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Interactive comment on "Hydrogeological conceptual model of andesitic watersheds revealed by high-resolution geophysics" *by* Benoit Vittecoq et al.

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We firstly want to thanks Patrick Lachassagne for his interest for our work and the ensuing extended short comments. Remarks and comments will help to improve the manuscript in the next step of the review process, following the recommendation of the handling editor.

The main objectives have been clearly identified and summarized by P. Lachassagne: (i) Improving knowledge of the hydrogeological functioning of an andesitic-type volcanism in a subduction zone (this kind of context being much less studied and documented) (ii) with helicopter-borne geophysics (which is clearly not so common in vol-

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canic context), (iii) bringing new correlations between age, transmissivity, permeability and resistivity and (iv) proposing a conceptual model and hypothesis about hydrogeological specificities of andesitic watersheds.

We below respond to the main topics, which include general, minor and additional comments.

Concerning geological and geophysical remarks, as pointed by P. Lachassagne, the existing geological map is of high quality and high resolution, notably in this area of the island. That is the reason why we choose those watersheds in order to test how helicopter-borne geophysics can develop hydrogeological models of andesitic watersheds. Considering aims, scope and readership of HESS journal, and the multidisciplinary angle of our paper, the challenge was to synthesize the essential data of each discipline (geology, geophysics, hydrogeology), necessary to support our results and then our hypotheses and discussion. Our results show the advantage of electromagnetic data to highlight the thicknesses, lateral extension and morphology of the different geological formations. Correlations with geological map and geological log from boreholes allow showing the interest of electromagnetic data and how this kind of survey can be used in areas where there is no geological map in order to better understand hydrogeological functioning.

As explain in chapter 3.1, the geophysical survey was conducted along the N-S direction with a resolution of an EM sounding every 30 m along flight lines, and with a 400 m line spacing (ie. One flight-line every 400 m in the E-O direction). As reminded by P. Lachassagne, and as explained in the introduction section and in paragraph 5.2, andesitic formation are classically marked by a high lateral and vertical geological variability whether within each formation or between successive formations. Consequently, our approach focus on interpreting geophysical data along the flight lines (rather than in the interpolated 3D block) precisely because of the limited lateral extension of permeable/impermeable facies within each formation. In most case, there is a good consistency between geophysical cross sections and the geological map. However, this consistency can only be demonstrated after conducting a work as the one presented here, as geophysical data interpretation is an iterative process depending on calibration data. Comparison with the few geophysical ERT available have also been done but, (1) as they only concern a small part of the Fond Lahaye valley, and (2) as they are not enough closed to flight lines, their interest with respect to our working scale and the objective of the paper is limited. Correlations between the two geophysical methods is interesting for borehole sitting but it is not the scope of our paper and of HESS journal.

On the contrary to what is hinted in the short comment, we clearly do not consider existing hydrogeological conceptual models of basaltic islands, cited and described in the introduction of our manuscript (lines 9 to 13, 19 and 20 and 28-29), as "old low resolution conceptual models" by P. Lachassagne. Each cited study contributes to the building of general knowledge, according to the methodologies used (geological and hydrogeological survey, numerical modelling, geophysics, hydrochemistry, etc.) and one challenge is the necessity to better constrain the internal structure of the volcanic edifices. Lachassagne et al., 2014 present what he called the nowadays needed and high-resolution model for complex volcanic islands, considering that groundwater mainly flows through few high hydraulic conductivity and low extension formations as a succession of perched aquifer. For instance Ecker, 1976 already expose that, in basaltic islands, groundwater flows were constrained between permeable and impermeable zones, these compartment being irregular in volume, shape and structure (resulting from many factors: initial relief, erosional phases between eruptions, morphology of lava flows, weathering, erosion, fracturing, tectonic movements, etc.) forming a kind of tortuous aquifer. Indeed, it is well known that volcanic formations exhibit, by definition (e.g. Ingebritsen et al., 2006), extreme spatial variability or heterogeneity, both among geologic units and within particular units, with large variation from core scale to regional scale, permeability being, especially in volcanic environment, a scale-dependent property.

Concerning the water balance remarks, In our approach, water balance are voluntarily presented at the beginning of the paper, in the chapter on general knowledge, as we synthesize existing data from different organizations (Meteorological agency, water office, ecological Ministry. . .) and existing results from rainfall/flow modelization. This will be better introduced and clarified in the introduction of this chapter. Details and references will be added regarding the methodology used to calculate the different hydrological terms of the water budget (Vittecoq et al., 2007, Vittecoq et al., 2010, Arnaud et Lanini, 2014, Stollsteiner et Taïlamé, 2017, data from Meteorological agency and the Ministry of ecology, etc.), in addition to uncertainties of the main measurements.

In terms of perspectives concerning water balance calculation, the national meteorological agency is working on the calibration of their new meteorological radar in order to provide better rainfall data for future research programs (allowing in the future detailed water balance calculation at a smaller scale, spatially and temporally). In parallel, the Ministry of Ecology is installing gauging stations and the water office tried to convince the operators to equip the water supply dams with volumetric meters.

Concerning the specific case of the Attila spring, it is hazardous to suggest that it could have a significant impact on the functioning of the studied watershed. “Pitons du Carbet” domes are a set of andesitic and dacitic domes covering an area of 20 km^2 which have intruded between 0.9 and 0.3 Ma (Germa et al., 2011). This ensemble is the highest point of the central part of the island, with five main domes exceeding 1000 m and smaller peripheral domes. Given their topographical position, a dozen of hydrological watershed originate within this ensemble. The topographic catchment of the upper Mitan river (Where Attila spring is situated downstream) is therefore not contiguous with the watersheds we studied, as they are separated by three watersheds. As exposed by Lachassagne, 2003, both the flowrate of the spring and the recharge upstream were very badly constrained and the spring flowrate used by Lachassagne, 2003 is an estimation. Using the same calculation methodology that Lachassagne (2003), we recalculate the water balance of this watershed using new recharge modelization (Arnaud et al., 2013), infiltration/runoff ratio provided by Vittecoq et al., 2007

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and Stollsteiner et Taïlamé, 2017, and the monitoring of water volume from the spring (Average value 6 l/s – max 10 l/s, but considering that the outflow is not monitored, 30% should be added). The conclusion is that the flowrate of this spring can largely be explained by the effective rainfall in the hydrologic watershed, in agreement with the geological structure of a dome, and confirm that this spring is not a regional outflow.

Concerning the correlation between transmissivity and age remarks, Fig 8B present both transmissivity and hydraulic conductivity values. As aquifer thickness are equivalent from one borehole to another, transmissivity and hydraulic conductivity show the same trend. Indeed, in this kind of fissured/fractured aquifer, water mainly flows into fractures, but, at the watershed scale, macroscopic hydrodynamic parameters values are of major interest than microscopic water velocity measurements at the fissure scale. In addition, resistivity data from the smooth inversion is obtained at macroscopic scale (one resistivity data for each of the 23 layers from 0 to 200 m depth).

Our results and correlation, (1) the older the formation, the lower its resistivity and (2) the older the formation, the higher its transmissivity, are relevant for the three studied aquifers, within the interval 10-100 ohm m and within a range of 0.9 to 5.5 Ma. The inferior limit (10 ohm m) is very important because below this value the correlations between resistivity and geological nature or hydrogeological property are not univocal. Several authors have put in evidence that this may correspond to high permeability formations saturated with saltwater (old confined water or seawater intrusion) or to impermeable clays. This clays resulting from meteorological or hydrothermal weathering process. The superior limit (100 ohm m) is also to consider, as there are no boreholes on the studied watershed with transmissivity / hydraulic conductivity values crossing formation with resistivity value higher than 100 ohm m.

We confirm that we consider that the domes exhibit rather high hydraulic conductivity, as described in the chapter 2.3 and 5.1 ("upper major perched aquifer. . . highly fissured and fractured, conferring a great hydraulic conductivity to this aquifer"). Champflor Borehole (50 m depth), situated 6 km north from the northern part of our studied water-

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shed (piton Lacroix) and drilled in 8α dacitic dome (893 $\pm$ 13 ka, Germa et al., 2011) shows a transmissivity value of 1.6 10-3 m^2 s-1, and confirms our opinion of a high hydraulic conductivity for theses domes – and higher that the transmissivity/hydraulic conductivity of the three studied geological formations. Furthermore, eruptive mechanisms of andesite and basalt lava flows on one hand, and intrusive domes on the other hand, are different. Intrusive domes are characterized by vertical fractures as shown on figure 9. Those fractures allows groundwater recharge to penetrate in depth, in agreement with water balance calculation. This mechanism of intrusion also explains that lava intrusion cross cut impermeable formations. Our correlation between age and hydraulic properties is then valid for the same kind of rocks (ie. Andesite and basalt lava flows in the context of subduction zone volcanic arc island). Consequently, the comparison of time evolution of lava flows and domes properties cannot be considered. This will be precise in the revised version.

Additional references:

Arnaud, L., Lanini, S.: Impact du changement climatique sur les ressources en eau de Martinique. Openfile BRGM Report RP-62676-FR, 2014.

Ecker, A.: Groundwater behavior in Tenerife, volcanic island (Canary-Islands, Spain). J. Hydrol. 28 (1), 73–86, 1976.

Ingebritsen, S.E., Sanford, W.E., Neuzil, C.E.: Groundwater in Geologic Processes. Cambridge University Press, 365 pp., ISBN 0-521-49608,1998 Second Edition., 2006.

Stollsteiner, P., Taïlamé, A.L.: Détermination des seuils de vigilance des niveaux d'eau souterraine en Martinique. Openfile BRGM Report RP-66058-FR, 2017.

Vittecoq, B., Lachassagne, P., Lanini, S., Ladouche, B., Marechal, J.C., and Petit, V. : Élaboration d'un système d'information sur les eaux souterraines de la Martinique : identification et caractérisations quantitatives. Rapport final. BRGM/RP-55099-FR, 2007.

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