Andesites: their origin and the role in the Earth evolution

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One characteristic feature of the planet Earth is the bimodal height distribution at the surface (Fig. 1). This is caused by the difference both in density and thickness of the Earth's crust. Two types of crusts, the oceanic and continental crusts, have been created at divergent and convergent plate boundaries, respectively, via. plate tectonics. The bulk composition of continental crust is andesitic (60 wt.% SiO_2), in marked contrast with the basaltic oceanic crust with ˜50 wt.% SiO_2. This raises the question of how intermediate continental crust forms from basaltic magmas produced in the mantle wedge of subduction zones.

The Izu-Bonin-Mariana (IBM) arc is a juvenile intra-oceanic arc and has a thick middle crust layer with *Vp* of ~6km/s, suggesting this arc to be an active site of both creation and growth of the continental crust. Petrological modeling, including remelting of the initial basaltic arc crust and magma mixing between mantle- and crust-derived melts, can successfully explain the layered crust-mantle seismic structure of the IBM. During this process, the sub-arc Moho is chemical transparent and permeable to the refractory melting residue of arc crust. This crust-mantle transformation or discharge of the 'anti-continent' could play the major role in the creation of intermediate continental crust.

The continental crust in detail possesses compositions typical of calc-alkalic series that often coexists with tholeiitic series in a single volcano. Resolution of the genetic relationship between these two types of andesitic magmas should, therefore, provide a better understanding of andesite genesis and arc crust evolution. Reexamination of petrographical and geochemical characteristics of these two magma series in the NE Japan arc provides a new insight into andesite genesis: (1) tholeiitic magmas are produced via anatexis of amphibolitic crust caused by underplating and/or intrusion of mantle-derived calc-alkalic basalt magmas into the arc crust, and (2) The mantle-derived calc-alkalic basalt magma mixes with crust-derived tholeiitic melts to form calc-alkalic andesite magmas.

The essential cause of operation of plate tectonics that creates both andesitic continental crust and basaltic oceanic crust and results in the bimodal height distribution is the temperature difference within the mantle and mantle convection. The upper thermal boundary layer of this convection corresponds to the lithospheric plate, but behaves naturally as a stagnant-lid, i.e., the plate should not move. The presence of liquid water at the surface, on the other hand, strongly reduces the yield strength and could cause the fracture within the stagnant-lid, triggering the plate subsidence or subduction. Parameters that govern the presence and absence of liquid water on the terrestrial planets are: the distance from the Sun and the mass of a planet. A conclusion of this consideration would be that the Earth is a shore planet because of the presence of the ocean, which seems to be a conclusion of a Zen dialog.

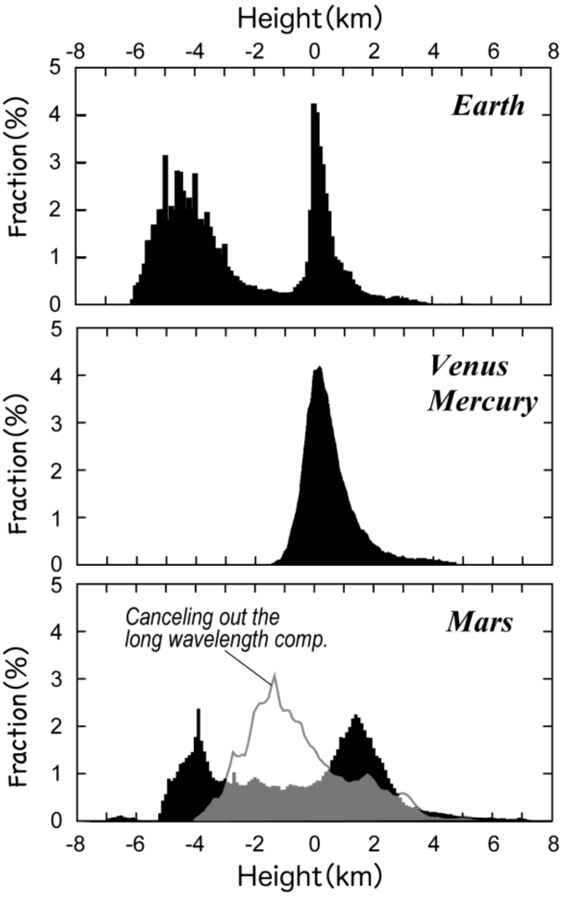

Figure 1. Hypsometry of surface tomography of the terrestrial planets.

Forecasting volcanic activity of Sakurajima

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Sakurajima is an andesitic volcano located on the southern rim of the Aira caldera. In the 20th century, three characteristic types of eruptions occurred: the 1914 gigantic flank eruption; the 1946 minor flank eruption; and frequent vulcanian eruptions at the Minamidake summit crater, continuing from 1955 for more than 50 years. The eruptive center has been shifted to the Showa crater, east of Minamidake since 2006 and the eruptive activity is characterized minor but more frequent vulcanian eruptions. The magma plumbing system of Sakurajima is approximated by a deep (~10 km) magma reservoir beneath the Aira caldera, shallow reservoirs (3–6 km) beneath the central cones, and a conduit connecting one of the shallow reservoir to the summit crater of Minamidake. From the inflation–deflation pattern and intensity of the vertical displacement, it is estimated that magma has been supplied to the deep reservoir at a rate of 10^7 m^3/year. Since the termination of the 1914 eruption, magma in the order of $10^9 m^3$ has been stored in the deep reservoir. Considering eruptions in 20th century, we have 3 scenarios for future eruptive activity: 1) frequent occurrence of vulcanian eruptions at the summit crater, 2) further more increase in eruptive activity at the Showa crater, finally reaching effusion of lava, and 3) a large flank eruption at two sides of the volcano.

The shallow reservoir is inferred from vertical displacements, a tilt vector showing the crater side up before the vulcanian eruptions, and an anomalously attenuated zone of seismic waves. The magma migrated from the deep reservoir to the shallow reservoir before the increase in vulcanian eruptivity at the Minamidake crater, as demonstrated by the relocation of the upheaval center of the ground deformation. The increase in seismicity of A-type earthquakes and the migration of their hypocenters toward the shallow part also support the migration of magma. The hypocenters of B-type earthquakes and explosion earthquakes with volumetric sources are concentrated beneath the crater. The hypocenters of A-type earthquakes generated by shear fractures surround the origins of B-type earthquakes and explosion earthquakes. The separation of the hypocenters indicates the existence of a volcanic conduit connecting the shallow reservoir to the bottom of the summit crater. The intrusion of magma into the conduit and smooth ascent up to the crater bottom induce strombolian eruptions and swarms of B-type earthquakes. The magma at the uppermost part of the conduit becomes a cap rock of the conduit against the following intrusive magma, which generates vulcanian eruptions. Upward tilt of the crater side and extensional strain are observed prior to both strombolian activities and the vulcanian activities that follow and turn into downward and contraction strain, respectively, associated with the eruptions. The volatility of the magma has an important role in vulcanian eruptions, in the formation of a gas pocket at the uppermost part of the conduit, and in sudden outgassing triggered by a pressure decrease in the conduit due to gas leakage.

Eruptive activity at the Showa crater has steadily increased since it resumed in June 2006, and 3660 vulcanian eruptions occurred during the period from 2008 to 2012. An inflation event that started in October 2009 was caused by the major pressure source estimated to be located at a depth of 12 km beneath the Aira caldera and a minor source obtained a depth of 5 km at the northern flank of Kitadake in addition to a source beneath Minamidake. Strain changes which indicate inflation were detected prior to explosions and the inflation strain lasted mostly 1 h. The strain changes were caused by a shallow pressure source less than 1.5 km. The inflation occasionally continued for more than 7 h with an addition of inflation of a deep source (4 km), which corresponds to the magma reservoir beneath Minamidake. The conduit to the Showa crater may be branched from the magma reservoir beneath Minamidake or from the major conduit connected to it. When inflationary ground deformation progressed at a high rate, the eruptive activity reached a peak from December 2009 to March 2010. This suggests that the accumulation of magma beneath the central cones of the Sakurajima volcano progressed simultaneously to a discharge of magma. The simultaneous progress of the accumulation and discharge of magma and the frequent occurrence of small vulcanian eruptions may be related to the small open conduit.

Sakurajima volcano in magma intrusion stage