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Thermal infrared remote-sensing detection of thermal information associated with faults: A case study in Western Sichuan Basin, China

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ABSTRACT

Using enhanced land surface temperatures (LSTs) image retrieved from Landsat ETM+, this article shows that thermal information associated with faults have been detected. These anomalies may be provided by geothermal natural convection through faults and partially influence the ground surface thermal environment. The study area in southern segment of Longmen Mountains thrust belt of Western Sichuan Basin contains complex faults and folds with recent earthquake activity. In order to study the faults for future oil exploration, we use LST data retrieved from Landsat thermal infrared band to detect the thermal information associated with faults. The LSTs are enhanced by filtering out anthropogenic activity and influence land cover classes, and interpolating to contour map. The spatial patterns of the enhanced images revealed the spatial correspondence between the thermal information and the dip planes of faults when compared with the explanation profiles and geologic features obtained from the 3D-seismic geophysical data. The thermal-affected ranges calculated and the statistically significant of regression model also indicate the result that the thermal information located near the faults are consistent with the faults' dip planes.

1. Introduction

Thermal information associated with faults have been detected. Lu et al. (2008) used Landsat ETM+ thermal image to find that thermal anomalies strongly correlated with faults in the certain scales in the Jiangshan-Shaoxing fault between Jinhua and Quzhou in the Zhejiang Province of China, and defined the areas, where temperature higher than the spatial background as thermal anomaly. Tronin (1996, 2000) indicated the existence of anomalous IR radiation flux at the surface over active and large scale faults in seismic active regions.

These fault thermal anomalies may caused by underlying thermal anomalies, because many studies show that faults and their associated fracture zones provide the path for the geothermal convection. Hanano (2000) pointed out that the highly permeable zones considered of great importance in geothermal systems are faults and fractures. Prol-Ledesma (2000) demonstrated that in the location of geothermal resources, the presence of main faults and high-density fracture zones proves useful and serves as a surface indicator of permeability. Blewitt et al. (2003) indicated that the spatial pattern of geothermal well temperatures is strongly correlated with the tectonic trans-tensional strain rates measured by GPS on a regional scale, which indicates that geothermal plumbing systems might be controlled by fault planes as conduits and by tectonic activity. Noorollahi et al. (2008) in Japan showed that faults correspond to high permeability and a preferential geothermal fluid circulation toward shallower geological formations. Furthermore, many researched also refer to the distance relationship between geothermal areas and faults. Noorollahi et al. (2007) found in 95% of the geothermal wells were located in a zone within 6000 m of the active faults in Japan. Yousefi et al. (2007) also used the distance of 6000 m to select potential geothermal areas based on faults and fractures in Iran in a map of scale 1:250,000. Noorollahi et al. (2007) also was discussed the different scale, as when the scale became 1:25,000, calculations showed 2000 m to be the typical association distance. However, in these cases, the distance statistics are based on the number of geothermal wells, a method which can not result in the accurate coverage of every part of the area. Given these concerns, the analysis of the space relationship between geothermal areas and faults requires further tools that could provide complete and wide coverage at the same time.

Remote-sensed thermal infrared (TIR) images have been used to detect thermal anomaly areas (most of them are geothermal) for many years, which offer the advantages of ease of repetition, high spatial resolution, short temporal sampling intervals, and wide area coverage (Allis et al. 1999; Lee 1978; Lagios et al. 2007; Coolbaugh et al. 2007).

The fault thermal anomalies are difficult to detect in TIR images because they are only slightly warmer than the ambient background

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temperature of anthropogenic activity and solar radiation. Furthermore, the success of efforts has always been limited by the difficulty of differentiating between several heating effects within different surface land covers. Many methods have been used to distinguish the presence of subtle fault thermal activity from false anomalies, including the identification of the magnitudes and the sub-pixel area coverage of the two different surface radiant temperatures (Dozier 1981), the multi-temporal mean method (Tramutoli et al. 2001), the mean grad method (MGM) (Chen et al. 2005), and the wavelet decomposition method (Chen et al. 2006). However, in the areas covered by vegetation, surrounded with buildings and crossed by rivers, background interference always confuses perception of any subtle fault thermal activity. This is further complicated by the fact that land surface temperatures (LSTs) contain a sum of different fractions of energy, and the noise caused by different types of land cover may affect the retrieval of the fault thermal anomalies from LST readings. Lu et al. (2008) used spatial pattern analysis and a regional geometric scale to effectively reduce the noise caused by confusion pixels, characterising the spatial distribution pattern of the fault thermal information through this method, and found that fault thermal anomalies strongly correlated with faults at a regional scale. Although it is noteworthy to detect the thermal anomalies around these faults, this cannot determine why the centres of the anomalies are offset several kilometres from the faults, nor which classes or parts of the underground faults influence the LSTs.

The primary purpose of this work is to determine the applicability of a combined technique of satellite image analysis and statistics in establishing the relationship between thermal information and faults. In addition, spatial pattern analysis should be improved by land cover simplification, supported by accurate 3D-geophysical seismic data and documented by a statistically significant relationship. In this study, we devote several sections to analysis of the spatial distribution pattern of the thermal anomalies surrounding the faults in the southern segment of Longmen Mountains thrust belt of Western Sichuan Basin, China, where complex faults and folds with recent earthquake activity. First, we derive LSTs from the Landsat ETM+ thermal bands. Second, we attempt to employ land use/land cover classification of the LST images to filter out noise in the form of the abnormal high temperatures caused by the effects of anthropogenic activity in built-up and bare land and the abnormal low temperatures caused by water and hill shade. Then, the enhanced and noise-reduced images that manifested as fragments are implemented by Kriging interpolation and classed to contour map. Finally, we compare the spatial pattern of the enhanced images with regional geological tectonic maps and with explanation profiles of seismic reflection time cross-sections, calculate the thermal-affected ranges and different scales for showing clearer fault thermal anomalies, and use the statistically model to analyse the spatial correspondence between the thermal information and the faults.

2. Study area and data

The study area is situated in the western area of the Sichuan basin, China, and is approximately bounded by latitudes 30.28° N and 30.49° N and longitudes 103.21°E and 103.43°E (Fig. 1). The area is covered by Jurassic to Quaternary rocks, which is acquired from Qionglai 1:200,000 Geology Map (1977). And many oil–gas fields and hydrocarbon reservoirs have been discovered, showing good exploration prospect in Upper Triassic Xujiahe Formation (Zhu et al. 2009).

Our study area locates the southern segment of Longmen Mountains thrust belt (Jin et al. 2010) which forms the western edge of the Sichuan Mesozoic–Cenozoic foreland basin and the southeastern boundary of the Qinghai-Tibet Plateau(Wang 1996) and defines a steep topographic escarpment in southwestern China. The area contains two folds which respectively stand for two systems of Longmen Mountains, as the Pingluoba Anticline in the west for the frontal fold-and-thrust belt and the Qiongxi Anticline in the east for the foreland depression belt. Along folds the thrust faults presented arc in the plane can be found mainly controlled by the thrust-napping effect of Longmen Mountains structure belt (Jin et al. 2010), and have the characteristics of

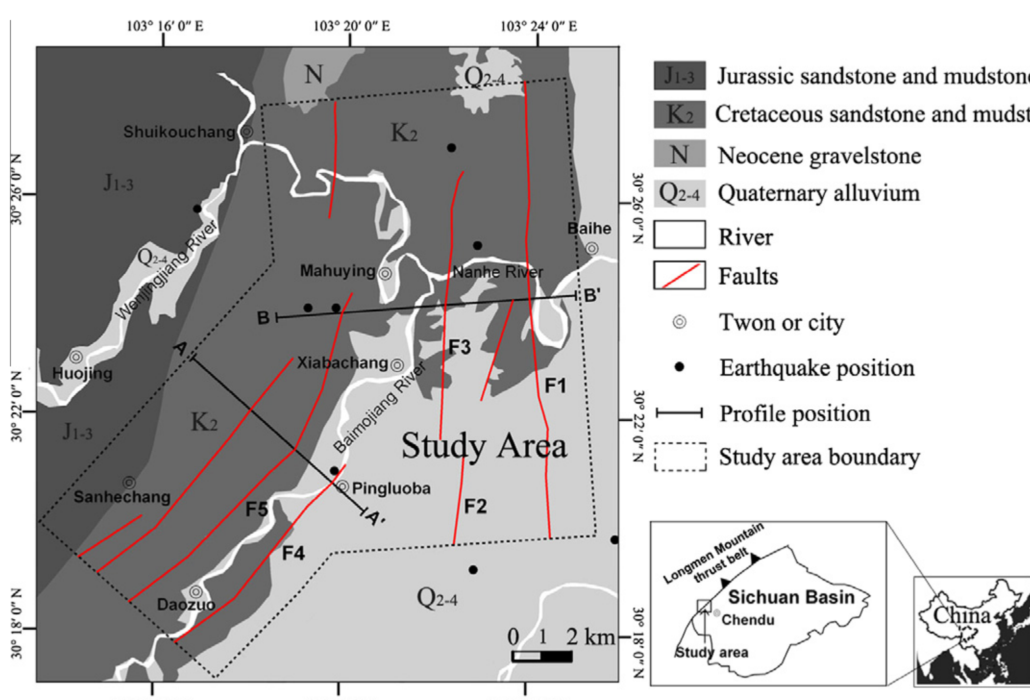

Fig. 1. The geologic map of the study area overlapped with pre-Jurassic faults, nature earthquake positions (magnitude >2.0) during the year 1990–2008, and geophysical seismic explanation profiles.