Paper presented at the 22nd Asian Conference on Remote Sensing, 5 - 9 November 2001, Singapore.

Evaluation of Multi-sensor Remote Sensing Data Applied Oil & Gas Exploration in the Loess Highlands, Ordos Plateau, China

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KEY WORDS: Multi-sensor remote sensing data, Loess Highlands, Oil and Gas exploration, China

ABSTRACT: With the rapid development of aerospace remote sensing technology worldwide, new sources of remote sensing provide some alternative options and methods for oil and gas exploration. This paper evaluates the characteristics of multi-source remote sensing data and the results of a case study in the Ordos region of China. This preliminary oil and gas exploration study using remote sensing technology examines the complex surface conditions in loess highland.

1. Geography and Data Type

1.1 Geography

The Ansai-Dingbian block is located in the central Ordos basin (E 108^o –E109^o 40’, N36^o 30’ – N37^o 4’) with an area of about 23000 km^2 (Figure 1). It is the extension of Maowusu desert in the north part, featuring an arid climate and sparse vegetation. The area is typical for semi-arid loess terrain in the central and southern parts of the Ordos, with numerous hillforms, entrenched by steep valleys as a result of intense erosion. The relief varies greatly with an elevation difference of 200-300m.

The drainage systems within the basin includes the Yellow River with a well developed dendritic drainage network. Rivers such as Luo River and Yan River are flowing from northwest to eastsouth into the Yellow River. The River bed have intermittant flow, and they are dry in the drought season. The annual average temperature is 9 - 10° C; The frost-free period lasts for about six months; the annual rainfall ranges between 300 and 600 mm, half of which occurs from July to September during storms and occasional hail storms.

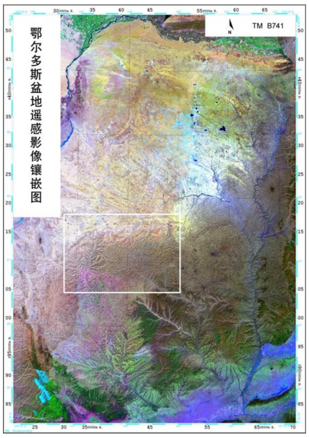


Figure 1. Location

.1.2 Remote Sensing Data Types

Image processing and multi-source information fusion processing of multi-temporal and multiplatform remote sensing data are important means in non-seismic surveys and studies of the loess highlands. The results of analysis and comparison indicate that multi-source remote sensing data can provide rich, reliable and useful information. The following remote sensing data were used in the study (Tables 1).

Map No.	Temporal	Map No.	Temporal
C1C10000002928	1999-11-22	MSSKR137’34	1976-01-26
TM127’34	1992-11-22	ETM127’34, 35	2000-04-26
TM127’35	1992-11-22	ETM128’34, 35	2000-05-19
TM128’34	1998-01-30	SPOT 268-274	1988-06-15
TM128’35	1987-04-22	RADARSAT S1	1998-08-13

Table 1. Data Type

2. Data Statistical Correlation and Image Process

2.1 Data Statistical Correlation

Season and other natural factors (composition, structure, weathering, terrain, vegetation and so on) cause the brightness of surface objects to vary in a statistically replicable way. Therefore, statistical analysis is a primary method for analysis of remote sensing data. Mean value and standard deviation are two most important parameters in statistical image analysis. They can indicate the range of resultant brightness and information volume.

The results of statistics showed that correlation factor matrix is the best parameter in statistics of multi-spectral images to indicate imagery information and geographical and geological features of imaged area. Imagery of same area at various dates of acquisition and season are remarkably different in terms of their statistics. They show a high correlation factor among images of TM data in Jan.1998, April & May, 2000 and MSS data in Jan. 1976.This can be attributed to little or complete lack of vegetation in this semi-arid loess area. The image taken in Sept. 1987 shows a significant change due to well developed vegetation. In order to improve the spectral features of surface objects and features of interest, correlation factors had to be lowered. After the creation of a new ETM and TM composite image, all the correlation factors were low, except $R_{2,3}$, $R_{2,4}$ and $R_{3,4}$. After completion of correlation statistics, three bands of B1, B3 and B5 from TM 128'34 (Sept. 87), two bands of B2 and B7 from TM 128'34 (Jan. 98) and B4 from ETM (April & May 2000)* were selected and combined to create a multi-temproal remote sensing image using map to map matching.

2.2 Imagery Processing

In remote sensing, tonal anomalies and subtle changes in information content are used as important indicators when applying imagery for oil and gas exploration. There are a number of imagery processing methods, e.g. contrast enhancement, band ratio, principal component analysis, or color spatial transform. In this study, the challenge was to combine these methods efficiently to pick up more rich, reliable and useful information through the process of merging multi-source and multi-temporal remote sensing data using the loess highlands as a study area. The following methods were utilized.

*The ETM data are created through mosaic of four ETM scenes: ETM 127’34,35 (26, April 2000) and ETM 128’34,35 (19, May 2000).

2.21 Contrast enhancement and band ratio

These two methods highlight the information contents of geological features and pick up color anomaly by enhancing and transform methods. Due to the sparse vegetation cover of the loess area in winter and thick loess cover itself, one encounters low image saturation; the three channels of color composite image data have a strong correlation.

Linear and non-linear transform of color composite imagery of B741 and B641 were followed by enhancement of brightness, and color and saturation space. This resulted in a significant improvement of contrast information and better saturation of the image data.

2.22 Principal composition analysis

Principal component analysis can eliminate the correlativity among parameters in characteristic vector and make characteristic selection. Moreover, it can focus the useful information in multiple bands on several composite imagery. It features mainly: a) no loss of image information as a result of transform, only a redistribution of information in new principal composition images; b) no correlation among principal component, so the principal component color composite imagery has more information and higher saturation and can reflect the tone difference among surface objects; c) the first principal component has the most information and high signal to noise ratio, the others decrease sequentially.

Principal component analysis is a main algorithm used in this study considering loess highland features. Its purpose is to compensate the lower TM data saturation and strong data correlation in order to enhance the color and brightness of surface objects and increase imagery information volume. Based on principal component analysis and combined with color space transform, a "remote sensing tonal anomalous anomaly imagery" can be obtained (Figure 2).

2.23 Information fusion of remote sensing imagery

Information fusion of remote sensing imagery is a method to process multi-source remote sensing data in an identical coordinate and create a group of new information or composite imagery through a specific algorithm. Various remote sensing data has different spatial resolution. The integration of merits of each one can compensate the lack of information in an individual image. Overall, this may result in an increase of information as well as significant improvement of accuracy in remote sensing imagery analysis.

2.24 Combination of remote sensing imagery and DEM data

The application of surface DEM (Digital Elevation Model) data can eliminated the geometric distortion in remote sensing imagery caused by terrain relief, improve the positioning accuracy of remote sensing imagery and create a realistic 3D imagery, providing precise geographic coordinate for surface survey. The digital elevation data can provide geologists with valley & trench map and water system map.

2.25 Linear density statistics of fault body

The linear structure density, i.e. total sum of linear structure development per unit area, is affected basically by force, stable and sustained time elapse effect and surface physical characteristics. Under known surface physical parameters, the linear structure density represents a function of crustal movement strength and tectonic movement. Migration and accumulation of oil and gas are often affected by faulting. Hence, determining the area and position of maximum linear faulting density in the basin is an important element in oil and gas prospecting. The distribution of linear structures and their density can indicate the trending of structural features. The fault density map of the Wugucheng area was derived from remote sensing imagery (Figure 3). The fault distribution in the northeastern section is evident in this figure; the red area indicates maximum faulting density.

3. Remote Sensing Imagery Comparison

3.1 Comparison of TM vs SPOT and TM vs RADASAT imagery

The spatial resolution is improved as well as feature identification of multi-spectral (Figure 4). The figure shows on the left the merged TM741 and SPOT data; on the right is Pan band imagery of SPOT image. In figure 5, on the left side is the merged imagery of TM741 and Radarsat SAR data; on the right is the SAR image. It can be seen that the fusion process with multi-sensor remote sensing data can maximized the information content of the overall data set. It also contributes to more distinct representation of structural surface features. This provides a useful source for mapping for geological applications.

3.2 Comparison of principal composition analysis

There is significant difference in the statistical results of principal composition analysis of remote sensing imageries taken at different time in the same area. The principal composition analysis was done with a combination of ETM data and multi-temporal data selected from the same area to obtain the primary composition imagery with numbers same of band Table 2 represents the approximate MSD share and dynamic range of various level of information in the imagery. There are color uneven and noise in the pseudo-color imagery constituted by levels 5, 4 and 2 selected from principal composition of ETM data, see left figure 6 while the pseudo-color imagery constituted by levels 6, 4 and 2 from multi-temporal fusion data exhibits uniform tone and rich information, see right figure 6.

We noticed level 2 of each principal component analysis. It usually presents various views resulted from major geological and topographical units and the reflected texture feature and structure feature exhibit substantial difference. The level 2 of ETM principal component analysis is showed on the left while that of multi-temporal fusion data on the right of figure 7. By comparison, the latter has a clear image anomaly which obviously highlights the subtle geological information with exploration significance.

MSD(%) / *Image*	**1**	**2**	**3**	**4**	**5**	**6**
ETM	96.76	2.44	0.57	0.14	0.07	0.03
ETM 与 TM	83.32	10.29	4.40	1.27	0.56	0.16

Table 2. Statistical MSD Distribution of ETM Data and Multi-temporal fusion Data

4. Conclusion

One of efficient method for imagery processing is pseudo-color composite with band combination and principal component selected based on statistics in primary composition analysis. As the remote sensing imageries for oil and gas exploration study, B741 is a suitable band combination. As the acquisition data for winter and spring in loess area, B641 combination is also a suitable band combination. On basis of primary composition analysis, HIS transform can provide good pseudo-color composite imagery. It can be used for transform between different bands in same imagery as well as composite process of different type of imagery.

Data screening and imagery processing have greatly suffered from the special natural and geographical conditions in loess highland. In light of requirement of interpretation and analysis in remote sensing petroleum geology, some trials have been done focused on the feature of available data, some of which gained good result, but the others not. Further study and investigation are required.

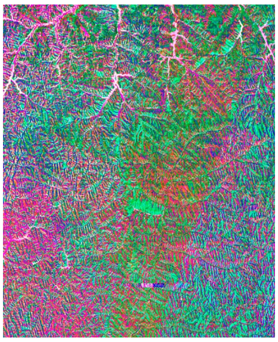


Figure 2. PCA(642)-HIS

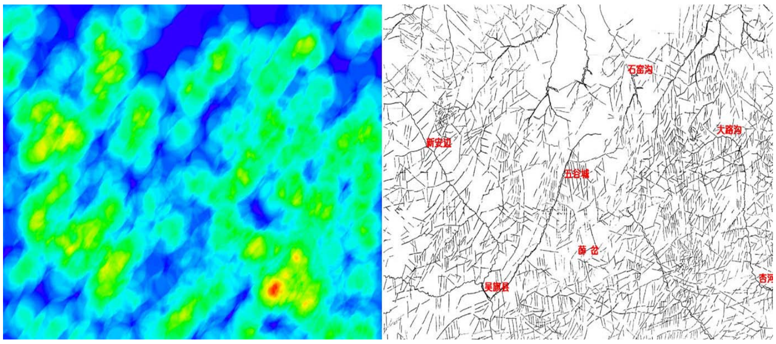
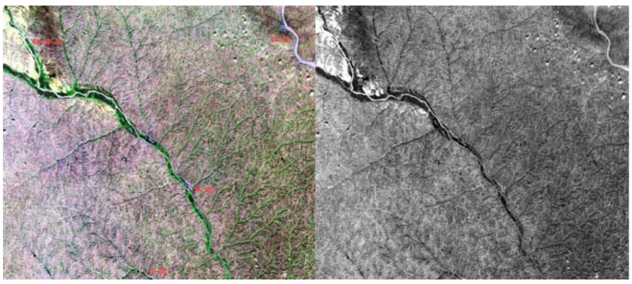
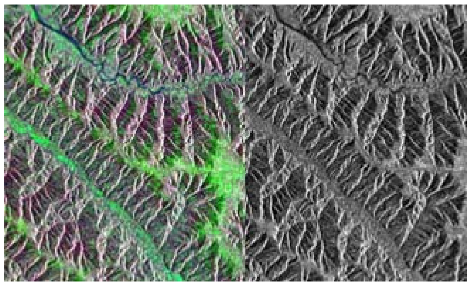


Figure 3. Linear structure density statistics of Wugucheng area



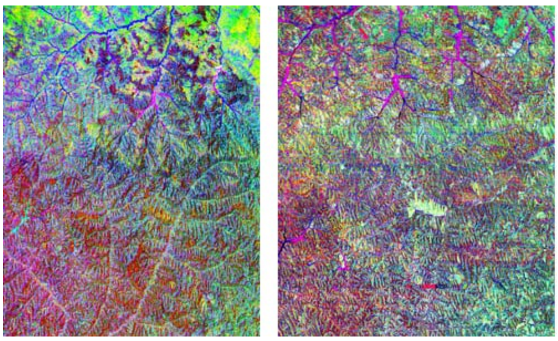
TM 741 + SPOT SPOT Pan band

Figure 4. Fusion Comparison of Data



TM 741 + SAR SAR imagery

Figure 7 Fusion Comparison of Data



PCA(542) PCA(642)

Figure 8 Comparison of Pseudo-color Imagery

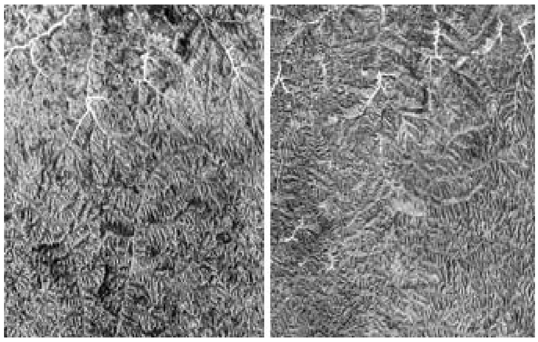


Figure 9. Comparison of Level 2 principal component analysis

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