Electrical Conductivity Structure of Miocene-Quaternary Volcanic Province in Svalbard

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Abstract

The Woodfjorden-Bockfjorden area in north-western Svalbard hosts the world northernmost onshore thermal springs, extinct Quaternary volcanoes, and Miocene lava flows overlying a Devonian sedimentary basin. In July 2023, the first 3D magnetotelluric (MT) survey was conducted in this volcanic region. MT data were collected at 12 sites using broadband instruments in the Devonian basin and near the Sverrefjellet volcano (30x30 km area). Data processing involved filtering and the complex impedance transfer function estimation in the frequency domain. Magnetic field data from observatories in Longyearbyen, Ny-Ålesund, and Hornsund improved the transfer function quality. The MT data were inverted using two methods: ModEM, a finite-difference inversion code, and DEVA3DMT, a hybrid finite-element code that incorporates surface topography and galvanic distortion effects. The resulting model reveals electrical resistivity anomalies in the upper crust possibly related to magmatic intrusions and deep fluid circulation linked to the Bockfjord volcanic complex (Fig. 1).

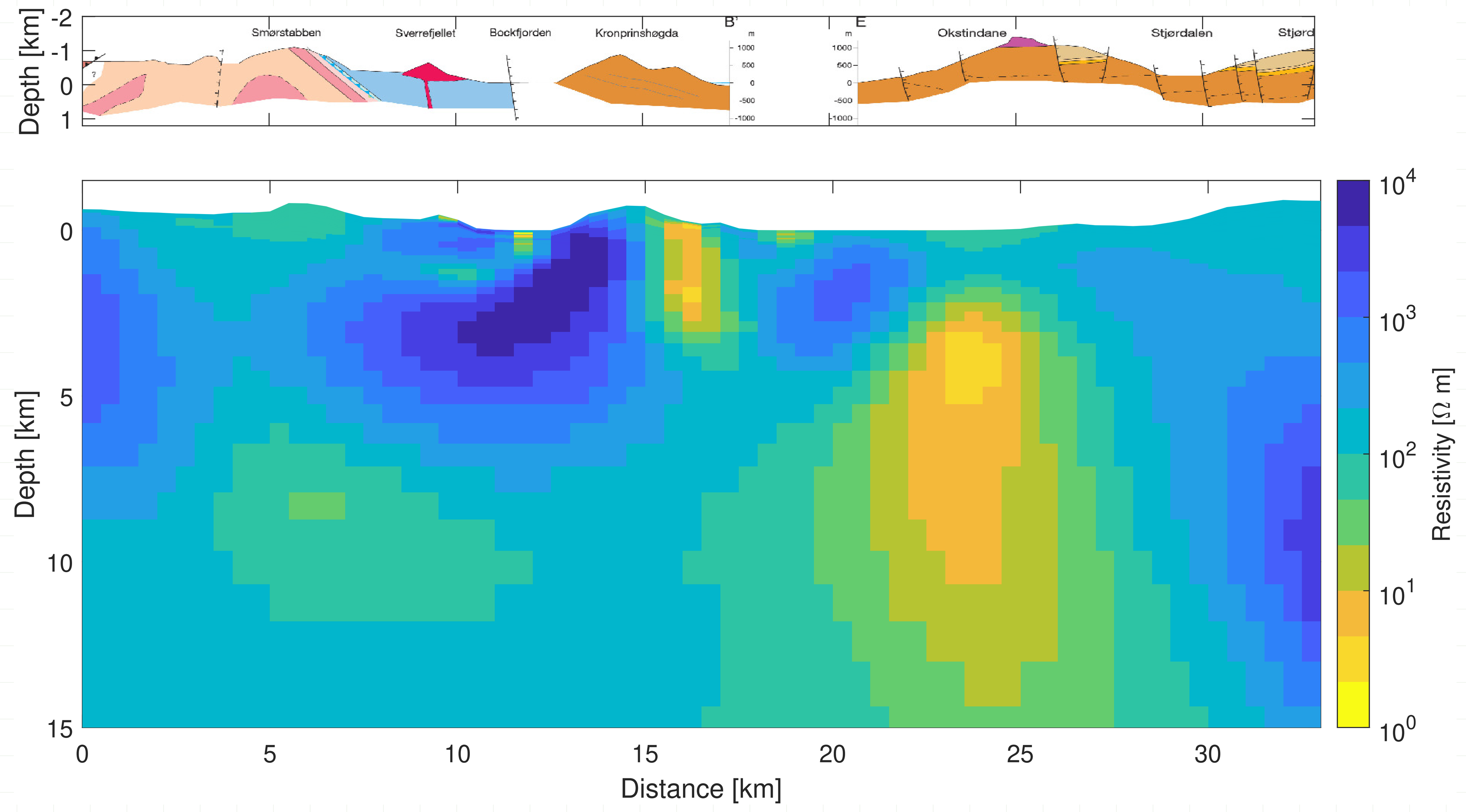

Figure 1: Vertical cross-section (West-East) through 3-D electrical resistivity model of the Woodfjorden study area obtained using DEVA3DMT code [Varılsüha, 2020]. See Fig. 5 for location. A schematic geological cross-section [Dallmann et al., 2005] is shown on the top.

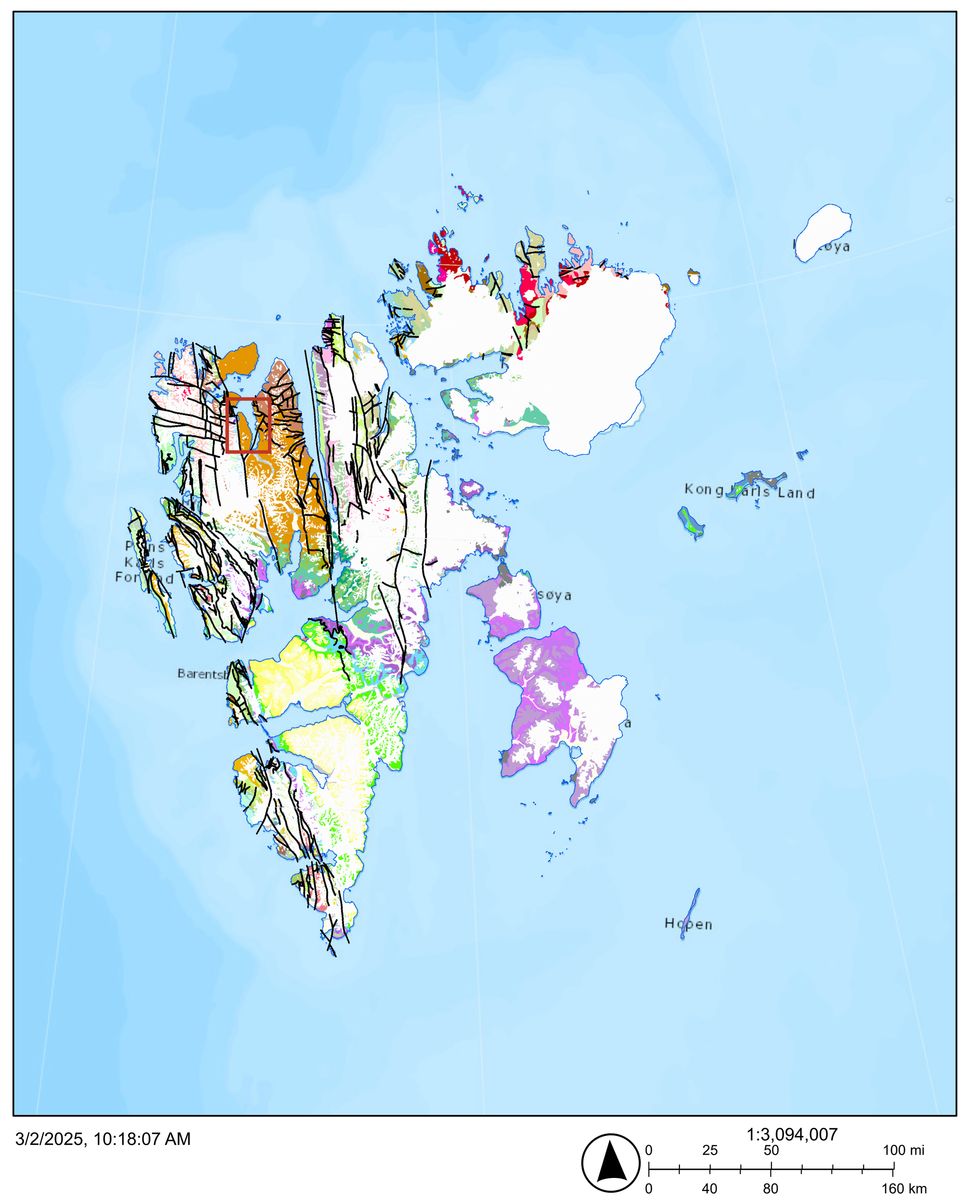

Figure 2: Geology of Svalbard and location of the MT survey area in Woodfjorden. The map is provided by the Norwegian Polar Institute.

1 Data and Methods

The broadband MT data were collected with two broadband instruments at 9 sites within the Devonian sedimentary basin, and 3 sites within the Mesoproterozoic basement near the Quaternary Sverrefjellet volcano (Fig. 3).

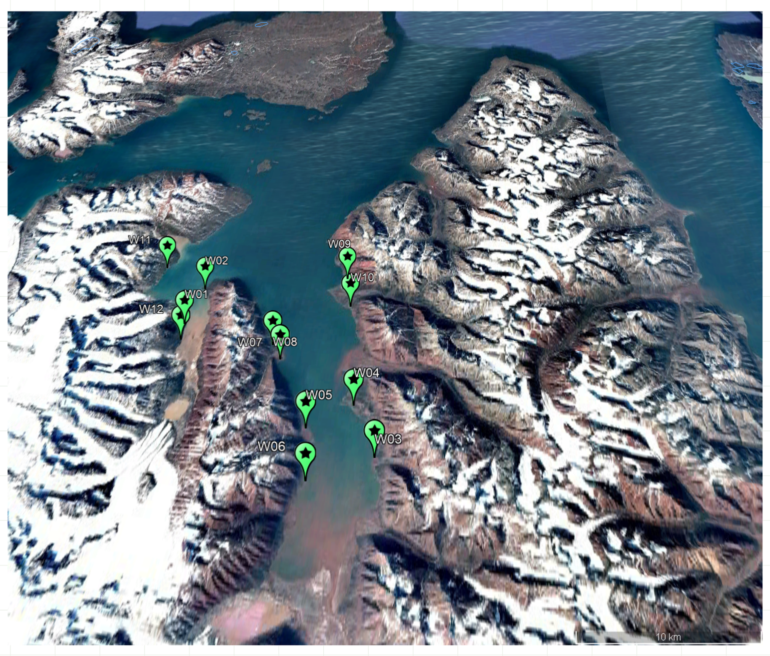

Figure 3: Topography and site locations of the Woodfjorden study area.

At each site, we obtained on average 20 hr of data with a sampling rate of 20 Hz and, and 2 hr of high-frequency data with (1 kHz) starting at midnight. The MT data processing included transforming time series into the spectral domain and the estimation of the impedance transfer functions (shown in Fig. 1) using robust regression. We have also used 1-s data recorded at the magnetic observatories in Ny-Ålesund, Longyearbyen and Hornsund as remote reference.

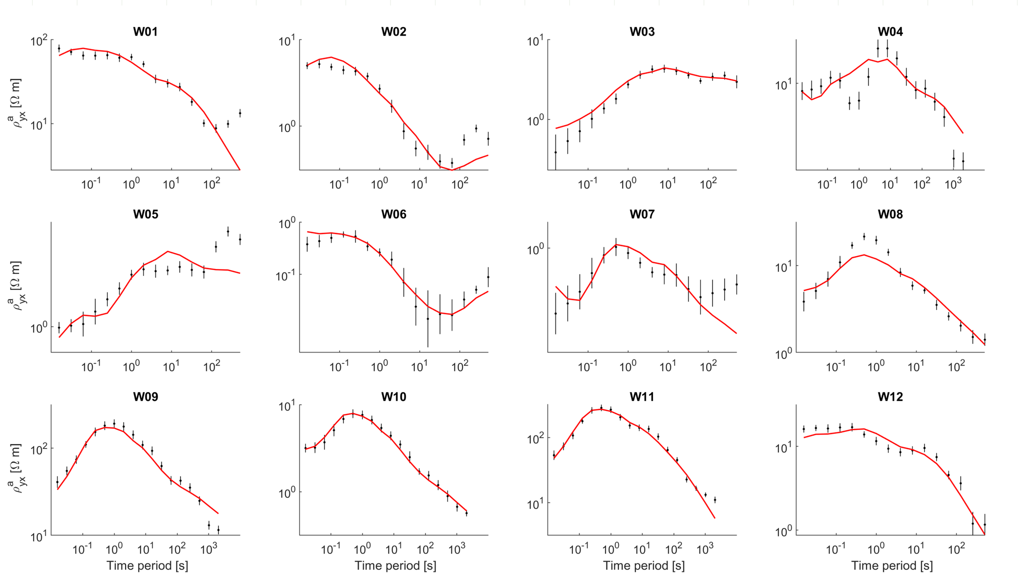

Figure 4: Data Example. Observed and modeled apparent resistivity computed from Z_{yx} impedance tensor component.

The 3D electrical resistivity model (shown in Fig. 5) was obtained by inverting the acquired MT data using the finite-difference 3-D MT inversion code ModEM [Kelbert et al., 2014]. We have also inverted the same data with the DEVA3DMT which better handles the topography variation [Varılsüha, 2020] (Fig. 1). The data analysis using the two inversion codes provided similar resistivity images with the largest difference in the uppermost 1-2 km associated with surface topography (cf. Figs. 1 and 7).

2 Results

2.1 3D Resistivity Model

The estimated complex impedance tensor data at 12 MT sites were modelled using ModEM inversion code. The inversion was performed using a Nonlinear Conjugate Gradient method with smoothing constraints. The inversion stopped at iteration 120 reaching rms of about 2.

The strong low-resistivity anomalies can be interpreted as indicative of crustal fluids. The center of the conductive anomaly is located approximately below the Lavatoppen outcrop and has the same orientation as a SW-NE fault shown in Fig.2. The Breibogen fault zone is visible in the electrical imaging in Figs. 1 and 5 as a shallow discontinuity, with a conductor coinciding with the location of the Troll thermal springs.

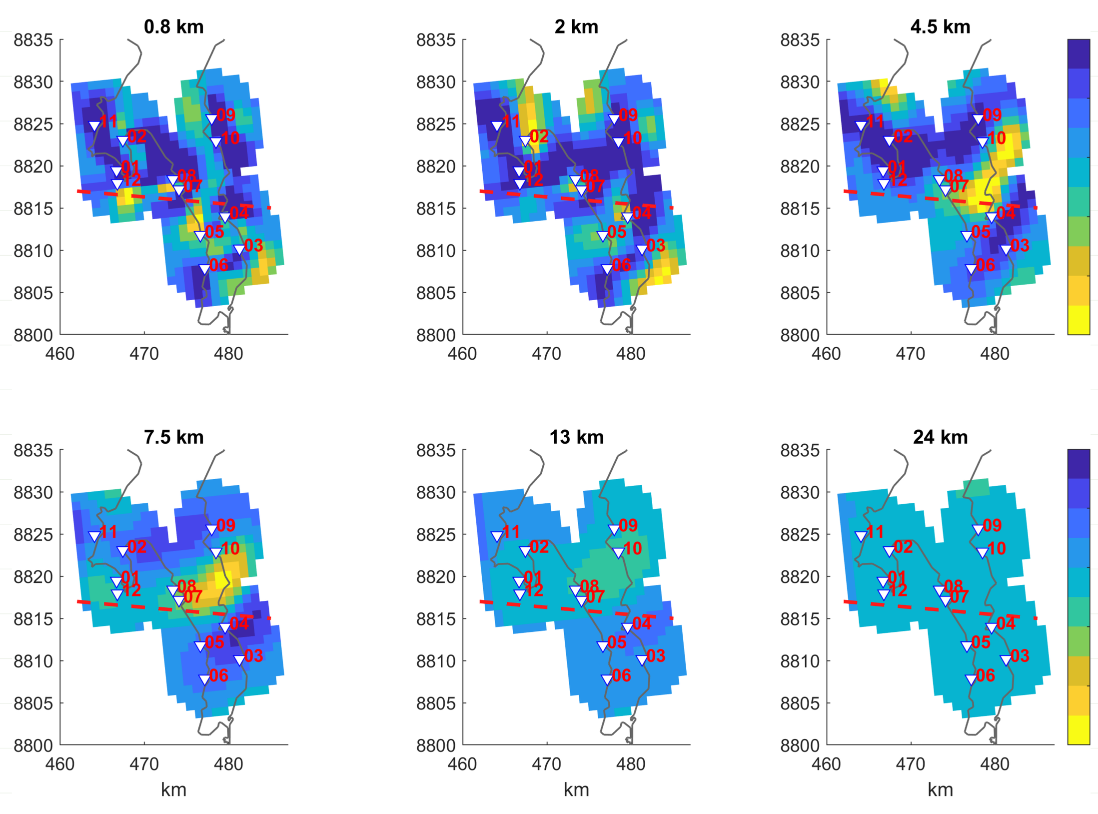

Figure 5: Depth slices through 3D electrical resistivity model. Cross-section in Figs. 1 and 7 is indicated with a dashed line.

2.2 Model Sensitivity

The linearized model sensitivity (Fig. 6) was obtained by computing the squared values of the Jacobian matrix at the final iteration and integrating over all periods and stations.

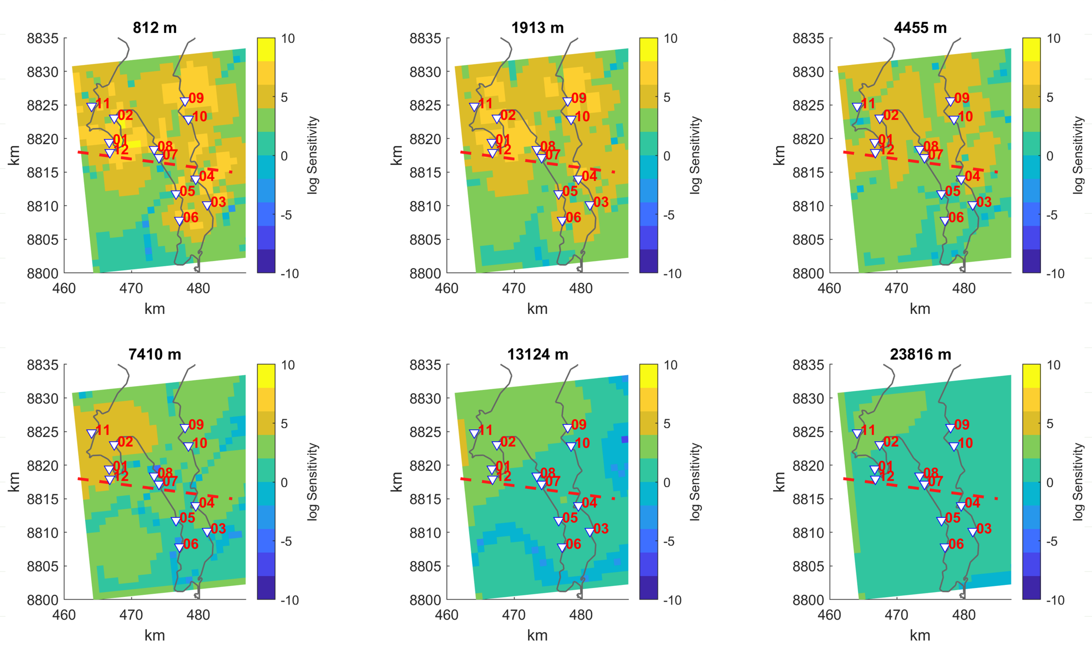

Figure 6: Model sensitivity. Cross-section in Figs. 1 and 7 is indicated with a dashed line.

2.3 Data Resolution Tests

The sensitivity of the data recorded at individual sites was tested by sequentially excluding each station and repeating the inversion using ModEM code. The large conductive and resistive anomalies located at depths of 2-10 km remain consistent.

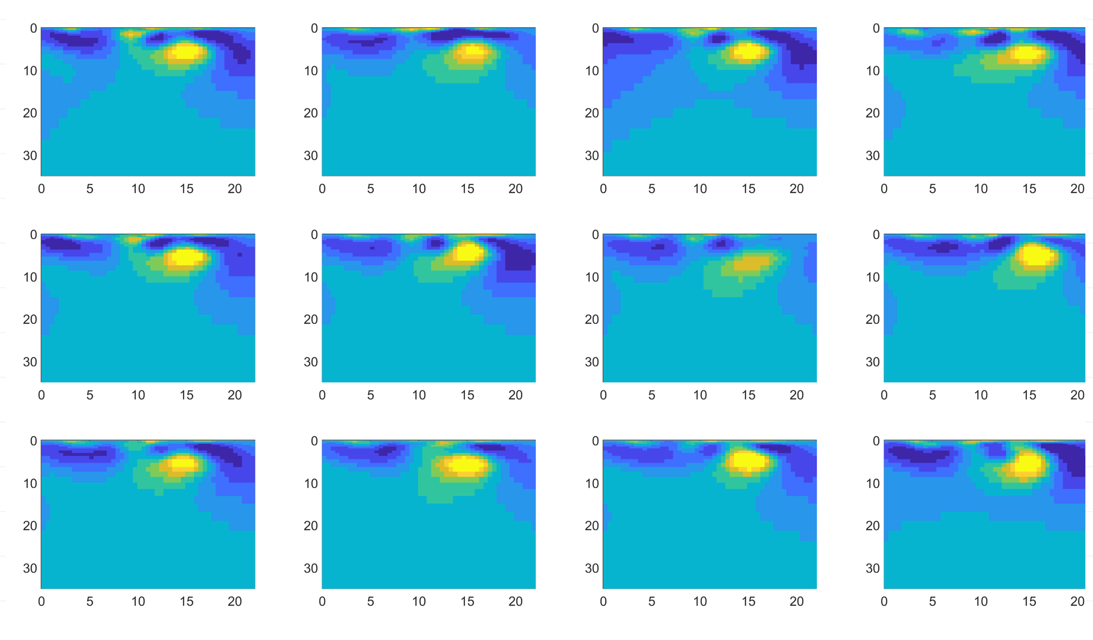

Figure 7: Jackknife test. The W-E cross-section through the 3D resistivity model. See Fig. 5 for location.

3 Conclusions

- First 3-D MT survey in Svalbard accompanied by extensive petrological sampling;
- The resolved frequencies of 0.01-1000 s allowed mapping electrical structure of the crust down to about 30 km depth;
- 3-D electrical resistivity model indicates conductive vertically elongated features (1-5 Ohm m) below the Devonian sediments;
- The resistive features of about 1-10 kOhm m at a depth of 2-5 km can be related to magmatic intrusions associated with the Miocene lava flows.

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