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P-from wave velocities and anisotropy of typical rocks the Yunkai Mts. (Guangdong and Guangxi, China) and constraints on the composition of the crust beneath the South China Sea

Shaocheng Ji[a,*], Qian Wang[a,1], Matthew H. Salisbury[b], Yuejun Wang[c], Dong Jia[d]

[a] Département des Génies Civil, Géologique et des Mines, École Polytechnique de Montréal, Montréal, Québec H3C 3A7, Canada
[b] Geological Survey of Canada-Atlantic, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2, Canada
[c] Department of Earth Sciences, Sun Yat-Sen University, Guangzhou 510275, China
[d] Institute of Energy Sciences, School of Earth Sciences and Engineering, Nanjing University, Nanjing 210093, China

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ABSTRACT

In order to provide constraints on the interpretation of seismic data of the crust beneath the South China Sea (SCS) and its continental margins, we have measured P-wave velocities and anisotropy as a function of hydrostatic confining pressure, up to 650 MPa, for 31 representative samples (i.e., granite, diorite, felsic gneiss, mylonite and ultramylonite, amphibolite, schist, and marble) from the Yunkai Mts (Guangdong and Guangxi Provinces, China) that represent the crystalline basement beneath the continental margins of the SCS. The intrinsic velocity of each crack-free rock increases with increasing density (ρ) which is linearly dependent on the chemical composition: ρ increases with increasing MgO, CaO, FeO + Fe_2O_3, and Al_2O_3 contents, but decreases with increasing contents of SiO_2 and Na_2O + K_2O. Most of the rocks have small (<4%) or moderate (4–8%) seismic anisotropy because (1) the contribution of quartz to the bulk anisotropy opposes that of feldspar, and (2) the rocks only contain small amounts of amphibole and/or mica. The interpretation of 12 seismic transects suggests that the crust of the Cathaysia block (the southern part of South China) has a mafic-to-felsic layer thickness ratio ($R_{m/f}$) of 41–43% and the ratio shows a general increase from the continental margin to the central basin. The high velocity (7.0–7.6 km/s) materials in the lower crust could be either the former lower crustal mafic rocks that were present before rifting, which have experienced less extensional thinning than the felsic upper crust, or the materials crystallized from mafic magma which underplated the lower crust from the partially molten upper mantle during rifting.

1. Introduction

During the past four decades a large number of laboratory measurements of P- and S-wave velocities and anisotropy have been performed on various types of rocks ranging from sedimentary, igneous and metamorphic rocks to upper mantle xenoliths (e.g., Ji et al., 2002; Ivankina et al., 2005; Bostock and Christensen, 2012). The studied samples were collected mainly from North America and Western Europe, Japan and the ocean basins (See Fig. 1 in Ji et al., 2007). Few samples from areas in central and southeastern Asia except the Dabie-Sulu ultrahigh- and high-pressure metamorphic belt (Kern et al., 1999, 2002; Wang et al., 2005a,b; Ji et al., 2007, 2009; Wang and Ji, 2009) have been experimentally measured at high hydrostatic pressures in terms of seismic wave velocities and anisotropy. The interpretations of seismic reflection, refraction and receiver function data from this vast region are severely limited by lack of ground truth rock physical property constraints. This paper presents experimental P-wave velocity and anisotropy data as a function of hydrostatic pressure for typical crustal rocks from the Yunkai Mts. (Guangdong Province and Guangxi Zhuang Autonomous Region, Fig. 1), which are thought to constitute the crystalline basement of the Cathaysia Block (i.e., Southern part of South China, Li et al., 2008; Shu et al., 2011), and discusses the implications for the composition of the crust beneath the South China Sea (SCS, Fig. 2).

The SCS is the largest marginal sea basin in Southeast Asia (Fig. 2). It is located tectonically at the junctions of the Eurasian plate, the Indo-Australian plate, the Philippines sea plate, and the Pacific plate. Surface wave tomography (Cao et al., 2002; Zhou

* Corresponding author.
E-mail address: sji@polymtl.ca (S. Ji).
[1] Present address: State Key Laboratory of Isotope Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China.

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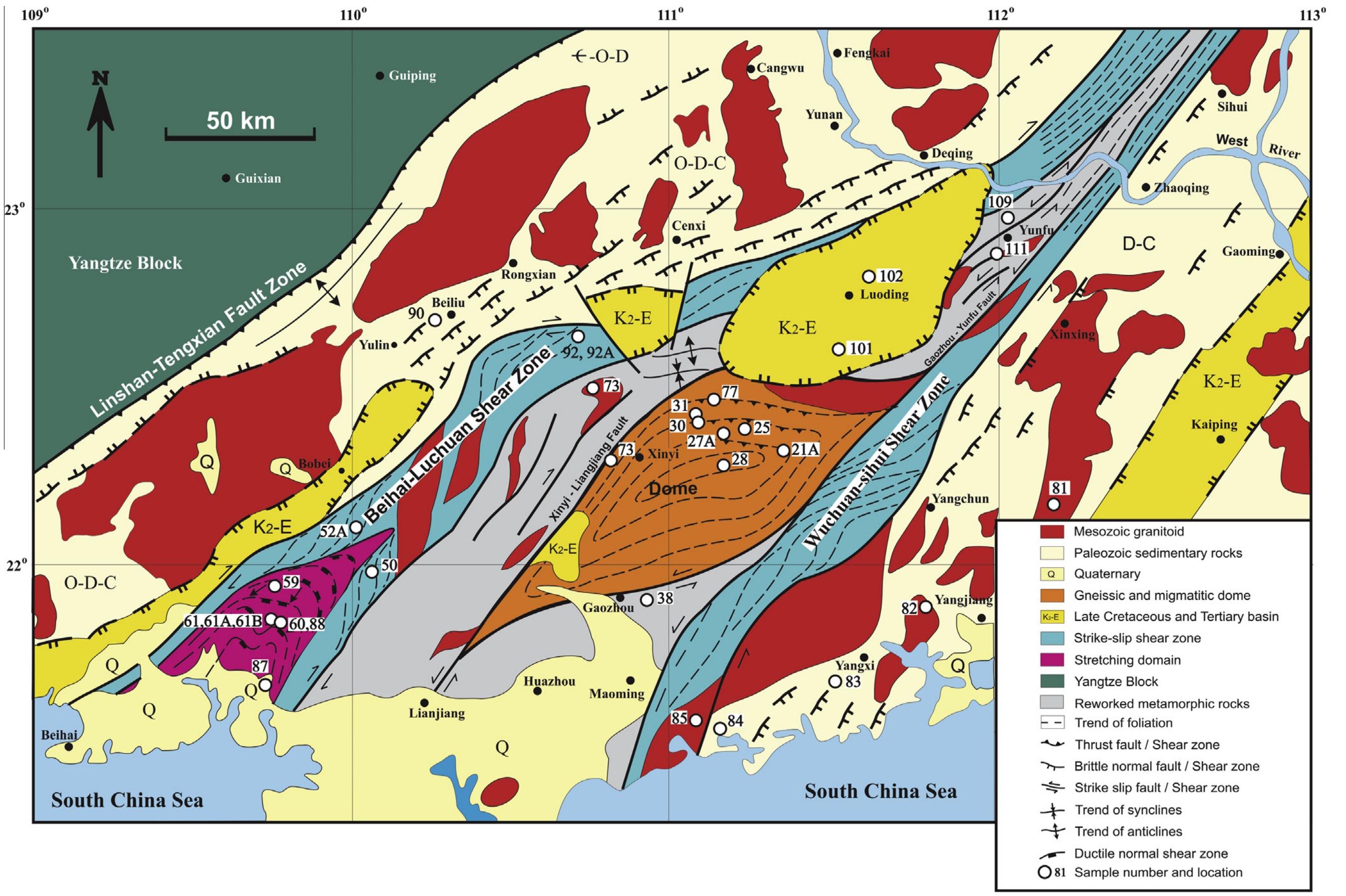

Fig. 1. Simplified geological map of the Yunkai Mts, South China. Circles show sample localities.

et al., 2012) suggested that the lithosphere thickness is 70–80 km beneath the northern SCS and 60–65 km beneath the Central basin (Fig. 2). The data from magnetic anomalies (Briais et al., 1993) show that the SCS seafloor spreading started 37.8 Ma ago (chron C17) and finished near 15.5 Ma ago (after chron C5C, 16.7 Ma). The SCS was <500 km wide at the time of chron C10 (28.7 Ma, Yeh et al., 2010). Several tectonic models have been proposed for the formation and evolution of the SCS: (1) The opening of the SCS was related to the pull-apart processes of the South China continent (including the Yangtze and Cathaysia blocks), caused by the left-lateral shear along the Ailao Shan-Red River fault zone in response to the India-Eurasia continent-continent collision and southeastward escape of the Indochina block during the Tertiary (Tapponnier et al., 1982; Briais et al., 1993). This model was based on plasticine experiments, field investigations along the Ailao Shan-Red River fault zone (e.g., Wu et al., 1989; Tapponnier et al., 1990; Leloup et al., 1995) and magnetic anomaly lineations (e.g., Briais et al., 1993). (2) The opening of the SCS was due to extension caused by an upwelling mantle plume beneath the SCS during the Cenozoic after the closure of the Tethys Ocean (e.g., Fan and Menzies, 1992; Li et al., 1998; Zhu et al., 2004). This model was based on petrological and geochemical studies of the Cenozoic basalts and mantle xenoliths from the region. (3) The SCS is a back-arc spreading basin related to subduction of the Indo-Australian plate and the Philippines Sea plate along the southeastern margin of the Eurasia plate (Hawkins et al., 1990; Stern et al., 1990; Aubouin, 1990; Xia et al., 2006). However, so far no consensus has been reached about how the SCS was formed due in part to the lack of constraints on the lithological composition of the crust beneath the SCS. Many important questions have not been answered: What are the extensional and thinning styles for the various layers with different compositions within the crust beneath the SCS? How did the Red-River shear zone extend in the SCS? Were the mafic materials added to the crust by the partial melting of a mantle plume or upwelling beneath the SCS? What was the mechanism of rifting? To answer these questions, one should use the existing seismic data from the SCS and adjacent continental margins. During the last three decades, more than 10,000 km of multiple wide-angle seismic or deep seismic profiles (Figs. 2 and 3) have been carried out in the SCS for fundamental research and particularly for petroleum and natural gas exploration (Liao et al., 1988; Hayes and Nissen, 2005; Nissen et al., 1995; Kido et al., 2001; Clift and Jin, 2001; Qiu et al., 2000; Yan et al., 2001; Huang et al., 2005; Zhao et al., 2003, 2006, 2007; Xia et al., 2008; Ruan et al., 2009; Wu et al., 2010, 2012; Yeh et al., 2010). However, the geological interpretation of the seismic data in terms of basement lithology, composition and structure has been severely limited due to the lack of ground truth petrophysical data for the basement rocks from the region. For this purpose, we conducted a detailed study on P-wave velocities and anisotropy of 31 representative samples from the Yunkai Mts on the northern margin of the SCS (Fig. 1) in order to provide some basic constraints on the seismic properties of the SCS basement. It is necessary to mention that S-wave velocities, shear-wave splitting, and petrofabric data for this set of samples have been reported in a separated paper (Ji et al., 2016).

2. Geological background of Yunkai Mts

The southern and in particular the northern margin of the SCS is thought to be underlain by metamorphic basement with lithological compositions similar to those of the Yunkai Mts. The metamorphic

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