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Application of electron spin resonance (ESR) dating to ductile shearing: Examples from the Qinling orogenic belt, China

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ABSTRACT

Shear zones are common structures in orogenic belts and elucidation of the tectonic evolution of these orogenic belts to a large degree depends on understanding the kinematics and timing of shear deformation. However, there is a lack of an accurate, fast and convenient way to determine the timing of deformation. In this paper, we apply the ESR (electron spin-resonance spectroscopy) dating method to three syntectonic quartz veins from the Funiushan tectonic belt in the Qinling orogenic belt in central China. The results agree well with the available ages of deformation in the area obtained through other dating methods. This demonstrates the accuracy and feasibility of using the ESR method to date quartz crystals formed during deformation. The method is fast and convenient, and satisfies the accuracy requirement. It is an effective means for determining the timing of deformation, especially in areas with intensive fluid activity during deformation.

1. Introduction

Ductile shear zones are common in the crust and most develop at the middle to lower crustal levels. In the last few decades, extensive studies have been carried out on ductile shear zones, especially concerning their geometry, kinematics, dynamics and rheology. They are one of the most important structures in orogenic belts and record multiple phases of metamorphism and deformation of continental margins from plate subduction to formation of collisional orogenic belts (Bell, 1981, 1985; Bell et al., 1986; Vigneresse and Tikoff, 1990; Wallance, 1990; Sibson, 1997; Zheng, 2004). Ductile shear zones of different kinematics can form at different stages of deformation and detailed studies of the kinematics and ages of deformation in the shear zones is a key component of structural analysis and can shed significant light on the tectonic evolution of the orogens concerned (e.g., Lin, 2001; Little et al., 2002).

The ages of ductile shear zones can potentially be determined through dating metamorphic minerals that grew/cooled during deformation or dating syntectonic intrusions (Bottrell et al., 1990; Cesare, 1994; Wang and Lu, 1997; Lin, 2001; Zhang et al., 2002) They can also be bracketed by dating both pre- and post-kinematic intrusions/minerals (Lin, 2001). However, it is not always easy to determine the age relationship between intrusions and ductile shear zone accurately. In addition, the cooling age of a syntectonic mineral can be younger than the actual age of deformation when deformation occurred at a temperature that is higher than the closure temperature of the mineral (Wang and Lu, 1997; Fossen and Dallmeyer, 1998; Lin, 2001; Xiang et al., 2007). Therefore, it is necessary to explore new methods for determining the ages of shear zones. In this paper, we apply the electron spin-resonance spectroscopy (henceforth ESR) dating method to syntectonic quartz veins in the Qinling orogen in central China.

The quartz veins concerned were developed in the Funiushan tectonic belt in the Qinling orogen. They formed in shear zones by metamorphic fluids secreted during deformation, and their formation ages represent the ages of ductile shearing (Newton, 1990; Smith and Yardley, 1999). Here, we report the results of ESR dating of selected syntectonic quartz veins from the area and compare them with the available ages of deformation obtained by previous workers from other dating methods. We demonstrate that ESR dating of quartz can be an effective means for dating shear zone deformation.

2. Geological background

The Qinling orogenic belt is part of the central orogen that separates north and south China. It is generally accepted that the Qinling orogenic belt formed by the convergence and collision between

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the South China Block and North China Craton. It is structurally complex and has a long history of evolution (Zhang, 1988, 1996; Liu et al., 1993; Song et al., 2009; Dong and Santosh, 2016).

The Qinling orogeny is divided into North Qinling Belt (NQB) and South Qinling Belt (SQB) by the Shang-Dan Fault (SDF). The southern boundary of tNQB is the Shang-Dan suture zone while the northern boundary is the Luonan-Luanchuan fault (LLF or Luo-Luan fault). The Luo-Luan fault zone and the Waxuezi-Qiaoduan (or Wa-Qiao) fault zone constitute the Funiushan tectonic belt in north Qinling. It is made up of a series of south-vergent thrusts and is thus also called the thrust-nappe structural series in north Qinling (Zhang et al., 2001). The Funiushan tectonic belt is made up of several sub-parallel ductile shear zones and the deformed rocks between them. The tectonic belt suffers multiphase tectonic activities but the structural characteristics of the main orogenic event are still well preserved. Typical mylonite and syntectonic quartz veins formed during ductile shear deformation at the middle to lower crustal levels (Zhang et al., 1996; Ren et al., 2010). Both the mylonitic foliation and the syntectonic quartz veins strike 110–120° and dip 74–85°N and the geometry of the quartz veins show sinistral shearing. It suggests that these syntectonic quartz veins formed by metamorphic fluids that secreted during deformation and flew in rock fractures. The age of the quartz veins thus represents the age of the ductile shearing. These quartz veins were sampled for ESR dating to constrain the age of the shear zones (Fig. 1).

3. Samples and analytical techniques

3.1. Sample descriptions

Three quartz veins were sampled for ESR dating from two ductile shear zones, the Luo-Luan and Wa-Qiao fault zones. Sample XN82 is from a quartz vein hosted in the Kuanping group in the Luo-Luan fault zone (Fig. 2a and d), sample XN73 from a quartz vein in a felsic mylonite in the Wa-Qiao fault zone (Fig. 2b and e), and sample XN129 from a quartz vein hosted in Erlangping group located south of the Wa-Qiao fault zone (Fig. 2c and f). Three fine viens are concordant to the foliations in the host rocks. They are mylonitized and quartz grains show evidence for widespread dynamic recrystallization (Fig. 2d–f). They are interpreted as syntectonic veins and the ages of the three samples represent the time of tectonic activities in the Funiushan tectonic belt in the Qinling orogen.

3.2. Analytical techniques

ESR refers to the resonance absorption effect caused by magnetic moment of unpaired electron spin. ESR is a technique for studying materials with unpaired electrons. EPR spectroscopy is particularly useful for studying metal complexes or organic radicals. ESR was first observed by Zavoisky in 1944. ESR dating measures the amount of unpaired electrons in crystalline structures that were previously exposed to natural radiation. Age of substance can be determined by measuring the dosage of radiation since the time of its formation (Ulrich et al., 1988). It has attracted the attention of geological scholars since Ikeya (1975) published the treatise about stalactites dating by this method. The method has been widely used in seismic geology, engineering geology, quaternary chronology and archaeology (e.g., Grün, 1989a, b; Huang, 1994; Lee and Yang, 2003), and quartz and calcite can both be dated by the method. In this article we attempt to determine the ages of ductile shear zones by dating syntectonic quartz veins or new quartz crystals from mylonites that (re)crystallized during shearing. For detailed information about the principle and counting process of ESR dating, the readers are referred to Grün (1989a, b), Huang (1994) and Liang et al. (1993), Liang and Gao (1999) and references therein.

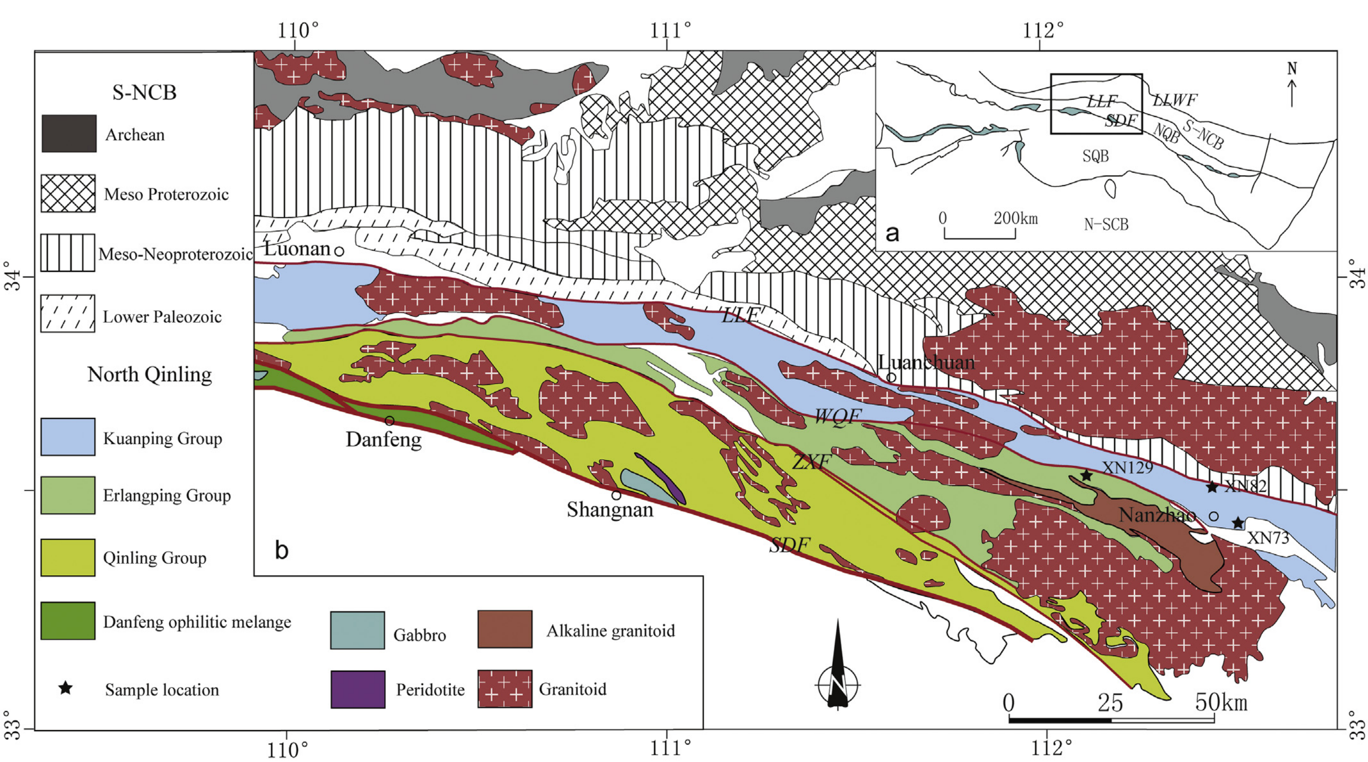

Fig. 1. (a) Sketch map showing the tectonic division of the Qinling (after Dong et al., 2013) and location of the study area. (b)Simplified geological map showing the locations of quartz veins dated in this study in the eastern Qinling belt. S-NCB, South North China Block; NQB, North Qinling belt; SQB, South Qinling belt; N-SCB, North South China Block; LLWF, Lingbo-Lushan-Wuyang Fault; LLF, Luannan-Luanchuan Fault; WQF, Waxuezi-Qiapduan Fautl; ZXF, Zhuyangguan-Xiaguan Fault; SDF, Shangdan Fault.