Imaging deep resistivity in 3D in coastal areas and volcanic islands: Toward a multi-method and multi-scale approach combining land and shallow water passive and active EM

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SUMMARY

3D resistivity imaging with Electromagnetic (EM) methods is commonly used in volcanic context. It is particularly useful to characterize geothermal reservoirs, thanks to the sensitivity of resistivity of the variation of types and levels of alteration (mapping clay cap to delineate reservoir). However, application of EM exploration techniques on coastal areas of volcanic islands can be challenging due to the high level of anthropogenic noise, proximity to the sea/land interface, strong variations in topography and near-shore bathymetry, and near-surface heterogeneities.

Magnetotellurics (MT) is the historical method and the only one capable of sounding at very large depths (>3km). But anthropogenic noise related to urbanization often limits its performances and therefore often restricts its use to quiet areas and coarse mesh surveys. Controlled Source EM in land, with the use of powerful active current source and lighter recording systems is an interesting alternative to overcome anthropogenic noise and increase data coverage and resolution close to populated or industrialized zones, but is more limited in depth (0-2km). Finally, Airborne EM shows limited investigated depth (0-300m) but can provide very dense coverage in the near surface poorly sampled by CSEM and MT.

Furthermore, all those methods are now quite common in land, but their use along the coast and in particular in shallow water is not obvious and almost never considered, whereas there is no reason for coastal geothermal reservoirs to be limited by the coastline. The two main reasons are: (1) costs and availability of deployment of adapted coastal /shallow water equipment (2) difficulty of modeling and inversion processing of the EM data considering accurately the topography, bathymetry and land/sea high resistivity contrast.

We try to summarize here the progress made in recent years to try to overcome those limitations and provide deep resistivity models of geothermal reservoirs bellow coastal areas on volcanic islands, based on the feedback from various coastal MT and CSEM surveys. We discuss the improvement provided by:

1) adapted instrumentation for shallow water MT
2) adapted instrumentation and protocols for land/shallow water CSEM
3) optimized processing of marine MT
4) 3D accurate modeling including topography/bathymetry and coastline
5) Marine shallow electrical resistivity mapping
6) 3D inversion of multi-method multi-scale workflow of MT/CSEM and including shallow resistivity

We illustrate the potential of this multi-scale multi-method approach with a large campaign conducted over the operated Bouillante geothermal field in Guadeloupe in the French Lesser Antilles, where a joint land/marine CSEM/MT + AEM + marine streamer was conducted in 2021-2022.

Keywords: Coastal EM, Volcanic islands, geothermal exploration, MT, CSEM, AEM, multi-method, multi-scale, joint 3D inversion