Journal of Asian Earth Sciences 139 (2017) 1–5

Contents lists available at ScienceDirect

Journal of Asian Earth Sciences

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

Preface

Deformation and rheology of the Asian continent

1. Introduction

The plate tectonic theory has been developed and accepted by most geologists since the last century when Joseph Barrell (1914) first introduced the concept of a strong lithosphere that overlies a weak fluid asthenosphere. The plate tectonic theory led to a revolution in geosciences in the 1960s of the 20th century, and explains well the tectonic evolution of the global lithosphere, especially the rigid oceanic lithosphere. But there are many problems when we apply the plate tectonic theory to the study of continents due to the large strength contrasts between oceanic and continental lithospheres. Compared with the oceanic lithosphere, the continental lithosphere has heterogeneous compositions, more complicated structures, long history, distinct rheological properties and lower deformation strength (Burov, 2011; Chen et al., 2012; Kirby, 1983). The continent has horizontally both marginal and inner-plate deformations and different rheological layers with the depth (Brace and Kohlstedt, 1980; Burgmann and Dresen, 2008; Kirby, 1983), which control the behavior of the continental lithosphere (Jackson, 2002). These properties, especially the rheological behavior, block the plate tectonic theory applying to the not-rigid continent. In the last decade, the continental rheology has become one of the cutting-edge research directions for the continental geodynamics (Burov and Watts, 2006).

Recently the experimental studies have achieved much progress for rock rheology. But most of experiments used man-made and very small samples (not natural) because of the sample size limit, very short time (shorter 10^{10} times than in nature). These short-time and small scale experiment results could not be commonly applied to study the very-long-time and very-large-scale natural continental rheology (Burov, 2011). There are plenty of natural rock rheological structures on the earth surface, by which we can directly study the continental rheological properties and avoid the uncertainties of the experimental studies. The results from natural rock rheological studies can reversely provide more practical boundary conditions for the experiment.

Therefore, we had an idea to organize a special volume of comprehensive studies on the continental deformation and rheology by both high P-T experiment and natural rock rheological structure analysis methods. We hope that the volume will help in achieving a better understanding of continental rheology, and will provide valuable and widely referred information source for the global earth science community.

1.1. Deformation and rheology in the middle crust

The middle crust is an important domain responding to the deformation of the continental lithosphere (Behr and Platt, 2011; Druguet and Hutton, 1998; Lloyd et al., 2011). The domain consists mainly of granitic rocks and is characterized by brittle-ductile transitional deformation. The rocks from the domain often suffered both brittle and ductile deformations with high rheological strength. Within the middle crust, the quartz grains have been involved into ductile/plastic deformation, while the plagioclase grains suffered transitional deformation from brittle to ductile (Rahl and Skemer, 2016). The middle crust is the most and strongest continental earthquake zone with low velocity and high conductivity in geophysics (Jackson, 2002; Lloyd et al., 2011), in which fluid-rock interactions are common (Wintsch and Yeh, 2013).

Strain localization is also the most important characteristics of strain accumulation and concentration in the continental middle crust (Druguet et al., 2013; Druguet and Hutton, 1998). Strain softening of crustal rocks is the most important triggering mechanism of strain localization. Different kinds of fluid-induced weakening mechanisms (e.g. hydraulic fracturing, reaction weakening and hydrolytic weakening etc.) and texture weakening (e.g. grain size reduction, preferred lattice orientation of crystals, banding of compositions) contributed significantly to strain localization (Czaplinska et al., 2015; Czertowicz et al., 2016).

To study the middle crust deformation, the surface outcropping in a metamorphic core complex (MCC) is a good target that records the fabrics from ductile domain to brittle domain during its exhumation. Although exhumation of metamorphic core complexes (MCCs) have been traditionally attributed to the collapse of orogenic over-thickened crust (e.g., Davis and Coney, 1979), but recent studies reveal that they could also result from the extension of the crust with normal thickness crust. In this volume, Liu et al. (2016) discussed the genesis of the Jinzhou MCC in southeastern Liaoning by detail detachment structure analysis, which shows that a pre-heated crust was responsible for the low flow stresses during the Jinzhou detachment faulting. Liang et al. (2017) provide detailed deformation strain and fabric analyses for the Xingcheng-Taili ductile shear zone and Yiwulüshan metamorphic core complex in the western Liaoning, which shows that the high-temperature shear zone was formed under lower stress conditions with higher strain rates, while opposite features exist in the lower temperature shear zone. These two MCCs detailed studies suggest that

http://dx.doi.org/10.1016/j.jseaes.2017.04.005

the genesis of the MCCs was related to the extension and thinning of normal thickness crust during deconstruction of the eastern North China Craton, instead of being a typical Cordilleran-type core complex that occurred in areas with over-thickened crust (Lister et al., 1984).

The Ailao Shan-Red River fault zone is a typical strike-slip fault related to the collision between Indian and Eurasian continents. Cao et al. (2016) carried out a detailed study to investigate how deformation promotes strain localization, and how the weak second phases and fluids trigger rheological weakening during retrogression near the ductile to brittle transition zone during the exhumation. while Wu et al. (2016), based on the detail microstructures, quartz c-axis fabrics, deformation temperatures and flow vorticity analyses, conclude that the northern Ailao Shan high-grade metamorphic belt has experienced progressive shear deformation from general shear-dominated flow progressively changed to a simple shear-dominated flow toward the late stage of ductile deformation.

Liang et al. (2016) describe a ductile shear zone along the Shangdan suture in Qiling. The quartz c-axis fabrics and kinematic vorticity suggest that the mylonites experienced ductile shear deformation under amphibolite facies conditions at temperatures of ∼ 500 - 650 °C with dextral shearing related to the collision between the North China and South China blocks along the Shangdan suture.

To investigate deformation mechanisms and the brittle–plastic transition that takes place in granitic rocks composed of quartz, plagioclase, and K-feldspar, Dang et al. (2016) carried out a high P-T leuco-granite deformation experiment study with a constant strain rate of $10^{-5}s^{-1}$ at different temperatures from 850 °C to 1050 °C and confining pressure (CP) of 300 MPa using a Paterson-type gas deformation apparatus. The study shows diffusion rims were observed between quartz, plagioclase, and microcline grain boundaries at 900–1050 °C with CP = 100–400 MPa. Partial melting appeared around plagioclase, microcline, and quartz grains at 1000 °C and 1050 °C. Microcline is a strong phase compared with quartz and plagioclase. Therefore, microcline is important for the brittle–plastic transition in granitic rocks, and the depth of that transition in the middle crust will be greater where the granitic rocks in the crust containing large amounts of microcline.

1.2. Partial melting and rheology

The rock deformation obeys the elastic-plastic rules in solid state before melting (Ramsay, 1982, 1980; Ramsay and Graham, 1970; Susan, 1981, 1973), but when the rock starts to melt and becomes to solid-liquid two facies deformed medium, the rock physical properties will be greatly changed with big drop of strength, which results in a big difference of the rock rheological behavior (e.g. Cavalcante et al., 2016; Gorczyk and Vogt, 2015; Herwegh et al., 2011; Sawyer, 1994; Vanderhaeghe, 2009; W. J. Collins and Sawyer, 1996). Anataxis is a basic and common geological transition process in the lithospheric evolution, which influences and controls the geophysical properties, deformation and rheology of the lithosphere (Brown et al., 2011; Lejeune and Richet, 1995; Renner et al., 2000; Takeda and Obata, 2003).

In this volume Zhou et al. (2016) provide an experimental study on creep of partially molten granulite under high temperature and wet conditions, which shows that at high temperatures of 1125–1150 °C, the samples were deformed mainly by grain boundary migration recrystallization accommodated by partial melting and metamorphic reactions characterized by neo-crystallization of fine-grained olivine. Partial melting at high temperatures of 1125–1200 °C, which induces grain boundaries slipping and enhances diffusion, has a significant weakening effect on the rheology of granulite. Chen et al. (2017) describe a nice natural metatexite-diatexite transition profile in Fuhu, Guangdong Province, SE China to evaluate the existence of three rapid strength drops of the rock-assemblage at melt fraction around 7%, 21%, and 41% respectively based on the published experimental data of partially molten rocks, the newly identified drop is termed as the ‘framework-melting transition’ at melt fraction around 21%.

1.3. Lithospheric rheology

The continent lithosphere has different rheological layers with the depth (Brace and Kohlstedt, 1980; Burgmann and Dresen, 2008; Kirby, 1983), which control the behavior of the continental lithosphere (Jackson, 2002). But there is no widely acceptable model for the lithosphere strength structure, such as ‘Jelly Sandwich’ model (Burov and Diament, 1995; Kirby, 1985; Ranalli and Murphy, 1987), which suggests a weak lower crust; ‘crème brûlée’ model (Burov and Watts, 2006; Jackson, 2002), which augured a weak upper mantle; ‘banana split’ model considers the weakness of major crustal fault zones throughout the thickness of the lithosphere, caused by various strain weakening and feedback processes (Burgmann and Dresen, 2008). Although the models are different, the fact of lithosphere with a rheologically layered structure is widely accepted (Burgmann and Dresen, 2008; Burov, 2010; Burov and Watts, 2006; Chen et al., 1983; Jackson et al., 2008; Wang and Cheng, 2012).

The tectonic stress field in the middle-upper-crust is closely related to the structure and rheology of the lithosphere. To determine the stress field in the deep crust, Li X. et al. (2016) investigate the focal mechanism solutions of 62 earthquakes that occurred between 2009 and 2015 in the Bohai Sea, eastern North China Craton and its surrounding areas using broadband seismic waveforms collected from 140 stations. The study suggests that the anomalous stress regime is caused by the local extension resulting from the movement of strike-slip faults under the action of the regional stress field. The existence of low viscosity bodies may indicate weakness in the crust that favors the accumulation of tectonic stress and triggers large earthquakes.

Oruç and Sönmez (2017) provide a study of rheological structure of the lithosphere in the Eastern Marmara Region, Turkey. A two-dimensional strength profile has been estimated for rheology model of the study area based on the Parker-Oldenburg gravity inversion algorithm and suggests that the rheological structure is consisting of a strong upper crust, a weak lower crust, and a partially molten upper lithospheric mantle.

Based on the high P-T experiment of natural granulite, Zhou et al. (2016) argued that a wet and cool continental lower crust may still be in brittle deformation regime, whereas a hot lower crust may likely have a weak layer with plastic deformation.

1.4. Rheological parameter estimation

In this volume, Sun et al. (2017) established a pinch-and-swell structure rheology gauge for determining rock paleo-rheological parameters in Taili, western Liaoning of North China, which can only be available under the condition that the viscosity ratio between the competent layer and its corresponding matrix layer is larger than 10. The competent layers of the pinch-and-swell structures were presented in the study as power-law flow with the values of stress exponent of the competent layer that increased with the thickness of the layer. Grain-size plays an important role in the rheology of pinch-and-swell structures.

Li Z. et al. (2016) present a combined field measurement and finite element modeling analysis of the mullions occurring on the contact of two granitic rocks with different grain size in Taili high-strain ductile shear zone, western Liaoning. The results show that the rheology and deformation