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Abstract

In order to investigate aquifers, several geophysical surveys have been carried out in the Baril area of the southern flank of Piton de la Fournaise volcano on Reunion in the Indian Ocean using audiomagnetotelluric (AMT), very-low-frequency (VLF) and self-potential (SP) methods. We present the results with emphasis on a comparison between SP data and the findings of geoelectric surveys. AMT soundings have indicated, from the surface downward, three layers: (i) resistive volcanic rocks, (ii) an intermediate resistivity layer, and (iii) a conductive basement attributed to a seawater-bearing aquifer. VLF measurements allow the mapping of the first layer apparent resistivity, and therefore its bottom, when the true resistivity is supposed to be isotropic and homogenous. When this assumption does not hold, only the SP method permits the mapping of this bottom. Because of the good agreement between the SP and electromagnetic results, we propose the SP method as the first tool that should be used in studying shallow hydrogeological structures in volcanic areas. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Hydrogeology; Self-potential method; Electromagnetic method; Piton de la Fournaise

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1. Introduction

The Baril area is located on the southern part of the Piton de la Fournaise volcano on the southeast of Reunion (Fig. 1). In order to study the hydrogeological structures and to detect the preferential groundwater circulations, several geophysical surveys have been carried out in this area. Like most parts of La Fournaise shield volcano, the Baril area is made up of piles of long and narrow basaltic lava flows. In general, these rocks are permeable. When they are present, impermeable layers correspond to thin tuffaceous paleosoils or to ancient valleys filled with detritals (alluvium, lahar deposits) (Coudray et al., 1990).

Two hydrogeological areas are usually distinguished on Reunion Island (Join and Coudray,

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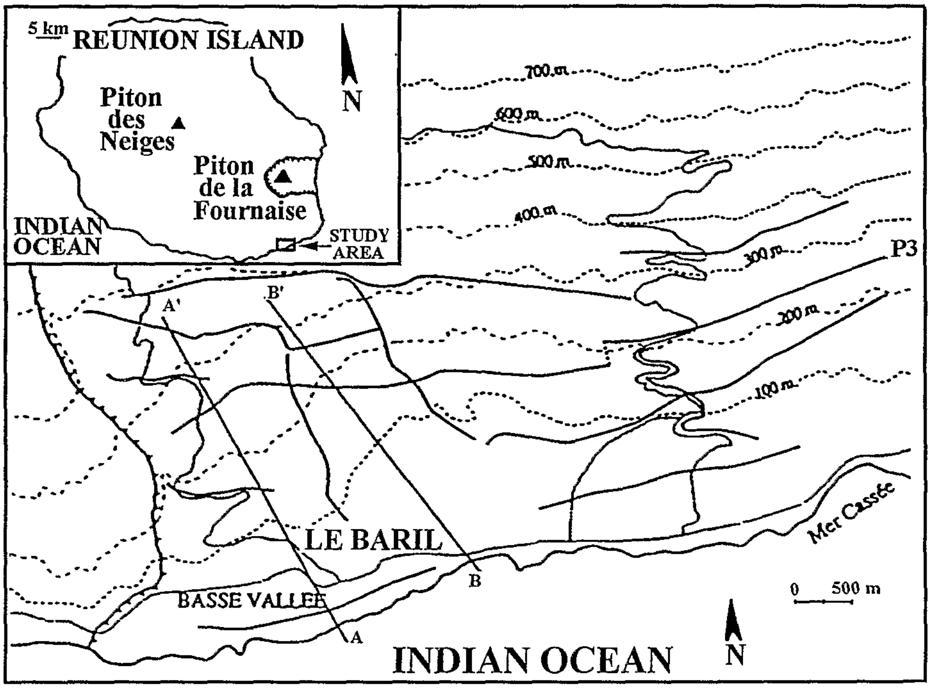

Fig. 1. The Baril area is located on the southern flank of Piton de la Fournaise (inset map). Locations of profiles AA' and BB', discussed in the text, are shown as well as VLF traverses (bold lines). Elevation contours (thin dashed lines) are in meters.

1993): a coastal area characterized by the occurrence of a basal aquifer in direct contact with seawater, and a high elevation inland area characterized particularly by perched sources supported by poorly permeable layers (Coudray et al., 1990).

This permeable context differs much from that of the Chaîne des Puys area where the SP method has been successfully applied to hydrogeological surveys (Aubert and Atangana, 1996). In Chaîne des Puys, groundwater flows at the bottom of permeable volcanic formations which lie on a granitic substratum.

The pattern of SP anomalies is more complex in the Baril area than in Chaîne des Puys. Consequently, interpretation of SP anomalies in terms of hydrogeological structures is less straightforward. Additional constraints were sought using electromagnetic surveys, audiomagnetotelluric (AMT) and very-low-frequency (VLF), carried out by Ritz et al. (1993).

In this approach, electromagnetic soundings are used to define geoelectrical sections in key areas whereas SP data are used to map the thickness variations of the unsaturated (i.e., resistive) medium overlying the saturated (i.e., conductive) medium.

One of the main objectives of this work is thus to carry out a joint interpretation of SP and electromagnetic data and to define the criteria of an optimized approach to the study of hydrogeological systems in the case of a young basaltic shield volcano.

2. Previous studies

2.1. SP results

A linear relation between SP anomalies and the thickness of the unsaturated zone has been observed on the volcano Adagsdar (Corwin and

Hoover, 1979), the Kilauea volcano (Jackson and Kauahikaua, 1987) and in Chaîne des Puys (Aubert and Atangana, 1996). Aubert et al. (1990) had previously verified this relationship on the basis of boreholes and SP data collected in the general context of volcanic formations covering a granitic basement. They have generalized the use of this relationship by naming SPS the surface which can be calculated when the relationship factor is applied to an SP profile or map values. The SPS surface represents the top of the water table when it exists, and/or the top of the conductive impermeable substratum.

The linear relation is usually found using borehole data and can be expressed as:

$$V(x,y) = V_0 + KE(x,y) \tag{1}$$

$V(x, y)$ is the range (in volts) of SP negative anomaly. $E(x, y)$ represents the thickness (in meters) of the unsaturated zone. K and V_0 are two constants, defined in volts per meter and in volts, respectively.

In the case of a uniform resistivity of the unsaturated medium, the equipotential surface is inferred in accordance with the relation:

$$\mathrm{d}V = K\mathrm{d}E \tag{2}$$

The altitude above sea level H of the SPS surface is calculated from relation (1), according to the values of $V(x, y)$ and $h(x, y)$, the altitude at the station (x, y) by:

$$H(x,y) = h(x,y) - E(x,y);$$

$$H(x,y) = h(x,y) - \frac{V_0}{K} - \frac{V(x,y)}{K}.$$

We then deduce:

$$H(x,y) = h(x,y) - \frac{V(x,y)}{K} - E_0 \tag{3}$$

where

$$E_0 = -\frac{V_0}{K}$$

E_0 (in meters) is the thickness of the unsaturated medium below the reference station of the

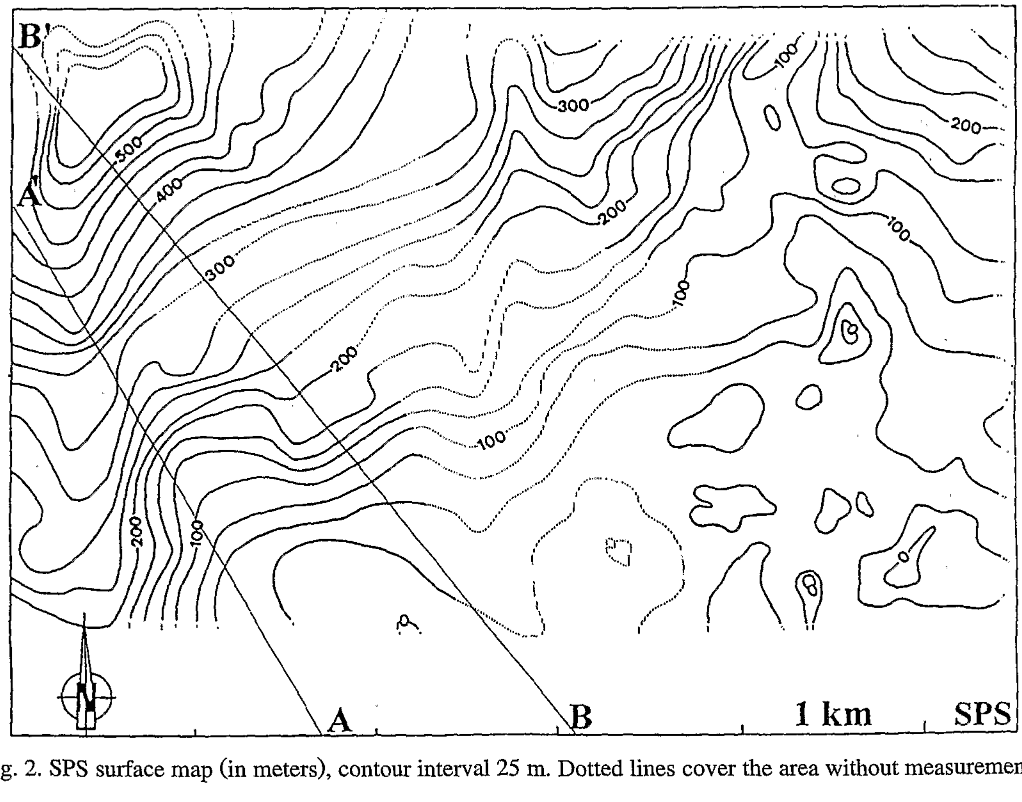

Fig. 2. SPS surface map (in meters), contour interval 25 m. Dotted lines cover the area without measurements.

SP values, where $V(x, y)$ is equal to zero by convention.

The SPS map (Fig. 2) resulting from the interpretation of smoothed SP data (running average) outlines (Aubert et al., 1993) (i) two thalwegs located to the East and to the West of the SPS map, and (ii) a mean 145°N general direction of slope which is not identical to the 180°N topographic slope of the area.

Drawn from this SPS map (Fig. 2), two SPS profiles AA′ and BB′, shown in Fig. 1, display the following characteristics: (i) the slope of the SPS surface on profile AA′ (Fig. 9) at 150 m elevation is about 2.5% and increases with altitude to attain 20% at the altitude of 400 m elevation; (ii) a sharp change of slope of the SPS surface is observed at 150 m elevation on profile AA′; (iii) the SPS profile BB′ (Fig. 11) shows a similar direction as on profile AA′, but without a break in the slope.

2.2. AMT results

Data interpretation of 35 AMT soundings distributed over the whole of the Baril area has allowed a precise geoelectrical subsurface picture to be obtained with sections consisting of two or three layers. The same profiles AA′ and BB′ already shown for the SP study (i.e., Fig. 1) illustrate the electrical structure of the Baril area (Figs. 3 and 4) and display (i) a coastal zone, characterized by a resistive top layer covering a very conductive layer and (ii) a second inland zone where an intermediate resistive layer appears beneath the top resistive layer. Its thickness is variable and increases inland.

Inferred models of thickness and resistivity displayed on maps by Courteaud et al. (1996), show precise lineaments and particular morphologies. For example, Fig. 5 is the altitude map of the top of the conductive substratum

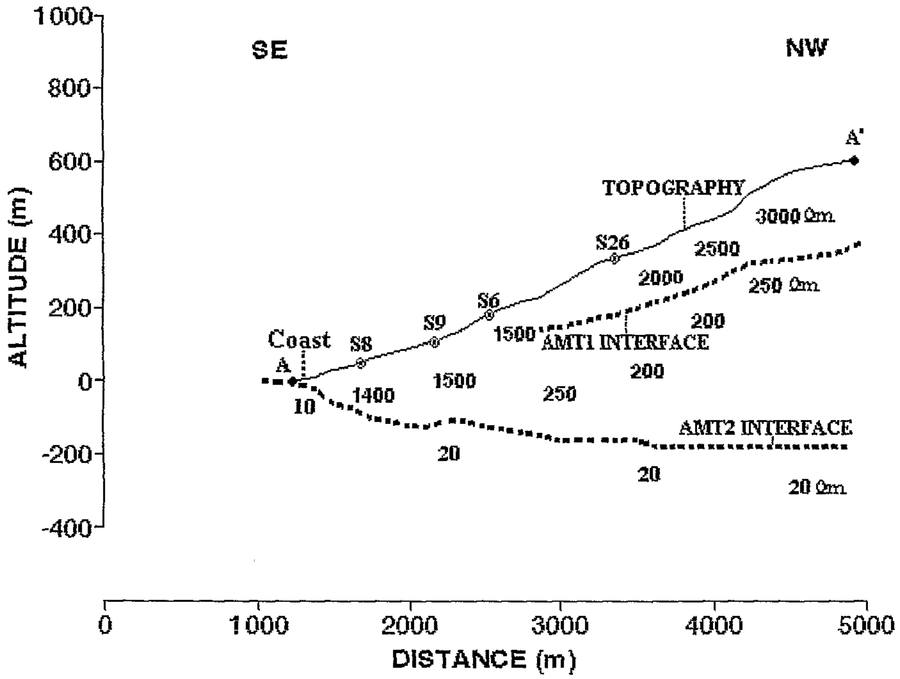

Fig. 3. Composite geoelectrical cross section obtained from AMT modelling. Profile AA′ is located on Fig. 1. Numbers are interpreted resistivities in ohm-meters. The letter S represents the AMT soundings.

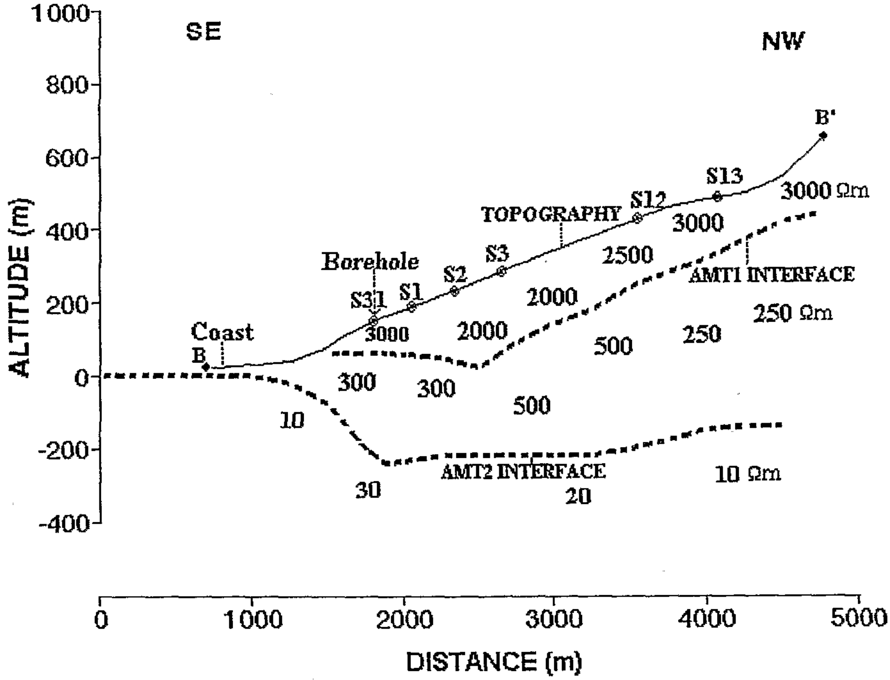

Fig. 4. Geoelectrical cross section obtained from AMT modelling. Profile BB′ is located in Fig. 1. Numbers are interpreted resistivities in ohm-meters. The letter S represents the AMT soundings.

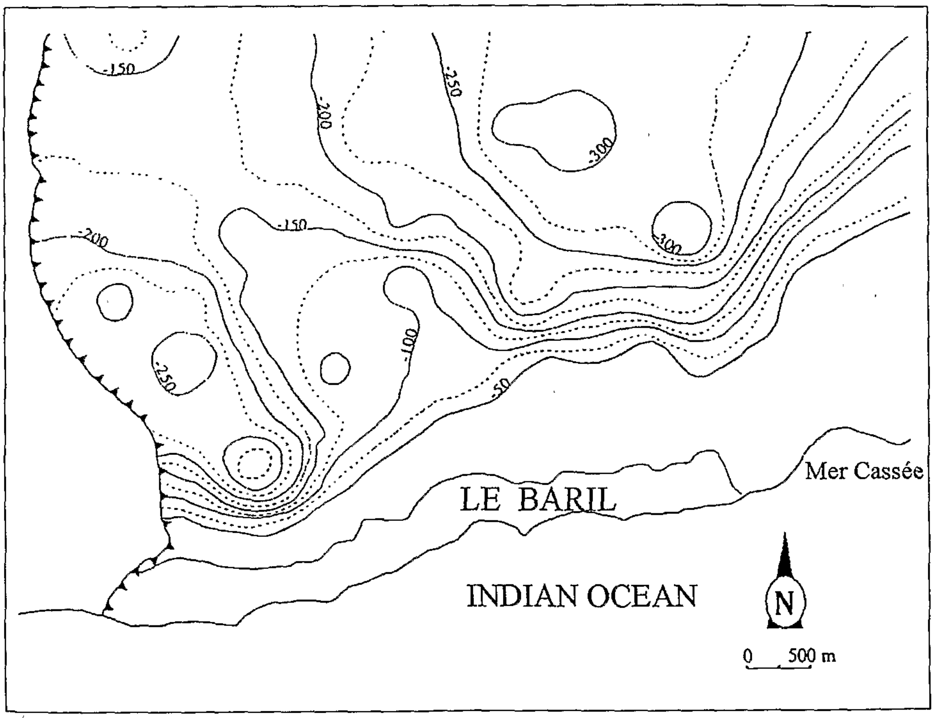

Fig. 5. Map of the top of the conductive substratum (in meters) as inferred from audiomagnetotelluric data (see text) (from Courteaud et al., 1996). Dotted lines are elevation contours.

obtained from all AMT models. This substratum is always below sea level and deepens inland. It can be interpreted as the top of the saltwater wedge (Courteaud et al., 1996).

The identified structures are a priori deeper than those given by the SP and VLF (discussed latter) results, but the evidence of 140°N morphological lineaments can be noted and compared to the general direction of the SPS surface. Another lineament in the 280°N direction also appears from contour line -50 m (Fig. 5) and corresponds to the general deepening of the conductor inland. This lineament is interpreted as a typical paleo-volcanic discontinuity corresponding to a littoral paleo-cliff covered by recent volcanic lava (Courteaud et al., 1996).

3. New VLF study

Whereas the AMT method uses the variation of natural electromagnetic fields, VLF uses signals from a remote radio transmitter in the 10–30 kHz wave-range. The electromagnetic fields created by these transmitters allow the study of the subsurface but limited to a region of some kilometres around the transmitter antenna. In the particular case of the VLF-R method (Fisher et al., 1983), the transfer function Z_{xy} (amplitude and phase) linking electrical field E_x to magnetic field H_y is measured. Assuming plane waves condition, the MT equations are used for estimating apparent resistivity and skin depth.

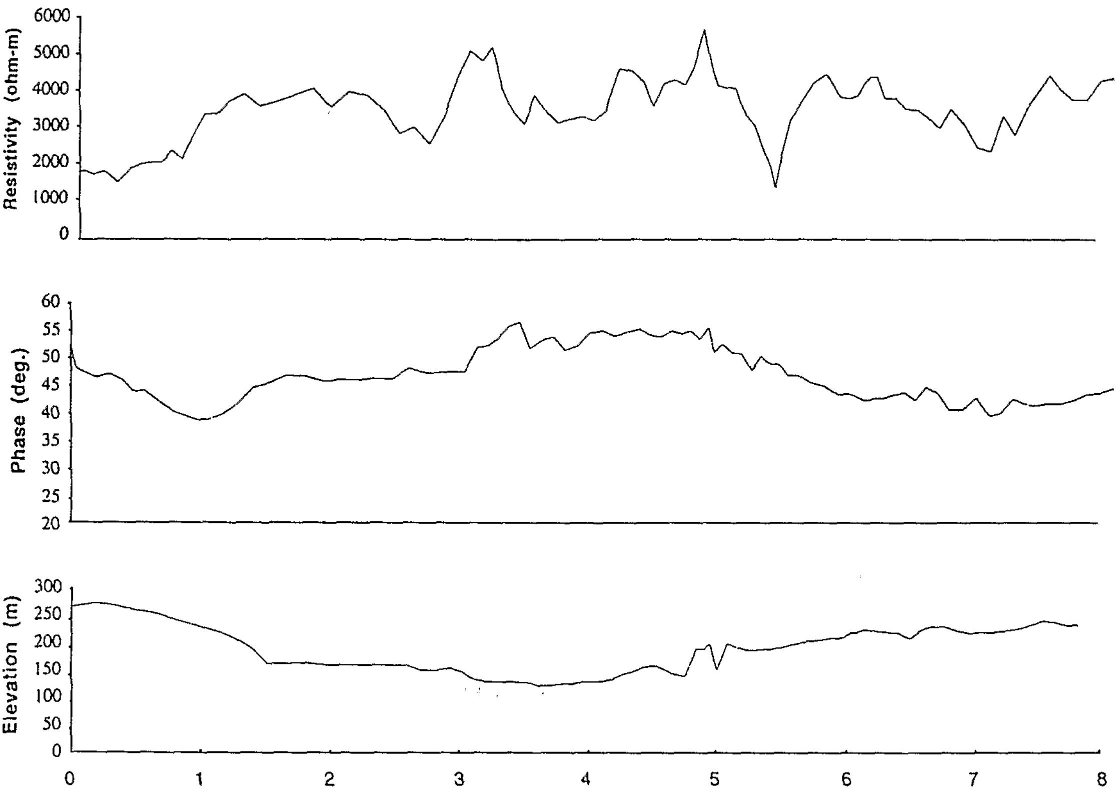

Fig. 6. Example of VLF data for the profile P3 (located on Fig. 1). Measured apparent resistivities (top panel), phases (middle panel) are plotted along profile P3 vs. distance westward in kilometers. The topographic section is also shown (lowest panel).

The distance between the transmitter used (Omega antenna with a frequency of 12.3 kHz) and our study area is about 65 km, i.e., not far from one wavelength (24.4 km). However, the maximum resistivity of volcanic formations in the Baril area is approximately more than 6000 Ω m, which corresponds to a skin depth of 350 m. This value remains small as compared to 24.4 km and the plane wave approximation seems to be valid for our purposes.

Considering a two-layer medium, the apparent resistivity and the phase shift measurements allow the determination of only two inversion parameters. Qualitatively, a phase greater than 45° indicates the presence of a conductive layer beneath a resistive layer, while a phase lower than 45° corresponds to a reverse layering of resistivities.

Using a T-VLF from Iris instruments (Bernard and Valla, 1991), measurements were made at 12.3 kHz with an interval of 20 m between stations. Numerous VLF traverses were made between 0 and 300 m elevation (Fig. 1) and, in general, the quality of measurements was good. For some of the successive stations, apparent resistivities vary from 1000 Ω m to more than 4000 Ω m (Figs. 6 and 7); however, the phase is generally less variable and greater than 45°. On the measured apparent resistivity profiles, variations of short wavelength are frequent, but they cannot be correlated to any observed outcropping formations, that are characterized by a uniform lava flow cover. The numerous gullies present over the area, of a few meters width and depth, do not correlate with the resistive anomalies. Similarly, those anomalies are independent of local topographic effects. Since the VLF method is known for its sensitivity to the presence of near-surface structures, it is highly probable that short wavelength anomalies are related to superficial subtle heterogeneities.

The VLF method is nevertheless particularly interesting in the case of the Baril area because of the presence of highly resistive formations

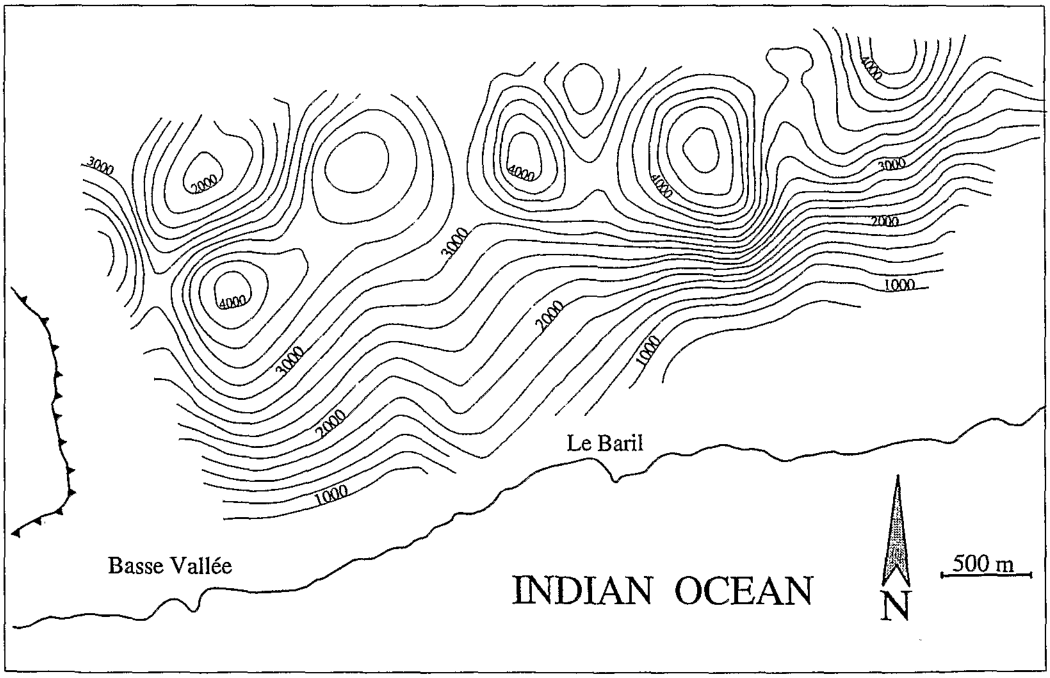

Fig. 7. Apparent resistivity map (in ohm-meters) inferred from VLF measurements.

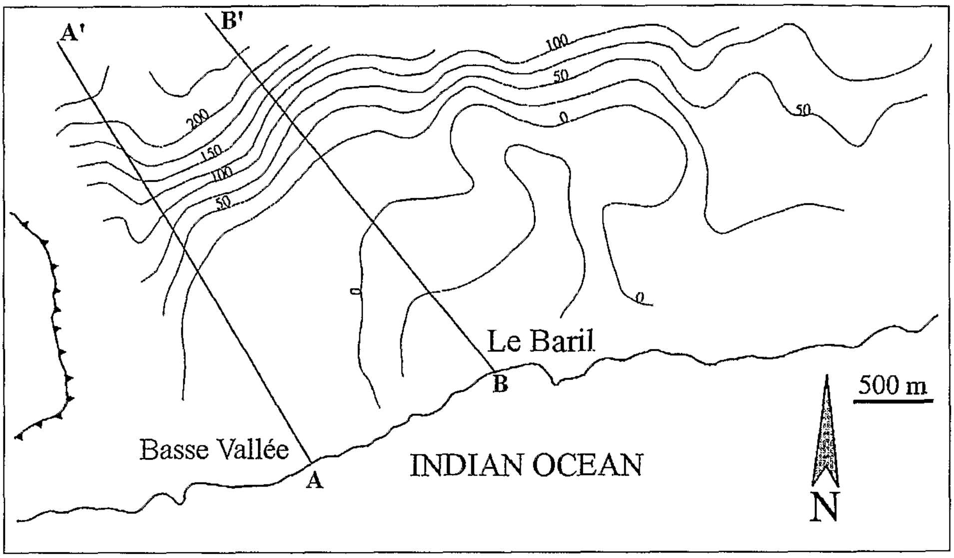

Fig. 8. Elevation map of the bottom of the first resistive layer derived from VLF measurements (Fig. 7). Contour interval is 25 m.

($>$ 1000 Ω m). It could allow the detection of the underlying conductor morphology and structures of the underlying environment. The phase and the resistivity maps were drawn using the smoothed VLF data (running average method). Fig. 7 shows the map of apparent resistivity that was smoothed once more in order to attenuate the anomalies caused by superficial heterogeneity. Fig. 8 indicates the bottom of the first resistivity layer from an interpretation described latter. From these two figures, the main feature is the increase of the apparent resistivity (from 1000 Ω m to 4000 Ω m) from the coast toward land. This increase of resistivity with altitude is less obvious for the upper parts of the study area where the zonation is different.

The morphological 140°N and 60°N morphological lineaments are less marked than on the AMT (Fig. 5) and SPS (Fig. 2) maps, but are nevertheless present and respectively correspond respectively to (i) a rough distribution of the isoresistivity curves according to an approximate 140°N direction, and (ii) an approximate boundary from which the resistivity values no larger change with altitude.

In short, the SP, AMT and VLF results appear to show obvious qualitative similarities.

4. Discussion

The geological and hydrogeological complexity of such a volcanic area and the lack of sufficient drillhole coverage complicate the interpretation of SP and VLF data. As a result, attempts to deal with any hydrogeological or geological interpretation from SP or VLF results could lead to different and erroneous conclusions when they are done separately. On the contrary, because of the evidence of qualitative similarities between the diverse geophysical maps, common hydrogeological explanations are expected.

The objective of this section is to make a simple comparative analysis of the different results of each method. We choose to compare the SPS surface to a geoelectrical interface derived from VLF measurements, both of them being subsequently compared to the AMT geoelectrical layering of the study area.

4.1. Preliminary geophysical conditions

Before we present the interpretative and comparative study, the basic starting conditions of each method must be considered.

First, the existence of an SPS surface is dependent on two preliminary conditions: (1) a high ratio of resistivity between the unsaturated zone and the second saturated (or impermeable) medium (Aubert and Atangana, 1996), (2) a permeability of porosity favourable to the generation of SP signals. It should be noted that (i) the SP method has been previously successfully applied for ratio values of about 10 (Aubert and Atangana, 1996), and (ii) in our study area, the ratio between the resistivity of two consecutive layers given by AMT models is within the same range (Figs. 3 and 4). The calculation of the SPS interface is based only on the distribution mode of equipotentials in the unsaturated zone. In the case of a high ratio of resistivity, the interface between two media is an equipotential surface.

Considering the VLF method, a high resistivity ratio corresponds to a phase greater than 45°. In this case of resistivity decreasing with depth, a second underlying more conductive layer may be expected in the VLF data; this is taken to be the SPS equipotential surface. We have therefore considered VLF measurements corresponding to phases greater than or equal to $45 \pm 3°$, (the permitted error on phases is approximately 3°).

4.2. Interface deduced from VLF data

The lack of borehole data does not allow constraining the interpretation of VLF anomalies; consequently, it will be essentially qualitative.

Calculation of the interface altitude between the first resistive medium and the more conductive second medium has been done using VLF measurements and a theoretical two-layer geoelectrical model.

We supposed that the resistivity and the maximum thickness of the first layer are known (ρ_1, $e_{1\max}$). The model used to aid the interpretation consists in a single layer of resistivity ρ_1 and thickness $e_{1\max}$ overlying an infinite half space of resistivity ρ_2. The resistivity ρ_1 is considered constant (no lateral variation), whereas the thickness varies. The choice for ρ_1 is given by AMT models (resistivity value representative of usually dry basaltic lava in La Fournaise volcano). The resistivity value of the second medium is chosen to provide a ρ_1/ρ_2 ratio greater than 5.

Among all the different models which have been tested, the best results, i.e., the model that gives results close to the SP results, have been obtained using: $\rho_1 = 6000\ \Omega$ m, $e_{1\max} = 200$ m and $\rho_2 = 600\ \Omega$ m. This values were used for the interpretation of VLF data.

From VLF data, the calculation of the thickness of the first medium was done with the model described above and using the Cagniard (1953) formula:

$$E\,(\text{km}) = \frac{\sqrt{T}}{8}\sqrt{10\rho_1}$$

where E is the thickness defined in kilometres, T the period of sinusoidal waves in seconds and ρ_1 the resistivity of the first medium in ohm meters.

The altitudes of the bottom of the first medium calculated from VLF data are presented as a contour map in Fig. 8.

4.3. Comparison between SP, AMT and VLF data

Comparison of the SPS maps (Fig. 2) and the interfaces deduced from VLF data (Fig. 8) reveals some obvious analogies. In order to highlight the similarities, we present sections drawn from the SPS surface and the VLF and AMT interfaces, for the two profiles located in Fig. 1. Considering these sections which are presented in Figs. 9–12, it appears that the different interfaces are nearly identical. More precisely, on profile AA', SPS and AMT curves (Fig. 9) have

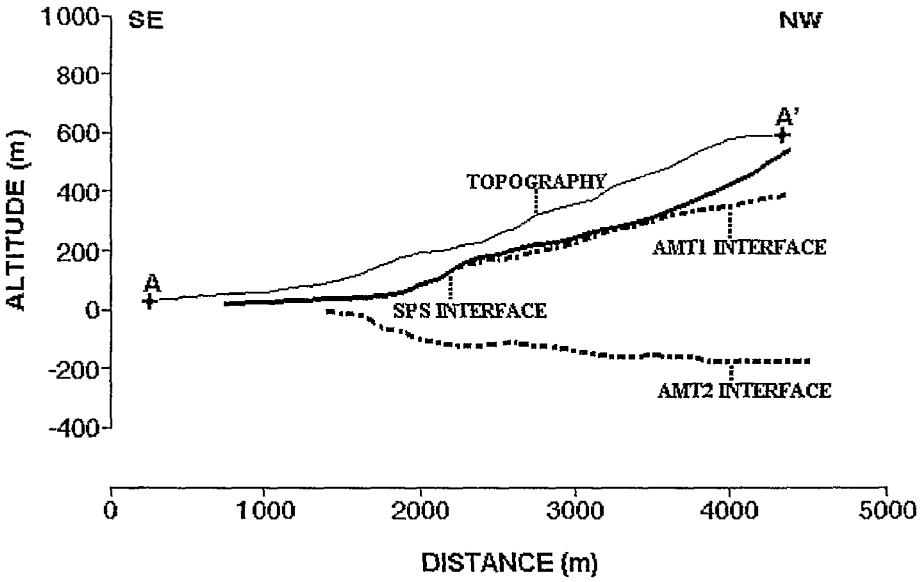

Fig. 9. SPS, AMT and corresponding topographic sections along profile AA' located in Fig. 1.

a similar shape from 160 to 320 m elevation, although the SPS surface is shallower than the AMT interface at altitudes higher than 320 m. The sharp break in the slope of the SPS surface along a 60°N trend (Fig. 2) matches with the steep transition from low to high resistivities (Fig. 3), and fits with the first layer thickening along the first layer of the AMT sections (Fig. 9). Furthermore, it can be seen, on Fig. 10, from 0 to 200 m elevation, that the SPS curve has the same trend as the VLF interface, but at slightly lower depths.

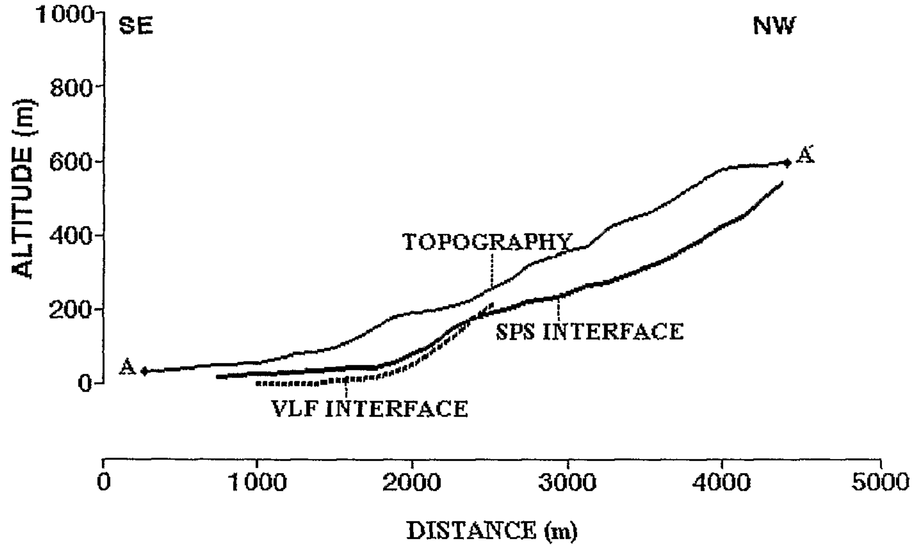

Fig. 10. SPS, VLF and corresponding topographic sections along profile AA' located in Fig. 1.

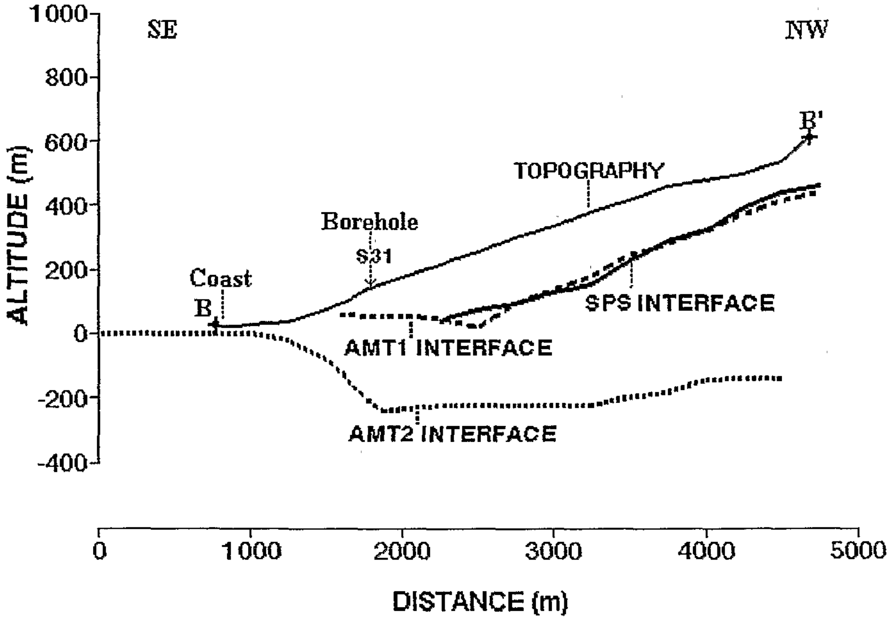

Fig. 11. SPS, AMT and corresponding topographic sections along profile BB′ located in Fig. 1.

Along profile BB′, from 320 to 640 m elevation (Fig. 11), the SPS surface and the AMT interface are qualitatively similar, although a perceptible divergence occurs around 2500 m on the horizontal distance axis.

In Fig. 12, SPS and VLF curves show a convincing superposition characterised by a similar seaward sloping.

This comparison sometimes shows a lower depth for the SPS surface compared to those of

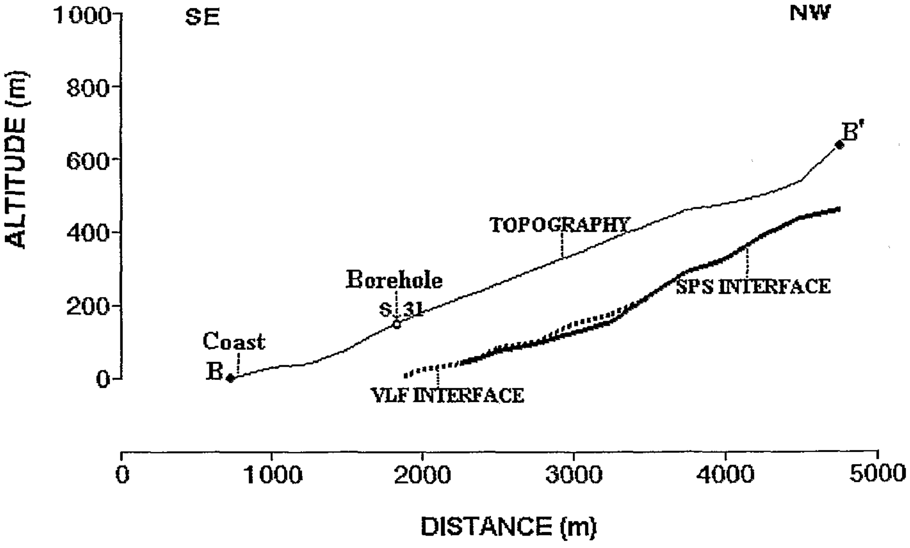

Fig. 12. SPS, VLF and corresponding topographic sections along profile BB′ located in Fig. 1.

the AMT first layer and VLF interface, especially for the upstream part of the study area (Fig. 9), and could be explained by the presence of a superficial thin conductive layer limiting the SP investigation depth. Such a thin conductive layer could probably correspond to argillaceous paleosoils or ash layers, which usually bear typical perched aquifers of the Piton de la Fournaise.

The mean slope of the first geophysical interface (15%) is greater than the basal aquifer slope calculated near the coast (0.3%) (Violette et al., 1997) but similar to the geological layer slope (10%). Aubert et al. supposed in a previous assumption (Aubert et al., 1993) that the SPS surface may be the piezometric surface of a perched aquifer. This is presently supported by a new hydrologic modeling of the Piton de la Fournaise (Violette et al., 1997). In this modeling, the lava flows dipping from the crater toward the ocean creating a succession of 'tiles' over which the water flows down to the basal aquifer as if over a tiled roof. This roof may be the first geophysical interface.

5. Conclusion

A comparison of SP, AMT and VLF data in the Baril area shows an obvious general convergence. These results constitute a important contribution in the understanding of the hydrogeological structures underlying the study area. The 60°N lineament identified by AMT measurement method is also shown by the interfaces defined from the VLF and SP data, as a sharp change in slope at 150 m elevation. This discontinuity is emphasized on the surface by a topographic step, and may correspond to a littoral paleo-cliff, a structure that is typical of the coastal volcanic morphologies of Piton de la Fournaise. The mean 145°N general slope of the SPS interface, which is not comparable to the 180°N topographic slope, is however similar to the direction of deepening of the AMT conductive basement (Fig. 5). This could be a consequence of a hitherto undescribed tectonic phenomenon.

Both the SP and VLF methods are thus found to be applicable for the delineation of shallow structures that determine the hydrogeological behaviour of this volcanic area. The simplicity and the portability of these methods (especially the SP method) permit high-density measurements and a wide area coverage. Such methods are particularly useful in the areas such as Reunion where access is difficult. The most interesting finding of our study is the identification of the geophysical surface SPS as the bottom of the first resistive medium. Depth investigation using the SP method will be limited by a surficial conductive layer, whatever the thickness of this layer may be. In this case, only the AMT method is capable of providing information on the layers beneath the conductive layer. Nevertheless, our results highlight the value of using the SPS surface as part of a hydrogeological study of young volcanic areas, because: (i) the morphology of the SPS surface reflects shallow structures that control groundwater circulations, and (ii) the SPS surface could be well-suited to locating areas of perched aquifers that are typically underlain by a thin conductor.

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References

Aubert, M., Antraygues, P., Soler, E., 1993. Interprétation des mesures de polarisation spontanée en hydrogéologie des terrains volcaniques. Hypothèse sur l'existence d'écoulement préférentiels sur le flanc sud du Piton de la Fournaise (île de la Réunion). Bull. Soc. Géol. France 164 (1), 17–25.

Aubert, M., Atangana, Q.Yéné, 1996. Self-potential method in hydrogeological exploration of volcanic areas. Ground Water 34 (6).

Aubert, M., Dana, I.N., Livet, M., 1990. Vérification de limites de nappes aquifères en terrain volcanique par la méthode de polarisation spontanée. C.R. Acad. Sci. Paris 311 (II), 999–1004.

Bernard, J., Valla, P., 1991. Groundwater exploration in fissured media with electrical and VLF methods. Geoexploration 27, 81–91.

Cagniard, L., 1953. Basic theory of the magnetotelluric method of geophysical prospecting. Geophysics 18, 605–635.

Corwin, R.F., Hoover, D.B., 1979. The self-potential method in geothermal exploration. Geophysics 44 (2), 226–245.

Coudray, J., Mairine, P., Nicolini, E., Clerc, J.M., 1990. Approche hydrogéologique. In: Lénat, J.F. (Ed.), Le volcanisme de l'île de la Réunion—Monographie—Publication du centre de recherches volcanologiques de Clermont-Ferrand, pp. 307–355.

Courteaud, M., Ritz, M., Descloitres, M., Robineau, B., Coudray, J., 1996. Cartographie AMT du biseau salé dans une zone littorale du Piton de la Fournaise, Ile de la Réunion. C.R. Acad. Sci. Paris 322 (II a), 93–100.

Fisher, G., Le Quang, B.V., Muller, I., 1983. VLF ground surveys, a powerful tool for the study of shallow two dimensional structures. Geophys. Prospect. 31 (6), 977–991.

Jackson, D.B., Kauahikaua, J., 1987. Regional SP anomalies at Kilauea. Volcanism in Hawaii. U.S. Geol. Surv. Prof. Paper 1350 (40), 947–959.

Join, J.L., Coudray, J., 1993. Caractérisation géostructurale des émergences et typologie des nappes d'altitude en milieu volcanique insulaire (île de la Réunion). Geodynamica Acta 6 (4), 243–254.

Ritz, M., Descloitres, M., Robineau, B., Courteaud, M., 1993. Etude géophysique VLF et AMT du secteur pilote du Baril. Rapport Université de la Réunion ORSTOM, 51 pp.

Violette, S., Ledoux, E., Goblet, P., Carbonnel, J.P., 1997. Hydrologic and therthermal modeling of an active volcano: the Piton de la Fournaise, Reunion. J. Hydrology 191, 37–63.

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