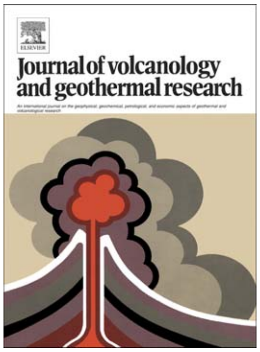

Reply to: Barazzuoli P., Bertini G., Brogi A., Capezzuoli E., Conticelli S., Doveri M., Ellero A., Gianelli G., La Felice S., Liotta D., Marroni M., Manzella A., Meccheri M., Montanari D., Pandeli E., Principe C., Ruggieri R., Sbrana A., Vaselli V., Vezzoli L., 2015. COMMENT ON: "*Borgia, A., Mazzoldi, A., Brunori, C.A., Allocca, C., Delcroix, C., Micheli, L., Vercellino, A., Grieco, G., 2014. Volcanic spreading forcing and feedback in geothermal resorvoir development, Amiata Volcano, Italia. J. Volc. Geoth. Res. 284, 16-31*". Journal of Volcanology and Geothermal Research, this issue.

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Introduction

Right from the abstract Barazuoli et al. (this issue) states what they consider to be the main issue with the paper by Borgia et al. (2014) that justifies their Comment: "*the supposed negative consequences of Borgia et al. (2014) for the Mt. Amiata volcanic-spreading on both contamination of shallow water and geothermal exploitation can likely be regarded as speculative*". Therefore, firstly, using a set of data (from a paper in preparation) independent from the volcanic spreading process, we need to briefly show why we think there is a direct hydraulic connection between the potable aquifer contained in the volcanic edifice and the underlying hydrothermal aquifer. Having clarified this point, we can reply to the questions raised in the "Comment" showing how volcanic spreading can enhance such connection. In order to facilitate the reader, in our reply, we have followed the same numbering used in the Comment of Barazzuoli et al. (this issue).

The interaction between the freshwater and the hydrothermal aquifers

It is common knowledge that fresh-water recharge in geothermal fields is essential for vapor production (Hunt, 2001); indeed the bulk of the geothermal vapour is generally meteoric water. At Amiata the first detailed study on this subject is that by Calamai et al. (1970). They show that within the geothermal aquifer, the original wellbore "shut in" pressure (the pressure before exploitation) decreased radially away from below Amiata volcano toward the peripheral geothermal fields. Therefore, following Darcy's Law, water can only flow radially away from below the volcano towards the geothermal fields, and there must be a "source of water" at the centre right below the volcano that can come only from the volcano. In fact, also the superficial heat-flow measurements increase radially from below the volcano toward the geothermal fields, indicating that the water is being heated up as it moves from below the volcano in a convective cell toward the geothermal fields (Allocca et al., 2013).

A significant lowering in the level of the volcanic aquifer occurred during the first few years of geothermal exploitation. Based on all available data (including calibrated geoelectrical surveys, well logs, and all data collected in the former decades for the Mercury mines) Calamai et al. (1970) present a before-geothermal-exploitation water table that has a 1200-m-elevation maximum in correspondence of the summit area of Amiata and that degrades radially away toward the volcano base with a gradient of about 1:10 (Fig. 1a). After the first 4 years of geothermal exploitation the water table, measured through calibrated geoelectrical methods, had decreased by about 200-300 m showing a relative minimum of 150-m in correspondence of the aquifer recharge area under the SW summit of the volcano (ENEL, 1966; Fig. 1b). The same local minimum has been measured by SEV (Marocchesi 2003) and repeatedly by magnetotelluric (Manzella, 2006). Since continuous borehole coring and logging (La Felice et al., 2014) have shown that there are no geoelectric anomalies that can produce such minimum, it follows that this is the actual topography of the water table and the groundwater must flow toward this minimum. In addition, because there are no pumping wells in in the area, the water can only flow from the minimum downward into the geothermal field (notably this is also the area of highest faulting). A similar interpretation was already given in Enel (1966).

The mentioned drop in water level corresponds to a measured 20-40 bars decrease in the underlying geothermal field pressure (Cataldi 1965). A direct positive correlation between water table level in the volcanic aquifer and the pressure of the hydrothermal aquifer has also been shown to exist (Caparrini et al., 2011), as well as an inverse correlation between springs flow rate and geothermal fluid extraction (Delcroix et al., 2006) – that is, as the production of fluids decreases, the pressure of the geothermal field, the elevation of water table and the spring flow rate increase.

Accordingly, the type of alteration minerals found in the David Lazzaretti Piezometer (see Fig. 1b for location) are consistent, although this may not be the only explanation, with the existence in the past of a water table at much higher elevation than the one measured today (La Felice et al., 2014). Calamai et al. (1970) state that the hydraulic connection between the freshwater aquifer, contained in the volcanic edifice, and the geothermal aquifer is through faults and volcanic conduits. Also the Tuscan Evironmental Protection Agency (ARPAT, 1997) and the electric company that exploits the geothermal fields at Amiata (Ceppatelli and Sabatelli, 2005), in addition to other authors, state that there is a direct connection between the fresh water aquifer contained in the volcanites and the underlying geothermal aquifer.

The potential up-flow of geothermal fluids into the volcanic aquifer is also well documented in the Amiata Volcano scientific literature; among the many, we mention only the following four evidences:

1) The presence of hydrothermal mineralization within the volcanic rocks testifies that hydrothermal fluids circulated within the volcanic edifice and its immediate substratum (cf. A.A.V.V., 1971; La Felice et al., 2014).
2) CO_2 and H_2S measurements show high soil emissions all along the summit faulted axial area of Amiata Volcano, indicating that hydrothermal gases cross the whole thickness of the volcanic aquifer (Frondini et al., 2009).
3) The gas emission and occasional eruption of geothermal fluids through shallow boreholes (Fig. 2), and the hydrothermal waters, which are drained from the contact between the volcanic rocks

and the sedimentary substratum at the Galleria Italia (Abbadia San Salvatore Mine; cf. A.A.V.V., 1971), demonstrate that hydrothermal fluids are in direct contact with the volcanic aquifer.

4) Continuous monitoring of the water table level and salinity (Fig. 3) of the volcanic aquifer at the Davide Lazzaretti Piezometer (La Felice et al., 2014), shows that in February 15-23 (2014), in correspondence of an increase in water table level of 2 m (1% increase of the aquifer thickness), the salinity increased by more than 30 ppm (35% increase). Apparently, the water table increase rate is so high that cannot be explained by rain water recharge only, and a fluctuation in the underlying hydrothermal-system pressure must be included to justify it (cf. Caparrini et al., 2011); in the subsequent months, the water table continued to increase by 8 m, while the salinity started to oscillate with amplitudes of about ±20 ppm (20%) and with a small average decrease; also, during June 15-29 in correspondence to a water table increase of 0.5 m the salinity increased by 50 ppm (more than 50% increase); in the following months (up to September 30) the water table increased by only 0.5 m, while the salinity decreased by 40 ppm (high-frequency, drastic salinity oscillations are also present during this period); from October 1 to November 20, the water table decrease by 0.6 m with an increase of salinity of about 15 ppm; from December 10 the water table continued to decrease by about 0.4 m (0.2% decrease) while the salinity decrease by 30 ppm (25% decrease). Clearly salinity and level of water table are uncorrelated and the variations in salinity imply sudden inputs of a saline component, which we postulate to be coming from the hydrothermal system, in response to the pressure variations induced by geothermal exploitation. Notably, during the 6-months period June-November 2014, were performed the start-up operations of the new 40-MWe geothermal power plant Bagnore 4. Unlikely, geothermal fluid production data are not unavailable.

In conclusion, we think that there are substantial scientific evidences for confirming what is the normal behaviour of any hydrothermal system, that is, a “convective cell” that has a fresh water recharge from the topographic high of Amiata Volcano and the upwelling of hot hydrothermal waters all around its base (Allocca et al., 2013).

Specific reply to the Comment

2. Stratigraphy

Lava flow units

a) Lava flow units have a distinct morphology: they are made up of levees, a channel, “parabolic” flow ridges within the channel, and a flow front that some times are characterized by ramparts (cf. Borgia et al., 1983; Linneman and Borgia, 1993). Because levees are formed at the flow front and lava composition can change through the duration of the eruption, it is common to find the older and youngest erupted lava (that may have different chemical and mineralogical composition) juxtaposed, respectively, in the levees and the channel, closer to the vent area. In addition, since the lava flows at Amiata are mostly secondary flows, originating from strombolian-like eruptive activity, blocks of older lava or magma left-over from previous eruptions (which may have different chemical and mineralogical composition) can be eroded from the side of the conduit, or picked up during magma ascent, and erupted with or thrown on top of the younger lava flows.

We observed that former sampling of the Amiata lavas has not always taken these aspects into account, leading to potential discrepancies with our work. We believe that the detail study of the morphology of the lava flows, conducted in our work, is the best and most accurate way to define flow units in accordance to the stratigraphic superposition principle. We recognize, though, that our work may be limited particularly for what concerns older flows, where the superposition principle cannot be determined. We invite the Authors of the “Comment” to use and improve our flow-units geologic map of Amiata Volcano and, based on this new map, resample the volcanic sequence.

Stratigraphic sketch Fig. 3

b) It is not clear to us how can anyone think that the “Internal Ligurids of Cretaceous age” are etheropic with the “Miocene-to-Quanternary marine and continental sediments”, while it is certain that from Miocene onward the regional and gravitational tectonic regimes affected both the Ligurid and, as they were deposed, the “Miocene-to-Quanternary marine and continental sediments”. This is what the sketch very naively meant to indicate. We thank the Authors of the Comment to let us clarify this point, though we point out that it is irrelevant to the Amiata volcanic spreading thesis of Borgia et al. (2014). Our stratigraphic sketch, nonetheless, brings up a novelty relative to former sketches (cf. Brogi et al., 2009), it shows the direct contact of volcanic rocks with the rocks of the hydrothermal reservoir, an important feature that allows hydraulic continuity between the potable freshwater and geothermal aquifers.

The Selagites

c) We use the term “Selagites”, for the intrusive rocks cropping out SE of Amiata Volcano, after the Geologic Map of Regione Toscana (2006-2009). Having no relevance for our model, we oversimplified the stratigraphy unifying all intrusive rocks together. We thank the authors of the Comment for making this clarification.

The pre-volcanic substratum

d) Yes, the rheology of the rocks that form the substratum of Amiata Volcano is very important. We describe the variety of substratum rocks in the appropriate detail useful for the scope of our thesis, giving proper references. It is irrelevant for the rheology of a rock mass if it belongs to oceanic, transitional or continental domains. The point is to demonstrate if this rock mass can flow under gravitational stresses. Given the observed deep-seated gravitational deformations – which we were not the first to describe (see Borgia et al., 2014, for references) – the answer can only be “yes”: these masses deform even under small differential loads. Indeed, the contact between the volcanic rocks and the shaley substratum of the southern flanks of Amiata is occupied by a cataclastic zone more than 15 m thick (La Felice et al., 2014), which, our direct observations during borehole coring and logging, indicated to be the result of active normal faulting from extension and sinking of the axial summit area of Amiata (Fig. 4); also, the volcanic substratum is so plastic that the borehole walls were observed to “shrink” in less than a few days.

Given the mechanical simplifications included in our model, it is surprising how close of a similarity there is between our results and the field observations. The gravitational tectonics observed at Amiata is so stringent that, we believe, it will soon become the text-book example for small-edifice volcanic spreading, just as Mauna Loa and Kilauea have become the example for large oceanic shields (Borgia, 1994), Etna for continental volcanoes (Borgia et al., 1992), and Olympus Mons for planetary settings (Borgia et al., 1990).

The evaporitic deposits

e) Apparently, the Authors of the Comment are not convinced that the load of the volcanic edifice “induces a stress in the units below the flysch deposits”. This is just a direct consequence of Newton’s second law. Accordingly, the uprising of the diapirs cannot enhance volcanic spreading. They are the effect (the result) of spreading, and with their growing load onto the substratum tend to inhibit it. Because of gravitational forces and the mass of Amiata Volcano edifice, shear stresses act on the substratum radially away from below the volcano. Again, the question is: have the Anhydrites a low-enough viscosity to become sheared under those stresses? Our answer is “yes”, because the high temperature hydrothermal fluids, by heating them up, reduced by even orders of magnitude their viscosity. The existence of diapiric tectonic in the Amiata Volcano area has been suggested many times in the past, and many mineral deposits are associated to them (cf. Cataldi, 1965; Baccos, 1966; A.A.V.V. 1971).

2.1 Hydrogeological implications

The borehole stratigraphy Ab-9, reported by us and by the Authors of the Comment, shows, below the volcanites, calcareous rocks that have cinnabar mineralization. In this area all the rocks of the Tuscan formations that are in direct contact with the volcanites, are highly tectonized (therefore characterized by secondary permeability) and have cinnabar mineralizations. These mineralizations, that are found in the volcanic rocks as well (cf. A.A.V.V., 1971), indicate hydrothermal circulation in direct contact with the volcanic aquifer, supporting our thesis. Our cross section does not show the contact between the volcanites and the Tuscan formations, simply because it passes to the side of this area.

3. Structural and Tectonic setting

a) The age of these structures is younger than the emplacement of Amiata volcano edifice, because they control the evolution of the drainage within and outside the volcano, forming sharp stream diversion and captures. Thus, we think that, even if these structures would be Neogene in age, they have been reactivated after the emplacement of the volcano. Compressive structures in this area are well known to exists, they tend to be concentric to the volcano (Calamai et al., 1970; Ferrari et al., 1996; Acocella, 2000) and to the best of our observations are coeval with its growth. We think that there are no evidences that these structures, even if formed at earlier times, have not been reactivated during volcanic spreading. Indeed, because of mass conservation, the extension found on the volcanic edifice is compensated by compression around the base of Amiata.

b) We think that the structural observations made on the volcanic rocks (namely kinematic indicators on small faults) cannot receive unique interpretations. Most of the structural features of the volcanic rocks, shown by the Authors of the Comment on their cited papers, can more easily be interpreted as the result of lava flow emplacement features, which are practically identical to tectonic striations (cf. Borgia et al., 2014, for references). This may explain why some geologists found right lateral, instead of left lateral, sense of shear. The fact that a paper has been “only presented as an abstract in a workshop” does not make it wrong, nor that it should not be cited. The Authors of the Comment fail to report our full sentence “*In fact, some morphologic features along the volcanic axis could suggest the existence of small regional components of shear (perhaps right lateral), overprinting the general spreading process (cf. Lagmay and Valdivia, 2006). Future work will attempt at verifying this thesis*”. As stated, we think that our volcanic spreading model is not meant to exclude strike-slip regional tectonics.

c) Normal faulting on the volcano is clearly marked by the relative vertical displacement across fault traces of the isochrones surfaces constituted by the top of lava flow units (see the following point d); this unquestionable evidence is clearly stated in Borgia et al. (2014) pag. 20-21; obviously rivers, which flow radially downward from the top to the base of the volcanic edifice, tend be diverted by the uplifted footwall faulted blocks. There are no lateral component of motions in Fig. 9 of Borgia et al. (2014), as stated in the figure captions, the arrows simply indicate river flow directions, not strike slip faulting.

d) Lava flows are emplaced in a sufficient short time (in geologic terms) that their top (or bottom) surface may be considered an isochrone. Thus, if an isochrones surface is displaced across a linear feature, that same feature must be the trace of a fault. There is no need of additional stratigraphic relationships or radiometric ages, because our observation is actually the geologic definition of “fault”.

4. Diapirism and volcanic spreading

a(1) It is not clear to us what the Authors of the Comment refer to. Our geologic map correctly indicates and describes the stratigraphic units mentioned by them, which are taken from the most recent literature (Regione Toscana, 2006-2009) and our field work. It can easily be appreciated in the field the degree to which the rocks become chaotic closer to the margin of the volcano. The "size of the elements" of these rocks, which in most cases have a significant clayey fraction, is what it counts for plastic deformation. Indeed, given the very large number of springs at the contact between the volcanic rocks and the substratum, these rocks tend to be water saturated just a few meters below the surface.

a(2) Many authors suggest the existence of diapiric-like structures in the Anhydrites and other formations at Amiata. The best examples are from the geologic cross sections of the Cinnabar mines of Abbadia S.S. (A.A.V.V. 1971), Bagni S.Filippo (Cataldi 1997), and Bagnore (Bets, 1962; Baccos, 1966; Leonardelli, 1975). The Authors of the comment seem to agree with the very plastic behaviour of the anhydrite formations at temperatures higher than 100 °C. However, their point should be reversed: since one can observe plastic behaviour and diapiric tectonics, what should be the viscosity of these rocks to give reasonable deformation rates? Our model indicates a value of 10^{18} Pa s. This is a much higher viscosity than that of pure anhydrites at 200 °C. Thus, correctly the Author of the Comment point out that the Burano Formation is harder than pure anhydrite because of the presence of dolostones.

b) Our field survey indicate that the original data produced by Cataldi (1967) are very convincing and fit perfectly the diapiric tectonics of the Burano Formation Anhydrites that are found at the base of the sequence, in agreement with our volcanic spreading model.

c) Apparently, the Authors of the Comment confuse the ramps frequently found in the lava flow fronts of highly viscous flows, with the actual tilting of lava flows. The occurrence of upward tilted flows at the periphery of the Amiata volcanic deposits is easily recognizable in the field (Ritttman, 1958; Ferrari et al., 1996) and indicated accordingly in our geologic map.

d) As indicated in our paper, this sediment intrusion, but also many other sediments intrusions found in the older lavas are clayey in nature and hardened by contact heat; they were plastic and became squeezed into the still-hot flows.

e) The lava blocks are found embedded within the Pietraforte formation rocks. They very probably were part of a detrital cover once resting on top of the substratum as the Authors of the Comment state, but were later involved in diapiric thrusting.

f) The stratigraphy of the Bagnore n. 10 well shows the rhyolite cover of lava blocks below the top soil, which is also shown in our map. The fact is that the well stratigraphy shows about 5 m of Ligurid units below this cover and then again 6 m of rhyolite lava. This observation fits very well with the former observation (point e), in which rhyolitic lava blocks are embedded into the Pietraforte formation. Notably the two areas are along the same diapiric-like structure at the margin of the volcanic edifice.

g) We thanks the Authors of the Comment of bringing up this very interesting point. This is, in fact, the case found at other volcanoes and it is not new. For instance, it is found on Conception in Nicaragua (Borgia and Van Wyk De Vries, 2003), and Etna (Borgia et al., 1992) and Vesuvius (Borgia et al., 2005) in Italy. Compared to these volcanoes, Amiata has two additional components that could facilitate magma degassing at depth in addition to spreading because of the load of the volcanic edifice. The first is the fact that the rigid basement is dipping outward away from the volcano – we have included this effect in our analytical model; the second is that even low-temperature hydrothermal fluids can drastically reduce the viscosity of the ductile basement (the anhydrites). Since we have not studied these problems at Amiata with respect to magma evolution, we can only speculate on the subject.

h) This is one other interesting observation made by the Authors of the Comment that we like to discuss further. Given that volcanic spreading at Amiata has created a set of active compressional structures all around the base of the volcano, it is a direct consequence that the growth of these structures has exerted a control on rivers and streams, which will tend to follow the axis of synclines, while the ridges will tend to develop along the axis of anticlines. Some of the anticline axes are reported also in Calamai et al. (1970) and in Acocella (2000). Indeed, we expand some of the earlier observations framing them in the volcanic spreading paradigm.

5. Input parameters for the dynamic model

a) The approximations included in the model, as the Authors of the Comment state, are described in detail Borgia et al. (2014). The model is actually quite elaborate including for the first time functions for a time-dependent topographic relief and a sloping basement. Despite the simplifications, and the very high non-linearity of the equations, it is remarkable how good our results are once compared to the field data. Therefore, we are confident that the approximation made cannot change the first-order-approximation results of our model. Among all approximations, probably, the most acceptable one is, actually, that of constant density within each geologic unit, because the average density of each unit can at most change by only a few per cent. We think that future work should concentrate on 3D modelling, more than on improving the volumetric distribution of density and viscosity.

b) We do not understand the comment. As stated above and clearly seen in Borgia et al. (2014) fig. 12, our model includes also a function that describes the time evolution of topography, which we used to investigate 4 different conditions that describe volcanic and basement rocks emplacement/erosion during spreading. We acknowledge that we have not investigated all possibilities, they where beyond the scope of the paper.

c) The existence of volcanic conduits does not affect our model, because deformation within the volcanic edifice is mainly controlled by the lateral flow of the ductile substratum. Conduits and faulting of the edifice, instead, constitute a perfect hydraulic connection between the potable volcanic aquifer and the underlying hydrothermal system. Given that most formations around the volcano can be considered clay-rich (that is, they are easily deformable and erodible), we expect the pre-volcanic topography to be relatively flat, at least in a radial direction. As stated, future work will attempt 3D modelling, which could include the original subvolcanic topography (i.e. valleys).

6. Conclusions

We think that our volcanic spreading model is very effective in describing the structural evolution of Amiata’s volcanic edifice. The work by Mazzoldi et al. (2015) on the natural and induced seismicity at Amiata brings in an additional component: active seismicity, on the volcanic spreading faults, indicate that this process is still active and faults maintained in a critically stressed condition. Indeed, our model shows that uplift and erosion of the clayey volcanic basement, as it is documented in the geology, facilitate volcanic spreading.

Volcanic conduits, critically-stressed extensional structures that cut the volcanic edifice and the immediate substratum of Amiata, and direct contacts between the volcanic rocks and the Tuscan Units, constitute the hydraulic pathway between the potable fresh-water aquifer contained in the volcanic edifice and the underlying hydrothermal system. Therefore, gaseous phases and hot fluids can flow upward (particularly through secondary permeability) carrying pollutants into the freshwater aquifer, while the freshwater recharges (particularly through primary permeability but also through faults) the exploited geothermal fields (cf. Borgia et al., 2014). The strong depressurisation (which is now perhaps as much as 200 bars) of the hydrothermal aquifers, induced by geothermal exploitation, has forced gaseous-phases to evaporate within the geothermal field, increasing the phenomena.

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Figure captions

Fig. 1. *Water table within Amiata Volcano as measured via borehole and calibrated geo-electrical methods:* ***a)*** *before geothermal exploitation (redrawn after Calamai et al., 1970), and* ***b)*** *about 5 years after the beginning of geothermal exploitation (redrawn after ENEL, 1966). Note that the water table has dropped by about 300, and has a minimum where the volcanic aquifer is drained toward the geothermal field. DLP is location of the David Lazzaretti Piezometer.*

Fig. 2. *Gases and drops of geothermal fluids erupted through an old shallow boreholes uphill from Abbadia San Salvatore on the eastern flank of Amiata Volcano, September 2007. In this borehole,*

as in many others, the volcanic rocks rest in direct hydraulic connection with the rocks of the Tuscan Formation that host the hydrothermal aquifer (Courtesy of Esteban Gazel Dondi).

Fig. 3. *Variation of salinity and water table level (below ground surface) versus time at David Lazzaretti Piezometer (see Fig. 1b for location). Clearly salinity and water table level are uncorrelated. Data points are hourly averages (data from Regione Toscana www.cfr.toscana.it). See text for explanation.*

Fig. 4. *David Lazzaretti Piezometer cores (see Fig. 1b for location).* ***a)*** *Core at 530 m depth (right), showing the cataclastic rhyolite lava.* ***b)*** *Core at 531 m depth, showing rocks that are already part of the substratum, themselves cataclastic with lava fragments; note the sharing surface (60°-70° of dip) with striations that, at close observation, indicate normal faulting. These cores show shearing bands that apparently become less inclined with depth implying strong, possibly active, shear deformation at the base of the volcanic edifice.* ***d)*** *Fault zone cored at 397 m depth showing a catacalstic zone about 3 m in thickness in the trachydacite****. e)*** *Same fault as in d): measurable striations indicate pure normal motion with an attitude of 343°/77°. This fault zone demonstrate that the downthrown block is the axial summit area of the volcano, in accordance with our model and in contrast with the right-lateral strike slip thesis of Brogi et al. (2010). At the David Lazzaretti Piezometer no other faults are present in the volcanic pile.*

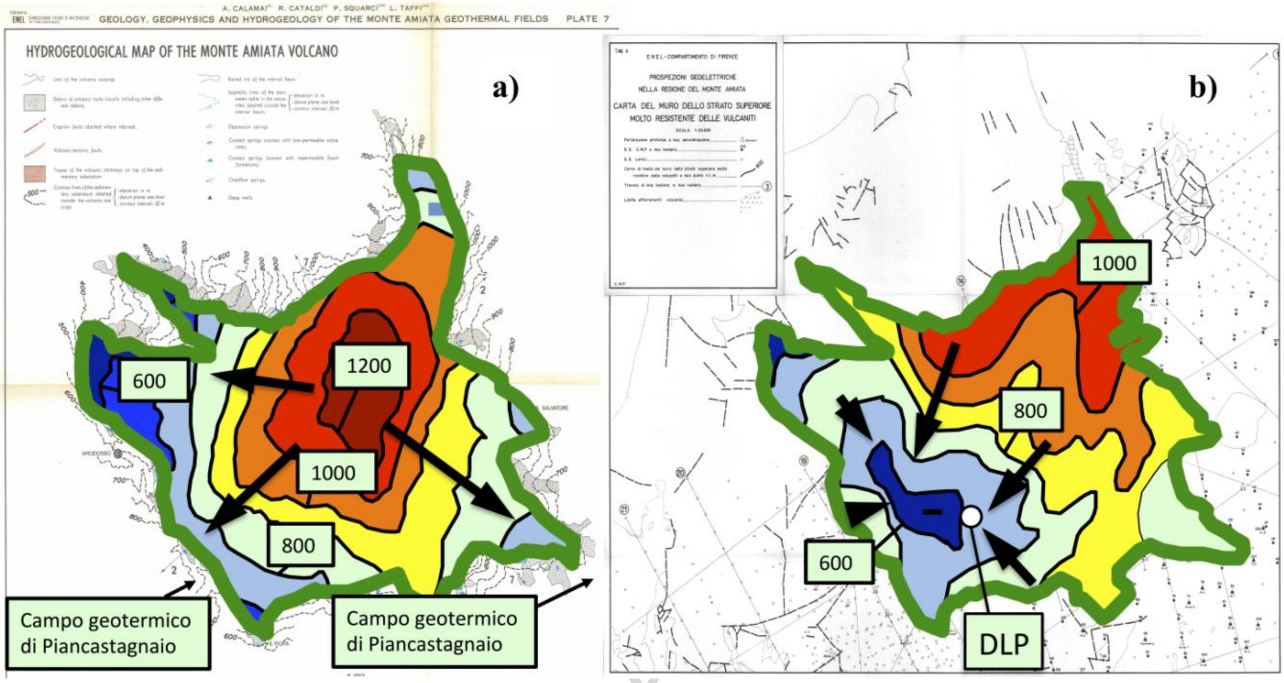
A. CALAMAI R. CATALDI P. SQUARCI L. TAFFI
GEOLOGY, GEOPHYSICS AND HYDROGEOLOGY OF THE MONTE AMIATA GEOTHERMAL FIELDS
PLATE 7
HYDROGEOLOGICAL MAP OF THE MONTE AMIATA VOLCANO
a)
1200
600
1000
800
Campo geotermico di Piancastagnaio
Campo geotermico di Piancastagnaio
ENEL - COMPARTIMENTO DI FIRENZE
PROSPEZIONI GEOELETTRICHE NELLA REGIONE DEL MONTE AMIATA
CARTA DEL MURO DELLO STRATO SUPERIORE MOLTO RESISTENTE DELLE VULCANITI
b)
1000
800
600
DLP

Figure 1


Drops of geothermal fluids erupted through a shallow borehole

Figure 2

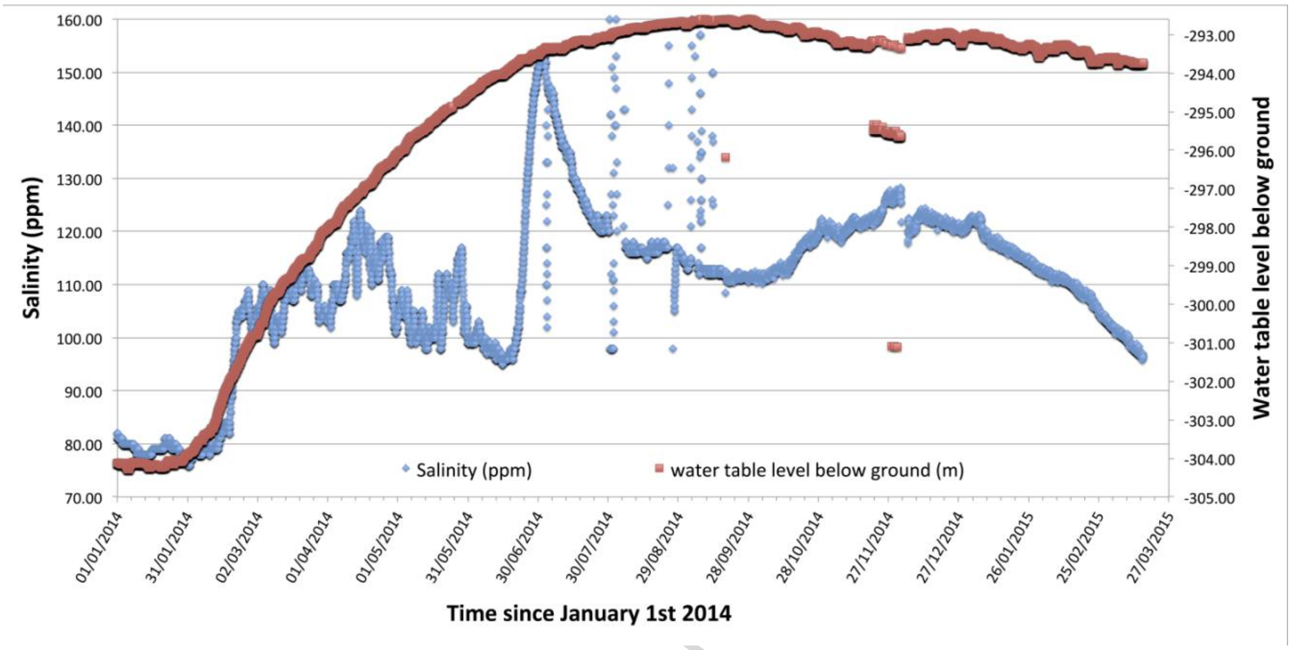
160.00
150.00
140.00
130.00
120.00
110.00
100.00
90.00
80.00
70.00
Salinity (ppm)
-293.00
-294.00
-295.00
-296.00
-297.00
-298.00
-299.00
-300.00
-301.00
-302.00
-303.00
-304.00
-305.00
Water table level below ground
Salinity (ppm)
water table level below ground (m)
01/01/2014
31/01/2014
02/03/2014
01/04/2014
01/05/2014
31/05/2014
30/06/2014
30/07/2014
29/08/2014
28/09/2014
28/10/2014
27/11/2014
27/12/2014
26/01/2015
25/02/2015
27/03/2015
Time since January 1st 2014

Figure 3

Fault plane with striations at about 400 m depth

Cataclastic zone at 397-400 m depth

Figure 4

Abstract

The volcanic spreading model by Borgia et al. (2014) is very accurate in describing the extensional structures found on the edifice and the radial compressional structures existing all around the base of Amiata Volcano. Volcanic conduits, extensional structures, and direct contact between the volcanic rocks with the Tuscan Units, constitute the hydraulic connection between the potable fresh-water aquifer contained in the volcanites and the underlying hydrothermal system. Therefore, gaseous phases tend to flow upward (particularly through faults) carrying pollutants into the freshwater aquifer, while the freshwater recharges (also through primary permeability) the exploited geothermal fields.