The Application of 3S Technology to Plank Road research and development of spatial information systems in the Qinling and Daba Mountains: I. Geographical, Geological and Historical Background

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URL: http://www.qinshuroads.org/

Abstract

Since ancient times, people have moved between the Guanzhong or "land within the passes" of Shaanxi to the plains of Sichuan, ancient Shu. The Qinling and Daba Mountains form a formidable barrier to communications but by a combination of navigating the terrain and developing innovative technology, called "Plank Roads", ancient people developed effective trade and traffic routes between the north and south. This paper is Part I of two papers that aim to explore how 3S technology can provide support for research into these events[1]. The Part I introduces the history, geography and geology of the region as background to our work and also provide background for English readers. The Part II focuses on options for using 3S technology. If you wish to find out more about China's Qinling Shu Roads you are welcome to visit the project Web Site.

Introduction

The name "Shu Roads" is a general term applying to the historical roads that were built through the mountainous East-West barrier formed by the Qinling, Micang and Daba mountain ranges. They linked the Wei river valley (or the Guanzhong) with its ancient capital at Chang'an (present day Xi'an) in the north and the Sichuan plain with its ancient capital at Shu (present day Chengdu) in the south. Many of the roads were built in the Qin (221-206 BCE) and Han (206 BCE to 220 CE) dynasties using natural corridors that had been discovered much earlier by ancient people. Some of the routes have been maintained and consolidated up to modern times. The establishment of these important traffic routes required the development of road building technology known as "Plank Roads" (Figure 1) by which ravines and steep sided gorges were traversed using trestles fixed into the rock face. These developments, together with the historical events associated with the traffic routes, have become part of China's historical and modern culture.

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[1] As discussed at the International Symposium on Historical Research of Plank Roads and applications of 3S Technology, Hanzhong, Shaanxi, China, May 16-18 2007.

Figure 1: Reconstructed Plank Road at Mingyue Gorge in Northern Sichuan

Between the northern and southern sections of the Qinling and Daba mountain ranges is the Hanzhong basin through which the Han River flows to meet the Yangtze River at Wuhan in Hubei. The Han River has provided a major East-West corridor to Hanzhong as the Hanzhong Basin has connected the Guanzhong and Shu since ancient times. The Museum at Hanzhong is preserving and conserving the rich heritage of the region including the cultural and historical aspects of its ancient Plank Roads. The authors of this paper are presently undertaking a pilot project to make use of the modern technologies of Remote Sensing, GIS and GPS to help map aspects of the Shu roads in a selected space and time of history. The project aims to develop components of an information system that will help the Museum and others to manage, preserve and conserve its geographically scattered relics as well as communicate the geographical and terrain aspects of historical lines of communication to scholars and visitors alike. This paper first provides an introduction to the geographical, historical and cultural background to the topic for English language readers. It then outlines how what is called in China “3S” technology (remote sensing, GIS and GPS) can provide useful tools and techniques to help in the research, management and preservation of the history as well as to support the growing interest in this aspect of China’s history by modern tourism.

The Geography, Geology and Geomorphology of the Qinling and the Shu Roads

The Qinling and Daba Mountains are part of a central mountain area of China running from the Kunlun range of Tibet and reaching almost to the sea near the Huai River of the North China plain. This mountain range separates China’s environment, climate, history and culture into north and south. The system forms a historical frontier region between north and south in the sense described by Mostern and Meeks [S.4][2] in these proceedings. The differences are especially clear between the three protected basins in the west of China that were linked by the Shu Roads. The most northerly is the watershed of the Wei River and its tributaries in Shaanxi. It has been known for a long time as the Guanzhong, or the “the Land within the Passes”, and is a site of prehistoric Chinese civilisation. It is where the Western Zhou (1100-771 BCE), Qin, Han, Sui (581-618 CE)

[2] References to papers in this Symposium are referred to as [S.1] etc and other references as [R.1] etc. They are grouped separately at the end of the paper.

and Tang (618-907 CE) as well as many originally foreign northern Dynasties grew and emerged to conquer and govern parts, if not all, of China. Chang'an (present day Xi'an) is a place which has been the centre of government for China for the longest period of its history. The Guanzhong takes its name from five major (and other minor) passes through the mountains that form the "gates" to the area through the mountain barriers and provided natural sites for fortification.

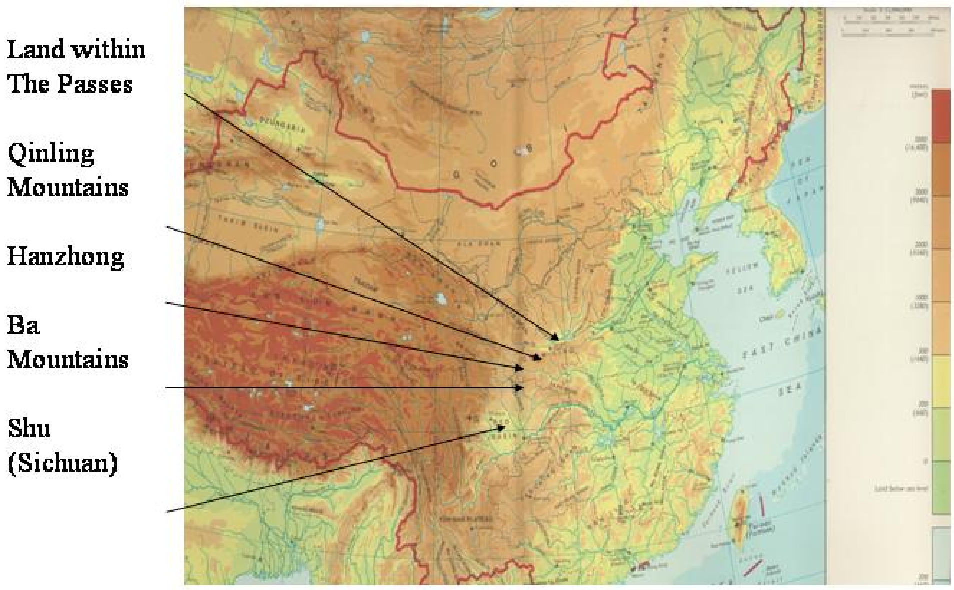

Figure 2: The three "lands within the passes" of Guanzhong, Hanzhong and Shu

Although the Guanzhong is best known, there are two other "lands within the passes" to the south (see Figure 2). To the far south, across the Qinling and Daba Mountain ranges lies the Sichuan basin. Although its archaeology is not as well-known as that of the Guanzhong, the Sichuan plain has also been the site of ancient civilisations which grew in parallel with those of the north and east. Sichuan has been a rich and fertile area and has often been able to avoid the turmoil of the east of China through its natural protection by the high mountains. However, it was also the natural resources of Sichuan that brought armies from the state of Qin across the Qinling in the Warring States period (481-221 BCE), building mountain roads to conquer and develop agriculture using advanced irrigation engineering.

Finally, between these two areas, south of the high Qinling mountains and north of the Daba and Micang mountains lies the Hanzhong basin. The Qinling mountains separate the drier, predominantly wheat growing areas in the north from the wetter and predominantly rice growing areas in the south. The climate and agriculture as well as the wildlife and natural vegetation in Hanzhong is transitional between north and south. The Hanzhong basin was known in ancient times as "Yu Pen" or the Jade Basin for its rich natural resources. These, together with its central location has made it the linking region for the traffic that grew as people found ways to move across the mountains between the Guanzhong and Shu and ways to move along the Han river to link Shu, Guanzhong and the lower Yangtze river area. The roads they built between north and south were the Shu Roads (see Feng Suiping [R.3]).

Geologically, it is thought (Meng and Zhang [R.5]) that the north and south sections of the Qinling (Daba being part of the south Qinling) were formed in geologically recent times (late Triassic to

Paleozoic) from collisions between the present north and south China blocks. The extensive folding and mountain building resulted in the change in climates between north and south China leading to north China drying, to Loess formation and to the separation of the present Yangtse and Yellow river basins. The subsequent cutting of river valleys both along and across the main east-west structure has formed a characteristic geomorphology of deep valleys separated by granite ridges. The sediments cut from the mountains filled valleys and small basins – such as Hanzhong. Although the tectonics of the south Qinling are different from those of the north, the mountains there are still inhospitable with sharp peaks separating steep ravines and fast flowing rivers.

Obviously, the flow of goods, people and communications across a divide like this will be difficult. However, the permeability of a barrier does not depend on how steep are the hill slopes but rather on whether there are connected ways through the system and whether people can learn to navigate the terrain as well as mariners have learned to cross equally formidable oceans to trade and interact. In the Qinling, the people of ancient times certainly found pathways from the north to the south and vice versa. Li Ye [S.2] and Shi Dangshe and Zhou Zhenghe [S.6] provide evidence of extensive communication since Paleolithic and Neolithic (prior to 2000 BCE) times and the Shang and Zhou (prior to 1000 BCE) periods. The way ancient people got to Shu from the rest of China must generally have been via the rivers and valleys since the ridges are generally very steep and sharp. This has meant using boats where possible along stretches of major rivers (as described in relation to the Han River by Shi Changcheng and Zhang Shujun [S.5]) and also using the valleys cut by rivers. But the rivers are confined to watersheds and so it is also necessary to be able to cross the watershed divides using saddle points of the terrain for the pathways to link and become Shu Roads. The significant terrain points at watershed divides make up many of the "gates" or "passes" that are so important in the history of the Shu roads.

Furthermore, even when the watershed divides can be crossed via a pass, the river valleys or sections of the river valleys are often steep, unstable and dangerous and as the ancient traffic grew there emerged a unique technology for linking valleys along mountainous cliffs to enable people and goods to pass through. These were the "Plank Roads". Through the steepest ravines, wood or stone planks were set into the cliff face and used to construct trestle roads over which trade, armies and cultures were to flow on structures that were often wide enough for horse-drawn carts and chariots to pass in two directions. Sections of Plank Road were widely used in all parts of the Shu roads. Sir Joseph Needham [R.7] in "Science and Civilisation in China" described the plank or trestle roads between the Wei valley and Sichuan as the "The greatest engineering work of Qin/Han road builders" and provides one of the most detailed discussions of the technology available in English. His enthusiasm is justified not the least by the fact that although the separation of China into north and south by the Qinling has played a role in China's history, it has not prevented China from developing a cultural and historical identity.

Shu Roads in Chinese history, literature and culture

River valleys that can be made into corridors using Plank Road technology and linked to valleys in other watersheds through mountain passes are the potential corridors through the mountains. However, the ways people have actually moved to link the north and south does not only involve geomorphology but also politics, conquest, power, culture, trade and human interactions as has been clearly described by Yang Dongchen [S.7]. From the combined effects of geography, history and culture emerged a system of Shu roads linking north and south. Seven major roads are recognised with four crossing the Qinling mountains and three the southern Daba and Micang mountains (see Figure 3). Naming from west to east, the four in the north were the "Old Road" (or Chencang Road), the Baoxie Road, the Ziwu Road and the Tangluo Road. Those in the south were named the Jinniu (or "Golden Ox") Road, the Micang (or "Rice Granary") Road and the Yangba (or "Lychee") Road. Another section of road (called the Lianyun or "Cloud Linked" Road) joined the Chencang Road with the Baoxie Road providing an alternative route. These roads occur constantly in the records and history of the region. The geographical extent is shown in Figure 3 in which major modern towns along the routes are linked by lines. The issue of how to define the tracks or actual paths between the places along the roads at different times in history is discussed in the Part II of this paper. The most recent (significantly updated) version can be found HERE.

Figure 3: A general route (linked places) map of the Shu roads crossing the Qinling between current Xi'an, Hanzhong and Chengdu.

The first major road seems to have been one built by the state of Qin in the Warring States Period. The road probably included sections of what were later called the Chencang and Jinniu Roads. There are stories that the road building was allowed by Shu for the Qin state to bring a gift of a "Golden Ox" to Shu but in the end, it simply brought the Qin army to annex Shu. This conquest took almost a hundred years to the mid-fourth century BCE, but vastly increased the power of Qin. Qin developed the resources of Shu, including the important irrigation structure at Dujiangyan (Shi Ji, 29 [R.9]) and Shu became a "rice bowl" for Qin. The Shu roads through the mountains provided essential supplies to the Qin state as it united China as the Qin Dynasty in 221 BCE.

In the Qin, Han and the Three Kingdom (220-230 CE) periods, well engineered Plank Roads were built, repaired and extended very widely through the Qinling and Daba mountains. With the possible exception of the Yangba Road, all of the major roads mentioned above were completed and used during this time. During the Western Han Dynasty, the Shi Ji, 29 [R.9] records how the state engineers convinced the Emperor to fund major works and extend the Baoxie Road so that rice and other materials could be brought to the Guanzhong via the Han River and the Bao and Xie rivers with a short linking land road across the Wulipo divide. As recorded by Sima Qian (translation by Burton Watson [R.9]) "When the road was finished it did in fact prove to be much shorter and more convenient than the old route, but the rivers were too full of rapids and boulders to be used for transporting grain".

A major event in Chinese history involving the Plank Roads occurred when the Qin Dynasty was overthrown by a coalition of rebels in 206 BCE. The "Grand Hegemon" Xiang Yu was fearful of another king setting up in the Qin capital at Xianyang near present day Xi'an in the "Land between the passes" (Guanzhong) and banished his major rival, Liu Bang, to be King of the three states of Han (present day Hanzhong), Shu (present day Sichuan) and Ba (present day Chongqing). There had been an agreement that the general who captured Xianyang (who turned out to be Liu Bang) would rule the Guanzhong, but Xiang Yu argued that Han, Shu and Ba were also “lands within passes” (Shi Ji, 7 [R.9]) and sent Liu Bang off (he hoped) there for a long stay.

Liu Bang and his troops travelled on Plank Roads to reach Hanzhong. On the advice of Liu Bang’s advisor Zhang Liang (who knew the Qinling well and has his temple near present day Liuba on the Lianyun Road) they burned the Plank Roads after they passed to discourage pursuers and convince Xiang Yu they did not intend to return. At Hanzhong, on the site of the present day Hanzhong Museum, is the Hantai or Han Platform where Liu Bang proclaimed the Han Kingdom. As it turned out, it was the also the platform from which Liu Bang launched his armies to reunite China as the Han Dynasty and became the first Han Emperor. There is too much to describe here and there are better places to find out. Interested people are referred to translations of Chinese books such as the Shi Ji [R.9] or to general histories such as Twitchett and Loewe [R.10] to explore the events of these times.

A strikingly similar event occurred after the final fall of the Han in 220 CE. At this time, China split into the Three Kingdoms of Wei (including the Guanzhong and Luoyang), Wu (with capital on the site of present day Nanjing) and Shu with its capital at Chengdu. The king of Shu was Liu Bei and he looked at himself as the successor of the Han so that his Kingdom was called “Han Shu” and he styled himself as Emperor. Just as his ancestor Liu Bang had a smart advisor called Zhang Liang, Liu Bei had a clever Prime Minister called Zhuge Liang. Zhuge Liang was also known by his style of Kongming and by an early appellation of Wolong or “Sleeping Dragon”. During his life he was given the title of Wuxiang Hou or the Marquis of Wuxiang, a township north of Hanzhong. Following his death, he was apparently entitled by the Shuhan emperor the “Faithful Martial Lord” or Zhong Wuhou and to this day, his ancestral temples and memorials refer to him as Wuhou, the Martial Lord. Zhuge Liang almost emulated Liu Bang’s success in a series of raids against Wei across the Qinling into the Guanzhong but was not successful. The stories of these times have become part of Chinese culture in the form of a famous historical novel (which is at least as much novel as history) called “San Guo Yan Yi” translated by Moss Roberts [R.4] as “Romance of the Three Kingdoms”. To find out how the Shu Roads also formed a stage for the romance of stirring history and heroic deeds you can do worse than to read this book. For the true history of these areas and events at the end of the Han there are more accurate accounts in English in de Crespigny [R.1; R.2] and other publications and translations based on the historical records of the time.

The Tang Period (618-907 CE) saw the Plank Roads remain part of literature and history as statesmen and poets such as Li Bai (also known as Li Bo) were sent to exile in Shu away from the court(s) in Chang’an and Luoyang. On one such occasion, Li Bai wrote a famous poem called “The Road to Shu is Hard” and a translation (eg Minford and Lau [R.6]) will give its reader a flavour of what it was like to travel through the Qinling at that time. In the poem, Li Bai describes the Plank Roads as “ladders to heaven”:

> “When earth collapsed and the mountain crashed,
> the muscled warriors died.
> It was after that when the ladders to heaven
> were linked together with timber and stone.”

The Tang Emperor of the time (Tang Xuan Zong) also travelled to Shu along the roads in exile as rebels invaded the capital. He came back along the Jinniu Road as an abdicated monarch and without his favourite concubine, Yang Guifei who had been forced to kill herself as his army fled to Shu. The Yangba Road was said to have been built earlier to bring Lychee from the south of China to Xi’an for the extravagant imperial concubine. The Song painting in Figure 4 shows a “map” of the emperor’s journey to Shu and it is possible to see Plank Roads winding up the steep and sharp ridged mountains on the left side of the image.

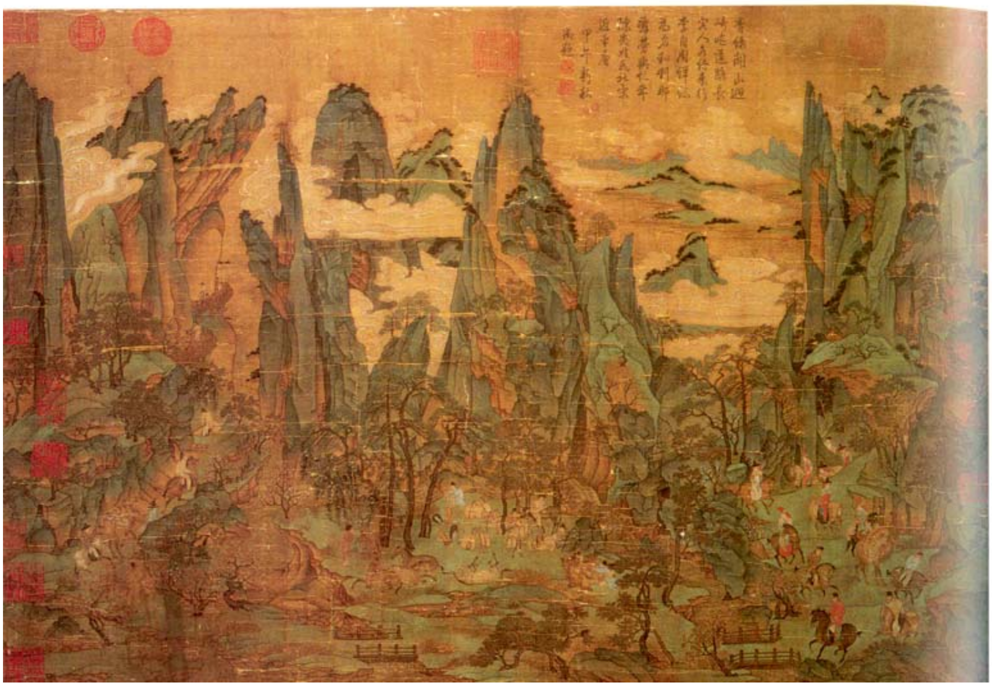

Figure 4: Tang Ming Huang's journey to Shu (US Library of Congress)

On the way back from exile in Shu, the Emperor wrote a poem at "Sword Gate Pass" (Jianmen Guan in northern Sichuan) in which he wrote (perhaps in remorse for his failing to be a virtuous Emperor)[3]:

> "Our tour complete our carriage returns
> to Sword Gate's cloud-barred peaks
> its mile-high screen of folded jade
> its cinnabar walls breached by heroes
> our pennants weave through the tapestry of trees
> ethereal clouds brush past our horses
> rising to the times depends on virtue
> how true is this description?"

In the Song (960-1279 CE), Yuan (1271-1368 CE), Ming (1368-1662 CE) and Qing (1662-1911 CE) times the Shu Roads continued as major routes of communication between north and south. Over that time the roads gradually became better paved and stabilised and the Lian Yun road and Bao river valley became sections of the main Post Road from Xi'an to Chengdu. This section was still the main road across the Qinling during the Republic of China (Min Guo 1912-1949 CE) and the 2000 years of history was recorded in literature and art, in calligraphy, in the records of travellers and on Stele and most importantly in the "Fang Zhi" or the regional and local gazetteers of everything that happened to people, the environment and at the local level. Much of the information is geographical but not mapped in the sense of modern mapping. This poses issues for the use of 3S that are discussed by Brian Lees [S.1]. They are also not always consistent as illustrated in the paper by Li Zhiqin [S.3] where he unravels the truth from a number of records and sources. But they are nevertheless a unique and significant source of written information on the Shu Roads.

The ancient engineering innovations and enterprise have continued to inspire modern Chinese as they have built a new country and modern times have seen equally great engineering feats as

[3] Translated by Red Pine [R.8] as "Reaching Sword Gate Pass after touring the Land of Shu".

present day "Shu roads" have come into existence. According to the English language *Shanghai Sunday Times* (Nov. 12, 1932)[4], in 1932 there were only 1269 miles (2040 km) of automobile roads in Sichuan and 235 automobiles, and in Shaanxi there were 1808 (2910 km) miles of automobile road and 414 automobiles. China as a whole had 39,350 miles (63,350 km) of automobile road and 43,834 automobiles. In 1952, the total length of roads in China had doubled to 126,700 km. By contrast in late 1997 there were 1.226 million km of road in China (about 10 times what it was in 1952) and 57,570 km of railroads[5]. Since then there has been a further massive growth of Tollways covering the country, including crossing the Qinling using tunnels and overpasses. It has been a dramatic change.

Between Chengdu and Xi'an in 1932 many of the roads were not much better than they were during the Qing period. The state of these roads has been recorded in old photographs from many sources preserved by the Hanzhong museum.

Figure 5: Travelling from Baoji to Hanzhong in the 1930's (Frank Moore collection)

A Highway from Hanzhong to Baoji (Baohan Highway) was built in the late 1930's and early 1940's along the section of the Shu Road that had been the main "Post Road" since the Yuan period. It was done as part of the war effort against the Japanese and heritage photographs show that the road to Shu was still "hard" at that time (see Figure 5). A railway from Wuhan to Hanzhong was also part of the war effort. Since 1949, a major railway has crossed from Baoji to Chengdu for the most part along the track of the Old (Chencang) Road. Extensive road building over some of the previous Shu Roads was undertaken with great effort and facing great hardships. In the same period, large dams were built at the two ends of the Baoxie Road to irrigate land and produce food. The "Plank Road Spirit" must have helped in the success of these efforts. Now it is possible to go from Hanzhong to Xi'an in two hours –but through modern tunnels rather than over ancient Plank Roads.

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[4] Quoted by G. B. Cressy in "China's Geographic Foundations", McGraw-Hill, 1934. This book provides useful information on the resources of Republican China prior to the Japanese invasion.

[5] Figures since 1949 are from China National Bureau of Statistics, Statistical Yearbook of China and other sources.

Conclusions

This first part of our paper has provided a basis for the second where the technologies of Geographic Information Science and spatial analysis are described and their application to Shu Road research in the project we are undertaking will be outlined. However, it has also provided an English language introduction to the Shu Roads that we hope will help interested English readers access further information and appreciate the papers and abstracts that together outline the opportunity now open to advance many aspects of Shu and Plank Road research and education.

Mountains, rivers and lakes have been subjects of Chinese art and literature since ancient times. In the history of the Shu Roads the terrain has been the ruling factor and the rivers the agents of change as well as communication. The geomorphology and geography of the Qinling, Micang and Daba Mountains is recorded in topographic maps and (in more recent times) in digital maps called Digital Elevation Models (DEMs). From these, the slopes, watersheds, streamlines, potential passes through divides, contours and the patterns of landforms and landform structure can be derived. On this background, the land surface and the land cover over time can also be derived from past records and modern remote sensing images and many inconsistencies resolved. For example, the extent of forests and the cycles of forestry can in many places be derived for historical times from the Fang Zhi, or local records (Zhang Haoliang [R.11]). Recent (but not necessarily completely up to date) land cover is often able to be checked using Google Earth and potential land cover can sometimes be derived from terrain and climate to provide a background to the history over which time there has been more change in climate than there has in terrain.

The location of roads and relics changed a great deal over historical times. The records help to reconstruct the changes but are not always complete. On a base of terrain and land cover information it is possible to place the archaeological record in a modern mapping framework. Using a combination of over-riding control by the terrain plus the local and regional records together with visits to the surviving relics, it is also possible to bring terrain, maps, land cover, archaeology and potential paths into a strict spatial and (in some cases) temporal framework using Global Positioning System (GPS) technology. The integration of records that are geographic but not map-based (which is the case with most local records) is not easy (Lees [S.1]) but it is often possible and in carrying it out, new information is often found. A modern map-based information can be managed in a “Geographic Information System” or GIS. The data and its links to history and environment can then be displayed and visualised in many ways – such as by using the easily accessed Google Earth. However, as seen from this introduction, the time based information on the names, the history, the locations and the spatial interactions involved is a major challenge for the system selected. The group of English language papers gathered here for this Symposium cover many of the critical aspects of such systems as may be needed to manage the data that government and tourism groups (to name only two) can use.

The arrival of modern road building and communications provides both another chapter for the complete discussion of Shu Roads as well as an urgent reason to manage the history and archaeology of the ancient systems. Modern roads have, in many places, obliterated relics and in other places, due to the actions of agencies and individuals, have led to relics being preserved in museums or as photographs, copies and rubbings rather than the original materials. In the second part of this paper, we will outline some of the benefits to this task that can be provided by modern map-based “3S” technology and the Geographic Information Science that has been discussed in a number of papers in this Symposium.

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References

This Symposium

[S.1] Lees, Brian. The language and grammar of maps.

[S.2] Li Ye. A broad overview of the Traffic in the Hanzhong Basin during Prehistoric Times.

[S.3] Li Zhiqin. Rectification of 12 Historical Records on Ancient Roads in the Qinling Mountain Region.

[S.4] Mostern, Ruth and Elijah Meeks. The Qinling Frontier and the Construction of Empire in China: Three Examples from Early and Middle Period History.

[S.5] Shi Changcheng and Zhang Shujun. Shipping activities in the Upper and Middle Reaches of the Hanjiang River in the Qing Dynasty.

[S.6] Shi Dangshe and Zhou Zhenghe. Early history of the Old Road: Exposition based on archaeological evidence.

[S.7] Yang Dongchen. Thesis that the through road system has been the life-blood of the Qinling and Ba Mountians.

General References

[R.1] de Crespigny, R. (1984). *Northern Frontier – The politics and Strategy of the Later Han Empire*. Faculty of Asian studies, Australian National University, 1984.

[R.2] de Crespigny, R. (1991). The Three Kingdoms and Western Jin: A history of China in the Third Century. *East Asian History*, **1**, 1-36; **2**, 143-164.

[R.3] Feng, Shuiping (2003). *The Northwest's little South China – Hanzhong*. Three Qin Press, Xi'an, Nov. 2003. (In Chinese).

[R.4] Luo Guanzhong (fl. 1360). *Three Kingdoms*. (Novel: Sanguo Yanyi) Translated by Moss Roberts. Foreign Languages Press, Beijing, 1994.

[R.5] Meng, Qingren, and Zhang, Guowei (2000). Geologic framework and tectonic evolution of the Qinling orogen, central China. *Tectonophysics*, 323(3-4), 183-196

[R.6] Minford, J. and Lau, J.S.M. (2000). *Classical Chinese Literature. Volume I: From antiquity to the Tang Dynasty*. The Chinese University of Hong Kong, Chinese University Press, Hong Kong.

[R.7] Needham, J., Wang, L. & Lu G.D. (1971). *Science and Civilisation in China. Volume 4. Physics and Physical Technology, Part III, Civil Engineering and Nautics.* Cambridge University Press.

[R.8] Red Pine (translator). (2003). *Poems of the Masters. China's Classic Anthology of T'ang and Sung Dynasty Verse*. Copper Canyon Press.

[R.9] Sima Qian (120 BCE). *Records of the Grand Historian*. Translated by Burton Watson, Three Volumes (Revised 1993): *Qin Dynasty*, *Han Dynasty I, Han Dynasty II.* Columbia University Press.

[R.10] Twitchett, D. and Loewe, M. (Eds). (1986). *The Cambridge History of China. Vol I, The Ch'in and Han Empires (221 B.C. – A.D. 220)*. Cambridge: Cambridge University Press.

[R.11] Zhang, Haoliang (1990). Notes on historical environmental records: Collected forest stele of the Ba Mountains. Yunnan University Press (In Chinese).

The Application of 3S Technology to Plank Road research and development of spatial information systems in the Qinling and Daba Mountains: II. 3S Technology and the Australia-China Project

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Abstract

Part II of this paper presents some of the tools of 3S and their application to the areas of historical geography that are part of Plank Road and Shu Road research and application. Maps, GPS, remote sensing, GIS, 3D modelling and terrain analysis are all key tools to explore the role of terrain in the history of the region. In particular, they can support growing needs to manage and preserve the relics and knowledge of the unique technologies developed to link the north and south of China. Part II describes how modern communications technology has recently provided the opportunity for many people to participate in the growth of knowledge and research. Finally, this Part II also describes the Australia-China Council (ACC) Project. The ACC project supported the introduction of 3S technology in this Symposium through the gathered international experts who presented papers and is currently undertaking two demonstration projects with the Hanzhong Museum.

Introduction

This paper follows from Part I where a brief introduction to the geography of the Qinling and Daba Mountains was provided plus an outline of some of the history and adventure that has surrounded the traffic routes between the north and south of China through these rugged mountains. The fundamental role that terrain has played in communications in this region and the unique Plank Road technologies that were invented to overcome its limitations were also introduced. The second Part covers some of the applicable technologies that are included under the term "3S" and also the Project that brought a group of experts in Geographic Information Science and interests in history, archaeology and tourism to take part in this international Symposium[6] on the current state of Plank Road research. The Project, which is supported in Australia by the Australia China Council, is also undertaking some specific pilot studies and demonstrations of the application of 3S to Plank Road Research and these will be described in a final section. If you wish to find out more about progress and recent findings in this project you are welcome to visit the Qinling Shu Roads Project Web Site.

3S technology to support Shu road research

What is 3S?

"3S" is a name for the combination of technologies individually called Global Positioning System (GPS), Remote Sensing (RS) & Geographic Information Systems (GIS). Despite being the youngest, GPS technology is now the best known of the three. Many cars, portable computers and mobile phones today use GPS technology and a young person can call their friend, send them their GPS location and a digital photograph of the surroundings and the friend's car can compute the

[6] The International Symposium on Historical Research of Plank Roads and applications of 3S Technology, Hanzhong, Shaanxi, China, May 16-18 2007.

best way to get to where the call was made from and also navigate the driver to the spot. GPS, mobile (cell) phones (especially text messaging) and the internet are modern and mobile technologies. Remote sensing and the activities generally grouped under GIS (such as 3D models of terrain and spatial objects) are quickly catching up in popularity. This has been propelled to a significant degree by the availability of Google Earth ([R.12]) and other software and the ready way they integrate with other modern and mobile technologies.

The most important aspect of these developments is that so many people are successfully using the tools. Technology provides tools for doing things and people make them work on their behalf. This paper describes some of the tools of 3S that are available and which can benefit the archaeological and historical studies being discussed at this Symposium.

Maps and Charts

Underlying the use of modern technologies of 3S is the very old one of map making. People have made and used maps since ancient times. The traditions of China and the west may be somewhat different in mapping but they are equally ancient (Needham and Wang, 1959 [R.22]; Yan et al., 1998 [R.26]). Maps contain, in graphical form, spatially located information and indications of how to navigate from one place to another and they provide the fundamental base for 3S applications. There are many forms of map and many ways to represent information that best suits the purposes of the application. In the west there has been a significant distinction between land maps and seafaring charts. Charts grew up with a tradition of collating actual observations in the locations where they were made, even if they were not known to be accurate, and maps tend to be derived from data observations with specified map accuracy but not display the base data in the product. For example, in the past, charts recorded all actual depth soundings as well as observations recorded in ship's logs but rarely used depth contours except as a background. In topographic maps, contours are primary information but the observations from which the contours were derived are rarely included – or available. Both approaches to representing spatial data are relevant to historical data.

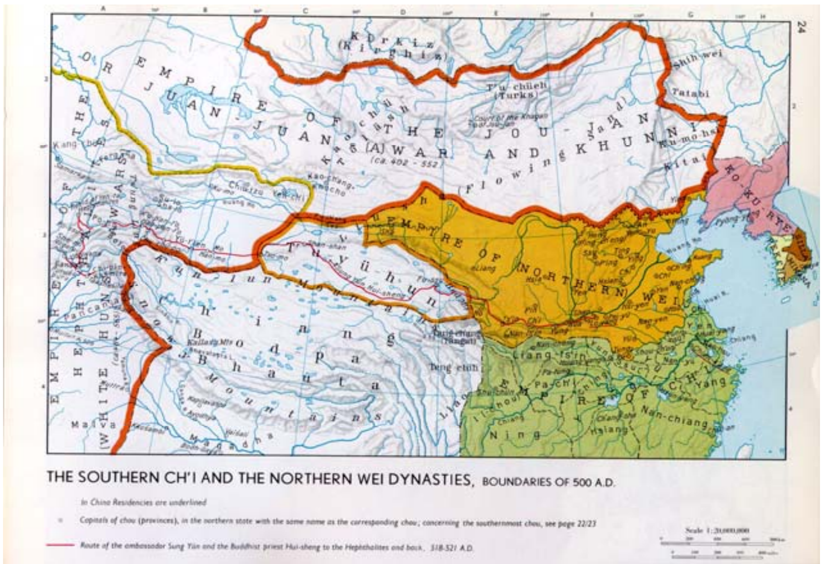

Figure 6: Map from Herrmann (1935, 1966 Edition) showing "chart"-like annotations and information collated on a map background

Relic maps cut on stele from the Song period were (until relatively recently) the only indications of what ancient Chinese maps were like. However, recent findings of Qin maps at Tianshui (Yan et al., 1998 [R.26]) and Western Han maps at Mawangdui (Yan et al., 1998 [R.26]) have shown that the original maps, drawn on wood, silk and (later) paper were practical maps of terrain (mountains, ridges and valleys), rivers, lakes and communication lines. They were obviously what a good general, or irrigation manager must have needed but unfortunately too few have survived to help with present day Plank Road research. In modern times, although maps have been extensively used in books about or including Chinese history (eg Blunden and Elvin, 1983, [R.4]), there have been relatively few general atlases or collations of Chinese history in a map framework available in the west. A famous European atlas of Chinese history is the one by Hermann (1935, [R.16]) which was updated in 1966 but, despite many discussions about its accuracy, has never been fully revised to include today's knowledge. One reason may be that Hermann's maps are like "charts" in that they incorporate data from many sources (see Figure 6) rather than a decision derived from the data in a map format. The best-known Chinese history atlas is "The Atlas of Chinese History" edited by Tan Qixiang (Tan, 1966; [R.25]). This atlas is a spatially presented gazetteer of place names and their locations and extent of territory from ancient times to the Qing period and is a good base for historical research[7].

GPS

Navstar GPS is one (but the only one fully operational) of a type of system called a Global Navigation Satellite Systems (GNSS). GPS uses accurately tracked orbiting satellites and atomic clocks to provide a means to measure location and time at any place where at least three and usually four of the total of 24 primary satellites in view. In the absence of prior information, four satellites are needed to solve for the position (x,y,z) and time (t) relative to the earth's centre in a frame fixed by reference to far stars. Converting these coordinates into those with meaning for mariners, pilots and surveyors requires choices of datum and baseline just like any mapping.

The satellite system is well documented by the providers of GPS instruments and on the web (e.g. the excellent beginners guide provided by Garmin Ltd. [R.11]). A GPS receiver will interpret the stream of satellite data (arriving at the rate of one observation per second) as a "Waypoint" (a recorded location at the person scale) or a "Track" (a string of recorded locations representing the actual trace of positions and times as the instrument or vehicle moves). A waypoint may be a single time sample or an average. Track data are analysed for heading, speed and other inertial information and there is no need for a track to be on the earth's surface and a Track may take the form of any trajectory in space/time.

Behind the practical use of GPS lies the map. GPS and maps are fully integrated in vehicle navigation systems to the extent that the vehicle can be tracked on the nearest road rather than at the measured location and waypoints can be defined as easily from a map as from a real location by GPS[8]. In this integration there is another term that is often used – the "Route". A route is a sequence of waypoints and it is the task of the system very often to navigate the route as well as it can and by whatever paths the map says are available. In archaeology, the GPS has become a familiar, if not essential, tool as a means to track activity, locate sites and locate potential sites during reconnaissance for later examination. Following field work, GPS data are used to combine data sets in the form of measurements or photographs (using the time base for coordination) and merge information from field expeditions with maps and other data or to display the location and activity in Google Earth or similar presentation system.

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[7] A comprehensive bibliography of Chinese materials on historical geography including gazetteers and old map collections can be found at [R.14]

[8] The distinction between a "waypoint" which records a GPS location or average position over time at the location and one defined from a map is rarely made in GPS systems but they have some important differences in practice.

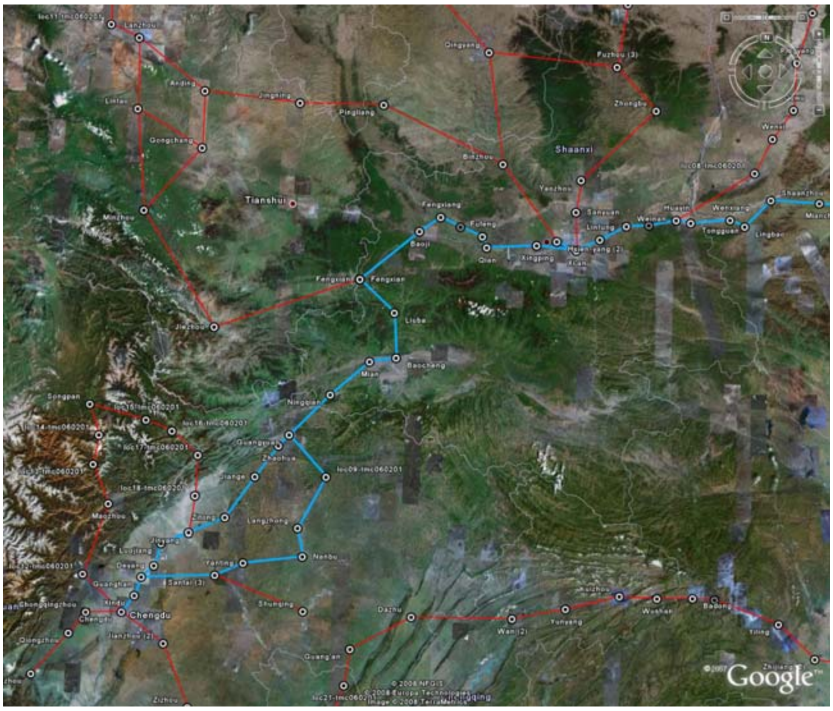

Figure 7: Ming Post Roads from the OWTRAD site [R.7] presented in Google Earth as a set of GPS Routes

The GPS data structure has special affinity with traffic and communications as well as traffic history. Waypoints can represent historical places in areas and can include time periods of interest. Routes can be a representation of journeys and communications that have moved from place to place in some time period in a specific order – such as a trade route (cf. the structures described on the Old World Trade-Routes web site [R.7]). Tracks can be representations of the actual paths by which the traffic made these journeys and are generally harder to validate than Routes. Time in this case is not GPS time but it is a natural component of the information and may be time intervals. General maps of the Shu roads can be simply managed and presented in such a "GPS" framework (see Figure 7).

For mapping of relics at a site, a GPS is usually not accurate enough. A good quality field GPS, without augmentation and a wide range of visible satellites from which to choose the four best, will provide accuracies down to less than 5m with averaging. Tracks recorded by a vehicle may only give accuracies of 10-15m even under good conditions, with a roof mounted aerial and using high sampling rate. In the Qinling and Daba Mountains there are also many places where few or no satellites can be viewed from a relic site or along sections of road through deep valleys. In these situations, one or both of using a Differential GPS (DGPS, [R.13]) and/or using traditional surveying at the fine scale within a site will be needed. DGPS requires either a second specially configured unit to be placed at a fixed location nearby and with good view of the sky (such as on a mountain top) or for there to be some form of augmentation (such as the Wide Area Augmentation Scheme or WAAS) available in the vicinity. These are advanced topics and will not concern this paper further.

Remote Sensing and images

Current remote sensing technologies use digital frame cameras and a variety of scanning and sensing instruments to map the earth, monitor activities on the surface, measure environmental conditions and monitor global change. Airborne data continue to provide the highest resolution images but already space data from commercially launched satellite platforms such as Quickbird

(3m and 70cm resolution) and Ikonos (4m and 1m resolution) compete with aerial imagery. Lists of images that are available, galleries and examples of applications including archaeology can be found at the Satellite Imaging Corporation [R.23] and Digitalglobe [R.8] websites.

The arrival of Google Earth in 2005 [R.12] made the product end of remote sensing something that is now used and appreciated every day by people all over the world. The high resolution images have also brought space remote sensing to a level where it is an adequate product for many applications in archaeology. In this symposium, the papers by Zhou [S.6] and Li and Huang [S.3] provide good examples of the ways in which remote sensing can be used in this context. For example, the city of Hanzhong can be viewed in Google Earth at a relatively low resolution with the standard background global image data. However, despite the cloud that often covers Hanzhong, there are images available at higher resolution. Figure 8 shows a clear Digitalglobe Quickbird image of Hanzhong which uses a “false colour” presentation in which the vegetation appears red.

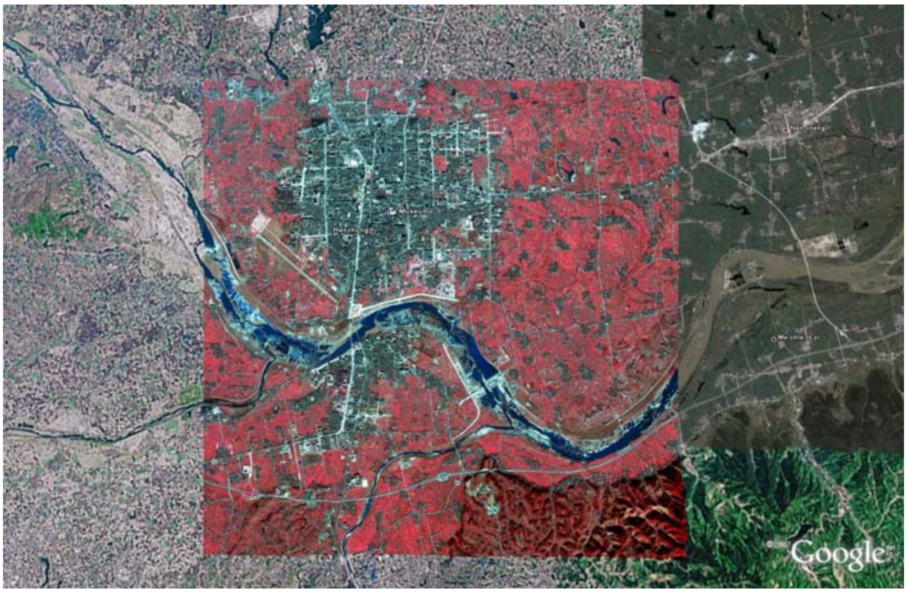

Figure 8: Hanzhong Quickbird image embedded into Google Earth. Image has near 1m resolution.

This image, which has sufficient resolution to see cars on the streets, may be used in Google Earth (as in Figure 8) and other systems against which to present and analyse information at a detailed scale for Hanzhong. Further uses of remotely sensed data will be addressed in the following sections.

Terrain data and DTM

Topographic maps evolved rapidly with the development of airborne remote sensing and stereo-photography. In the past, the terrain was mapped by manually tracing contours or sampling heights along transects in stereo-photographs. For example, the topographic maps being used in the present project (see Figure 9) have all been derived from Soviet era aerial surveys flown in the 1960’s. They were later contoured by machine in Russia from original points collected from the photography. Limitations to the extent of ground survey have created some issues about vertical levelling and datum that are currently being addressed to bring these data into accord with GPS and satellite based data.

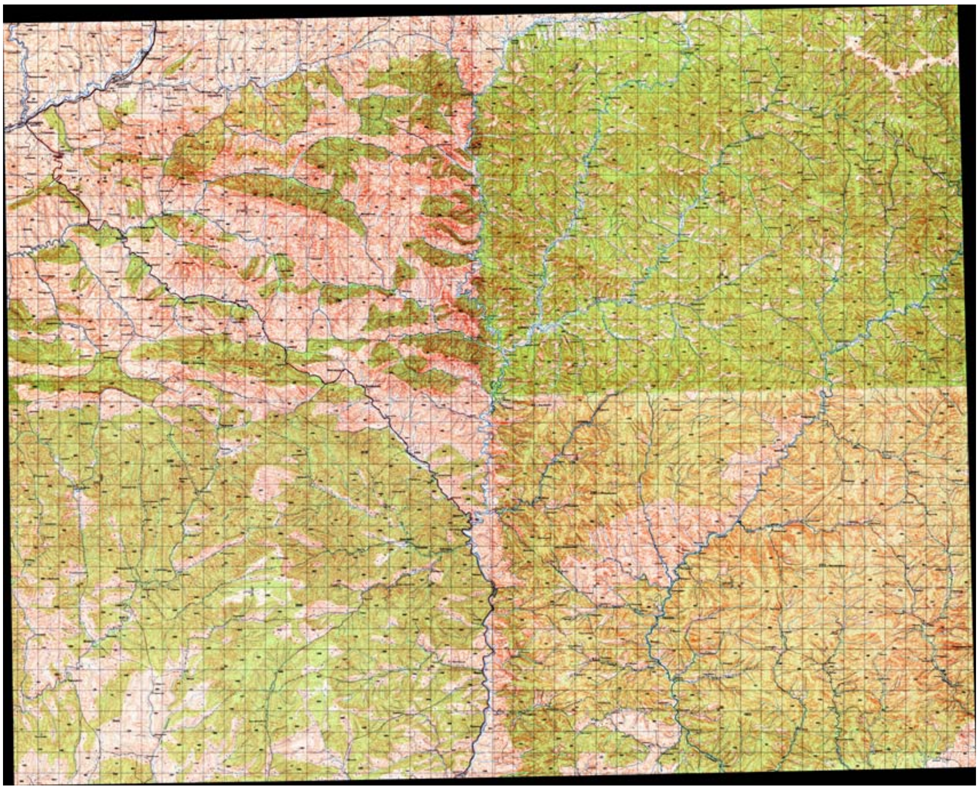

Figure 9: Mosaic of four Russian 1:100,000 Topographic Map sheets centred on Jiangwozi with 20m and 40m contours in Gauss-Kruger (UTM) projection. Resolution of scanned map is 6m.

In modern (post-1960) times, people have moved to develop digital representations of terrain as grids of points. These are called Digital Elevation Models (DEMs) with each grid point being the height above some datum at the point or an average height in some neighbourhood. In the past, such digital data were derived by digitising the contours, streamlines and spot heights from the existing topographic maps. This may still be the only available way to create high resolution DEMs for the Qinling. However, time will see the provision of better DEMs for the area based on photography or space images. Space based DEMs are derived from sensors on satellites managed by a number of countries, such as SPOT, Ikonos and QuickBird.

The mapping of terrain has also been advanced by the availability of the Shuttle Radar Topography Mission (SRTM) [R.24]. The SRTM product is based on remotely sensed Doppler SAR radar which was used to measure range and angles to the earth's surface and derive a global map of surface terrain. SRTM is directly observed data but it is not a direct measurement of altitude. The SRTM data are provided without restriction worldwide at a resolution of about 90m (3 arc sec). They are also available in the US at 30m (1 arc sec). SRTM has already enabled historical geographers to pose geographical and terrain questions at a global scale and Mostern and Meeks [S.4] demonstrate how historical geography of barriers can be advanced with the availability of consistent global data.

With an effective DEM in place, image processing can be used to create a "DTM" or Digital Terrain Model. By "DTM" is meant elevation together with derived terrain products such as slopes, curvatures, terrain points, streamlines, ridges and contours, watersheds, catchments and sub-catchments (see Figure 10). A DTM can also provide the information needed to estimate the optimum routes for new roads as well as the volume of soil that may have to be moved for each option. In the historical applications being discussed here, it is obviously possible to use similar techniques, at an appropriate scale, to identify potential routes for trade and the movement of goods. The recently built tollways through the Qinling were almost certainly planned using 3D models of surface terrain and the subsurface. However, unlike modern engineers, the ancient road-builders did not have tunnelling as an option.

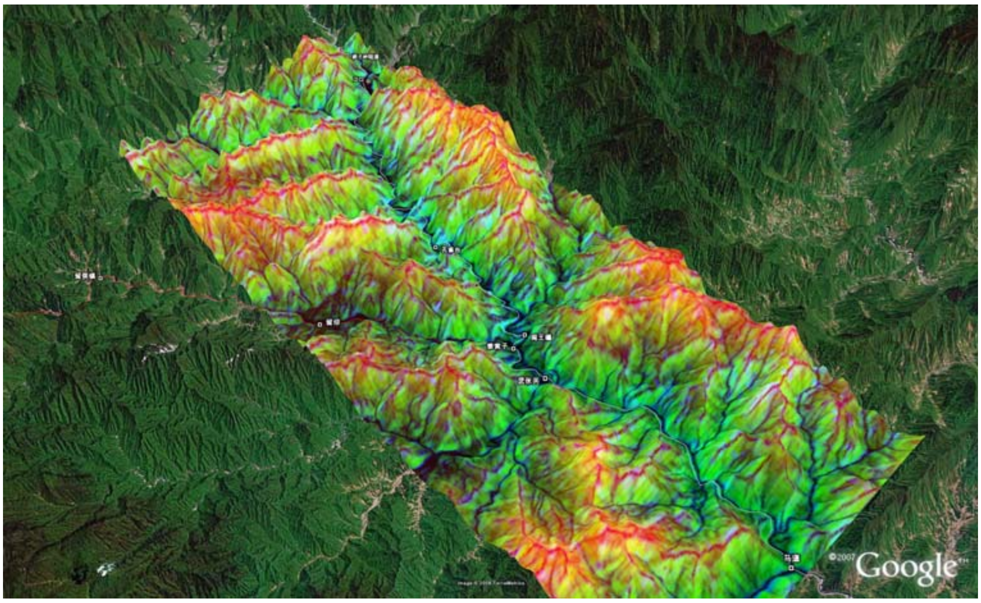

Figure 10: 3D model of terrain using SRTM data processed to a DTM with slope and curvature and imported into Google Earth for visualisation.

GIS and spatial information systems

In the past, a GIS was a (relational) database with information held against spatial objects that was combined with means to input, manage and display the data (see, for example, Burrough, 1988 [R.5]; McGuire et al., 1991 [R.19]). However, in recent years the distinctions between GIS and other spatial data and graphics processing systems such as image processing and Computer Aided Design (CAD) have grown indistinct. The methods used have now come to depend primarily on the needs of the analysis and input data types. Modern systems have evolved to allow the spatial objects (eg models of buildings, property boundaries or a road network) to be combined with image data, analysed together and presented and visualised in a combined format. Archaeology needs this combination as much as any field. The merging of different data types (including multi-media data) is described in the paper by Zhou [S.6] and an example of embedding what at one time were seen as CAD 3D architectural modelling operations into historical GIS is provided by Li and Huang [S.3].

For archaeology and history, time is a critical information dimension. Relatively few GIS systems handle time and time periods in more than a simple way. One exception is the TimeMap system devised by scientists at Sydney University in Australia (Johnson, 2004 [R.18]) and presented at the Symposium during a software demonstration by Andrew Wilson. Time information needs to be included to identify time series, time intervals and events. Like GPS data, historical data exists in a place-time (4D) structure. Many scholars in China and the west are currently working to establish the name, location and events associated with places at different historical periods (see, for example, the activities involved in the Harvard Yenching Institute China Historical GIS[9] at [R.15]) and deriving "gazetteers" to manage the data (as in the ADL Gazeteer, [R.1]). The technology of GIS can handle this kind of input information but it is crucial that the data structures and data management be carefully defined and considered before the data bases are populated.

[9] The CHGIS provides China historical data sets and software to registered users. In China, this information is accessible from the Center for Historical Geography, Fudan University, Shanghai [R.6].

This is a job for all the parties involved. For case studies and ideas in the initial stages, a useful web resource is “Digital Historian” [R.27].

Processing and Presentation

The tools that now exist to implement these technologies are diverse and range from simple and free to complex and expensive. Sophisticated software systems such as ArcGIS and ArcMap [R.10] for GIS, ERDAS [R.10] for image processing, AutoCAD [R.3] for CAD and other advanced systems for 3D visualisation and presentation are common tools used by well-equipped consultants and researchers. With these tools, maps, images, DEMs, photographs and historical data can be set up in an integrated framework, analysed and displayed. It is likely that in the beginning at least, the demonstrations of 3S technology in the Qinling will make use of these sophisticated systems.

It is also likely that in the future, the users of the data and information systems will wish to extend and build on the base that is provided to them. Such access can either be provided by special tools and interfaces that allow development and extension under control of larger specialised systems or through the ability of users to interface other software products to undertake their own developments. One of the most exciting of modern developments has been the ready access that now exists to relatively low-cost tools that were previously only available to experts and commercial firms for GIS, CAD and image processing.

Google Earth [R.12] came onto the scene when Google Inc. bought Keyhole Inc and released “Google Earth” in 2005. Since it became public, Google Earth has led to a dramatic rise in public interest in geospatial technologies throughout the world. Google Earth and similar systems, such as NASA Worldwind [R.21] and Microsoft Virtual Earth [R.20] include composited space imagery, a background global DEM (SRTM) and the capacity to add GIS information and CAD 3D structures (examples are available in Google 3D Warehouse at [R.12]). In the future these systems will be major avenues for the spread of information and the participation of many people in the applications of 3S to the history of the Qinling and the Shu Roads. Zhang and Wang [S.5] broach these and other aspects of widespread participation in their paper on Public Participation GIS (PPGIS).

Whilst this potential for access and participation is exciting, the tools selected and the personnel involved must also depend on the level of detail and complexity needed in a project. At this time it is likely that historical architectural models with the level of detail and quality presented here by Li and Huang [S.3] will require complex software and skilled operators. Similarly, SRTM is too coarse for many applications involved in archaeology at relic sites. Deriving sufficiently resolved DEM data and integrating them with other spatial data, including currently available maps, still presents a technical degree of difficulty that needs expert input and sophisticated GIS tools. Hill (2006, [R.17]) is a valuable resource for issues involved in georeferencing of this kind.

In order to successfully choose a pathway among these many options, users need to be clear on the needs of their work and the purpose of their use of GIS for historical research. An important issue (Lees [S.2]) is whether history and literature can be integrated into a modern geodetic framework at all? It is clear that roads and events took place in a physical and mappable framework. The problem is that they have not been recorded and communicated in this way. It may be that what should be produced for historical GIS is be more like the traditional mariners chart than a modern topographic map. Mostern and Meeks [S.4], however, have skilfully and successfully combined historical literature and geography in their paper and provide an important guide to this aspect of the task. Whatever is done, given the wealth of choices available, the present situation provides exciting prospects for historians, archaeologists and 3S practitioners.

Australia-China project on 3S Technology

The Australia-China Council (ACC) [R.2] was established by the Australian Government in 1978 to promote mutual understanding and foster people-to-people relations between Australia and China. They have financially supported the project described here that is being undertaken cooperatively with the Hanzhong Museum. The introduction to 3S technology into the present Symposium has been an important step as experts in 3S have joined experts in Plank Road research to present the current state of historical, literary and geographical knowledge as well as the opportunities for 3S technology to enhance the research and applications.

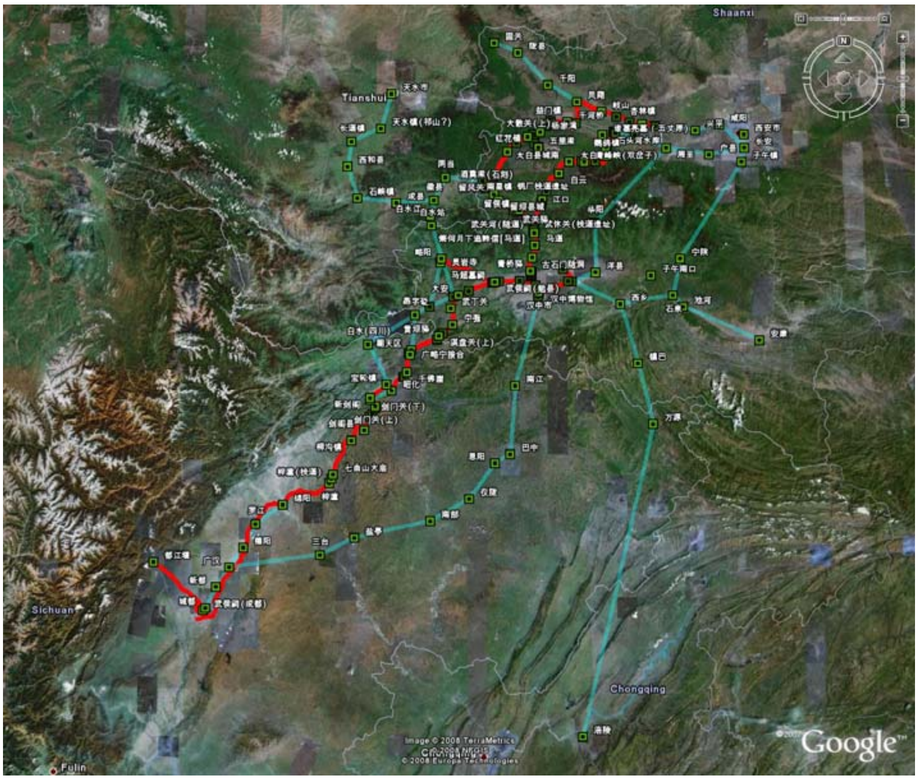

Figure 11: Draft presentation of modern towns, places, tracks and routes related to Shu Roads

The Project has also commenced two demonstrations in 3S in the Qinling. One aims to create a presentation of the major Shu road routes that may be displayed in Google Earth or other KML[10] compatible systems. In this system, the photographs and other base information are stored on a web server and the places are all current locations where the towns or archaeological relics have been significant in Shu Road history. The Tracks are track segments derived from GPS data collected along roads as near as possible to original routes of Shu Roads. "Routes" link places by lines and provide a default means to indicate the path of Shu Roads where no track information is available. A draft version is shown in Figure 11. The most recent version can be found HERE.

The second area of demonstration is a pilot DEM based project. This pilot project involves participation by researchers from Xi'an University of Science and Technology (http://www.xust.edu.cn) and has two stages. The first uses SRTM data with appropriate software for analysis and visualisation. The work being undertaken incorporates Russian Topographic Maps (1:100k, 20-40m contours), field studies and surveys and uses Google Earth as a presentation environment. The Russian maps can also provide routes of modern but pre-1960

[10] Keyhole Markup Language was the open XML language serving interchange of Google Earth iknformation but has now become an international standard for presentation systems.

roads and DEMs for places where now there are major dams (such as Shimen, Xieyuguan, Bai Shui etc). The second stage involves constructing and using the data of the first stage with a higher resolution DEM derived by integrating different data sources. The second stage allows visualisations to be presented at a finer scale. The pilot project is being framed to serve the geographical needs for historical Plank Road research and also opportunities to advance tourism. The papers by Mostern and Meeks [S.4], Zhou [S.6] and Carter and Vargas [S.1] provide important demonstrations of these meeting points between the technology and its application. The aim is to increase awareness and interest in Plank Road history among academics, tourism groups and people of many countries. Outcomes from this project can now be found HERE.

Conclusions

The development of Plank Road technology along mountainous stretches of the Shu Roads that enabled communications between north and south is a significant component of China's history and culture. This symposium has included the latest research and knowledge available in this area. Part I of this paper provided a brief introduction to the history for English readers. It also discussed the role of terrain which led easily to the topics of historical geography that are currently strongly supported by the 3S technology described in Part II.

The 3S technology described in Part II represents only a few of the possible tools that can be applied. The use of web references in the paper will hopefully allow readers to move from this introduction and the 3S papers in this symposium to many other ideas and possible technologies. The emphasis here has also been on presenting options and accessible tools for user participation. The potential for participation has increased dramatically in the last two or three years and the Symposium has occurred at an ideal time. In the future, it is likely that mapping, remote sensing, GPS, GIS, 3D modelling and terrain modelling all bring benefits to Plank Road research and applications. It will also hopefully also help development of historical preservation and conservation and the cultural and historical developments that will enrich national and international tourism.

Acknowledgements

The Australia-China Council ([R.2]) has provided valuable financial support for this project and the Hanzhong "International Symposium on Historical Research of Plank Roads and Applications of 3S Technology". SRTM data are the property of NASA and were obtained with permission from the JPL site at [R.24]. The Google Earth images (Figure 7, Figure 8, Figure 10 and Figure 11) were created using Google Earth Pro licensed from Google Inc. [R.12]. The Quickbird image of Figure 8 is used under license from Digital Globe [R.8]. The data in Figure 7 were obtained from the OWTRAD web site [R.7] with permission of Matthew Ciolek. They were posted on the site by Prof. Mark Elvin of the Australian National University. Trademarks and proprietary names have been respected by reference to an appropriate web site. In Australia, Zhang Meiyi and Li Lingtao provided excellent translations for this paper and some other English language papers. In China, Xie Hongxia provided important editing and advice on the translations. Staff at Hanzhong Museum and students at the Institute of Soil and Water Conservation, Yangling, provided significant support and help for this work

References

This Symposium

[S.1] Carter, C. and Vargas, C.S. (1) The Royal Roads of the Inca; (2) Tourism and the Inca Trails.

[S.2] Lees, Brian. The language and grammar of maps.

[S.3] Li Hongba and Huang Bo. 3D Visualization and Real-time Simulation of Historic Sites.

[S.4] Mostern, Ruth and Elijah Meeks. The Qinling Frontier and the Construction of Empire in China: Three Examples from Early and Middle Period History.

[S.5] Zhang Guolun and Wang Peixin. Reconstructing historical sites: A web-based PPGIS Approach.

[S.6] Zhou Tianyin. Using Multi-Scale Spatial Data in Environmental Monitoring and Management.

General References

[R.1] Alexandria Digital Library Gazeteer http://middleware.alexandria.ucsb.edu/client/gaz/adl/index.jsp

[R.2] Australia-China Council web site http://www.dfat.gov.au/acc/

[R.3] AutoCAD/AutoDesk Software http://usa.autodesk.com/adsk/servlet/home?siteID=123112&id=129446

[R.4] Blunden, C. and Elvin, M. (1983). *A cultural atlas of China*. Equinox (Oxford) Ltd.

[R.5] Burrough, P.A. (1988). *Principles of Geographical Information Systems for Land Resources assessment*. Clarendon Press, Oxford.

[R.6] Center for Historical Geography, Fudan University, Shanghai http://yugong.fudan.edu.cn/default.asp

[R.7] Ciolek, M. (1999) Old World Trade Routes (OWTRAD) at: http://www.ciolek.com/owtrad.html

[R.8] Digitalglobe (Quickbird) home page http://www.digitalglobe.com/

[R.9] Digital Historian (a group dedicated to the discussion of all issues relating to the use of technology for historical scholarship) http://www.arts-humanities.net/digital_historian

[R.10] ESRI GIS and Mapping Software http://www.esri.com/

[R.11] Garmin Ltd. GPS Guide for Beginners http://www8.garmin.com/manuals/GPSGuideforBeginners_Manual.pdf

[R.12] Google Earth software and download site http://earth.google.com/

[R.13] Information Note on Garmin GPS systems - DGPS http://www.gpsinformation.org/dale/dgps.htm

[R.14] Hahn, T.H. Classified Bibliography of Reference Works on Chinese Historical Geography (web site) http://www.gatheringmountains.net/Geoweb/

[R.15] Harvard University Yenching Institute China Historical GIS website at: http://www.fas.harvard.edu/~chgis/

[R.16] Herrmann, A. (1966). *An Historical Atlas of China*. (Second revised Edition, originally published in 1935). Aldine Publishing Company, Chicago.

[R.17] Hill, Lynda L (2006). *Georeferencing: The Geographic Associations of Information*. Cambridge, Massachusetts, USA: The MIT Press, 260p.

[R.18] Johnson, I. (2004). Putting Time on the Map: Using TimeMap for Map Animation and Web Delivery. GeoInformatics, July/August 2004. (http://acl.arts.usyd.edu.au/)

[R.19] Maguire, D.J., Goodchild, M.F. and Rhind, D.W. (eds.) (1991). Geographical Information Systems: Principles and Applications. Avon, Longman Scientific and Technical.

[R.20] Microsoft Virtual Earth software and materials http://www.microsoft.com/virtualearth/

[R.21] NASA World Wind gallery and software http://worldwind.arc.nasa.gov/

[R.22] Needham, J. and Wang, L. (1959). Mathematics and the Sciences of the Heavens and the Earth. Volume 3 of *Science and Civilisation in China* (Joseph Needham, Ed), Cambridge University Press.

[R.23] Satellite Imaging Corporation (Ikonos) home page http://www.satimagingcorp.com/gallery.html

[R.24] Shuttle Radar Topography Mission home page http://www2.jpl.nasa.gov/srtm/

[R.25] Tan Qixiang (Ed) (1996). The Historical Atlas of China. 8 volumes. China Cartographic Publishing House, Beijing.

[R.26] Yan Ping, Jin Yingchun, Zhou Rong, Sun Guoqing, Yin Junke, Qiu Fuke & Han Beisha (1998). *Treasures of Maps – A collection of maps in Ancient China*. Harbin Cartographic Publishing House.

[R.27] "Digital Historian" (a group dedicated to the discussion of all issues relating to the use of technology for historical scholarship) http://www.arts-humanities.net/digital_historian

Australian Government | Australia-China Council