Formation Lithology Identification Technology along Railway in Complex and Dangerous Mountainous Area Based on Hyperspectral

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Abstract. In view of the difficulties during implementation of conventional survey methods for railway projects in complex and dangerous mountainous areas, the section from Maoxian to Songpan in Chengdu-Lanzhou Railway with complex terrain and bad climate is selected as the research area to extract hyperspectral remote sensing technology content of the research area. Based on the research of indoor hyperspectral image processing, outdoor rock sample collection and indoor spectrum analysis, establish a suitable feature extraction and lithologic recognition classification method according to the unique spectrum integration feature of hyperspectral remote sensing image. Use the visible short wave infrared hyperspectral data of the latest domestic Gaofen-5 satellite, carry out the lithologic plotting experiment in the key areas of the section from Maoxian to Songpan in Chengdu-Lanzhou Railway, and make accuracy evaluation by selecting a certain way for the mapping results. It provides important thematic information for regional lithologic investigation, and provides strong technical support for selection, survey and design of Chengdu-Lanzhou Railway construction, which is helpful for similar projects.

1. Introduction

In the western mountainous areas of China, it is very difficult to implement conventional survey methods due to the harsh environment and extreme climate. Hyperspectral remote sensing technology can detect, identify, classify and analyze the ground objects through satellite images and professional data processing software. Hyperspectral remote sensing technology has its own advantages in essence. Compared with the traditional methods of remote sensing technology, hyperspectral remote sensing technology can achieve more accurate and convenient detection and identification in the western complex and dangerous mountain areas [1]. The advantages of hyperspectral remote sensing in lithologic identification and classification [2] largely meet the mapping accuracy requirements of thematic maps such as lithology classification maps, lithologic zoning maps and alteration information. Along with the development of social mass production and constant improvement of science and technology, the portable spectrometer and high-resolution spatial hyperspectral satellite which are gradually put into use promote the application of hyperspectral technology in the field of geology, which is conducive to the mapping work in lithologic identification, geological and mineral Investigation and other aspects through remote sensing technology [3].
The natural geographical environment of Western China is extremely poor, especially in the alpine and uninhabited mountainous areas. In addition, the unique landform of mountains and valleys and the conventional transportation mode and its long distance from the central and eastern regions of China make the conventional geological investigation and research quite difficult. In view of this situation, it is of epoch-making significance to find and research a type of accurate and convenient detection and identification technology for the western alpine and unmanned mountainous areas [4]. On the one hand, hyperspectral remote sensing can represent the geological entity and structural information. On the other hand, it can also detect the earth's surface or even some deep-seated areas to some extent. According to the natural geographical environment of the alpine mountain area, the stratum lithologic exposure is apparent, and there is little well-developed and dense vegetation, which creates favorable conditions for the lithologic identification of hyperspectral remote sensing in the western complex and dangerous mountain area [5].

Based on the fact that it is very difficult to carry out conventional survey methods for railway projects in complex and dangerous mountainous areas, the section from Maoxian to Songpan of Chengdu-Lanzhou Railway with complex topography and climate is selected as the research area. Carry out the lithologic mapping experiment and accuracy evaluation in the research area on the basis of the spectral indoor measurement and analysis of rock samples and according to infrared hyperspectral data, so as to provide important thematic information for regional lithologic survey and provide strong technical support for selection, survey and design of railway construction.

2. Overview of the research area
Chengdu-Lanzhou Railway is located in the eastern edge of the Qinghai-Tibet Plateau and in the urgent transition of alpine canyon area from the second step of China's terrain (ground elevation is 500-700m) to the first step of China's terrain (ground elevation is 3,000-5,600m). The railway crosses Longmen Mountain, Minshan Mountain, West Qinling Mountain and other mountains, and crosses Minjiang River, Bailong River and other major rivers. The terrain is high in the north and west and low in the south and east with strong terrain slicing, and the relative height difference is more than 1,000m. The railway overcomes the relative height difference among huge mountains and valleys several times, and the longitudinal slope forms the shape of "W".

The climate features of the research area (section from Maoxian to Songpan in Chengdu-Lanzhou Railway) are significantly different. The three-dimensional mountain climate is apparent with distinct dry and rainy seasons and large temperature difference. Along the railway, there is a transition from subtropical monsoon climate to plateau monsoon climate in alpine cold zone. Due to the rapid uplift of Longmen Mountain, climate change can be described as "four seasons in one mountain and different weathers in a long distance". The climate changes from hot and humid climate zone to cold plateau monsoon climate zone.

The strata in Maoxian are mainly Longmen Mountain and Barkam. The strata in Barkam are distributed in most areas of the county, accounting for more than 90% of the working area. There are mainly Triassic System, Permian System, Carboniferous System, Devonian System, Silurian System, Ordovician System, Cambrian System, etc. The strata in Longmen Mountain area are mainly Permian System, Carboniferous System, Sinian System and pre-Sinian System, and the igneous rocks are mainly granite distributed in the north of Qixingguan.

3. Spectral analysis of rock samples
In the research area, the rock samples are collected in the field. Obtain the spectral curves of the typical rocks collected from the complex and dangerous mountainous areas in the west of China (along the section from Maoxian to Songpan in Chengdu-Lanzhou Railway) through ASD spectrometer. Meanwhile, the spectral data are processed by ViewSpecPro and Envi software.

The rock spectral curves captured by ASD spectrometer show their specific characteristics in different spectral ranges. In this study, spectral curves of different rocks and samples of the same lithology are compared and analysed [6-8].
Through the spectral angle mapper (SAM) matching (processed in Envi5.3), the spectral curve of the rock samples collected outdoors is matched with the spectrum in the standard spectrum library, and a certain amount of spectrum with high matching degree is identified (Fig.1, Fig.2), and the accuracy of the outdoor sampling is identified and verified according to the types of outdoor rock samples and the known geological data (Table 1).

Table 1. Statistical table of spectral angle matching information of each lithology

| Serial number | Name                | Match spectrum name | Spectral angle score | Spectral library                        |
|---------------|---------------------|---------------------|----------------------|-----------------------------------------|
| Y4            | Phyllite            | Phyllite            | 0.717                | jhu_lib(meta_crs.sli)                   |
| Y2-3          | Phyllite            | Phyllite            | 0.717                | jhu_lib(meta_crs.sli)                   |
| Y7-2          | Phyllite            | Phyllite            | 0.519                | jhu_lib(meta_crs.sli)                   |
| Y7-2          | Phyllite            | Phyllite            | 0.519                | rock_jhu_becknic_2868.sli               |
| Y10-1         | Metasandstone       | quartz sio2         | 0.811                | rock_jhu_perkin_2101.sli                |
| Y10-2         | Metasandstone       | quartz sio2         | 0.902                | rock_jhu_perkin_2101.sli                |
| Y15-1         | slate               | Red slate           | 0.911                | rock_jhu_perkin_2101.sli                |
| Y14-1         | Metamorphic quartz  | pink quartzite      | 0.716                | rock_jhu_becknic_2868.sli               |
|               | Sandstone           |                     |                      |                                         |
| Y11-1         | Metasandstone       | Phyllite            | 0.496                | jhu_lib(meta_crs.sli)                   |
| Y16-1         | Carbonaceous slate  | Chiastolic           | 0.870                | rock_jhu_becknic_2844.sli               |

Fig.1 Spectrum matching map of phyllite (Normal spectrum)  
Fig.2 Spectrum matching map of metamorphic sandstone (Remove envelope)

Compare the lithologic spectral angle matching information in Table 1. The spectrum curves of phyllite (Y4), metasandstone (Y11-2), slate (Y15-1), metamorphosed quartz sandstone (Y14-1), metasandstone phyllite (Y11-1), carbonaceous slate (Y16-1), etc. are compared by spectral angle mapper matching, and it is found that except the advantages of the spectrum curves of samples collected outdoors in spectrum, other spectral features basically match the spectrum curve in the standard library. Meanwhile, the accuracy of outdoor sampling is verified.
4. Extraction and recognition of lithologic information from hyperspectral remote sensing data

4.1. Hyperspectral image preprocessing
Gaofen-5 satellite of China's high-resolution earth observation system was officially put into use on March 21, 2019. It is a satellite with the highest spectral resolution in China and the first full spectral hyperspectral satellite which realizes comprehensive observation of atmosphere and land in the world [9]. It can realize the integrated application of multiple observation data, pre-process the obtained image data, greatly help the later research and improve the accuracy of this study [10]. The specific preprocessing process is shown in Figure 3.

![Fig.3 Gaofen-5 hyperspectral data preprocessing process](image)

Gaofen-5 used in this study makes geometric correction of the preprocessed images with the RPC parameters and 30-meter DEM. Finally, the images are resampled by bilinear interpolation, and the geometric precision correction image with 30-meter resolution is obtained (Fig. 4).

![Fig.4 Gaofen-5 geometric correction result](image)

4.2. Selection of lithologic information extraction method
Extract features on hyperspectral data through MNF and PCA, and analyze the band under each extraction of features. It mainly includes the image eigenvalues, information amount and image noise of each principal component. The comparative analysis shows that compared with MNF, the dimensionality reduction speed of PCA is faster and the noise is less, while the dimensionality reduction of MNF is more nonlinear.

In conclusion, MNF method is better for dimensionality reduction of Gaofen-5 hyperspectral data. In the later processing, the dimensionality reduction data of MNF method will be selected for end member extraction.

4.3. Spectrum end member extraction
Due to the shadow of vegetation, snow and mountain in the image data in this study, we mask these areas to make the calculation more convenient and remove the interference [11]. PPI algorithm is a method based on human-computer interaction supervision, which can add the prior knowledge of
human brain to carry out end member extraction. In this paper, PPI method is selected for end member extraction experiment.

This study adopts MNF method for dimensionality reduction of the data, makes MNF transformation of the original data, then carries out PPI computation in ENVI.

The purity of each pixel in hyperspectral image data can be calculated by the end member extraction technology of pure pixel index. The higher the pure pixel index obtained, the more single the type of ground object contained in the associated pixel. When using the pure pixel index experiment, it is necessary to pay special attention to the above three parameters: band number, iteration times and threshold, and their values will directly affect extraction of the pure pixel index, and then affect the end member extraction. The pure pixel index extraction is shown in Figure 5.

Through N-dimensional visualization, select the end-member spectrum, match the spectrum of obtained end members with the laboratory test spectrum library, finally identify and establish the end member spectrum library in the research area (Fig. 6). According to the end member type of the matched spectrum, only phyllite, metasandstone and metamorphosed quartz sandstone are matched within the coverage of Gaofen-5 image in the research area.

![Fig.5 Image (left) and corresponding PPI image (right)](image)

![Fig.6 Study area end element spectrum](image)

4.4. Lithologic identification in the research area

4.4.1. Spectrum identification
This study selects the traditional spectrum matching method called spectral angle mapper (SAM). Because most of the rock spectral features are mainly distributed in the infrared band, and the features between 2000-2500nm can best reflect the spectral features of lithology, the visible light part differs greatly due to the influence of environment and weather[12], this study mainly selects the end member wave spectral curves of various rocks in 2000-2500nm band for matching, and the spectral curve is shown in Figure 6. It can be seen from the figure that there are many end member spectra in the same rock. The spectrum features differ due to different weathering degree of rocks.

4.4.2. Accuracy evaluation method
The process of accuracy evaluation is tedious and it requires a strict evaluation mode. In order to ensure the authenticity of accuracy evaluation results, the selection of evaluation indicators during evaluation shall follow the principles of dominance, operability and measurability. This study adopts the method of confusion matrix based on pixel for evaluation. Four indexes are selected to evaluate the accuracy, which are overall accuracy, user accuracy, producer accuracy and Kappa coefficient.

4.4.3. Lithologic matching and analysis
Carry out monolithologic matching based on ENVI5.3 spectral angle mapping module. Recognize and match phyllite, metasandstone, slate, metamorphosed quartz sandstone and metasandstone phyllite. Through many tests, obtain the appropriate matching angle threshold of each rock. Due to the lithologic difference, the selection method of threshold is set up many times, and the matching results are analyzed with the outdoor sampling data and the geological map of the research area to finally determine the matching angle threshold of each rock: except that the maximum spectral angle of #17
metamorphosed quartz sandstone is 0.04, the maximum spectral angle of other rocks is 0.05. The lithologic mapping of the research area is realized with the spectral angle mapping, as shown in Figure 7.

According to the results of spectral angle identification, the same rocks can be combined to obtain the hyperspectral remote sensing lithologic identification information distribution map of Gaofen-5 in the research area, as shown in Figure 8.

4.4.4. Accuracy evaluation of matching results
Take 1:200000 geological map data (Maowenfu and Songpanfu) for reference, extract each lithologic interesting area as the reference data for accuracy evaluation according to the data of sample points collected outdoors, and evaluate the accuracy of hyperspectral remote sensing lithologic identification by confusion matrix analysis [13].

According to the analysis of confusion matrix (Table 2), the overall accuracy based on SAM mapping of Gaofen-5 hyperspectral image in the research area is 86.758%, and kappa coefficient is 0.8038. In terms of the classification effect of each lithology, the producer precision of metamorphosed quartz sandstone, quartz sandstone and phyllite are 81.82%, 86.23% and 90.75% respectively, of which the classification accuracy of phyllite is the highest. It can be seen from the image that the discrimination of phyllite is more apparent than other rocks.

| /                  | Metamorphic quartz sandstone | Metasandstone | Phyllite | User accuracy |
|--------------------|------------------------------|---------------|----------|---------------|
| Metamorphic quartz sandstone | 126                          | 1             | 0        | 99.21%        |
| Metasandstone      | 0                            | 238           | 8        | 96.75%        |
| Phyllite            | 2                            | 25            | 206      | 88.41%        |

Producer’s accuracy = 81.82% 86.23% 90.75% /

Overall accuracy = 86.758%  Kappa coefficient = 0.8038

5. Conclusion
The hyperspectral remote sensing image of Gaofen-5 contains a lot of information, which can be applied in geology, ecology, hydrology, etc. The successful application of hyperspectral technology in lithologic mapping can effectively improve the exploration and research of government departments and manufacturers for outdoor geological work, and provide favorable conditions for design and production. This paper studies Tibetan Qiang Autonomous Prefecture of Ngawa, uses Gaofen-5 hyperspectral image data, and finally evaluates the lithology mapping and accuracy of the research area through the preprocessing of hyperspectral data, data dimensionality reduction, end member extraction.

The following is the research results and innovations:

- Gaofen-5 hyperspectral image is used in the research area for the research processing such as band rejection, radiation calibration, broken line repair, stripe removal, geometric correction, image trimming, etc.
- Obtain the outdoor rock spectrum data along the Maoxian-Songpan section in Chengdu-Lanzhou Railway, and successfully establish the special spectrum library of complex and dangerous mountainous areas.
- During hyperspectral feature extraction, it is concluded that MNF can reduce the dimensionality quickly and retain the nonlinear features of hyperspectral data better, and have more abundant feature information by comparing MNF and PCA dimensionality reduction methods.
- Monolithologic identification and classification in the research area: through the end member extraction of MNF dimensionality reduction data and the identification of hyperspectral image data, the lithologic distribution map of the research area is obtained. The total classification accuracy is
86.758% and Kappa coefficient is 0.8038. The overall classification effect is better and the classification accuracy is higher.

- Preliminarily obtain a set of geological and lithologic mapping methods and technical models based on hyperspectral image along the railway in the complex and dangerous mountainous area, which provides convenience for the following railway selection and survey.

Acknowledgement

Fund Project: Sichuan Science and technology plan project (2018GZ0051)

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