Hydrogeological Survey and Satellite Remote Sensing in the Dunhuang Area

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Abstract: Mogao Grottos are located at the eastern foot of the Mingsha Mountain, 25km southeast of Dunhuang City. The caves were excavated into the cliff on the west bank of the Daquan River. The wall paintings in the caves are subject to the severe deterioration generated by recrystallization of salt. It relates with the movement of water/moisture in rock formation. Through the satellite image analysis and geological survey, it has been clarified that the movement of ground water is governed by the fault system. The geographical nature is specified by the aggressive tectonic movement from the south.
Key words: Salt, Water, Remote Sensing, Fault.

1. Introduction

Dunhuang is located in 1900km west of Beijing as shown in Fig.1.The whole of Mogao Grottos (Fig.2) in 25km southeast of Dunhuang City is the world's largest stone cave monument. During 1000 years between 4th and 14th centuries, nearly 1000 caves had been excavated into the conglomerate cliff, and 492 caves are decorated with wall paintings and murals. They have been registered as the World Cultural Heritage since 1987.

There are few people who can be aware of the movement of ground water and moisture throughout rock formations. It happens even in arid region, and the case of the Great-Sphinx in Egypt was reported as a typical example by Tanimoto, et al.Groundwater can incredibly

Fig.1. Location of Dunhuang

Fig.2. Mogao Grottos

move in far distance, sometimes over several thousand kilometers through pores in solid rock, fissures, and faults. When groundwater, even moisture, moves along the same pass repeatedly over a long time, salt substance is transported one place to another, and evaporation accelerates the accumulation of salt. It happens behind many wall paintings in Mogao caves and generates the separation of painting.

2. Weather conditions

The average annual temperature is 11°and the average annual precipitation are about 23mm in this area. Rain fall is concentrated in summer namely from June to August, and summer rain occupies 58% in the annual amount. On the other hand, the amount of annual average evaporation amounts to 4347mm, and it is 187 times higher than the precipitation[1].

3. Geological environment

The Dunhuang basin is surrounded by Sanwei Mountain and Aerjin Mountain as shown in Fig.3, which are prolonged in the direction of southwest-northeast. Aerjin Fault Belt stretches over a length of 2000km along the shear-compression fault in the western of China[2]. Mogao Grottos were excavated in the

Quaternary conglomerate layers which had been formed by long-lasting frequent floods on the foundation rock. The foundation rock consists of two different strata. Namely, the Precambrian stratum was strongly thrusted over the Pleistocene by the aggressive tectonic movement. After the last Iceage time around 10,000~12,000 years ago, rivers such as Shule, Yulin, and Dang repeatedly flowed into the Dunhuang basin from south to north, and the floods formed a 100~140m thick conglomerate layer. The geological profile of Mogao Area in the direction of East-West is as shown in Fig.4.

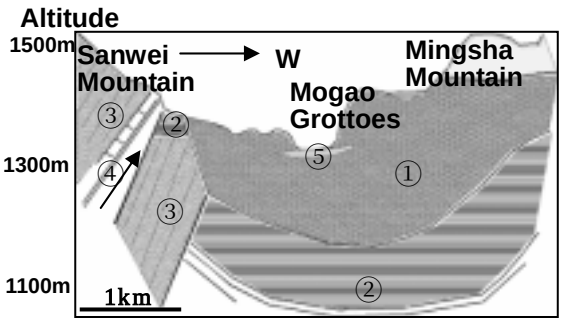

Fig.4. Geological Profile[3)]
① conglomerate, ②granite, ③schist, ④mylonite, ⑤Q_4-sediment

4. Remote Sensing

The OH^-clay mineral near 2.2μm and the carbonate mineral near 2.35μm show strong absorption respectively as their own characteristic wave length. According to the characteristics, clay mineral and carbonate mineral can be extracted. That is effective in finding mineral deposits. Exposed ground in arid and semi-arid areas can be applied this advantage. Because the Dunhuang basin is an arid region that has a few vegetation, it is a suitable area to grasp geological structure by remote sensing.

The data used in this study are obtained from Landsat5, and JERS-1. They are the Dunhuang and circumference observed in 1996 and 1997. In analysis, several combination of bands are chosen in order to emphasize difference in reflectance pattern of the rock. Next, they are put the creation of false color image and ratioing image into operation. Fig. 5 is a false color image (B:G:R=2:3:4) (B:G:R shows the band which assigns blue, green, and red) around Mogao Grottos. Fig.6 is a false color image (B:G:R=2:4:7) of Sanwei Mountain. Sanwei Mountain Fault and Guanyinjing Fault which affect the stability of Mogao can be shown clearly from Fig.6. As Sanwei Mountain Fault series, although Guanyinjing fault has branched with Sanwei Mountain fault, it touches Sanwei Mountain fault and inset the bottoms of the Mingsha Mountain foundation at the westernmost end. Moreover, we can know that some granite (blue) have intruded into Sanwei Mountain Palaeozoic stratum from Fig.6. In the north side of Sanwei Mountain, because the granite is cut off Sanwei Mountain Fault, it suggest us that the tectonic movement

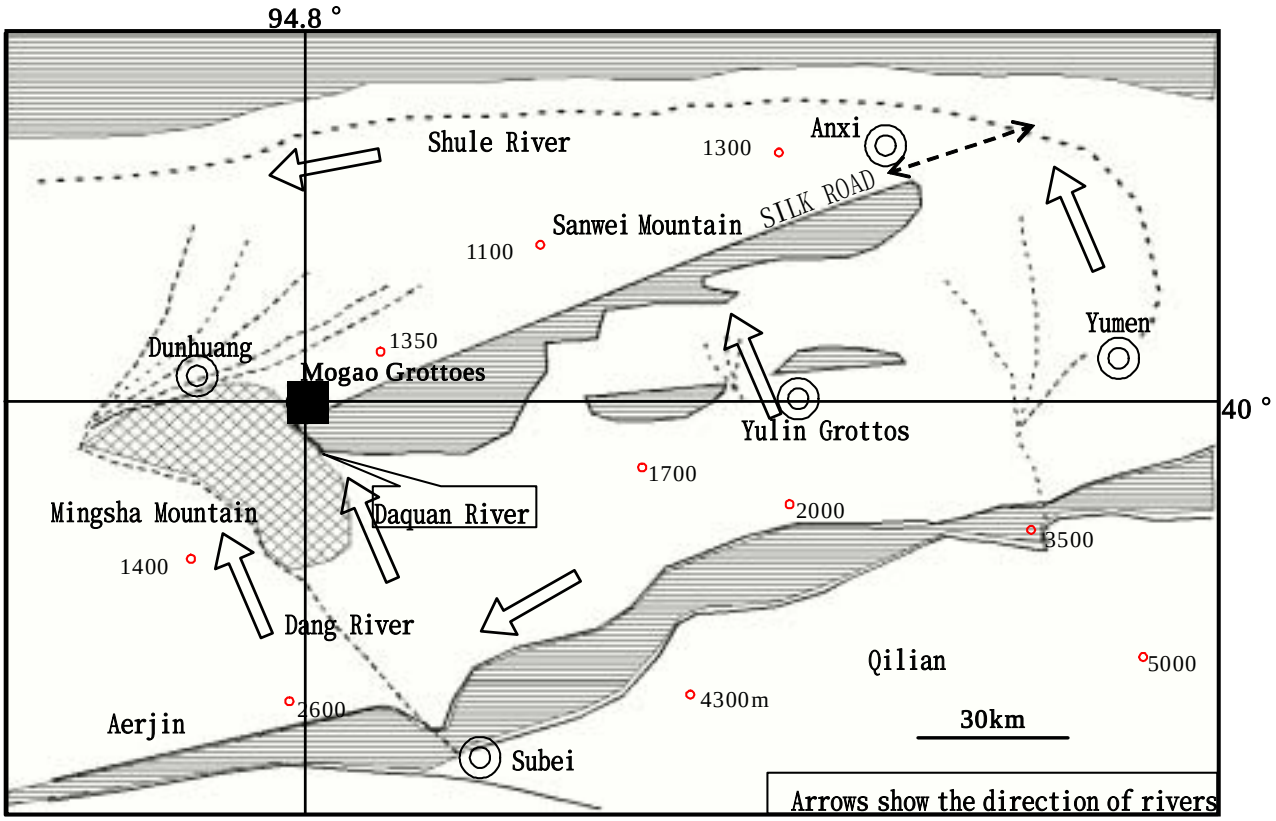

Fig.3 Topographical position of Mogao

which took place in Sanwei Mountain Area happened after the granite intrusion of granite had intruded. Through this image, Sanwei Mountain is presumed to have been formed in the following order as shown below.

1. Formation of metamorphic rock of Precambrian age as base rock,
2. Intrusion of granite,
3. Fault movement and its resultant crushing action,
4. Upheaval of the earth's crust,
5. Fault movement and its resultant crushing action,
6. Formation of conglomerate strata in Quaternary Period.

The Daquan River runs from south to north as a whole across the Sanwei Mountain Range whose average hight is approximately 1300~1500 meter from the sea level. The area is a part of the Qilian Mountain Range which has been subjected the heaviest tectonic movement in China. Therefore, there are two representative directions of major faults clearly showing aggressive thrusting namely the directions of northeast-southwest and east-west. They form a typical network showing two sets of parallel faults. Looking at the flow path of the Daquan River in detail, the river changes its flow direction at many intersecting points of parallel faults in two directions. The base rock (gneiss) has been crushed heavily and turned in anti-clockwise. Large dislocation can be easily observed in the strike direction.Fig.7 shows the distribution of DN value (concentration value) which was obtained with the Band 1 of JERS-1. Three features can be observed along the Daquan River such that the weathered stratum, the vegetation and the metamorphic belt are shown by light blue, red, and yellow, respectively. The blue color shows the path of the river.

8. Discussions and Conclusions

We conclude as follows:

1. The Dunhuang basin originates in intense structure movement ranging from the Paleozoic to a long period of time as an alteration zone, showing fault, fold, and joint. The rock formations contain well developed fissures. The formation of Daquan River, which affects Mogao Grottos, is governed by the faulting and jointing by tectonic movement.
2. The result of the false color image and ratioing by focusing onto the reflectance pattern of rocks shows a good agreement with the results obtained by our geological survey.
3. Based on the geological observation over the wide area by remote sensing, it is clearly shown that a flow in two directions leads groundwater to the Mogao Grottos. The circumstance of the Mogao Grottos has been obviously affected by groundwater and high moisture content.

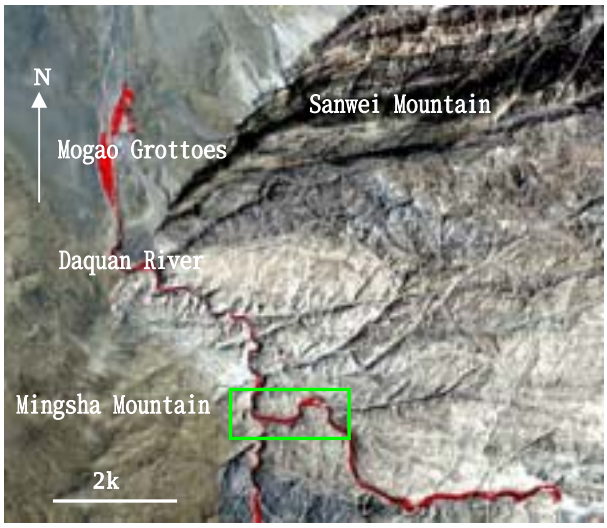

Fig.5. Satellite Image through Landsat5 (Band B:G:R=2:3:4,Green Area: enlarge in Fig.7)

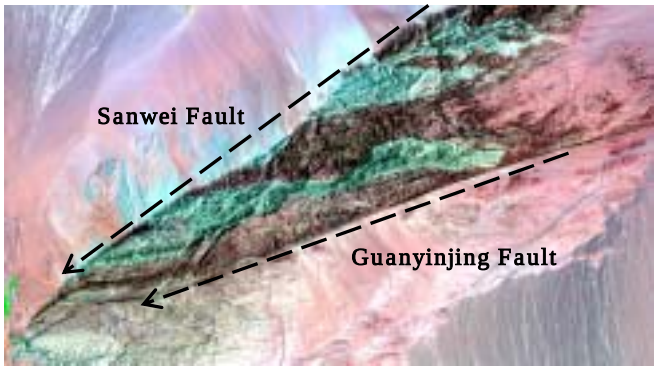

Fig.6. Landsat5 TM Image (Band B:G:R=2:4:7)

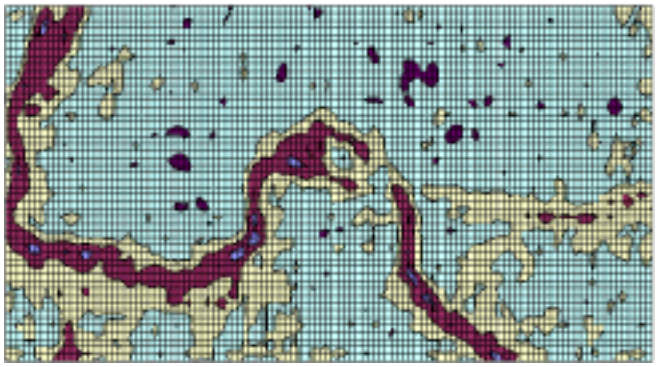

Fig.7. Daquan River through JERS-1

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