Constraints on Ground Deformation Processes at the Tulu Moye Volcanic Complex, Main Ethiopian Rift

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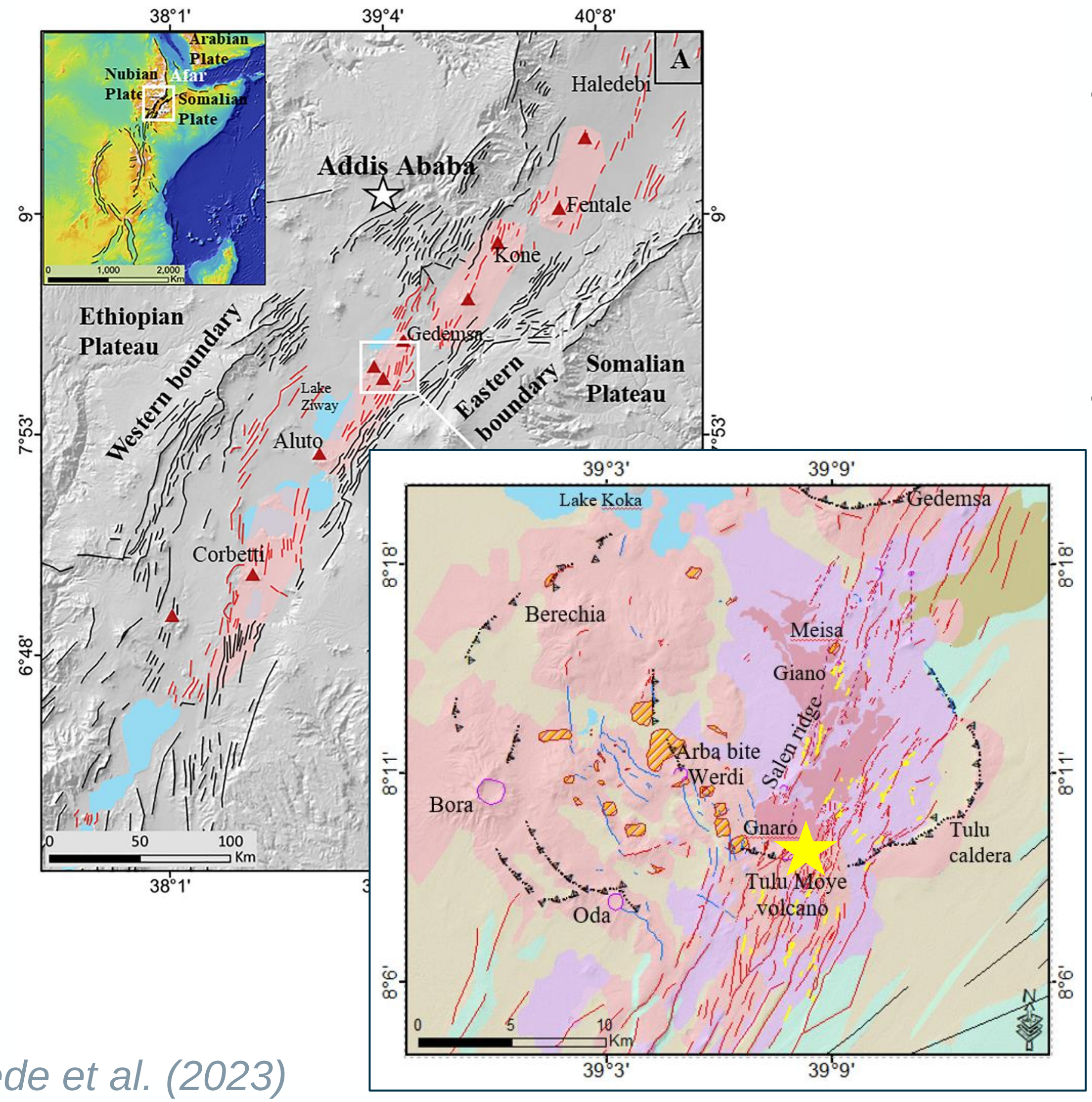
The Tulu Moye Volcanic Complex

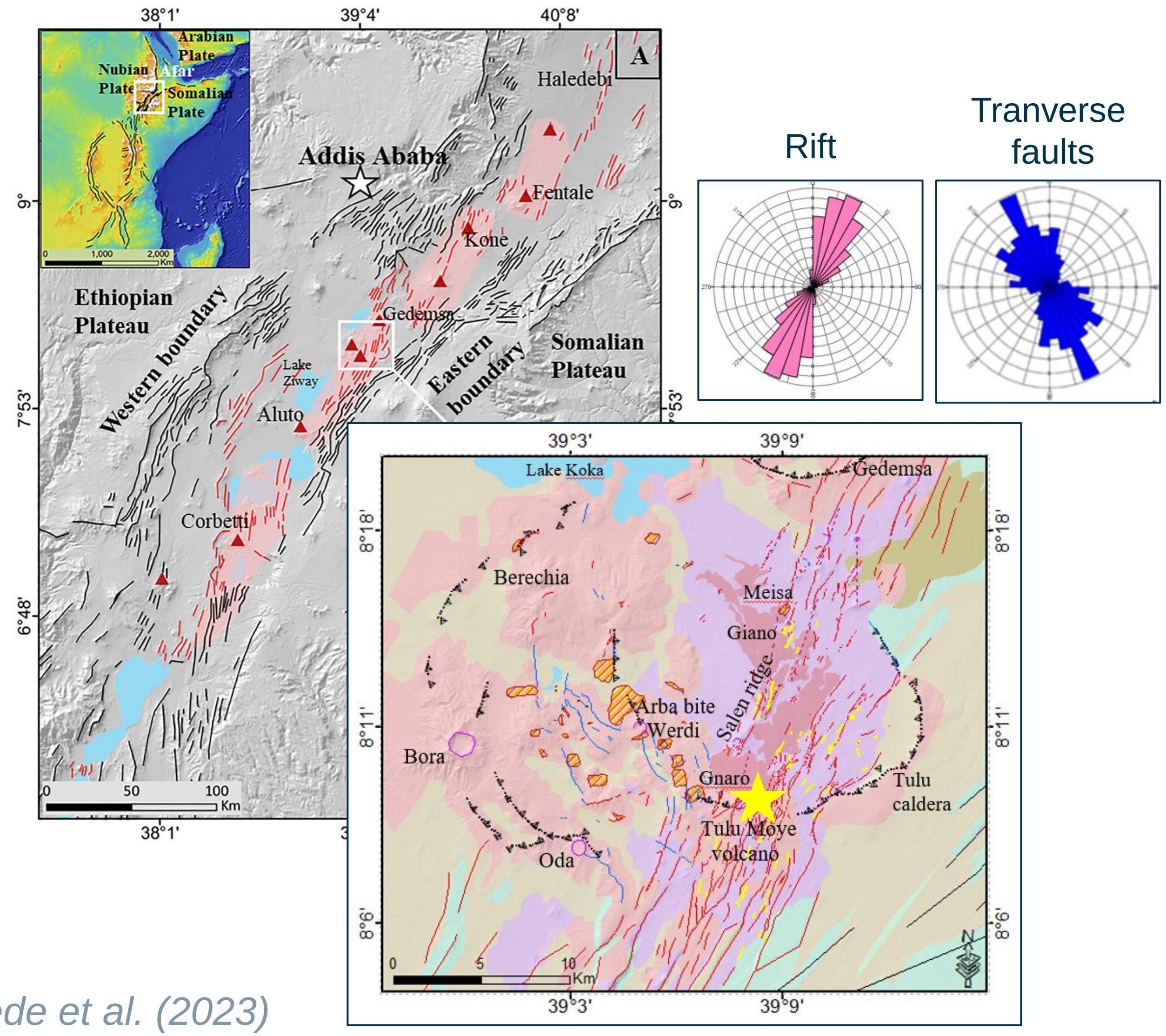


Kebede et al. (2023)

- Tulu Moye volcanic complex is located within the active Main Ethiopian Rift

- Intense heat flows and hydrothermal activity make this site **perfect for geothermal energy** exploitation and exploration

The Tulu Moye Volcanic Complex

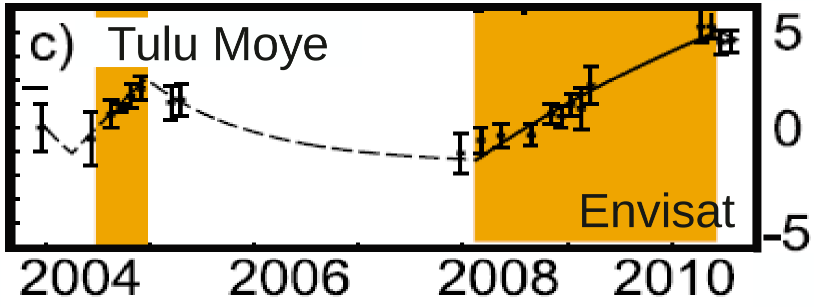


Kebede et al. (2023)

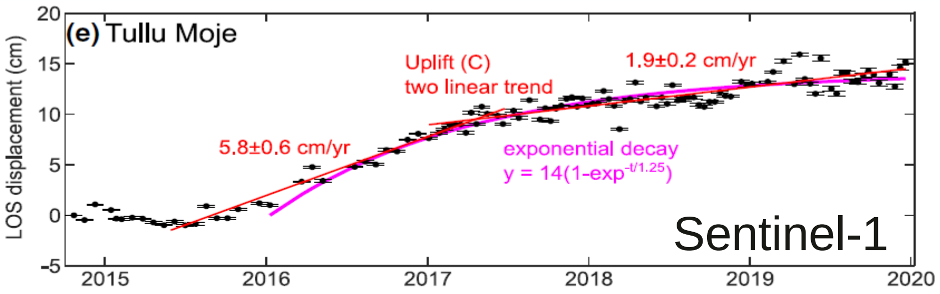
- It is characterized by a caldera system hosting Bora, Berecha, and Tulu Moye
- NNE-striking and NNW-string cross-cutting faults dissect the caldera
- The volcano is active and deforming but the nature of the **deforming source is debated**

The importance of Tulu Moye

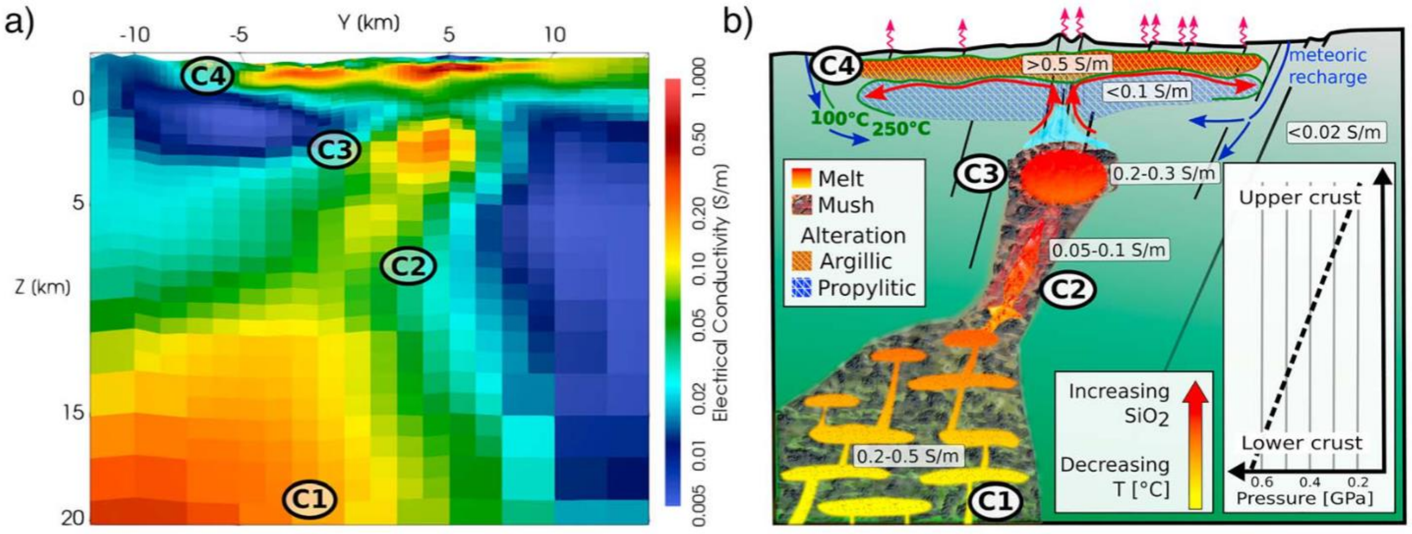
Magmatic Vs. **Geothermal** source



Modified from Biggs et al. (2011)



Modified from Albino and Biggs (2021)



Samrock et al. (2018)

Alternating **uplift** and **subsidence** caused by a 2.5 km deep **magma body**

Alternating **uplift** and **subsidence** caused by a **shallow hydrothermal source (C4)**

Objectives

We combined **Sentinel-1 time-series**, average **velocity maps**, **modeling** and independent **Magneto-Telluric** (MT) and **seismicity** data to:

1) Investigate the **locus, magnitude and style of deformation**

2) Constrain the **causes of deformation**

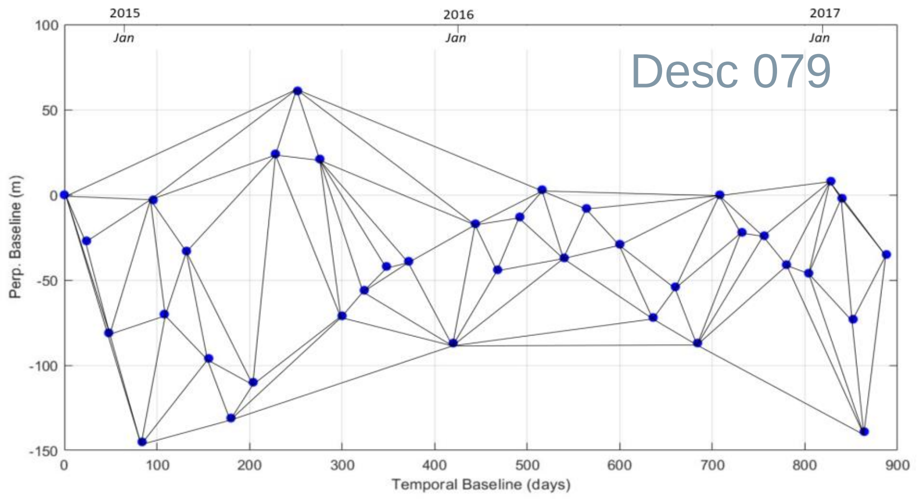
3) Build up an **integrated model of the magmatic and hydrothermal system**

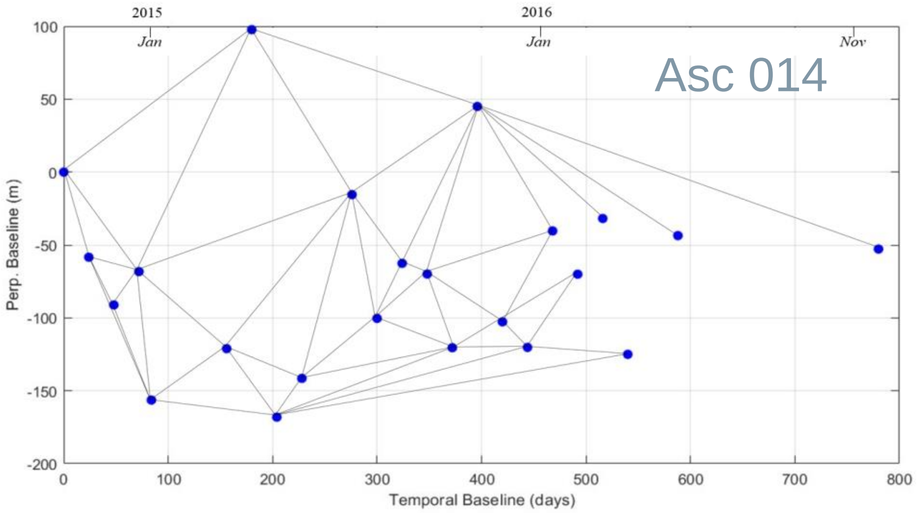
Methods

- We used the P-SBAS (Parallel Small BAseline Subset) approach implemented into the **ESA Geohazards Exploitation Platform (GEP)**

- Sentinel-1 **average velocity maps** from ascending (087) and descending (079) orbits **for the period 2014-2017**

- **Time-series** covering **2014-2022** (desc) and **2014-2017** (asc)

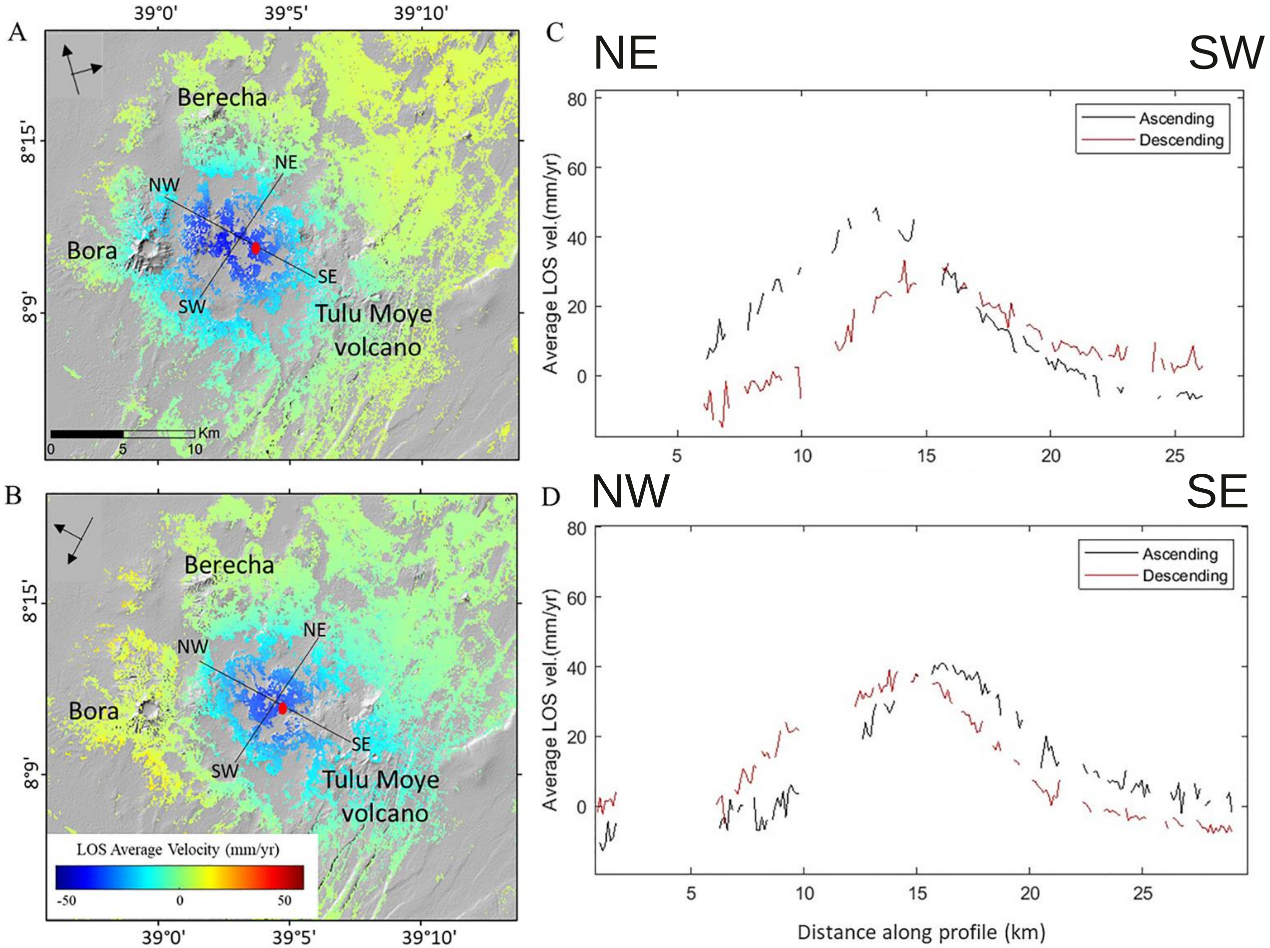




Kebede et al. (2023)

Results

InSAR average velocity maps 2014-2017



- Velocity maps shows **uplift** up to **40 mm/yr** between the Bora, Bericha and Tulu Moye volcanoes
- The deformed zone covers about **100 km^2**, **elongated** in a **NW-SE** direction

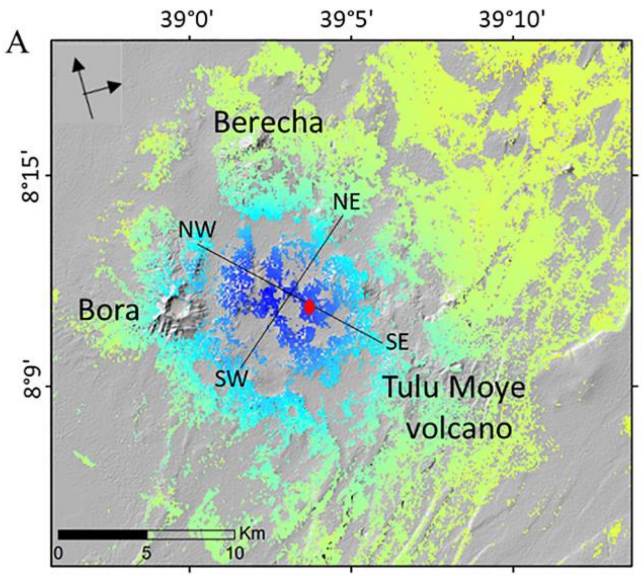
Kebede et al. (2023)

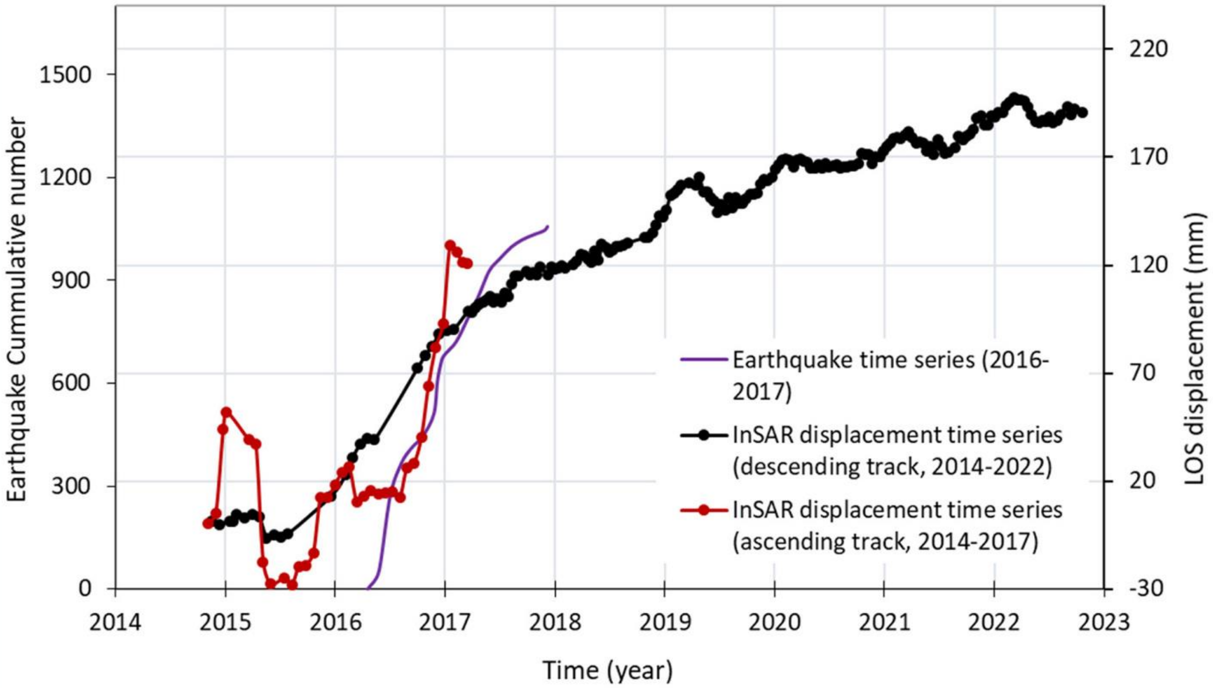
Results

InSAR time-series

- Deformation began in mid-2015 with a **rapid uplift phase (40 mm/yr)** until 2017

- After 2017 uplift continued but **slowed down (12 mm/yr)** until 2022

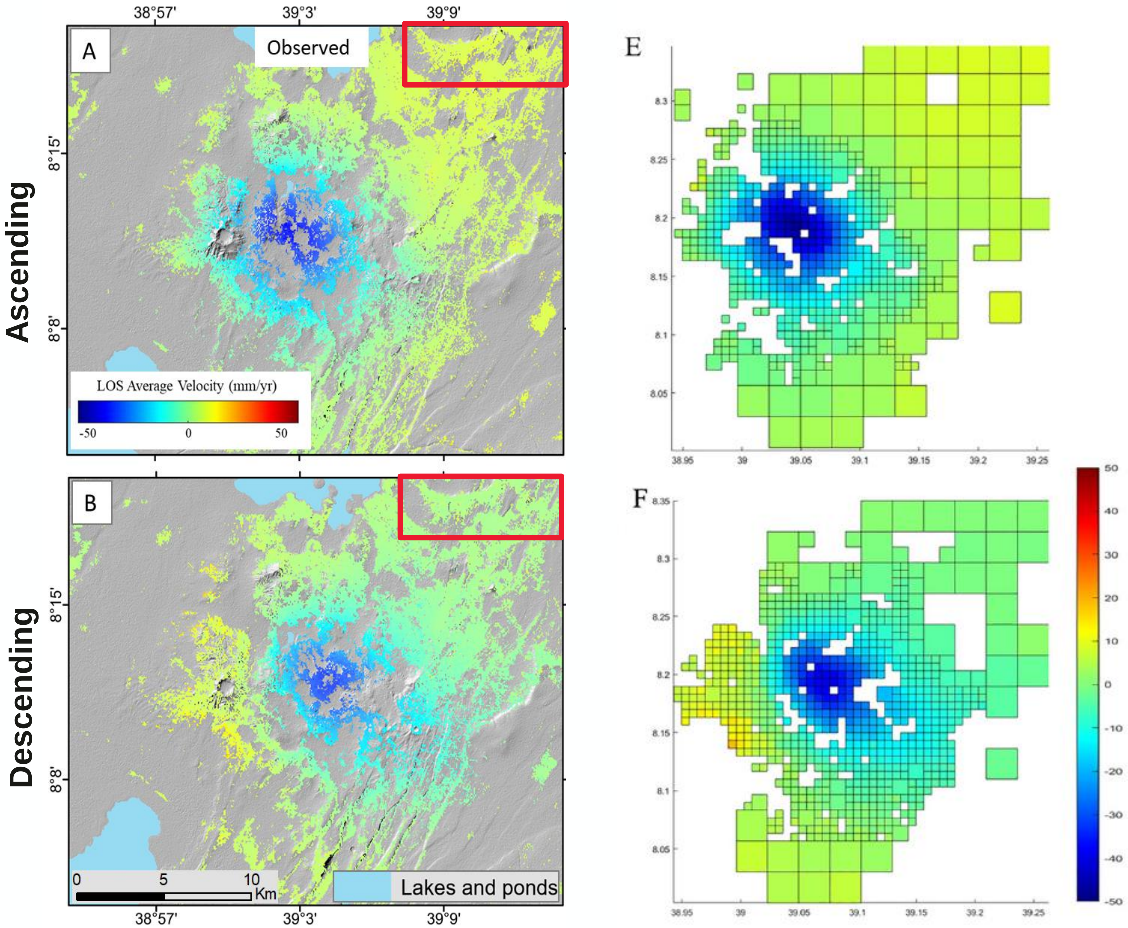




Modified from Kebede et al. (2023)

Results

InSAR Modeling



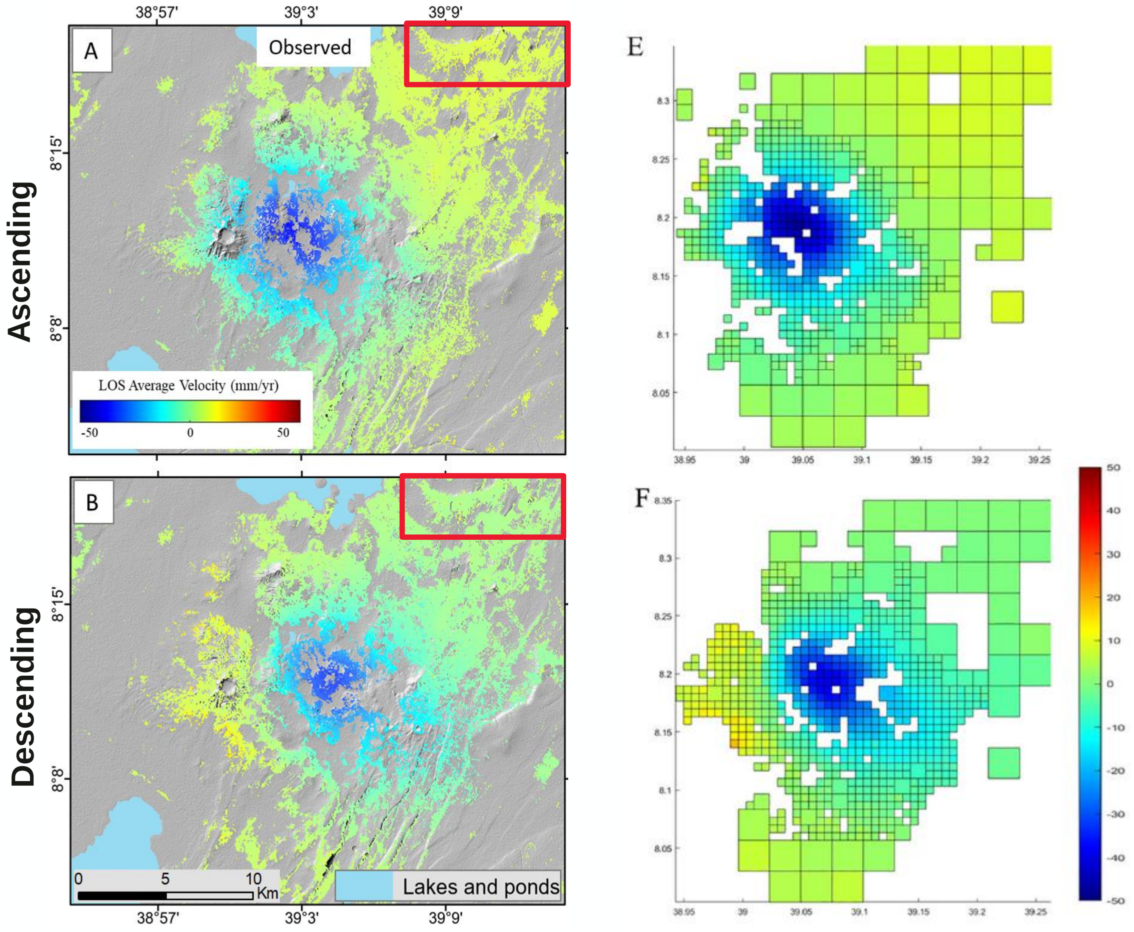
Kebede et al. (2023)

Subsampling of velocity map using a **quadtree partitioning** algorithm (Jónsson et al. 2002)

Creation of a variance-covariance matrix (vcm) of the spatially correlated noise sampling the area at the top right corner of the velocity map

Results

InSAR Modeling



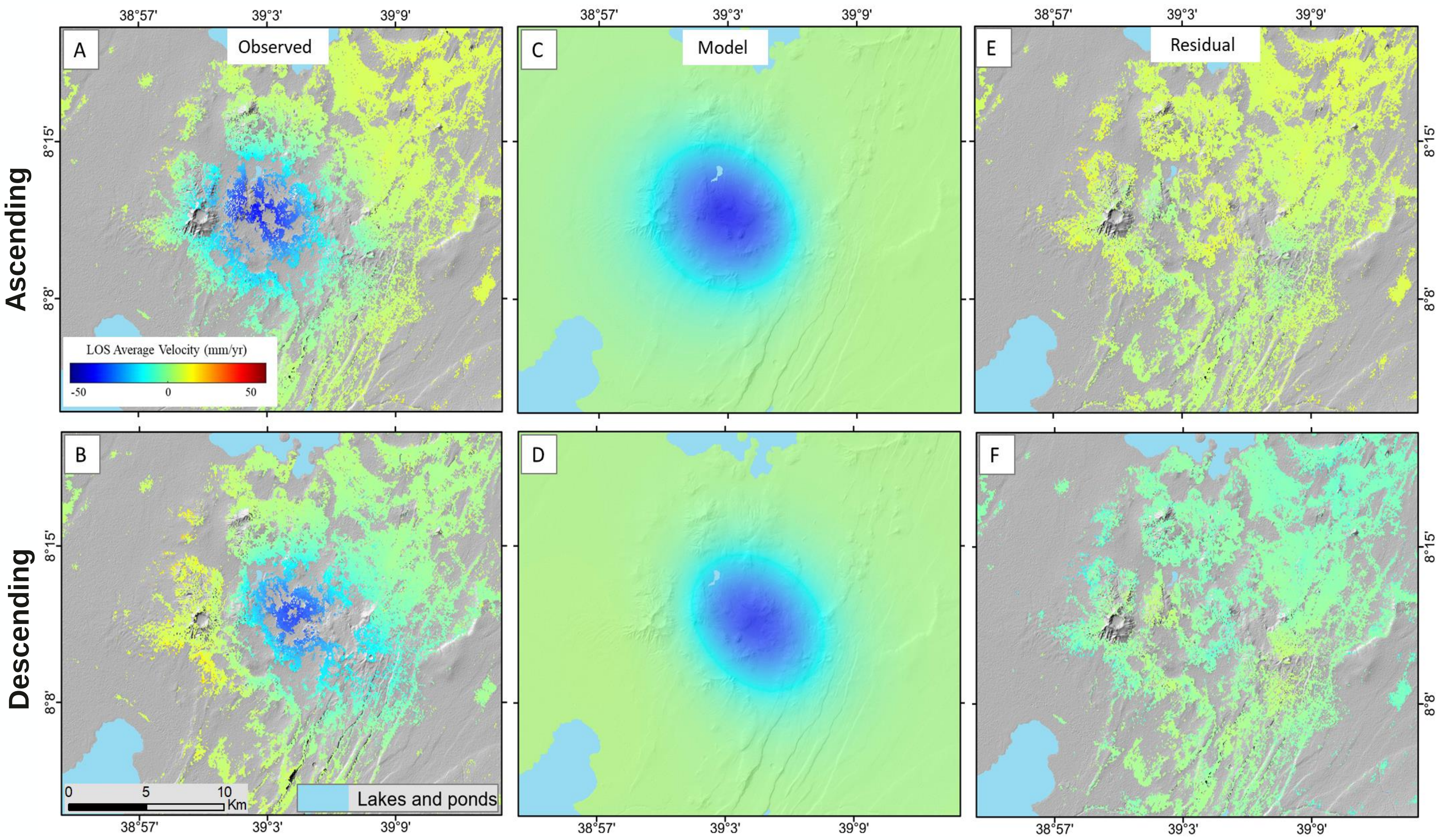
Kebede et al. (2023)

Weighted Joint inversion of ascending and descending velocity maps assuming **Okada** tensile dislocation source **(sill)**

We used a **Monte-Carlo simulated annealing** algorithm followed by a derivative **quasi-Newton method** (Cervelli et al., 2001)

Results

InSAR Modeling



Kebede et al. (2023)

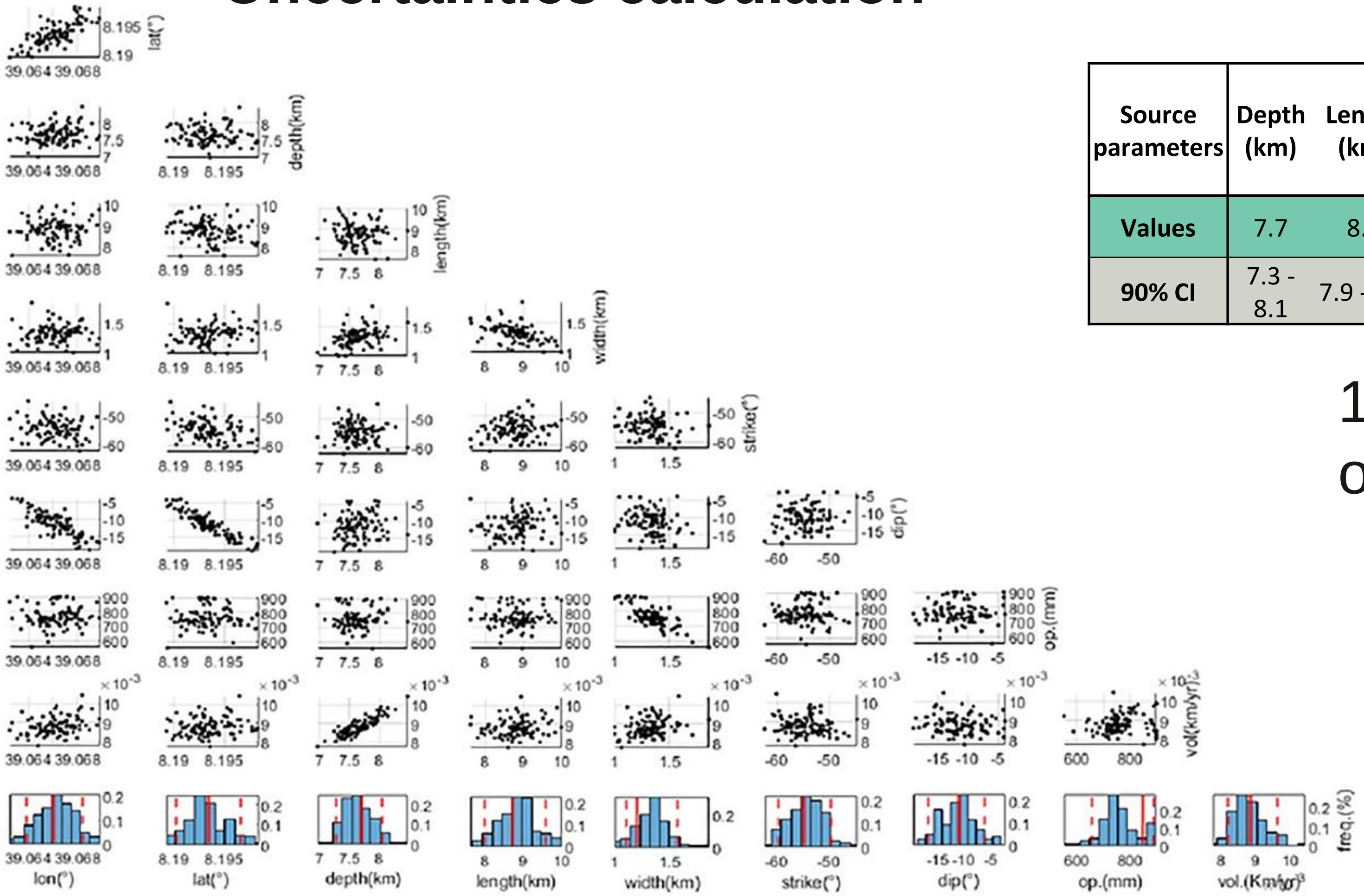
The best-fit model suggests a **NW-striking sill** located at a **depth of 7.7 km**

Opening rates are **0.85 m/yr** = volume change rate **8.9 x 10^6 m^3/yr**

Results

esa

Uncertainties calculation



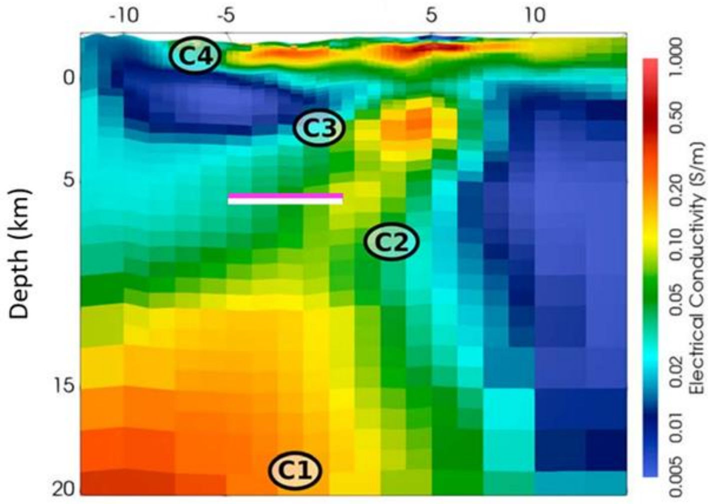
Source parameters	Depth (km)	Length (km)	width (km)	Opening (m/yr)	Strike (°)	Dip (°)	Longitude (°)	Latitude (°)	Calculated Volume (m^3/yr)
Values	7.7	8.7	1.2	0.85	55 NW	11 SW	39.066	8.194	8.9
90% CI	7.3 - 8.1	7.9 - 9.6	1 - 1.6	0.66 - 0.89	60 - 50 NW	17 - 6 SW	39.064 - 39.068	8.190 - 8.197	8 – 9.6

100 inversion using simulations of the spatially correlated noise

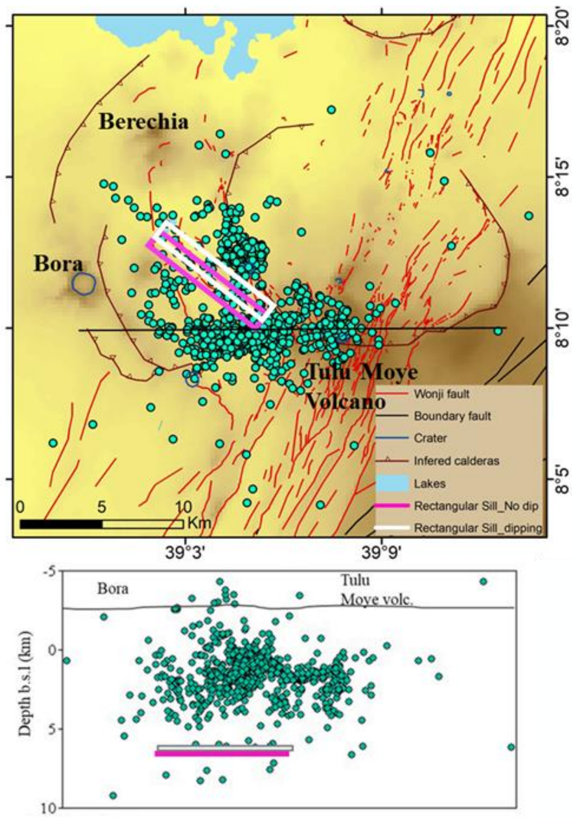
All the parameters remain well constrained withing narrow ranges of variability

Kebede et al. (2023)

Discussion



MT-derived Electrocondictivity of the Tulu Moye area *(Samrock et al., 2018)*



- The sill locates at upper edge of the high conductive **partial melt zone** in MT studies
- It is ~1-2 km **below** the base of the **cluster of micro-seismicity** during 2016-2017 (Greenfield et al., 2019)
- The sill is **sub-parallel to** the nearby **NW-striking faults** and caldera rims, suggesting a **structural control**

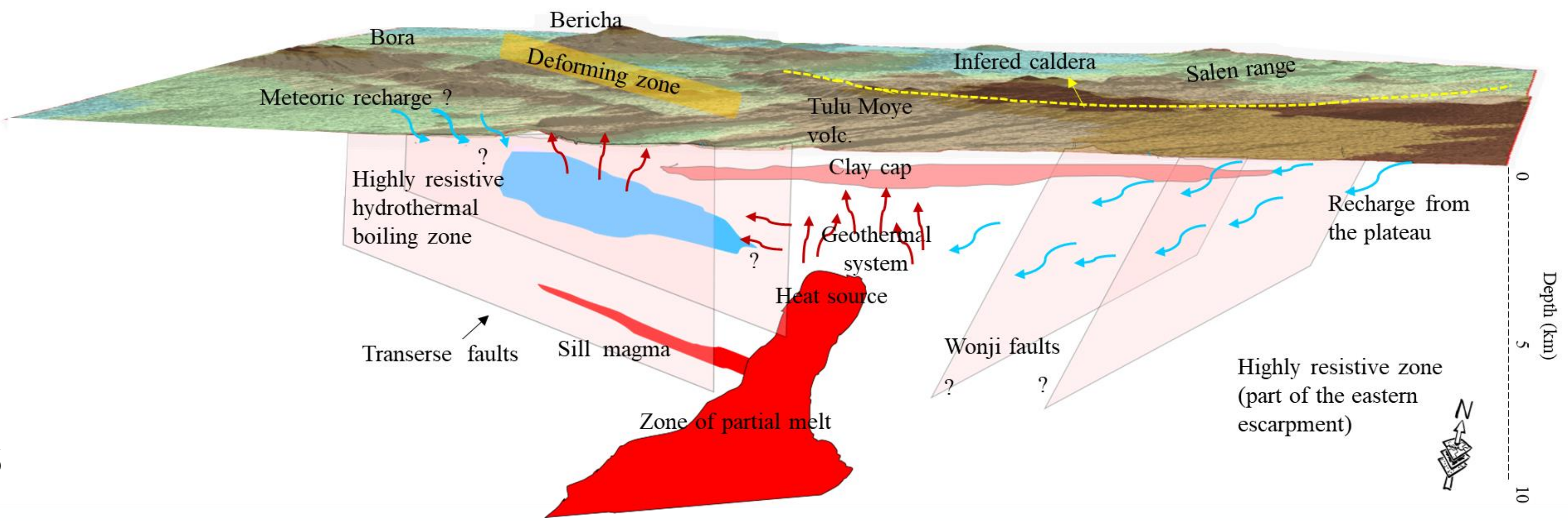
Kebede et al. (2023)

Conclusion

- NW-oriented faults likely act to channel flow of magma into an elongate sill shape and favor fluid migration at surface

- The inflating sill is below surface manifestations, and micro-seismicity indicating it may be an **important heat source in the western part of the geothermal system**

- Alternating uplift and subsidence could be explained with inflation of magmatic system (uplift) and degassing of the hydrothermal sytems similar to other volcanoes in the MER (Aluto)



Thank you!

Forward modeling using a Mogi source

Mogi Source parameters	Depth (km)	Volume (km^3/yr)	Longtiude (°)	Latitude (°)
Ascending values	5.65	0.0078	39.063	8.191