Evidence of active magmatic rifting in Ma'alalta marginal volcano (Afar, Ethiopia)

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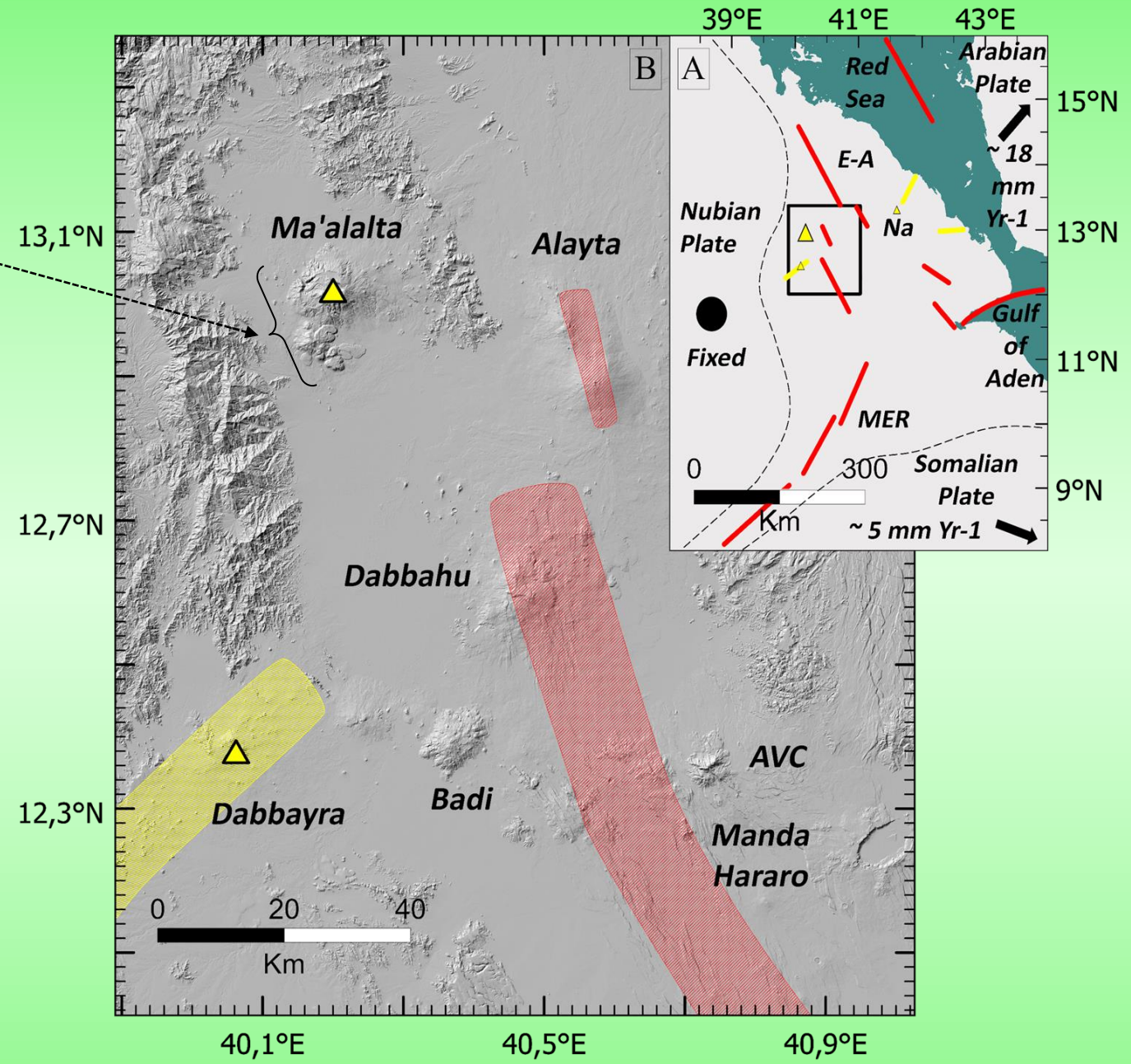
Overview and aim

Ma'alalta stratovolcano is located close to the western margin of Afar and it was classified as a *marginal unit* (Barberi et al., 1974; Wiart et al., 2005). However, in reality little is known about the petrology, geochemistry and tectonics of Ma'alalta and how they relate to the tectonics of continental breakup in Afar.

The aim of the study is to investigate the Ma'alalta volcanic region with an integrated volcanological, geochemical, petrological and seismological approach, in order to understand the characteristics of its magmatic production, the relationship of the volcano with the other rift segments and the current magmatic and tectonic activity.

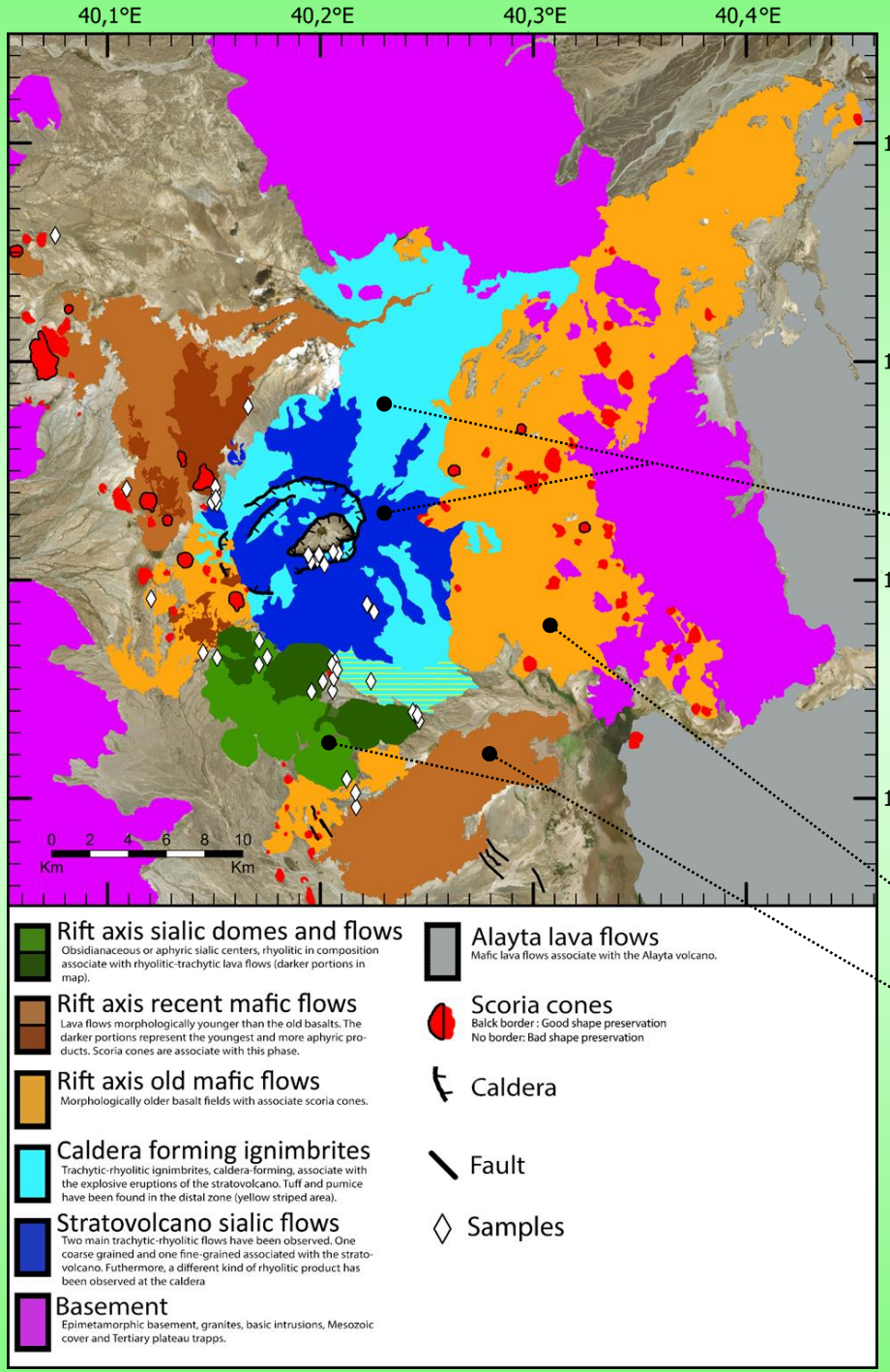
Barberi, F., Santacroce, R., & Varet, J. (1974). Silicic peralkaline volcanic rocks of the Afar Depression (Ethiopia). Bulletin Volcanologique, 38(2), 755-790.

Wiart, P., & Oppenheimer, C. (2005). Large magnitude silicic volcanism in north Afar: the Nabro Volcanic Range and Ma'alalta volcano. Bulletin of Volcanology, 67(2), 99-115.



A)Regional map of Afar and B) Topography of the Ma'alalta area. In red the magmatic segments, in yellow, marginal volcanoes (triangles) and transverse structures. E-A - Erta'Ale; Na - Nabro; MER - Main Ethiopian Rift; AVC - Ado'Ale volcanic complex.

Geological map and relative chronology of Ma'alalta



We identified two phases of activity integrating petrographic analysis, a satellite-based map of the erupted products and the relative chronology of the volcanic units.

The stratovolcano and caldera forming phase (S-Cf phase)

- Sialic lava flows that built the stratovolcano and ignimbrites corresponding to the caldera forming phase.
  This phase started around 0.55 ± 0.05 Ma (Barberi et al. 1972) and is nowadays extinct or quiescent.

The rift axis phase

- Old mafic flows emplaced on the stratovolcano products.
- Recent mafic flows and sialic domes and flows emplaced during the same time-period. They are the youngest products of Ma'alalta.

Barberi, F., Borsi, S., Ferrara, G., Marinelli, G., Santacroce, R., Tazieff, H., & Varet, J. (1972). Evolution of the Danakil Depression (Afar, Ethiopia) in light of radiometric age determinations. The Journal of Geology, 80(6), 720-729.

Volcanological evidence

S-Cf phase

No mafic products observed. Highly crystalline flows and voluminous explosive activity from a central vent.

Rift axis phase

Transitional mafic magma associated with aphyric and obsidian-rich sialic magmatism of peralkaline affinity erupted from several scattered vents that produced small volume eruptions as domes or lava flows.

Petrological evidence

S-Cf phase

Mineral geobarometry along with the two important caldera structure indicate a ~4.5 km depth magma chamber.

Rift axis phase

The mafic magma storage ranges from ~14 to ~24 km depth, suggesting along with the presence of reversed zoning crystals, the presence of a stacked magma plumbing system.

Geochemical evidence

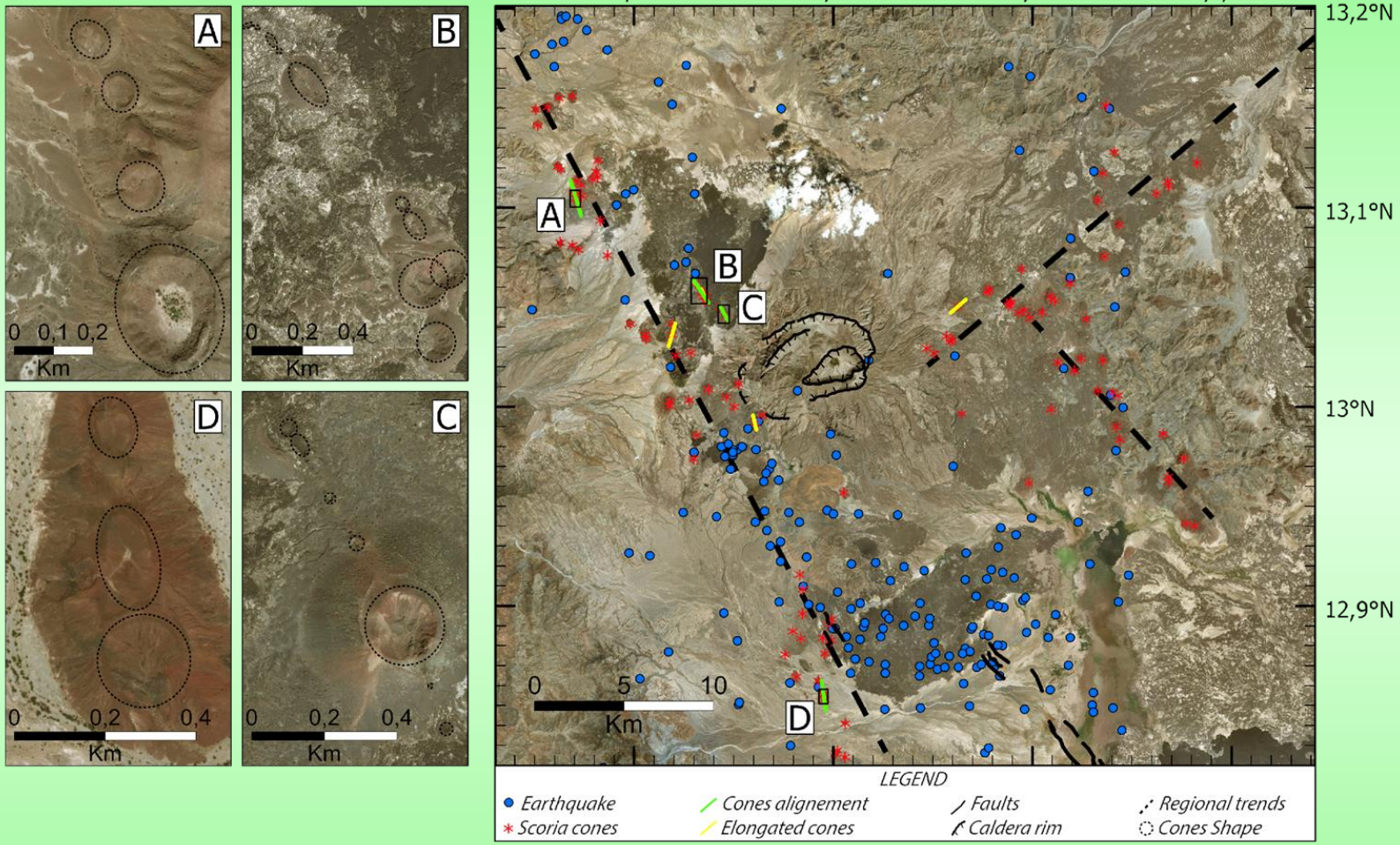
Major and trace elements indicate that the differences between the erupted products of the two phases are mainly due to a different degree of fractional crystallisation, more extended in the rift axis phase.

The pattern of the variation diagrams of all Ma'alalta products show good correlation with the Dabbahu trends.

Structures and seismicity

S-Cf phase

- East of the stratovolcano 26 cones are aligned 49° N defining along with the caldera a NE-SW trend.
- No recent seismic activity.

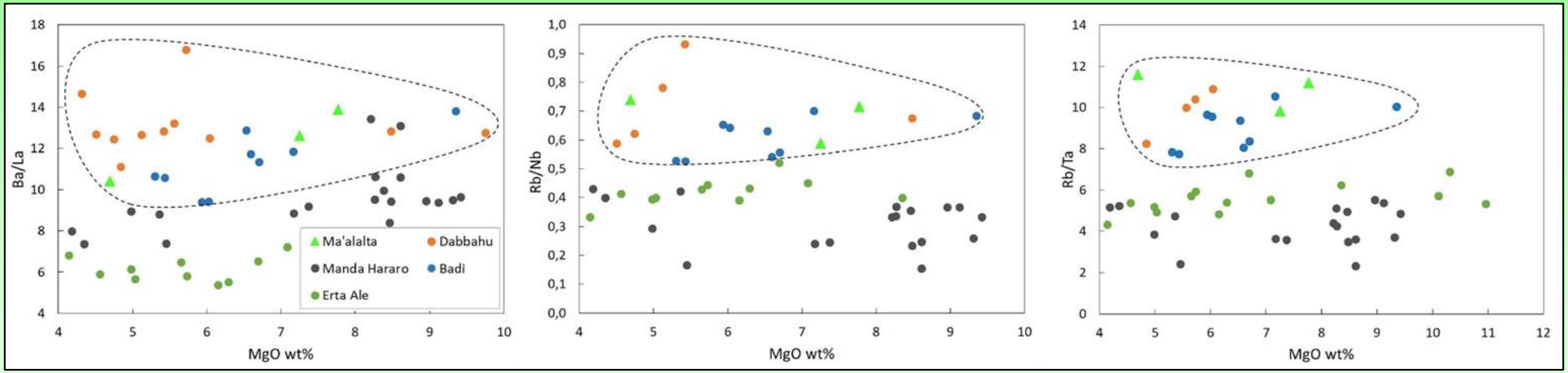


Rift axis phase

- West of the stratovolcano 70 cones strike 332° N with several elongated and aligned cones in the same direction.
- A NNW-SSE trend of earthquakes correspond to the rift axis volcanism.

The distribution of magmatic activity and seismic episodes associated with the rift axis phase define a ~35 km long magmatic segment trending NNW-SSE west of the stratovolcano.

Mafic magmas (MgO wt% > 4) comparison to axial volcanism



- The products of Ma'alalta, Badi and Dabbahu are systematically enriched in LILE/HFSE with respect to fissural products of Manda-Hararo or the Erta Ale range.
- A higher interaction of the magma with the lithospheric mantle lead to low HFSE.

- So, the decrease in extension at increasing distances from the centre of the rift axis lead to less vigorous magma ascent and more intense interaction with the lithosphere giving higher LILE/HFSE for Ma'alalta, Badi and Dabbahu as compared to fissural products, where extension is more localised.

Conclusions

Ma'alalta experienced an initial sialic stratovolcanic activity but it is now an active rift segment.

Based on:

- The types of eruptions and erupted products;
- The distribution of the recent seismic activity;
- The magma storage conditions;
- The structural arrangements.

We show that localised axial extension can be heavily offset towards the rift margin.

Rift axis phase:

- Scattered, small volume and effusive eruptions;
- Aphyric, obsidian-rich and peralkaline magmatism;
- Stacked plumbing system with at least two magma storage levels;
- Magmatic segment parallel to the Red Sea rift;
- LILE/HFSE ratios similar to axial volcanoes.