Tectonophysics 601 (2013) 112–124

Contents lists available at SciVerse ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Differences in magnetic properties of fragments and matrix of breccias from the rupture of the 2008 Wenchuan earthquake, China: Relationship to faulting

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ARTICLE INFO

Article history:
Received 5 November 2012
Received in revised form 28 April 2013
Accepted 5 May 2013
Available online 14 May 2013

Keywords:
Magnetic properties
Fault breccia
Seismic faulting
Wenchuan earthquake

ABSTRACT

Rock magnetic and mineralogical analyses were performed on fragments and matrix of six fault breccias from the Zhaojiagou outcrop of Yingxiu–Beichuan Fault, which was the main fault ruptured during the 2008 Wenchuan Mw 7.9 earthquake, at Leigu Town, Beichuan County, Sichuan Province (China). The matrix, which is generally enriched in dolomite, feldspar and clay minerals, but depleted in calcite, has much higher low-field magnetic susceptibility and magnetization, and lower coercivity in comparison with fragments and bulk samples. Magnetic behavior of the bulk samples and fragments is dominated by dia-/paramagnetic components, in contrast, small amounts of partially oxidized magnetite and lepidocrocite are present in the matrix. A simple conceptual model associating faulting-related effects was proposed to explain these significant differences in magnetic properties of fragments and matrix. During coseismic slip, intense shear may crush the pre-existing magnetic grains in fault rocks into finer ones; while stress and frictional heating, to a little extent, induce magnetic changes and thermochemical alterations of magnetic mineralogy in fault breccias, respectively. During interseismic periods, meteoric fluids would infiltrate and percolate into fault zone, and cause dissolution, precipitation and recrystallization of Fe-bearing minerals. As the diverse permeability structure and grain size of fragments and matrix, these effects would modify their magnetic mineralogy at various levels. Consequently, faulting-related effects, especially the fluid movements, taking place over many previous earthquake cycles, would be the most likely reasons for the observed different magnetic properties in fragments and matrix. It further proposes that magnetic studies of fault breccias would provide clues to help understand seismic faulting and history of fault activity.

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1. Introduction

The fault core, which is considered to represent fault zone in the seismogenic regime (Agosta and Aydin, 2006; Caine et al., 1996), generally evolves by grain comminution mostly consisting of early bulk crushing and late abrasion of grains, ultimately leading to the consumption of breccia materials in favor of fault gouge (Billi, 2005; Storti et al., 2003). This process thus usually results not only in physical degradation of fault zone, but also in geochemical and mineralogical alteration (Holland et al., 2006; Schulz and Evans, 1998). Consequently, it is pointed out that fault rocks record major episodes of fault movement, being one of the most important issues for understanding not only the nature of fault zones, but also the entire history of fault motion (Sibson, 1977; Tanaka et al., 2001). Fault rocks thus have been widely investigated in microstructure (Hausegger et al., 2010; Isaacs et al., 2007), grain size distribution (Billi, 2005; Hattori and Yamamoto, 1999; Storti et al., 2003; Wilson et al., 2005), mineral assemblage (Chen et al., 2007; Isaacs et al., 2007; Matsuda et al., 2004), geochemical composition (Chen et al., 2007; Isaacs et al., 2007; Kolodny et al., 2005; Tanaka et al., 2001), and permeability structure (Caine et al., 1996; Chen et al., 2011; Evans et al., 1997), to better understand their development and their physical/chemical attributes.

Despite the wealth of data about fault cores and related rocks, to date, magnetic properties of fault rocks are still scarce (Ferré et al., 2005; Fukuchi, 2003; Hirono et al., 2006; Mishima et al., 2006; Tanikawa et al., 2008), although it is believed that magnetic properties of fractured rocks are generally changed by the fragmentation and consequent alteration of magnetic minerals (Hailwood et al., 1992). Among fault rocks, fault breccia is a common product along upper crustal fault zones, particularly in the top few kilometers of crust. It is made up of the survivor coarse grains (i.e., fragments) and the surrounded fine materials (namely, matrix) that are generally produced by local fragmentation of larger particles (Woodcock and Mort, 2008). Thus, a comparative analysis of fragments and matrix in a breccia would yield information on the evolution of seismic fault.

In a previous paper, Yang et al. (2012) reported on differences in some magnetic properties comparing breccia fragments and matrix material from the Zhaojiagou outcrop of the Yingxiu–Beichuan fault,

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http://dx.doi.org/10.1016/j.tecto.2013.05.002

which ruptured during the Wenchuan earthquake in 2008 (moment magnitude Mw = 7.9). In the present paper, further mineralogical and magnetic analyses (e.g., thermomagnetic and low-temperature demagnetization) of these fragments and matrix are conducted to extend the previous work and (1) to document detailed magnetic properties of fragments and matrix of fault breccias, (2) to reveal the reasons responsible for the differences in magnetic properties between fragments and matrix, and (3) to infer their potential relationship with faulting-related effects.

2. Geologic settings and samples

The Longmenshan (LMS) thrust belt, about 500 km long and 30–50 km wide, lies between the Songpan–Ganzi terrane (a Triassic orogenic belt) to the west and the Paleozoic–Cenozoic sediments of the Sichuan basin to the east. It is dominated by four major northeast-trending thrusts: the Wenchuan–Maoxian fault (WMF), Yingxiu–Beichuan fault (YBF), Guanxian–Anxian fault (GAF), and Pingwu–Qingchuan fault (PQF) (Fig. 1). The fault system cuts Neoproterozoic basement metamorphics marked by steeply westward dipping detachments (e.g., the Pengguan complex, PGC), which is overlapped on the Sichuan foreland basin (Xu et al., 2008). The YBF, trending N30–55°E and dipping 50–80° to the northwest, was the main fault that ruptured in the Wenchuan earthquake that occurred on May 12, 2008. A north–northeast-striking rupture with a length of ~270 km was produced along the YBF, with a maximum displacement amounting to 8.0–10.0 m and 5.0–6.0 m in the vertical and horizontal directions, respectively (Liu-Zeng et al., 2009). Field investigation showed that most of surface ruptures occurred along a pre-existing shear zone in the LMS thrust belt. Generally, the main co-seismic shear zone consists of a fault core that includes a narrow fault gouge zone of <15 cm in width (generally 1–2 cm), a fault breccia zone of <~3 m in width, and a wide damage zone of >5 m in width that is composed of cataclastic rocks (Lin et al., 2010).

At the Zhaojiagou village (31.81°N, 104.43°E), Leigu Town, Beichuan County, the fracture zone of YBF extends laterally about 8 m. The fault plane strikes N45°E and dips 64–78°NW, and a fault scarp with ~8 m of vertical displacement was produced by the 2008 Wenchuan earthquake (Fig. 2a). The hanging wall protoliths consist of fine sandstones and carbonates, whereas the footwall is sandstone. The principal slip surface cuts through the carbonate layers. Different types of fault rocks occur across fault zone. From west to east, they are (1) shattered limestone, (2) fractured limestone, (3) crushed breccias, (4) gray and dark black gouge, (5) crushed breccias, (6) shattered breccias, and (7) fractured sandstone (Fig. 2b and c). The internal structure of the fault zone is relatively simple. Only one principal slip zone can be found and no branches exist. The width of the fault core is extremely narrow (~20 cm), consisting of ~2-cm-thick gray gouge in the center and weakly foliated yellowish crushed breccias besides. An even thinner black gouge layer (~3 mm) is developed adjacent to the gray gouge. The nonclay fault rocks are progressively cemented toward the fault center (Fig. 2c).

Microstructure of fault rocks is shown in Fig. 3. Dense X-shaped fractures are developed in breccias, and network of fractures increase toward the gouge, while fragmented grains also get finer. Gouge is foliated, and the formation of color bandings may be due to the different mineral compositions or grain sizes (Fig. 3a). Multiple deformation events and healing processes are clearly evidenced by cross-cutting veins, aperture filling, and fragment cementation (Fig. 3b), and dilatant fractures, dissolution textures, as well as the precipitation of new phases (Fig. 3c). The cemented breccias generally have little fractures (Fig. 3d).

Fifteen hand samples, including host rock, fault breccias and gouge, collected crossing the fault zone at this site, were magnetically studied by Yang et al. (2012). In the present study, six breccia samples of them were subjected to further magnetic and mineralogical analyses. Samples include shattered (ZJG-4) and crushed breccias (ZJG-6, -7, -8) next to the footwall damage zone, and crushed breccias (ZJG-12, -13) adjacent to the hanging-wall damaged zone.

The diagnostic character of fault breccias is the fragments-embedded-in-matrix texture (Fig. 4). The fragments are surrounded by a matrix of fine-grained comminuted material and clay minerals. The fragments show irregular, angular to slightly rounded, boundaries, indicating fragment wear, attrition, and fragment rotation.

In the laboratory, fragments and matrix of these breccias were separated following the procedure of Kolodny et al. (2005). Samples were broken up by hammer, cutter and pliers to sufficiently small pieces so that fragments could be separated from matrix by

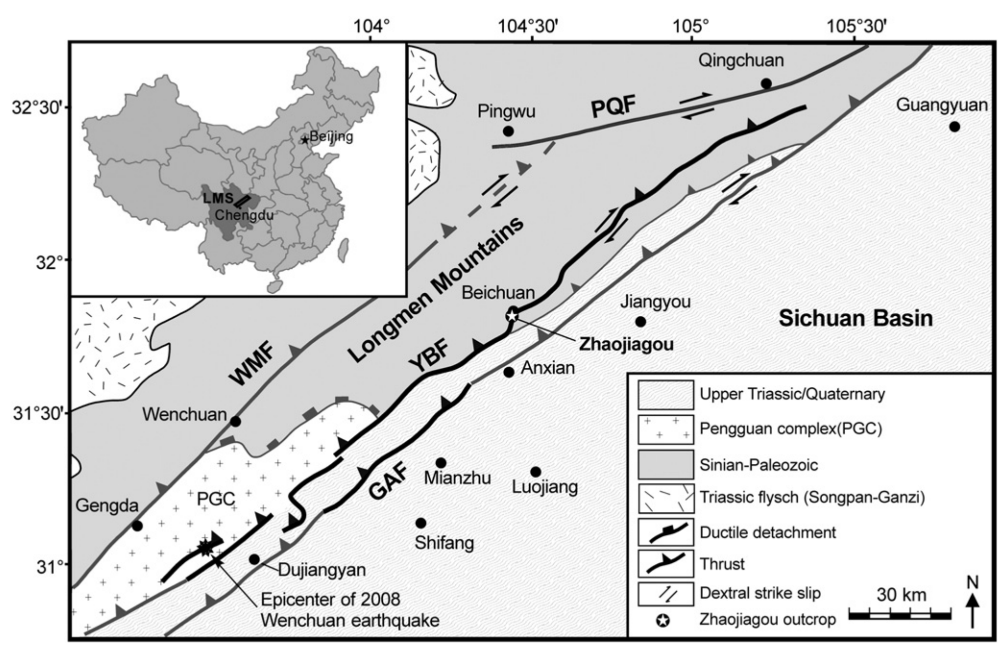

Fig. 1. Geological map of the central part of the Longmenshan (LMS) fault zone (compiled after Verberne et al., 2010). The coseismic surface ruptures induced by the 2008 Wenchuan Mw 7.9 earthquake are indicated by the bold portions of the various fault traces. YBF, Yingxiu–Beichuan fault; WMF, Wenchuan–Maoxian fault; GAF, Guanxian–Anxian fault; PQF, Pingwu–Qingchuan fault.

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