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Multilayer stress from gravity and its tectonic implications in urban active fault zone: A case study in Shenzhen, South China

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ABSTRACT

It is significant to identify urban active faults for human life and social sustainable development. The ordinary methods to detect active faults, such as geological survey, artificial seismic exploration, and electromagnetic exploration, are not convenient to be carried out in urban area with dense buildings. It is also difficult to supply information about vertical extension of the deeper faults by these methods. Gravity, reflecting the mass distribution of the Earth's interior, provides an alternative way to detect faults, which is more efficient and convenient for urban active fault detection than the aforementioned techniques. Based on the multi-scale decomposition of gravity anomalies, a novel method to invert multilayer horizontal tectonic stresses is proposed. The inverted multilayer stress fields are further used to infer the distribution and stability of the main faults. In order to validate our method, the multilayer stress fields in the Shenzhen fault zone are calculated as a case study. The calculated stress fields show that their distribution is controlled significantly by the strike of the main faults and can be used to derive depths of the faults. The main faults in Shenzhen may range from 4 km to 20 km in the depth. Each layer of the crust is nearly equipressure since the horizontal tectonic stress has small amplitude. It indicates that the main faults in Shenzhen are relatively stable and have no serious impact on planning and construction of the city.

1. Introduction

Active faults across urban area are great potential threats. Their activity may cause severe damage to lifelines, critical facilities, and local utility distribution systems. Destructive earthquake caused by urban active faults may result in huge economic loss and a large of casualties, such as San Francisco earthquake in 1906, Tokyo earthquake in 1923, Tangshan earthquake in 1976, and Chi-Chi earthquake in 1999. Active fault exploration is of particular importance by considering the rapid social and economic development in urban area.

Most urban active faults become concealed faults with sparse rock outcropping and unobvious trace, usually covered by Quaternary unconsolidated sediments. There are several approaches to detecting concealed faults. Geological survey infers faults from the symbols of physiognomy, reduplicate layers, slickenside, etc. (Berberian, 1995; Egan et al., 1999; Wu and Xu, 2003; Gong et al., 2004; Wu et al., 2005; Picotti et al., 2009). Artificial seismic exploration obtains geometric parameters of faults from crustal velocity structure using seismic data (Bleibinhaus et al., 2007; Karastathis et al., 2007; Sato et al., 2009; Sultan et al., 2012). Electromagnetic exploration identifies faults from underground geologic structure inverted by apparent resistivity, geoelectricity, electromagnetic wave, and so on (Murthy et al., 2001; Slater and Niemi, 2003; Rashed et al., 2003; Nguyen et al., 2005; Bhosle et al., 2007; Kondo et al., 2008; Huang and Lin, 2010; Suski et al., 2010; Audru et al., 2001; Yalçiner et al., 2013). These techniques may be practical for shallow structure study, but not applicable for deeper sources. It is difficult to give information about vertical extension of the deeper faults by these methods. Due to dense buildings and municipal facilities on ground, these methods might also be inconvenient in urban area. As an alternative method, gravity is a good tool for inferring subsurface structures (Sultan et al., 2012; Tigli et al., 2012; Saleh and Saleh, 2012; Wang et al., 2012; Evariste et al., 2014), because gravity implies density distribution inside the earth and can subsequently be used to invert tectonic stress.

Shenzhen, one of the fastest-growing cities in the world, is situated in Southern China's Guangdong province and adjacent to Hong Kong. Many active faults have been found across Shenzhen urban area. As the city is expanding, numerous large buildings and municipal facilities have been constructed on or close to the fault zone. It is imperative to understand the active faults. In the last few decades, various geophysical techniques have been constantly applied to study faults in Shenzhen except gravity (Tan et al., 2000; Sun et al., 2007; Chen et al., 2010; Yu, 2010). Previous studies demonstrate that the Shenzhen fault zone has undergone a long period of tectonic activity. It is still partly active

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today although the activity is very weak. The activity can be examined with earthquake focal depth distributions (Pamukçu et al., 2014). In the past several decades, earthquakes with maximum magnitude less than 4 and focal depths ranging from 5 km to 25 km were recorded in this area. The progresses of researches on the Shenzhen fault zone are detailedly reviewed in Yu (2010).

The present work is an attempt to study the Shenzhen fault zone based on gravity observation. Wavelet multiscale analysis was used for gravity anomaly separation. Hereafter crustal density and tectonic stress distributions in different depths were inverted in order to advance the knowledge regarding the Shenzhen fault zone.

2. Tectonic and geological setting

The study area is located at the southeast edge of Cathaysia block, which is a part of South China Continent (SCC). SCC, a major continent block of East Asia, has experienced a long term and complicated tectonic evolution (Zhang et al., 2013). As the convergence center of three modern plates, the present tectonic activities of SCC are influenced by the Indian–Eurasian collision, the subduction of the Pacific plate and the Philippine Sea plate. In the global plate tectonic situation, SCC is suffered from southeastward pushes resulting from uplift of Qinghai–Tibet plateau, with the addition of compression generated from the northwestward subduction of the Philippine Sea plate (Fig. 1). A tectonic feature of the Cathaysia Block is the extensive distribution of large-scale NEE-trending faults.

The study area is tectonically a Neopaleozoic depression developed on the Caledonian folding basement, superposed and reworked by Mesozoic and Cenozoic structures. Rifting and magmation in different periods resulted in poor continuity and absence of strata. Rocks behind Cenozoic have suffered varying degrees of metamorphism. Complicated geological structures in Shenzhen were generated after numerous tectonic events since Caledonian (Sun et al., 2007).

The Shenzhen fracture zone can be distinguished into three sets of NE, NW and WE trending faults (Fig. 2). NE-trending fault belt including F1–F4 is the dominant crustal tectonics, which is viewed as the southwest end of Lianhuashan fault zone which belongs to the Neocathaysian structural system. NE faults traverse the whole urban area slantingly with the length of about 150 km and control the distribution of stratum, intrusive body and metamorphic rocks in this area. Compared with NE faults, NW and WE faults are less developed with smaller scale, mostly intersecting with the NE faults. The general structures are in a strike–slip to normal faulting regime. The horizontal principal compressive stress is dominantly NNW- and NW-trending, almost perpendicular to the major fault trend. The stress orientation is consistent with the regional tectonic background (Liu, 2001). The maximum horizontal shear stress is mostly less than 1 MPa (Tan et al., 2000). The stress field indicates that the Shenzhen fault zone is relatively stable.

Topography from SRTM DEM (Jarvis et al., 2008) is illustrated in Fig. 3a. In the north, south and northeast, Shenzhen is primarily surrounded by small hills composed of granites and volcanics. In the southwest, topographic features are characterized by alluvium terraces. Four-grade paleo-denudation surfaces and three-grade alluvium terraces have been developed in the fault zone since ~1.8 Ma. A series of small Quarternary intermontane basins and valleys is developed with axis orientation of NE–SW or ENE–WSW same as trending of the major faults within the fault zone. Most of these basins and valleys are located in the older fracture and or the limestone strata undergoing strong karstification, while no fault and marked deformation have been observed in the sediments of the Late Pleistocene and Holocene. This might suggest that no remarkable faulting has occurred in the fault zone at least since the middle of the Late Pleistocene (Lu and Sun, 1991).

Although the region is tectonically and geologically stable, geophysical phenomena such as minor earthquakes show that the Shenzhen fault zone is still partly active. The deepest foci of observed crustal events within the fault zone reach nearly to 30 km (Tan et al., 2000). It indicates that the fault zone has extended into the lower crust or even the upper mantle. The deep crustal discontinuity is confirmed by other geophysical studies (Xie et al., 1997; Fletcher et al., 1997; Sewell et al., 2000). The recent crustal structure from deep seismic sounding shows that a high-velocity (7.1–7.4 km/s) layer in lower crust is absent in the study area (Li et al., 2006). The crust is only 28–30 km thick with a

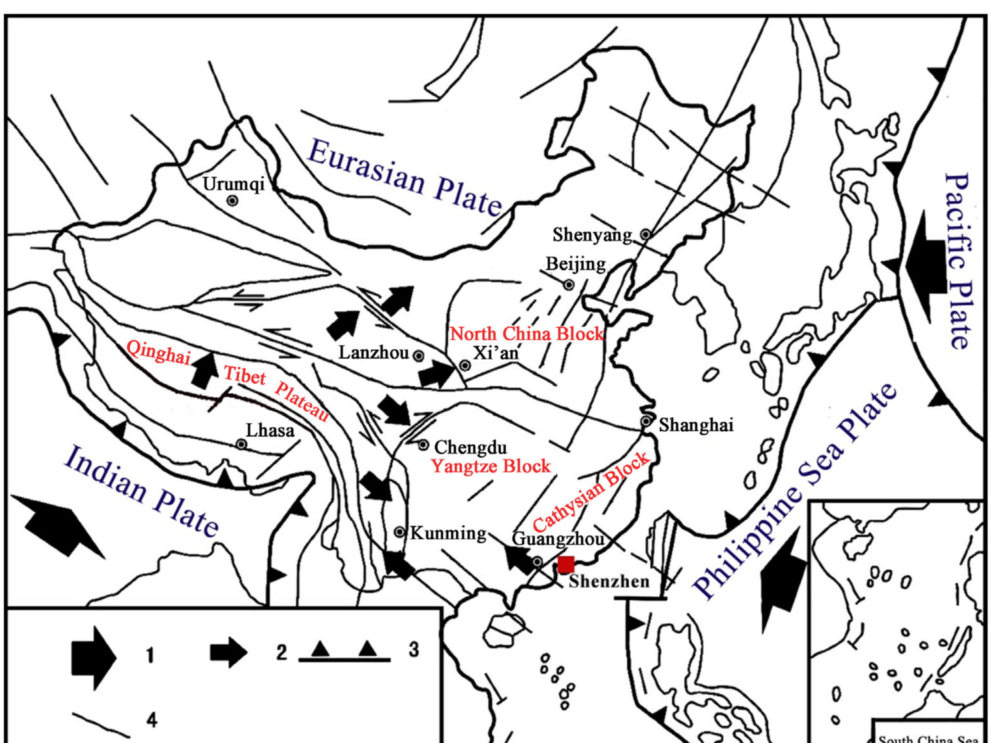

Fig. 1. Tectonic background and location of the study area (modified from Yu, 2010). 1: motion direction of plate, 2: motion direction of blocks, 3: plate boundary, 4: main fault systems.