CHINESE GEOGRAPHICAL SCIENCE
Volume 16, Number 2, pp. 95-101, 2006
Science Press, Beijing, China

ANALYSIS OF REMOTE SENSING ARCHAEOLOGY ON TRAFFIC FUNCTION TRANSFORMATION OF TONGJI GRAND CANAL IN SUI AND TANG DYNASTIES

WANG Xin-yuan[1,2,3], HE Hui[2,3], ZHOU Ying-qiu[2,3], GAO Chao[2,3], HAN Shuang-wang[2,3]
(1. Department of Earth and Space Sciences, University of Science and Technology of China, Hefei 230026, P. R. China;
2. Anhui Workstation of Remote Sensing Archaeology, Joint Laboratory of Remote Sensing Archaeology, Chinese Academy of Sciences/Ministry of Education and State Administration of Cultural Heritage, Wuhu 241000, P. R. China;
3. College of Land Resources and Tourism, Anhui Normal University, Wuhu 241000, P. R. China)

ABSTRACT: In China, most directions of river flowing are from west to east. During historic period, since the water traffic played an important role, it was very important to form a cross-horizontal net of water carriage route. Canals should be dug so as to make up the lack of north-south river. Tongji Grand Canal, dug in the first year of Daye (605 A.D.) in the Sui Dynasty, was the important component of north-south system of Grand Canals in China. It promoted economic and social development of the Sui, Tang and Song dynasties (605 A.D.-1279 A.D.). As Tongji Canal (i.e. Tongji Grand Canal) flowed across the Huaibei Plain, which is aggraded by abundant mud and sand deposit resulted from the Huanghe (Yellow) River flooding, many traces (such as old channel) and human culture heritages were buried under mud-sand. Tongji Canal was silted up, and disappeared in the Jin Dynasty (1115 A.D.-1234 A.D.). From then on, there were many different stories about the flowing route of the canal in historical literature. Based on space-bone and air-bone remote sensing imagery, we attempt to search the old channel of Tongji Canal, and supplement historical record. The paper discusses transformation process of Tongji Canal's traffic function, and resumptively summarizes the reasons of the transformation, which results from synthetic function of physical geographical, political, economic, and social conditions.

KEY WORDS: Tongji Canal; Traffic Geography; functional transformation; remote sensing archaeology

CLC number: TP79 Document code: A Article ID: 1002-0063(2006)02-0095-07

In China, most directions of river flowing are from west to east. During historic period, since the water traffic played an important role, it was very important to form a cross-horizontal net of water carriage route. Canals should be dug so as to make up the lack of north-south river. There was a far long history in Chinese canal development. From local north-south canal cutting in the Spring and Autumn Period and Warring States Period (770 B.C.-222 B.C.), to primary formation of the national scale water transportation net in the Qin and Han dynasties (221B.C.-220A.D.), then to the formation of the canal net among the Changjiang (Yangtze) River, the Huaihe River, the Huanghe (Yellow) River, the Haihe River in the Wei, Jin, and Southern and Northern dynasties (265A.D.-581A.D.), and to the formation of the political and economic centre along the south-north Tongji Grand Canal (shortly named Tongji Canal) with Luoyang and Kaifeng in the Sui, Tang, Song dynasties (605A.D.-127A.D.), and finally to cutting the Jing-Hang Grand Canal in the Yuan, Ming, Qing dynasties (1260A.D.-1911A.D.), those showed the intelligent and ability of ancient people in China.

After the Sui Dynasty unified the whole nation, Emperor Suiyang ordered to carry through the Tongji Canal project to contact rich and populous regions of the southern China and the national capital—Chang'an. Tongji Canal, as one of four great projects, was excavated in 605A.D. The canal length was 630km. It went through about 600 years, from the Sui Dynasty to Tang, Five Dynasties, Northern Song, to Southern Song, to be abandoned. It was not only main traffic artery of the south-north transportation in ancient China, but also the bridge of the economic and cultural exchanges, so we called it the life's river for the three dynasties of Sui,

Received date: 2005-05-25
Foundation item: Under the auspices of the National Natural Science Foundation of China (No.40571162), the Natural Science Foundation of Anhui Province (No.050450401), Natural Science Foundation of Anhui Provincal Education Department (No. 2004kj65zd), Postdoctoral Foundation of University of Science and Technology of China
Biography: WANG Xin-yuan (1964-), male, a native of Lu'an of Anhui Province, professor, Ph.D., specialized in RS Archaeology. E-mail: xinyuanw57@vip.sina.com

Tang, Song. As Tongji Canal flowed across the Huaibei Plain, which is aggraded by abundant mud and sand deposit from the Huanghe River, many landforms and human culture heritages near it were buried under mud and sand. Tongji Canal was silted up, and disappeared in the Jin Dynasty (1115A.D.-1234A.D.). After then, there were many different stories about the flowing route of the canal in historical literature.

1 FLOWING ROUTE OF TONGJI CANAL

1.1 Discovery by Remote Sensing Technology

When many specialists and scholars were quarreling about the exact position and flowing direction of the ancient canal—Tongji Canal, we acquired a radar remote sensing mosaic imagery that was provided by Institute of Remote Sensing Application of Chinese Academy of Sciences. The radar remote sensing imagery is a narrow ScanSAR image (300km×300km) that was obtained by Canadian Radar Satellite 1 in 1997. C wave band with wave length of 5.6cm was employed and HH polarization style was adopted. By rectifying and handling, the imagery resolution was 50m×50m (distance×azimuth).

As a side-looking activity imaging style, radar remote sensing transmits the pulse to the Earth's surface where it is then scattered. The backscattered signal (radar echo) is detected by the antenna and recorded by the switch to the receiver. Radar remote sensing has sensibility for condition of land surface roughness (ULABY et al., 1981; GUO et al., 2000; EVANS et al.,1992). By fractal analysis and radar remote sensing demonstration of surface of fluvial and alluvial fan in Ejin Banner, Inner Mongolia, we found that C wave band of HH polarization has sensitive reflection to rough region in earth surface (WANG et al., 2001). The radar imagery has special advantage to some objects with linear structure (such as electric wire, water system, road, valley, steep cliff, fault, etc.) (BORENGASSER and TARANNIK, 1998; WANG et al., 1991). As dihedral angel beam reflector's function, a slope surface of long-strip hillock on plain which is irradiated in right angle by microwave would produce strong backscatter (Fig. 1). That is the reason why bright line appears on Fig. 1 radar image. On meek ground surface of the Huaibei Plain, the bright line on radar image makes an appeal to our attention, because the linear stretch direction is coincident with the Grand Canal's line.

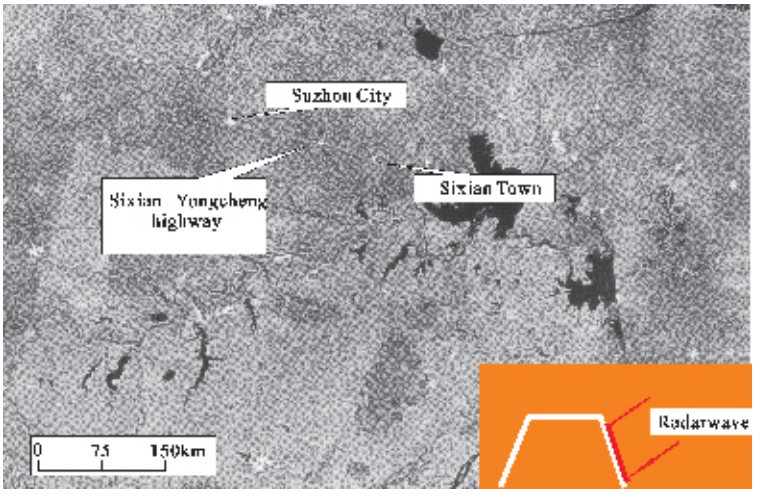

Fig. 1 Bright line on radar satellite image

For acquiring more detailed information, we compared Landsat TM imagery with Radarsat imagery in the same region. In TM432-R-G-B composed imagery (Fig. 2), surface features, such as highway, water-system, etc., are clearly shown, but the Tongji Canal could not be stood out. The case adequately shows the advantage of radar remote sensing to researching such type of objects.

1.2 Tongji Canal Remains

From May to October in 1999, the research of Tongji Canal was made in Liuzi of Suixi County, Huaibei City, Anhui Province. Anhui Institute of Archaeology made great basic researches. A stone wharf and some sinking ship of the Tang Dynasty buried in mud-sand was discovered in the Grand Canal, a large quantity of china in the Tang/Song period were excavated out. Later on, the special subject researchers from Anhui workstation of remote sensing archaeology, studying of archaeology, geography, history etc., combining satellite and air-bone remote sensing imageries with survey on June 16-28, 2002, studied Tongji Canal section in Anhui Province, and collected the special data from more than 40 surveys including the course of river, river embankment, river flowing direction, width of stream, etc. We discovered

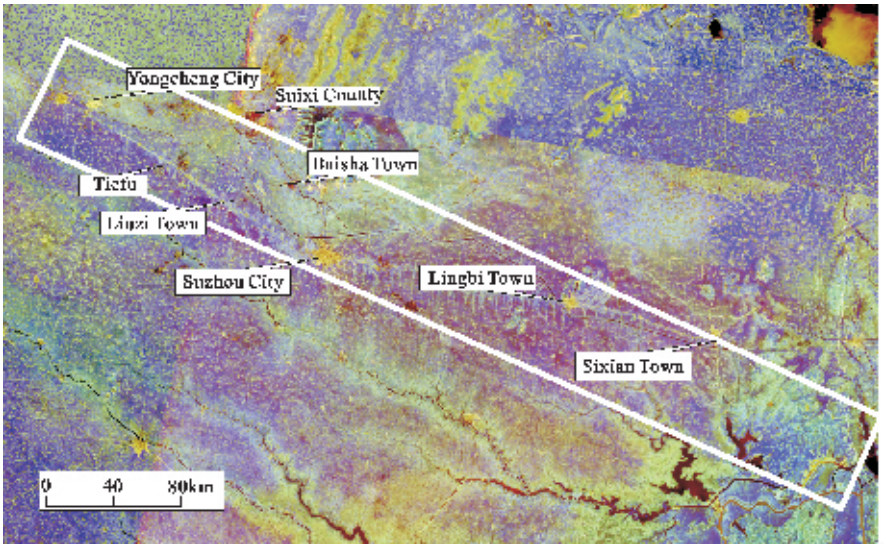

Fig. 2 Landsat 7 RGB (432) composed image

the connection line between river embankment and river bed (Fig. 3), which provided the definite proof for dike and river bed existence. By researching, we could get the following results:

(1) The section of Tongji Canal in Anhui Province has been built into a major inter-provincial highway which links Henan, Anhui and Jiangsu provinces. Although the former dams built in the Sui Dynasty does not exist now,

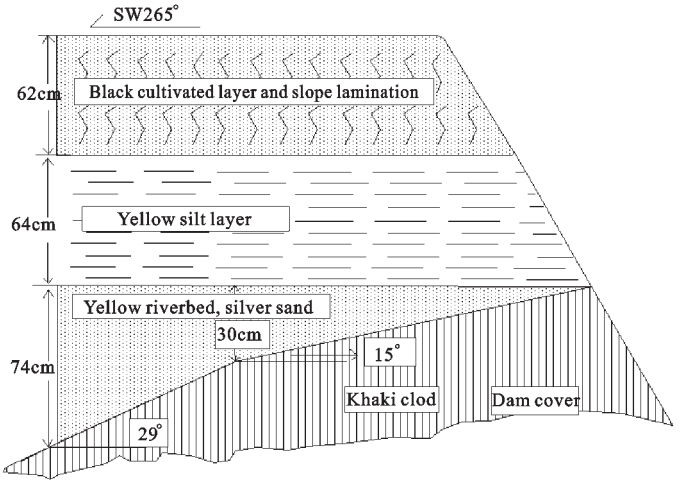

Fig. 3 Section plane of dyke and riverbed near Xiguan Bridge

the ridges of various heights of the former dams can still be found along the road, and the highest point is about 2m higher than the ground. The bright line we mentioned above is the canal dams and deposited mud-sand of the river-bed, which can be detected and shown on the radar imagery.

(2) Baisha Town has a north-south ancient canal relic about 38m away from the north edge of the highway. Now, the bottom of the canal is 5.5m deep, the width is about 15m at the bottom and about 25m between the upper rims. The evidence of the ancient canal becomes more and clearer by digging slopes of the ditch. Remains such as pottery from the Tang ceramics, animal bones and crashed tiles were also found at the bottom of the canal, which can reflect scenes of shipping of cargoes and living of the boatmen on the ancient canal.

(3) There is a small segment of Tongji Canal leaving over Sixian Town. The water flows into Hongze Lake. However, the canal course has become narrower and shallower. Now, the canal is so shallow that it is impossible to pass any boats. In the 1970s, an about 10m-long ancient boat deck was exhumed near the canal. Archaeologists found some remains such as china bowls, china fragments and skeletons of human bodies. At the same time, several stacks of millet cereals on the riverbed, which were about 10m^2, were also unearthed. It validated the record in historical books that here river was too shallow to pass the Suiyang Emperor's dragon boat which re-

quired to be dragged by human force. Those cereals had been used to alleviate the friction between the boat-bottom with riverbed.

(4) There is a part of the canal remains neibouring the West Erpu Village in Yongqiao District, Suzhou City. Lot of pottery fragments were found near the Sanba Town. A pier of the Yongqiao Bridge was exhumed from underground at the construction site of a commercial bank. A crucible was found at the bottom of the basement, which is round bottom and flat rim, and there were 49 pieces of grain of boiled copper and iron residues with various shapes in it. A large number of china fragments, which could be dated back to the Sui Dynasty, were found at West Erpu Village. It is very important that a boundary tablet of Qixian County was found there. The tablet body was engraved to guide different directions of and distances to important cities. It was regarded as the mark on the Yongqiao Bridge showing directions of roads. The remains of the tablet were 86cm long, 41cm wide and 85cm thick. This tablet has much higher value in research, because it showed not only the scope of Qixian Country, but geographical directions and mileage of the cities concerning.

1.3 Course of Tongji Canal

The course of Tongji Canal, which had been built in the Sui Dynasty, is defined on the basis of the historical account from "Picture Records about Counties of Yuanhe Period" and "A Record of All Boundaries of Yuanfeng Period", RS imagery and field investigation. The mouth of upper reaches of Tongji Canal was located in Heyin County (north to Xingyang, Henan Province). The water course flowed through Xingze (now Guangwu County, Henan Province), Guancheng (Zhengzhou City now), Yangwu (now within boundary of Zhongmou County), Zhongmou (now Zhongmou County), Junyi (namely Daliang in the Sui and Tang dynasties, now Kaifeng City), Chenliu (now southeast of Kaifeng City), Gushu (now southeast of Shangqiu City), Xiayi (now Xiayi County), Yongcheng (now Yongcheng County), Linhuan (now Linhuan Town of Suixi County, Anhui Province), Suzhou (now Suxian County and Suzhou City), Lingbi (now Lingbi County), Xiaqiu (now Sixian County), and Xucheng (now 25km away to the west of Xuyi County, Jiangsu Province). At last, it runs into the Huaihe River at Xuyi (now northeast of Xuyi). The total length of the canal is 630km long (Fig. 4).

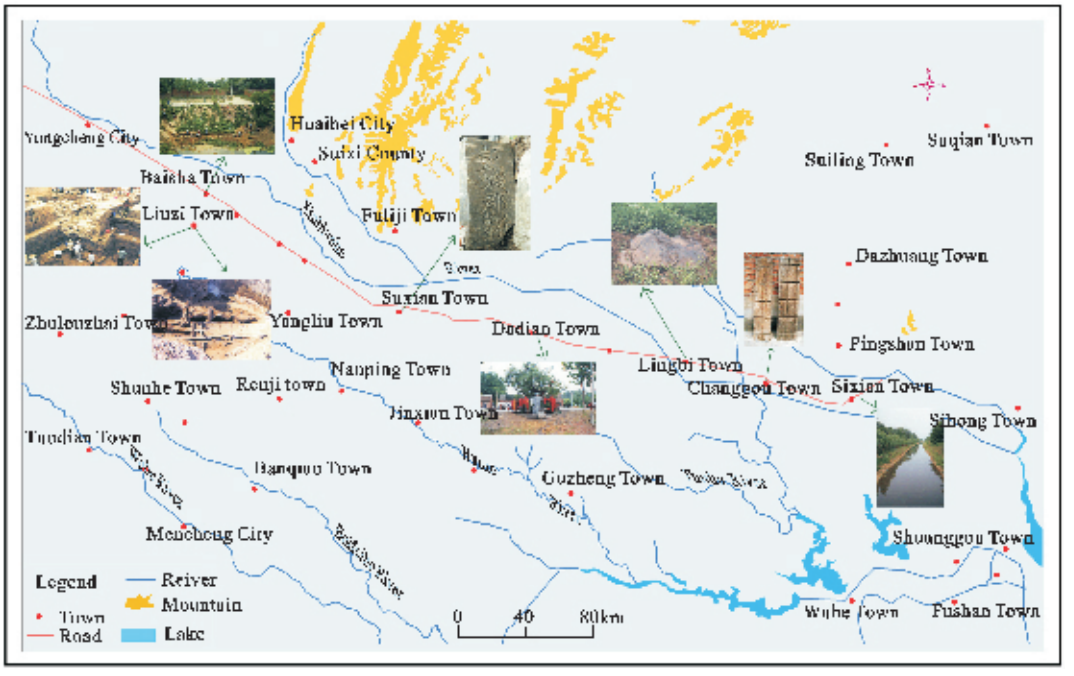

Fig. 4 RS interpretation map of Tongji Canal Course (part) and landscape photos

2 FUNCTIONAL TRANSFORMATION OF TONGJI GRAND CANAL IN HISTORY

2.1 Prosper Water-carriage Traffic as Main Artery

Tongji Canal of the Sui Dynasty had been renamed as Bianhe Canal or Bianhe River in the Tang and Song dynasties. The excavating of Tongji Canal in the Sui Dynasty brought enormous public grumbling, but the human being in two dynasties of Tang and Song had really got abundance profit. From the middle of the Tang Dynasty, there were about 6000 - 7000 boats sailing on the Bianhe River every year, on which countless cereals and

other goods were shipped on the canal. People then described it as "fruits of labor people, who lived in 43 states in the southeast of China, were taken away by the river" (LIU, 2000). This vividly showed that the Bianhe Canal was the lifeline of people from the middle of the Tang Dynasty .

At the end of the Tang dynasty, the Bianhe River was destroyed by General Yang Xing of Huainan to defend General Zhu Wen's invading the south of China. There became a swamp from the southeast of the Yongqiao Bridge to the north of Suxian County (SIMA, 2000), the course of the canal gradually being deposited since then. After the Five Dynasties, the emperor of Shizong of Later Zhou Dynasty (954- 959) ordered to dredge up the river, the shipping had regained. When the economic center of the Song Dynasty shifted to the south of China, the Bianhe River communicating the Changjiang River with the Huaihe River exerts more traffic benefit.

At that time, millions of Dan (1 Dan =50kg) of rice was transported from the areas of the Changjiang River, the Huaihe River, Hubei Province and Zhejiang Province, along with uncountable products, to the capital by shipping. Among rivers and canals, this Bianhe River was the most important one (XIA, 1980). It is very important to maintain the economy of the political center of Song Dynasty. The prosperous prospect of two banks of the Bianhe River in Kaifeng City was described in the famous traditional Chinese painting "The Outing at Bianhe River in Spring", which was a very glory picture for trading along the Bianhe River and an epitome for whole socio-economy of the Song Dynasty.

It is the first archaeological discovery of stone wharf in the canal in Liuzi of Suixi County, which provides new references to the researching into regulation of transportation by water, and the facilities on the canal construction. Moreover, 8 buried ships and more than 20 kilns of porcelain that were made at Sui, Tang, and Song dynasties were discovered in the site (DCTAAP, 2002). That reflected the great development of Chinese economy at that time.

2.2 Traffic Evolution of Tongji Canal from Land Route to Water Ways

Because the sand silting up, fight and other factors, Tongji Canal gradually silt up in the Southern Song Dynasty (from 1165A.D. to 1174A.D.), which was abandoned at that time. Some canals had already changed into the cornfield, some become highway, and the rest even had been covered with house. After he was sent to the Jin Kingdom on diplomatic mission in 1169A.D., LOU Yue detailed what he saw on this way in Chinese history literature books such as Bei Xing Ri Lu (Northbound Diary). He reported: on the December of the fifth year of Qiandao (A. D.1169), he had riden 80li (1li= 0.5km) on a horse, then stayed at Lingbi. Went away a several li, he saw that the Bianhe River was dry, after three days, his carriage had left for 60li to Jing'an Town where he had breakfast. Then, he went 60li to Suzhou where he stayed for a night. From Sizhou Town, he saw that the Bianhe River channel was full of sand as high as the dam along the bank and all vehicles walked on the river bed, which was even higher than the top of house. On the return journey (1170A.D.), he recorded the same vision again what he looked. He said: when he passed back the Bianhe River, he saw a plenty of wheat in cornfield at the bottom of the riverbed.

Due to chaos caused by war, the canal was abandoned and filled with sands. It is impossible to keep up with water transportation in the past. Most part of the canal course had already become the highway or farmland, or even building. For example, Tongji Canal in Anhui Province had developed into the highway from Sixian Town to Yongcheng City. In Suixi County, the ancient channel is turned into sections of a highway. From Suxian County to Sixian Town, the highway was built on south bank of the canal. At the same time, there were a lot of cities and towns along the highway, such as Liuzi, Yongqiao, Lingbi and so on. On the whole, the prosperity and decline of those cities and towns were related with the Bianhe River. So, we could say that opening the Bianhe River promoted the region's prosperity, and closing the canal the region's decline. So, along with the silence of the Bianhe River, the role of those cities and towns gradually degraded.

3 REASON OF CHANGE OF TRANSPORTATION FUNCTION OF TONGJI GRAND CANAL

The Tongji Canal had played an important role in politics, economy, culture, traffic and so on in history. For example, this canal could not only irrigate and relieve the burden of flood, but also transport goods. At that time, it promoted the economy and culture prosperity in both sides of the river, and made the business town develop for a time. What reason made the canal disappear and the function change? There are the following three reasons of natural condition, politics and economy.

3.1 Deposited Mud-sand from Huanghe River

The middle Huanghe River flowed through Shanxi Province, Shaanxi Province and Gansu Province, which was thick and loose loess plateau. In rainstorm, the large

quantity of sediment could be carried to the Huanghe River. The river's carrying sand is the highest in the world. The Tongji Canal which channeled the Huanghe River to Huaihe River mainly flowed through plain area. Its topography was gentle, and slope degree was small. So, the two factors made water flow slowly, and the plenty of sand was deposited. The Huanghe River's sediment annually transported amounted to 1.6×10^9t, among which about 1.2×10^9t was sand transported into the sea, about 400×10^6t deposited on the bottom of the river. So, the Huanghe River has been famous for its incline to piling up, to breaking out and to changing its course (ZHENG, 1939). In the first month of each lunar year of the Tang Dynasty, the government dredged the channel (LIU, 2000) in order to keep shipping unimpeded.

Most time in 3000 years ago, average temperature was 2℃ more than today (ZU, 1973), which favored plant growing, and benefited water and soil conservation. In the middle and low valley of the Huanghe River, ancient people dug innumerable canals on two sides of the river. The large rivers such as the Jihe River, the Luohe River, the Puhe River, and lots of branch lied in the sides of the Huanghe River, and many lakes scattered in its both sides. Those rivers and lakes shared the responsibility of releasing the silt-up sand and flood discharge.

At the late Tang Dynasty, the primary forests were destroyed, and the pasturages were changed into farmland, which caused the serious soil erosion. The air temperature obviously kept descending, generally 1℃ or so lower than it is today (ZU, 1973). It prevented plant growing. From the Northern Song Dynasty, the Huanghe River came into flood again. Since King Zhouding's fifth year (602 B. C.), the Huanghe River changed its way six times, among which two times happened in the Song and Jin dynasties, and the flood broken out more than a hundred times. The Bianhe River overflow was reported more than twenty times in Song Shi Ben Ji (Song Dyansty History Original Rrecord) and Wu Hang Zhi (Five Vocations Record). At that time, the rulers did not realized that the controlling flood of the Bianhe River basically depended on controlling sand, consequently they simply blocked up or banked up dyke. As a result, the branches of the rivers were all packed. At the same time, the lakes connecting these rivers were gradually piled up to discard. Without branches of rivers and lakes to release excessive water, people had to banked up dyke high. But the riverbeds were filled more quickly, for a long time, they become above the dam. Looking from dam to bottom, the people looked like to live in the deep valley (JI, 1990). When flood happened, the dam was unavoidable to be broken off. At the same time, the large quantity sediment with the flood would silt up. And going with war's chaos and other reasons, Tongji Canal was abandoned inevitably.

3.2 Political Reasons for Canal Disuse

From the Tang Dynasty to the Song Dynasty, although they all enjoyed the benefits of the Tongji Canal, people made more efforts to dredge channel and maintain the canal unobstructedly shipping. Usually, there was a small clearing once a year and a big one every three years. But from the middle period of the Tang Dynasty, "The Betray of An Lu-shan and Shi Si-ming" made the work of dredging Tongji Canal stop for 8 years. When Emperor Dezong ascended throne, he mistakenly put Lu Qi and other ministers in very important positions. The ministers did many bad things arousing rebellions in several areas. The traffic management of the Tongji Canal was cut off by the local government from time to time. After "the Jingkang National Shame of the Song Dynasty", the Jin Kingdom took up the Huanghe River valley, and the Song's government withdrew to south. The whole country became two parties of the Southern and the Northern, and the two became enemy. The Tongji Canal water transport was stopped. The Jin Kingdom was only to loot the wealth of the central plain. They did not dredge the canal. Additionally, when the war broke out, dam of the Huanghe River was usually broken to resist enemy, and it cause the Huanghe River water flooding. After 1194 A.D., the Huanghe River was breached at Yangwu, the water went down south, taking up the channel of the Sihe River to flow into the Huaihe River, and into the sea, more than 600 years. The event caused the Tongji Canal silting up chronically, and the riverbed was heightened up several meters. The Tongji Canal was discarded. Later, the Yuan Dynasty established capital in Beijing, but they had no mind to lead the Huanghe River to return the past way. It made Tongji Canal thoroughly lose the chance of development.

3.3 Economic Reasons for Canal Disuse

The middle-lower reach of the Huanghe River in North China is "the Cradle of Chinese National Cultures", there was once the richest area in China. Due to "the Betray of An Lu-shan and Shi Si-ming", the frequent wars, and setting up a separatist regime by local force of arms, the economy of the Huanghe River area was seriously damaged. On the contrary, the south of China was relatively stable. Emperor Zhao Gou of the Southern Dynasty adopted a series of positive measures to develop the economy in order to solidify his power. As a result, the Tongji Canal's importance, which transported sup-

plies from south to north for the capital, was weakened, and finally disappeared. It is another reason that Tongji Canal was abandoned. So far, Tongji Canal finished its historical duty.

4 CONCLUSIONS

The Tongji Grand Canal was one-time design, one-time building, and one-time opening to navigation, which showed high scientific level in investigating and measuring route line, controlling water quantity, and making use of natural and artificial waterway. It also indicated great creative power of Chinese people. Of course, we could not obliterate Emperor Suiyang's contribution to this great project at that time.

A number of cultural remains prove what Tongji Grand Canal ever promoted economic development and social culture exchange in the Sui, Tang, Northern Song and Southern Song dynasties. As the limitations of people's knowledge at that era, it was inevitably influenced by natural conditions, especially, mud and sand depositing from the Huanghe River. When change of natural environment and renew of the historical dynasty, involving many factors such as nature, society, economy, politics etc., the Tongji Grand Canal was abandoned inevitably in history. The old channel was changed into highway. Although the highway sequentially plays traffic function, great change has taken place in all aspect of the society, whose status in transportation and economy could not compare to its vigorous water transportation in the past. Those show that the process of mankind development constantly depends on natural environment. In this process, the human being has been creating some things and also abandoning some things, without ceasing. All these are the witness of the history of the mankind development, and also are base of studying civilization of the mankind themselves.

We should point out what we do not discuss geologic tectonic function in the evolution of the Tongji Grand Canal. In fact, we have noticed physical function to canal's migration, such as their evolution relationship of Jiang- Huai Grand Canal (from Chaohu Lake to the Huaihe River) with Tongji Canal, as well as Jing- Hang Grand Canal (from Hangzhou City to Beijing City). We are preparing to research the tectonic function.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of K C Wang Education Foundation, Hong Kong, and greatly thank Mr. Daniel Routh's help for my paper.

REFERENCES

BORENGASSER M X, TARANNIK T V, 1988. Structural geology and regional tectonics of the mineral county area, Nevada, using shuttle imaging radar-b and digital aeromagnetic data [J]. Int. J. Remote Sensing, 9(5): 967- 980.

DCTAAP (Department of Cultural Treasures and Archaeology in Anhui Province), 2002. Report of Liuzi Site [M]. Beijing: Science Press. (in Chinese)

EVANS D L, FARRR T G, VAN J J et al., 1992. Estimates of surface roughness derived from synthetic aperture radar (SAR) data [J]. IEEE Transactions on Geoscience and Remote Sensing, 30 (2): 382- 388.

GUO Hua-dong, LIU Hao, WANG Xin-yuan et al., 2000. Subsurface old drainage detection and paleo-environment analysis using spaceborne radar images in Alashan Plateau [J]. Science in China (D), 43(4): 439- 448.

JI He, 1990. Study on the reason of Tongjiqu abandon [J]. Study on Cultural Treasures, (10): 287- 291. (in Chinese)

LIU Xu, 2000. Old Book of Tang Dynasty (Volume 123) [M]. Beijing: China Book Department. (in Chinese)

SIMA Guang, 2000. Zi Zhi Tong Jian (Volume 292) [M]. Beijing: Yanshan Publishing Company. (in Chinese)

ULABY F T, MOORE R K, FUNG A K, 1981. Microwave Remote Sensing (Volume1: Fundamental Remote Sensing) [M]. Massachusetts: Addison-Wesley Publishing Company,

WANG Chao, GUO Hua-dong, ZHANG Yun-he,1991. Radar Imagery for structural analysis in Bayinnorgong Region, North China [A]. In: GUO Hua-dong (ed.). SAR Image Analysis and Its Geological Application [C]. Beijing: Science Press, 103- 107. (in Chinese)

WANG Xin-yuan, FAN Xiang-tao, LIU Hao et al., 2001. Analysis of radar wave back scatter coefficient for fractal feature of roughness surface of Gobi in North-easten Ejin Qi, Inner Mongolia [J]. Journal of Soil and Water Conservation, 15(3): 116- 119.(in Chinese)

XIA Cong-qi, 1980. A History of Song Dynasty [M]. Beijing: China Book Department. (in Chinese)

ZHENG Zhao-jing, 1939. History of China Water Conservancy [M]. Beijing: The Commercial House. (in Chinese)

ZU Ke-zhen, 1973. Elementary Study of Late 5000 Years Climate in China [J]. China Science, (2): 168- 189. (in Chinese)