Muography of Oman Ophiolites

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Outline

I. Introduction
(see also Prof. Umino's talk at Muographers GA 2022, Tokyo)

II. Instrumentation

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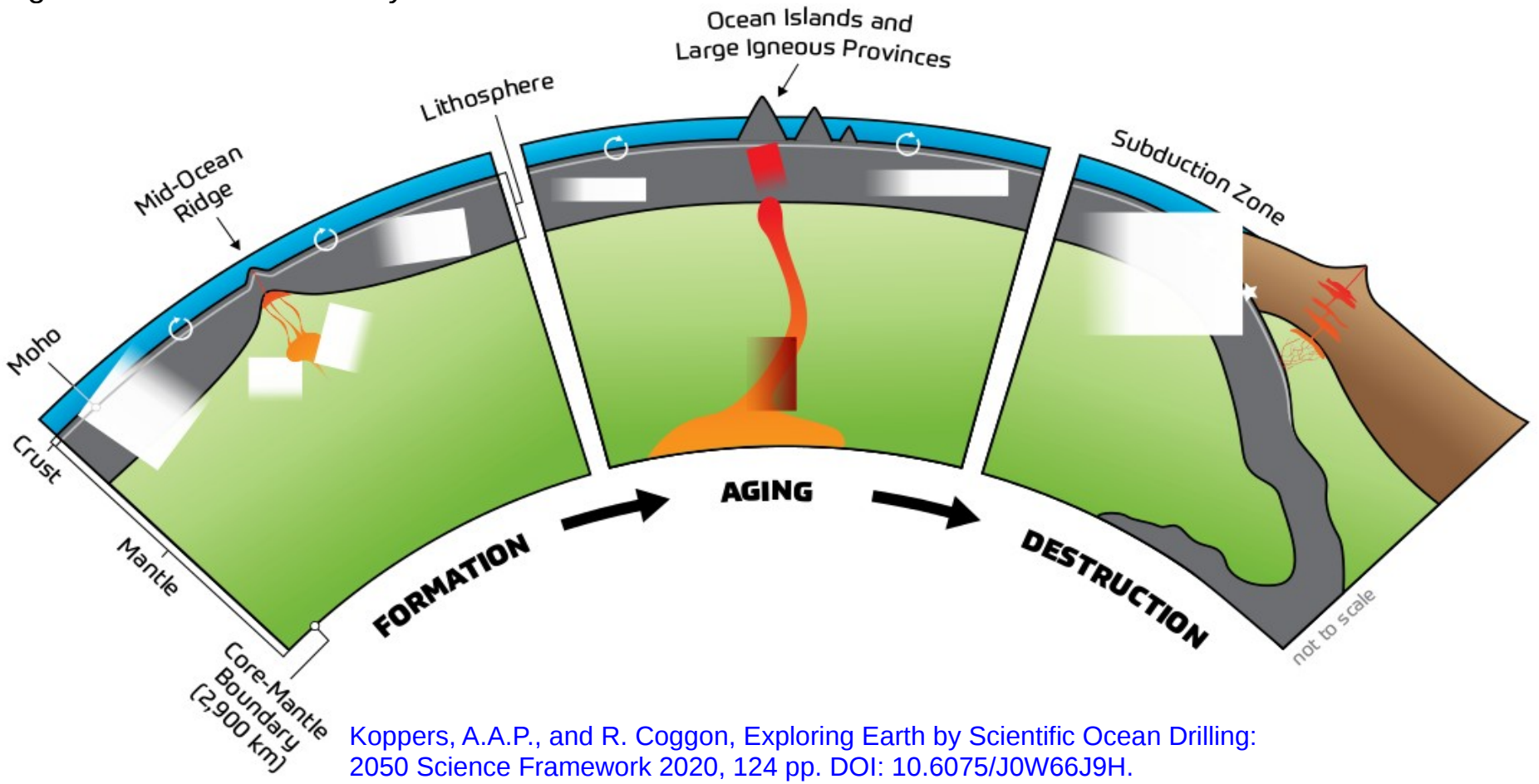
IV. Summary

I. Introduction

- **Oceanic litosphere (crust and upper solid mantle) cycle (1. formation, 2. evolution and 3. desctruction)** occurs over tens to hundreds of million years.

- **Cycle of matter and energy**
  produces critical resources to economy,
  governs the occurrence various natural hazards from earthquakes to volcanic eruptions and regulates Earth's climate system.

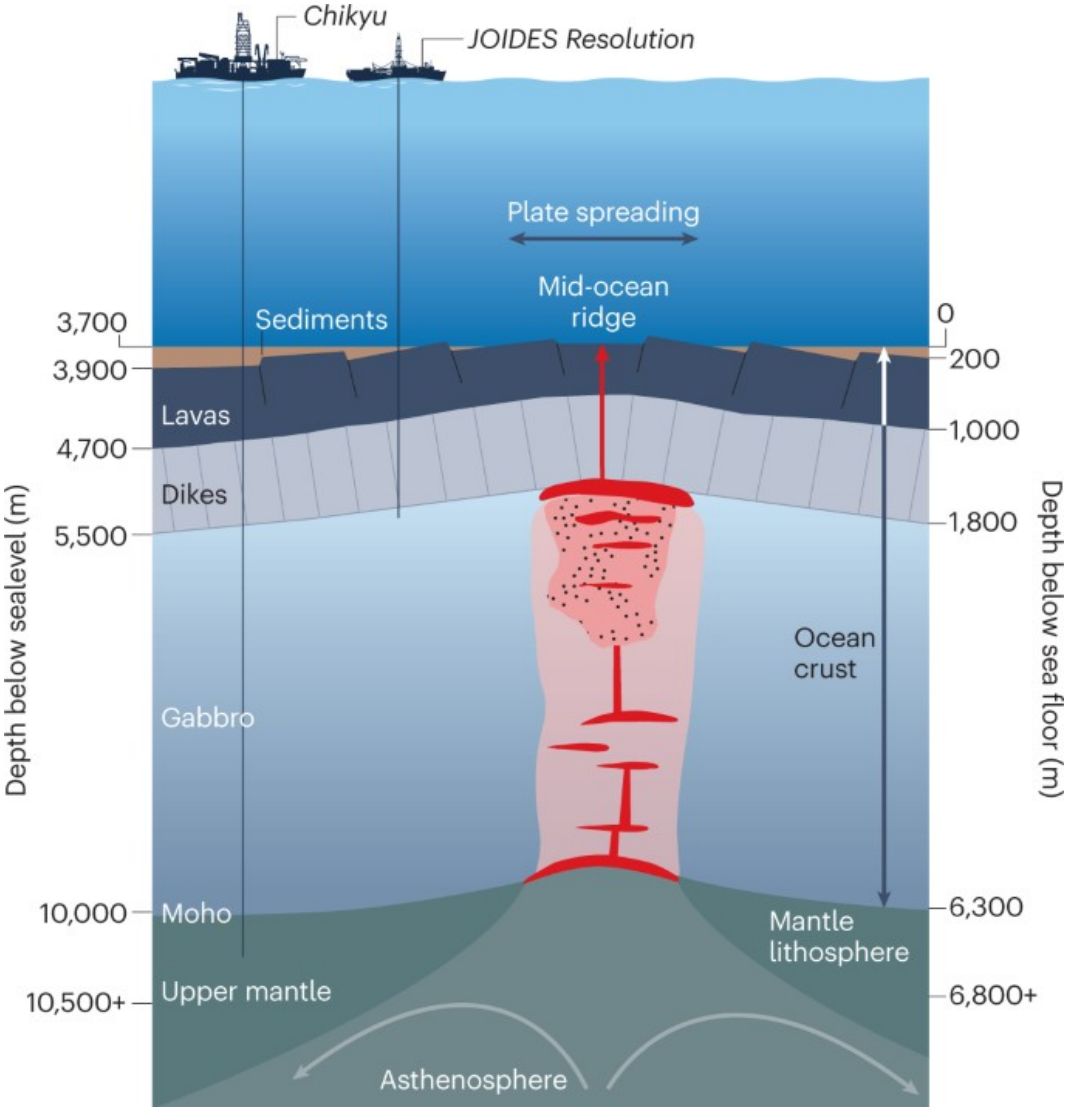


Koppers, A.A.P., and R. Coggon, Exploring Earth by Scientific Ocean Drilling: 2050 Science Framework 2020, 124 pp. DOI: 10.6075/J0W66J9H.

Scientific Ocean Drilling: Mohole 2 Mantle (M2M)

- **Scientific ocean drilling aims to collect fundamental data on the plate tectonic cycle since 1960s**
  - **Mantle drilling** addresses the following questions:
    - What is the composition and structure of Earth's convecting mantle?
    - What is the geological nature of Mohorovičić discontinuity (Moho) and Layer 2/3 boundary?
    - How the oceanic crust formed and evolved?
    - What are the limits of deep life?
  - M2M was proposed by the International Ocean Drilling Program (IODP) in 2012

    → Drilling is expected to be started in 10 years.



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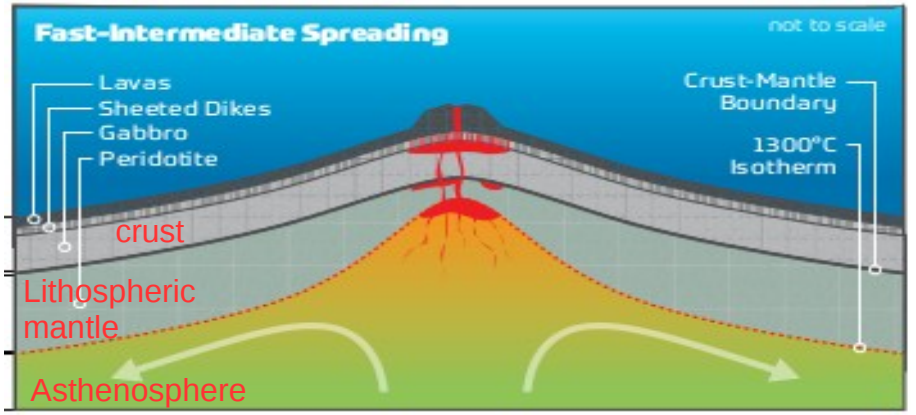
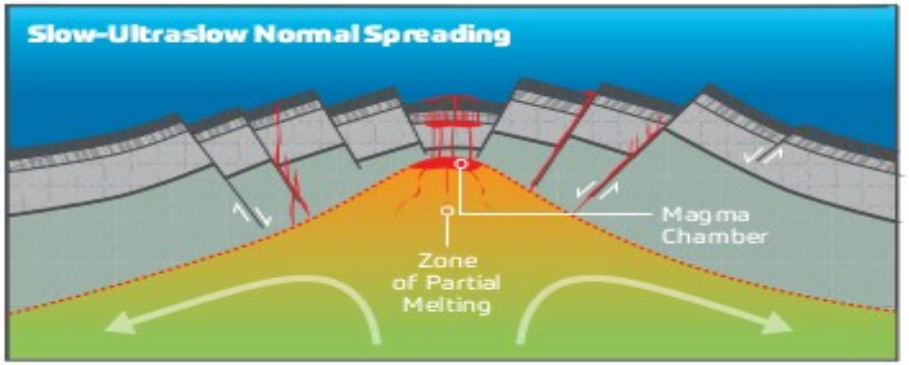
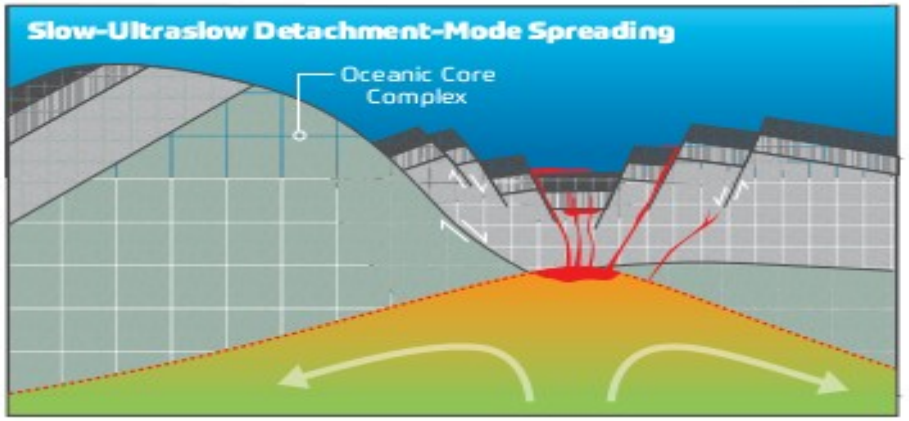
Actual Knowledge and Scientific Questions

- **Volume, composition and architecture of crust depends on the seafloor spreading rate and the nature of underlying mantle (1967)**
  - fast spreading →
    tectonic extension dominates that is leading to heterogenous crust
  - Ultra slow spreading →
    low angle detachment faulting that result in exposure of mantle rocks (periodites, pyroxenites)
- Magma chamber depth negatively correlated with fast spreading rate → shallower magma chamber has higher magma supply rate

  (see Prof. Umino's talk at Muographers 2022 GA)
- **Questions:**
  - **Why and how does the crustal structure (layer 2/3) depend on spreding rate?**
  - **What is the geological nature of Moho?**







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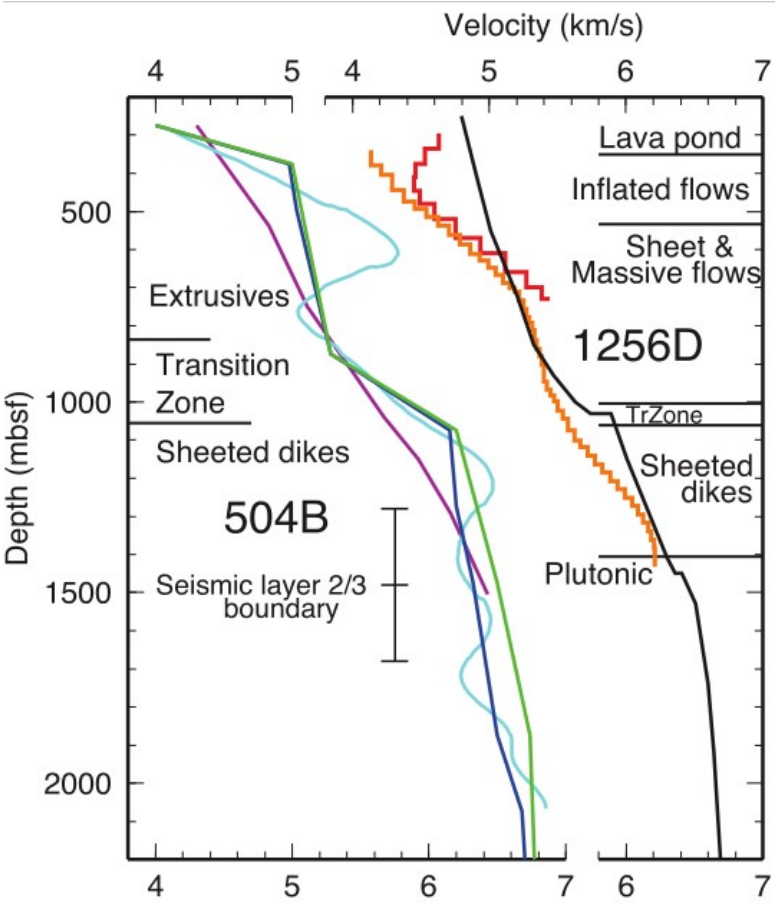
Oceanic litosphere in Ophiolites

- Only one vertical seismic profile reached seismic layer 2/3 boundary and **Moho has not yet been reached** → geological nature is not yet well understood
- Different seismic layers (layer 2/3 boundary and Moho) are exposed above ground in ophiolites

→ **Ophiolites help to understand the correlation between oceanic structure and geology**



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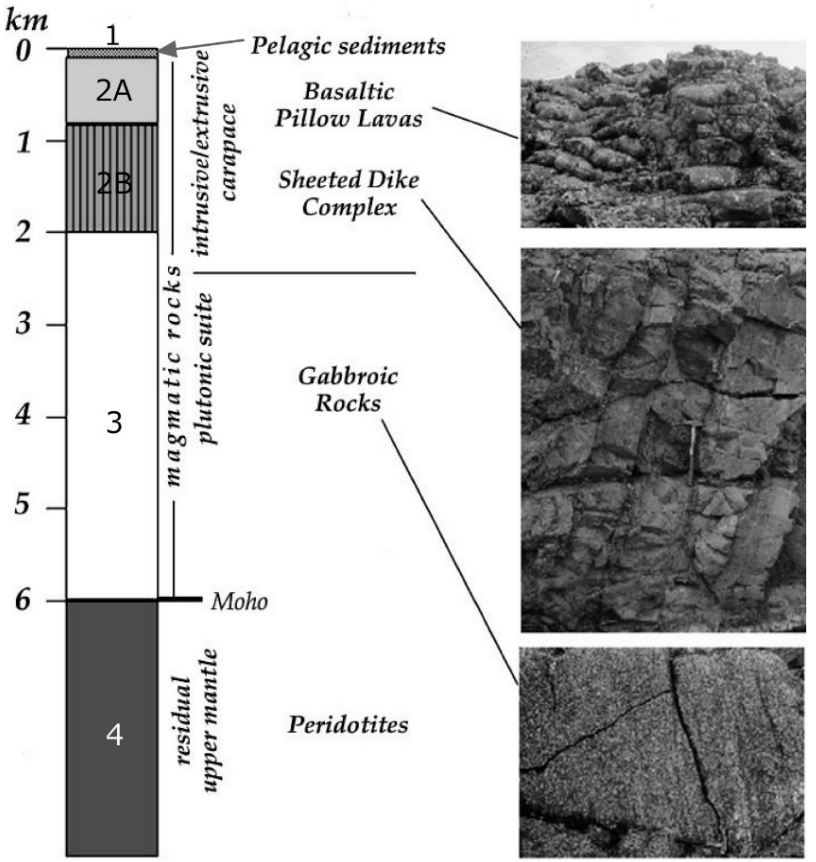

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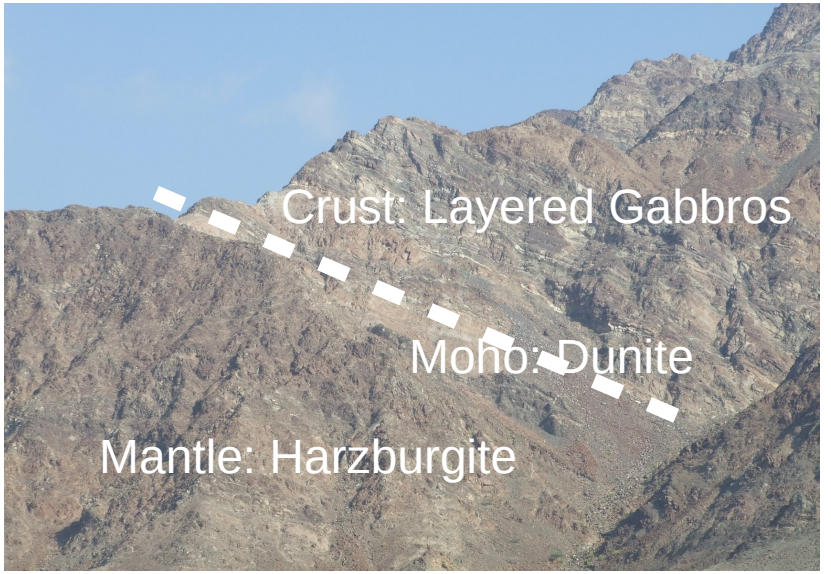
Muography of the Oman Ophiolites

- Sampling is available but sampling density is low
  → seismic velocities are different
- **Objective: better understand the geologic nature of the crust/mantle (Moho) and upper/lower crustal boundaries of the Oman Ophiolites**
- Muographic images of the bulk density structure can be compared to the seismic data of the ocean floor
- The Oman ophiolite is the largest and best preserved fragment of oceanic lithosphere in the world, extending 80 km × 500 km
- **Oman ophiolites oceanic crustal structure is similar to the structure of East Pacific Rise**

  → data can be compared with the structure of the Pacific Plate, the target of the IODP-805 MoHole to Mantle (M2M) Proposal



Photos provided by Prof. Umino

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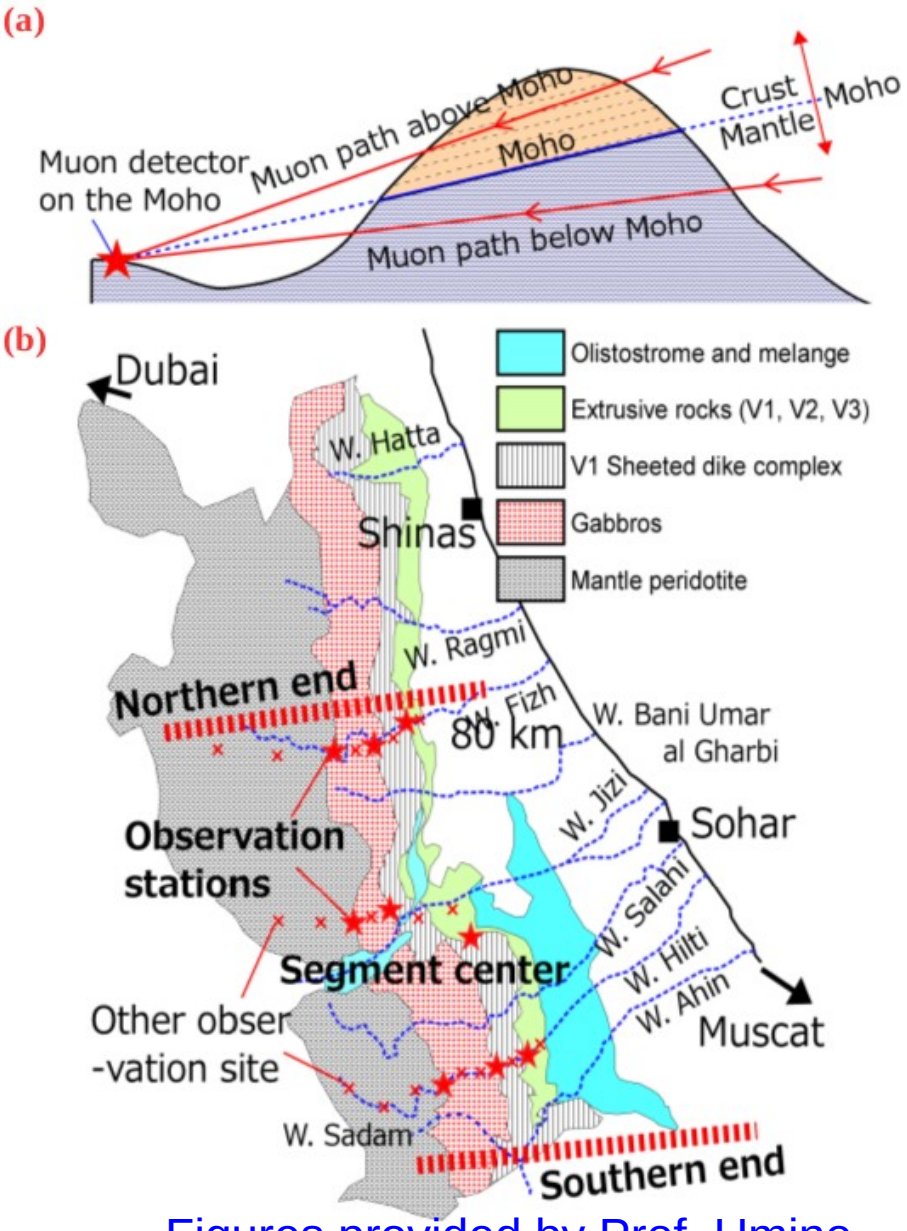
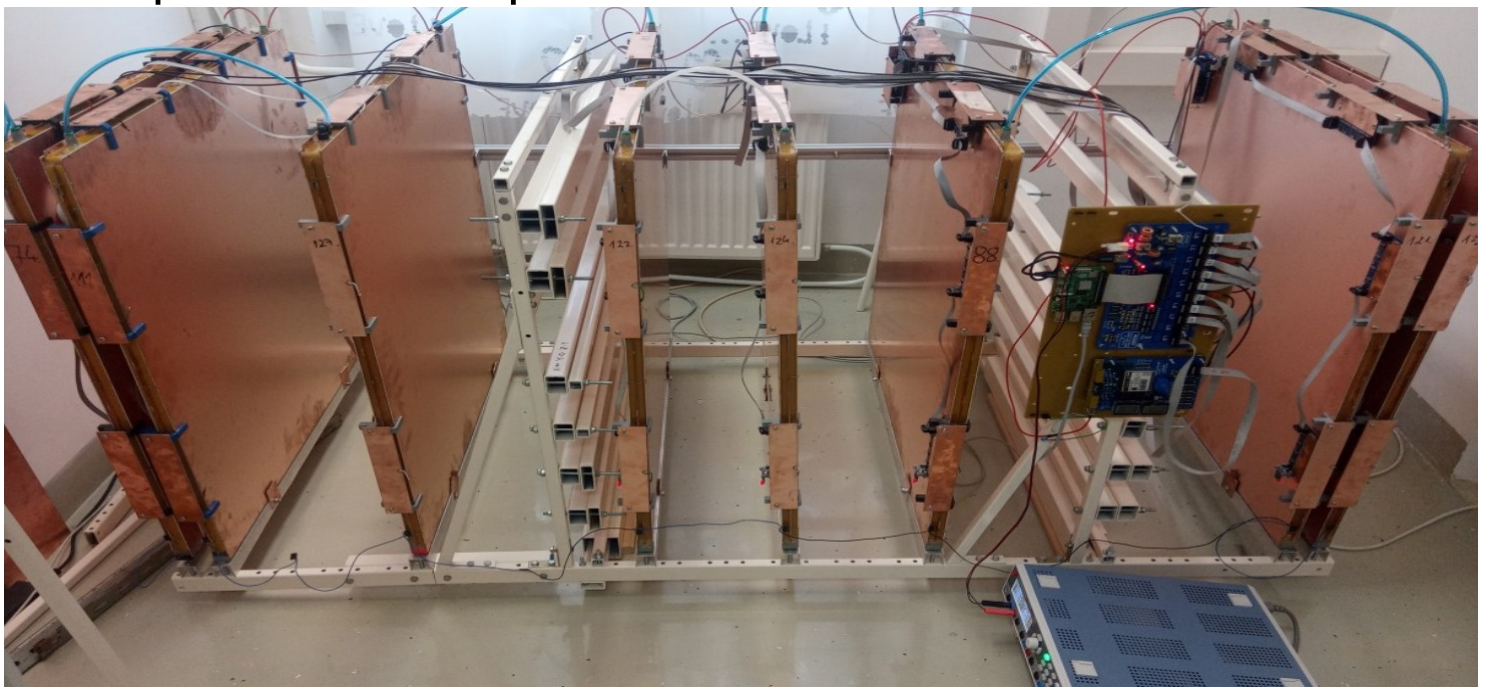


Figures provided by Prof. Umino

II. Instrumentation

- **MWPC-based Muography Observation System:**
  (see more in talk by D. Varga)
  - 8 tracking layers each with a spatial resolution of 4 mm, >95% trigger and >98% tracking efficiencies,
  - Rasperry PI controlled DAQ with a deadtime of 100 microsec,
  - Total power consumption of about 6 W.



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http://www.eu-jp-tthelpdesk.eu/technologies/muographic-observation-instrument/

III. Muon Flux Calculation

- **Aim:** find appropriate locations for the measurments via estimating measurement time
- **Inputs:**
  - Digital Elevation Model data (28 m by 28 m),
  - Detector's location (X,Y,Z) and orientation (azimuth, zenith),
  - Detector angular binning and distance between first and last tracking layers,
  - Densities of different two different layers (e.g., 3.130 g/cm3 for crust and 3.350 g/cm for mantle).
- **Calculation is performed for each angular bin:**
  - Path-length is calculated by an iterative algorithm → density-length → muon energy threshold (CSDA),
  - After rotation transformation, flux values are quantified for crust and mantle via integrating muon spectra based on Modified-Gaisser model, http://arxiv.org/abs/1509.06176
  - Detector factor is calculated: sensitive surface area x covered solid angle
  - Measurement time is given as follows.
    Time = sigma^2 F_crust / $(\text{F\_crust} - \text{F\_mantle})^2$ / Detector Factor

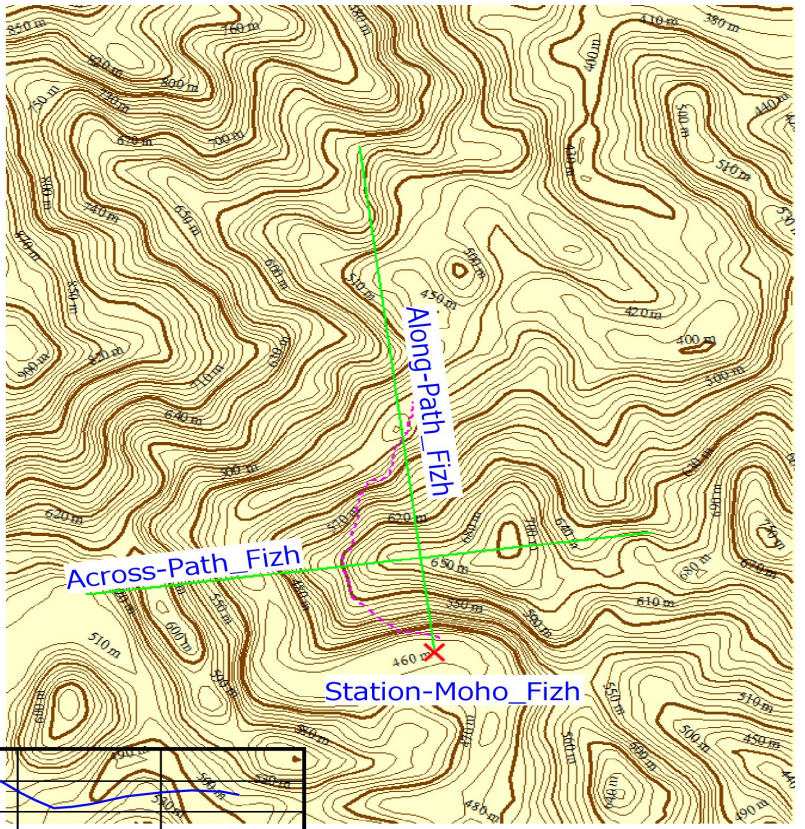
Site Candidate Wadi Fizh for Muography of Moho

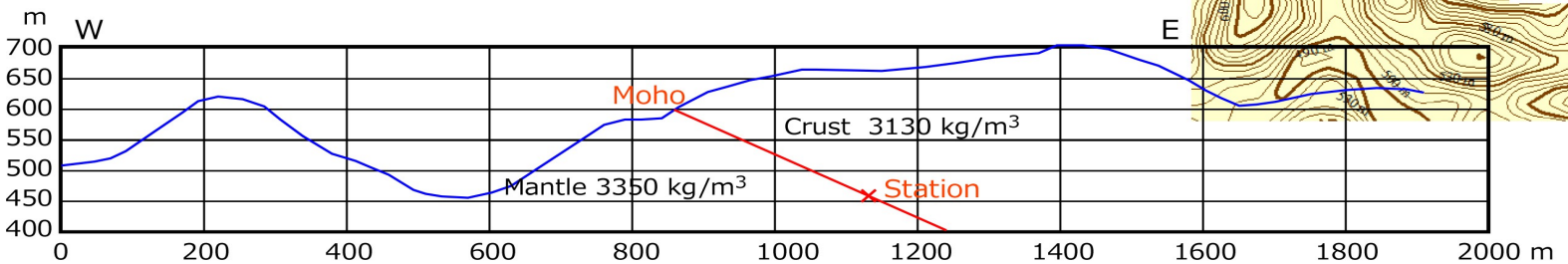
Wadi Fizh
Layer 3 (Gabbro)/ Layer 4 (Mantle peridotite) boundary = Moho

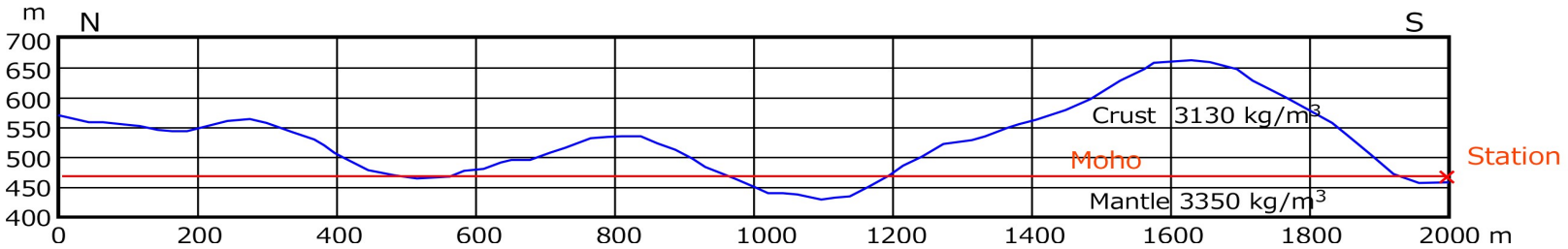
Station-Moho_Fizh	428697.441	2705007.913	457.544
MOHO_FIZH-NW	428714.791	2705059.336	459.637
MOHO_FIZH-SE	428621.617	2705991.694	444.299

Moho plane:
Strike: 352.48°
Dip: 27.36°
Dip azimuth: 82.48°

Gabbro: 3130 kg/m^3
Peridotite: 3350 kg/m^3







Figures provided by Prof. Umino

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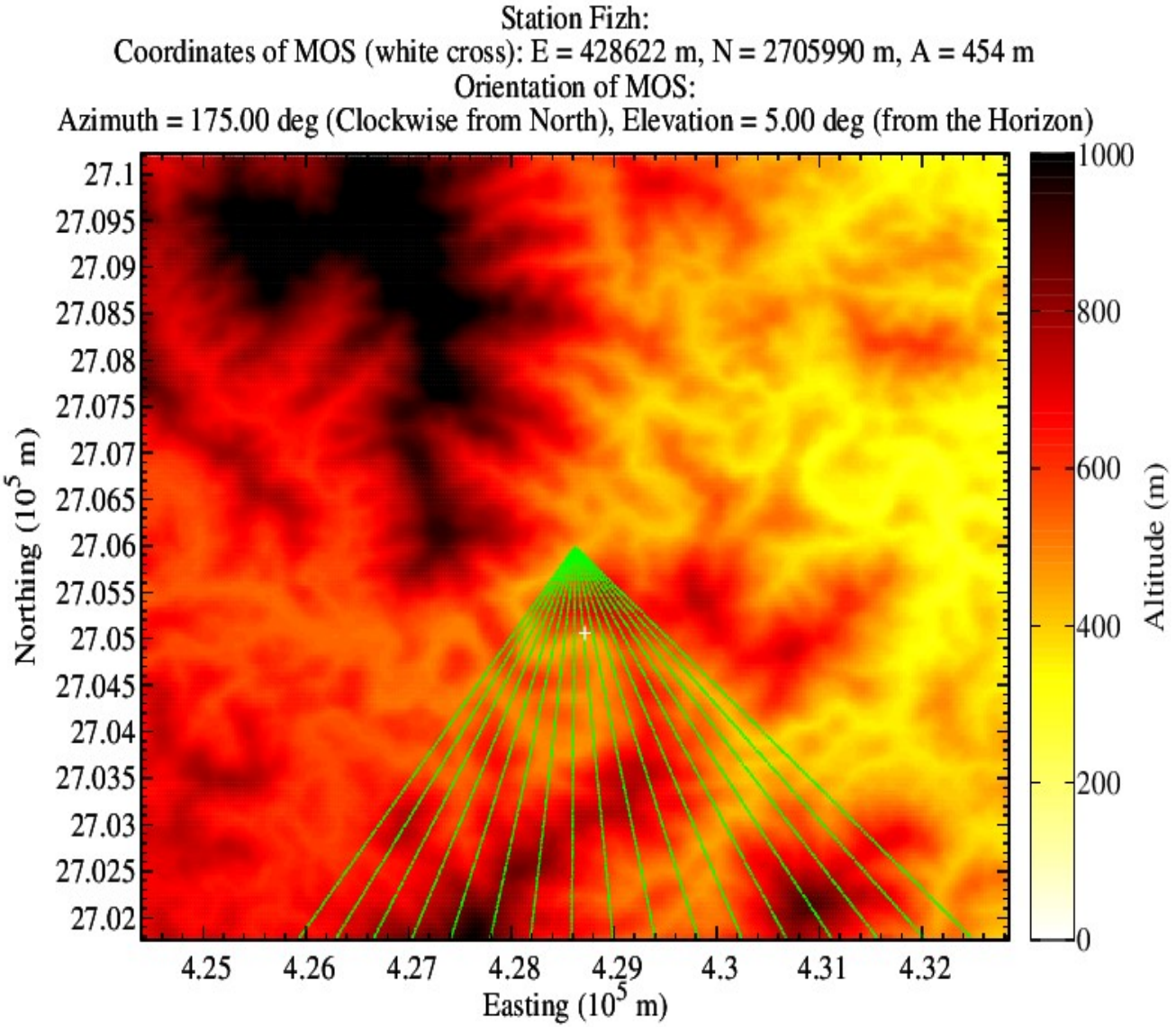

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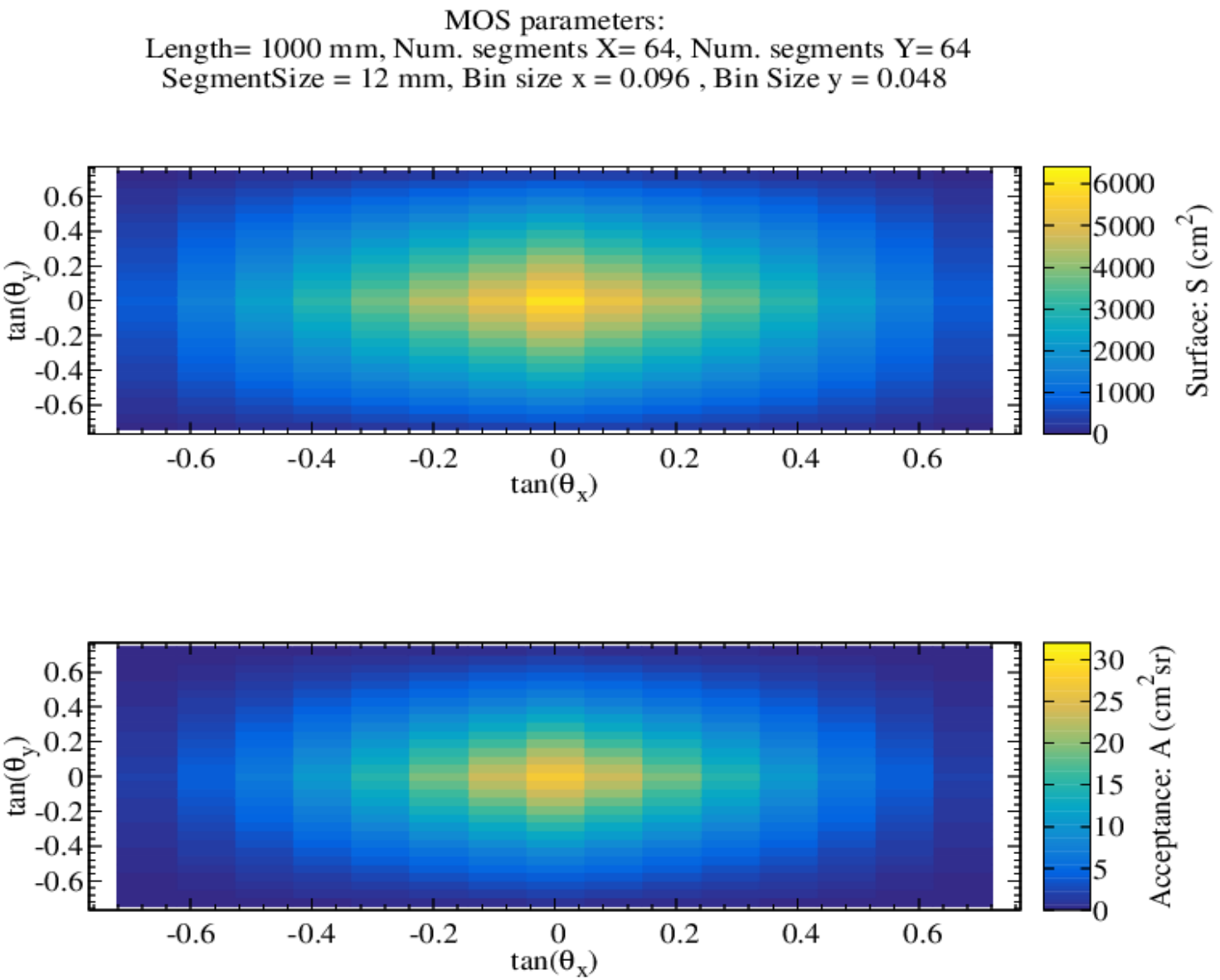

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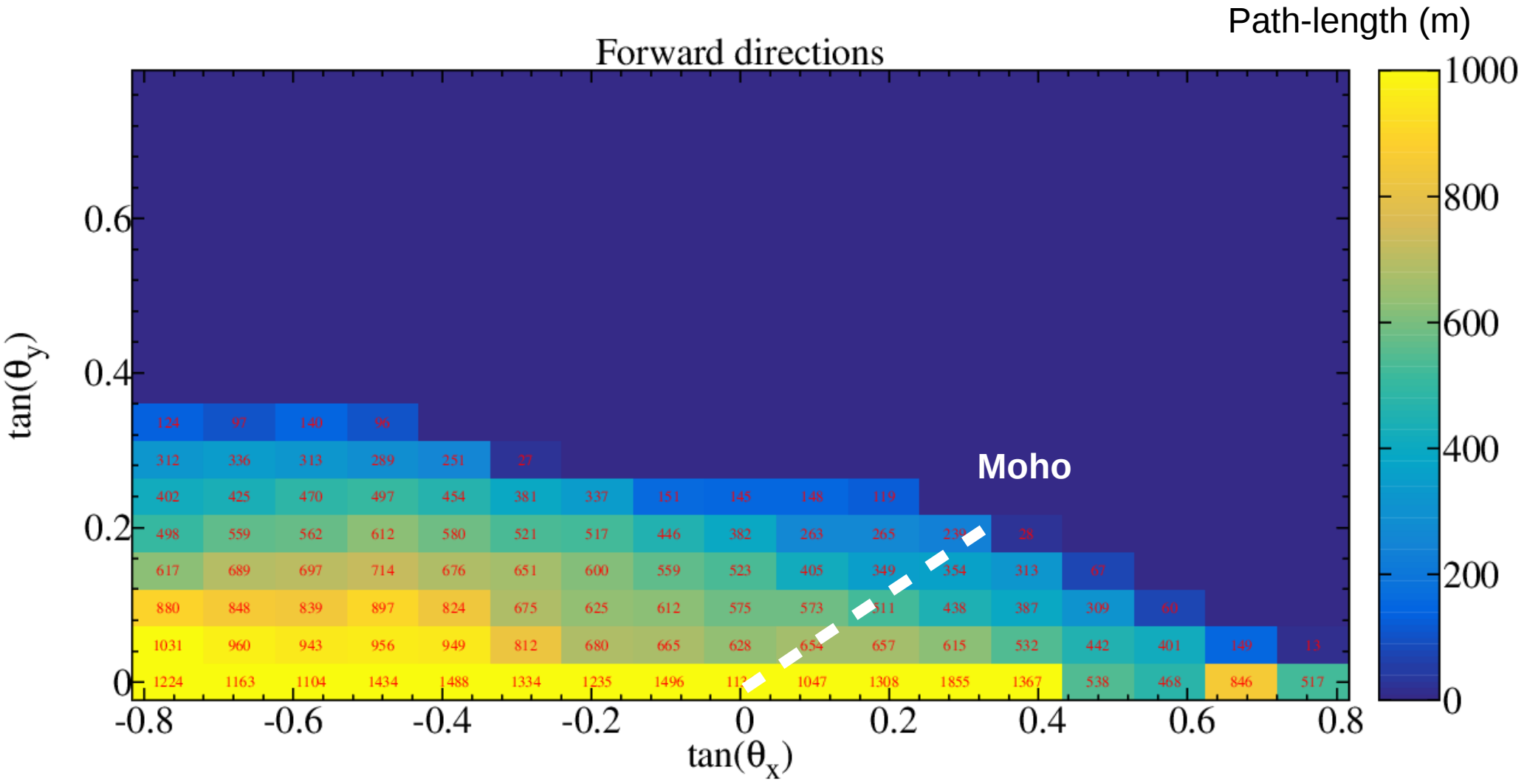

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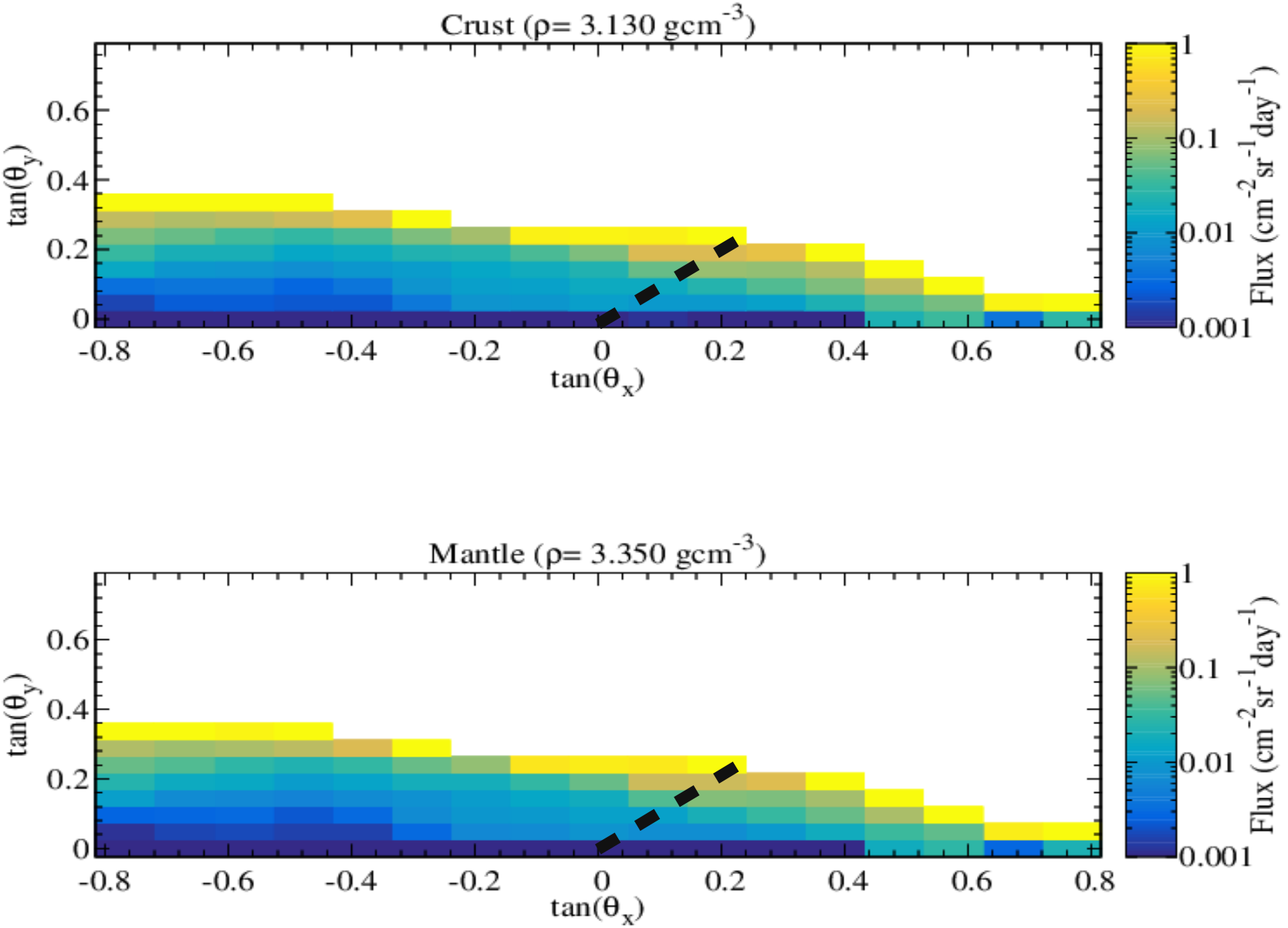

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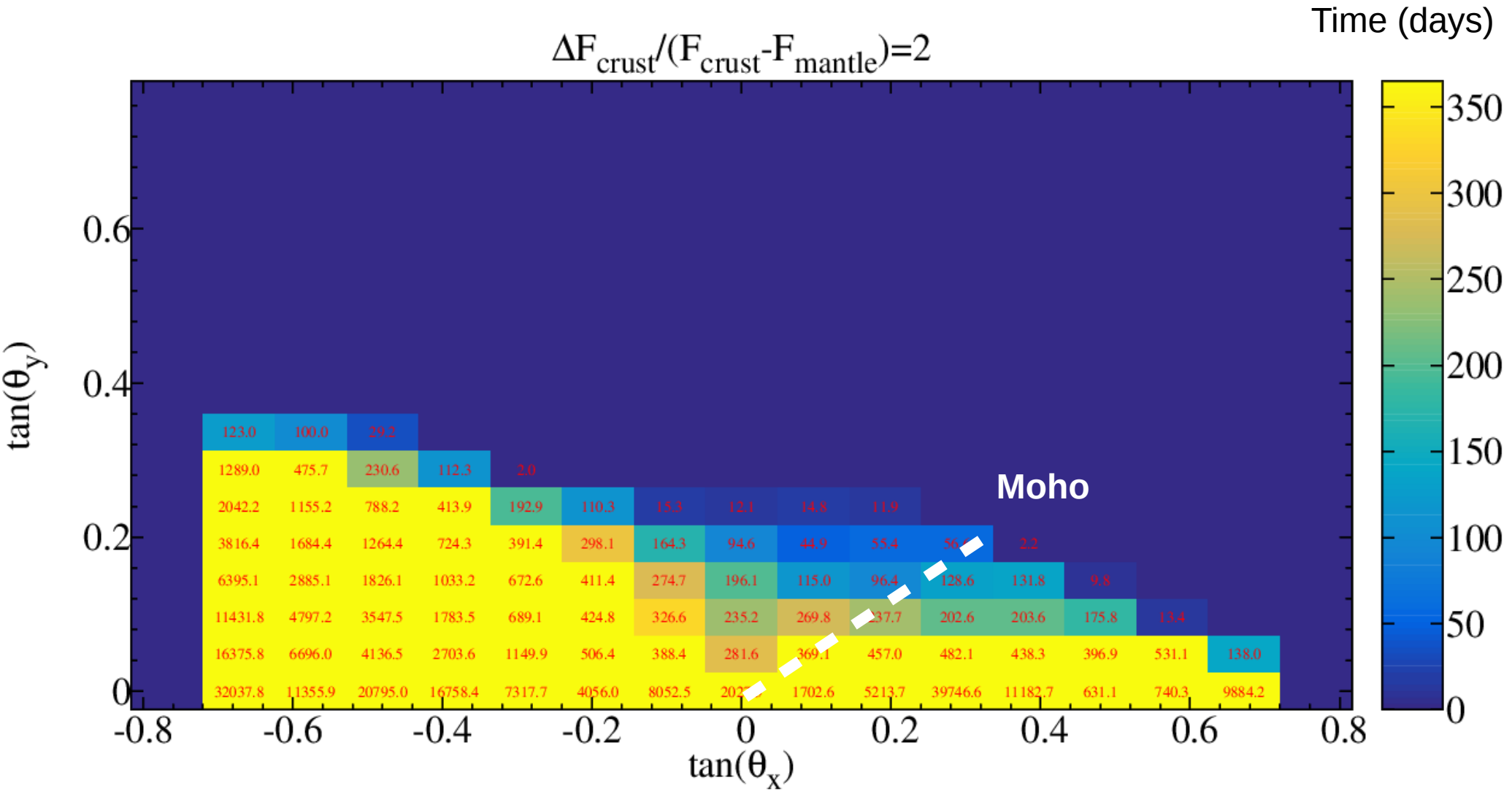

V. Summary

- The geological nature of oceanic lithosphere is not fully understood
- Moho has not yet reached by ocean drilling → ophiolites can provide information
- Muography can extract density information from Ophiolites with a relatively good spatial resolution → comparison with seismic and later ocean drilling data will be possible
- Data acqisition is planned to be started for muography of Moho at Wada Fizh and Wada Ays in 2023

Thank you for your attention!

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