Geoscience Frontiers 4 (2013) 1–6

Contents lists available at SciVerse ScienceDirect

China University of Geosciences (Beijing)

Geoscience Frontiers

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

GSF Focus

The second continent: Existence of granitic continental materials around the bottom of the mantle transition zone

Kenji Kawai [a,b,*], Shinji Yamamoto [b,c], Taku Tsuchiya [d], Shigenori Maruyama [b]

[a] Department of Earth Science, University of California, Santa Barbara, CA 93106, USA
[b] Department of Earth and Planetary Sciences, Tokyo Institute of Technology, Ookayama 2-12-1, Meguro, Tokyo 152-8551, Japan
[c] Department of Earth Science and Astronomy, Graduate School of Arts and Sciences, The University of Tokyo, Komaba 3-8-1, Meguro, Tokyo 153-8902, Japan
[d] Geodynamics Research Center, Ehime University, Bunkyo-cho 2-5, Matsuyama, Ehime 790-8577, Japan

ARTICLE INFO

Article history:
Received 5 July 2012
Received in revised form
23 August 2012
Accepted 29 August 2012
Available online 17 September 2012

Keywords:
Continental growth
Granite
First principles
Mantle transition zone
Tectonics
Geodynamics

ABSTRACT

It has been thought that granitic crust, having been formed on the surface, must have survived through the Earth's evolution because of its buoyancy. At subduction zones continental crust is predominantly created by arc magmatism and is returned to the mantle via sediment subduction, subduction erosion, and continental subduction. Granitic rocks, the major constituent of the continental crust, are lighter than the mantle at depths shallower than 270 km, but we show here, based on first principles calculations, that beneath 270 km they have negative buoyancy compared to the surrounding material in the upper mantle and transition zone, and thus can be subducted in the depth range of 270–660 km. This suggests that there can be two reservoirs of granitic material in the Earth, one on the surface and the other at the base of the mantle transition zone (MTZ). The accumulated volume of subducted granitic material at the base of the MTZ might amount to about six times the present volume of the continental crust. Our calculations also show that the seismic velocities of granitic material in the depth range from 270 to 660 km are faster than those of the surrounding mantle. This could explain the anomalous seismic-wave velocities observed around 660 km depth. The observed seismic scatterers and reported splitting of the 660 km discontinuity could be due to jadeite dissociation, chemical discontinuities between granitic material and the surrounding mantle, or a combination thereof.

© 2012, China University of Geosciences (Beijing) and Peking University. Production and hosting by Elsevier B.V. All rights reserved.

1. Introduction

Continental crust has long been considered to be gravitationally stable on the Earth's surface because its density is lower than the underlying mantle. Hence, it was thought that continental crust, once formed, must accumulate on the Earth's surface, following the steady-state accumulation of tonalite-trondhjemite-granodiorite (TTG) magmas produced by plate tectonics. However, in contrast to this traditional view, ubiquitous subduction of TTG crust was proposed by seismological and geological studies of consuming plate boundaries, leading to new concepts of tectonic erosion and arc subduction (von Huene and Scholle, 1991; Yamamoto et al., 2009; Isozaki et al., 2010; Stern, 2011). This suggests that the fate of subducted TTG material and its total amount in the present mantle must be of primary importance of mantle dynamics, because granitic materials include a large amount of radiogenic elements.

Considerations of thermal evolution for the Earth's mantle suggest that intense continental growth must have occurred in the Hadean to Archean, because higher mantle temperatures in the ancient Earth produced extensive amounts of TTG magma (Tatsumi, 1989; Korenaga, 2006). This suggests that a volume amounting to more than 100% of the present continental crust must have been formed on the ancient Earth (Fyfe, 1978). Recent active investigations on the U-Pb and Lu-Hf isotopic systematics of detrital zircon show that the formation of continental crust started 4.4 Ga and that at least 70% of the existing continental crust was produced from the mantle before 2.5 Ga (Harrison, 2009; Belousova et al., 2010).

* Corresponding author.
E-mail address: kenji@geo.titech.ac.jp (K. Kawai).

Peer-review under responsibility of China University of Geosciences (Beijing).

Production and hosting by Elsevier

1674-9871/$ – see front matter © 2012, China University of Geosciences (Beijing) and Peking University. Production and hosting by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.gsf.2012.08.003

However, Archean crust dominates only a small portion (5%–10%) of the Earth's continents, and vestiges of Hadean crust are only preserved in detrital zircons (Harrison, 2009). To explain this discrepancy (called the continental paradox), a means of long term destruction and subduction of Archean TTG has been proposed (Scholl and von Huene, 2007; Shimoda, 2009).

Subduction and recycling of differentiated material into the mantle are of considerable significance not only for continental growth models (Armstrong and Harmon, 1981) but also for creating mantle heterogeneity (Zindler and Hart, 1986). Trace element and isotopic studies of ocean island basalts have pointed out the presence of long-lived (1–2 Ga) recycled components related to ancient oceanic/continental crust stored in the deep mantle (Hofmann, 1997). However, the amount and fate of continental crust subducted into the mantle throughout the Earth's history remain poorly understood.

The traditional geological point of view was that continental crust is not subducted into the deep mantle, due to its buoyancy. However, it has been proven that continental crust (metasediment and tonalitic gneiss) subducted to depths of 150–200 km can later be exhumed to the surface (Chopin, 2003). But if continental materials are subducted to depths greater than 270 km depth they will not return to the Earth's surface because subducted granitic materials are no longer buoyant at depths greater than 270 km, at which coesite, a high pressure polymorph of SiO_2, transforms to stishovite (Irifune et al., 1994). After further subduction, these materials will be buoyant again compared to the surrounding mantle at the base of the MTZ (23.8 GPa), due to the dissociation of ringwoodite to Mg-perovskite and magnesiowustite. Thus subducted granitic material can be expected to be trapped at depths of 660 km (Irifune et al., 1994; Rapp et al., 2008; Wu et al., 2009). To confirm this we conduct first principles studies of the elastic properties expected for granitic materials at depths greater than 270 km, discussed below.

Previous studies (e.g., Anderson and Bass, 1986; Li et al., 1998; Irifune et al., 2008) have suggested that seismic velocities in pyrolite composition measured in laboratory are higher than seismological observations such as PREM (Dziewonski and Anderson, 1981). There has been controversy on what produces the anomalous seismic-wave velocity and density changes observed at depths of around 660 km. Separated oceanic crust has been suggested to be a candidate to explain this anomaly (e.g., Karato, 1997; Fig. 1A). On the other hand, recent experimental (Irifune et al., 2008) and theoretical (Cammarano et al., 2009) studies suggest that the PREM (Dziewonski and Anderson, 1981) velocities are higher than those of adiabatic pyrolite (Ringwood, 1975) in the lower part of the MTZ and that either subadiabatic temperatures of 400 K or seismically faster chemical composition such as harzburgite is required to explain the velocity difference (Irifune et al., 2008; Fig. 1B). However, it is unlikely that a temperature decrease of 400 K occurs in this depth range throughout the entire mantle. Also, light harzburgite could be gravitationally unstable. Moreover, the fast PREM velocities in the uppermost lower mantle cannot be explained even by the most depleted composition, harzburgite (Cammarano et al., 2009).

As none of the above possibilities seemed acceptable, we proposed a new model: TTG-enriched material in the mantle transition zone (Kawai et al., 2009; Fig. 1C). Here we examine whether subducted granitic material could produce the anomalous velocity and density discrepancies observed in the lowermost MTZ and the uppermost lower mantle. To our knowledge, this possibility has not previously been considered, probably because theoretical results on the elastic properties of granitic materials were not previously available.

2. Methods and results

We calculate the density and elasticity of TTG crust by means of *ab initio* density functional computation methods. Archean TTG is low on potassium feldspar (Martin et al., 2005). Here, we assume a hypothetical TTG crust, whose mineral proportion has the molar fraction albite:quartz is 1:7 (Komabayashi et al., 2009). Albite dissociates into quartz and jadeite at 2–3 GPa (at 70–100 km depth) and 1300 K (Birch and LeComte, 1960) and jadeite then further dissociates into an assemblage of stishovite and calcium ferrite (CF)-type phase at about 23 GPa (at 640 km depth) and 1300–1500 K (Yagi et al., 1994; Kawai and Tsuchiya, 2010). SiO_2 polymorph undergoes a phase transition from quartz to coesite at 70–100 km depth and from coesite to stishovite at depths of 250–300 km. The approximate mineral proportion of TTG has the molar fraction jadeite:stishovite is 1:8 after the coesite-stishovite transition and CF:stishovite is 1:9 after jadeite dissociation. In this study we compute the density and seismic velocities, v_P and v_S, of TTG assemblage in the pressure range between 10 and 50 GPa, taking the Voigt-Reuss-Hill averages of elastic constants for jadeite, a CF-type phase and stishovite, which have recently been calculated based on first principles (Kawai and Tsuchiya, 2010). Our calculations show that increases of the density and P and S velocities associated with the jadeite dissociation at a pressure of about 23 GPa are 4.4%, 6.1%, and 8.1%, respectively (Fig. 2).

The major component in pyrolite composition is wadsleyite in the 15–20 GPa pressure range and ringwoodite in the 20–23.5 GPa range; it dissociates into perovskite (pv) and ferropericlase (fp) at about 23.5 GPa. In this study, we approximate pyrolite as forsterite

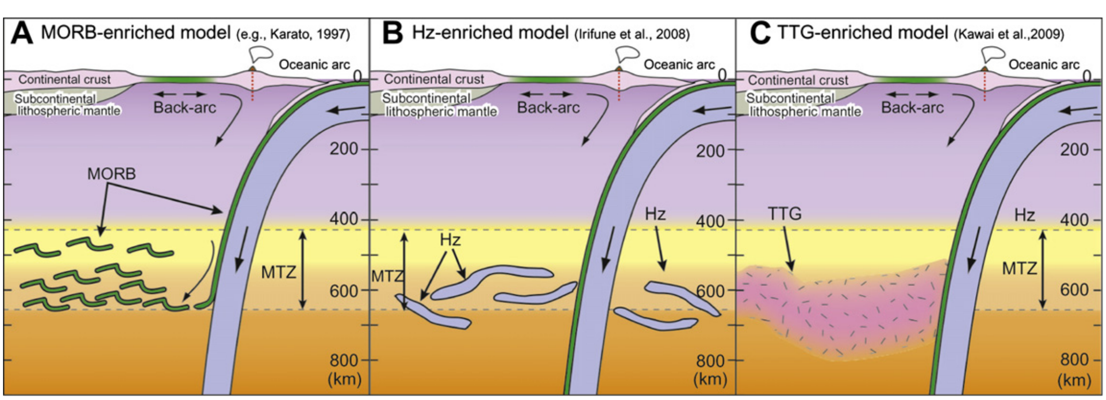

Figure 1. Models to explain the velocity anomaly in the MTZ (410–660 km depth range). A: MORB-enriched model (e.g., Karato, 1997) due to segregation of the MORB crust at the MTZ; B: Harzburgite (slab-restite)-enriched model by Irifune et al. (2008); C: TTG-enriched model (Kawai et al., 2009).

Download English Version:

https://daneshyari.com/en/article/4681860

Download Persian Version:

https://daneshyari.com/article/4681860

Daneshyari.com