Electrical Resistivity Tomography applied to a complex lava dome: 2D and 3D models comparison

Angélie Portal[1], Yannick Fargier[2], Jean-François Lénat[1] and Philippe Labazuy[1]

1 - LMV, OPGC, CNRS/UMR6524, Université Blaise Pascal, 5 Rue Kessler, 63038 Clermont-Ferrand (France)
2 - CEREMA – Direction Territorial Normandie Centre, 11 rue Laplace – CS2912 – 41029 Blois (France)

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a.portal@opgc.univ-bpclermont.fr

1 - Introduction

The inner structure of volcanic domes is very complex due to a succession of intrusion, extrusion, explosion and collapse phases during their growth.

Their eruptive activity is associated with extrusion of viscous lava, lava flows, pyroclastic and debris avalanche deposits as well as a strong hydrothermal activity. Because large ranges of resistivity values are expected in such geological formations, the ERT method is well suited to study the internal structure of volcanic domes.

In this study we present a comparison of 2D and 3D models of electrical resistivity distribution on the case study of the Puy de Dôme trachytic lava dome. We also present a geological interpretation of the edifice summit part.

Figure 1: The Puy de Dôme volcano (right) is a trachytic lava dome in the central part of the Chaîne des Puys volcanic field (French Massif Central).

2 - Inversion method

Inverse problem uses measured data to infer the values of the parameters characterizing the investigated system (Tarantola, 2005). Electric data modelling is a nonlinear process needing to compute iteratively a succession of forward models.

The following **Gauss-Newton approach** combined to an **Occam regularization** is used for inversion (Lines and Treitel, 1984, Constable and al., 1987):

$$(G^T C_d^{-1} G + \lambda C_m^{-1})\Delta m = G^T C_d^{-1} r - \lambda C_m^{-1}(m - m_{ref})$$

where :
- G: sensitivity matrix
- m: model parameters
- C_d and C_m: covariance matrices on data and model respectively
- λ: Marquardt parameter or damping factor (determine by decreasing)
- r: inversion residual
- m_{ref}: reference model

3 - 2D and 3D modelling

Two inversion processes, based on the approach described above, are proposed:

- **2D inversion** using **RES2DINV** software (Loke and Barker, 1996),
- **3D modelling** through **CoLibRI** package (Fargier, 2011).

RES2DINV includes the topography through a grid-mesh distorsion after inversion (Loke, 2011) whereas CoLibRI integrates the relief before inversion.

The sensitivity matrix, quantifying the effect of a model parameter perturbation on a simulated measurement, is also resolved through two different approaches.

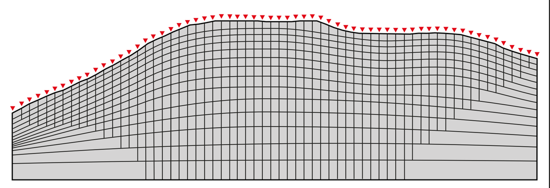
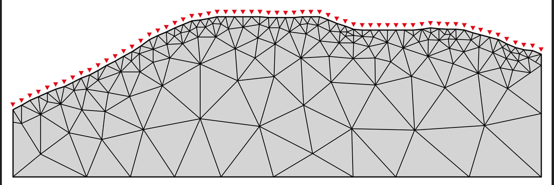
	RES2DINV	CoLibRI
Discretization	Rectangular cells	Tetrahedrons
Topography		
Sensitivity matrix	Analytical solution $G(x,z)=\frac{1}{4\pi^2}\int_{-\infty}^{\infty}\frac{x(x-a)+y^2+z^2}{(x^2+y^2+z^2)^{1.5}((x-a)^2+y^2+z^2)^{1.5}}dy$	Adjoint operator $\frac{\partial V_{ABMN}}{\partial \rho} = \int J_A J_M dt - \int J_A J_N dt - \int J_B J_M dt + \int J_B J_N dt$

Table 1: Comparison of the characteristics of the two inversion softwares (Loke, 2011, Fargier, 2011)

4 - ERT surveys on the Puy de Dôme

The Puy de Dôme is a 11,000 years old trachytic dome. The complexity of its structure has been highlighted by recent multi-method geophysical imaging surveys (Portal and al., 2013).

In order to improve our knowledge on its formation, new multi-electrode ERT profiles have been carried out in the summit area *(Table 2, Figure 2)*.

Profile name	Electrode spacing	Electrode number	Data point	Symbols
lr00031-33*	5m	128	1153	+ + +
lr00034-36*	5m	128	1070	+ + +
lr00019-27°	5m - 10m	96	1057	+ + +
lr00017-18°	5m - 10m	83	701	+ + +
lr00026	5m	64	458	+ + +

*Table 2: Characteristics of the 7 ERT profiles carried out on the summit part of the Puy de Dôme volcano between 2011 and 2014. Symbols refer to the location map. *: half-length roll-along acquisition || °: overlapped profiles*

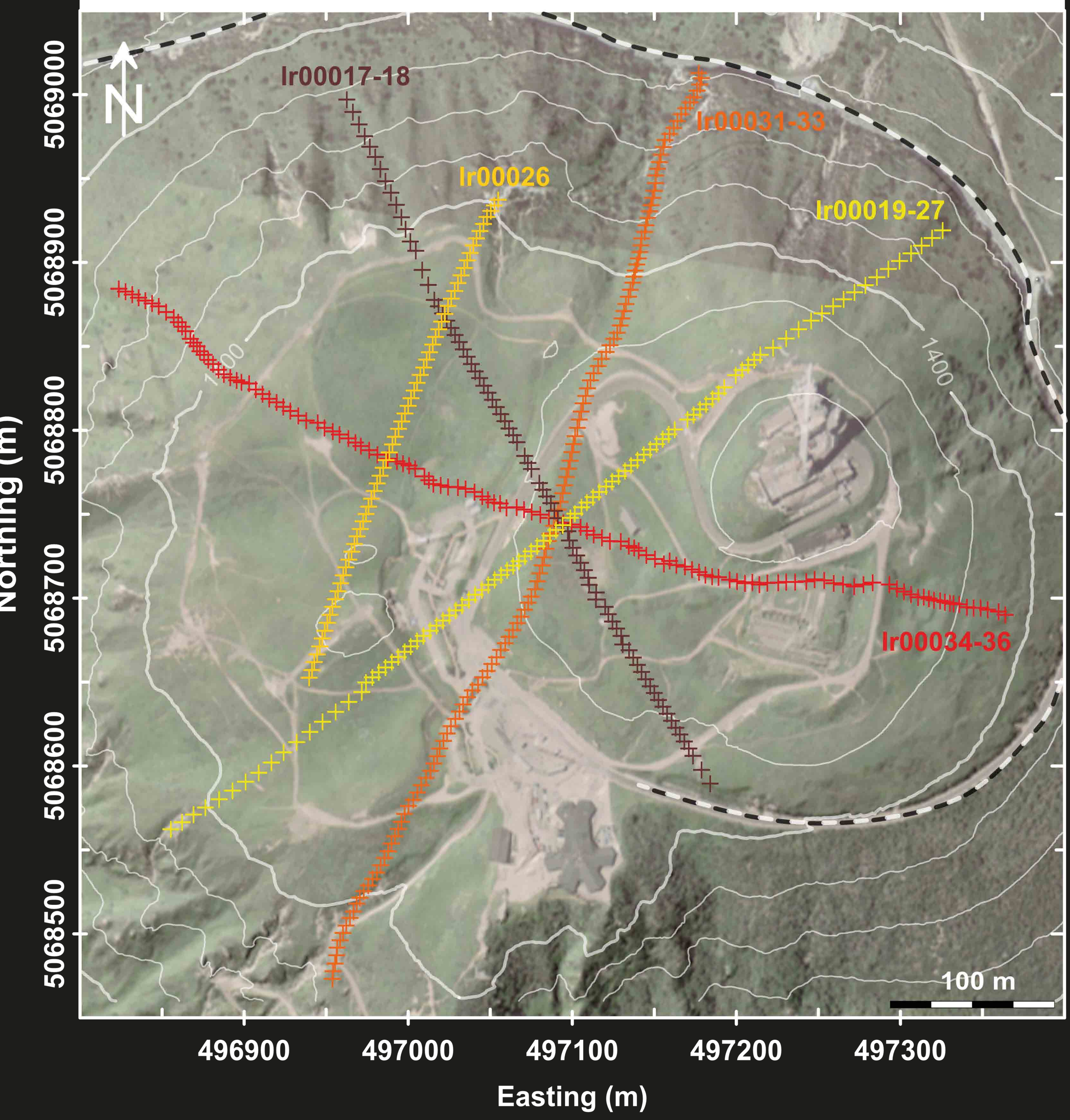


Figure 2: Location map of the ERT profiles on the Puy de Dôme summit part. The profile names are indicated. Coordinates are in WGS84 UTM 31N.

5 - Inversion models

a) Results

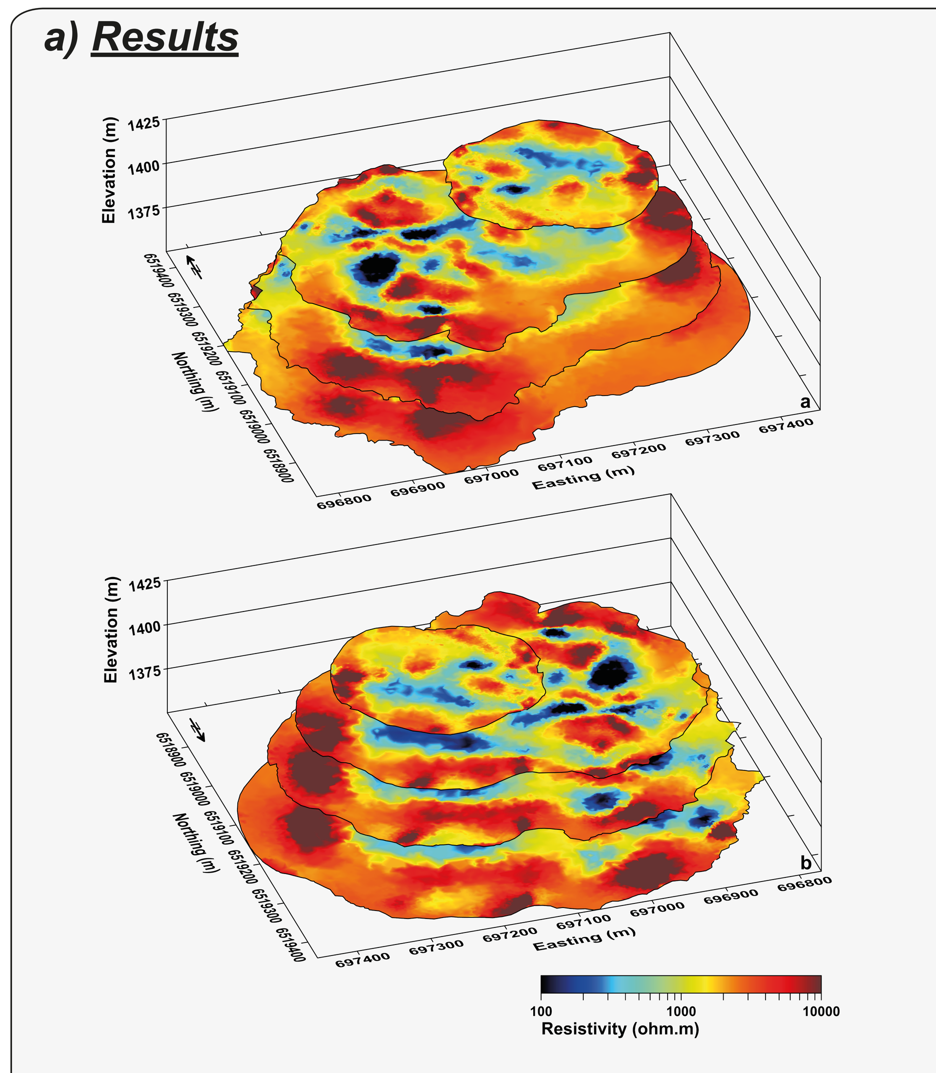


Figure 3: Horizontal slices in the 3D model of the resistivity distribution. RMS error is 9.3% after 8 iterations. View from SW (a) and NE (b). Coordinates are in WGS84 UTM 31N.

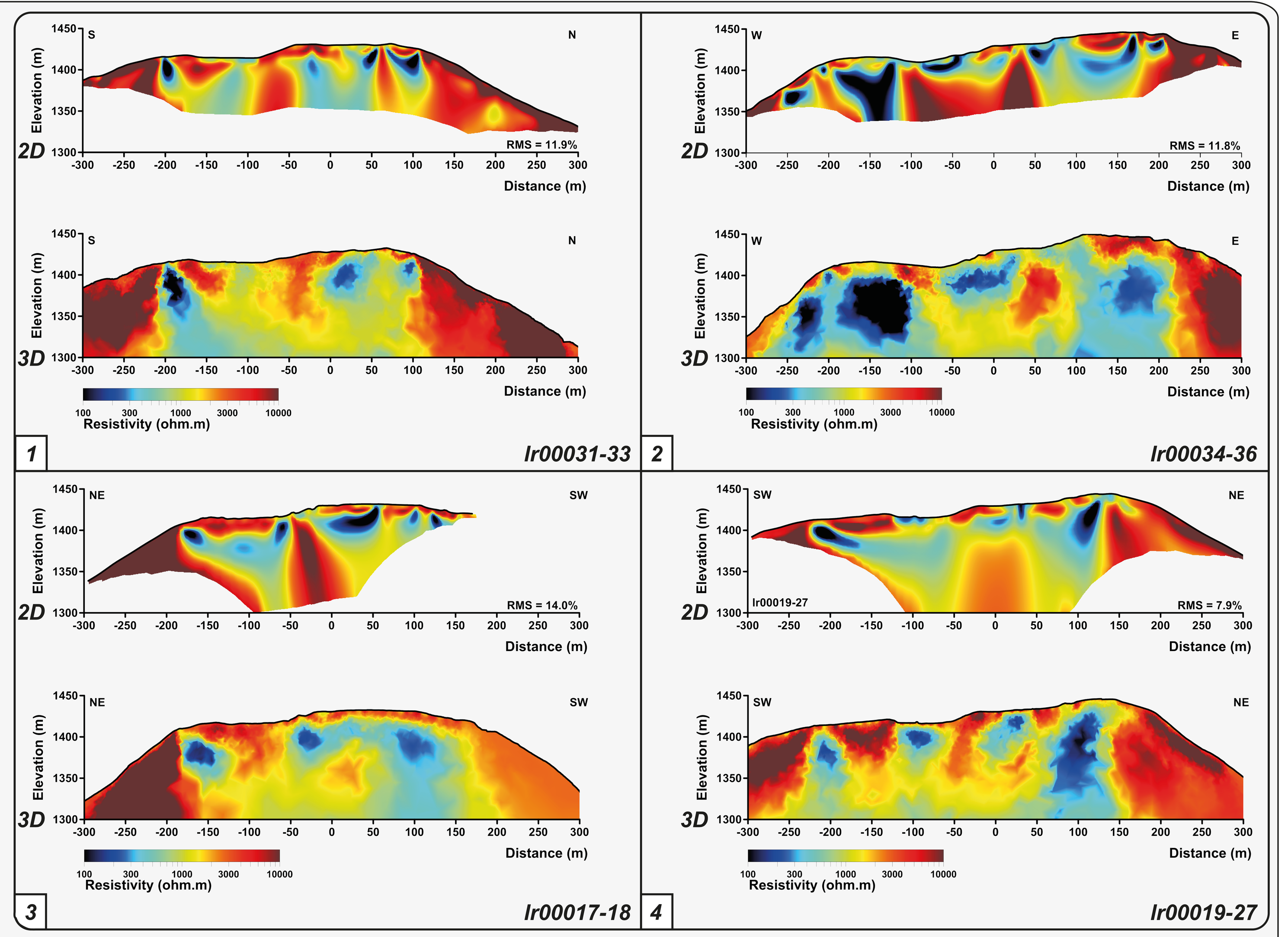


Figure 4: 2D inversion models and their corresponding slices in the 3D model. 2D inverse models RMS errors are indicated (for 3D model see figure 3). Colorscale is the same for all figures.

b) Models analysis

- 2D/3D comparison

- 3D model allows a more extensive description of the resistivity distribution *(Figure 3)*.
- The shallow layers are equally well resolved by the 2D and 3D models.
- At depth, the 2D models resolution decreases more rapidly than that of the 3D one. This results in downward oriented streaks of resistivity values on 2D sections *(Figure 4)*.

- Qualitative description

- Both 2D and 3D models show a strong heterogeneity of the dome summit area.
- Clear differences in resistivity pattern and values between the central area and the periphery highlight a heterogeneous core surrounded by more homogeneous resistive formations.

c) Geological interpretation

- The high resistivity values at the periphery may be explained by the presence of water undersaturated and mostly unaltered rocks. Highest resistivity values zones (ρ≥10 kΩ.m) suggest the presence of massive rocks.
- The central part shows a complex distribution and a wide range of resistivity values. Low resistivity values zones (ρ≤300 Ω.m) suggest intense hydrothermal alteration.

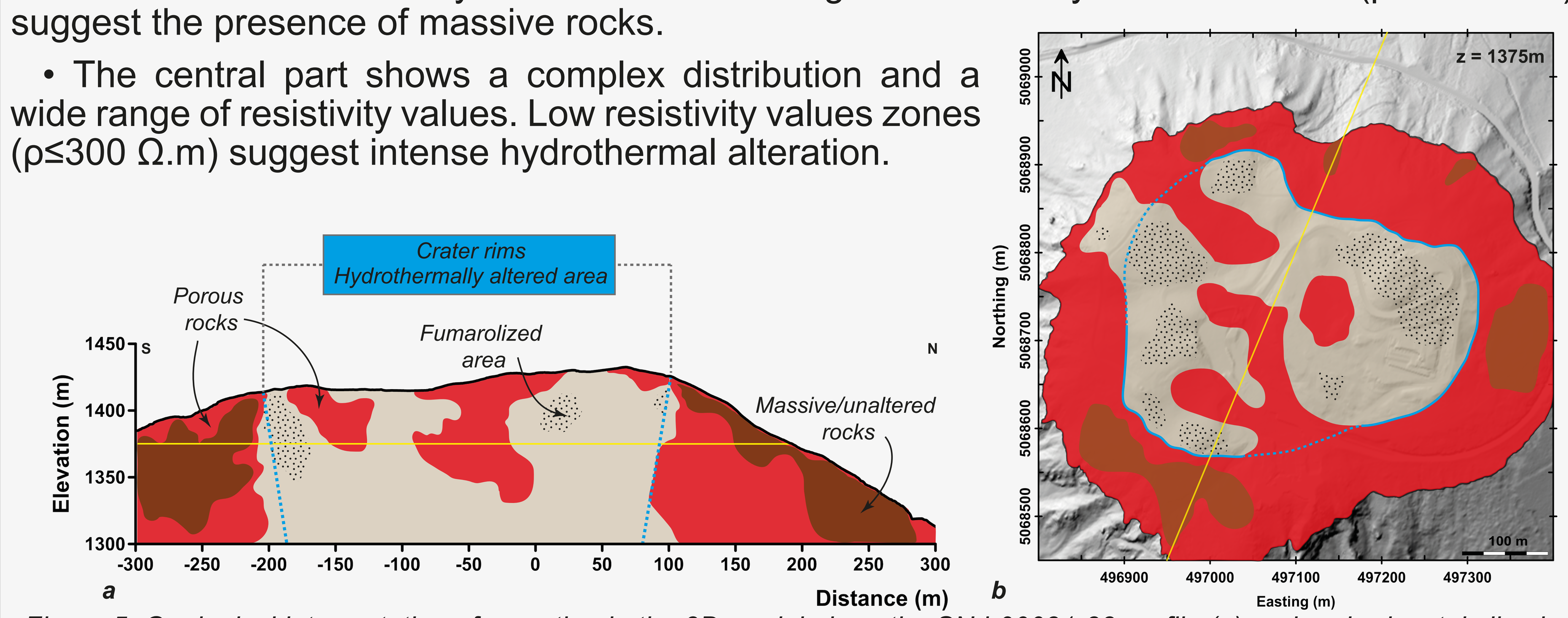


Figure 5: Geological interpretation of a section in the 3D model along the SN lr00031-33 profile (a) and an horizontal slice in the model at 1375 m in elevation (b). Yellow lines represent the location of the horizontal slice on (a) and of the section on (b).

- **The central part, the vent or the crater area of the dome, appears to be filled with massive blocks, breccias and pyroclastites (as it can be observed on active composite domes). Low resistivity zones, inferred to be the most hydrothermally altered parts, are more developed near the borders of the crater area.**

6 - Conclusion

- This study demonstrates that, thanks to sufficient data coverage, the 3D models obtained using CoLibRI software provide more information both at depth and in the periphery of the studied zone than the 2D models obtained with RES2DINV software.
- The 3D models thus allow us to clearly identify the heterogeneous filling of the crater area and the more homogeneous upper flanks of the dome.

References

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