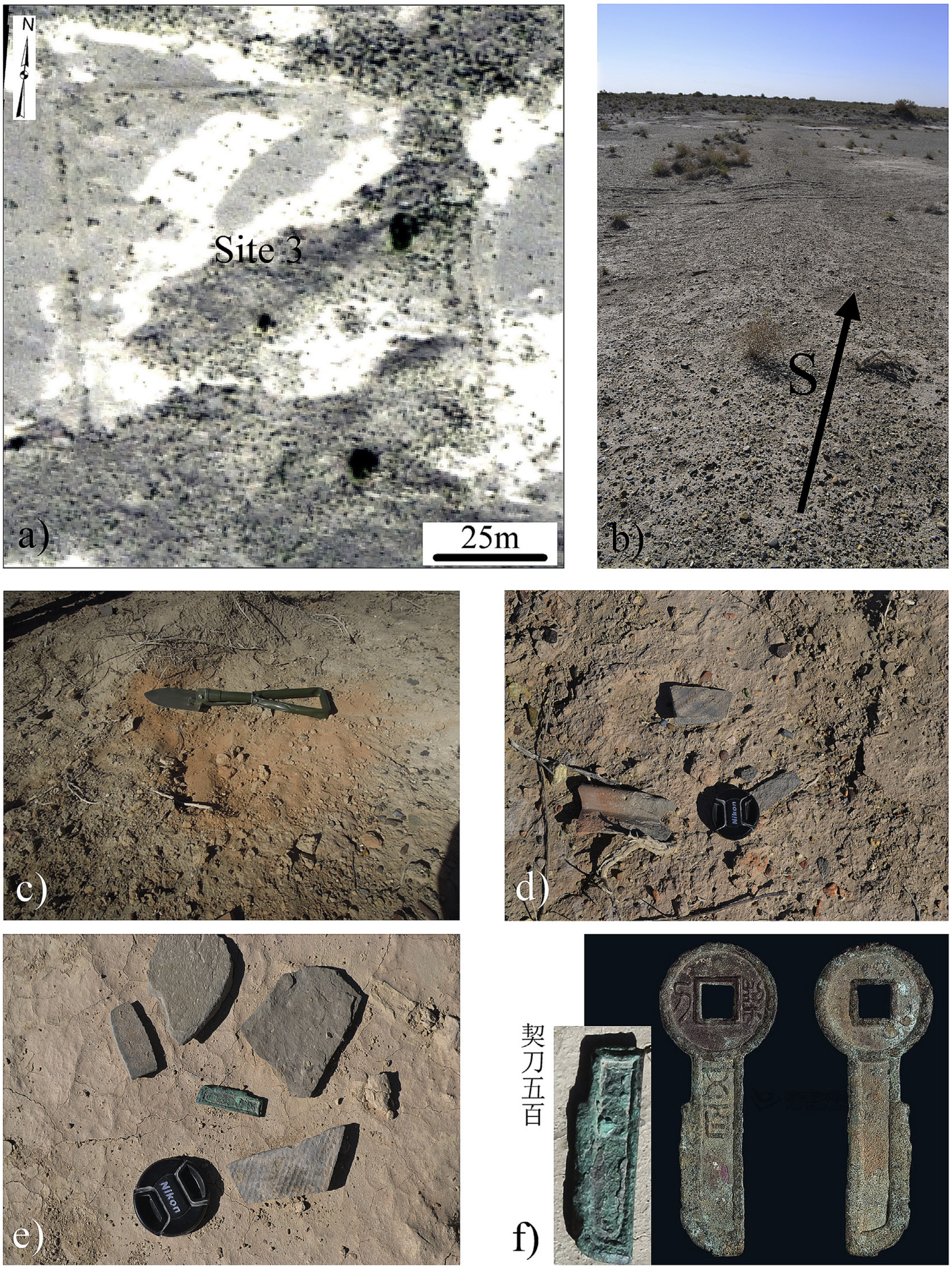


**Fig. 8.** a) WV-2 VHR image of Site 3; b) western wall-base of Site 3; c) reddish burnt soils; d) several pottery fragments and one broken "Qidaowubai" coin found in Site 3 (e); f) knife-shaped currency for reference.

next-step research, the model could be updated to build the new buffers for the HJY and BTY stations, by using radar and Lidar techniques which could offer the subsurface conditions and the high precision DEMs (McCauley et al., 1982; Stewart et al., 2014; Van Zijverden and Laan, 2005), respectively. The spatial locations of HJY and BTY stations were mapped on the Landsat ETM + image (Fig. 10) based on previous studies (Li B C, 1996; Li Z Y, 2008).

Dunhuang Manuscript P.2005 described GCY station as follows: "GCY courier station is located 25 Chinese li (13.5 km) northwest of JTY courier station". In this study, Site 1 of Lucaogou was found to be located ~11.5 km northwest of JTY, and the distance traveled along the bank of the dried river is approximately 13.5 km. The construction scale of courier stations ranged from 30 m × 30 m–70 m × 70 m in the Tang Dynasty (Li, 1994, 1996). It is important to state that the size of Site 1 of Lucaogou (43 m × 43 m) falls within the range of normal courier station construction. This study proposes that Site 1 of Lucaogou was considered the ruin of GCY station in light of the good fitting of distance, direction, and


**Fig. 9.** Google Earth VHR images of confirmed courier stations. a) Guazhou station was found inside Ancient Suoyang, the metropolis of medieval Guazhou; b) XQB station was found in Ancient Pochengzi, a county of medieval Guazhou; c) CLY station was found inside Ancient Liugongcheng, a county of medieval Shazhou; d) Shazhou station was found inside Ancient Dunhuang, the metropolis of medieval Guazhou.

scale, and based on a number of ancient remains observed at this site and its surrounding area.

Site 2 & 3 of Lucaogou, located on the northern margin of the Xishawo Desert, likely served as twin military facilities of the northwestern frontier during the early Han Dynasty. Dunhuang Manuscript P.2005 described the CTY station as follows: "CTY courier station is located 25 Chinese li (13.5 km) northwest of the GCY courier station". In this study, from the Site 1 of Lucaogou to Site 2 of Lucaogou, the average crow-fly distance is ~7.2 km, and the distance traveled along the margin of the Xishawo Desert is approximately 12 km. This study proposes that Site 2 of Lucaogou, considered the ruin of twin ancient facilities, were continuously used from the Han to Tang dynasties based on a number of remains observed at the sites and their surrounding area. Also, we assumed that a bit more of the surrounding areas west of Site 2 of Lucaogou were considered part of CTY station in light of the fitting distance and direction.

Given the aforementioned findings, this study has fully reconstructed the royal road system for the first time. With a length of at least 315 Chinese li (170 km) and ten courier stations, the royal road system to ancient Dunhuang is the most important exchange system yet identified and mapped in the Northwestern Hexi Corridor of Northwest China (Fig. 10).

Both Dunhuang Manuscripts P.2005 and P.5034 described the royal road system to ancient Dunhuang as follows: "The old royal road system, from Guazhou to Shazhou, was changed and moved northward in order to decrease the distance traveled, avoid the unpredictable trouble from desert and mountains, and against harassment activities from the Tibetan Empire to the south". These words indicate the old royal road system to ancient Dunhuang in the early Tang Dynasty was dangerous, and the courier stations on the old royal road system were abandoned. The new route of royal road to medieval Dunhuang, cross the Lucaogou region, was

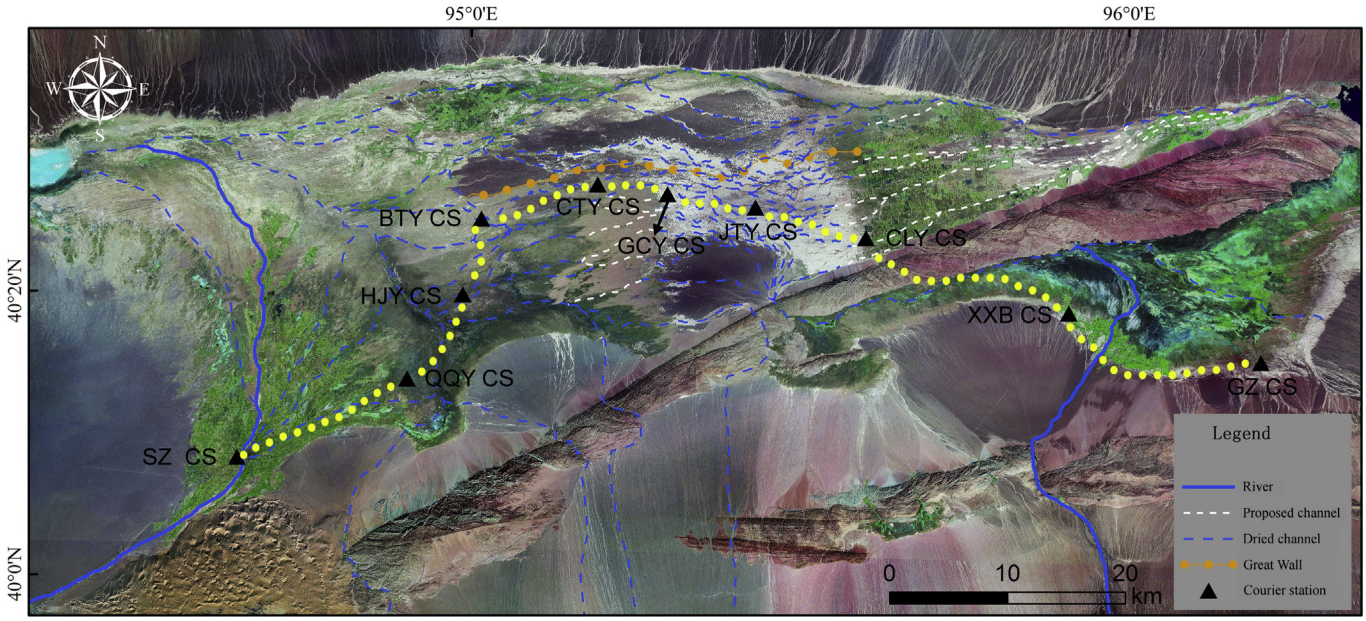


**Fig. 10.** Reconstruction of the royal road system to medieval Dunhuang on Landsat ETM + images.

founded after the founding of the Zhou Dynasty (690–705 A.D.) by the Empress Wu in 691 A.D. (Li B C, 1996; Li Z Y, 2008).

The royal road system acted as a route for the military and also provided a belt for cultural communication with the Tarim Basin. The non-destructive, highly integrated survey provided accurate information on the position, shape and dimension of the courier stations. All of the remotely sensed data were structured in an open database that can always be updated with newly available information; moreover, it can represent a valuable starting point for planning and optimizing future studies on the ancient settlement. The described features of the royal road system may offer significant opportunities for archaeological prospection and historic research.

## 6. Conclusions

The integrated application of RS, GIS and GPS have allowed very detailed identification, localization, and mapping of various types of archaeological features (dried channels, the Han Dynasty-period Great Wall, courier stations, and ancient city ruins) present in this study site. The royal road system to ancient Dunhuang was reconstructed by analyzing the final results and previous studies.

China is the most ancient, continuous civilization on this planet, with a history of over 5000 years and a huge number of historic records and archaeological sites, like the Dunhuang Manuscripts and the 3rd National Cultural Relic Census, respectively. Dunhuang Manuscripts are precious historical-geographical materials for studying ancient Dunhuang and the Hexi Corridor. The census data were used as a reference for positioning the courier stations.

Multiple sources of remote sensing data were employed for this study. Landsat ETM + data are limited by their resolution, but provide a good view of dried river channels. ZY-3 high resolution PAN images provide the capacity to extract traces of the Han Great Wall. The pansharpened VHR WV-2 images and Google Earth data are also effective, especially in the aspect of detecting and mapping small archaeological features.

Two prospective sub-areas belonging to ROIs of courier stations marked in the study area were created through a buffer and overlay analysis of the data in a GIS. Despite difficult working conditions, the GPS-based field survey executed in Lucaogou succeeded in confirming the suspected sites from the pansharpened VHR WV-2 images. Moreover, the ground-truthing data in the study area were used to verify and complete information given by the proposed GIS methods.

In addition to delineating the changes of the royal road system to ancient Dunhuang, this might aid future studies for archaeological, agricultural, political, and paleo-climate research efforts in the area. As a whole, our archaeological prospection based on the 3S approaches—RS, GIS and GPS—enabled us to detect unknown monuments, providing new insights for future archaeological research of the Hexi Corridor on the Silk Road.

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