Hydrol. Earth Syst. Sci. Discuss.,
https://doi.org/10.5194/hess-2018-637-AC1, 2019

Hydrology and Earth System Sciences
Open Access
Discussions

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

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Received and published: 8 March 2019

We thanks Tatiana Izquierdo Labraca for her consideration for our work and for agreeing reviewing our manuscript for publication in Hydrology and Earth System Sciences. Her relevant comments will clearly help to improve the manuscript.

Responses to specific comments:

C1: The authors have included the thermal springs as part of the hydrogeological model; however, more specific information is needed to fully understand them and their role in the hydrogeological conceptual model.

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Discussion paper

R1: In the present form of the manuscript, the two thermal springs are presented in chapter 2.3.2 and their hydrogeological functioning is briefly described in chapter 5.6. More details will be added in the revised manuscript accordingly to the information we have regarding those thermal springs. Information about the geological and hydrogeological local settings of those two springs will be added in the chapter 2.3.2 and their role in the hydrogeological conceptual model will be clarified in chapter 5.6. We also consider to add a second figure to the conceptual model in order to show, from another angle, a cross section from north to south in the Case Navire River, and through the two thermal springs.

C2: Another table with supplementary information is needed with the available data for the analyzed springs (location, geology, discharge, seasonality, etc.)

R2: As recommended, a table with spring database will be added.

C3: Page 5, line 24: you mention that piezometer 3 characterizes a confined aquifer (figure 4) however according to the cross-sections interpretation there is no unit to confine the aquifer. The supplementary information table says it crosses 1a unit although that unit does not appear in table 1. Could you please include a more detail explanation? Maybe including the boreholes location in the cross-sections?

R3: The geological log of piezometer 3 shows that andesitic lavas are covered by 20 m of argilized material, which may correspond to clayey scree or clay alluvium. This clayed horizon confines the aquifer in this valley. The title of the column “alluvial depth” will be modified to include information about the superficial formation such as clayed material, highly weathered lavas or argilized alluvium.

1α and 1βol are both from the first volcanic phase of the Morne Jacob volcano. Table 1 (and also figure 8) already include 1α and 1βol characteristics. We will correct the code of table 1 by "1α and 1βol", and columns 1α and 1βol will be aggregate in the supplement boreholes table 1 for clarity.

The drilling is located near the 8000 m abscissa on the C5 cross section. We didn't plot this borehole on the cross section as the flightline was flown over the valley flank and not over the bottom of the valley. Considering the lateral extension of lavas, the 1α/1βol is not imaged on the flank.

C4: The water balance section needs to improve the methodology of the obtained values. Temporal series used for rainfall and evapotranspiration values should be specified and the method used for the evapotranspiration calculation should be included or at least a reference for them. How did you estimate GwR and the runoff values?

R4: 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. Some details and references have also to 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 al., 2014, Stollsteiner et Taïlamé, 2017, data from Meteorological agency and the Ministry of ecology, etc.), in addition to uncertainties of the main measurements.

RET are spatialized data from Arnaud et al., 2014, following the methodology detailed in Vittecoq et al., 2010. GwR/runoff ratio have been calculated by Vittecoq et al., 2007 (over the period 1987-1990) and Stollsteiner et Tailamé, 2017 (over the period 2008-2015) using global model with reservoir Tempo and Gardenia (© BRGM).

C5: Page 8, line 12: a specific analysis was conducted in the springs." Which one? Please provide a brief explanation of the methodology.

R5: Resistivity were extracted manually from the 3D resistivity model. Cells situated upstream springs were selected. This extraction was done for all of the 24 springs of the database (this database will be include in the revised version) and the sentence modified for clarity.

Responses to minor corrections (in RC1-Supplement.pdf):

R6: page 1, line 4: Yes, we mean overexploitation. This will be modified in the revised version of the manuscript.

R7: page 2, line 9: The reference Izquierdo, 2014 was added.

R8: page 3, line 20: Explanations about the objective "age is not the key factor controlling hydraulic conductivity" are given below.

Thanks to the interpretation of the geological, geophysical and hydrogeological data, we highlight, for the present study (i.e. the watersheds and the three studied aquifers, within the interval 10-100 ohm.m and within a range of 0.9 to 5.5 Ma) that (1) the older the formation, the lower its resistivity and (2) the older the formation, the higher its transmissivity. This last result is also consistent considering the results of Vittecoq et al., (2015) obtained on an older aquifer (15 Ma) on Martinique Island, with higher hydraulic conductivity and lower resistivity than the ones observed in the present study.

Consequently, unlike hot spot basaltic islands, hydraulic conductivity of the studied aquifers (subduction zone andesitic volcanism) does not decrease with age. On the contrary, our results show an increase with age. Nevertheless, time itself is not the activating factor and only few geological processes can cause an enhancement of permeability. Given (1) the tectonic and seismic context of the subduction zone, (2) the fact that earthquakes are known for increasing permeability (e.g. Rojstaczer et al., 1995, Ingebritsen et al., 2008) and (3) the fact that earthquake induced modification of permeability have been observed in Martinique (Lachassagne et al., 2011), we interpret the observed permeability increase as the consequence of earthquake tectonic fracturing.

It should be noted that this process must be superimposed with others geological process occurring on the same time and acting to reduce permeability, such as weathering process or hydrothermal argilisation. Intense hydrothermal weathering and fracture sealing by geothermal fluid could indeed create an impermeable caprock with very low resistivity (e.g. Browne, 1970, Simmons et Browne, 1990, Dobson et al., 2003), as supposed for hyaloclastites 1H.

We rephrased the last objective of our paper in that way: “(v) strengthen the hypothesis of Vittecoq et al., 2015 that, in contrast with the basaltic islands, hydraulic conductivity may increase with age in andesitic-type volcanic island.”

R9: page 3, line 28, 29: we agree, we will add that the rainfall map is included in figure 1B.

R10: page 3, line 30 and 32: This is a translation mistake. We mean urban community / urban area. Fort-de-France is part of CACEM urban community, which also includes the cities of Schœlcher, Saint-Joseph and Le Lamentin.

R11 (page 6, line 9): Piton Lacroix will be added in figure 1.

R12 (page 9, line 30): We agree, we mean limit of the extension of andesitic lavas.

R13 (page 10, line 4): The sentence was rephrased: “A part of effective rainfall (18%-40% depending on the watershed as shown in fig. 5) deeply infiltrates through the fracture and in the rooting of andesitic domes 9αbi”.

R14 (page 10, line 26): the sentence was rephrased, as the second hypothesis is the most likely: “The very low resistivity (6-10 ohm m) of Hyaloclastites 1H cannot correspond to actual salt water intrusion as they are now situated higher above sea level. Their very low resistivity could result from hydrothermal weathering (e.g. Browne, 1970, Simmons et Browne, 1990). These low resistivity hyaloclastites would thus be an evidence of a hydro-thermalized caprock of an underneath geothermal system”.

R15 (Fig 1): Yes, we agree. We replaced the number by the associated name in the figure.

R16 (fig 1): all the boreholes and springs shown on this figure are used in our paper. Boreholes and springs outside the watershed are in the same geological/hydrogeological formations and are necessary as proxy for statistical analysis.

R17 (fig 2): Some flight lines outside the watershed will be removed. The color of the flight lines will also be changed, for clarity.

R18 (fig 4): Piezometric levels increase since 2009/2010 are linked to the variation of effective rainfall (cf. table below). The years 2006 to 2009 have suffered a rainfall deficit, while the year 2010 and 2011 where excess and followed by two normal years.

Difference with the average annual effective rainfall: 2005: +35%, 2006: -19%, 2007: -17%, 2008: +1%, 2009: -26%, 2010: +30%, 2011: +60%, 2012: +4%, 2013: +5%, 2014: -29%, 2015: -34%

R19 (figure 7): Yes, the elongated rectangle down is a borehole. The figure will be modified to add this information, likewise the dotted lines that are actually faults. Orientations of C4 and C5 will also be added (from north to south).

R20 (figure 8): Andesitic and basaltic lavas “4-5.5 Ma” correspond to 1α and 1βol (see also R3)

R21 (figure 9 - Thermal springs): See R1 for our response.

R22 (figure 9 – Downstream the water tank): Yes we agree, diffuse springs are observed and the river drains the aquifer in this part of the valley. We will add a specific mark.

R23 (figure 9 - Title): We agree, and we proposed “Hydrogeological conceptual model, at watershed scale, of an andesitic system in a context of subduction zones”.

R24 (table 1 - 1βol): Yes we agree, we consider 1βol as a major aquifer at the scale of the island (and also 1α, cf. R3). Figure 2 also show that 1α and 1βol are found mainly at the East of Alma and Case Navire watersheds, but the angle of view of the conceptual model does not allow showing them. Given that (1) 2α, 1α and 1βol follow each other in time (2) they are all aquifer (keeping in mind that they are heterogeneous with permeable and impermeable facies, cf. chapter 5.2, lines 22-25), and (3) this is a conceptual model, we propose to modify the legend with generic items: andesitic domes, lavas, debris flows, andesitic aquifer and hyaloclastites.

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