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S-wave velocities and anisotropy of typical rocks from Yunkai metamorphic complex and constraints on the composition of the crust beneath Southern China

Shaocheng Ji [a,*], Qian Wang [a,1], Tongbin Shao [a], Hiroto Endo [b], Katsuyoshi Michibayashi [b], Matthew H. Salisbury [c]

[a] Département des Génies Civil, Géologique et des Mines, École Polytechnique de Montréal, Montréal, Québec H3C 3A7, Canada
[b] Institute of Geosciences, Shizuoka University, Shizuoka 422-8529, Japan
[c] Geological Survey of Canada-Atlantic, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia, B2Y 4A2, Canada

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ABSTRACT

In order to constrain the interpretation of seismic data from receiver functions and deep profiles of the crust beneath southern China (Cathaysia and Yangtze blocks), we have measured S-wave velocities (V_s) and splitting as a function of hydrostatic confining pressure up to 650 MPa for 22 representative samples (i.e., granite, diorite, felsic gneiss and mylonite, amphibolite, schist, and marble) from the Yunkai metamorphic complex (China) that represent the crystalline basement beneath the region. The experimental data were combined with electron backscattering diffraction (EBSD) analysis of rock-forming minerals to constrain variations of V_p/V_s ratios and understand the origin of seismic anisotropy. The crusts beneath the Yangtze and Cathaysia blocks have different average thicknesses ($H = 35.4 \pm 6.3$ km and 29.8 ± 1.8 km, respectively) but display almost the same V_p/V_s values (1.73 ± 0.08 and 1.74 ± 0.04, respectively). These ratios correspond to an average of bimodally distributed granitic and gabbroic lithologies which are dominant, respectively, in the upper and lower crusts, instead a homogeneous andesitic composition of the overall crust. Positive and negative correlations between H and V_p/V_s occur in west and east parts of southern China, respectively. The negative correlation indicates basaltic underplating from a partially molten mantle wedge above the subducting Pacific plate into the southern China crust, whereas the positive correlation implies that much larger thinning strain has taken place in the high temperature mafic lower crust (high temperature) than in the low temperature felsic upper crust during Mesozoic-Cenozoic tectonic extension.

1. Introduction

The crust of a planet should have a bulk composition of basalt if it is generated by single-stage partial melting of peridotitic mantle (Anderson, 1989). This is the case of the Earth's oceanic crust which is only ~7 km thick on average. However, the Earth's continental crust, which has an average thickness of 34 km although the craton, shield and orogen are ~40 km thick, has an average composition of intermediate or andesitic bulk composition (e.g., Rudnick and Fountain, 1995; Rudnik and Gao, 2014; Hacker et al., 2015). In order to explain this character, compositional differentiation by intracrustal multiple partial melting and subsequent removal of the residual materials (mafic or ultramafic cumulates) from the continent into the mantle are assumed to have taken place throughout Earth history. Delamination of dense eclogite, which has been transformed from mafic igneous and metamorphic rocks, from the lower crust of thickened orogenic belts into the upper mantle, and subduction of mafic layers within the continental slabs into the upper mantle are believed to have been two important geological processes for the recycling of crustal materials. Although the composition and structure of the continental crust have been studied extensively during recent decades, many questions remain, not only regarding its evolution, but also its fundamental properties and behavior. Certain properties appear common to the continental crust, such as a trend toward higher P- and S-wave velocities (V_p and V_s) with increasing depth. But it is often unclear whether these increases are caused by increasing lithostatic pressure (Ji et al., 2009), changes in chemical composition (Rudnik and Gao, 2014; Huang et al., 2013), metamorphic reactions or phase transformations (Hacker et al., 2011). In particular, there has been a general lack of understanding of the spatial distribution of lithologies within the continental crust beneath each tectonic block with a different geological setting, due to its inaccessibility. It is still unclear whether the andesitic composition of the bulk continental crust is produced by a relatively homogeneous

* 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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distribution of intermediate composition through the whole crust or an average of a bimodal distribution of granitic and gabbroic lithologies which predominate, respectively, in the upper and lower crusts. Previous lithological and seismological investigations yield two distinct results. Xenoliths (e.g., Downes et al., 1990; Leyreloup et al., 1977; Rudnick, 1992; Zhou et al., 2002) and exposed deep-sited terranes of high grade metamorphic rocks (e.g., Fountain and Salisbury, 1981; Ji and Salisbury, 1993; Ji et al., 1993; Percival et al., 1992) which represent the deep crust are commonly a mixture of lithologies ranging from granite or felsic gneiss to gabbro or mafic gneiss with an overall average composition approximating diorite. However, seismic compilations from Europe and North America show that the lower crust typically has P-wave velocities of 6.8–7.2 km/s, which are significantly higher than the average crustal velocity of 6.45 ± 0.21 km/s (Christensen and Mooney, 1995), indicating a predominance of mafic composition for the lower crust. It is thus important to determine if this pattern present elsewhere.

Southern China consists of the Yangtze block in the northwest and Cathaysia block in the southeast (Fig. 1, Sun, 2016). Deep seismic sounding profiles (e.g., Deng et al., 2011, 2014; Li et al., 2015; Zhang et al., 2013; Zhao et al., 2010, 2013) and measurements of teleseismic receiver functions at hundreds of broad-band seismic stations (Chen et al., 2010; He et al., 2013, 2014; Hu et al., 2003; Huang et al., 2010, 2012, 2014, 2015; Li et al., 2013; Ma and Zhou, 2007; Shen et al., 2013; Xu et al., 2007; Zhao et al., 2015) have been performed in southern China during the last 15 years. Interpretations of the seismic data are severely limited, however, by lack of rock physical property constraints from the region. Justified interpretation of the geophysical data in terms of geology and tectonics should go through carefully geological mapping, high pressure experiments and petrophysical investigations in order to eliminate the multiple-solutions ambiguity. For this reason, we carried out new high-pressure experimental measurements of S-wave velocities and anisotropy as a function of hydrostatic pressure in typical crustal rocks from the Yunkai metamorphic complex (Guangdong Province and Guangxi Zhuang Autonomous Region), which are thought to constitute the crystalline basement in southern China (Shu et al., 2015; Wang et al., 2007, 2013a, 2013b). The experimental results together with electron backscattering diffraction (EBSD) analysis of rock-forming minerals from representative samples enable calibration of seismic properties of the crustal rocks, and aid in the interpretation and analysis of what have been measured from the crust beneath the Yangtze and Cathaysia blocks using seismological methods. More specifically, the ground truth study allows justified interpretation of the crustal composition that is consistent with conceptual understanding and quantitatively consistent with all available data, and helps to minimize errors in the interpretation.

2. Geological background of Yunkai Mts.

The boundary between the Yangtze craton and the Cathaysia block (Fig. 1) is marked by the Shaoxing-Pingxiang fault (Ji et al., 2009; Shu et al., 2015). To the northwest of this boundary fault, the Yangtze block is characterized by a metamorphosed Archean crystalline basement (3.2–2.9 Ga, Jiao et al., 2009) and an overlying sequence composed of weakly metamorphosed Neoproterozoic (0.74–0.84 Ga) to middle Triassic marine sedimentary rocks. These sedimentary rocks were folded with fold axes aligned N40–60°E, which are approximately parallel to the Shaoxing-Pingxiang fault. To the southeast of the boundary fault, the Cathaysia block, which represents one of several fragments derived from the Gondwana supercontinent (He et al., 2013), is characterized by a dense array of Jurassic-Cretaceous granitoids and rhyolites (Zhou et al., 2006), and Late Triassic to Early Cretaceous continental basins. The igneous rocks, which formed by crustal melting (Jahn et al., 1990), fall into three main age groups: 180–160 Ma, 160–140 Ma, and 140–79 Ma, corresponding to the early, mid, and late Yanshanian periods, respectively (Wang et al., 2013a). The early Yanshanian volcanism is a K-rich calc-alkaline series interlayered with continental or shallow water detrital rocks. However, the late Yanshanian volcanism, which is associated with continental red beds along NE-SW-trending grabens, is related to intracontinental rifting. The basement of the Cathaysia block is Paleo- to Neoproterozoic continental crust which is chiefly composed of amphibolite-facies metamorphic rocks such as schists, gneisses, amphibolites, and migmatites. Based on zircon inheritance ages of the Phanerozoic granitoids, previous workers suggested five stages of Precambrian accretion for the Cathaysia block, which occurred at 2.5, 2.1, 1.9–1.7, 1.4–1.2, and 1.1–0.8 Ga (Chen and Jahn, 1998; Jahn et al., 1990; Wan et al., 2010; Wang et al., 2007; Yu et al., 2010). The collision between the

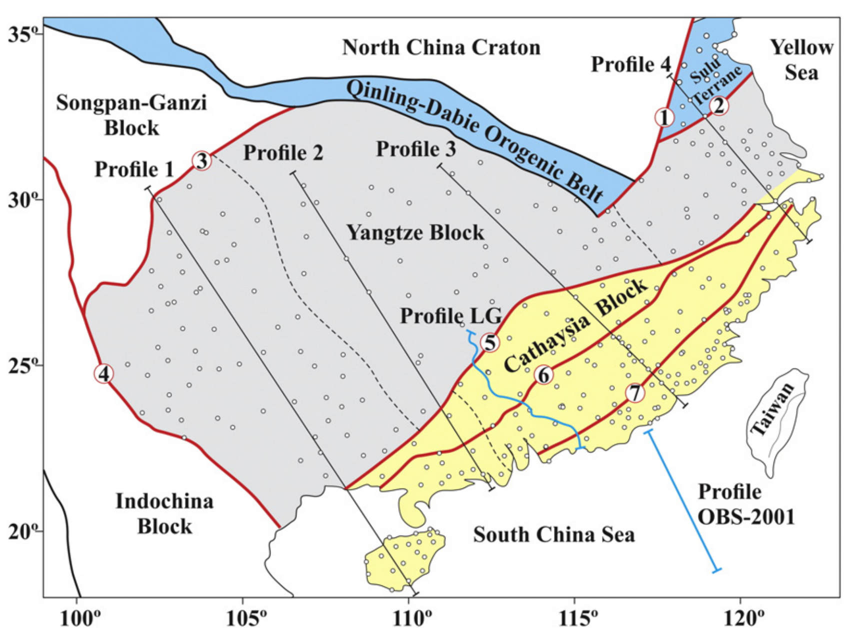

Fig. 1. Tectonic framework of southern China, distribution of seismic stations for receiver function studies (open circles) and location of two V_p–V_s-depth profiles (LG and OBS-2001). F1: Tanlu Fault; F2: Jiashan-Xiangshui Fault; F3: Longmen Shan Fault; F4: Ailao Shan-Red River Fault; F5: Shaoxing-Pingxiang Fault; F6: Beihai-Luchuan shear zone; F7: Zhenghe-Dapu Fault. Boundaries of the subdomains in each block are marked by dotted line.