Press Releases

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Japan Agency for Marine-Earth Science and Technology

Syncollisional Magmatism in Arc-Arc Collision Holds Key to Continental Growth
- Evidence from Tanzawa Plutonic Complex -

Overview

Scientists from the Institute for Research on Earth Evolution (IFREE) at the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), and the National Institute of Polar Research (NIPR)have provided new insights into how continental crust evolves during arc-arc collision. They have determined the formation age of the Tanzawa plutonic complex (TPC, *2), a suite of young granitic rocks located in the Izu collision zone (ICZ, *1), an active collision zone in central Japan. The TPC ages have been obtained by a new technique capable of dating young crustal rocks with greater precision than before and have revealed syncollisional magma generation and subsequent rapid emplacement of plutons during the arc-arc collision, indicating that island arc collision and accretion are significant in the growth of continents.

The evolution of the continental crust, revealed in a modern arc-arc collision zone, is an important key in understanding how continental crust was produced early in the Earth's history, when arc-arc collision was a much more common geological phenomenon.

The study, led by Kenichiro Tani, IFREE, will be published in the March 1st issue of the US science journal Geology.

Title:	Syncollisional rapid granitic magma formation in an arc-arc collision zone: Evidence from the Tanzawa plutonic complex, Japan
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Background

The Earth's outermost solid layer, known as the crust, consists of continental crust (made up mainly of granite) and oceanic crust (made up chiefly of basalt). Early in the Earth's history, most of the Earth's surface is considered to have been covered by a basaltic oceanic crust. Such primary oceanic crust was then gradually transformed into continental crust at subduction zones, where oceanic plates subduct beneath another plate, sinking deep into the Earth. The magmatism associated with the subduction generates a chain of volcanic islands at the surface, commonly referred to as an island arc, and forms juvenile continental crust. It is believed that successive collisions between island arcs and their resultant accretion gave rise to the present vast areas of continental crust. Despite the importance of arc collision during growth of the continental crust on the early Earth, the detailed processes during the collision are poorly understood.

Recent seismic studies by other scientists at JAMSTEC suggest that juvenile continental crust is presently forming beneath the Izu-Bonin-Mariana (IBM) arc, an intraoceanic arc formed by the subduction of one plate of oceanic crust beneath another plate of oceanic crust. The northern end of the IBM arc is colliding against the Honshu arc, driven by the northward movement of the Philippine Sea Plate. As a result, the area constitutes a globally unique on-going arc-arc collision zone, which is called the Izu collision zone (ICZ).

As a consequence, the IBM arc and the ICZ are important analogues in understanding how continental crust formed from incipient oceanic crust, and later how it evolved through arc collisions early in the Earth's history. In particular, the exposed granitic plutons of the TPC offer valuable clues as to how the continental crust grew and evolved during the collision.

The granitic rocks of the TPC were previously considered to represent the deep granitic layer of the IBM arc, uplifted and exposed during the arc-arc collision. The origin of the TPC, including when and how it formed, however, was poorly understood due to limitations in the geochronological tools to date young granitic rocks such as the TPC plutons.

Summary of the method

The age of the formation of the TPC was determined by dating zircon crystals separated from TPC granitic and gabbroic rocks. The zircons were dated using their U-Pb isotopic compositions (*3) measured on the Sensitive High Resolution Ion Microprobe (SHRIMP-II) at the National Institute of Polar Research (Fig. 1). The U-Pb isotopic compositions of zircons allow accurate and precise dating of igneous rocks (rocks solidified from magma), such as granite. This method has been widely used for dating rocks that are hundreds of millions to billions of years old. Scientists at IFREE and NIPR have developed and refined sample preparation and analytical techniques to allow much younger rocks, such as those formed several millions of years ago, to be dated using the U-Pb isotopic compositions of the zircon crystals.

Trace element compositions of the TPC zircon crystals were also determined to understand the geochemical characteristics of the magma that formed the TPC rocks, using Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS).

Results and discussions

The new TPC ages reveal that most parts of the TPC plutons were formed around 5 to 4 million years ago, post-dating the onset of the IBM arc-Honshu arc collision (Fig.2). This does not agree with the previous hypothesis that the TPC is an uplifted and exposed deep crustal sequence of the IBM arc. Instead, it indicates that the main pulse of TPC formation was related to the collisional magmatism, which has then led to the growth of new continental crust.

The zircon U-Pb dating of TPC plutons has also revealed rapid post-emplacement cooling rates of up to 660 degrees Celsius per 1 million years, which makes the TPC one of the most rapidly cooled granitic plutons on Earth. These rates indicate that the granitic magma, produced simultaneously with the IBM arc-Honshu arc collision, rose and cooled rapidly. In addition, the TPC plutons intrude into the Tanzawa block, a block of the IBM arc accreted to the Honshu arc around 7 million years ago. Together, these findings suggest that the TPC granitic magma formed and solidified within just 2 to 3 million years of the inception of the collision, implying extremely rapid crustal growth in the ICZ.

The trace element compositions of the TPC zircon show a distinctive influence from sediments derived from the continental Honshu arc during the TPC magma genesis (Fig.3). The results indicate that the composition of the juvenile IBM crust was modified and evolved by the collisional magmatism, attaining a continental-like geochemical signature during the collision (Fig.4).

Future perspectives

This study highlights the importance of the TPC as a present-day analogue for continental growth through arc-arc collision early in the Earth's history. The rapid crustal growth and modification processes that have been revealed by these scientists' work on the TPC will offer an important reference in understanding the collisional processes in ancient collision zones.

Meanwhile, a scientific team led by JAMSTEC is currently proposing ultra-deep drilling in the IBM arc, taking an advantage of innovative technology of the Deep-sea Drilling Vessel CHIKYU. The proposed project will allow scientists to collect core samples directly from juvenile granitic crust uninfluenced by a pre-existing continental crust. The comparison between such juvenile arc crust and crust evolved through arc-arc collision at TPC will provide an invaluable opportunity to comprehensively understand the formation and growth of the continental crust during the early history of the Earth.

***1. Izu collision zone (ICZ)**

The Izu-Bonin-Marina (IBM) arc and the Honshu arc collide in the western part of the Kanto area, central Japan. This zone is highly deformed and shows complex geological structures as a result of the collision, and is known as the Izu collision zone (ICZ). ICZ is a globally unique because it is the only area where an active intraoceanic arc (IBM arc) is presently colliding with a mature arc (Honshu arc). The collision commenced 15 million years ago, causing successive accretion of juvenile IBM arc crust on to the Honshu arc.

***2. The Tanzawa plutonic complex (TPC)** is a suite of granitic plutons exposed in the southern part of the Tanzawa Mountains in the Izu collision zone. It is situated in the Tanzawa block, the rock group accreted by the collision between Izu-Bonin-Mariana (IBM) arc and the Honshu arc. The TPC is considered to have originated as granitic IBM plutons that were uplifted and exposed during episodes of the IBM arc-Honshu arc collision.

***3. Zircon U-Pb age analysis**

Zircon is a uranium-rich mineral. Radioactive uranium constantly decays into lead. The time that has elapsed since the zircon crystallized can therefore be calculated from precisely analyzing the uranium and lead isotope compositions within the zircon, providing age estimates of the zircon-bearing rocks. The Sensitive High Resolution Ion Microprobe (SHRIMP-II) allows radiometric ages to be determined from spots on the zircon surface less than a few tens of microns in diameter (Fig.1).

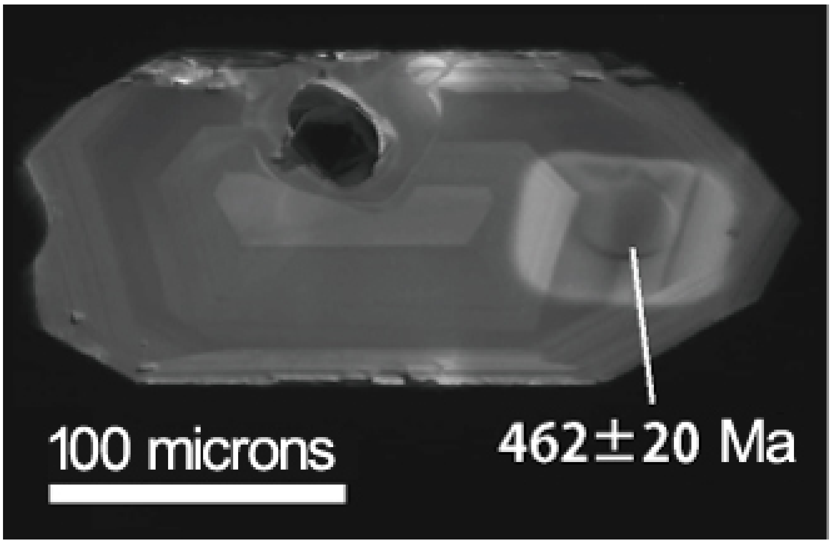

Figure 1. TPC zircon crystals used in age analysis

SHRIMP-II analysis allows accurate radiometric dating of spots on the zircon surface less than 30 microns in diameter.

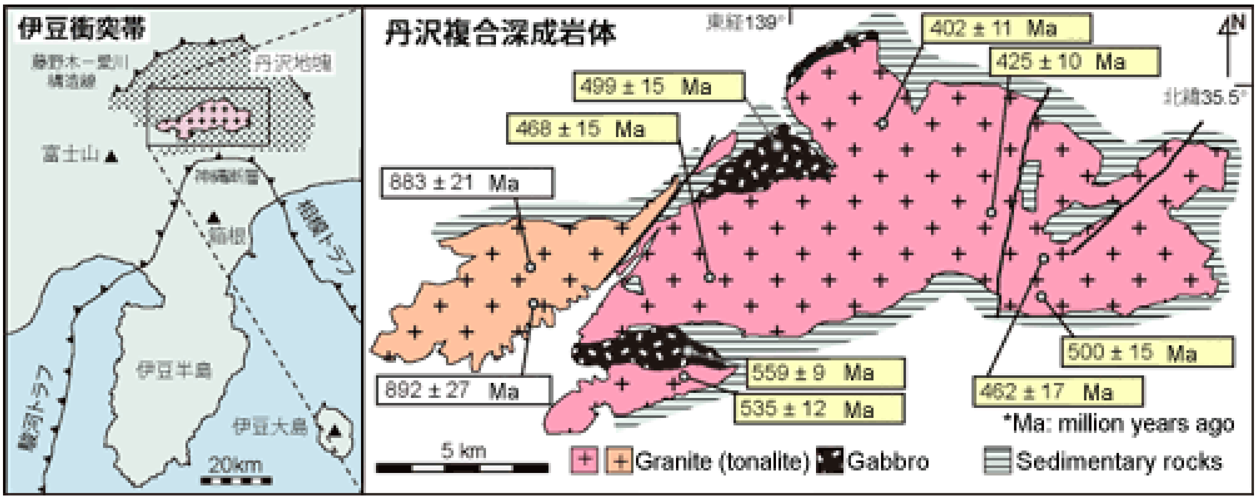

Figure 2. Geologic map of Tanzawa plutonic complex (TPC) with newly obtained zircon U-Pb ages (based on the geological map by Kawate and Arima, 1998)

Most parts of the TPC plutons are 5 to 4 million years old, younger than the onset of the Tanzawa block collision (which was approximately 7 million years ago). This indicates that the TPC was formed by syn-collisional magmatism.

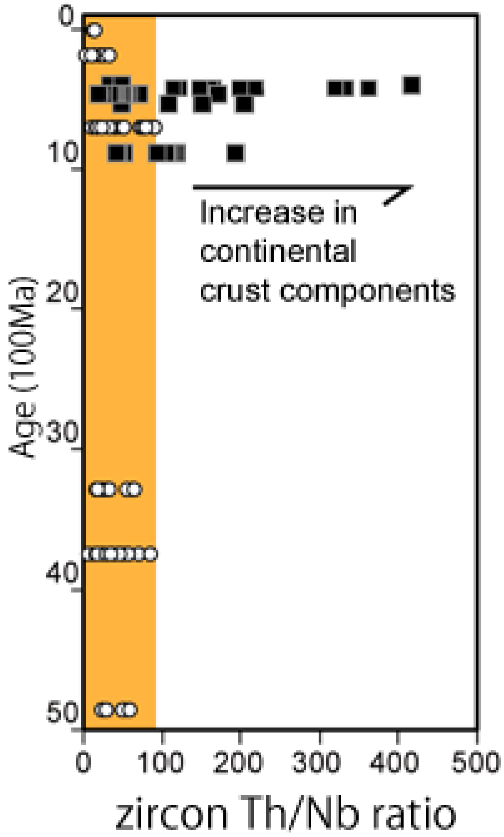

Figure 3. A: Zircon Th/Nb versus age plot of Tanzawa plutonic complex (TPC)

Zircon Th/Nb ratios of the TPC granitoids (solid squares) are distinctively higher than those from non-collisional IBM granitoids (open circles). Elevated Th/Nb ratios indicate continental crustal components from the Honshu arc are involved in the genesis of the TPC magma.

***Zircon Th/Nb ratio**
Thorium (Th) is primarily enriched in mature (i.e., continental) sediments. Sediments of the mature Honshu arc show higher Th/Nb ratios compared to those of the juvenile IBM arc.

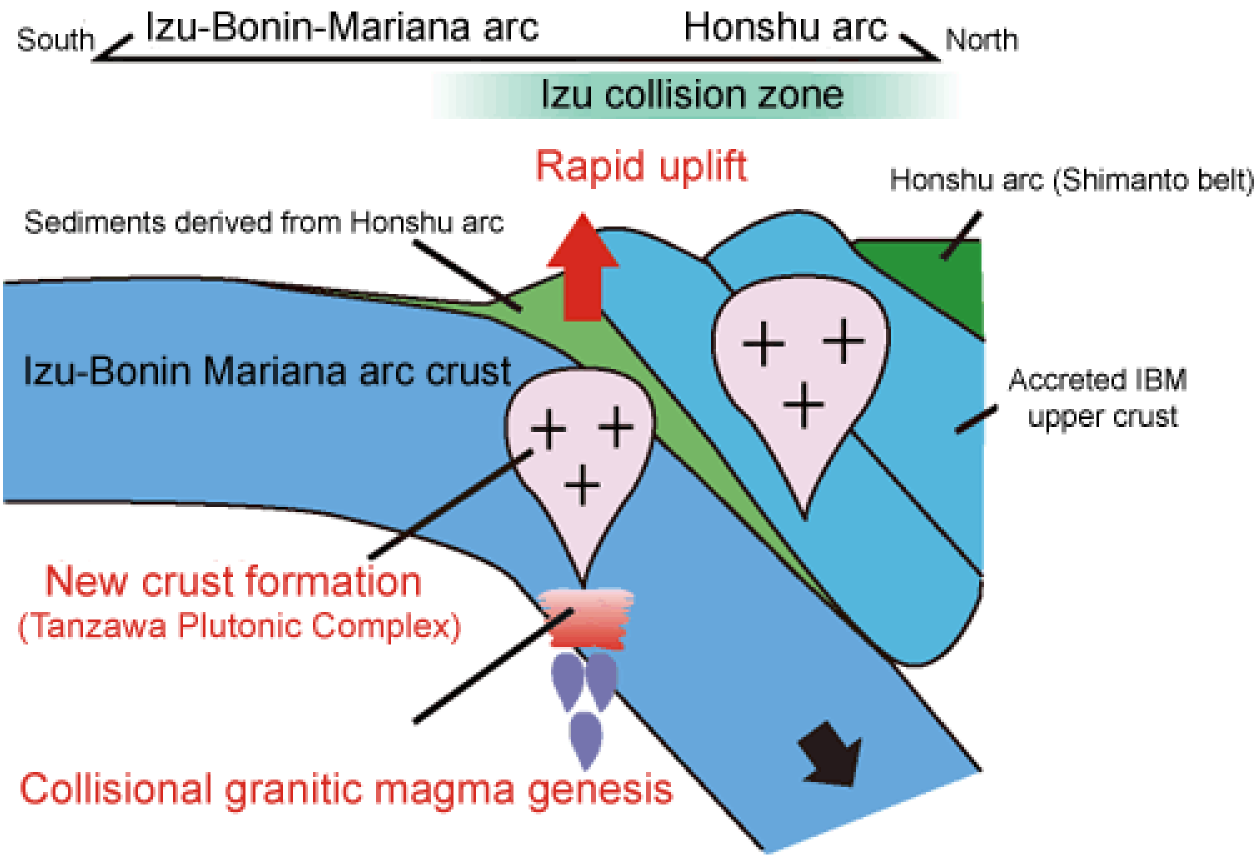

Figure 4. Schematic north-south cross section through the Izu collision zone

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