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Late Mesozoic magmatic plumbing system in the onshore–offshore area of Hong Kong: Insight from 3-D active-source seismic tomography

Shaohong Xia [a,*], Dapeng Zhao [b]

[a] CAS Key Laboratory of Marginal Sea Geology, South China Sea Institute of Oceanology, Chinese Academy of Sciences, Guangzhou 510301, China
[b] Department of Geophysics, Tohoku University, Sendai 980-8578, Japan

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ABSTRACT

We used active source wide-angle seismic data to determine a high-resolution P-wave crustal tomography beneath the onshore–offshore area of Hong Kong at the southern end of a broad belt dominated by the late Mesozoic intrusive and extrusive rocks in the coastal region of Southeast China. The active source data are much more precise than the natural earthquake data and so can be used to study the fine crustal structure. Our results reveal a localized high-velocity anomaly in the lower crust offshore between Hong Kong and Dangan Island, which may reflect basaltic underplating that is closely associated with formation of voluminous silicic eruptions and granitoid plutons in the onshore–offshore area of Hong Kong. Tilted high-velocity zones connecting with the localized high-velocity anomaly in the lower crust are clearly visible in the entire crust beneath Dangan Island and the calderas of Hong Kong. Taking into account the previous geochemical, petrologic and numerical modeling results, we think that the tilted high-velocity zones may be the results of mingling of mafic and felsic end members and extreme degree of crustal partial melt extraction necessary to generate a large amount of extrusive rocks in the calderas, reflecting cooled magma conduits as a manifestation of solidified Late Mesozoic magmatic plumbing system in the crust. Considering the petrologic and geochemical characteristics of the late Mesozoic granites and basalt in Southeast China, we suggest that subduction and dehydration of the paleo-Pacific plate might trigger the basaltic magma underplating and result in extensive crust–mantle interaction, which not only provided necessary heat energy to cause the crustal partial melting, but also added minor mafic materials to the newly generated granitic melts. This model explains our tomographic results as well as the intimate mingling of coeval mafic and silicic magmas in Hong Kong. Intersecting faults could play an important role in forming magma conduits and loci of fissure-like volcanic centers.

1. Introduction

As one of the world's major urban communities, Hong Kong is located in a large zone dominated by Upper Jurassic to Lower Cretaceous intrusive and extrusive rocks in the coastal region of Southeast China (Davis et al., 1997; Fig. 1). Its development is hindered by the rugged terrain and steep-sided islands, which highlights the need for systematic and accurate geological information, and the importance of understanding geological processes (Fletcher, 1997). The geology of Hong Kong has been investigated in an extensive spectrum of research including structural control and tectonic setting of the Mesozoic volcanism (Campbell and Sewell, 1997), U–Pb zircon ages for the Mesozoic igneous rocks (Davis et al., 1997; Sewell et al., 2012), geochemistry of coeval Mesozoic plutonic and volcanic suites (Sewell and Campbell, 1997), volcanic–plutonic connections in a tilted nested caldera complex (Sewell et al., 2012), and neotectonic fault activity (Ding and Lai, 1997). These studies revealed the existence of four distinct periods of the Mid-Jurassic to the Lower Cretaceous volcano-plutonism, and identified the spatial distribution and geometry of the Jurassic and Cretaceous calderas, dykes and plutons which were structurally controlled by NE-, NEE- and NW-trending faults (Fig. 1b), and established close connections in time and space between magma chambers and their overlying calderas by exceptional exposures of a tilted Early Cretaceous nested caldera complex in southeastern Hong Kong. Most of the previous studies, however, are confined to geochemistry, petrology, chronology and outcrop investigations of the Late Mesozoic magmatism in the onshore area of Hong Kong. So far, there have been very few geophysical studies on the location and geometry of magmatic plumbing systems of Late Mesozoic large silicic calderas and

* Corresponding author.
E-mail addresses: shxia@scsio.ac.cn (S. Xia), zhao@aob.gp.tohoku.ac.jp (D. Zhao).

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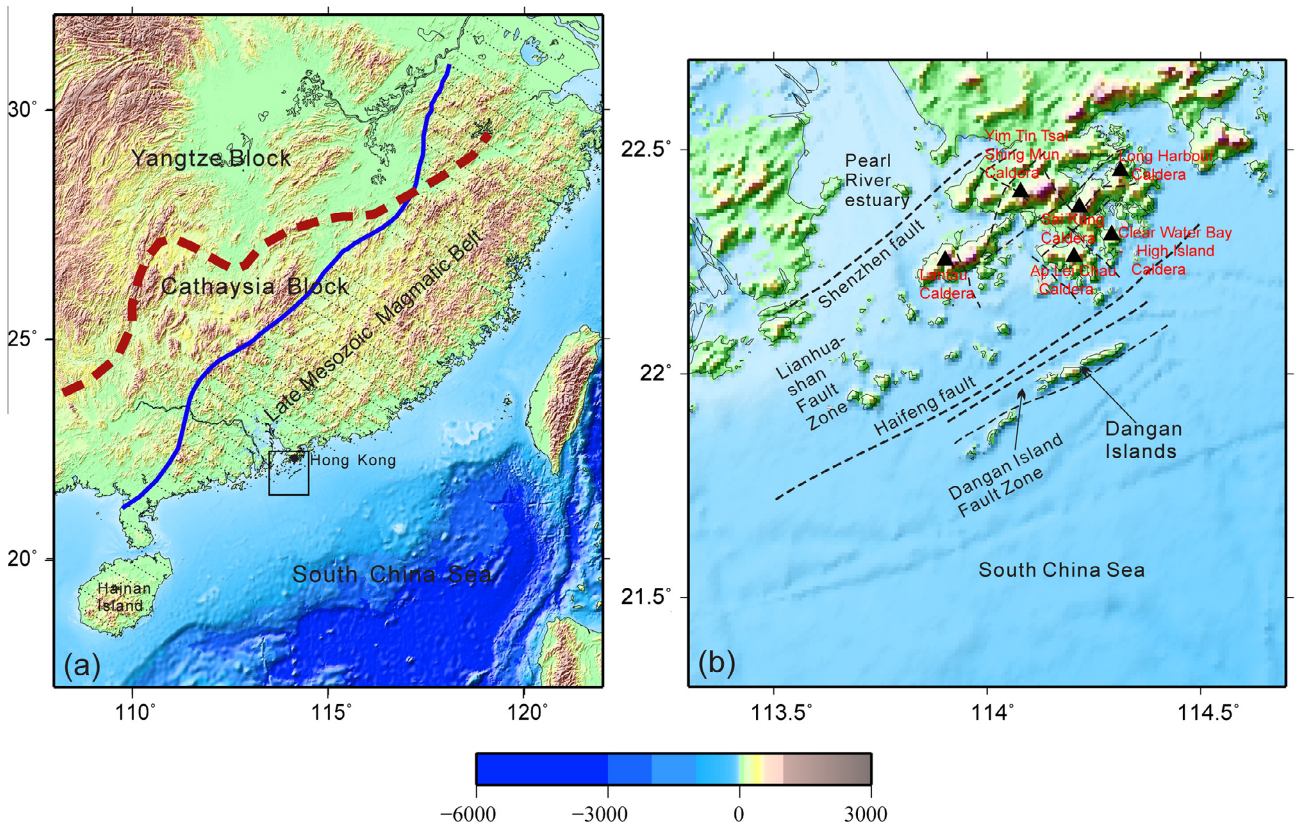

Fig. 1. (a) Tectonic background of South China. The bold red dashed line denotes the estimated boundary between the Yangtze Block and the Cathaysia Block. The gray hatched part denotes the Late Mesozoic magmatic belt in Southeast China. The box shows the present study area. (b) Distribution of faults and Late Mesozoic calderas in the study area. The triangles show the locations of identified calderas. The dashed lines denote the faults that are closely associated with the calderas and magmatism. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

plutonic masses in and around Hong Kong, except for a gravity model of the crust along a section (Fletcher et al., 1997). Among the various geophysical methods, seismic techniques provide a robust way for high-resolution structural imaging of the medium and they have been applied widely to various regions of the world (e.g., Christensen and Mooney, 1995; Tian et al., 2007; Xia et al., 2007b; Padhy et al., 2011; Cheng et al., 2011, 2014; Zhao, 2012; Chen et al., 2014; Liu et al., 2014). Velocities of seismic waves provide information on compositional variations and physical properties of materials in the crust and mantle (e.g., Judenherc and Zollo, 2004; Xia et al., 2008a,b; Gupta et al., 2009; Yamada et al., 2009; Zhao et al., 2011, 2013).

For a better understanding of the Late Mesozoic magmatism in and around Hong Kong, an onshore–offshore wide-angle seismic experiment was carried out in 2004 (Xia et al., 2007a). The relationship between the crustal structure and local earthquake distribution was investigated using the data collected by the experiment (Xia et al., 2012). In this work we reprocess the wide-angle seismic data to determine a more precise and detailed crustal tomography of the study area by averaging 100 inverted 3-D crustal models using a Monte Carlo method, and conduct extensive synthetic tests to examine the spatial resolution and reliability of the tomographic images. Then we focus on the velocity structure beneath the calderas and its implications for the Late Mesozoic magmatic plumbing system and possible role of basaltic underplating in magmatism beneath Hong Kong.

2. Tectonic setting

Mesozoic plutonic and volcanic rocks crop out over approximately 85% of the land area of Hong Kong (Davis et al., 1997). The U–Pb dating of Mesozoic igneous rocks from Hong Kong has constrained the timing of four major periods of volcanism and plutonism at 165–160 Ma, 148–146 Ma, 143 Ma and 141 Ma (Davis et al., 1997; Sewell et al., 2012), indicating that magmatism occurred in discrete episodes. The isotope signatures of Mesozoic granites revealed that the magmatic suites had a mantle origin with a decreasing crustal contribution from two distinct sources (Sewell and Campbell, 1997). The earliest mantle-derived magmas with higher $^{87}Sr/^{86}Sr_0$ ratios and lower ε_{Nd} values in the northwestern Hong Kong contained a Late Archaean crustal component, whereas in the southeastern Hong Kong the younger magmas were contaminated by a more mafic Mesoproterozoic crustal component (Sewell, 1992; Darbyshire and Sewell, 1997). The strongest mantle influence is shown by magmas that were intruded along the boundary between the two dominant crustal sources, suggesting that a major crustal discontinuity that promoted the passage of magmas to the surface is present at depth beneath Hong Kong between Late Archaean and Mesoproterozoic terranes (Sewell and Campbell, 1997). This discontinuity is situated approximately along the axis of the Lianhuashan Fault Zone that can be traced for over 400 km through the marine provinces of SE China of 30–50 km wide, and it is one of the dominant structural features of SE China (Ding and Lai, 1997). Numerous volcanic centers and plutonic assemblages exist in this zone, suggesting that the Lianhuashan Fault Zone was a major locus of magmatic activity throughout the Late Mesozoic. The NE-trending Shenzhen and Haifeng faults define the NW and SE boundaries of the Lianhuashan Fault Zone (Chen, 1987; Lai and Langford, 1996; Fig. 1b). This fault zone has been reactivated periodically since the Proterozoic with the characteristics of numerous ductile shear belts that display both