Study on oil and gas exploration in sparse vegetation areas by hyperspectral remote sensing data

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Oil microleakage can cause the land surface vegetation to be abnormal. An oil and gas exploration method based on the vegetation information in the hyperspectral remote sensing images is proposed. It's used to probe the effectiveness of extracting the oil and gas microleakage information, with the vegetation anomalies in the remote sensing images. A decision tree based on the vegetation index is taken to extract the anomalies areas of vegetation in the CASI images. It's shown by the experiment that there are some potential for the exploration of oil and gas in the areas covered by sparse vegetations.

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The main components of oil and gas leakage migrate and gather in the soil, replacing the original air, which will change the soil environment of the plant roots and affect the plant health[1,2]. For example, the chlorophyll content of plants will reduce, and the red edge position of plant will shift toward the shorter wavelengths. These changes can be monitored through the reflectance spectrum of plants.

The above anomalies of vegetation spectrum, caused by oil and gas leakage, have been studied by many scholars[3,4]. Meer *et al.* studyed the high-resolution reflectance spectra of Douglas fir trees and found that Douglas fir trees growing in areas of gas production had higher reflectivity in the 550—650 nm region, and the sharp rise in reflectivity at 700 nm shifted towards shorter wavelengths[5]. Bammel *et al.* conducted a geobotanical reflectance study at five areas in the Bighorn basin, and the study showed that the most effective indicator of hydrocarbon-induced stress in sagebrush plants was a consistent blue shift[6]. Wang *et al.* found the obvious phenomenon of "blue shifting" of vegetation spectrum in their studies[7−9].

Although the abnormal reaction of vegetation to the hydrocarbon microseepage has been confirmed before, few people have carried out the research in taking advantage of the abnormal vegetation information in hyperspectral remote sensing images to detect oil and gas. In this letter, the hyperspectral remote sensing image is used to verify the validity of the oil and gas detection method based on the abnormal phenomenon of vegetation reflectance spectrum: the red edge shift to shorter wavelengths.

But there is still one point to be explained. The blue shift intensity will not change with the changes of plant density, theoretically. When the plant anomalies are studied with remote sensing images, because of the "proximity effect" in the process of imaging, the plant spectrum will be affected by the surrounding exposed surface. In this sense, the greater the plant density, the better for the research, but the premise is that the vegetation type is single which will not be always met in the lush plant areas. To avoid the problem, in this letter, the hyperspectral remote sensing images with high signal-to-noise rate (SNR) and high aerial resolution is used; the research area is covered by sparse plants with almost single type[10], and the vegetation index red edge position (REP), which is not sensitive to ground changes, is used to extract the abnormal plants.

The Yulin gas field in the northeastern of Erdos basin in China was selected to be the test area. There is sparse vegetation covering on the ground. In the test area, removing the farmland areas, the remaining surface of the desert is mainly covered by the Artemisia Ordosica Krasch, which is showed in Fig. 1. That's to say the vegetation type is almost single in the test areas, and it creates the conditions for the work of information extraction of the hydrocarbon microseepage based on vegetation anomalies.

The hyperspectral data was obtained by the airborne hyperspectral imaging spectrometer (AHIS), which is equipped with the dual spectral camera (CASI-1500 and SASI-600).

Considering the vegetation phenomenon of "the red edge shifts towards shorter wavelengths" on the alteration zone, the classification system of the

Fig. 1. Main vegetation of the test area: Artemisia Ordosica Krasch.

decision tree, constructed by the nodes of the normalized difference vegetation index (NDVI) and the vegetation REP, is proposed and used to extract and classify the abnormal vegetation in the CASI image.

The method of linear four point interpolation is used to extract the REP of vegetation from the spectral data[11]. The calculation process is that calculate the reflectivity of the deformation of the red edge, and then calculate the wavelength corresponding to the reflectivity of the deformation point.

$$R_{\mathrm{i}} = \frac{R_{670} + R_{780}}{2}, \quad (1)$$

$$\lambda_{\mathrm{i}} = 700 + 40\frac{R_{\mathrm{i}} - R_{700}}{R_{740} - R_{700}}. \quad (2)$$

The decision tree used in this letter is shown in Fig. 2, and the structure can be described as follows:

1) The first node: the NDVI. Calculate the NDVI value of every pixel in CASI images, and determine the NDVI threshold through the cluster analysis, the data subsets that are higher than the threshold value represent the region with higher vegetation coverage, and they are taken to the next layer classification; the others represent the region with no or low vegetation coverage, and they are not taken to the further study.

2) The second node: the REP. Calculate the REP value of every pixel, and determine the REP threshold through the cluster analysis, the data subsets that are lower than the threshold value represent the region having abnormal phenomenon of "the red edge shifts towards shorter wavelengths" and they are taken to the next layer classification; the others represent the region having no abnormal vegetation, and they are not taken to the further study.

3) The third node: REP. Determine the threshold of the abnormal area obtained by last layer classification through the cluster analysis, then the data are further divided into two subsets, the data subsets that are lower than the threshold value represent the region with more obvious phenomenon of "the red edge shifts towards shorter wavelengths", and they are treated as the abnormal area at the first level; the others are treated as the abnormal area at the second level.

The CASI image is classified, using the decision tree mentioned above, and the result is shown in Fig. 3(a). The red dots represent the areas that at the first abnormal level, and the cyan dots represent the areas that at the second abnormal level.

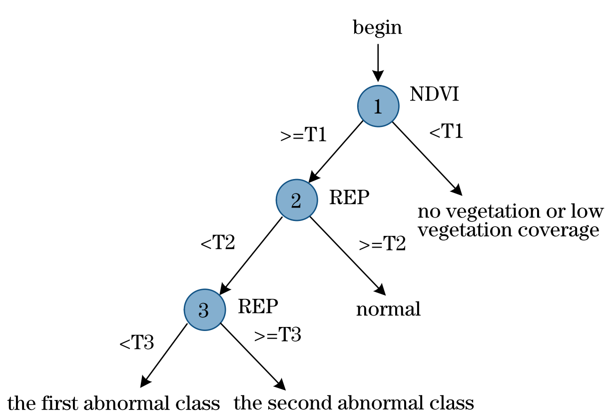

Fig. 2. Structure of the decision tree.

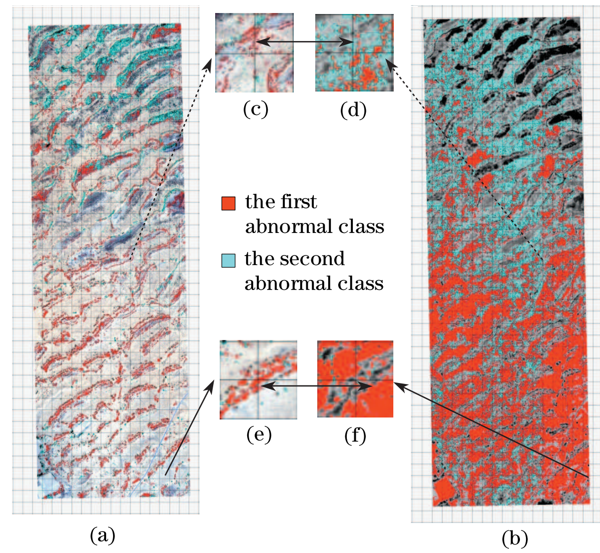

Fig. 3. (Color online) Comprehensive analysis of the anomalies of vegetation and alteration mineral. (a) Classification of vegetation of CASI; (b) classification of alteration mineral of SASI; (c) the outlier distribution of vegetation of the first constituency; (d) the outlier distribution of alteration mineral of the first constituency; (e) the outlier distribution of vegetation of the second constituency; (f) the outlier distribution of alteration mineral of the second constituency.

In order to verify the approach's validity, the classification result of the SASI image is given out in Fig. 3(b), which is based on the anomaly information of alteration mineral in the bare surface. The method of processing the SASI image is as follows: the alteration spectral curve of the bare surface in the known gas field is taken as the reference spectra, and the method of the spectral angle mapping (SAM) is applied to the SASI image. This method has been shown to be effectively to extract the alteration mineral anomaly in the hydrocarbon microseepage zone[5,12].

Analysis Figs. 3(a) and (b) qualitatively, we can find that the classification results of vegetation in CASI image and alteration mineral in SASI image are highly consistent in spatial distribution.

In order to verify the effectiveness of the proposed method more accurately, the classification results of CASI and SASI are gridded, and the intervals are 2" both along the latitude and longitude direction, and the consistent degree between those two results of classification are calculated statistically.

The statistical standards are shown in Table 1. Figures 3(c) and (d) are the classification results of CASI and SASI, drawn from the same geographical location. The black double arrow between them shows the same vegetation coverage area in the image of CASI and SASI. It can be seen that the distribution of the abnormal classes in this position are not consistent, while the two shown in Figs. 3(e) and (f) are consistent.

The statistical result is as follows: the study area is divided into 615 squares, 580 of which are consistent between the results of CASI and SASI, and the other 35 squares are inconsistent, and the coincidence rate is 94.3%. This high coincidence rate illustrates that the method of exploring oil and gas, taking advantage of the

Table 1. Statistical Standards of Consistency between the Classifications of CASI and SASI

Consistent Yes/No	Abnormal Level of Classification Results of CASI		Abnormal Level of Classification Results of SASI	
	First	Second	First	Second
Yes	√		√	
Yes		√		√
No	√			√
No		√	√	

vegetation abnormal information of "the red edge shifts towards shorter wavelengths" has certain application potential.

In conclusion, considering the typical characteristic of the sparse vegetation area in the northwestern of China, the classification system of the decision tree based on the vegetation abnormal phenomenon of "the red edge shifts towards shorter wavelengths" is proposed and used to extract the information of the hydrocarbon microseepage. Its validity is verified through the analysis of the experiment. The results show that there are some potential for oil and gas exploration in the typical area covered by sparse vegetation, using the method proposed in this paper.

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