

# Mapping a paleodrainage system of the Keriya River using remote sensing data and historical materials

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**ABSTRACT:** Deformation and changes of the Keriya River, one of the ancient Four Green Corridors which through the Taklimakan Desert from south to north in the Tarim Basin, recording the changes of climate-environment and the ancient Silk Road of the region. According to the archaeological data, historical materials and paleoclimates information, its eco-environment and climate have taken great changes since the 1.09Ma B.P, especially during the recent 2000 years, which lead to many famous ancient cities having been abandoned and the south route of the Silk Road has been moved southward. This study illustrates the capability of the remote sensing data (radar data, topographic data and optical images) and historical materials, in mapping the ancient drainage networks. We mapped a major paleodrainage system of Keriya River, which have linked the Kunlun Mountains (south route of the Silk Road) to the Tianshan Mountains (middle route) through the Taklimakan Desert, possibly as far back as the early Pleistocene. The Keriya River will have important implications for not only the understanding of the paleoenvironments and paleoclimates of Tarim Basin from the early Pleistocene to the Holocene, but also the changes of the Silk Road.

**Key words:** remote sensing data, historical materials, paleochannel, Keriya, Tarim Basin, Silk Road

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## 1 INTRODUCTION

The ancient green corridor of Keriya River is one of the four green corridors which have linked the Kunlun Mountains to the Tianshan Mountains through the Taklimakan Desert and has important significance in the agriculture, culture, ecosystem, transportation, politics, and economy. While this region is now hyper arid, remains of paleoriver systems (both erosional and depositional features) have been detected using remote sensing imagery, leading some authors to propose paleodrainage pathways between south route of the Silk Road and the middle route (Zhou, 1990; Bi & Wang, 2007; Shao & Gong, 2011; Guo et al., 2000; Gao et al., 2012; Li

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W P et al., 2000). Until now, however, detection and reconstruction of paleodrainage systems has been hampered by the sand dunes in the region.

The study area is part of a large flat and quicksandy region in middle Tarim Basin (Fig.1). The region has been famous as the Silk Road because it is a main artery of the intercommunication between the Oriental and the Occident and the living fossil of the interaction of human beings. The present Keriya River is more than 800 km long, which starts with two main tributaries (north-eastern Kulap and western Wugeyeke) that connect in the Kangsulake initial Oasis region. The river system then flows north through the piedmont of the Kunlun Mountains, and forms a large aggraded valley plain and oasis in Yutian. The Daliyaboyi Oasis in the lower reach of the present Keriya River is located in the middle of the Taklimakan Desert. The paleochannel of the lower reach of the ancient Keriya River, more than 600 km, was buried by the quicksand. The sand dunes of the extensive sand seas preclude detailed reconstruction of any possible connection to the Tarim River in the optical images, but a 600 km-long link to the Tarim River through the north of the Taklimakan Desert paleochannel is truth according to the radar data, as well as the ancient maps.

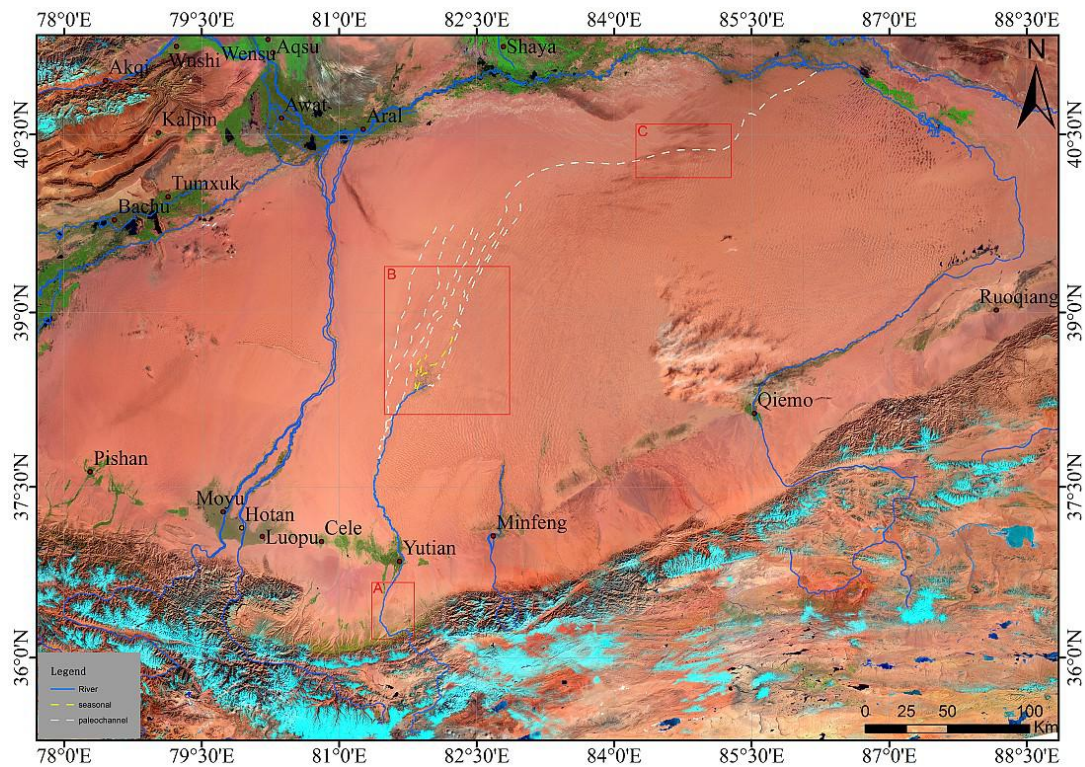


**Fig.1** Overview of the study area and Landsat TM color composition (bands 7, 4, 2) images

Previous studies undertaken in Taklimakan Desert region, revealed that optical images(Landsat MSS) were of great success for the fuzzy recognition of paleochannels in areas characterized by the difference of the material spectral, which are barely seen using other remote sensing products and the ancient maps, mainly those required a great deal of man power and specific knowledge and skills. However, the analysis of radar (SIR-C) and digital elevation data (SRTM) from a sanded area indicated a myriad of paleochannels not detected using only optical images. The ancient maps and historical records are the important information, for instance Sven Hedin found the Kelaton ancient city under the help of the *Great Tang Records on the Western Regions*(Xuan, 646).

The Keriya River, a mega-paleodrainage originating in the Kunlun Mountains was flowing northward to the

Tarim Basin. The present work has the main goal of testing remote sensing data and historical materials in order to characterize these paleochannels and potentially use them to better reconstruct the latest geological history of Tarim Basin. In addition, contrasting the results from radar and topographic data might help to decipher why these features could not be recognized with basis on the optical data, while in other sanded locations of Tarim Basin these data were successful for mapping of paleochannels in immediately adjacent areas. The paleodrainage system of the Keriya River is the basis fluvial features and recording the changes of climate-environment of this region, and playing an important role in studying the changes of Silk Road.

## **2 Data and Methodology**

### **2.1 Topographic data**

The SRTM radar topographic data (<http://earthexplorer.usgs.gov/>) were obtained on a near-global scale, to generate the first and most complete high-resolution digital topographic database of the Earth. The data was obtained using the C and X bands, but only the C-band products, at 3 arcsec (~90m at the equator) spatial resolution, are freely available, thus they were used for this study. The SRTM uses the C-band wavelength to penetrate dry sand and portray the near-surface topography (Robinson et al., 2006; Ghoneim and El-Baz, 2007). The SRTM data were principally used in topographic analysis of the study area, to delineate the drainage network of the Keriya River system. The process involved constructing a mosaic from the SRTM to cover the basin area, followed by surface runoff routing based on the 8-cell neighborhood (D8) approach (Jensen and Domingue, 1988).

The SRTM-90m data were preprocessed to improve information potential and to allow morphometric analyses. The applied modifications were pixel thinning (from 3" to 1") after removal of data failures, with a slight smoothing directed to a reduction of artifacts and distribution of the spatial randomness according to procedures detailed by Valeriano *et al.* (2006), in order to highlight the topographic and morphologic features of interest for this study.

### **2.2 Optical images**

The multispectral Landsat ETM+ images with 15m pixel resolution available from the United State Geological Survey (<http://earthexplorer.usgs.gov/>) are used for visual interpretation of the narrow paleochannels and surface features in the study area. Landsat images have provided the basis for mapping of the paleochannels in the Tarim Basin, where the morphological aspects of the buried features can be exceptionally observed due to its physiographic nature dominated by water and vegetation.

Water is the key element for formation and survival of the ancient populus and tamarix spp. can be taken as indicators for distribution of groundwater and ancient stream courses in the Taklimakan Desert. The change of the Keriya River (drawdown of groundwater level) seriously impacts the growth of the desert plants growing in the zones between the watersheds, even lead to withering and death of the forests of populus euphratica growing along the river banks and the paleoriver channels. Wherever in the Taklimakan Desert water is available, there will be vegetation. Wherever in the Taklimakan Desert populus is available, there will be river banks and paleoriver channels. The present study extracts the possible paleochannels according to the ETM+ image

interpretation experience in the desert region.

### 2.3 Radar images

Spaceborne Imaging Radar-C (SIR-C), the first multi-spectral and multi-polarization SIR-C/X-SAR data between latitudes 57°N and 57°S, is part of an imaging radar system that was flown on board two Space Shuttle flights (9 - 20 April, 1994 and 30 September - 11 October, 1994). Many examples of subsurface imaging of fluvial channels followed (e.g., McCauley et al., 1982; Berlin et al., 1986; Stern and Abdelsalam, 1996; Robinson et al., 2000; Craddock et al., 2010), as well as examples of dikes buried as much as 2 m beneath alluvium in the Mojave desert, California (Blom et al., 1984). The high-resolution SIR-C images, 23.5 cm multiple polarized L-band with 25m pixel spacing, were used for this paper.

Penetration of the radar waves becomes possible if the dry surface cover material is fine grained (less than one-fifth of the imaging wavelength) and physically homogeneous. This allows the radar signal to penetrate dry sand without significant attenuation (Roth and Elachi, 1975) up to depths of approximately 2-5 m in the case of L-band radar (McCauley et al., 1982). Smooth deposits would appear dark owing to specular reflection of the radar wave away from the receiving antenna, whereas coarse deposits or rock surfaces would appear bright because of diffuse reflection (Jensen, 2000). The data processing started with image geo-referencing and transformation. All the SIR-C images were preprocessed while minimizing any loss in dynamic contrast by applying as few adjustments as possible. The Enhanced Frost Filter (Lopes et al., 1990) was applied to the data with 3×3 pixel size windows to reduce the speckle effect and enhance visual interpretation of the radar images.

### 2.4 Historical materials

The ancient Chinese civilization—one of the world’s earliest—composed and preserved a large number of historical materials on the Western Regions from Han to Qing Dynasty. These materials are widely used in the research of paleogeography, paleogeology, paleoclimatology, paleoecology and archaeology nowadays. These materials, which were abstracted as maps and digitized in the used ESRI ARC-INFO software v.10, has been employed for generating the digital ancient maps in the present study. The historical materials (Table 1), such as historical records (HR), ancient maps (AM), academic and literary writings (ALW) are used in this study to validate and supply the results derived from the remote sensing data.

**Table 1** The list of the historical materials in this study

| Name                                             | Type   | Author                                           | Dynasty       |
|--------------------------------------------------|--------|--------------------------------------------------|---------------|
| <i>Book of Early Han</i>                         | HR     | Ban Gu (32-92 AD)                                | Eastern Han   |
| <i>New Book of Tang</i>                          |        | Song Qi (998-1061)&<br>OU Yangxiu (1007-1073 AD) | Northern Song |
| <i>Records of Rivers</i>                         |        | Li Daoyuan (469-527 AD)                          | Northern Wei  |
| <i>Great Tang Records on the Western Regions</i> | ALW    | Xuan Zang (602-664 AD)                           | Tang          |
| <i>Records of Rivers in the Western Regions</i>  | AM&ALW | Xu Song (1781-1848 AD)                           | Qing          |
| <i>Han Xiyu Tukao</i>                            |        | Li Guangting (1812-1880 AD)                      | Qing          |

### 3 Result

SRTM data were able to furnish a subtle view of the paleochannels that occur on sanded terrains adjacent to this study area, as documented on previous studies; they were totally effective to reveal these features in the Sahara and Simpson Desert. Based on the SRTM-derived drainage system, the upper reaches of the Keriya River had a good view of the subsurface channels. However, this area, located at the Taklimakan Desert, shows an abundance of morphological features related to a paleodrainage system that can be recognized, with lesser or higher precision, using other radar and optical products.

As is evident from the historical materials (Ban, 1962; Song and OU, 1975; Li D Y, 1958; Xu, 1823; Li G T, 1870), the Keriya was a massive river system with the densest populus euphratica forest in some regions, particularly in its middle reaches. Pan et al. (2008) have even indicated the presence of large paleolakes systems in its reaches that located at the middle of Tarim Basin. The Keriya Paleobasin spanned about six degrees of latitude, through the Taklimakan Desert. The paleodrainage system of the ancient Keriya River has three major branches from desert to the west, north and east in the lower reaches (Fig.1). The three largest branches (north-western, northern and north-eastern) together constituted more than one half of the basin area. They branched at the Daliyaboyi Oasis, which is well known today for its beauty and Kerian.

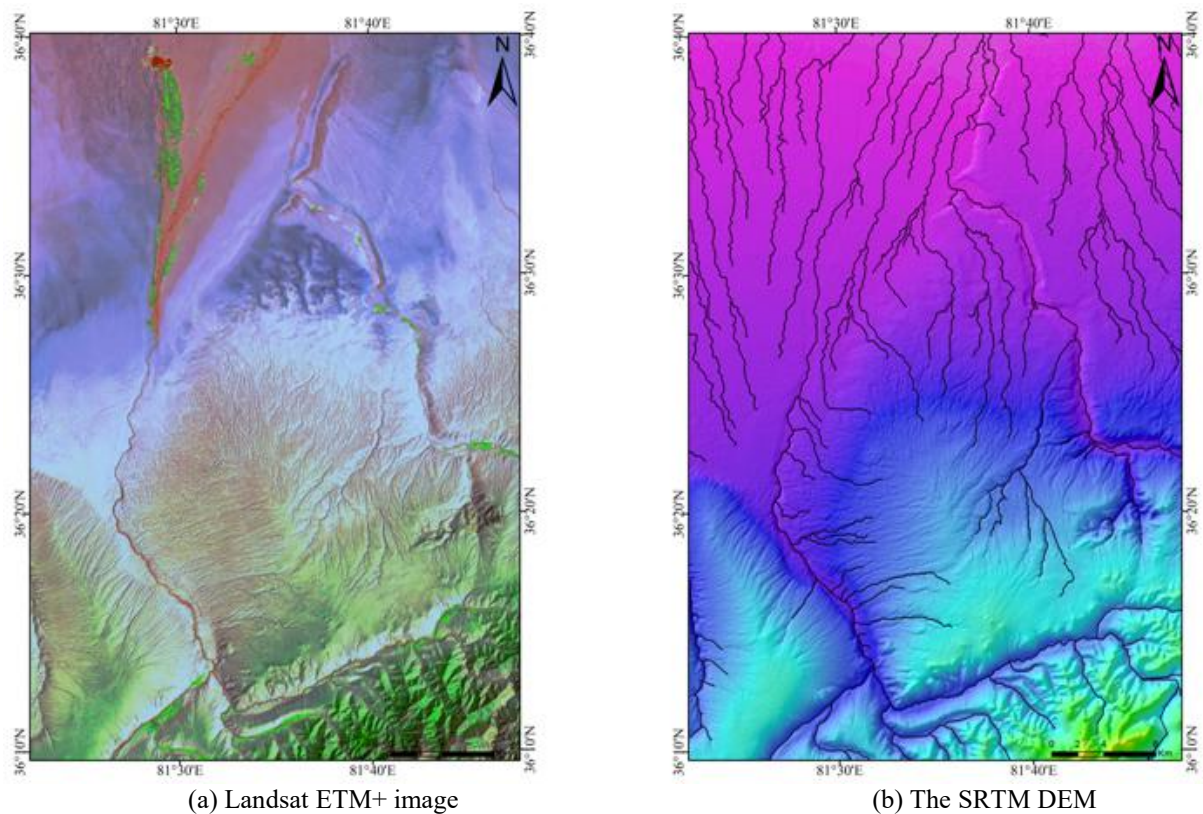


**Fig.2** (a) covering an area in upper reaches of the Keriya River showing the dominance of surface sand deposits, (b) SRTM-generated channels. (see inside A-box in Fig.1 for location)

The majority of the paleochannels in the study area was more promptly recognized using optical images. Hence, these features could be easily observed on Landsat images (Fig.3), particularly using a R(7)G(4)B(2). The image resulting from this procedure provided an excellent view of the paleochannels, which are highlighted in contrasting light colors with respect to the areas surrounding them. It is interesting to note that three series of the paleochannels, eastern, northern and western, were delineated from the Landsat composition images (Fig.3).

Hedin (1899) investigated the Taklimakan Desert in 1897; there were two main channels in Daliyaboyi. In some years the Keriya River flowed through the eastern channel, and in other years this river took the western channel. At that time the river course was quite long and water flowed to 100 km north of the Daliyaboyi.

Trough the observation of the result derived from the Landsat composition images, this study proposes that stream capture of Niya Paleoriver channel by the eastern branch of the Keriya paleoriver (Fig.3), and the western paleochannel flowed into the Khotan paleoriver then northward into the Tarim River (Fig.1). The geomorphology indicates that the Keriya River did not flow straight from south to north while it flowed into the Tarim river, but eastward and then into the Tarim River (Fig.1). The eastern channel, more than 600 km, is the latest paleochannel of the Keriya River. Historical materials (Xu, 1823; Li G T,1870; Stein, 1921) and  $^{14}\text{C}$  radiocarbon dating materials show that the eastern branch of the Keriya paleoriver flowed through the northern Taklimakan Desert into the Tarim River at about 400 B.P(Zhou, 1990).

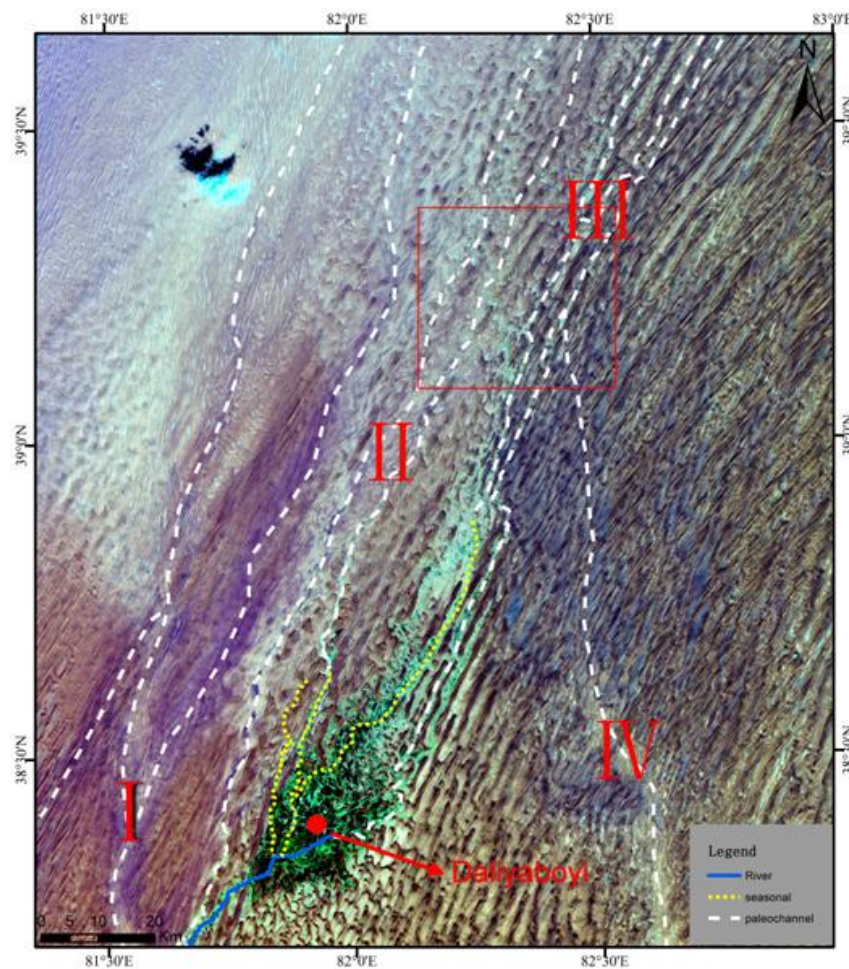
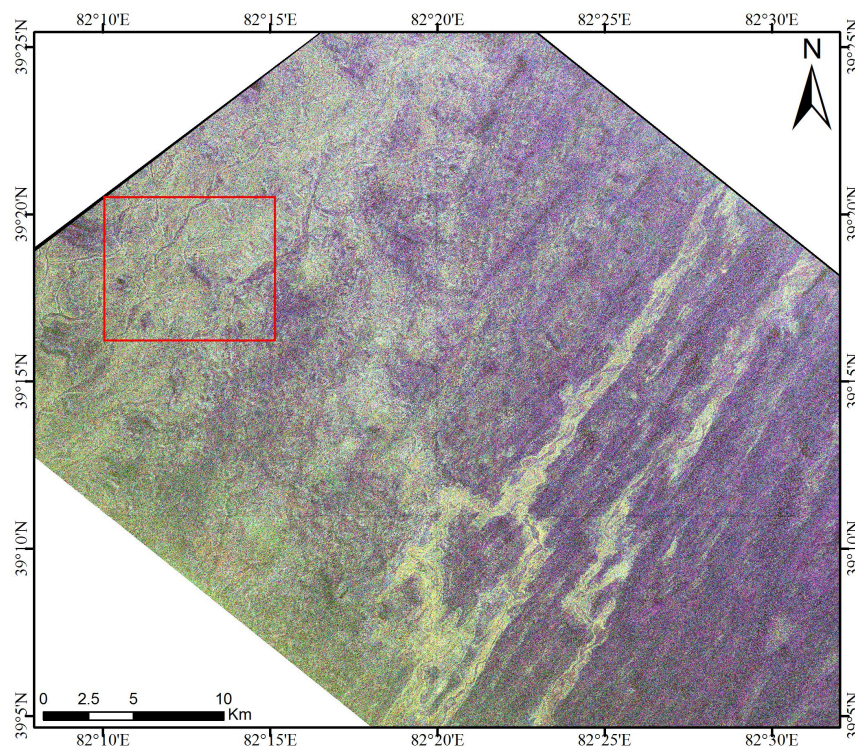


**Fig.3** Landsat ETM+ R (7) G (4) B (2) compositions, see inside B-box in Fig.1 for location, with paleochannels highlighted by brighter colors. (I-western branch, II-northern branch, III-eastern branch, IV-paleochannels of the Niya River)

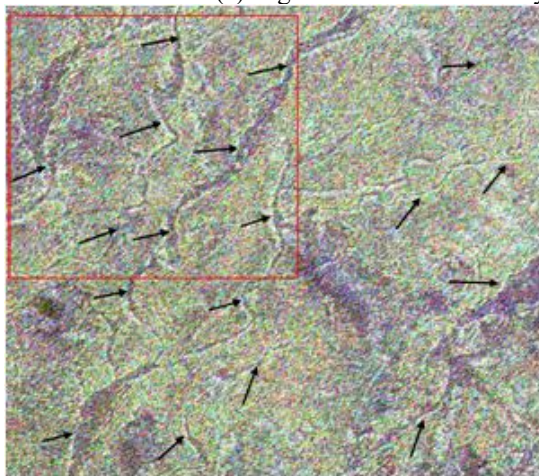
Because of the subsurface imaging ability of radar in desert regions, the Spaceborne Imaging Radar (SIR-C) L-band data were registered to a Landsat Thematic Mapper (TM) mosaic covering the study area (Fig.3). This enabled the mapping of paleodrainage channels (hence, ancient topography or paleoenvironments) of now dry and sand-buried courses of rivers and streams. The high-resolution (25m) SIR-C L-band images reveal that fluvial features in the Taklimakan Desert are closely linked to voluminous accumulations of sand (Fig.3). This

includes the high sand dune concentrations in the middle of the Tarim Basin, where three major paleochannels lead from the Daliyaboyi Oasis northward toward the Hotan and Tarim River through the densest concentration of dunes (Fig.4).

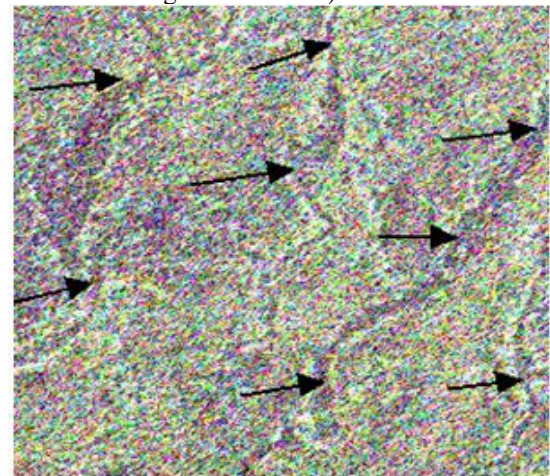
The SIR-C 25m image did not detect the paleochannels mapped with basis on ETM+ data, but it provided, in general, a good view of several other paleochannels in the study area (Fig.4.a,b). However, the paleochannel contours were not entirely satisfactory to generate a precise map, and the tracing of many smaller size paleochannels was ambiguous. Likewise, the SIR-C-25m image failed to reveal all the paleochannels present in the study area, but where detected, the paleochannels could be delineate with great precision (Fig.4.c). Despite the fact that some paleochannels could not be recognized in these Radar products, it is interesting to note that channel continuity was best achieved in those areas where these features could be seen (Fig.4.b,c).



(a) A general view of the study area (see inside box in Fig.3 for location).



(b) A detail from the inside box in (a) for location.



(c) A detail from the inside box in (b) for location.

Fig.4 SIR-C 25m of the study area. Arrows locate the paleochannels.

The Tarim Basin has a long cultural history, which is best known through the Silk Road, which crossed the Tarim Basin from east to west and was one of the most important trade routes for many centuries (Le Coq 1928; Hedin 1936; Weggel 1985; Fülling 1999). Since the Chinese Han Dynasty around 2 000 years ago, goods have been exchanged between the Roman Empire and China. Although the Keriya River dries up in the Taklimakan Desert nowadays, the historical literature and geomorphological features provide a record of the changes of hydrology and landscapes. The zone along the old riverbeds can be interpreted as an oasis. Historical maps and literature show that the Keriya River flowed through the Taklimakan Desert into the Tarim River at about 2000 B.P. The same environmental conditions occurred in the sixteenth century and at the beginning of the nineteenth century (Yang 1991). These last two wet events are simultaneous with the global ice expansion of the Little Ice Age (Grove 1988).

The Keriya River called as Jiandeli River or Dadeli River in the *New Book of Tang*, and Pimochuan in *Great Tang Records on the Western Regions*, and Keridiya River in the *Records of Rivers in the Western Regions*. On the western side of the Daliyaboyi there are ruins of oases with dead populus stems now present (Yang 2001). Ancient channels indicate that the Keriya River flowed through this area, and even at the end of the nineteenth century there were a large number of dead Populus stems (Hedin 1899). On the terrace of the paleochannel there are a few ruins of human settlements that extend in an area 6 km north-south and 4 km east-west (Yang 2001). The most famous is the ancient town of Kelaton.

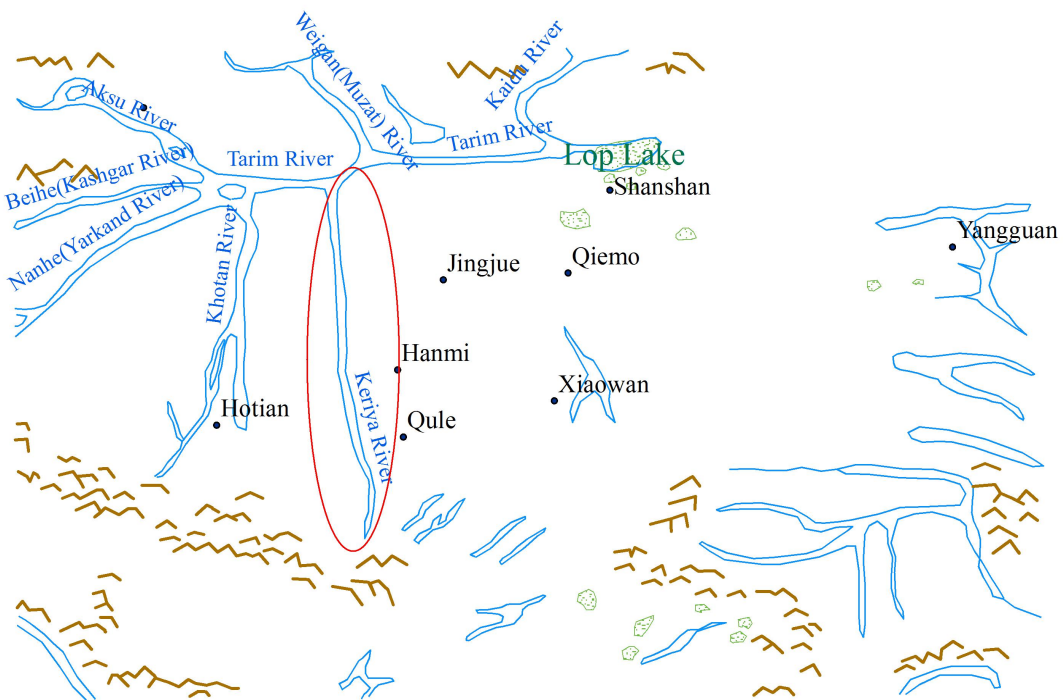


**Fig.5** Geographical location of the Keriya River in the Western Han Dynasty, recorded in the *Han Xiyutukao* according to the *Book of the Early Han*. (The red circle indicates the position of the Keriya River, which has been flowed into the Tarim River)

#### 4 Discussion and conclusion

The paleochannels of the Keriya River has been mapped here by integrating SIR-C scenes with SRTM data, Landsat ETM+ images and Historical Materials. With a length of at least 1500 km, the Keriya paleobasin is one

of the largest paleodrainage systems yet identified and mapped in the Taklimakan of Northwest China. In addition to delineating the former drainage patterns of the Keriya basin, this study might aid future exploration for groundwater and oil resources, and help to inform the Silk Road, archaeological, and paleoclimates research efforts in the study area.

Images derived from SRTM, SIR-C and ETM+ data reveal three series of the paleochannel in northern Daliyaboyi ancient oasis where it may have been connected to rivers in the Hotan River to the west, and the Tarim River to the north and east. Comparisons amongst several remote sensing products reveal that many paleochannels in the Taklimakan Desert are missed if only SRTM, SIR-C or ETM+ products are taking into account. These are good only for mapping of paleochannels displaying digital elevations higher than surrounding areas due to a slight increase in terrain topography, as demonstrated in a previous work based on field surveys. It has been proposed that many paleochannels in Keriya River basin show a slightly convex up morphology due to differential compaction on contrasting other sandy channel. Paleochannels that were abandoned more recently, did not have time to develop this positive relief due to the lack of burial compaction. Consequently, they are not recognized in digital elevation models.

The described features of the Keriya Paleobasin may offer significant opportunities for natural resource exploration. The Keriya valley acted as a conduit for surface water and also provided space for groundwater storage and recharge into the underlying Taklimakan Aquifer. Given that the modern annual precipitation of the region is only 30 mm (Zhang, 1987); modern recharge through surface inputs cannot be expected to take place in the lower reaches of the Keriya River. However, seasonal intense glacial and snow meltwater runoffs in the Kunlun Mountains could lead to considerable recharge through the buried channels of the Keriya Paleoriver. In addition, the deep depression of the Tarim Basin may hold considerable reservoirs of oil and natural gas at depth.

## REFERENCE

- Bi J T and Wang X X. 2007. Researches and application of geospatial technology to the history of the Silk Road. *Arid Land Geography*, 30(6):954-961
- Berlin G L, Tarabzouni M A, Al-Nasser A, Sheikho K M and Larson R W. 1986. SIR-B sub-surface imaging of a sand-buried landscape: Al Labbah Plateau, Saudi Arabia. *IEEE Transactions of Geosciences and Remote Sensing*, 28:595-602
- Blom R C, Crippen R E and Elachi C. 1984. Detection of subsurface features in SEASAT radar images of Means Valley, Mojave Desert, California. *Geology*, 12:346-349
- Ban G. 1958. Book of Early Han. Beijing: Zhonghua Book Company Press
- Craddock R A, Hutchinson M F and Stein A. 2010. Topographic data reveal a buried fluvial landscape in the Simpson Desert, Australia. *Australian Journal of Earth Sciences: An International Geoscience Journal of the Geological Society of Australia*, 57:141-149
- Fan Z L, Chen Y L and Wang Y J. 2006. Study on the Tarim River and Its Watercourse Evolution in Xinjiang: Recorded in the Records of Rovers. *Arid Zone Research*, 23(1):8-15
- Fülling A. 1999. Chinas Norden – Die Seidenstrasse. Bielefeld: Brackwede
- Guo H D, Liu H, Wang X Y, Shao Y and Sun Y. 2000. Paleodrainage detection and paleoenvironments analysis of subsurface with shuttle imaging radar data in Alaxa plateau. *Science China Earth Science*, 30(1):88-96
- Gao Z H, Shao Y, Gong H Z, Liu L and Yuan M H. 2012. Archaeological study on Qimo ancient city using SAR remote sensing data. *Synthetic Aperture Radar, 2012. EUSAR. 9th European Conference on*: 649-652
- Ghoneim E and El-Baz F. 2007. The application of radar topographic data to mapping of a mega-paleodrainage in the Eastern Sahara. *Journal of Arid Environments*, 69:658-675
- Grove JM (1988) The little ice age. Methuen, London
- Hedin S A. 1899. Durch Asiens Wuesten, Bds 1 & 2. Leipzig: Brockhaus, 496-512
- Hedin S A. 1936. Die Seidenstrasse. Leipzig: Brockhaus

- Jensen S K and Domingue J O.1988. Extracting topographic structure from digital elevation model data for geographic information system analysis. *Photogrammetric Engineering and Remote Sensing*, 54:1593–1600
- Jensen J R. 2000. Remote Sensing of the Environment: An Earth Resource Perspective. Englewood Cliffs, NJ : Prentice-Hall
- Li W P, Hao A B and Liu Z Y.2000. Research on groundwater exploitation prospect of the Tarim Basin. Beijing: Geology Press
- Lopes A, Touzi R and Nezry E.1990. Adaptive speckle filters and scene heterogeneity. *IEEE Transactions on Geosciences and Remote Sensing*, 28:992–1000
- Li D Y. 1958. Records of Rivers. Beijing: Business Press
- Li G T. 1870. Han Xiyu Tukao
- Le Coq A .1928. Die buddhistische Spätantike in Mittelasien. Berlin: Reimer
- McCauley J F, Schaber G G, Breed C S, Grolier M J, Haynes C V, Issawi B, Elachi C and Blom R. 1982. Subsurface valleys and geoarchaeology of the Eastern Sahara revealed by Shuttle Radar. *Science*, 218:1004–1020
- Nie H F. 1991. Watercourse features and distribution of the lower reaches of the Keriya River. In: Report about the scientific exploration and investigation of the Keriya River and the Taklimakan Desert. Beijing: China Science and Technology Press, 22-26.
- Pan Y B, Li D P, Guo F F, He Z F, Pei J L, Liu J, Zhao Y. Geomorphological features of the Keriya River valley and the early-middle Pleistocene great lake of the Tarim basin. *Geological Bulletin of China*, 27(6): 814—822
- Robinson C , El-Baz F, Ozdogan M, Ledwith M, Blanco D, Oakley S and Inzana J. 2000. Use of radar data to delineate palaeodrainage flow directions in the Selima Sand Sheet, Eastern Sahara. *Photogrammetric Engineering and Remote Sensing*, 66:745 – 753
- Roth L E and Elachi C.1975. Coherent electromagnetic losses by scattering from volume inhomogeneities. *IEEE Transactions of the Antennas and Propagation*, 23:674–675
- Robinson C A, El-Baz F, Al-Saud T S M and Jeon S B. 2006. Use of radar data to delineate palaeodrainage leading to the Kufra oasis in the eastern Sahara. *Journal of African Earth Sciences*, 44:229–240
- Stern R J and Abdelsalam M G.1996. The origin of the great bend of the Nile from SIR-C/X-SAR imagery. *Science*, 274:1696–1698
- Song Q and Ou Y X. 1975. New Book of Tang. Beijing: Zhonghua Book Company Press.
- Stein M A. 1921. Detailed report of explorations in Central Asia and westernmost China. London: Oxford. Clarendon Press. Reprint: Delhi. Motilal Banarsidass. 1980
- Valeriano M M, Kuplich T M, Storino M, Amaral B D, Mendes J N and Lima D. 2006. Modeling small watersheds in Brazilian Amazônia with SRTM-90m data. *Computers and Geosciences*, 32:1169-1181.
- Weggel O. 1985. Xinjiang–Das zentralasiatische China: Eine Landeskunde. Hamburg: Institut für Asienkunde.
- Xuan Z. 646. Great Tang Records on the Western Regions
- Xu S. 1823. Records of Rivers in the Western Regions (Vol. 1)
- Yang X (1991) Geomorphologische Untersuchungen in Trockenraeumen NW-Chinas unter besonderer Beruecksichtigung von Badanjinlin and Takelamagan. *Gott Geog Abh* 96:1-124
- Yang X.2001.The oases along the Keriya River in the Taklimakan Desert, China, and their evolution since the end of the last glaciations. *Environmental Geology*,41: 314-320
- Zhou X J. 1990.Textual Research on the Matter of the Keriya River Flowed into the Tarim River. In: Report about the Scientific Exploration and Investigation of the Keriya River and the Taklimakan Desert. Beijing: China Science and Technology Press, 40-46
- Zhang J B and Deng Z F. 1987. Introduction of Xinjiang Precipitation. Beijing: China Meteorology Press
- Shao Y and Gong H Z. 2011. Primary interpretation on shorelines of vanished Lop Nur Lake using multi-source SAR data. *Journal of Remote Sensing*, 15(3): 645–650