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On-site: MAKUHARI MESSE, Chiba, Japan
Online: all over the WORLD

Studying Oceanic Lithosphere via Cosmic-ray Muography of Samail Ophiolite

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Outline

I. Scientific Background and Objectives

II. Data Collection and Image Processing

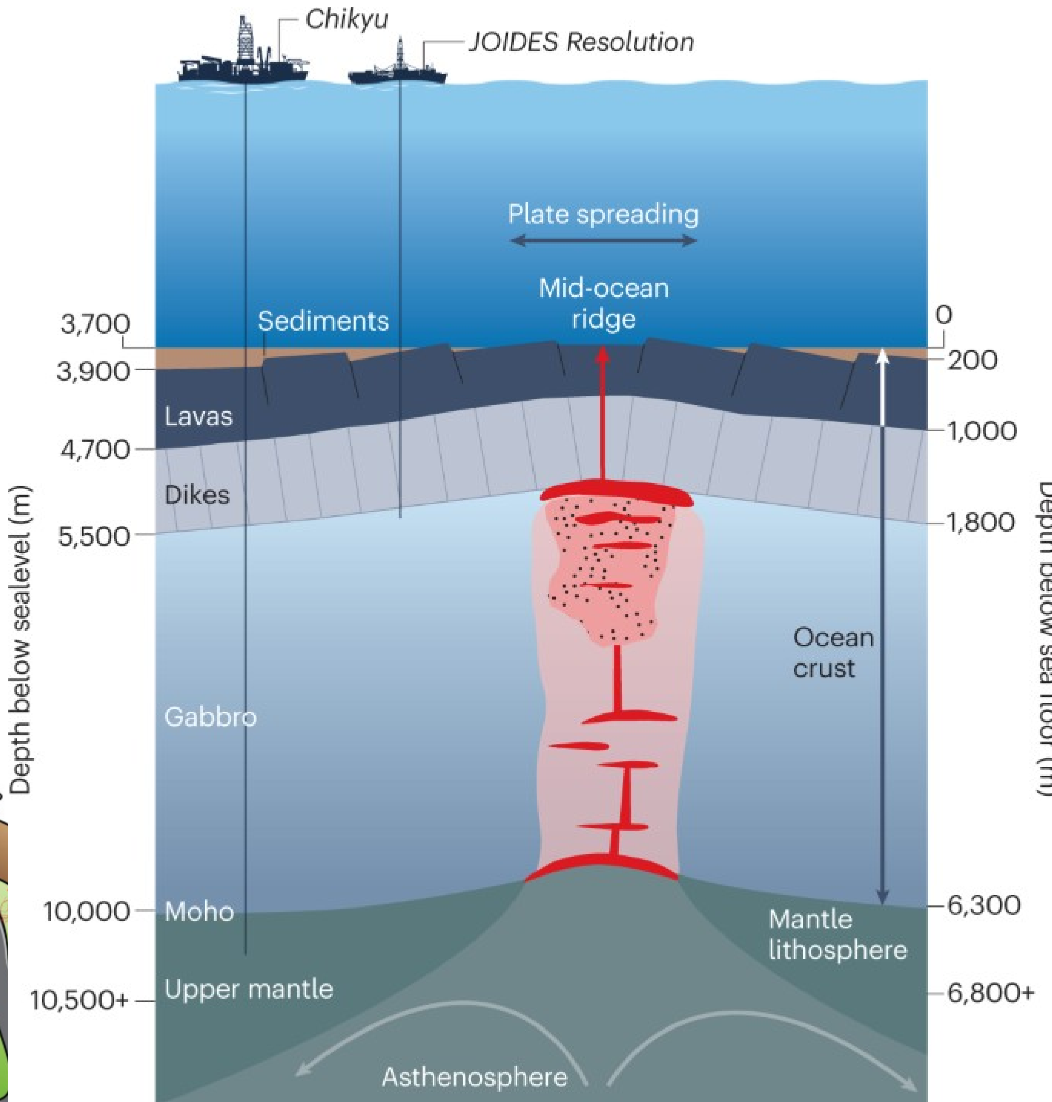
III. First Results from a Moho at Wadi Fizh

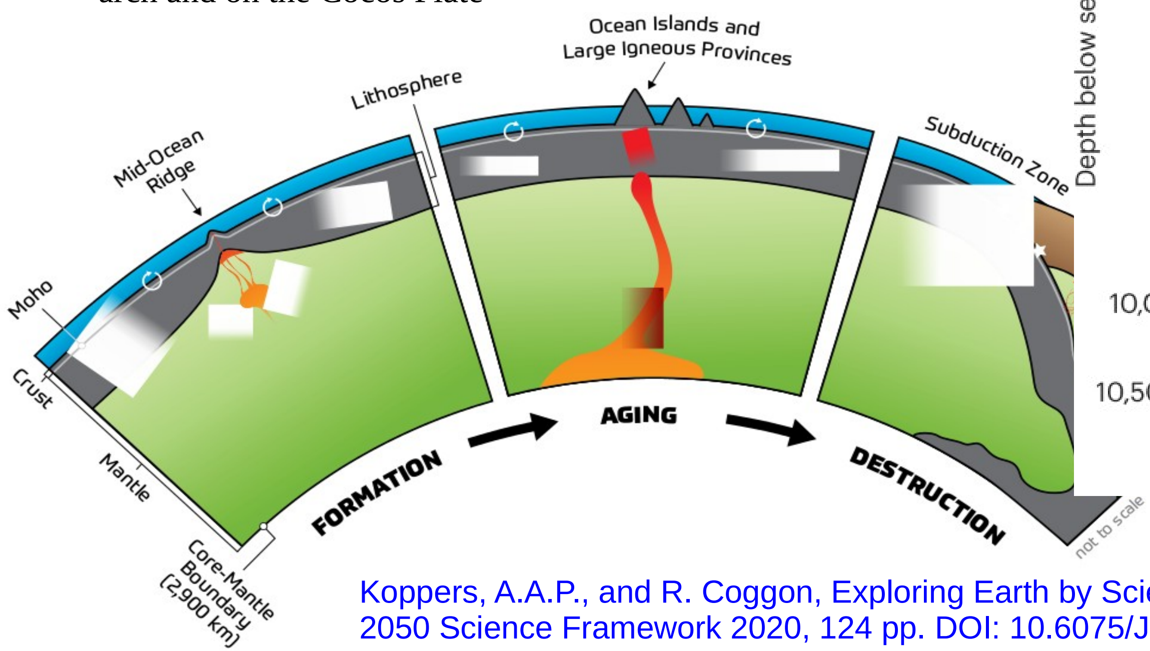
IV. Summary

I. Scientific Backround and Objectives

- **Oceanic lithosphere (crust + upper solid mantle) cycling: (1) formation, (2) evolution, (3) desctruction** occurs over a few tens to hundreds of million years.
- **Cycle of matter and energy** produces critical resources to economy, governs the occurrence of various natural hazards from earthquakes to volcanic eruptions and regulates Earth's climate system.
- **Combining the geophysical surveying of ocean basins and petrological studies via in situ sampling** of the segments of oceanic lithosphere in different tectonic environments is expected to advance the understanding of the nature of oceanic lithosphere
- Oceanic drilling (since 1960s) has already revealed critical pieces of evidences about plate tectonics, break up of continents, etc.
- Recently, Integrated Ocean Discovery Program's (IODP) MoHole to Mantle (M2M) drilling proposal aims to reach the Moho and the underlying mantle at three candidate sites including the Hawaiian arch and on the Cocos Plate

Teagle, D.A.H. Re-energizing the quest of drilling to the mantle. Nat Rev Earth Environ 4, 207–208 (2023). https://doi.org/10.1038/s43017-023-00413-0

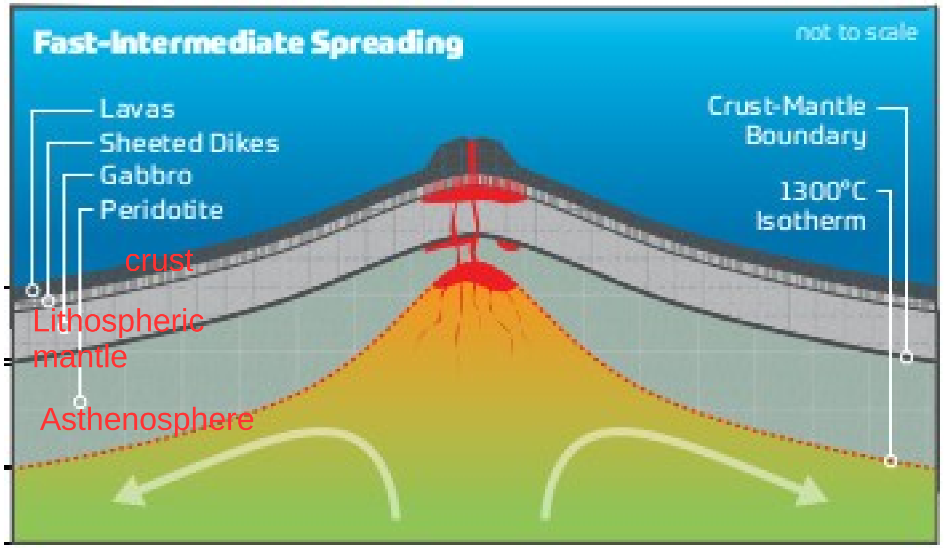


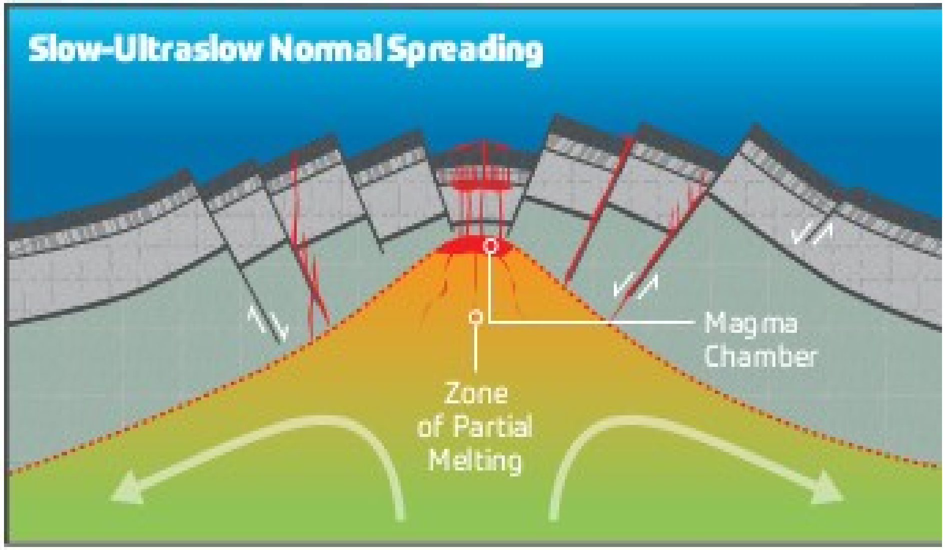


Koppers, A.A.P., and R. Coggon, Exploring Earth by Scientific Ocean Drilling: 2050 Science Framework 2020, 124 pp. DOI: 10.6075/J0W66J9H.

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 results in exposure of mantle rocks (periodites, pyroxenites)
- Magma chamber depth negatively correlated with fast spreading rate → shallower magma chamber has higher magma supply rate
- **Questions:**
    - **Why and how does the crustal structure depend on spreding rate?**
    - **What is the geological nature of Moho?**



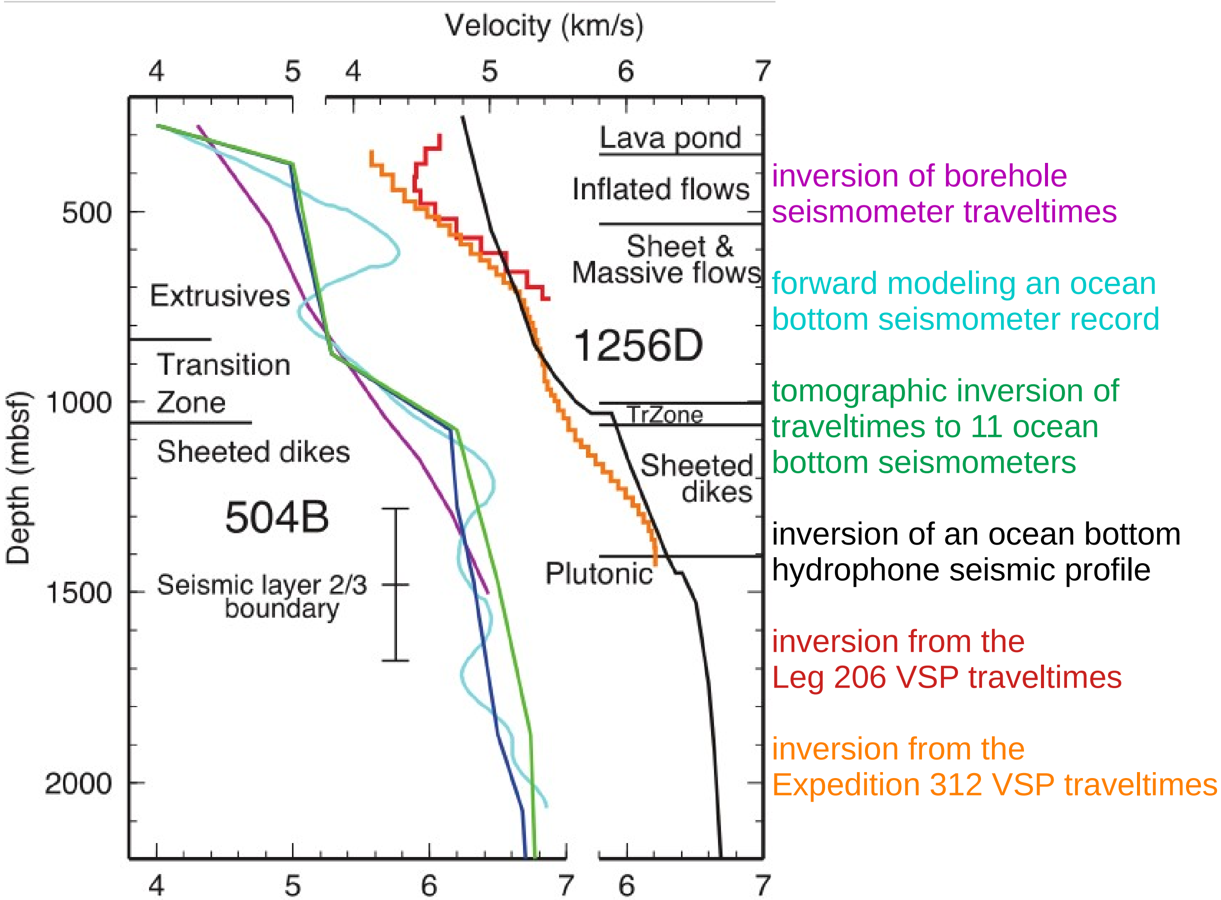


Koppers, A.A.P., and R. Coggon, Exploring Earth by Scientific Ocean Drilling: 2050 Science Framework 2020, 124 pp. DOI: 10.6075/J0W66J9H.

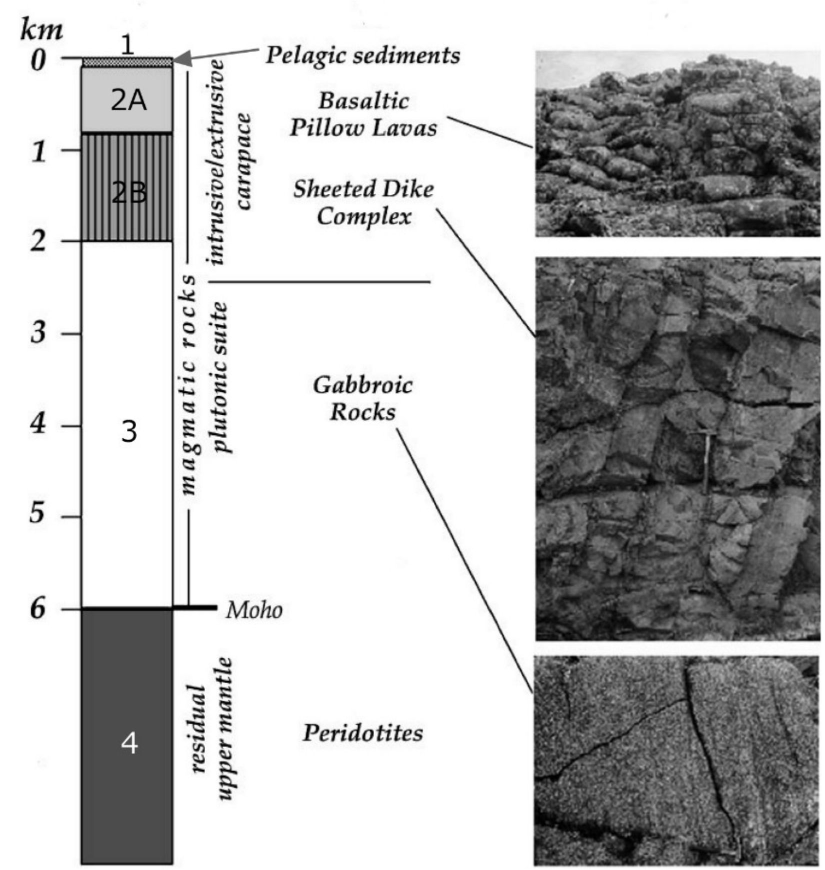
Oceanic lithosphere in Ophiolites

- 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
- Sampling is available but sampling density is low → **seismic velocities are different**
- **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**



Swift, et al. 2008. Velocity structure of upper ocean crust at Ocean Drilling Program Site 1256. Geochim. Geophys. Geosys., 9, Q10O13, DOI:10.1029/2008GC002188

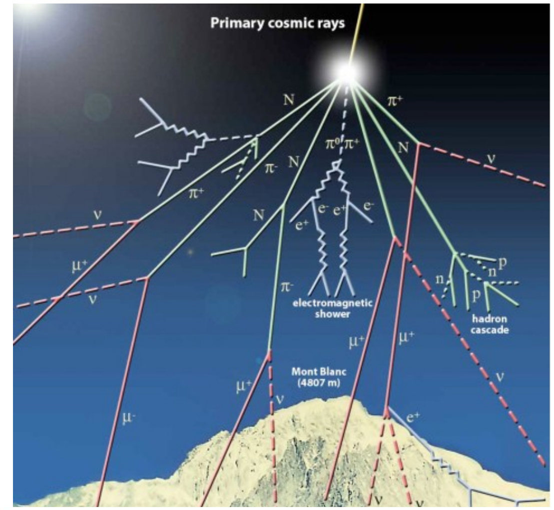


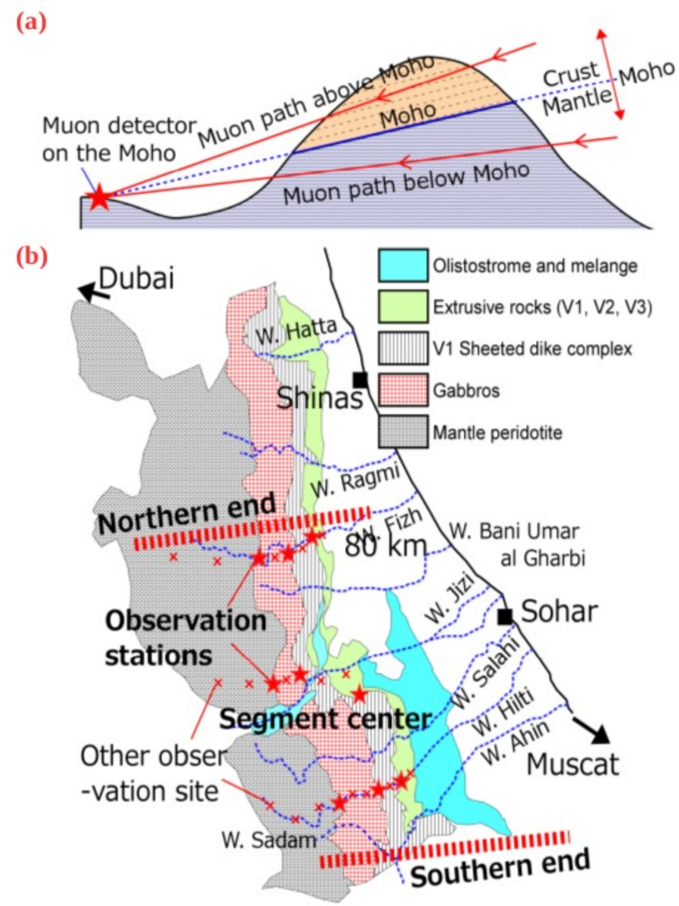
Karson, J.A., Geological structure of the uppermost oceanic crust created at fast- to intermediate-rate spreading centers. *Annu. Rev. Earth Planet. Sci.* **2002**, 30, 347. DOI: 10.1146/annurev.earth.30.091201.141132.

Muography of Samail Ophiolite

- **Objective:** better understand the geologic nature of the **crust/mantle (Moho)** and **upper/lower crustal boundaries** of the Samail ophiolite
- **Muography allows the imaging of the mass density structure** of large edifices via tracking of cosmic-ray muons (non-destructive, passive, remote technique)
- Muographic images of the bulk density structure can be compared to the seismic data of the ocean floor
- The Samail ophiolite is the largest and best preserved fragment of oceanic lithosphere in the world, extending 80 km × 500 km
- **Samail ophiolite oceanic crustal structure is similar to the structure of East Pacific Rise**

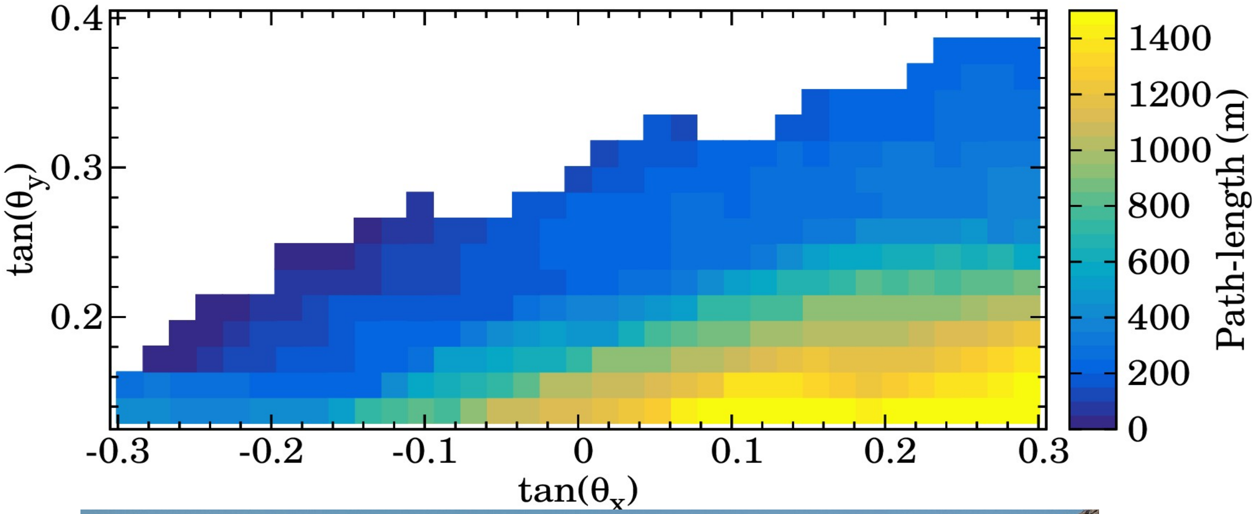
  → data can be compared with the structure of the Pacific Plate, the target of the IODP-805 MoHole to Mantle (M2M) Proposal

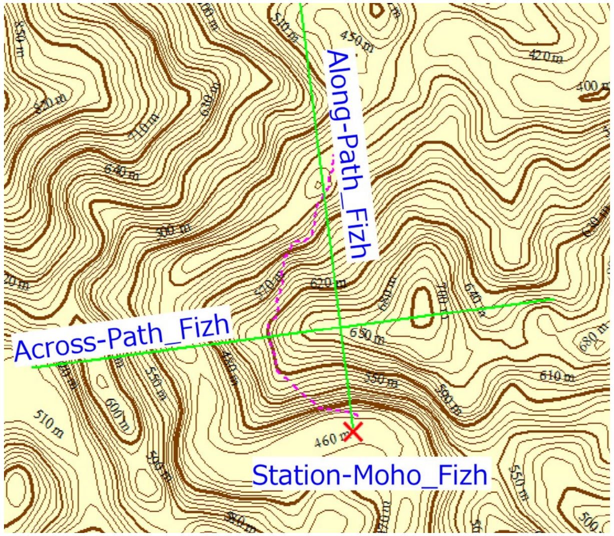


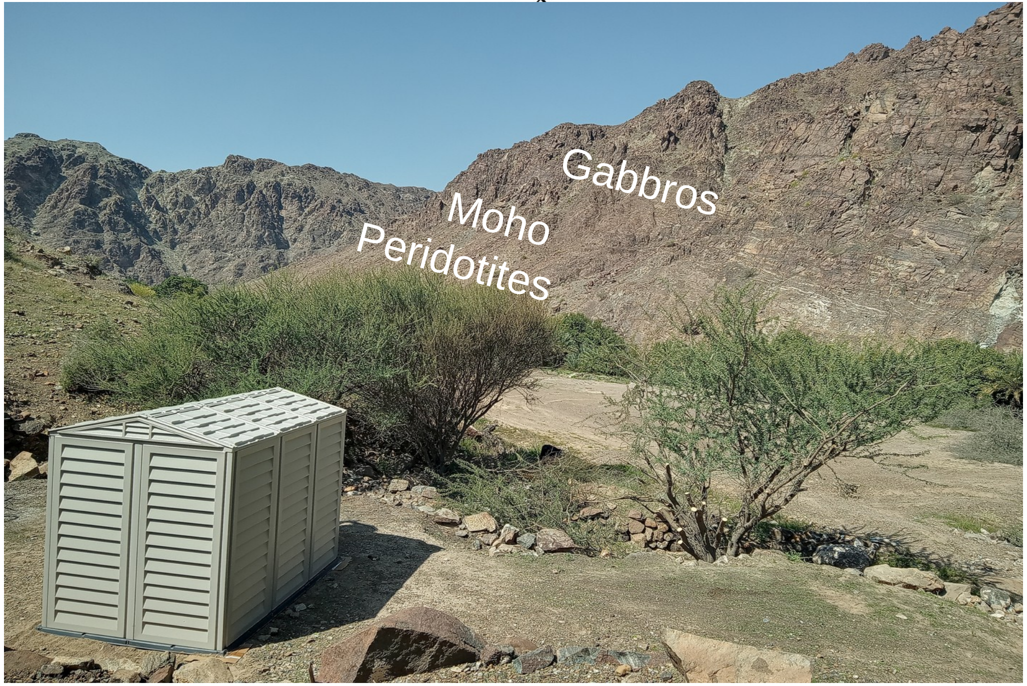


Oláh, L., Umino, S. et al. Plans for Muography of Samail Ophiolite. Journal of Advanced Instrumentation in Science, JAIS-499, (2024). DOI: 10.31526/JAIS.2024.499

II. Data Collection and Image Processing
The first Run at a Moho at Wadi Fizh







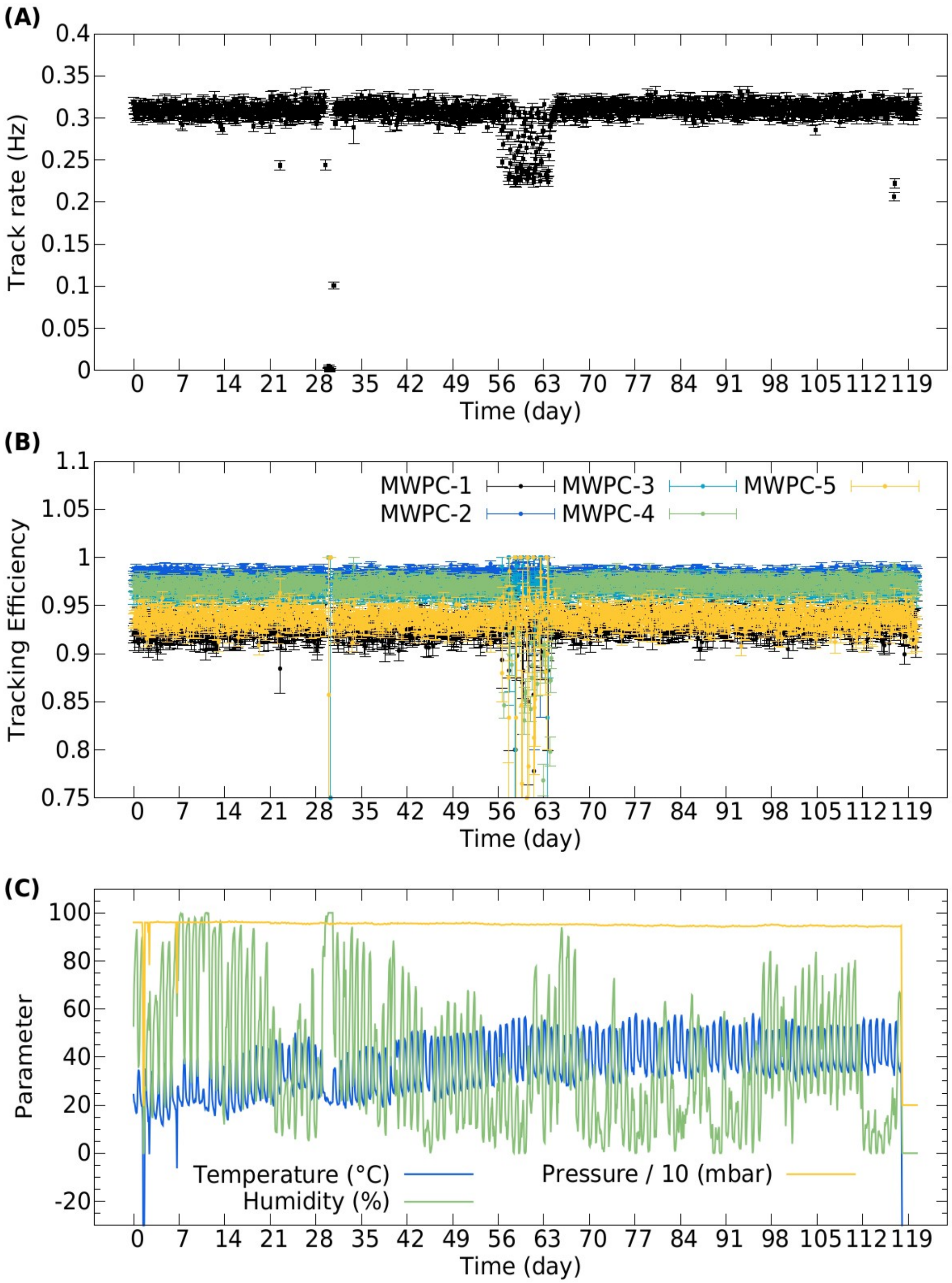
Observation location & orientation:
Lattitude: 24.45655 deg
Longitude: 56.29703 deg
298 deg from north

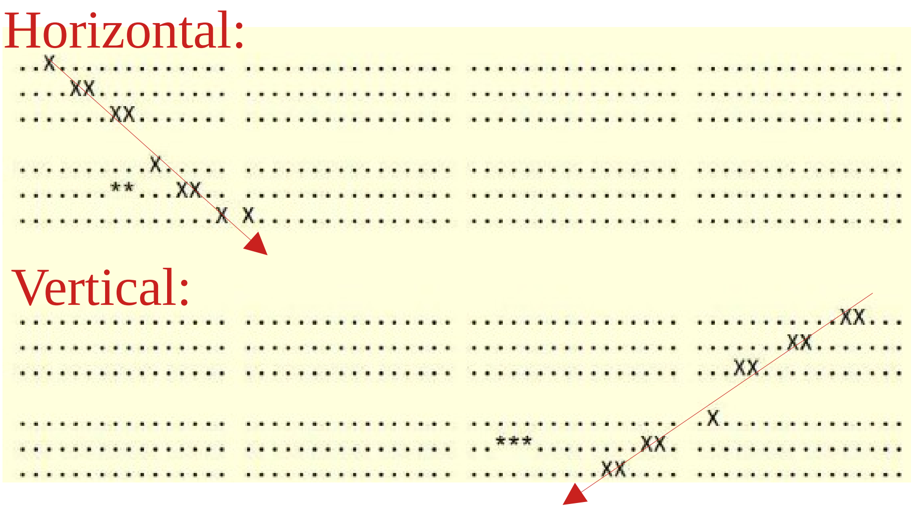
Instrumentation

- **Muon tracker:**
  - Seven 80 cm × 80 cm sized Multi-wire proportional chambers (MWPCs) **provide 1+1 dimensional position information → tracking of muons** (spatial resolution of 4 mm, >95% trigger and >98% tracking efficiency)
  - Rasperry PI-based detector control and data acquisition system
  - Total power consumption of about 6 W
  - Power supply:
    110 V (60 Hz) AC (+ 100 W solar panel)
  - Gas supply:
    Ar + CO_2 (80:20), flow of 1-2 L/h

D. Varga, L. Oláh, G. Hamar, H. K. M. Tanaka, T. Kusagaya:
Muographic Observation Instrument, WO2017187308A1
https://patents.google.com/patent/WO2017187308A1/en
D. Varga et al. Advances in High Energy Physics, 2016, 1962317
https://doi.org/10.1155/2016/1962317
L. Oláh et al. Scientific Reports, 8, 3207, 2018 https://doi.org/10.1038/s41598-018-21423-9

Data Reconstruction and Operational Performance





- **Data acquired into ASCII files and offline data analysis was conducted:** Cluster reconstruction on each MWPC and combinatorial track reconstruction

  L. Oláh et al. Scientific Reports, 8, 3207, 2018
  https://doi.org/10.1038/s41598-018-21423-9

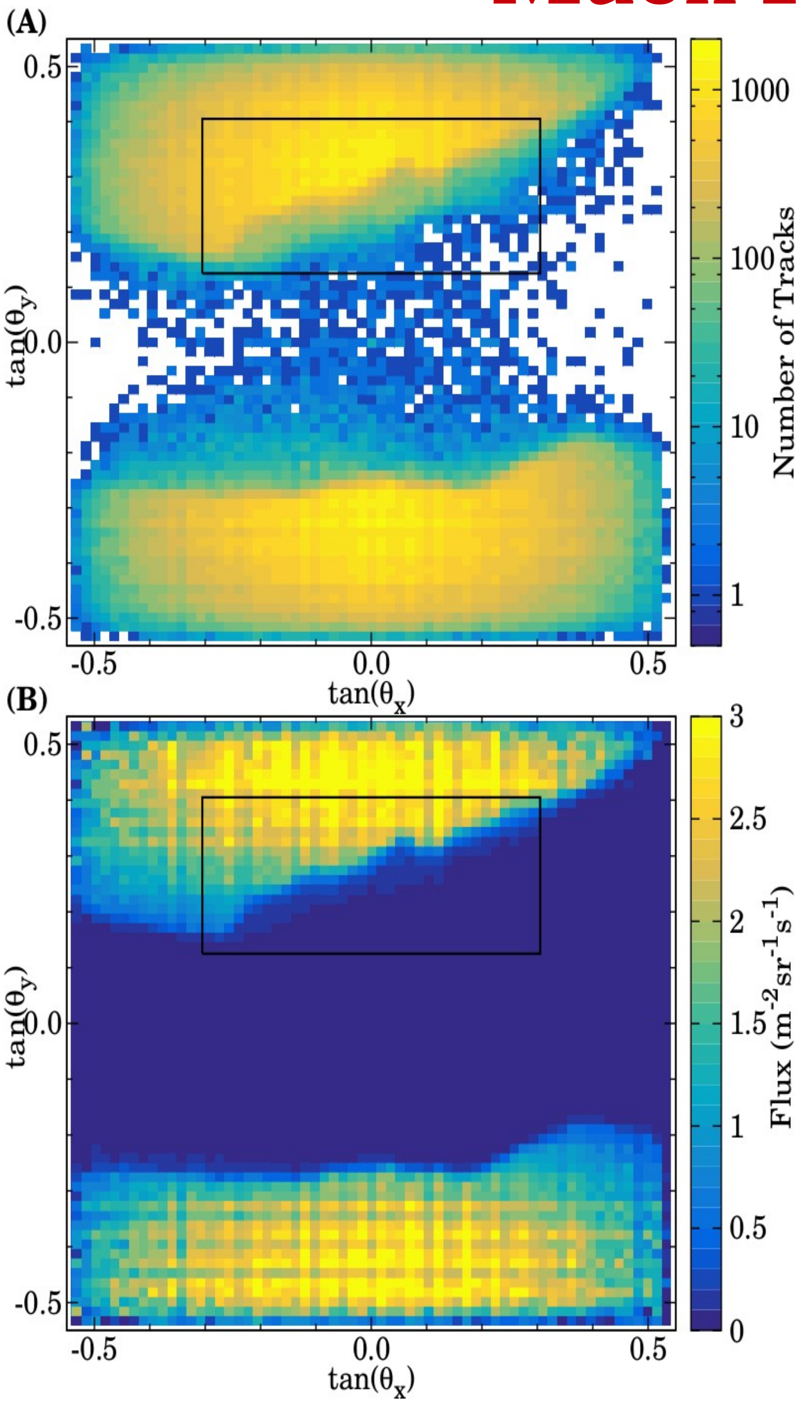
- Track rate is measured around 0.3 Hz

- Trigger and tracking efficiencies are respectively measured above 93 % and 94 % for each MWPC

- Daily variations of temperature and humidity are significant

Oláh L. et al. First Muography of Samail Ophiolite at Wadi Fizh. Journal of Geography (Chigaku Zasshi) Accepted paper.

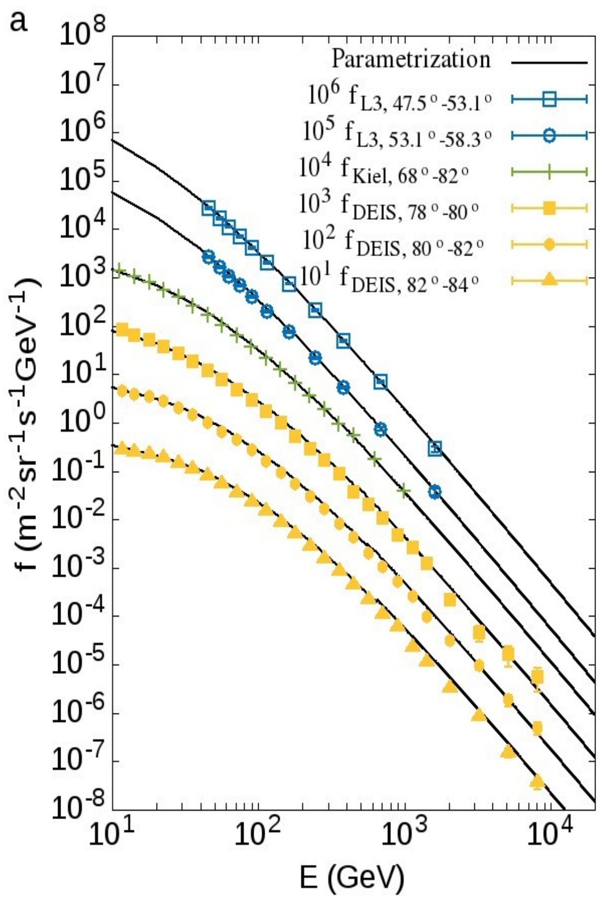
Muon Flux Measurement

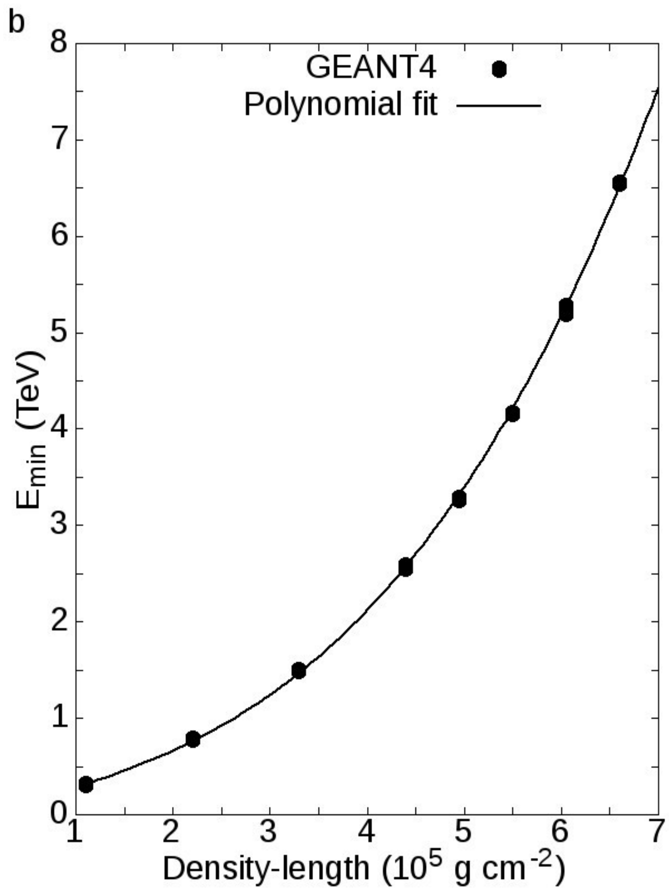


- **Track selection:** ADC > 200, χ2/NDF < 1.5.
- **Muon flux** is quantified by the number of tracks divided by the detection area, solid angle and measurement time.
- **Tracks visualize the ridge of the ophiolite** with a slope binning of 15 mrad that corresponds to 5 m spatial resolution from a distance of 300 m

Density Imaging

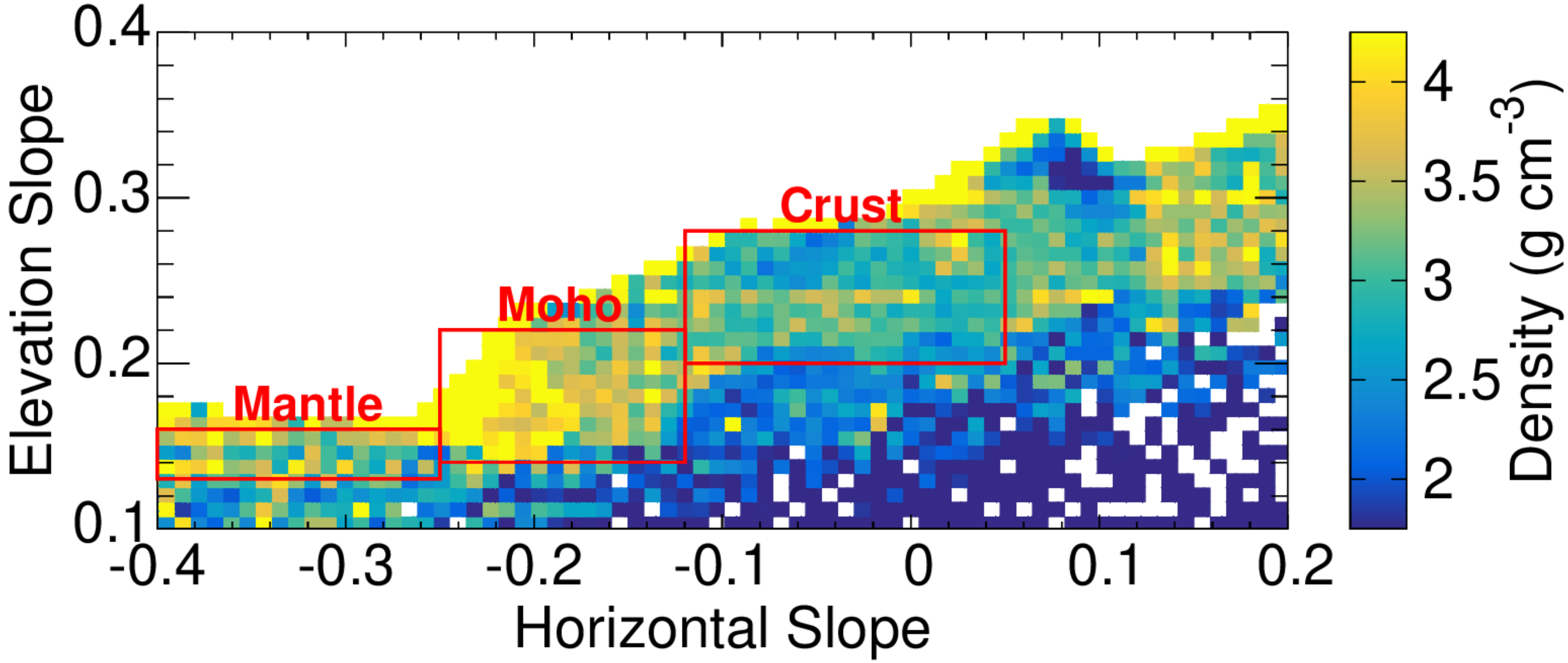
- Density-length values were quantified for each angular bin („pixel”) via comparing the measured flux to the modeled fluxes determined for different density-lengths.
- The modeled fluxes were given by numerical integration of zenith-angle and energy depedent spectra from minimal energies that required for muons to penetrate the ophiolite.
- Density is density-length divided by path-length calculated from digital elevation model (DEM, 5 m×5 m) of the measurement site.



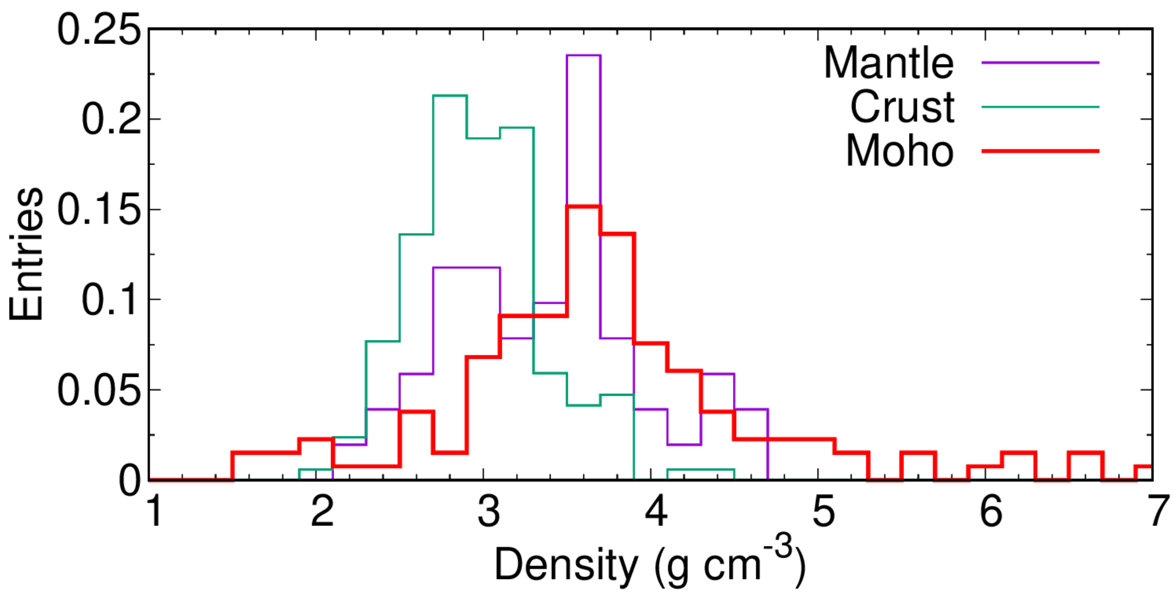


L. Oláh et al. Scientific Reports, 8, 3207, 2018
https://doi.org/10.1038/s41598-018-21423-9

III. First Results



- Different regions can be distuingished in the muographic density image of the ophiolite with pixel size of 2.5 m×2.5 m
- **Crust has relatively lower density due to alteration of gabbros**
- The Moho has not yet been explored



	Mean (gcm-3)	RMS (gcm-3)
Mantle:	**3.38**	**0.58**
Moho:	**3.60**	**0.77**
Crust:	**2.97**	**0.40**

IV. Summary

Ophiolites help to understand the correlation between oceanic structure and geology.

We proposed cosmic muon imaging for exploring the density structure of tranzition zones.

Plans for Muography of Samail Ophiolite. Journal of Advanced Instrumentation in Science, JAIS-499, (2024).
DOI: 10.31526/JAIS.2024.499

First muographic image of a Moho has been captured at Wadi Fizh in the Samail ophiolite.

The crust has lower density due to higher degree of alteration of gabbros.

First Muography of Samail Ophiolite at Wadi Fizh. Journal of Geography (Chigaku Zasshi) Accepted paper.

Thank you for your attention!

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Supporters:

- **Joint Usage Research Project (JURP) from the ERI, University of Tokyo**
  https://www.eri.u-tokyo.ac.jp/en/joint-usage-top/
- **TKP2021-NKTA-10 and othe grants for instrument development from National Research, Development and Innovation Office, Hungary**
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