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# Supplementary material: Volcanism and tectonics unveiled in the Comoros Archipelago between Africa and Madagascar

## *Document complémentaire : Volcanisme et tectonique découverts le long de l'archipel des Comores entre l'Afrique et Madagascar*

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## 1. Multibeam bathymetry, backscatter, and acoustic water column imaging

During the SISMAORE cruise (Figure 2), the vessel-mounted MultiBeam Echosounder System (MBES RESON 7150 at 12 or 24 kHz) acquired 80,000 $km^2$ of multibeam bathymetry and backscatter data around the volcanic islands of the Comoros archipelago. This survey complements the previous BATHYMAY [Guennoc, 2004], MAYOBS [Rinnert et al., 2019], PTOLEMEE [Jorry, 2014], PAMELA-MOZ1 [Olu, 2014], and PAMELA-MOZ4 [Jouet and Deville, 2015] surveys, as detailed in Counts et al. [2018], and the French Navy's Hydrographic Service (SHOM) surveys [Tzevahirtzian et al., 2021].

The bathymetric and backscatter data from the cruise were fully corrected from the ship's motion, navigation, and water sound velocity (Figure 3). A tidal correction (SHOM reference tide) and removal of doubtful soundings were applied with Ifremer's GLOBE seafloor mapping software [Poncelet et al., 2021]. Next the cleaned bathymetry was used to create a gridded bathymetry with 30 m resolution. The vertical accuracy of the multibeam bathymetry data is about 0.1–0.2% of the water depth, i.e. 5 m for a depth of 3500 m [Deplus et al., 2019]. To classify and characterise the seabed type, we processed the MBES backscatter data using Ifremer's SonarScope Software (v2017) software and the validity of the same flag [Augustin and Lurton, 2005]. The backscatter map is not corrected for topographic effects and angular variations of backscatter strength. Processing was applied consistently throughout the whole study area. Dark and light intensities correspond to geological substrates similar to lava flows and soft sediments, respectively.

Multibeam acoustic water column data [Thinon et al., 2020a] were also acquired by the vessel-mounted MBES for the detection of active fluid and gas outflows. No active fluids and gas outflows were detected in the Comoros archipelago during the SISMAORE cruise, except in the Fer à Cheval area east of Mayotte [Feuillet et al., 2021; REVOSIMA newsletters].

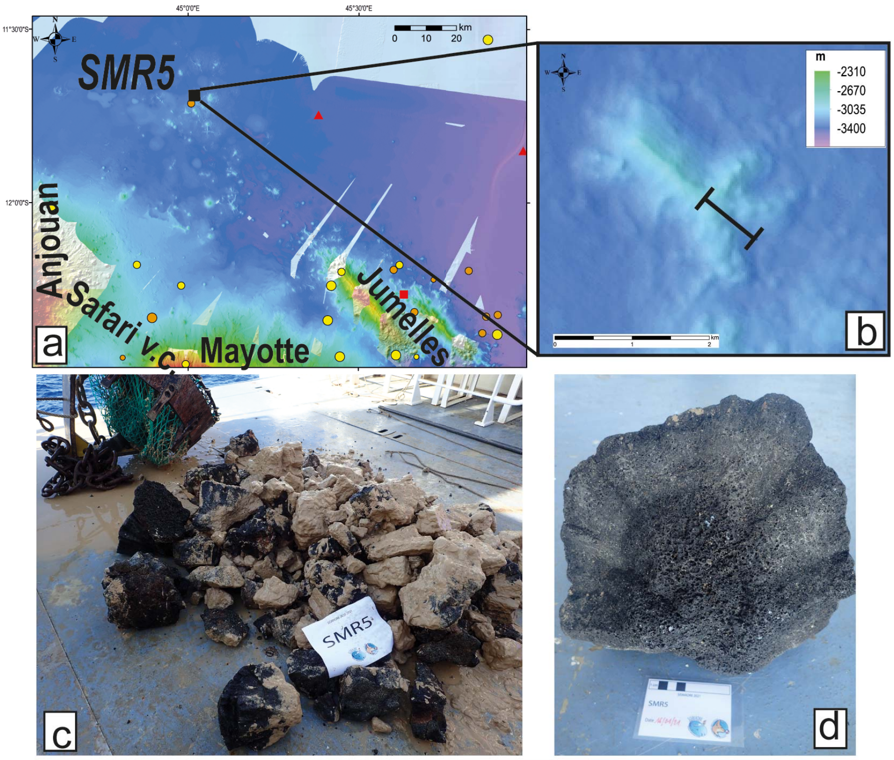
## 2. Rock sampling and gas analysis

Five dredge samples (Figure 2) retrieved mainly volcanic rocks on the flanks of Zélée bank (SMR1), the Jumelles (SMR2) and Chistwani volcanic chains (SMR4), and a seamount in the Mwezi province (SMR5) [Thinon et al., 2020a]. At macroscopic scale, these rocks are similar to those described on land in the Comoro Islands [Bachèlery and Hémond, 2016, Debeuf, 2004, Pelleter et al., 2014, and references therein] and offshore of Mayotte [Berthod et al., 2021a,b]. Dredge SMR5 in the Mwezi province collected popping rocks [Figure 5 and Supplementary Figure S1, Thinon et al., 2020a]. These rocks consist of very fresh, black, aphyric and vesiculated basalt pillows with glassy margins. The basalt contains arkose and quartzite xenoliths, some with melted shapes, and rare olivine xenocrysts. Detailed petrological, geochemical, and dating studies of these rocks are in progress. Popping results from bursting of vesicles filled with overpressured gas upon transport from ambient seafloor to surface pressure [e.g., Hekinian et al., 1973, Moreira et al., 1998, Pineau et al., 1976]. Preliminary analysis indicates that the gas in the vesicles contains 4.24% carbon dioxide (Supplementary Figure S1(e)). The $\delta^{13}C$ value of this gas is −11.0‰ (VPDB), which is in the range of magmatic carbon in oceanic basalts [Pineau and Javoy, 1983]. By comparison, in North Atlantic popping rock 2ΠD43 from the mid-Atlantic ridge (13° 46′ N, 3510 m depth), $\delta^{13}C$ varies from −21.7‰ to −11.6‰ in uncrushed samples and is −11.2‰ in inclusions of popping rocks samples [Pineau et al., 1976].

## 3. Sub-bottom profilers and high-resolution 48-channel seismic profiles

Sub-bottom profiler data totalling 10,000 km (Figure 2) were collocated to the MBE bathymetry and backscatter data with 2.8–5.1 kHz records in the imbricated mode. Vertical resolutions of ~25 cm and penetration depths of ~100 m into the sedimentary succession were achieved.

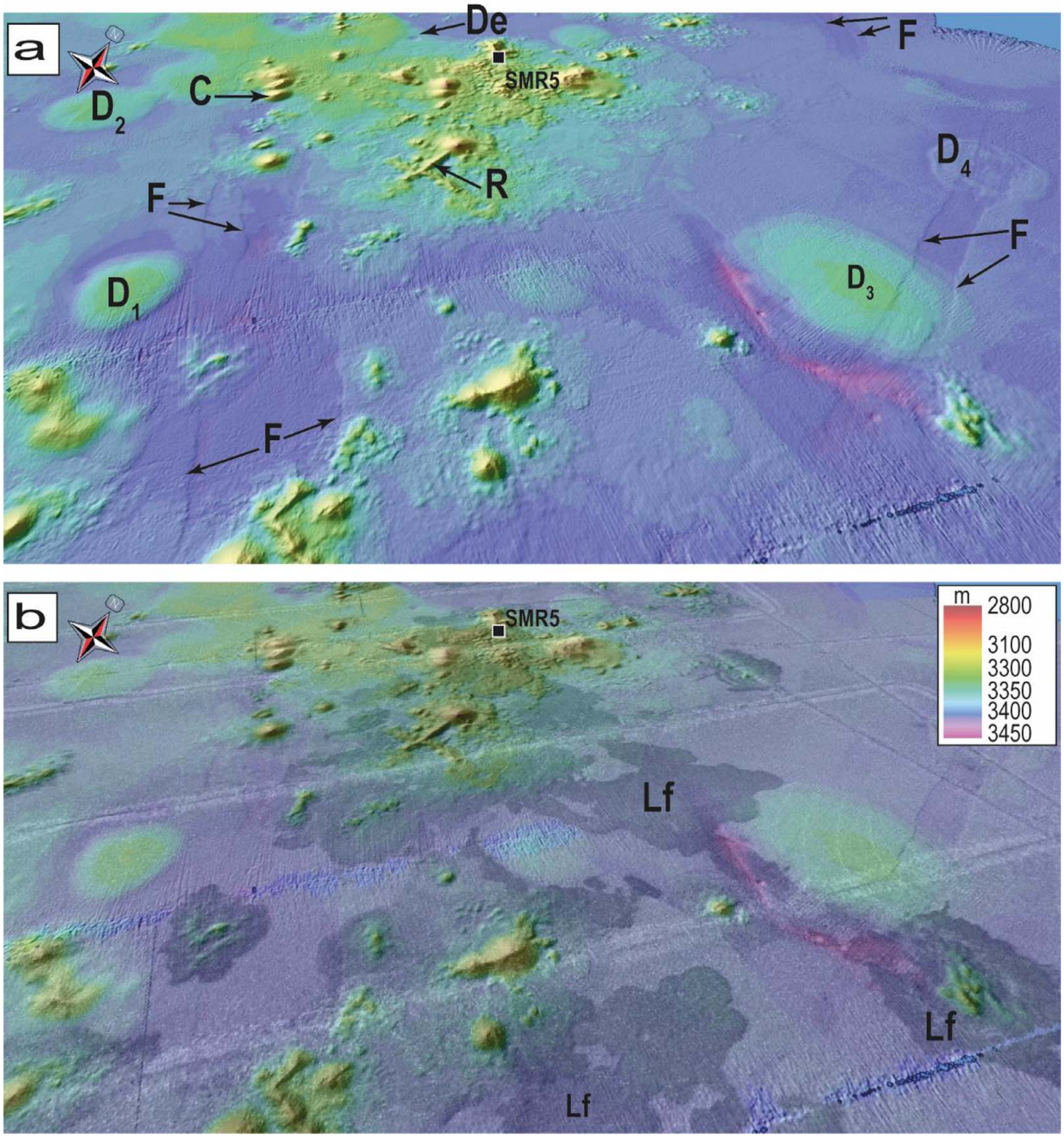
A total of 6730 km of 48-channel seismic reflection profiles (acquired at a speed of 10 kn) were processed onboard by denoising, filtering, data enhancement, water velocity stacking, and time migration. Two airguns (45 and 105 cu.in.) and a 300 m streamer were used to image the subsurface down to ~3 s twtt below the seafloor.



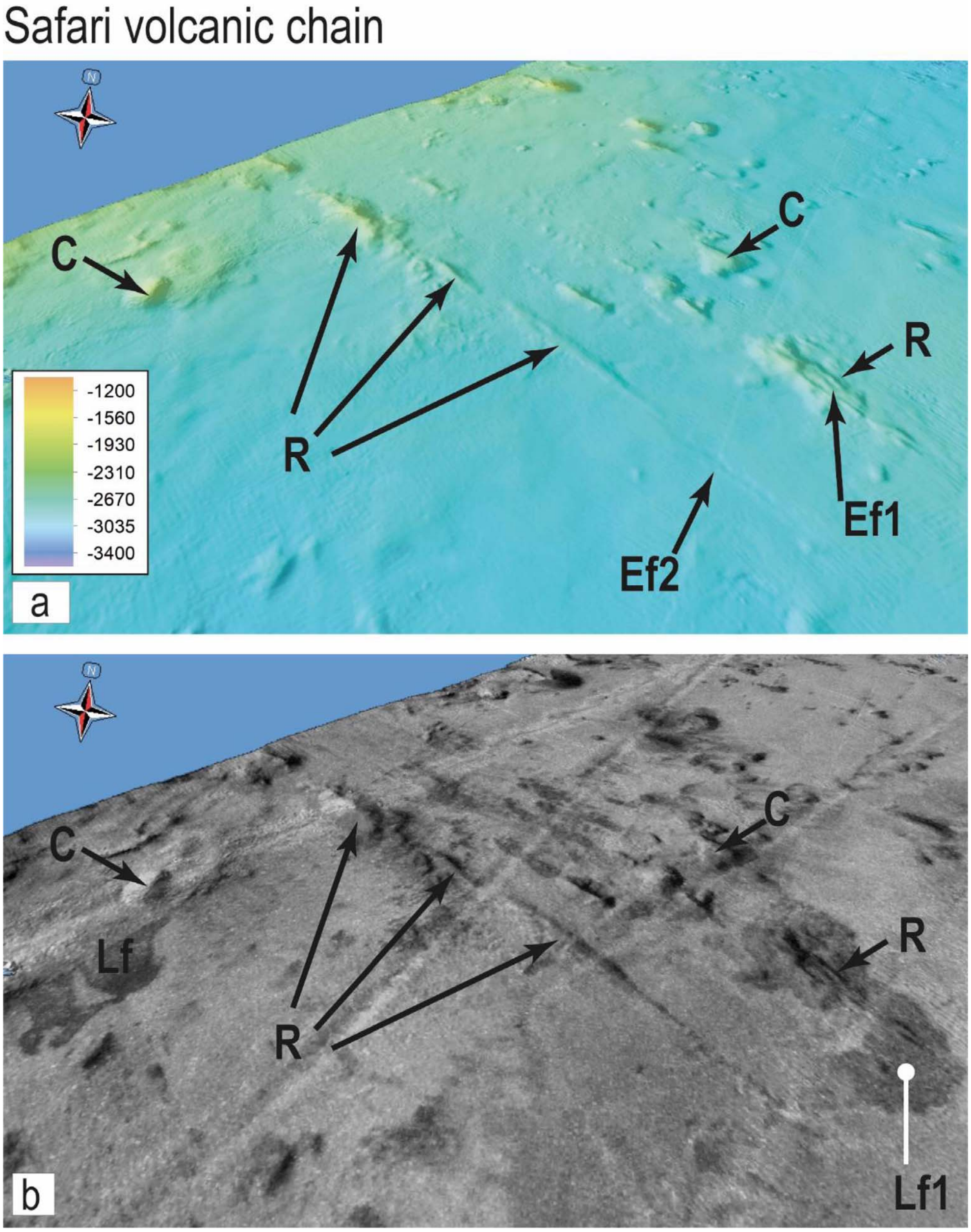

| e Sample number "Popping rocks" - SMR05 | concentration % | Limite % | Value ‰ vs V-PDB |
|---|---|---|---|
| Pressure (in mb) at the 1st trigger | 1003 | | |
| CO2 | 4.24 | 0.001 | |
| Ar | 0.89 | 0.001 | |
| O2 | 18.9 | 0.001 | |
| N2 | 76.1 | 0.001 | |
| He | < | 0.005 | |
| H2 | < | 0.005 | |
| H2S | < | 0.005 | |
| CH4 | < | 0.0002 | |
| C2H6 | < | 0.0002 | |
| C3H8 | < | 0.0002 | |
| Iso-butane Iso-C4H10 | < | 0.0002 | |
| n-Butane n-C4H10 | < | 0.0002 | |
| Butane Total C4H10 | < | 0.0004 | |
| Pentane Total C5H12 | < | 0.0002 | |
| Hexane Total C6H14 | < | 0.0002 | |
| *Total* | 100.1 | | |
| δ13C | | | -11.0 |
| *Incertitudes : 3%* | | | |
| *Incertitudes He H2: 5%* | | | |
| *Temperature=22°C* | | | |

**Supplementary Figure S1.** Basaltic popping rocks from dredging sample SMR5. (a) Location on the bathymetric map (see Figure 3 for legend). (b) Trajectory of the dredge on a seamount of the Mwezi province. (c) Photo of the dredge. (d) Photo of a rock sample. (e) Analysis of gas from SMR5 popping rocks.

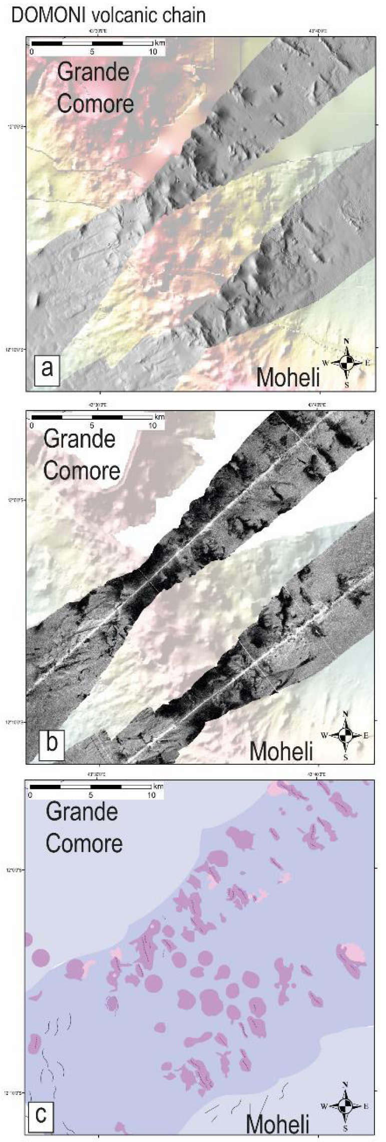
**Supplementary Figure S1.** (**cont.**) Gases were collected from samples put in vacuum-sealed bottles. Percentages of detected $CO_2$, Ar, $O_2$ and $N_2$ are given in Supplementay Figure S1(e). Stable carbon isotopes in $CO_2$ were analysed in a continuous flow by a GasBench isotope ratio mass spectrometer (IRMS; interface: GasBench II). Gas was introduced into a chromatographic column (PoraPlot Q, isothermal at 40 °C under helium flow), then transferred into the IRMS (Delta plus XP). Results are expressed as $\delta^{13}C$ in permil with respect to the VPDB standard with an analytical standard deviation of ±0.5‰. Analytical accuracy was controlled by a $CO_2$ standard gas with certified isotopic composition. Analyses were performed in triplicate at two dates to check for instrumental drift over 4 weeks; the standard deviation between both analyses was ±0.08‰.




**Supplementary Figure S2.** Oblique view of the bathymetry of the Mwezi province showing some examples of volcanic edifices, faults (F) and dome-shaped forced folds (D). See Figure 5 for the legend.




**Supplementary Figure S3.** Oblique view of the bathymetry of the Safari volcanic chain showing some examples of N130°E trending alignments of volcanic edifices, N130°E trending ridges (R), eruptive fissures (Ef) and lava flows (Lf). See Figure 5 for the legend.




**Supplementary Figure S4.** (a) Bathymetry of the N160°E-trending Domoni volcanic chain between Grande-Comore and Mohéli from SISMAORE data (greyscale) and previous bathymetric surveys [colour; Tzevahirtzian et al., 2021]. (b) Backscatter profile showing seafloor reflectivity in the area of (a). (c) Interpretive map of the area of (a) showing volcanic edifices (see Figure 4 for the legend). The Domoni volcanic chain is 2000 m high (summit at 700 m depth) and 15–20 km wide.

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