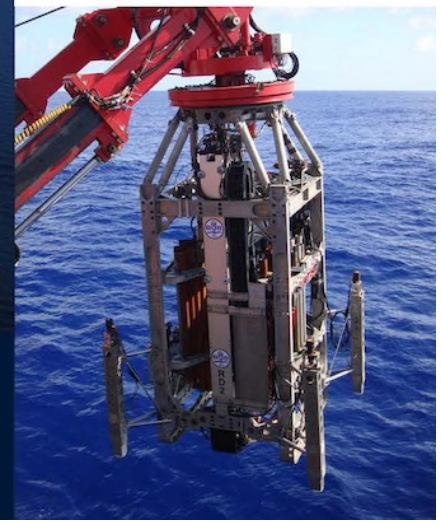


DRILLING EARTH SCIENCE

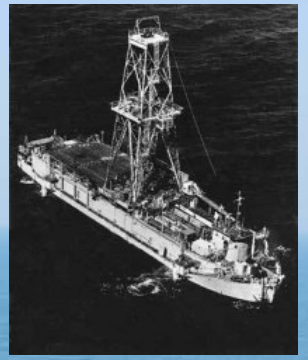
Probing the Deep Earth: Mantle Drilling Projects

We still haven't found what we are looking for

Katsuyoshi Michibayashi (Nagoya University/JAMSTEC)

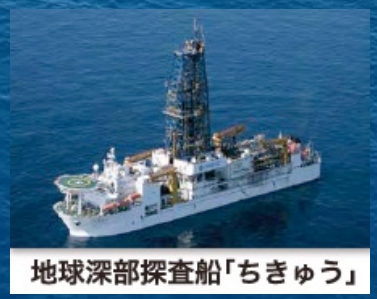
Scientific Ocean Drilling

DRILLING EARTH SCIENCE

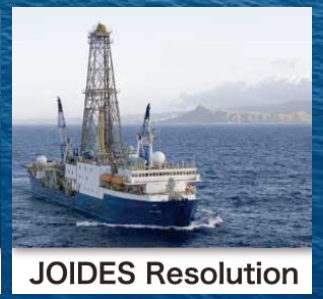


More then 50 years history of scientific ocean drilling since legacy programs stated in 1960's, IODP continues its exploration on global ocean.

1909	Discovery of Mohorovičić discontinuity
1915	Continental Drift by A. Wegener
1958 -1966	Project MoHole (USA)
1968 - 1983	Deep Sea Drilling Project, DSDP (USA)
1985	*JOIDES* Resolution operation
1985 - 2003	Ocean Drilling Program, ODP (21 nations)
2003	Integrated Ocean Drilling Program, IODP
2005	D/V *Chikyu* operation
2013	International Ocean Discovery Program, IODP



地球深部探査船「ちきゅう」

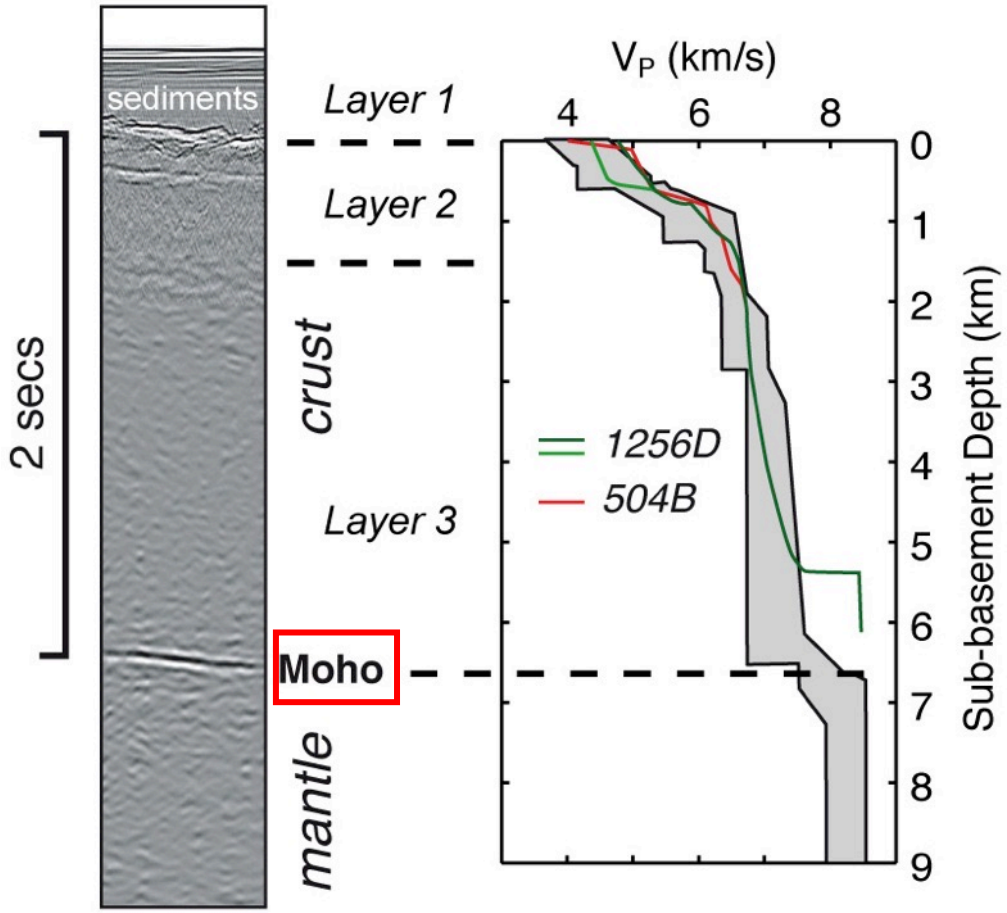


JOIDES Resolution

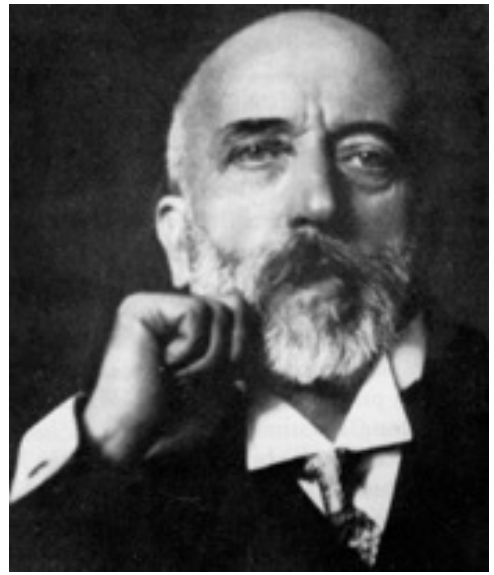
特定任務掘削船(MSP)

Provided by J-DESC

Mohorovičić Discontinuity (Moho): Intense Seismic Reflection, which seismically defines the boundary between crust and mantle in the Earth

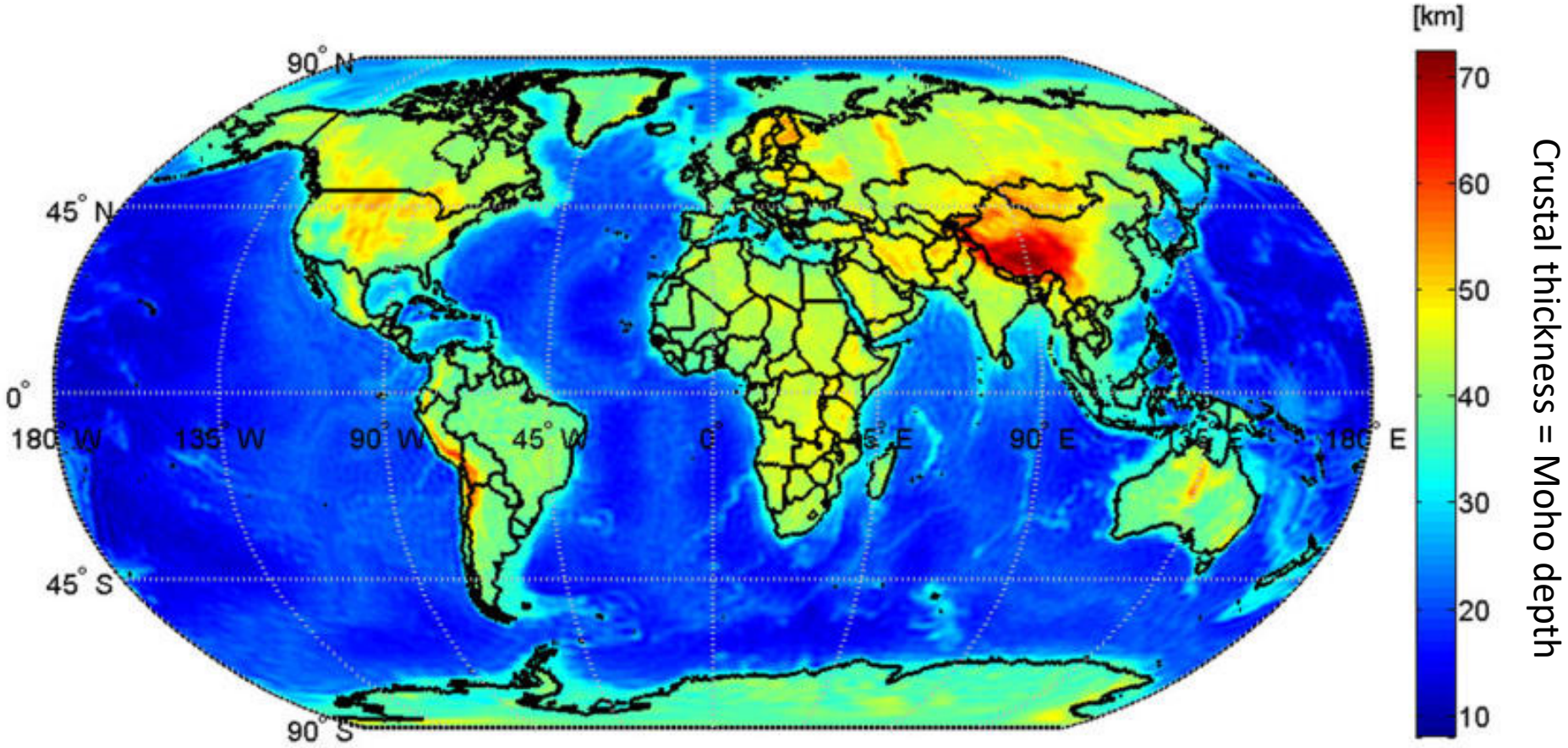


Seismic imaging of Pacific lithosphere



Andrija Mohorovičić
モホロビチッチ

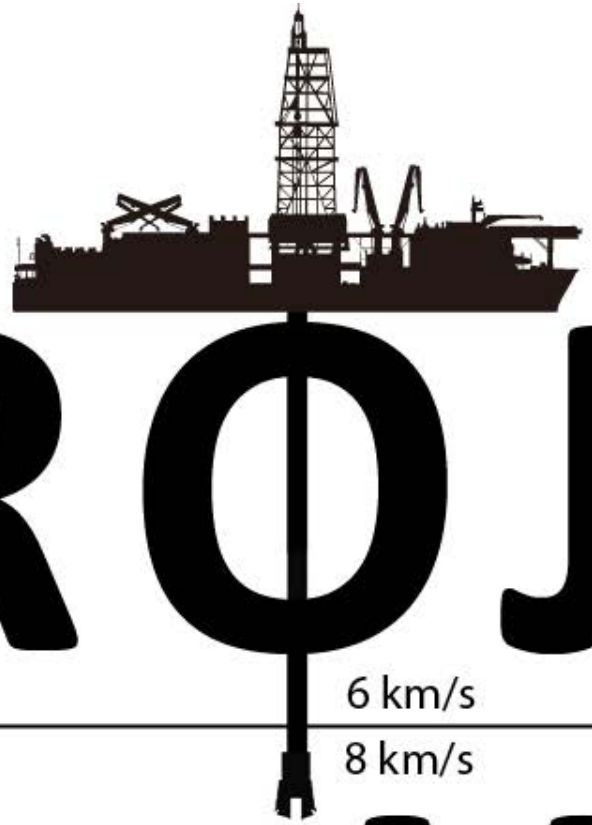
Constant MOHO depth in the global ocean seems to be the robust evidence for homogeneous cooling of the Earth



Global map of Moho depth (from GOCE data, 2012)

Moho depths are quite similar among oceans in contrast to those in continents

The MoHole: Journey to the Earth's Mantle

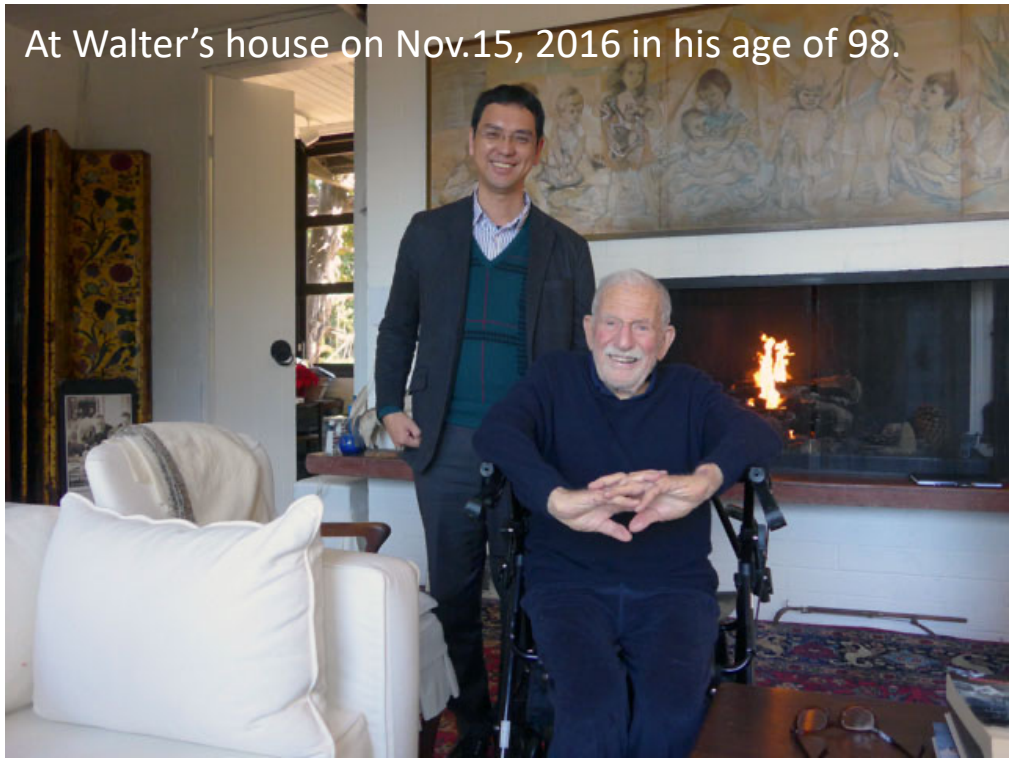


DRILLING EARTH SCIENCE

Phase I (1957-1961) of Project Mohole [MoHo + Hole = MoHole]

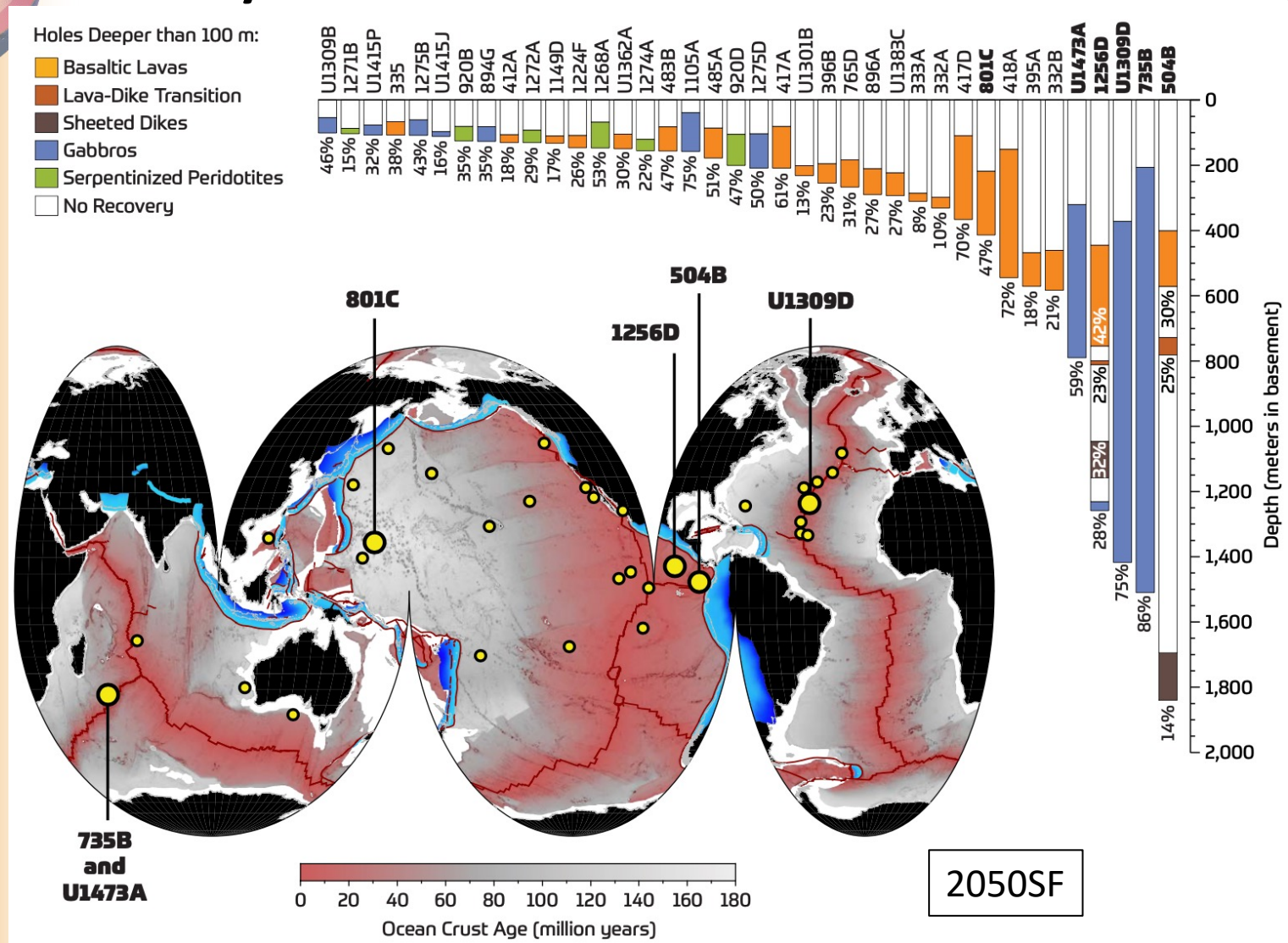
Walter H. Munk proposed to drill toward the Mantle.
"What good will it do to get a single sample of the mantle?"

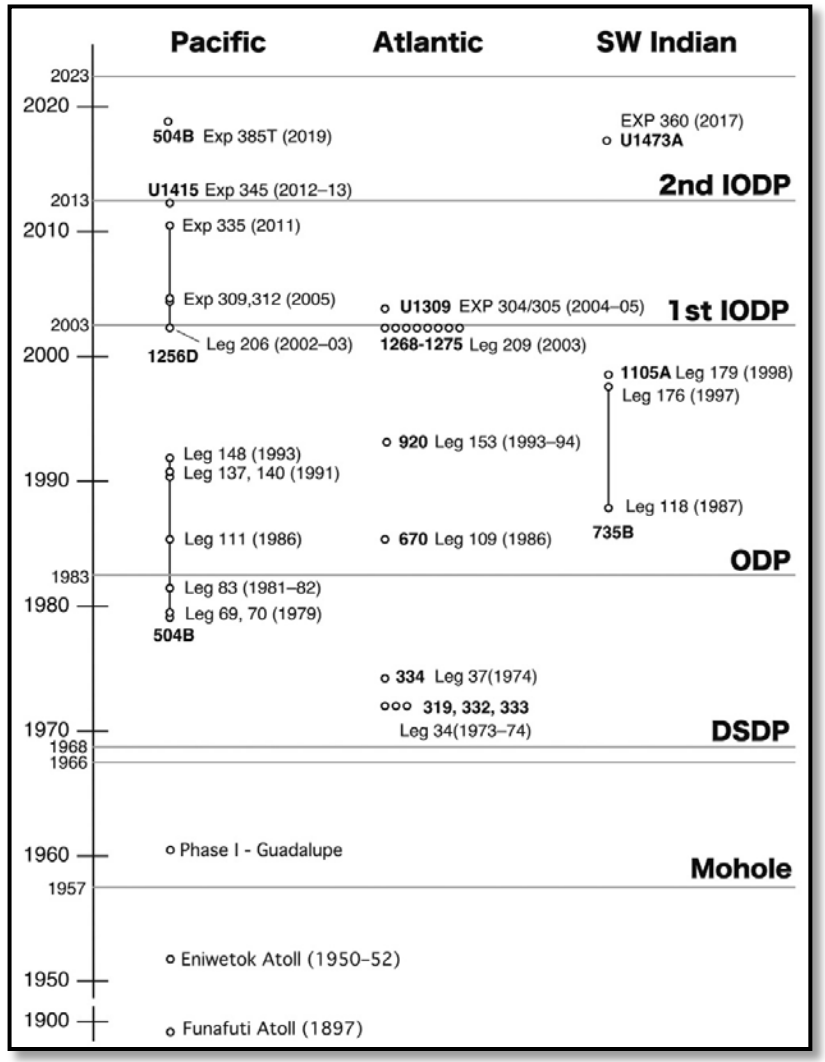
Project Mohole Meeting around a table aboard the vessel CUSS I off Guadalupe Island in the Pacific Ocean, 1961.



Walter has at least visited to CHIKYU on board in 2016 in a very last moment of his century life.

Only a few tens basement drilling sites since 1960's

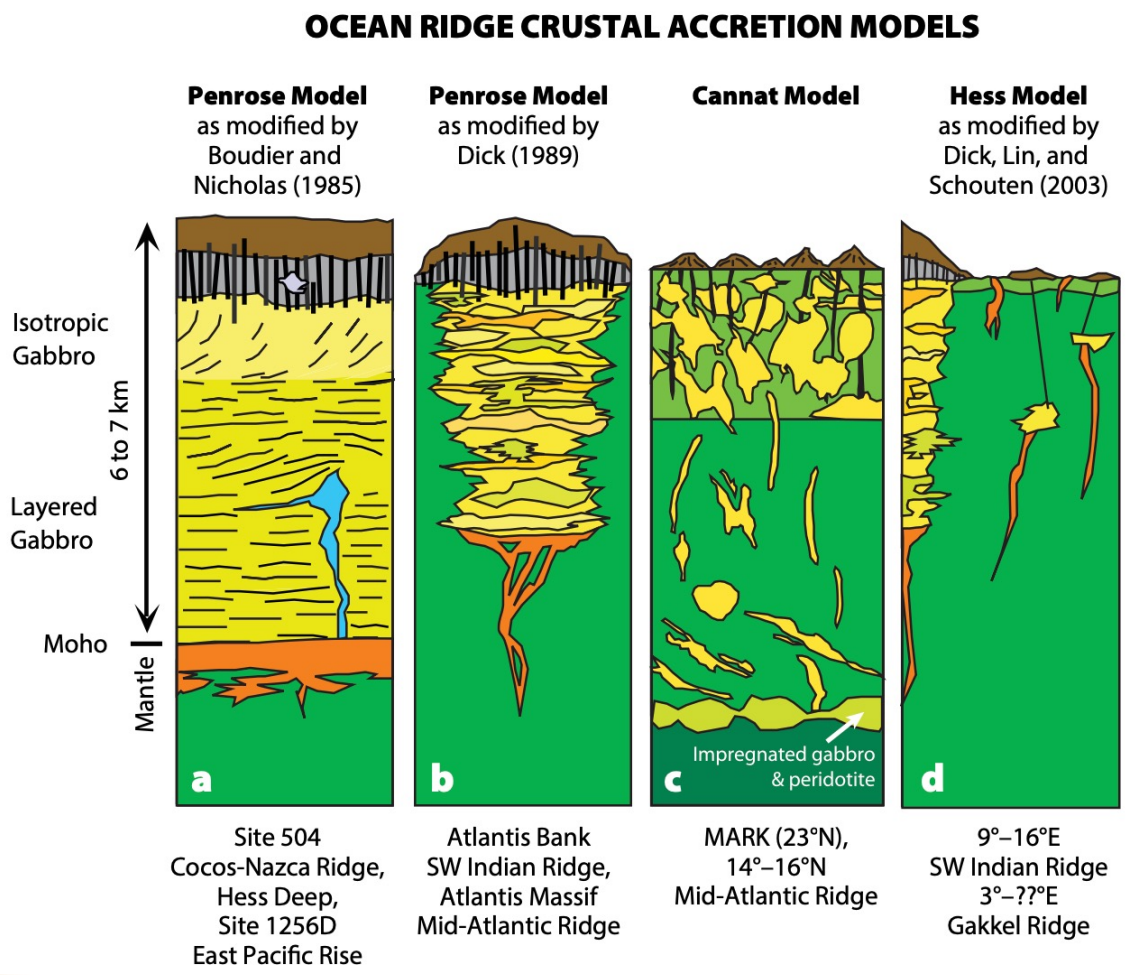




Location map of a borehole drilled more than 100 m into the deep-sea floor during the deep-sea drilling program from 1968 to 2020.

Michibayashi (2021, 地学雑誌)

Various lithological models in ocean floor question why the Moho depth is so constant?



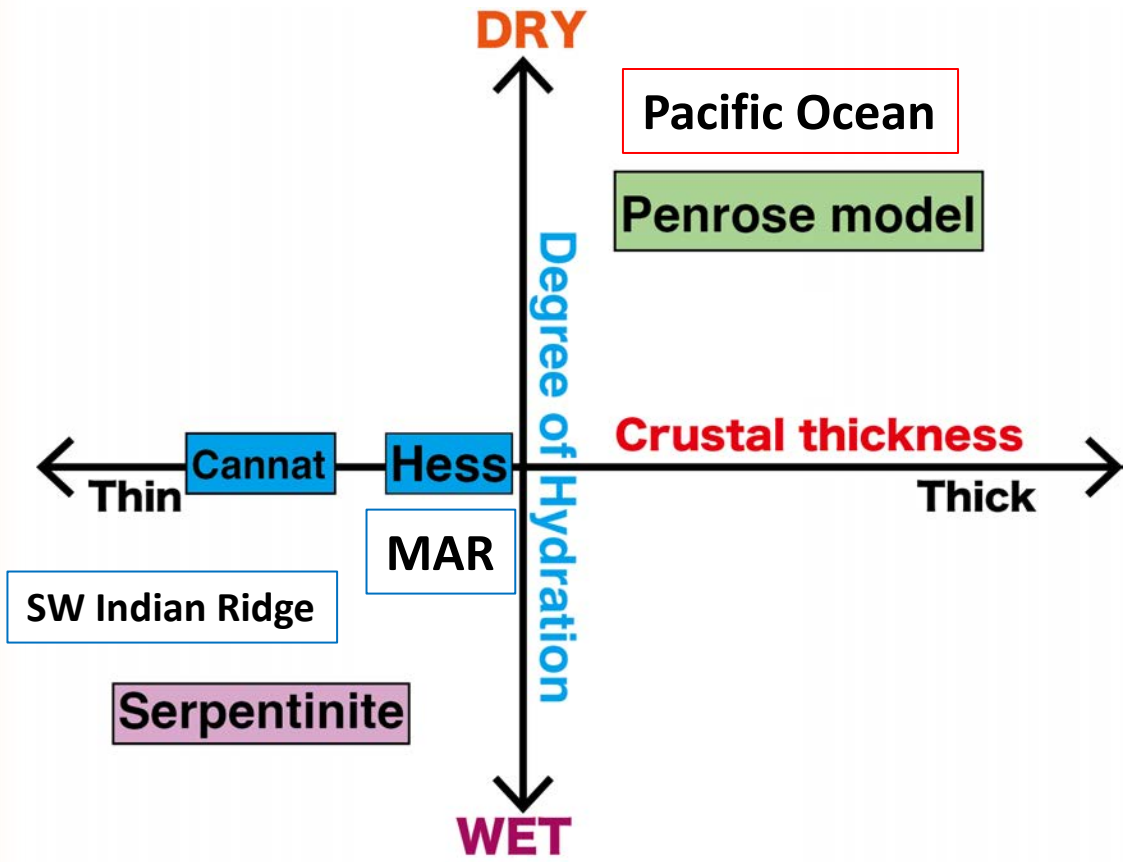
Michibayashi et al. (2019, Oceanography) after Dick et al. (2006)

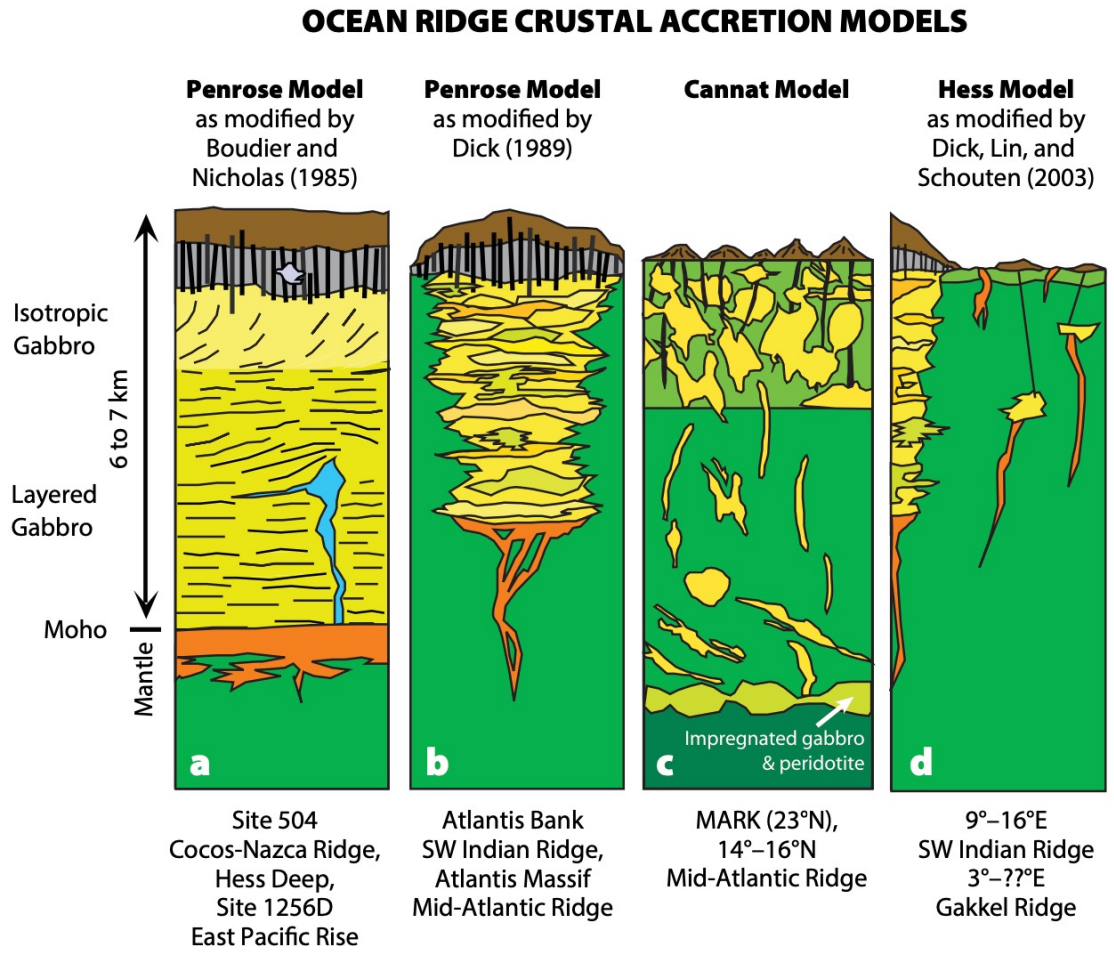
Is the Moho the interface between :

- magmatic crust & residual mantle ? (Model 1)
- magmatic rocks of different compositions ? (Model 2)
- serpentinized mantle & fresh mantle ? (Model 3)
- mantle + magmatic intrusions & mantle ? (Model 4)

Problem unsolved!

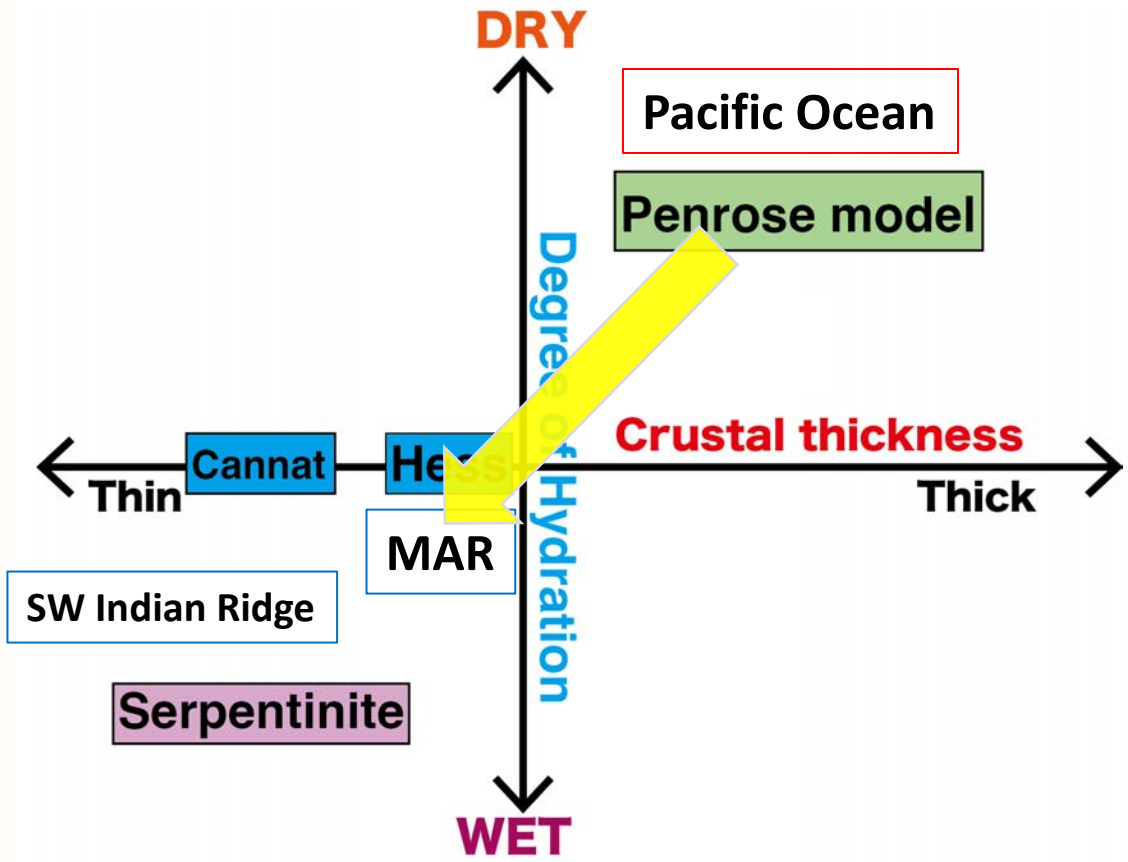
Oceanic lithosphere could be characterized by crustal thickness and wet conditions

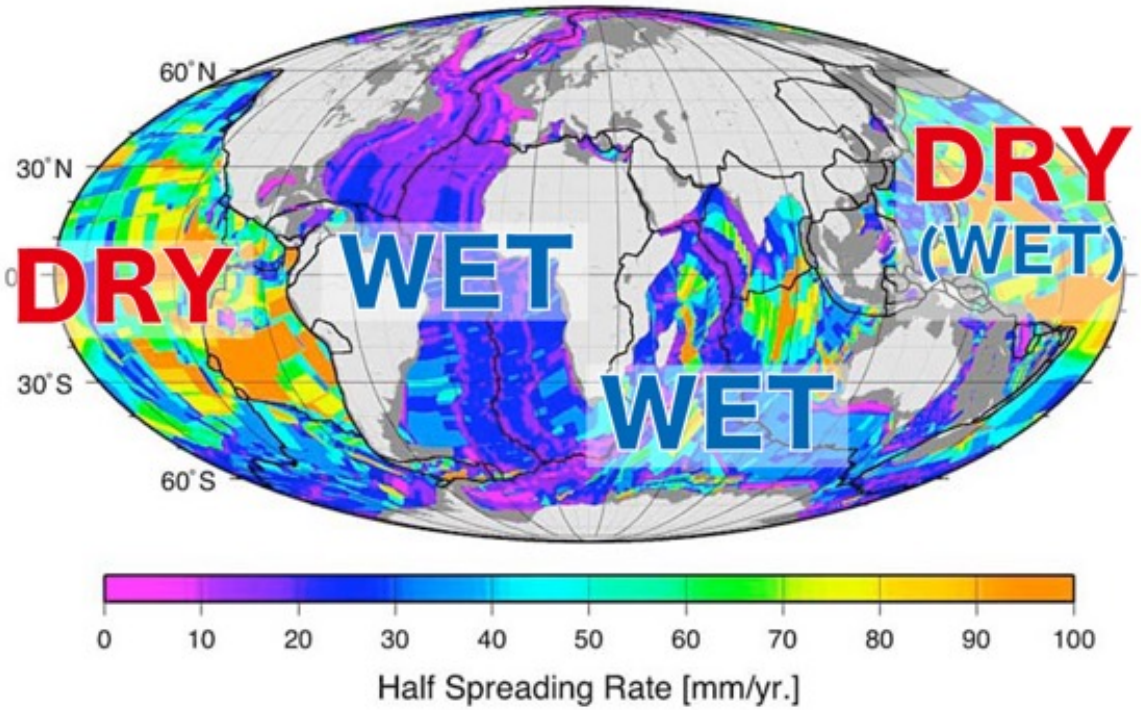




Michibayashi et al. (2019, Oceanography)

How WET the ocean floor is ?





Modified after Muller+(2008)

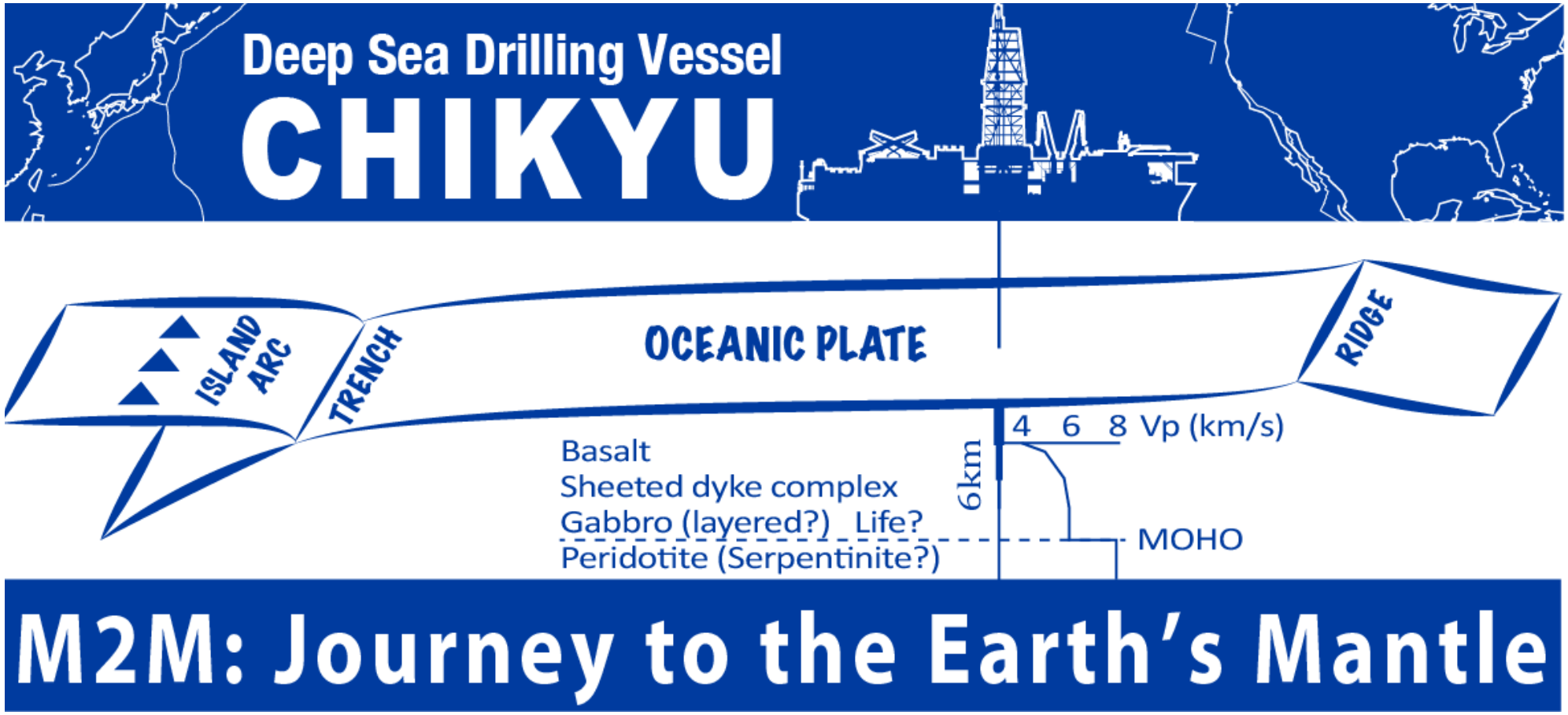
Each ocean floor has unique feature.

DRY OCEAN appears to be closing, WET OCEAN is slowly expanding?

CHIKYU is still waiting for a Mantle drilling project since 2005

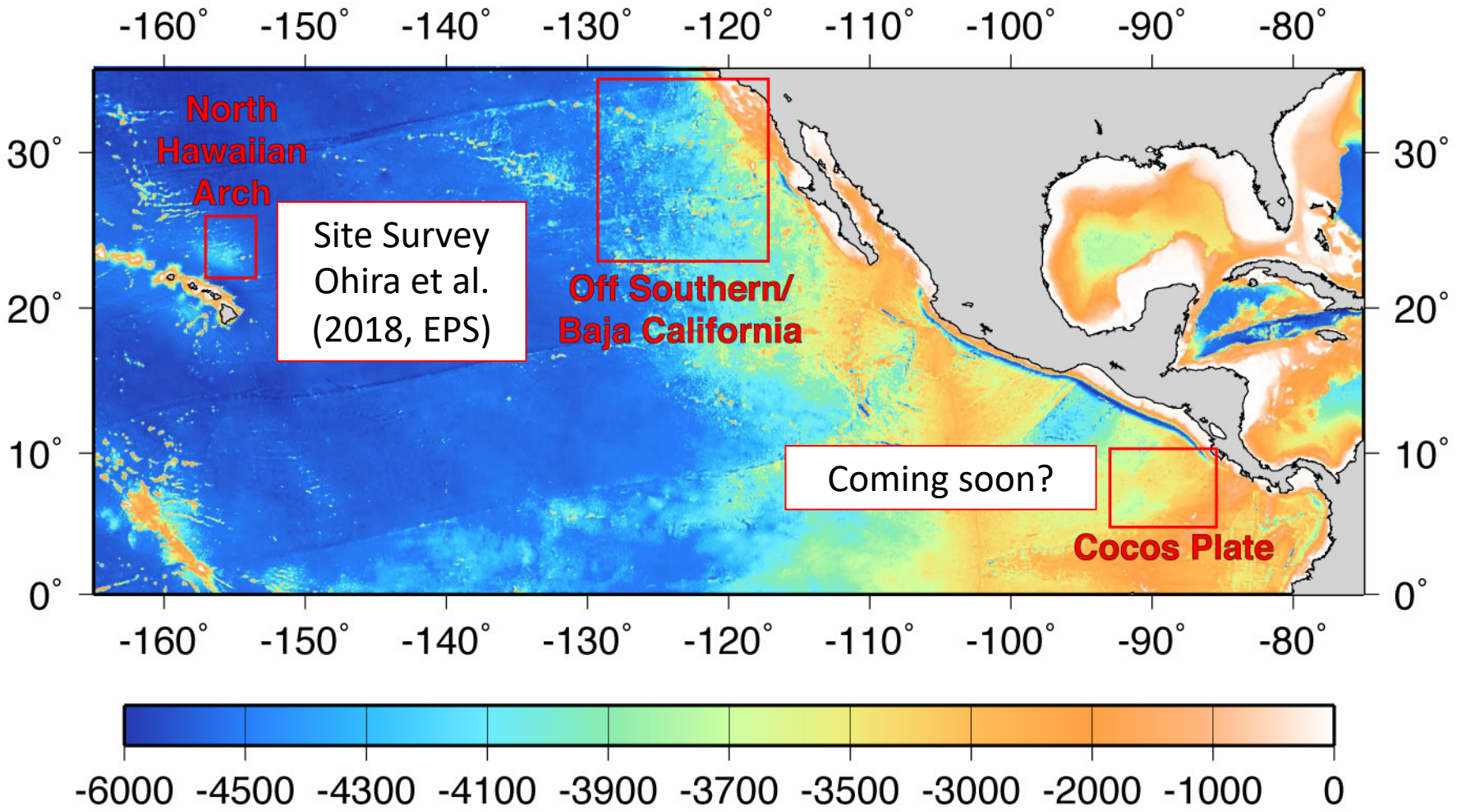
DRILLING EARTH SCIENCE

The **Mohole** project has been updated to be **M2M (MoHole to Mantle)** in 2012



The deep mantle drilling proposal lead by Prof. Susumu Umino et al. (Japan 4, USA 1, UK 1 & France 1) with 60 co-proponents (Japan 21, USA 19, UK 9, Canada 5, France 4, Germany 2)

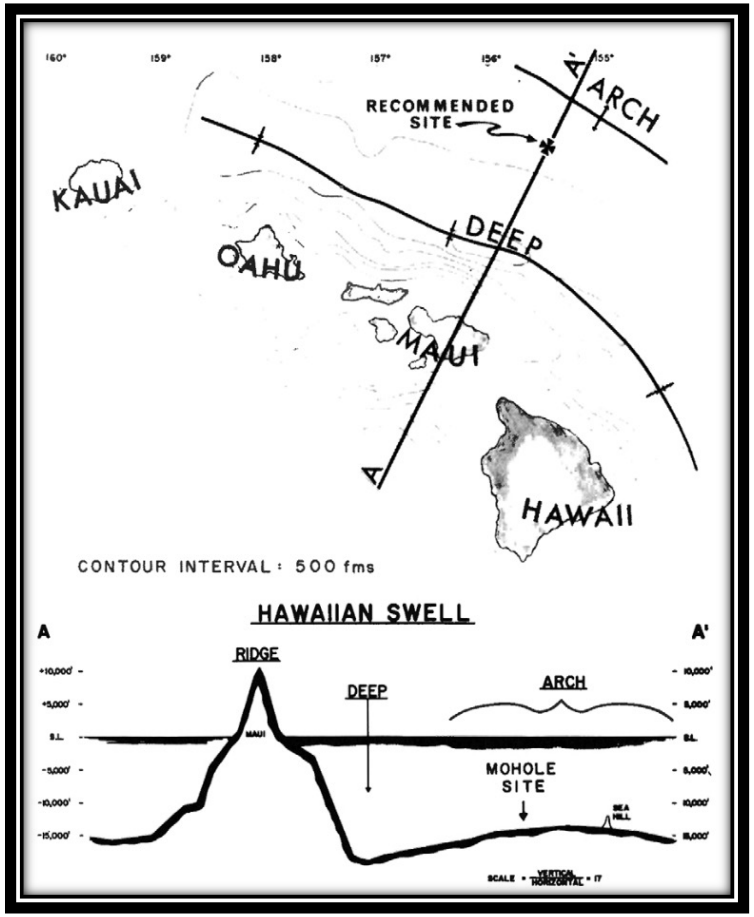
Selected regions for M2M have been proposed



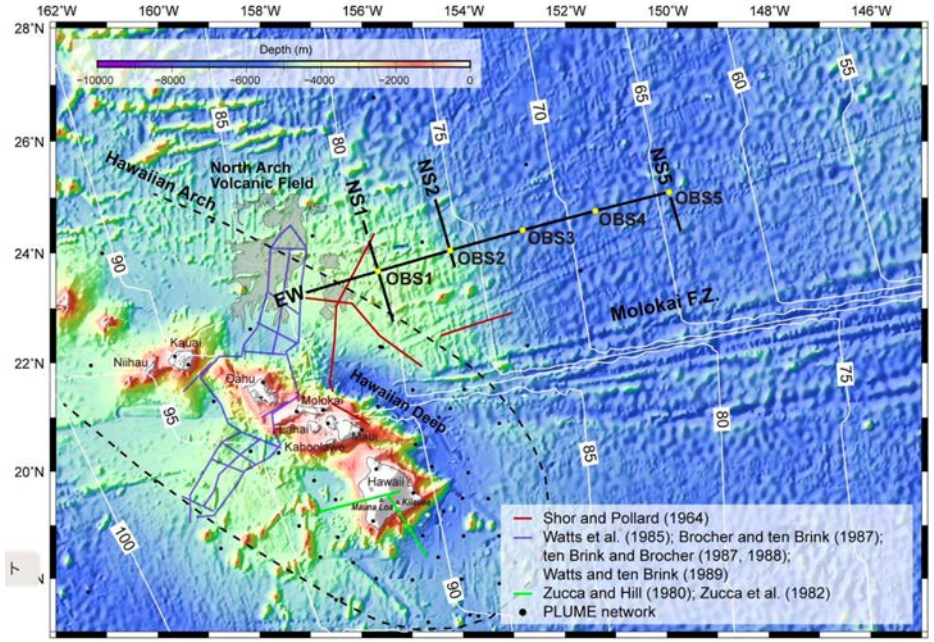
Additional site surveys are still required

(partly scheduled or applying/waiting for funding)

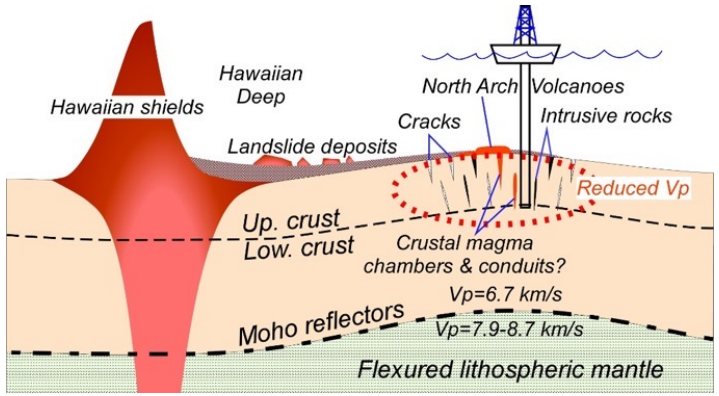
What a coincidence in the candidate site between Mohole (1966) and M2M (2012)!



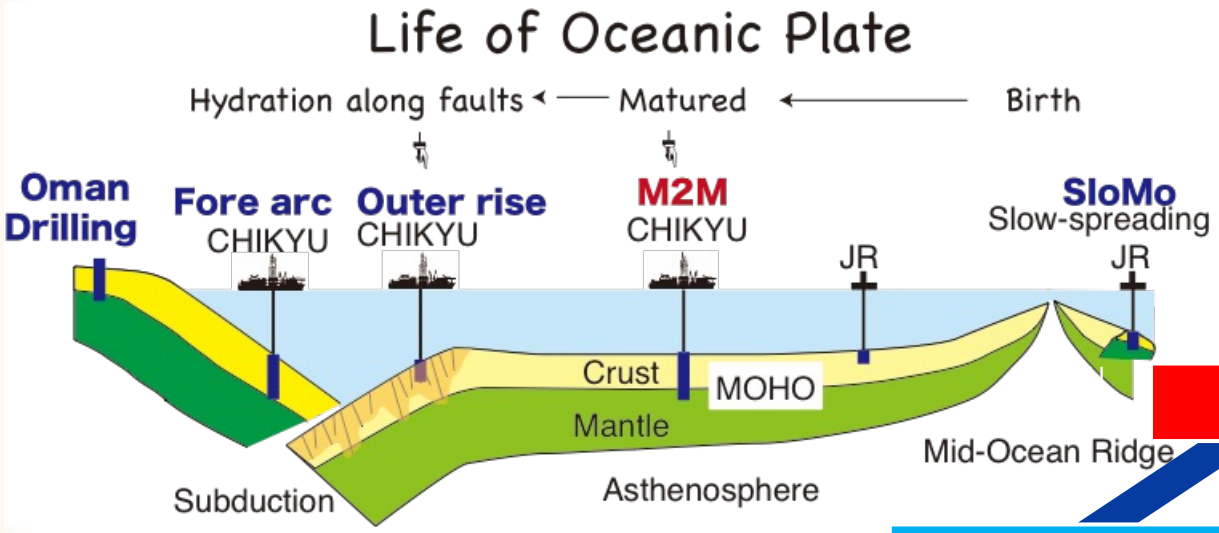
The MOHOLE site proposed in the Phase 2 of the Mohole project (Side, 1966)



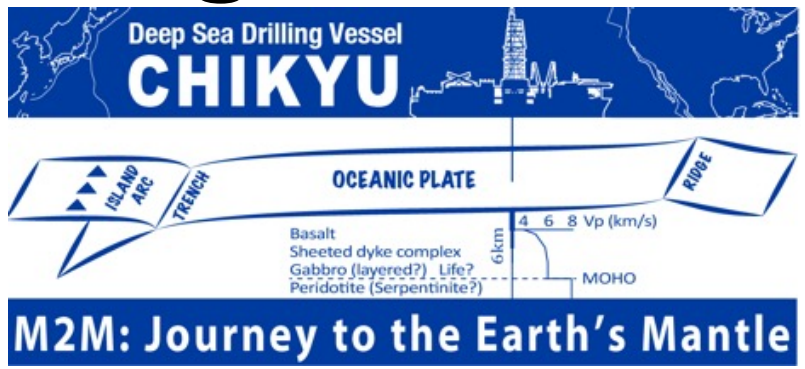
Ohira et al. (2018, Earth, Planets and Space)



The Road to the Mantle Drilling



Morishita et al. (2021)



Off Hawaii Drilling — Deep water-intermediate depth Hard-rock Drilling

Fore-arc Mantle Drilling — Deep water-depth Hard-rock Drilling

Outer Rise Drilling (H-ODIN, BFS) — Pretty Hard Hard-rock Drilling

SloMo — Hard-rock intermediate-depth Drilling

Godzilla Megamullion Drilling — Hard-rock shallow-depth Drilling

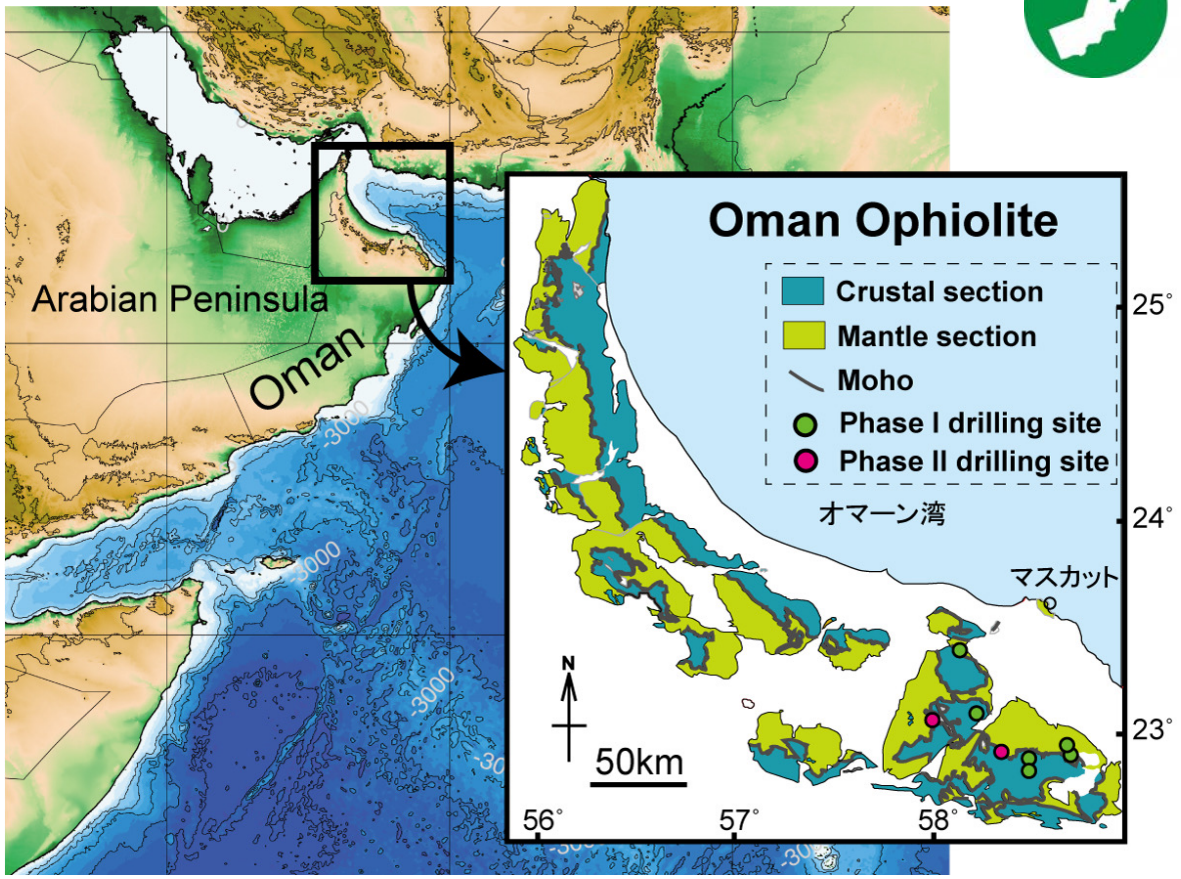
ICDP Oman Drilling Project — Hard-rock analyses on D/V CHIKYU

2016-2018

Oman Drilling Project: Background

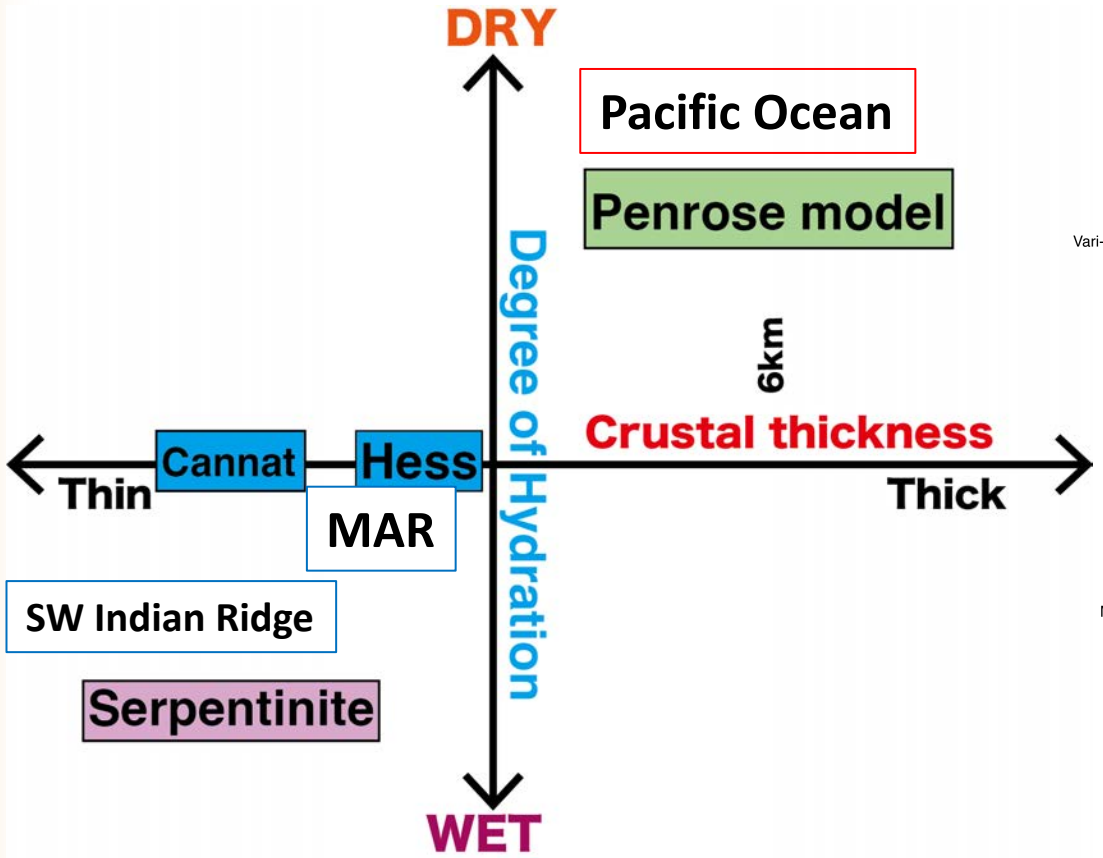
The Samail Ophiolite, in Oman and the United Arab Emirates, is the largest, best-exposed section of oceanic lithosphere in the World.

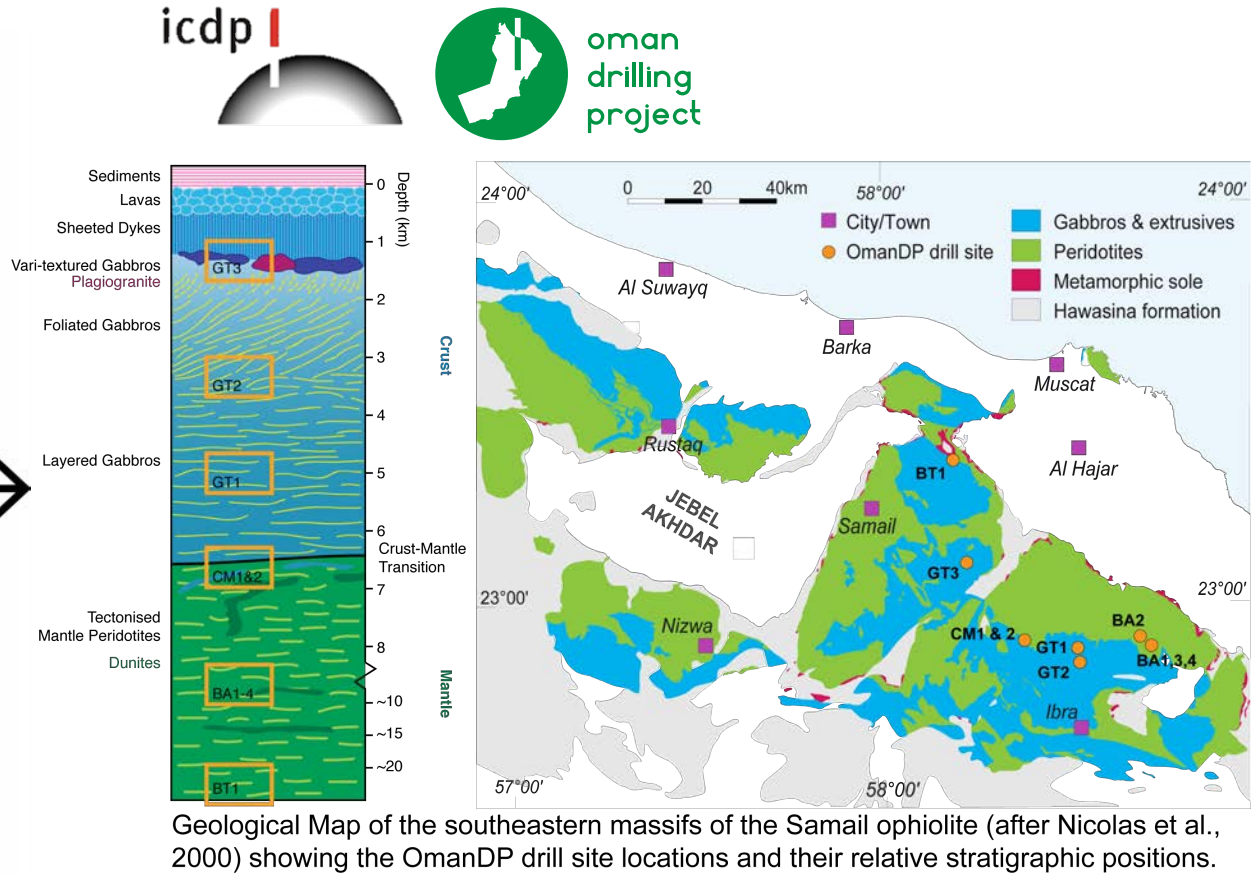
- sample the whole ophiolite sequence (crust and mantle)
- in a series of diamond- and rotary-drilled boreholes
- analysis of rock core
- geophysical logging
- fluid sampling
- hydrological measurements
- microbiological sampling



JGR special issue (2020-2022), Lithos special issue in progress!

Oman Drilling Project (2016–2018)





Geological Map of the southeastern massifs of the Samail ophiolite (after Nicolas et al., 2000) showing the OmanDP drill site locations and their relative stratigraphic positions.

To test Penrose model and water-rock interaction

Oman Drilling Project
CM Site (Crust-Mantle Boundary)

icdp

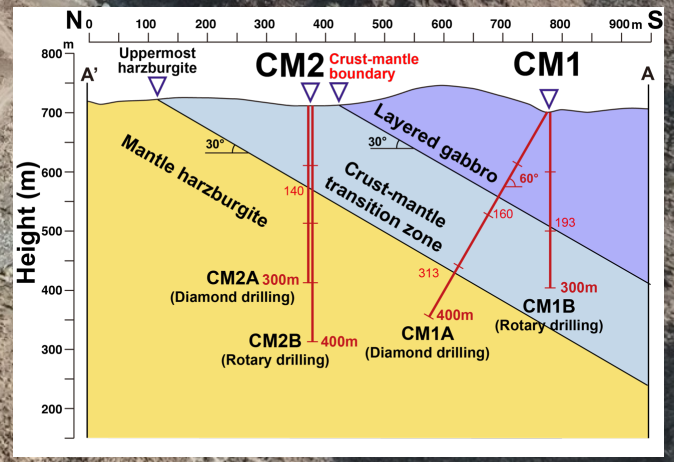
oman drilling project

Oceanic Crust

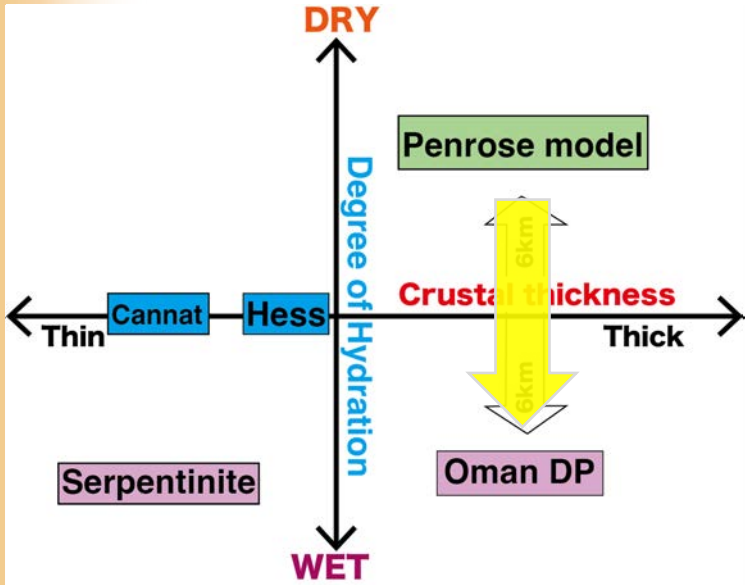
CM2

CM1

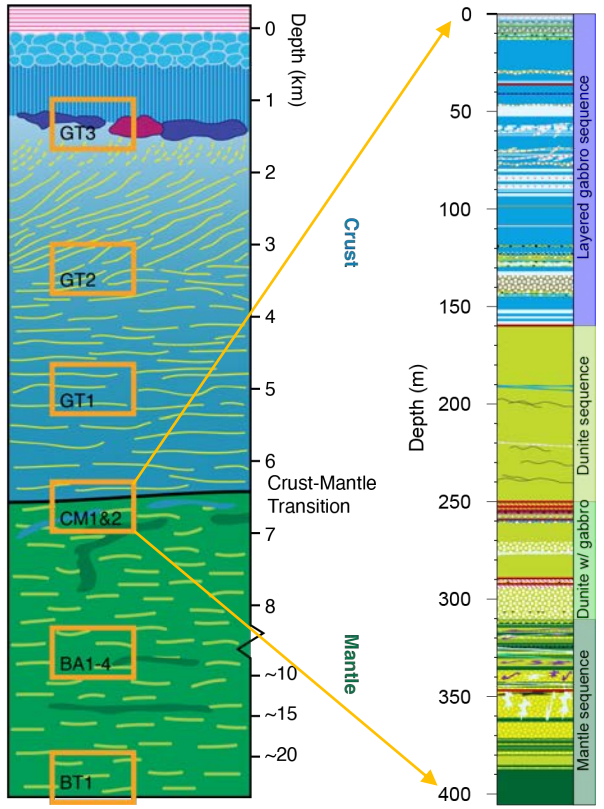
Uppermost mantle



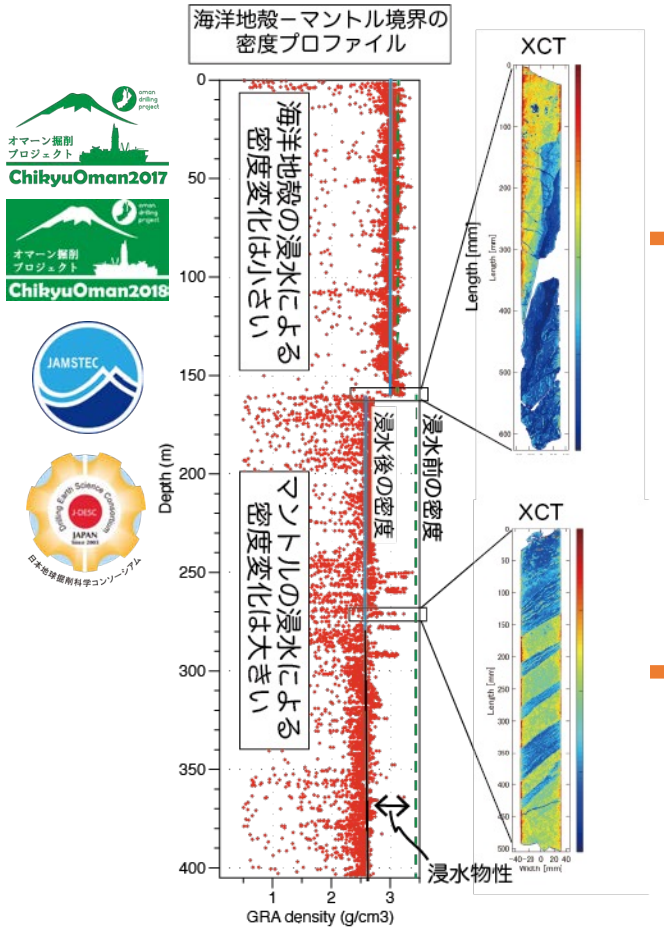
Oman Drilling Project (2016–2018)



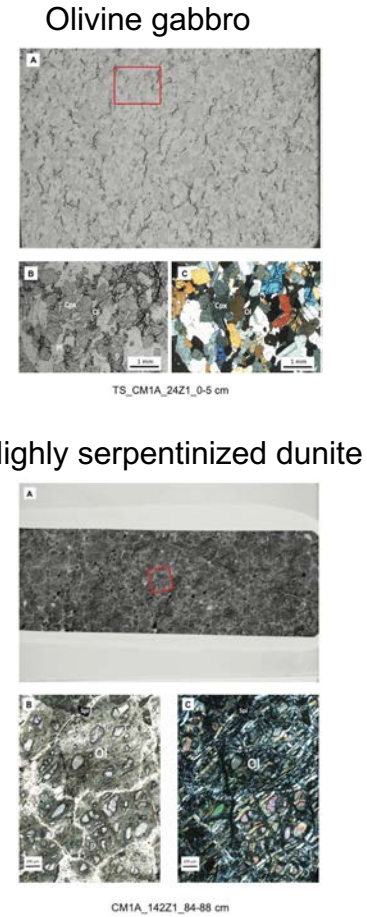
Oman drilling cores are prety wet unlike the Penrose model



Nicolas+(2000)



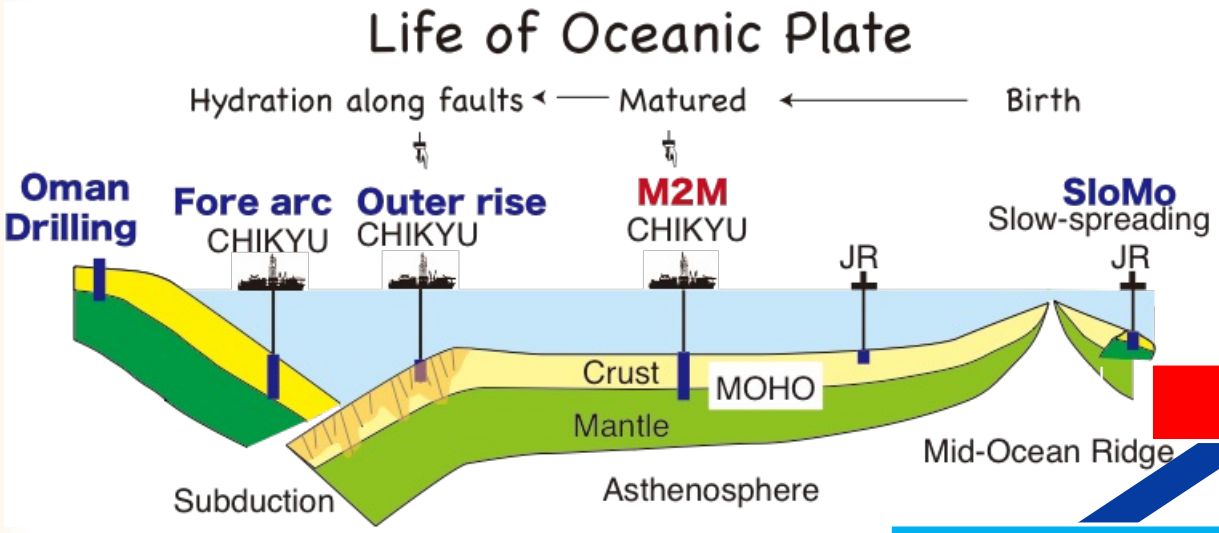
Kelemen+(2020) Michibayashi+(2018 AGU) Katayama+(2021)



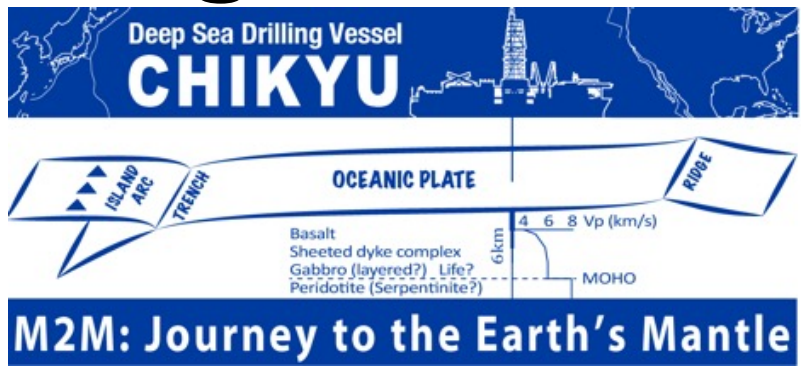
Kelemen+(2021)

Mantle could get wet, although ocean crust could be less wet (e.g., Yoshida+20)

The Road to the Mantle Drilling



Morishita et al. (2021)



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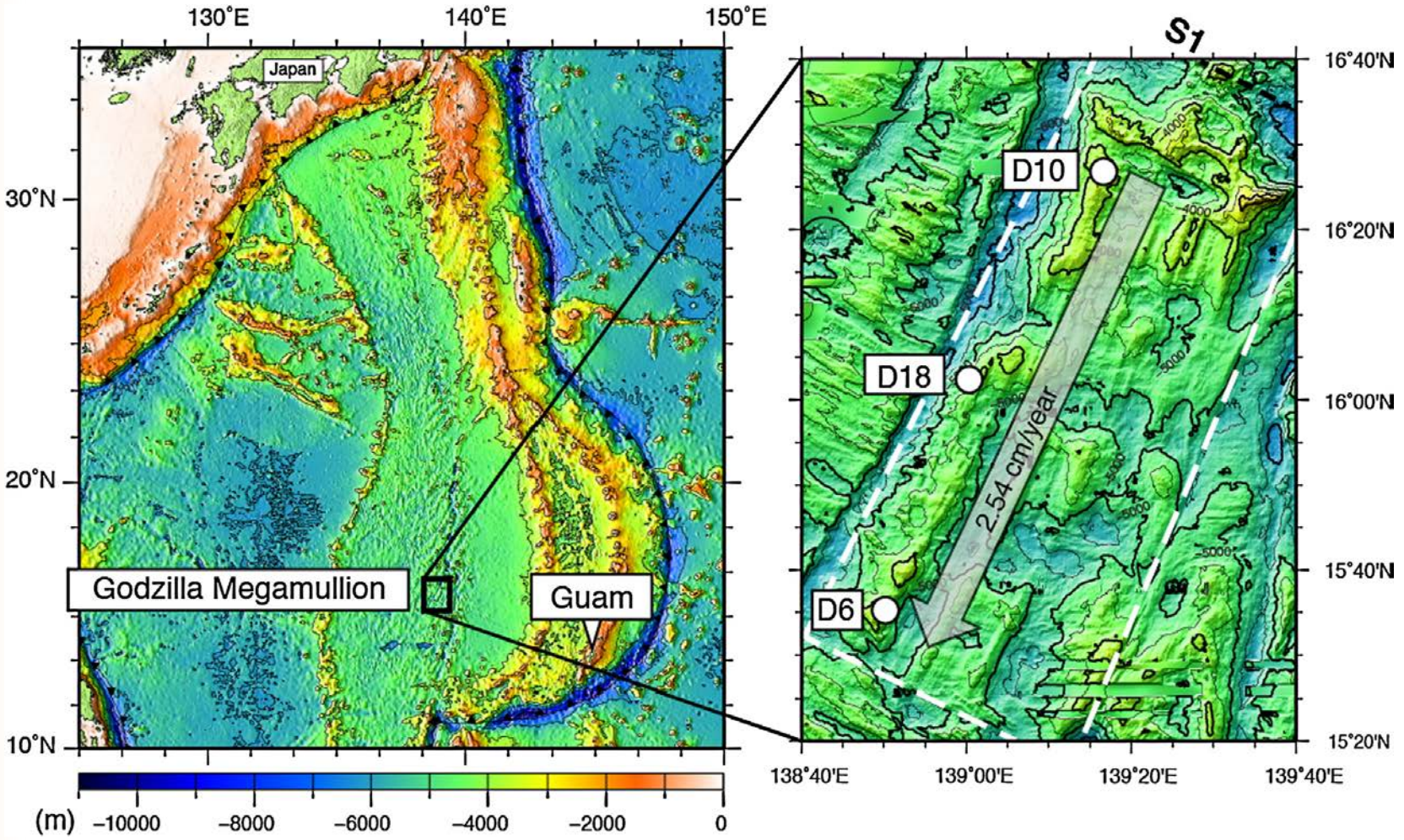
2016-2018

Probing the Deep Earth via hard-rock drilling has great demand after more than 50 years since the end of the Mohole project

Godzilla Megamullion Project, Coming Soon!?

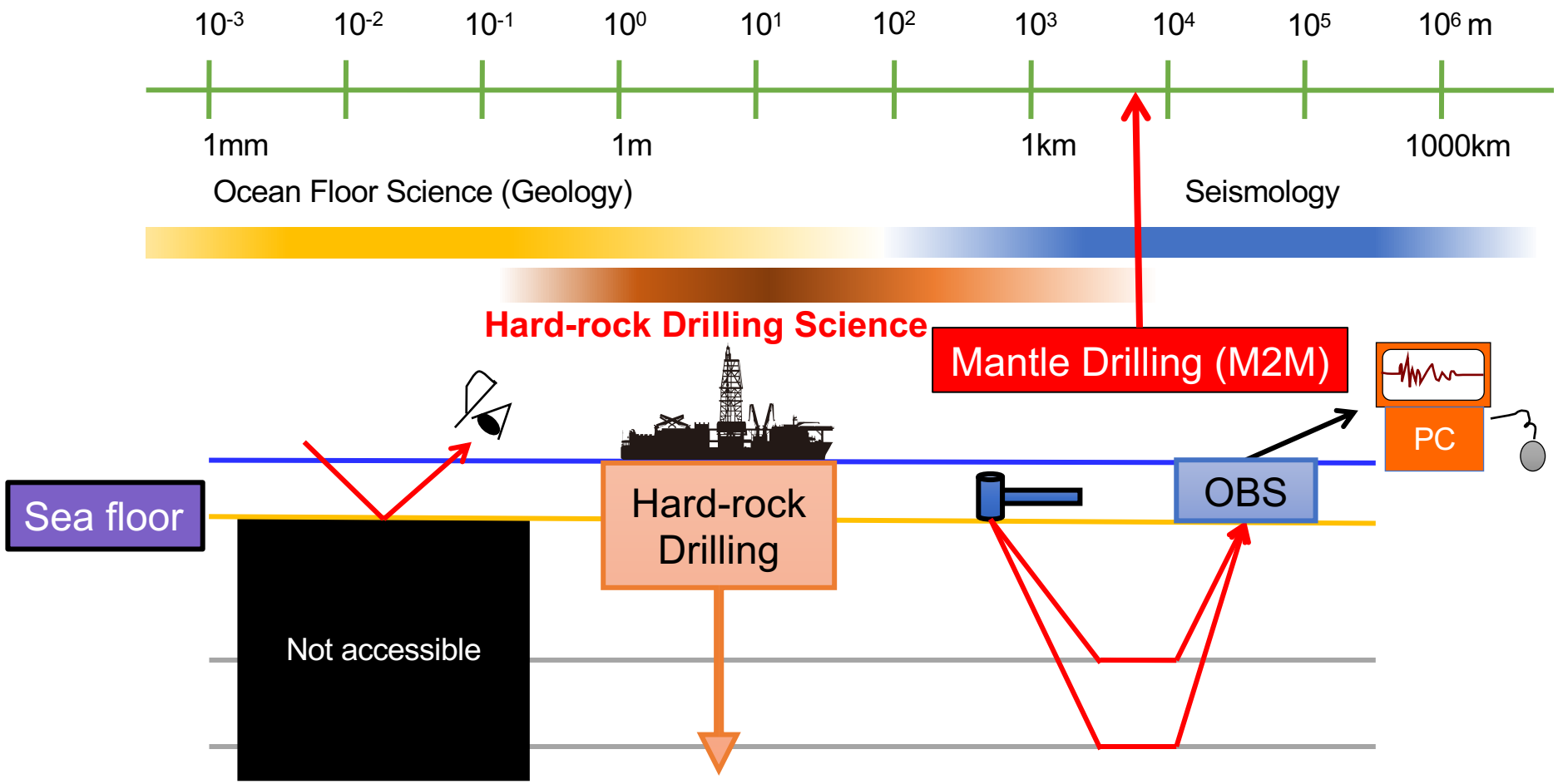


PI: Yashiko OHARA

ごじらマントル君

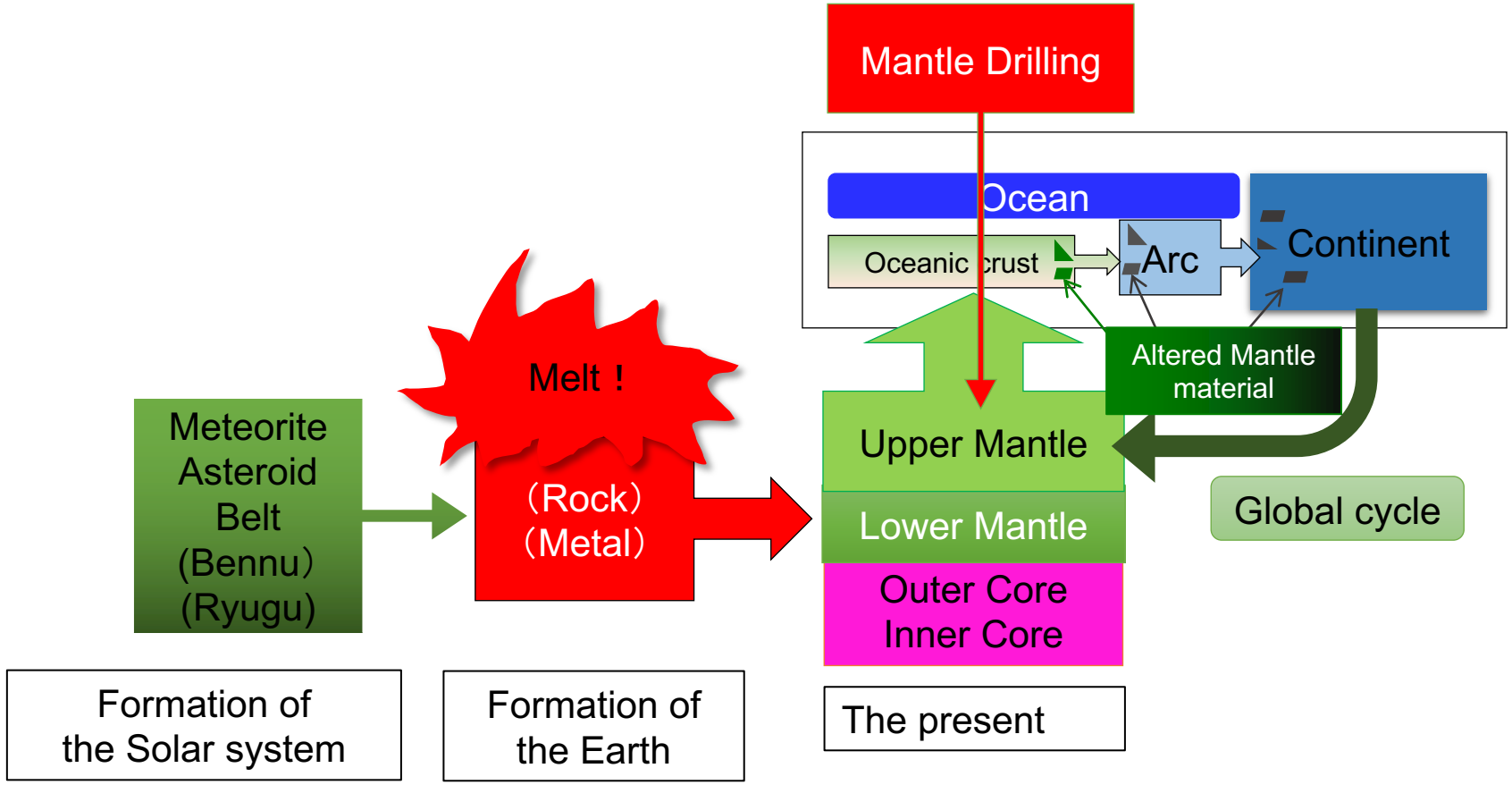
This project may be the first Mantle Drilling Project

Hard-rock Drilling Science is the link between ocean floor science (geology) and seismology



Moreover, Mantle Drilling is not only for Earth Science, but it must also be for Planetary Science

Earth history ＝ Cooling history of a planet in the Solar System



How far can we understand the evolution of this planet without mantle drilling?

DRILLING EARTH SCIENCE

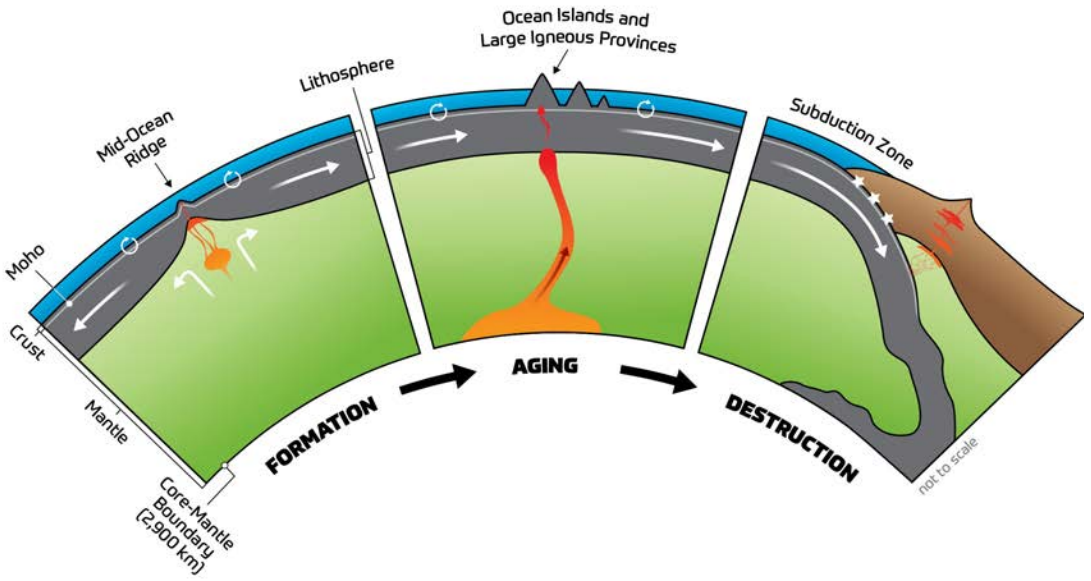
STRATEGIC OBJECTIVE O2

THE OCEANIC LIFE CYCLE OF TECTONIC PLATES

Investigating the genesis, aging, motion, and destruction of oceanic lithosphere

SUMMARY

Earth repaves more than half its surface every ~200 million years. The formation, evolution, and destruction of oceanic lithosphere is an integral part of the plate tectonic cycle and establishes boundary conditions for Earth's climate system. It drives the global cycling of energy and matter that buffers Earth's environmental conditions and makes Earth's surface habitable. Oceanic lithosphere cycling produces critical economic resources and governs the occurrence of earthquakes, tsunamis, and volcanoes that pose hazards to society. To date, we have only explored a small fraction of Earth's oceanic lithosphere and to relatively shallow depths. To answer fundamental questions about our planet's central rock cycle and plate tectonics requires scientific ocean drilling of crustal sections that span the life cycle of oceanic lithosphere and the full spectrum of plate accretion modes, plate boundary types, intraplate magmatic processes, and subduction styles.

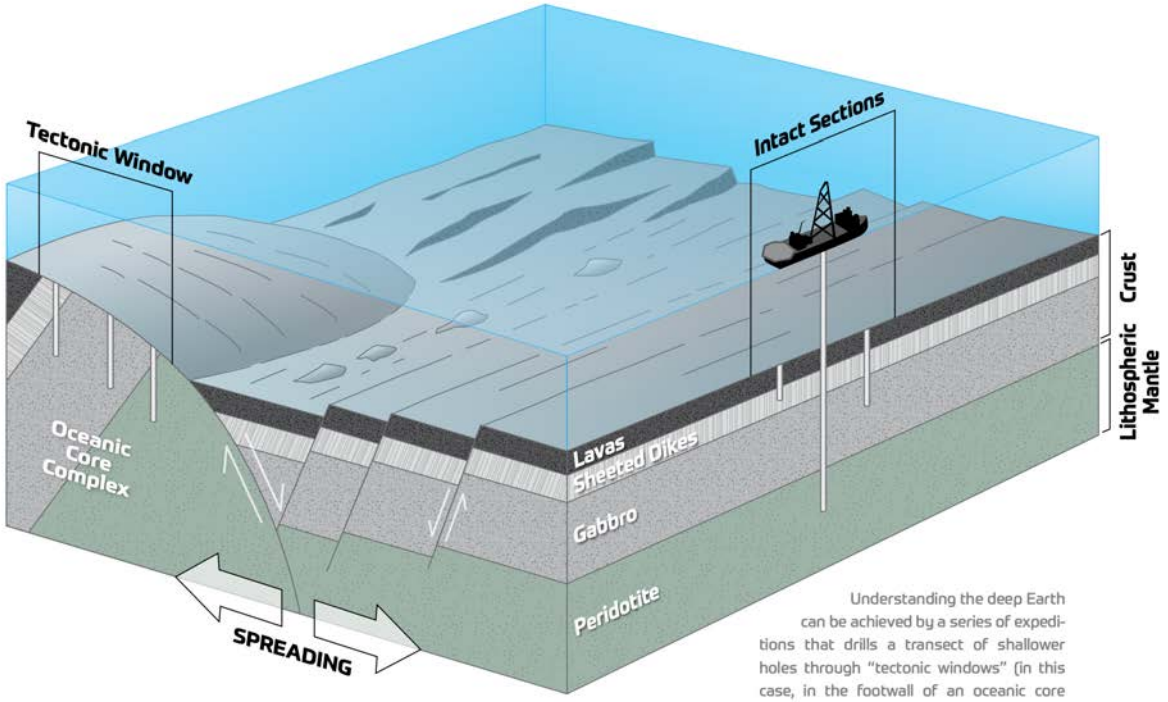


FLAGSHIP INITIATIVE A2

PROBING THE DEEP EARTH

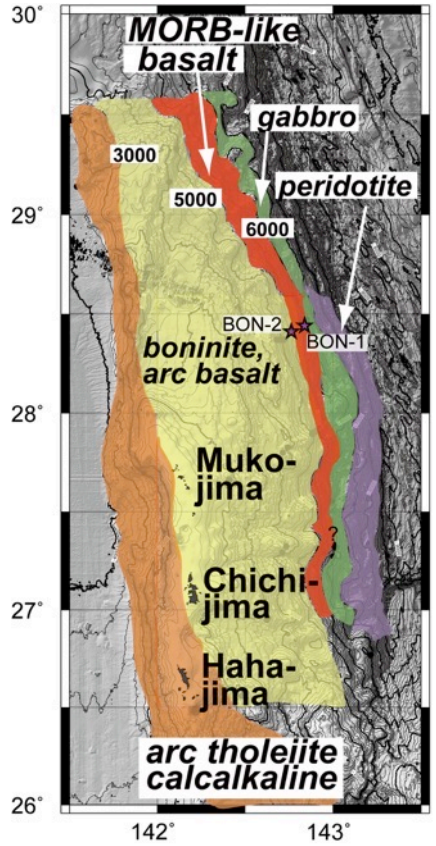
SUMMARY

Scientific ocean drilling has long aspired to penetrate deep into Earth's oceanic crust and its underlying mantle. Achieving this objective is still pushing the limits of technology and thus remains elusive. New multidecadal scientific ocean drilling strategies seek to probe the deep Earth and to finally reach the upper mantle via a series of interconnected, ambitious expeditions that will take full advantage of emerging drilling, coring, logging, and monitoring technologies. This deep drilling will lead to a better understanding of Earth's formation and evolution; the nature of Earth's deep interior and its geodynamic behavior; the interrelationships between the deep Earth and geological, biogeochemical, and climate cycles; and the limits of life.

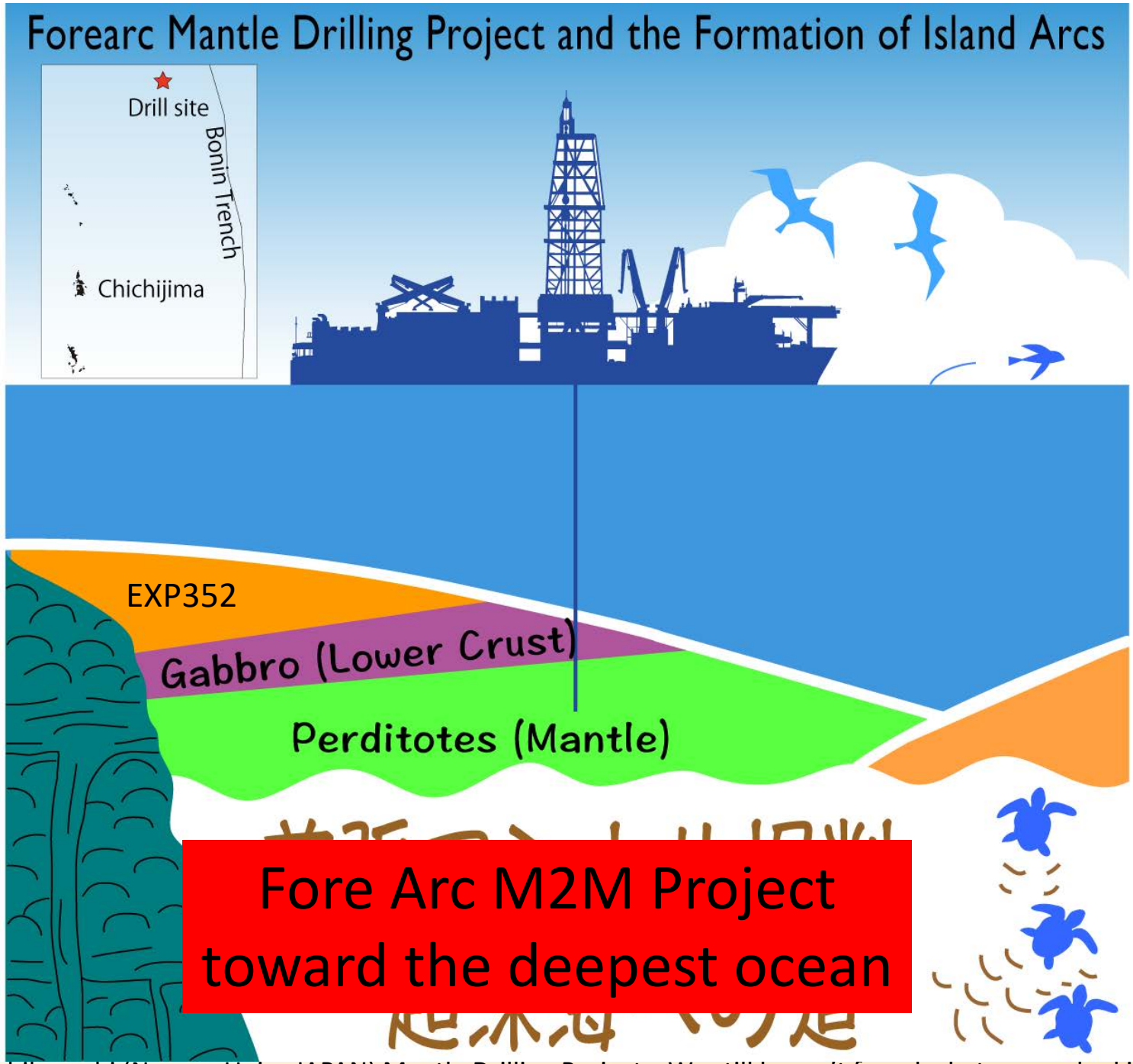


Understanding the deep Earth can be achieved by a series of expeditions that drills a transect of shallower holes through "tectonic windows" (in this case, in the footwall of an oceanic core complex) or penetrates the full, approximately 6–7 km thick, oceanic crust in one hole in normal magmatic crust. *Illustration by Antony Morris and Geo Prose*

[Keynote2] Deep Earth: Katsuyoshi Michibayashi (Nagoya Univ., JAPAN) Mantle Drilling Projects: We still haven't found what we are looking for

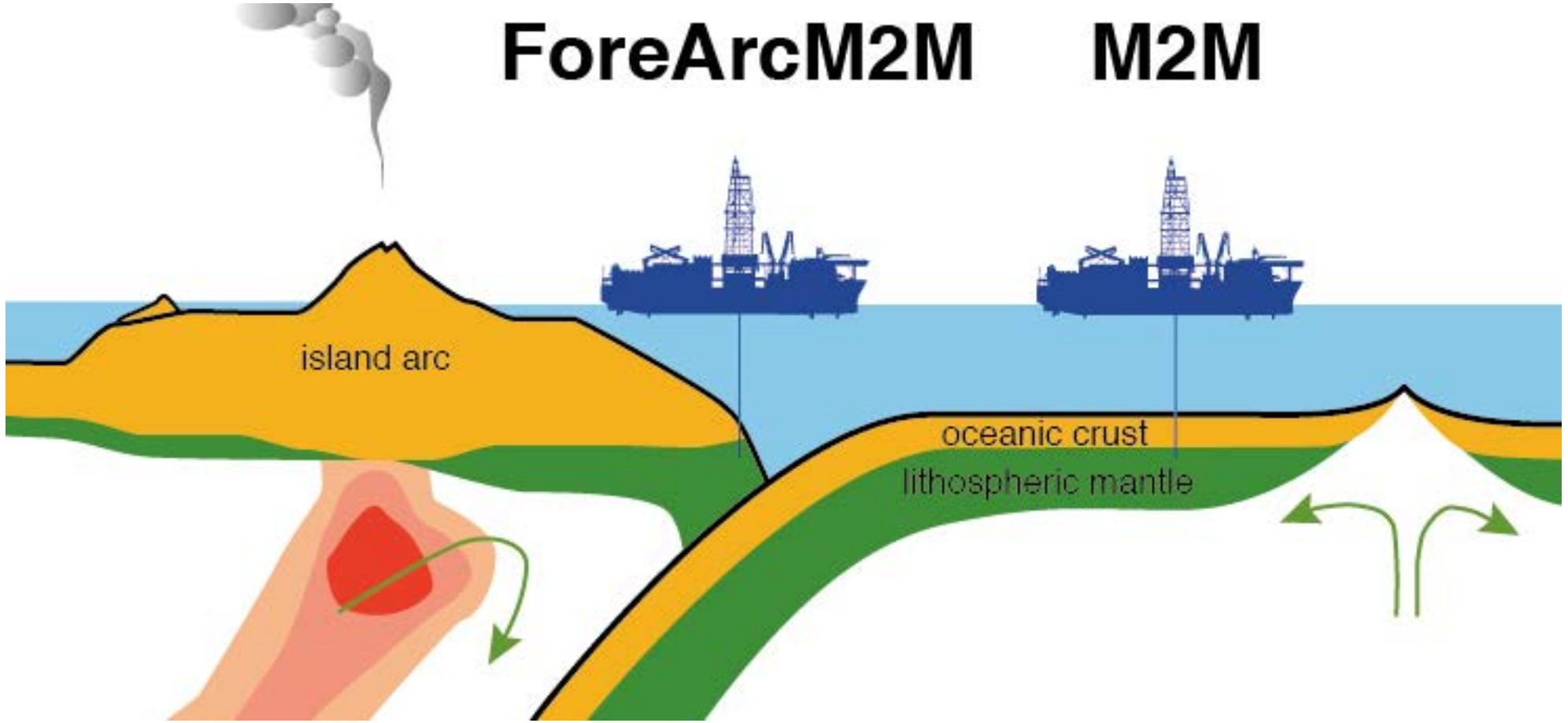


After Ishizuka et al. (2011)



Fore Arc M2M Project
toward the deepest ocean

Fore Arc M2M will drill into mantle from sea floor at 6000 mbsl instead of 6000 m of oceanic crust!



We hope to submit a full proposal of Fore Arc M2M in a few years