

## Drilling into the Memory of the Earth –An Introduction to International Ocean Discovery Program

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Why is this planet to be the Earth? This is a fundamental question to be answered, since the Earth is the only planet in this solar system that is habitable and drives plate tectonics. This lecture introduces an effort of probing the interior of the Earth that aims at understanding the evolution and origin of this planet.

### 1. Structure of the solid Earth

The solid Earth is composed of discrete layers bordered by seismic discontinuities that can be observed due to the abrupt changes of physical properties. Experiments that can reproduce the P-T conditions of the Earth's interior have provided key constraints on the origin of seismic discontinuities within the mantle: those at 400 km, 670 km, and 2700 km depths may be caused by phase transitions of  $\text{Mg}_2\text{SiO}_4$  such as olivine  $\rightarrow$  spinel  $\rightarrow$  perovskite  $\rightarrow$  post-perovskite, respectively, at pressures corresponding to depths of discontinuities. The mantle occupies  $\sim 80\%$  volume of the solid Earth and is composed 'solid' rocks with peridotite compositions. This estimate is based on a simple mass balance calculation using compositions of the primitive carbonaceous chondrite and the iron meteorite representing the whole solid Earth and the Earth's core, respectively. However, direct sampling of the mantle rock has not been achieved so far.

### 2. What is IODP?

In order to get rocks directly from the mantle, we have to drill in the ocean, because the oceanic crust ( $\sim 6$  km-thick) is much thinner than the continental crust (30-70 km-thick). Furthermore, the ocean covers  $\sim 70\%$  of the Earth's surface and has recorded various kinds of global changes. This reasoning has motivated scientific ocean drilling since 1968. The International Ocean Discovery Program (IODP) is a currently-running international marine research collaboration between 26 nations using three types of specialized ocean drilling platforms. Japan is one of the leading nations of IODP and has provided a cutting-edge, riser-equipped deep sea drilling vessel, CHIKYU, which is capable of drilling up to 7,000m deep sea floor. CHIKYU is now working out the Nankai Trough off the Kii Peninsula in order to understand the causes and processes of mega-earthquakes along the subduction zone plate boundary. Also sample return from the mantle is one of the final goals of IODP and can be done solely by CHIKYU.

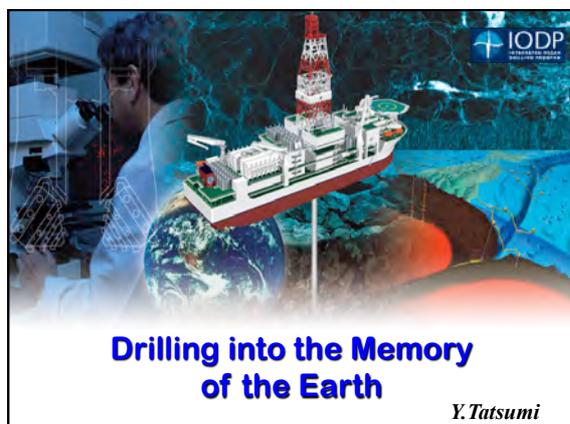
### 3. Project IBM: Ocean creates continent?

One characteristic feature of the planet Earth is the bimodal height distribution at the surface. 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.%  $\text{SiO}_2$ ), in marked contrast with the basaltic oceanic crust with  $\sim 50$  wt.%  $\text{SiO}_2$ . This raises the question of how andesitic 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  $V_p$  of  $\sim 6$  km/s that is identical to an average  $V_p$  of the continental crust. It may be thus suggested that this arc is 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 andesitic continental crust. Our high-pressure experiments show that the anti-continent is always denser than the surrounding mantle, suggesting that this planet makes simultaneously continent and anti-continent at the top and the base of the mantle, respectively.

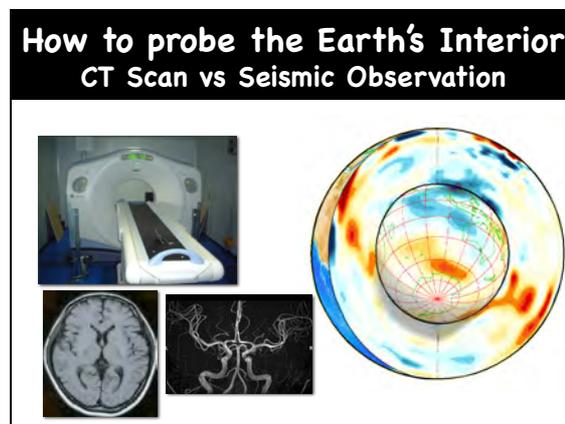
The above attractive scenario, however, assumes that the middle crust of the IBM arc possesses compositions similar to those of the continental crust. In order to verify our hypothesis, we should get and analyze rocks of the middle crust. Project IBM including an ultra deep drilling (~4km below sea floor) is now internationally endorsed as one important CHIKYU project in next 10 years.



**Drilling into the Memory of the Earth**

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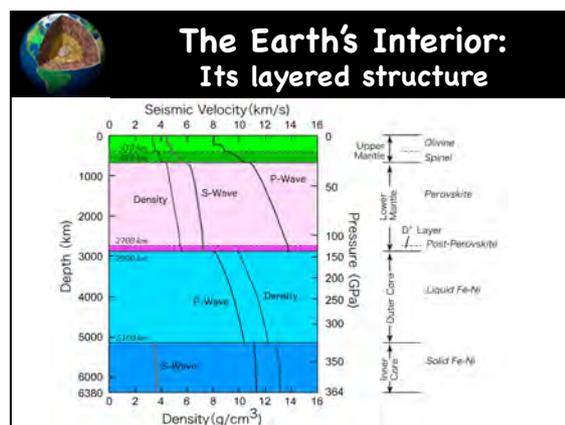
### How to probe the Earth's Interior CT Scan vs Seismic Observation



### How to probe the Earth's Interior High-P/T Experiments



Our team first reached to the center of the Earth in 2011



### The Earth's Interior: How to get sample

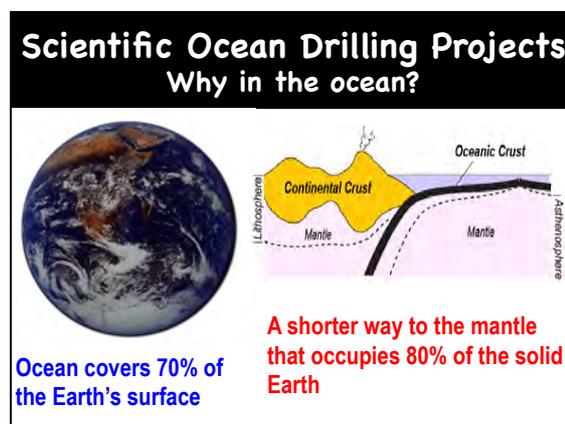
**Endoscopy**



**Drilling**



### Scientific Ocean Drilling Projects Why in the ocean?

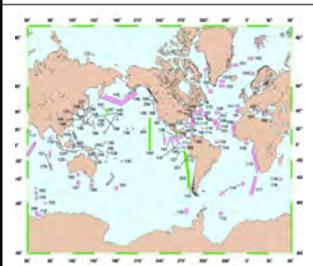


Ocean covers 70% of the Earth's surface

A shorter way to the mantle that occupies 80% of the solid Earth

## Scientific Ocean Drilling Projects

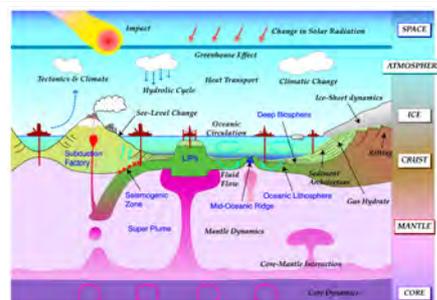
- DSDP (1968-1975): US only
- IPOD (1975-1985): US + 5 nations
- ODP (1985-2003): US + 22 nations



### Great Hits

- Operation of plate tectonics
- Discovery of gas-hydrate
- Extreme climate change
- Subsurface biosphere
- etc.

## IODP since 2003: towards comprehensive understanding of the Earth system evolution



## Lineup of IODP Platforms

Mission Specific PFs



Europe  
USA  
Japan

JOIDES Resolution (non-riser)

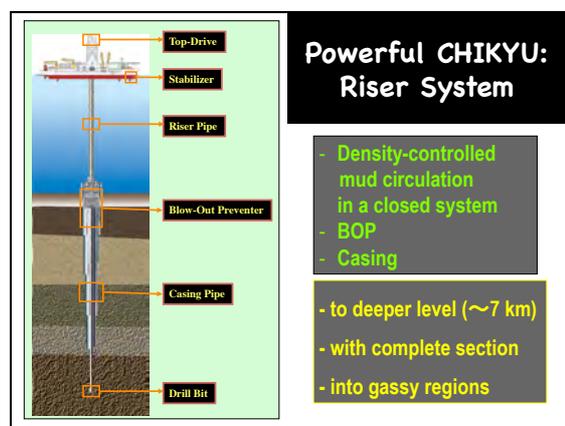
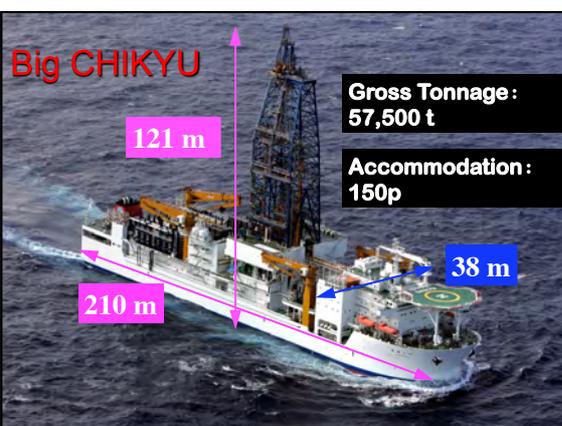


Chikyu



## Riser Vessel: CHIKYU (地球)

- Chikyu is:
- big
  - powerful
  - intelligent
  - comfortable



**Intelligent CHIKYU: DPS**

Fix the position within 1.5% of the waterdepth

Within 30m $\phi$  for 2000m waterdepth

**CHIKYU: A floating laboratory**

**Comfortable CHIKYU**

**CHIKYU Now: on expeditions at Nankai Trough for seismogenic zone experiments**

**NanTroSEIZE Drilling Project**

*What mega-earthquakes are  
Why mega-earthquakes are caused*

**Long-Term Borehole Monitoring**

**Ocean-floor cable network**

