

## Special Issue: Vesuvius monitoring and knowledge

# Groundwater geochemistry of the Mt. Vesuvius area: implications for volcano surveillance and relationship with hydrological and seismic signals

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**ABSTRACT**

Geochemical data obtained between 1998 and 2011 at the Mt. Vesuvius aquifer are discussed, focusing on the effects of both the hydrological regime and the temporal pattern of local seismicity. Water samples were collected in a permanent network of wells and springs located in the areas that are mostly affected by the ascent of magmatic volatiles, and their chemical composition and dissolved gas content were analyzed. As well as the geochemical parameters that describe the behavior of groundwater at Mt. Vesuvius, we discuss the temporal distribution of volcano-tectonic earthquakes. The seismological data set was collected by the stations forming the permanent and mobile network of the Istituto Nazionale di Geofisica e Vulcanologia - Osservatorio Vesuviano (INGV-OV). Our analysis of seismic data collected during 1998-2011 identified statistically significant variations in the seismicity rate, marked by phases of decreasing activity from October 1999 to May 2001 and increasing activity from August 2004 to mid-2006. The water chemistry shows peculiar patterns, characterized by a changeable input of CO<sub>2</sub>-rich and saline water, which must be related to either a changing stress field or an increased input of CO<sub>2</sub>-rich vapor. The water chemistry data from 1999 to 2003 account for both higher fluid pressure (which induced the seismic crisis of 1999 that peaked with a 3.6-magnitude earthquake in October 1999) and the increased input of CO<sub>2</sub>-rich fluids. The highest emission of CO<sub>2</sub> from the crater fumaroles and the corresponding increase in dissolved carbon in groundwater characterize the phase of low seismicity. The termination of the phase of intense deep degassing is associated with a change in water chemistry and a peculiar seismic event that was recorded in July 2003. All these seismic and geochemical patterns are interpreted according to temporal variations in the regional and local stress field.

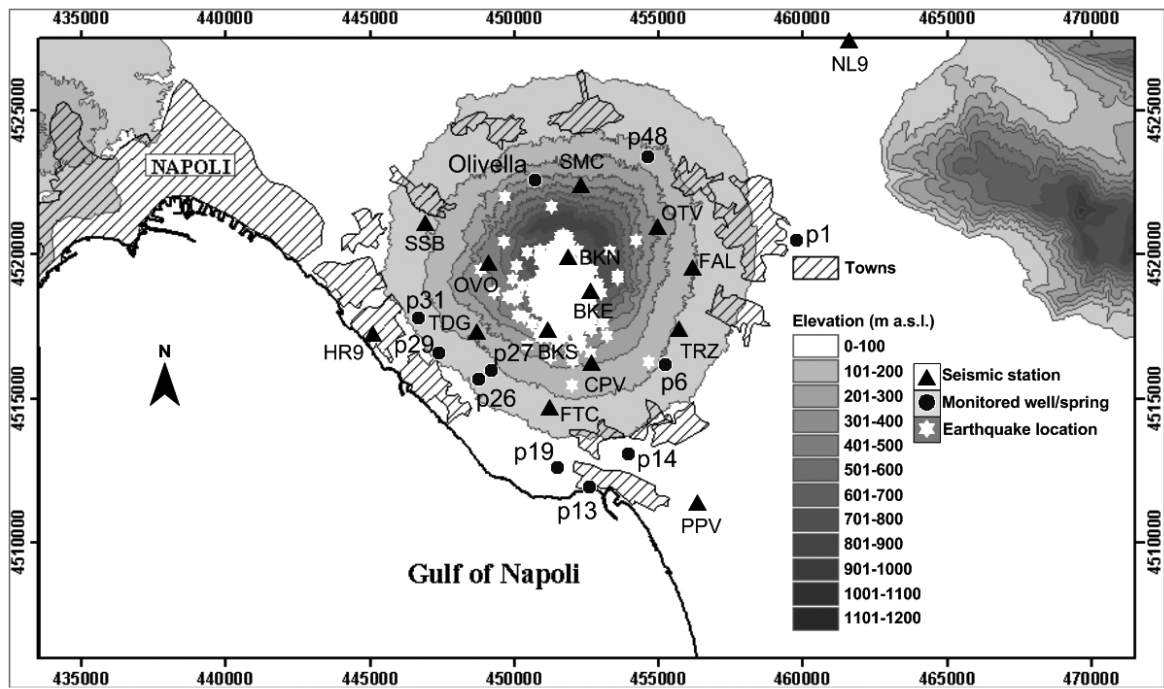
**Introduction**

Fluids circulating in volcanic edifices are attracting increasing interest from scientists, mostly because their role in triggering flank instability, phreatic explosions, and eruptions has been documented in dozens of cases

worldwide [Day 1996, Reid 2004, Thomas et al. 2004]. Internal pressurization of magmatic volatiles and hydrothermal systems can lead to dramatic steam blasts and, eventually, to eruptions [Hill et al. 2002]. The fluid pore pressure can also be changed by external mechanisms, such as variation of the stress field or, more generally, variation of the porosity/permeability of volcanic rocks. Static or dynamic stress changes, which have a clear expression in seismicity, exert a significant control on fluid patterns and eventually on the ascent of melts [Newhall et al. 2001, Hill et al. 2002, Mortimer et al. 2011]. The reciprocal roles of tectonics and magmatic/hydrothermal activity, and their influence in determining the so-called crises, is still under investigation [Roeloffs et al. 2003, Gottsman et al. 2007]. Monitoring of groundwater in volcanic systems is useful for predicting changes in the tectonic and volcanic stress field [Newhall et al. 2001, Hurwitz and Johnston 2003, Biagi et al. 2004, Koizumi et al. 2004]. Changes in water level in some wells were observed prior to the 2000 eruption of Mt. Usu, Japan [Shibata and Akita 2001], and is a frequent characteristic in eruptions of Mt. Vesuvius [Bertagnini et al. 2006].

Mt. Vesuvius hosts a shallow aquifer which receives magmatic/hydrothermal gases mostly in correspondence of the main tectonic lineaments [Federico et al. 2002]. Some changes in water and dissolved gas composition have been recorded in concomitance with the seismic crisis that occurred in 1999 [Federico et al. 2004, Madonia et al. 2008].

The present study aimed at elucidating the roles of both the stress field and the magmatic/hydrothermal degassing in changes in water chemistry in the vesuvian shallow aquifer. We report on the composition of major ions, temperature, and dissolved gas con-



**Figure 1.** Map of the Mt. Vesuvius area showing the locations of earthquakes and measuring points of the seismic and geochemical surveillance networks.

tents (which were partly reported by Madonia et al. [2008]) measured between 1998 and 2011 at selected springs and wells located on the lower flanks of Mt. Vesuvius. Temporal variations of water chemistry can be attributed to either changes in porosity/permeability and fluid circulation or the input of  $\text{CO}_2$ -rich vapor, and provide insights into the present rest period. Finally, we compare the variations of the geochemical parameters with those of the seismic activity.

## Study area

### *Geological summary*

With a radius of ca 10 km, the Somma-Vesuvius complex (1281 m a.s.l.) in southern Italy is a polygenetic volcanic complex composed of an old stratovolcano (Somma), which is mainly preserved on the northern sector of the edifice, and the younger cone of Mt. Vesuvius (Figure 1). The Somma-Vesuvius complex developed within a wide gravimetric anomaly located in the central part of the Campanian Plain (a depression bordered by Tertiary and Mesozoic carbonate massifs) named the Acerra graben [Scandone et al. 1991, Marzocchi et al. 1993]. This anomaly is related to the subsidence of the carbonate basement lying about 2 km beneath Mt. Vesuvius. The stratovolcano developed at the intersection of two regional tectonic fault systems (running NW–SE/NNW–SSE and NNE–SSW/NE–SW). In addition to these two regional structures there are also local eruptive fractures aligned in the E–W and N–S directions inside the Somma caldera and on the

southern flank of the volcano [Bianco et al. 1998].

The volcanic activity of the volcanic complex has been characterized by the alternation between pyroclastic eruptions (separated by quiescent periods) and open conduit phases, characterized by Strombolian and effusive activity [Santacroce et al. 1994, Cioni et al. 1998]. The Somma volcano mainly consists of lava flows (K-rich basalts and latites) and minor pyroclastics (strombolian scoria fall deposits) and was active between 25 and 18 ka BP [Santacroce 1987, Ayuso et al. 1998]. Four Plinian eruptions between 18 ka BP and A.D. 79 caused the summit to collapse and gave rise to the formation of a multistage summit caldera (i.e., the Somma caldera) [Santacroce 1987, Andronico et al. 1995, Principe et al. 1999, De Vivo and Rolandi 2001]. After the sub-Plinian eruption in 1631, an open conduit phase lasted until the 1944 eruption, since when the volcano has been in a state of weak volcanic-hydrothermal activity characterized by diffuse  $\text{CO}_2$  degassing and low-temperature fumarolic activity in the crater area, thermal submarine features, and low seismic activity [Aiuppa et al. 2004, Del Pezzo et al. 2004, Frondini et al. 2004, Caliro et al. 2011].

### *Seismicity*

The natural vesuvian seismicity mainly consists of volcano tectonic (VT) earthquakes [Chouet 1996], which are characterized by clear P- and S-wave packets and a high-frequency content, mostly peaking in the band 5–15 Hz. They are usually located within a volume centered along the crater axis, at depths shallower than

about 4 km below sea level (b.s.l.). The transition zone between the volcanic edifice and the carbonate basement, at 2-3 km b.s.l., coincides with the maximum of the spatial distribution of the hypocenters [Saccorotti et al. 2002, Scarpa et al. 2002, Del Pezzo et al. 2004].

Assumptions about the source dynamics for the vesuvian VT earthquakes involve failures in the brittle rocks, with strike-slip and normal/reverse dip-slip focal mechanisms. A wide variety of nodal plane orientations is indicated, but overall the directions are NW-SE and NE-SW [Bianco et al. 1998, Ventura and Vilardo 1999]. The P and T axes are mainly assumed to be present along the NNE-SSW and ESE-WNW directions and along the ESE-WNW and NNE/N-SSW/S directions, respectively [Bianco et al. 1998, Ventura and Vilardo 1999, Zollo et al. 2002].

According to Del Pezzo et al. [2004], the deepest events are associated with average stress drop between 1 and 10 MPa and are mainly caused by the release of regional tectonic stress in the prefractured carbonate basement. On the other end, the shallowest earthquakes are characterized by stress drop of up to 1 MPa and are probably triggered by increasing pore fluid pressure caused by changes in the hydrothermal aquifer, which is located beneath the crater at about 1 km b.s.l.

Madonia et al. [2008] revealed two statistically significant variations in the seismicity behavior between 1998 and 2005: in May 2001 and July 2004. Two phases corresponding to these variations can be identified. The first is relative to the 1999 crisis. The highest-magnitude (3.6) earthquake since the last eruption (in 1944) occurred during this crisis, at 07:41 UT on October 9, 1999. This earthquake was located about 4 km beneath the crater area, inside the carbonate basement. Several studies have demonstrated that this event was generated by tectonic stress release along a pre-existing fracture system [Ventura and Vilardo 1999, Zollo et al. 2002, Del Pezzo et al. 2004]. This was followed by a sequence of low-energy earthquakes, and the seismic activity decreased up to May 2001. Low levels of seismicity were observed until July 2004, when a slight increase in the seismicity rate marked the beginning of the second phase.

#### *Hydrogeology*

Two main aquifers exist in the vesuvian area [Corniello et al. 1990, Celico et al. 1998]: (1) a deep carbonate aquifer hosted in the buried Mesozoic series beneath the Campanian Plain and recharged by precipitation falling on the Apennines, and (2) a shallower volcanic aquifer (the vesuvian aquifer) hosted in fractured lavas and coarse-grained pyroclastic deposits of the Somma-Vesuvius complex. As generally observed in stratovolcanoes, water at Mt. Vesuvius circulates in sev-

eral overlapping water bodies separated by impermeable fine-grained pyroclastic layers. The transmissivity values of these aquifers range from  $10^{-4}$  to  $10^{-1} \text{ m}^2 \cdot \text{s}^{-1}$  [Celico et al. 1998], with the highest values ( $10^{-2}$  to  $10^{-1} \text{ m}^2 \cdot \text{s}^{-1}$ ) being found on the southern flank of the volcano. The exchanges between the deep and shallow water bodies are easier in this area due to both the volcanic cover being thinner and the presence of fractures in the carbonate basement, which facilitate upward water circulation.

The numerous studies concerning the chemistry of Somma-Vesuvius groundwaters have clarified the mechanisms of gas-water-rock interactions, highlighting the role of volcanic  $\text{CO}_2$  in controlling rock leaching and water chemistry [Caliro et al. 1998, Celico et al. 1998, Federico et al. 2002, Aiuppa et al. 2005, Caliro et al. 2005]. Analysis of stable isotopes in dissolved gases ( $\text{CO}_2$  and He) have demonstrated that magmatic volatiles are actively transported by groundwaters flowing along the main faults and fractures, trending NW-SE and NE-SW, which affect both the volcanic edifice and the sedimentary basement [Federico et al. 2002]. Moreover, a systematic contrast in the chemical compositions of the groundwaters flowing on the southern and northern sectors of the volcanic edifice has been demonstrated, with the former being typically characterized by higher outlet temperatures, total dissolved solids, and dissolved  $\text{CO}_2$  contents. These findings clearly indicate that the gas supply is lower on the northern sector of the volcano than on the southern one, which could be ascribed to a structural-geological control of water circulation. According to Federico et al. [2002], carbonate groundwaters flowing from the Apennines to the Tyrrhenian Sea would interact with the central conduit system, thus becoming heated and gas-charged by the ascending hot fluids sustained by deep magma degassing. Further south these  $\text{CO}_2$ -charged carbonate groundwaters may represent a  $\text{CO}_2$  source for the shallow volcanic aquifer, for example in the Torre Annunziata area, where the carbonate aquifer lies at a depth of only 500 m [Celico et al. 1998]. In an alternative proposed model the northern walls of the Somma caldera represent an impermeable barrier to water infiltration, thus forcing groundwaters to flow southward [Federico et al. 2002, Caliro et al. 2005], in which case the groundwaters would dissolve  $\text{CO}_2$  mainly in the crater area [Caliro et al. 2005].

#### **Methods**

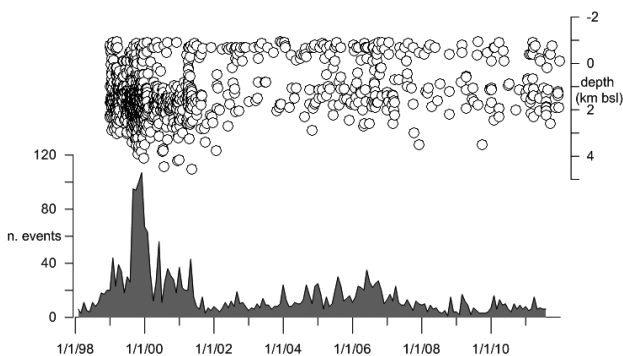
The seismological monitoring of Mt. Vesuvius is performed by INGV-OV personnel using a permanent seismic network that has been active since 1972. Currently the monitoring network consists of 10 stations

equipped with short-period geophones, of which 3 are three-component stations and 2 are short-period three-component digital stations. Moreover, six broadband three-component digital stations are present in the crater area. The installed sensors are 1-Hz velocimeters (Geotech S13 and Mark LE-3D) and broadband sensors (Guralp CMG 40T and Trillium 120P). Seismic data are continuously acquired at  $100 \text{ sample}\cdot\text{s}^{-1}$ , transmitted to an acquisition center in Naples, and stored on hard disks. More information is available in Giudicepietro et al. [2010].

The Mobile Seismic Network of INGV-OV has installed four digital stations at Mt. Vesuvius. MARSlite and Lennartz M24 devices equipped with three-component broadband sensors (Guralp CMG-40T or Lennartz LE-3D/20s) operate on the volcano. The signals are acquired in situ at a sampling rate of 125 or 100 Hz. Further technical details are available elsewhere [Castellano et al. 2012].

A seismic catalogue of Mt. Vesuvius, which contains the occurrence time and the duration magnitude ( $M_D$ ) values of the VT earthquakes, has been compiled since 1972. The relation between the magnitude and the seismic trace duration was calibrated by Del Pezzo et al. [1983] for vesuvian VT earthquakes recorded on the vertical component of the OVO station, located in the western sector of the volcano (Figure 1). Figure 2 shows the monthly distribution of the number of VT earthquakes based on this catalogue. The vesuvian VT earthquakes included in the catalogue were localized using a 3D probabilistic algorithm (NonLinLoc) [Lomax et al. 2000] over the 3D velocity model inferred by Scarpa et al. [2002]. The hypocenter depth as a function of the time is reported in Figure 2.

The hydrogeochemical parameters of the vesuvian aquifer have been monitored since 1998. The first hydrogeochemical monitoring network consisted of 10 private wells that were mainly used for irrigation and 2 springs (Figure 1). Currently the network consists of six



**Figure 2.** Hypocentral depths of vesuvian VT earthquakes as functions of time (upper panel) and the monthly number of VT earthquakes (lower panel).

wells and two springs, while temperature is recorded hourly at selected sites (data not shown). Temperature, pH, Eh, and alkalinity were determined by sampling with conventional field instrumentation; laboratory determinations were carried out at INGV, Palermo, following the procedures described by Federico et al. [2002]. The concentrations of major ions were measured by applying ion chromatography to filtered ( $\text{Cl}^-$ ,  $\text{NO}_3^-$ , and  $\text{SO}_4^{2-}$ ) and filtered and acidified ( $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ , and  $\text{Mg}^{2+}$ ) samples, with an analytical uncertainty of  $<5\%$ . The dissolved gases in water samples were measured after equilibration in a host gas (Ar) and extraction, following the procedure described by Capasso and Inguaggiato [1998]. Analyses were performed using a gas chromatograph (Perkin-Elmer 8500), equipped with 4-m Carbosieve II columns and two detectors (hot wire and flame ionization), with Ar as the carrier gas. The analytical uncertainty was  $<5\%$ .

## Results

The number of VT earthquakes peaked at the time of the October 1999 seismic crisis. The earthquakes belonging to this crisis occurred in the prefractured carbonate basement in response to a release of the regional tectonic stress and are characterized by deep locations and large reductions in stress drop values [Del Pezzo et al. 2004]. The effects of this crisis lasted until the beginning of 2002, after which the seismic activity decreased to very low levels. The hypocenters clustered within the volcanic edifice at depths in the range 0-2.5 km diminished dramatically, and those deeper than 2.5 km practically disappeared. Moreover the stress drop assumed low values. As asserted by many authors [Saccorotti et al. 2002, Del Pezzo et al. 2004], it is likely that most of these VT earthquakes were caused by variations of the pore fluid pressure. These variations could be induced by the local stress perturbations themselves or by charging and discharging mechanisms of the shallow aquifer.

On July 20, 2003, an anomalous low-frequency earthquake with a quasimonochromatic spectrum in the frequency band of 3.5-4 Hz was recorded by all of the stations of the INGV-OV seismic network. It was located at about 4 km b.s.l., and Bianco et al. [2005] reported that it was probably of hydrothermal-volcanic origin.

A slight seismic anomaly began in August 2004, after which the number of VT earthquakes began to increase, reaching a relative maximum in 2006 before returning to very low values. This period included an earthquake (on August 30, 2005) at the very shallow depth of 300 m a.s.l. Using a combination of seismological and geochemical methods, Madonia et al. [2008]



modeled the source mechanism of this VT earthquake as the superposition of tensile cracking and shear failures. The crack opened along the direction orthogonal to the maximum stress axis of the faulting, due to an increase of the pore fluid pressure. This increase could in turn be caused by the variation of the local stress field that enhanced the upward migration of thermal fluids. The 2005 year was also characterized by the absolute minimum of deep seismicity.

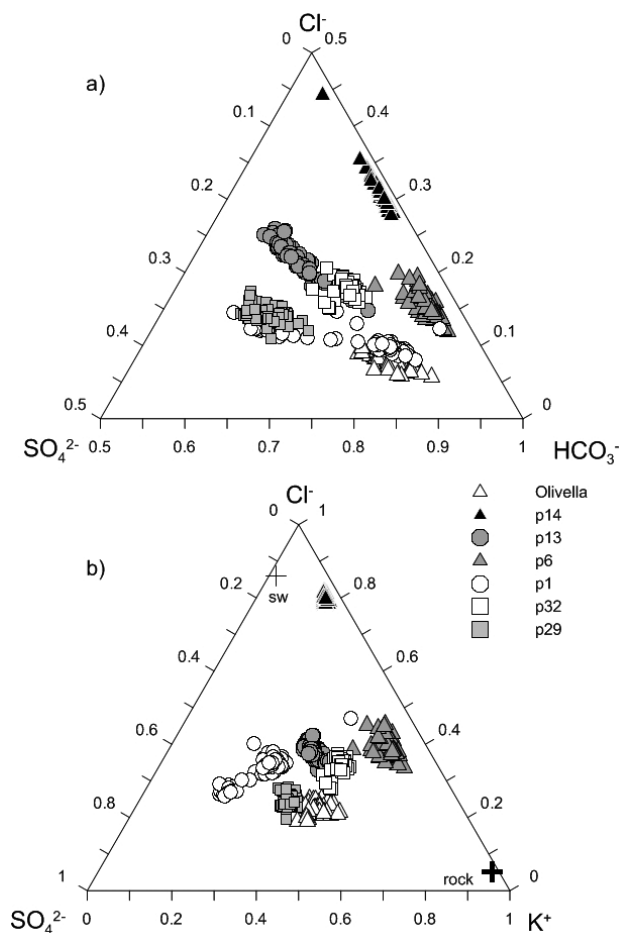
As shown by Federico et al. [2002, 2004], the waters circulating through the vesuvian aquifers are characterized by large spatial and temporal variations in chemical composition (Figure 3). In general, these waters are rich in  $\text{HCO}_3^-$  and their alkali content (here represented by the  $\text{K}^+$  content) is strictly controlled by the  $\text{CO}_2$ -driven mechanism of rock dissolution. Nevertheless, a variable enrichment in either  $\text{Cl}^-$  or  $\text{SO}_4^{2-}$  with respect to the volcanic rock is observed. Sample 14 shows the lowest relative content of  $\text{SO}_4^{2-}$ , while its relative content of  $\text{Cl}^-$  is higher than that in the host rock.

As suggested by Federico et al. [2002], the southern sector of the vesuvian aquifer is characterized by the local ascent of brine-type warm fluids along faults. Among collected samples, well 14 is the most saline ( $\text{Cl} = 2000 \text{ mg}\cdot\text{l}^{-1}$  on average) and, together with spring 13, it is the warmest, which suggests that it is contaminated by hot  $\text{Cl}$ -rich brines.

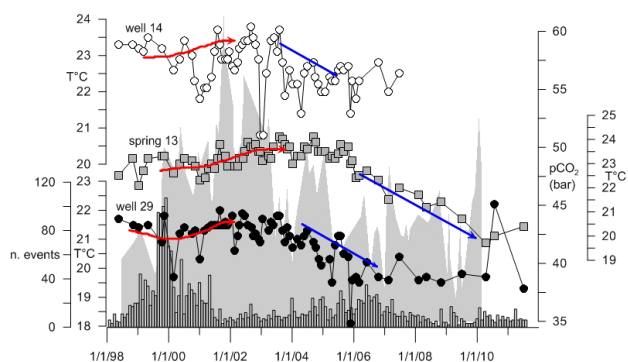
The enrichment in  $\text{SO}_4^{2-}$ , which is mostly observed in samples (namely sites 13, 19, and 29) collected in the Torre Annunziata–Torre del Greco area (where S-rich gas manifestations have been identified along the coast), can be attributed to either the oxidation of hydrothermal S-bearing minerals (i.e., pyrite) or the dissolution of a  $\text{H}_2\text{S}$ -bearing gas phase by groundwater during circulation at depth [Federico et al. 2002]. The enrichment of  $\text{SO}_4^{2-}$  in a few of the wells can be ascribed to the contribution of fluids related to human activities, in particular to the use of SO and N-rich fertilizers or rural sewage, as suggested by Federico et al. [2004]. This effect is evident in samples 47 and 19, which also have higher  $\text{NO}_3^-$  contents (see Appendix).

During the monitored period the vesuvian groundwater exhibited compositional variability, which can be quantified as  $\text{SO}_4^{2-}/\text{HCO}_3^-$  and  $\text{Cl}^-/\text{SO}_4^{2-}$  ratios (Figure 3a). Moreover, significant changes in water salinity are observed at some sites. Figures 4-7 plot the time trends of some significant parameters at selected sites during the entire monitored period.

Figure 4 displays the time trends of the water temperature measured at sites 13, 14 and 29. A common feature is the small ( $<1^\circ\text{C}$ ) and slow increase in temperature after the 1999 earthquake, with a marked decrease of as high as  $4^\circ\text{C}$  occurring after 2003 or 2006 (spring 13).

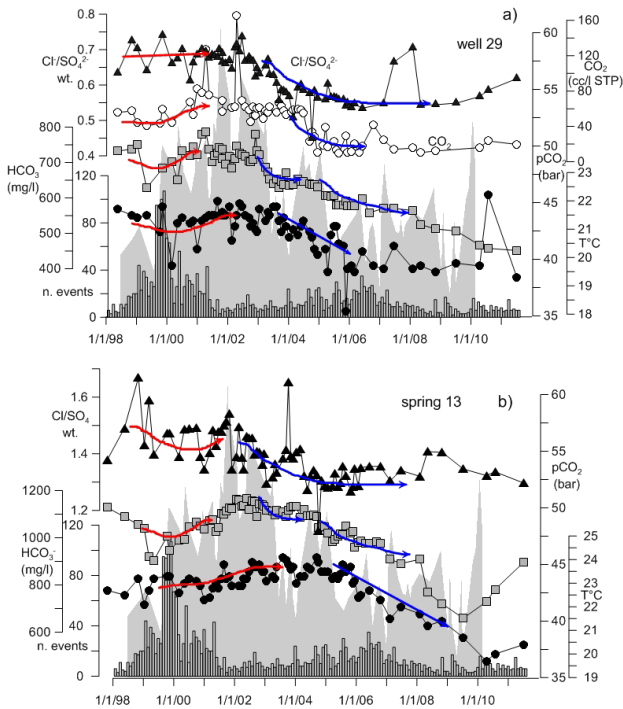


**Figure 3.** a)  $\text{Cl}^-$ - $\text{SO}_4^{2-}$ - $\text{HCO}_3^-$  triangular diagram. b)  $\text{Cl}^-$ - $\text{SO}_4^{2-}$ - $\text{K}^+$  triangular diagram. The average composition of lava and scoriae from Belkin et al. [1998] and the point representative of seawater are plotted for comparison. Concentrations are expressed in units of  $\text{mg}\cdot\text{l}^{-1}$ .



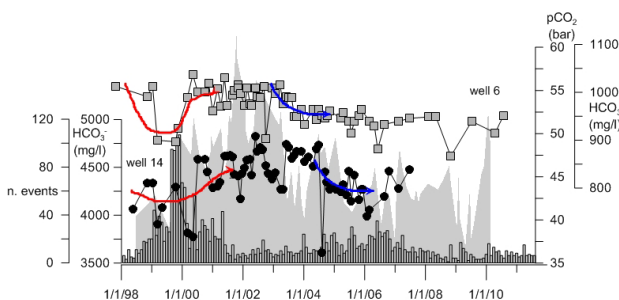
**Figure 4.** Time trends of water temperature at wells 29 and 14 and spring 13. Arrows indicate phases of increases (red) and decreases (blue) in temperature. The time trend of  $\text{pCO}_2$  values, computed for the hydrothermal aquifer by Caliro et al. [2011], is plotted as a shaded area. The histogram shows the monthly number of seismic events.

Temperature variations are paralleled by changes in chemical parameters, as shown in Figures 5-7. Figure 5 shows the time trends of  $\text{HCO}_3^-$  contents,  $\text{Cl}^-/\text{SO}_4^{2-}$  ratios (for sites 13 and 29), dissolved  $\text{CO}_2$  content (for site 29), and water temperature. The time trends of estimated  $\text{pCO}_2$  for the hydrothermal system, computed



**Figure 5.** a) From top to bottom: time trends of the  $Cl^-/SO_4^{2-}$  ratio (triangles), dissolved  $CO_2$  content (open circles),  $HCO_3^-$  content (squares), and water temperature (filled circles) at well 29 (Torre del Greco). b) From top to bottom: time trends of the  $Cl^-/SO_4^{2-}$  ratio (triangles),  $HCO_3^-$  content (squares), and water temperature (filled circles) at spring 13 (Torre Annunziata). Arrows indicate phases of increases (red) and decreases (blue) in the plotted parameters. The time trend of  $pCO_2$  values, computed for the hydrothermal aquifer by Caliro et al. [2011], is plotted as a shaded area. The histogram shows the monthly number of seismic events.

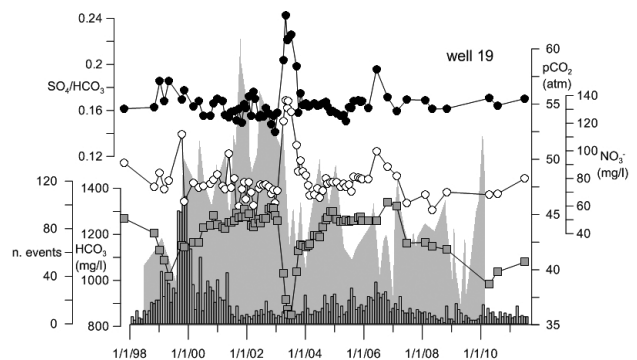
from chemical data of fumarole FC2 by Caliro et al. [2011], are shown in Figure 5 as a shaded area. At well 29, the above-described time trends of temperature follow the changes in dissolved  $CO_2$  content fairly well, with both dramatically decreasing after 2004. The  $HCO_3^-$  concentration exhibits a relative minimum coinciding with the November 1999 earthquake, and then increases along with  $CO_2$  until 2002-2003, when a long-lasting decreasing trend begins, with an overall decrease of about 30%, which is approximately paralleled by



**Figure 6.** Time trends of  $HCO_3^-$  contents at wells 6 and 14. Arrows indicate phases of increases (red) and decreases (blue) in  $HCO_3^-$  contents. The time trend of  $pCO_2$  values, computed for the hydrothermal aquifer by Caliro et al. [2011], is plotted as a shaded area. The histogram shows the monthly number of seismic events.

changes in the  $Cl^-/SO_4^{2-}$  ratio. From 2006 onward, while  $Cl^-/SO_4^{2-}$  ratio remains steady, the  $HCO_3^-$  content continues decreasing. Similarly, the  $HCO_3^-$  content, temperature, and  $Cl^-/SO_4^{2-}$  ratio at site 13 follow very similar trends in the months before and after the 1999 earthquake. Thereafter, while  $Cl^-/SO_4^{2-}$  starts decreasing in 2003 before remaining steady from 2006 onward,  $HCO_3^-$  and temperature start long-lasting decreasing trends in 2004-2005 that stop in 2009-2010, with an overall decrease in the  $HCO_3^-$  content of almost 50%. The time trends of  $HCO_3^-$  contents at two other  $CO_2$ -rich sites from the Torre Annunziata area, namely wells 6 and 14 (Figure 6), confirm the above-described general pattern, characterized by relative decreases in 1999, followed by marked increases soon thereafter and new long-lasting declines from 2003 or 2004. The chemical variations observed at well 19 (Figure 7) in the Torre Annunziata area are worth noting. During 1998-2003 its  $HCO_3^-$  content shows time trends very similar to those for the other described sites. A sharp negative peak in  $HCO_3^-$  was detected in mid-2003, paralleled by comparable positive peaks in the  $NO_3^-$  content and  $SO_4^{2-}/HCO_3^-$  ratio, which last only a few months. The  $HCO_3^-$  finally declines after 2007, which is still ongoing.

Figure 8 illustrates the time trends of some geochemical parameters measured at a spring (yield  $<0.1$   $l \cdot min^{-1}$ ) located on the northern flank of the volcano (Olivella spring; Figure 1). This site shows significant modifications in the water and dissolved gas chemistries and pH at the beginning of the investigated period, corresponding to the seismic sequence of October 1999, which have been attributed to the stress-induced input of acidic volcanic gases – essentially  $CO_2$  and  $H_2S$  [Federico et al. 2004]. An overall increase in  $HCO_3^-$  is evident after the November 1999 earthquake, paralleled by a simultaneous slight decrease in pH (about 0.2 pH units



**Figure 7.** From top to bottom: time trends of the  $SO_4^{2-}/HCO_3^-$  ratio,  $NO_3^-$  content, and  $HCO_3^-$  content at well 19. The time trend of  $pCO_2$  values, computed for the hydrothermal aquifer by Caliro et al. [2011], is plotted as a shaded area. The histogram shows the monthly number of seismic events.

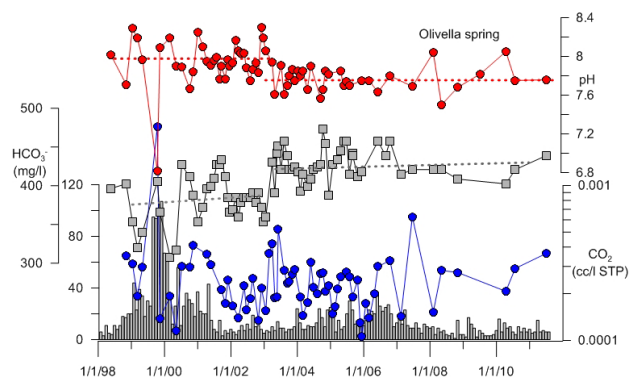
on average) and a marked decline in the  $\text{NO}_3^-$  contents (from 60 to 20  $\text{mg}\cdot\text{l}^{-1}$ ), which represents a marker for the shallower polluted endmember. The compositional change appears particularly evident after 2003.

Finally, time trends of dissolved  $\text{CH}_4/\text{CO}_2$  molar ratios at selected sites (where  $\text{CH}_4$  is detectable) – namely sites 1, 31, and 48 – are shown in Figure 9, in which the  $\text{CO}_2/\text{CH}_4$  ratios measured at fumarole FC2 are plotted as a shaded area [Caliro et al. 2011]. We can observe relatively high  $\text{CH}_4/\text{CO}_2$  ratios at wells 1 and 31 in 1999 (and low  $\text{CO}_2/\text{CH}_4$  ratios at fumarole FC2), followed by very low values during 2000-2001, when  $\text{CO}_2$  progressively increased to  $\text{CH}_4$  at the crater fumarole [Caliro et al. 2011]. Since 2002, progressively higher  $\text{CH}_4/\text{CO}_2$  ratios have been measured in dissolved gases, remaining almost steady during the entire analyzed period. This coincides with the decrease in  $\text{CO}_2$  concentrations at the fumaroles in the crater area.

### General discussion

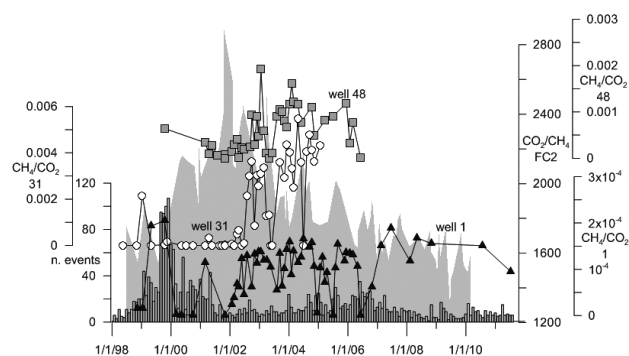
According to previous studies, water circulation on Mt. Vesuvius occurs in different overlapped water bodies that are characterized by different temperatures and salt contents. Higher salinity and Cl content characterize the deep-circulating and gas-charged fluids (partly contaminated by brines in the southern and western sectors), whereas the shallower endmember has a typical bicarbonate-richer composition [Federico et al. 2002, 2004]. Where the brine contribution is small (i.e., at well 6), the water salinity is almost exclusively controlled by the extent of the  $\text{CO}_2$ -driven rock-leaching and, ultimately, by the amount of interacting  $\text{CO}_2$ . Therefore, time changes in the water chemistry at the sampled sites can be reliably ascribed to changes in the mixing proportions of the deeper and shallower endmembers and to the input of  $\text{CO}_2$ .

The mixing proportions of the deeper and shallower endmembers are reliably related to the water flow rate within the aquifers, which in turn results from the variation of pressure gradients and/or permeability, according to the Darcy's law, which describes water flow in porous media. In a volcano-hydrothermal setting we can expect variations of fluid pressure to be controlled by magma degassing and/or the heat and vapor supply to hydrothermal systems [Day 1996, Reid 2004, Thomas et al. 2004]. Additionally, changes in pore pressure can be attributed to changes in the pore space volume, due to stress or self-sealing processes [Kim et al. 1997, Lazear 2009, Mortimer et al. 2011]. As suggested by Madonia et al. [2008], the crustal deformation that caused intense seismic activity in 1999 could also have changed the fluid circulation, as suggested by



**Figure 8.** From top to bottom: time trends of the pH,  $\text{HCO}_3^-$  content, and dissolved  $\text{CO}_2$  content at Olivella spring. The histogram shows the monthly number of seismic events.

water chemistry data (Figures 5-7). Analysis of the entire data record reveals a clear-cut compositional difference between the first 5 years of observations and the later period. In general, the salinity, temperature, and  $\text{CO}_2$  and  $\text{HCO}_3^-$  contents of the wells were highest before 2003, since when (and especially after 2005) there has been a systematic decrease in these parameters characterizing the vesuvian aquifer. We suggest that the higher  $\text{Cl}^-/\text{SO}_4^{2-}$  ratios measured during 1998-2003 at wells 13 and 29, paralleled by higher temperatures and  $\text{HCO}_3^-$  and  $\text{CO}_2$  contents, are indicative of a higher fluid pressure resulting from both the preseismic crustal deformation and the magmatic gas release corresponding to the 1999 seismic crisis. It is worth noting that the fluids emitted from fumaroles in the crater area indeed display the highest magmatic He and  $\text{CO}_2$  contributions for typical hydrothermal gases ( $\text{CH}_4$  and  $\text{H}_2\text{O}$ ) from 2000 to 2003 [Caliro et al. 2011]. The short-lived and moderate decreases in salinity and  $\text{HCO}_3^-$  contents observed in the few months of 1999 when the largest number of seismic events occurred [Madonia et al. 2008] could be ascribed to fracture reopening and an increase in permeability caused by the intense seis-



**Figure 9.** Time trends of  $\text{CH}_4/\text{CO}_2$  molar ratios in the dissolved gas phase at selected sites (namely wells 1, 31, and 48). The time trend of  $\text{CO}_2/\text{CH}_4$  molar ratios, measured at the crater fumarole by Caliro et al. [2011], is plotted as a shaded area. The histogram shows the monthly number of seismic events.



micity. As demonstrated by both field data and numerical modeling, the increase in permeability should favor the circulation of shallow fluids at greater depth [Lazear 2009], thus supporting that the shallow water endmember predominated over the deeper one.

After 2003 there was a clear-cut change in water circulation at several sites – namely 6, 13, 19, and 29, that marks an increasing contribution of the shallower Cl-poorer endmember relative to the deeper saline one. Interestingly, a dramatic change was recorded at well 19 in 2003, where a peak in the  $\text{NO}_3^-$  content (which probably reflects the contribution of shallower polluted water) is paralleled by a decrease in the  $\text{HCO}_3^-$  content.

Mid-2003 was also characterized by the occurrence of an anomalous low-frequency seismic event. Cusano et al. [2013] classified this event as a Long Period (LP) earthquake. The spectral and coda envelope analyses provided evidence of the dominance of sustained low-frequency oscillations, typical of the long-period seismicity (fluid-filled crack resonance). The presence of fluids at the depth of the vesuvian LP event (about 4 km b.s.l.) support the conceptual geochemical model of the volcanic system of Mt. Vesuvius depicted by Caliro et al. [2011], in which the brine sources were positioned just shallower than the LP hypocenter.

On these grounds and taking into account the variations in the groundwater chemistry described in the present work, we suggest that the LP seismic event that occurred in summer 2003 could have caused a pressure decrease that was sustained until that moment by the degassing of magmatic volatiles (mostly  $\text{CO}_2$ ), as observed by Caliro et al. [2011]. The pressure drop could have increased the circulation of shallower fluids into a deeper aquifer, thus explaining the change in chemical composition and the decrease in the saline contents of fluids at the monitored sites.

While the water composition indicates the dominant contribution of shallow water since 2003, the temperature and/or  $\text{CO}_2$  and  $\text{HCO}_3^-$  concentrations at some wells (namely wells 26, 13, 14, and 29) remained high until 2005-2006. This would support inputs of water vapor and  $\text{CO}_2$  into the shallow aquifer, and we cannot exclude that this is also an effect of a reduced confining pressure in the hydrothermal aquifer caused by the 2003 event. Otherwise, as observed in Figure 8, an increase in  $\text{HCO}_3^-$  content from 2003 at Olivella spring is paralleled by a slight reduction in pH (of about 0.2 units), which supports a subsequent higher input of  $\text{CO}_2$ .

The time trends of  $\text{CH}_4/\text{CO}_2$  ratios measured at selected wells (where dissolved  $\text{CH}_4$  is detectable, at  $>10^{-5}$  cc·l $^{-1}$  STP) are compatible with the  $\text{CO}_2/\text{CH}_4$  ratios measured at the crater fumarole [Caliro et al. 2011], and support that the contribution from the hydrother-

mal vapor has been greater than that from the magmatic  $\text{CO}_2$ -richer gases since 2003. Additionally, the  $\text{CH}_4/\text{CO}_2$  ratios in groundwater can vary due to a reduced flux of deep gases, since these gas species have different solubilities in water. Indeed, partial dissolution of gases in water can modify the original gas composition as an effect of the specific solubility coefficients and the relative amount of residual gas, according to a Rayleigh-type fractionation [Federico et al. 2002, Caracausi et al. 2003, Capasso et al. 2005]:

$$\left(\frac{[\text{CH}_4]}{[\text{CO}_2]}\right)_{\text{liq}} = \left(\frac{K_{H,\text{CO}_2}}{K_{H,\text{CH}_4}}\right) \cdot \left(\frac{[\text{CH}_4]}{[\text{CO}_2]}\right)_{\text{gas,in}} \cdot \left(\frac{m_{\text{CO}_2}}{m_{\text{CO}_2,\text{in}}}\right)^{\left(\frac{K_{H,\text{CO}_2}}{K_{H,\text{CH}_4}} - 1\right)} \quad (1)$$

where subscripts liq, gas, and in indicate the liquid phase, gas phase, and initial condition, respectively,  $K_{H,\text{CH}_4}$  and  $K_{H,\text{CO}_2}$  are Henry's constants for the gas species  $\text{CH}_4$  and  $\text{CO}_2$ , and  $m_{\text{CO}_2}$  is the number of moles of  $\text{CO}_2$ . Given the large difference in Henry's constant between  $\text{CH}_4$  and  $\text{CO}_2$  (39,900 and 1667 atm·mol·mol $^{-1}$ , respectively, at 25°C [Wilhelm et al. 1977]), the exponent in Equation (1) is  $<0$ . Therefore, a dramatic reduction in the fraction of the residual gas (i.e.,  $\frac{m_{\text{CO}_2}}{m_{\text{CO}_2,\text{in}}} \ll 1$ ) due to the progressive dissolution in water can be expected to increase the  $\text{CH}_4/\text{CO}_2$  ratios.

The lower salinities, temperatures, and  $\text{CO}_2$  contents from 2006 onward clearly indicate a reduced input of volcanic volatiles and lower fluid pressure in the volcanic aquifer.

## Conclusions

The chemical analyses of water and dissolved gas samples obtained during 1998-2011 indicate that the geochemical behavior of the vesuvian aquifer is strictly controlled by variations in the input of deep-seated volcanic gases and in the stress field. The changes in the stress field, which were responsible for the seismic crisis of 1999, and the almost simultaneous increased input of  $\text{CO}_2$ -rich vapor, significantly affected the recorded composition and temperature of the groundwater. Indeed, an increase in fluid pressure characterized the period from 1998 to 2003, inducing a change in water circulation and the predominance of a deeper water endmember over the shallower one in the vesuvian aquifer. Moreover, the groundwater temperature and dissolved carbon contents (in terms of both  $\text{HCO}_3^-$  and  $\text{CO}_2$ ) are clearly indicative of inputs of  $\text{CO}_2$  and steam until 2005-2006. The termination of the phase of intense deep degassing, as observed in the crater area and in groundwater, is associated with a pressure decrease evident in the water chemistry and paralleled by a peculiar seismic event that was recorded in July 2003. The recent observations of low salinity, temperature,



and dissolved carbon contents in groundwater provide strong evidence for reduced pressure in the volcano-hydrothermal system at Mt. Vesuvius. The variations of specific geochemical parameters can therefore be ascribed to either stress-induced changes in water circulation or changes in the inputs of deep gases. The multidisciplinary approach and the comparison with geophysical signals applied in this study have made it possible to ascertain the roles of the stress field and the degassing of hydrothermal/magmatic systems in producing the observed changes. This has implications when evaluating the reciprocal effects of tectonics and volcanic/hydrothermal activity, which is an open field of investigation.

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Appendix

**Site 6**

| Date (mo/yr) | T (°C) | pH  | Eh (mV) | Na <sup>+</sup> (mg/l) | K <sup>+</sup> (mg/l) | Mg <sup>2+</sup> (mg/l) | Ca <sup>2+</sup> (mg/l) | Cl <sup>-</sup> (mg/l) | NO <sub>3</sub> <sup>-</sup> (mg/l) | SO <sub>4</sub> <sup>2-</sup> (mg/l) | HCO <sub>3</sub> <sup>-</sup> (mg/l) | TDS (mg/l) | CH <sub>4</sub> cc/1STP | CO <sub>2</sub> cc/1STP |
|--------------|--------|-----|---------|------------------------|-----------------------|-------------------------|-------------------------|------------------------|-------------------------------------|--------------------------------------|--------------------------------------|------------|-------------------------|-------------------------|
| 11/98        | 16.9   | 5.9 | -270    | 142                    | 252                   | 83                      | 58                      | 209                    | <0.1                                | 36                                   | 990                                  | 1770       | 5.E-01                  | 1060                    |
| 1/99         | 16.8   | 5.9 | -130    | 136                    | 242                   | 83                      | 57                      | 202                    | <0.1                                | 39                                   | 1010                                 | 1770       | 1.E+00                  | 1090                    |
| 3/99         | 16.4   | 6.1 | -90     | 141                    | 258                   | 81                      | 57                      | 210                    | 0.5                                 | 39                                   | 850                                  | 1710       | <0.0001                 | 520                     |
| 10/99        | 16.7   | 5.8 | -120    | 144                    | 252                   | 90                      | 59                      | 168                    | 0.5                                 | 41                                   | 990                                  | 1660       | 5.E-01                  | 1200                    |
| 11/99        | 16.9   | 5.9 | -280    | 149                    | 243                   | 89                      | 64                      | 170                    | 0.3                                 | 34                                   | 990                                  | 1710       | 7.E-01                  | 943                     |
| 3/00         | 16.8   | 6.1 | -275    | 146                    | 250                   | 84                      | 59                      | 168                    | 4.3                                 | 36                                   | 990                                  | 1730       | n.m.                    | n.m.                    |
| 5/00         | 16.8   | 5.9 | -200    | 151                    | 259                   | 89                      | 56                      | 165                    | 1.9                                 | 31                                   | 1040                                 | 1790       | 2.E-01                  | 990                     |
| 7/00         | 17.1   | 5.8 | -180    | 139                    | 240                   | 92                      | 67                      | 181                    | 1.5                                 | 44                                   | 1030                                 | 1770       | 2.E-01                  | 1230                    |
| 10/00        | 16.7   | 5.7 | -210    | 136                    | 241                   | 92                      | 52                      | 149                    | <0.1                                | 34                                   | 1000                                 | 1680       | n.d.                    | 1520                    |
| 11/00        | 16.6   | 5.8 | -160    | 134                    | 235                   | 85                      | 54                      | 171                    | <0.1                                | 38                                   | 1020                                 | 1740       | 4.E-01                  | 1240                    |
| 1/01         | 16.5   | 6.0 | n.m.    | 137                    | 251                   | 75                      | 57                      | 168                    | 0.2                                 | 36                                   | 960                                  | 1690       | 5.E-02                  | 740                     |
| 3/01         | 16.6   | 5.9 | n.m.    | 144                    | 242                   | 78                      | 71                      | 170                    | <0.1                                | 35                                   | 1010                                 | 1740       | 6.E-04                  | 970                     |
| 4/01         | 16.7   | 5.9 | -50     | 137                    | 237                   | 84                      | 55                      | 155                    | 3.0                                 | 40                                   | 970                                  | 1700       | 5.E-01                  | 950                     |
| 5/01         | 17.1   | 5.7 | 24      | 134                    | 230                   | 88                      | 59                      | 148                    | 0.2                                 | 34                                   | 1030                                 | 1770       | 7.E-02                  | 1190                    |
| 6/01         | 17.1   | 5.9 | 57      | 135                    | 234                   | 88                      | 57                      | 174                    | 0.2                                 | 45                                   | 970                                  | 1700       | <0.0001                 | 830                     |
| 8/01         | 16.7   | 5.9 | -85     | 138                    | 241                   | 89                      | 62                      | 179                    | 5                                   | 45                                   | 990                                  | 1750       | n.m.                    | n.m.                    |
| 9/01         | 16.6   | 5.9 | 60      | 144                    | 243                   | 89                      | 66                      | 171                    | 4.3                                 | 46                                   | 1000                                 | 1760       | n.m.                    | n.m.                    |
| 10/01        | 16.7   | 5.9 | -34     | 144                    | 239                   | 93                      | 66                      | 165                    | 3.7                                 | 47                                   | 1020                                 | 1770       | 4.E-02                  | 850                     |
| 11/01        | 16.6   | 5.8 | 25      | 143                    | 237                   | 90                      | 64                      | 169                    | <0.1                                | 35                                   | 1010                                 | 1750       | <0.0001                 | 450                     |
| 12/01        | 16.7   | 6.0 | 15      | 134                    | 241                   | 84                      | 64                      | 160                    | <0.1                                | 33                                   | 1000                                 | 1710       | n.m.                    | n.m.                    |
| 1/02         | 16.7   | 5.9 | -130    | 136                    | 234                   | 81                      | 60                      | 177                    | <0.1                                | 59                                   | 970                                  | 1720       | 1.E-01                  | 1030                    |
| 2/02         | 16.7   | 6.1 | 30      | 141                    | 236                   | 81                      | 58                      | 144                    | <0.1                                | 39                                   | 1010                                 | 1710       | 6.E-02                  | 1030                    |
| 3/02         | 16.4   | 5.9 | -200    | 142                    | 248                   | 83                      | 61                      | 173                    | <0.1                                | 43                                   | 980                                  | 1730       | 2.E-01                  | 680                     |
| 4/02         | 16.8   | 5.8 | -36     | 144                    | 238                   | 89                      | 59                      | 187                    | <0.1                                | 35                                   | 970                                  | 1720       | 3.E-01                  | 830                     |
| 5/02         | 16.9   | 5.9 | -38     | 143                    | 236                   | 86                      | 58                      | 168                    | <0.1                                | 59                                   | 1010                                 | 1760       | 5.E-01                  | 870                     |
| 6/02         | 16.9   | 6.0 | -20     | 149                    | 249                   | 87                      | 62                      | 174                    | <0.1                                | 47                                   | 990                                  | 1760       | 1.E-01                  | 820                     |
| 7/02         | 17.5   | 5.9 | -200    | 149                    | 248                   | 87                      | 62                      | 171                    | <0.1                                | 48                                   | 990                                  | 1750       | 5.E-01                  | 850                     |
| 9/02         | 17.4   | 5.9 | -180    | 139                    | 236                   | 80                      | 56                      | 168                    | <0.1                                | 36                                   | 1010                                 | 1730       | 6.E-01                  | 820                     |
| 9/02         | 16.7   | 5.9 | -180    | 138                    | 235                   | 78                      | 55                      | 168                    | <0.1                                | 37                                   | 900                                  | 1610       | 8.E-01                  | 850                     |
| 12/02        | 16.3   | 5.8 | -90     | 138                    | 239                   | 79                      | 55                      | 146                    | <0.1                                | 39                                   | 1010                                 | 1710       | 4.E-04                  | 710                     |
| 1/03         | 16.50  | 5.6 | -110    | 141                    | 236                   | 81                      | 52                      | 163                    | 3                                   | 33                                   | 1000                                 | 1700       | 1.E-01                  | 770                     |
| 3/03         | 16.9   | 5.8 | -120    | 158                    | 248                   | 86                      | 57                      | 170                    | <0.1                                | 44                                   | 1020                                 | 1780       | 2.E-04                  | 760                     |
| 4/03         | 16.9   | 5.9 | -150    | 153                    | 243                   | 85                      | 55                      | 210                    | <0.1                                | 37                                   | 980                                  | 1760       | 1.E-04                  | 830                     |
| 5/03         | 17.3   | 5.9 | -210    | 139                    | 248                   | 84                      | 53                      | 172                    | <0.1                                | 36                                   | 990                                  | 1720       | 1.E-04                  | 710                     |

Table A1 (continues on next page).



HYDROLOGY AND SEISMICITY ON MT. VESUVIUS

Site 6

| Date (mo/yr) | T (°C) | pH   | Eh (mV) | Na <sup>+</sup> (mg/l) | K <sup>+</sup> (mg/l) | Mg <sup>2+</sup> (mg/l) | Ca <sup>2+</sup> (mg/l) | Cl <sup>-</sup> (mg/l) | NO <sub>3</sub> <sup>-</sup> (mg/l) | SO <sub>4</sub> <sup>2-</sup> (mg/l) | HCO <sub>3</sub> <sup>-</sup> (mg/l) | TDS (mg/l) | CH <sub>4</sub> cc/1STP | CO <sub>2</sub> cc/1STP |
|--------------|--------|------|---------|------------------------|-----------------------|-------------------------|-------------------------|------------------------|-------------------------------------|--------------------------------------|--------------------------------------|------------|-------------------------|-------------------------|
| 6/03         | 17.6   | n.m. | -180    | 144                    | 252                   | 87                      | 55                      | 174                    | <0.1                                | 38                                   | 990                                  | 1740       | 2.E-03                  | 670                     |
| 7/03         | 17.5   | 6.0  | -190    | 140                    | 248                   | 85                      | 56                      | 182                    | <0.1                                | 47                                   | 990                                  | 1750       | n.m.                    | n.m.                    |
| 8/03         | 17.3   | 6.0  | -170    | 136                    | 241                   | 89                      | 54                      | 190                    | <0.1                                | 58                                   | 990                                  | 1760       | 3.E-02                  | 820                     |
| 9/03         | 17     | 5.9  | -110    | 135                    | 243                   | 91                      | 60                      | 172                    | 0.19                                | 60                                   | 950                                  | 1710       | 3.E-01                  | 860                     |
| 10/03        | 16.9   | 5.8  | -250    | 138                    | 247                   | 87                      | 54                      | 163                    | <0.1                                | 57                                   | 950                                  | 1700       | 3.E-01                  | 1000                    |
| 12/03        | 16.6   | 5.9  | -120    | 135                    | 239                   | 83                      | 60                      | 174                    | <0.1                                | 37                                   | 960                                  | 1690       | 3.E-01                  | 900                     |
| 01/04        | 16.5   | 5.5  | -210    | 132                    | 234                   | 82                      | 58                      | 165                    | <0.1                                | 49                                   | 930                                  | 1650       | 6.E-01                  | 800                     |
| 4/04         | 16.7   | 5.7  | -290    | 138                    | 244                   | 82                      | 58                      | 176                    | 4.34                                | 38                                   | 960                                  | 1700       | 3.E-01                  | 800                     |
| 5/04         | 17     | 5.9  | -140    | 134                    | 241                   | 84                      | 58                      | 176                    | <0.1                                | 47                                   | 940                                  | 1680       | 6.E-02                  | 780                     |
| 6/04         | 16.9   | n.m. | -110    | 135                    | 245                   | 87                      | 60                      | 181                    | <0.1                                | 44                                   | 960                                  | 1720       | 5.E-01                  | 860                     |
| 8/04         | n.m.   | n.m. | n.m.    | 137                    | 243                   | 89                      | 59                      | 192                    | <0.1                                | 56                                   | 950                                  | 1730       | 5.E-01                  | 790                     |
| 9/04         | 16.9   | 5.8  | 140     | 142                    | 254                   | 90                      | 61                      | 201                    | <0.1                                | 72                                   | 950                                  | 1770       | 4.E-01                  | 770                     |
| 10/04        | 16.8   | 5.9  | -85     | 127                    | 246                   | 79                      | 63                      | 178                    | <0.1                                | 61                                   | 950                                  | 1710       | 5.E-01                  | 840                     |
| 11/04        | 16.7   | 5.9  | -85     | 138                    | 243                   | 83                      | 59                      | 172                    | <0.1                                | 42                                   | 960                                  | 1700       | 8.E-01                  | 840                     |
| 3/05         | 16.8   | 5.8  | -100    | 138                    | 254                   | 86                      | 50                      | 176                    | <0.1                                | 46                                   | 950                                  | 1700       | 3.E-01                  | 850                     |
| 4/05         | 16.7   | 5.9  | 43      | 127                    | 227                   | 81                      | 58                      | 165                    | <0.1                                | 38                                   | 960                                  | 1650       | 2.E-01                  | 760                     |
| 6/05         | 16.9   | 5.8  | -180    | 137                    | 244                   | 91                      | 64                      | 195                    | <0.1                                | 54                                   | 940                                  | 1730       | 4.E-01                  | 730                     |
| 7/05         | 16.9   | 5.9  | -160    | 136                    | 241                   | 91                      | 63                      | 202                    | <0.1                                | 67                                   | 920                                  | 1720       | 4.E-04                  | 650                     |
| 8/05         | 16.9   | n.m. | n.m.    | 137                    | 245                   | 89                      | 62                      | 189                    | <0.1                                | 67                                   | 940                                  | 1730       | 4.E-01                  | 760                     |
| 10/05        | 16.8   | n.m. | n.m.    | 135                    | 243                   | 88                      | 63                      | 189                    | <0.1                                | 44                                   | 950                                  | 1710       | 5.E-01                  | 770                     |
| 11/05        | 16.4   | 5.7  | n.m.    | 134                    | 241                   | 86                      | 63                      | 172                    | <0.1                                | 41                                   | 960                                  | 1700       | 5.E-01                  | 790                     |
| 3/06         | 16.7   | n.m. | n.m.    | 141                    | 242                   | 88                      | 62                      | 207                    | <0.1                                | 50                                   | 940                                  | 1730       | 7.E-01                  | 820                     |
| 6/06         | 17     | 5.7  | n.m.    | 139                    | 247                   | 90                      | 65                      | 217                    | <0.1                                | 101                                  | 880                                  | 1740       | 4.E-01                  | 710                     |
| 2/07         | 16.7   | n.m. | n.m.    | 141                    | 244                   | 93                      | 66                      | 225                    | <0.1                                | 38                                   | 940                                  | 1750       | n.m.                    | n.m.                    |
| 6/07         | n.m.   | n.m. | n.m.    | 138                    | 239                   | 95                      | 70                      | 218                    | <0.1                                | 41                                   | 950                                  | 1750       | 5.E-01                  | 820                     |
| 2/08         | 16.8   | 5.9  | -200    | 140                    | 245                   | 92                      | 63                      | 214                    | <0.1                                | 40                                   | 950                                  | 1740       | 3.E-01                  | 840                     |
| 5/08         | 16.9   | n.m. | -50     | 142                    | 248                   | 99                      | 71                      | 235                    | <0.1                                | 35                                   | 950                                  | 1780       | n.m.                    | n.m.                    |
| 10/08        | 17.0   | 5.9  | -240    | 127                    | 218                   | 86                      | 63                      | 226                    | <0.1                                | 56                                   | 870                                  | 1640       | n.m.                    | n.m.                    |
| 7/09         | 17.0   | 6.0  | -220    | 135                    | 245                   | 94                      | 63                      | 232                    | <0.1                                | 48                                   | 940                                  | 1760       | n.m.                    | n.m.                    |
| 4/10         | 17.1   | n.m. | -170    | 127                    | 218                   | 92                      | 67                      | 191                    | <0.1                                | 47                                   | 920                                  | 1660       | n.m.                    | n.m.                    |
| 7/10         | 17.5   | 5.9  | n.m.    | 130                    | 237                   | 92                      | 63                      | 221                    | <0.1                                | 37                                   | 950                                  | 1730       | 3.E-01                  | 760                     |

Table A1 (continued from previous page).

Site 13

| Date (mo./yr) | T (°C) | pH   | Eh (mV) | Na <sup>+</sup> (mg/l) | K <sup>+</sup> (mg/l) | Mg <sup>2+</sup> (mg/l) | Ca <sup>2+</sup> (mg/l) | Cl <sup>-</sup> (mg/l) | NO <sub>3</sub> <sup>-</sup> (mg/l) | SO <sub>4</sub> <sup>2-</sup> (mg/l) | HCO <sub>3</sub> <sup>-</sup> (mg/l) | TDS (mg/l) |
|---------------|--------|------|---------|------------------------|-----------------------|-------------------------|-------------------------|------------------------|-------------------------------------|--------------------------------------|--------------------------------------|------------|
| 5/98          | 22.5   | 6.0  | -90     | 179                    | 328                   | 105                     | 188                     | 360                    | 20.6                                | 242                                  | 1090                                 | 2490       |
| 11/98         | 23.2   | 6.0  | -100    | 185                    | 350                   | 101                     | 167                     | 460                    | <0.1                                | 275                                  | 1060                                 | 2590       |
| 1/99          | 22.1   | 6.2  | -70     | 175                    | 327                   | 101                     | 180                     | 390                    | 3.2                                 | 273                                  | 1040                                 | 2490       |
| 3/99          | 22.7   | 5.9  | -110    | 180                    | 330                   | 101                     | 174                     | 420                    | 0.4                                 | 262                                  | 920                                  | 2390       |
| 5/99          | 23.2   | 5.9  | -260    | 170                    | 333                   | 95                      | 166                     | 360                    | 0.2                                 | 256                                  | 900                                  | 2290       |
| 10/99         | 23.3   | 6.7  | -110    | 173                    | 342                   | 88                      | 164                     | 340                    | 3.5                                 | 231                                  | 1010                                 | 2320       |
| 11/99         | 23.3   | 6.0  | -250    | 159                    | 321                   | 91                      | 149                     | 320                    | 6.8                                 | 219                                  | 950                                  | 2240       |
| 3/00          | 22.6   | 6.0  | -270    | 171                    | 307                   | 92                      | 169                     | 340                    | 5.0                                 | 247                                  | 990                                  | 2320       |
| 5/00          | 23.0   | 6.0  | -160    | 179                    | 326                   | 96                      | 157                     | 380                    | 3.1                                 | 255                                  | 990                                  | 2360       |
| 7/00          | 23.2   | 6.0  | -60     | 178                    | 324                   | 104                     | 186                     | 400                    | 3.1                                 | 268                                  | 1050                                 | 2500       |
| 10/00         | 23.1   | 6.0  | -200    | 200                    | 360                   | 112                     | 179                     | 420                    | <0.1                                | 281                                  | 1070                                 | 2620       |
| 11/00         | 22.9   | 5.9  | -180    | 171                    | 306                   | 96                      | 180                     | 380                    | 1.8                                 | 274                                  | 1050                                 | 2450       |
| 1/01          | 22.3   | 6.0  | n.m.    | 167                    | 340                   | 95                      | 223                     | 390                    | <0.1                                | 265                                  | 1040                                 | 2480       |
| 3/01          | 22.4   | 6.0  | n.m.    | 185                    | 325                   | 105                     | 191                     | 390                    | <0.1                                | 280                                  | 1070                                 | 2560       |
| 4/01          | 22.8   | 6.0  | -35     | 177                    | 325                   | 107                     | 192                     | 390                    | <0.1                                | 263                                  | 1080                                 | 2530       |
| 5/01          | 23.0   | 6.0  | 34      | 181                    | 326                   | 109                     | 191                     | 400                    | <0.1                                | 282                                  | 1030                                 | 2520       |
| 6/01          | 22.8   | 5.93 | 44      | 184                    | 335                   | 108                     | 186                     | 430                    | 5.2                                 | 293                                  | 1040                                 | 2580       |
| 7/01          | 23.2   | 5.99 | -220    | 206                    | 362                   | 111                     | 192                     | 460                    | 6.7                                 | 310                                  | 1100                                 | 2740       |
| 8/01          | 23.8   | 5.74 | -100    | 216                    | 365                   | 116                     | 184                     | 470                    | 5.0                                 | 312                                  | 1100                                 | 2760       |
| 9/01          | 23.2   | 5.93 | -100    | 215                    | 372                   | 117                     | 194                     | 490                    | 4.3                                 | 324                                  | 1110                                 | 2830       |
| 10/01         | 23.3   | 5.93 | -100    | 227                    | 386                   | 123                     | 198                     | 480                    | 1.2                                 | 313                                  | 1130                                 | 2860       |
| 11/01         | 22.9   | 5.95 | 55      | 205                    | 353                   | 120                     | 200                     | 440                    | <0.1                                | 329                                  | 1120                                 | 2770       |
| 01/02         | n.m.   | 5.8  | -90     | 217                    | 390                   | 119                     | 233                     | 470                    | <0.1                                | 341                                  | 1160                                 | 2940       |
| 02/02         | 22.9   | 5.8  | -70     | 220                    | 376                   | 112                     | 206                     | 480                    | 30.4                                | 323                                  | 1160                                 | 2880       |
| 03/02         | 22.9   | 5.9  | -200    | 227                    | 400                   | 119                     | 224                     | 500                    | <0.1                                | 360                                  | 1130                                 | 2960       |
| 04/02         | 23.2   | 5.9  | -150    | 214                    | 386                   | 116                     | 230                     | 450                    | <0.1                                | 335                                  | 1140                                 | 2870       |
| 05/02         | 23.2   | 6.0  | -20     | 224                    | 384                   | 119                     | 207                     | 460                    | <0.1                                | 314                                  | 1170                                 | 2870       |
| 06/02         | 23.5   | 6.1  | -6      | 223                    | 382                   | 112                     | 216                     | 460                    | <0.1                                | 317                                  | 1120                                 | 2830       |
| 07/02         | 23.9   | 6.1  | -190    | 231                    | 390                   | 114                     | 210                     | 470                    | <0.1                                | 325                                  | 1160                                 | 2900       |
| 08/02         | 23.7   | 6.0  | -350    | 231                    | 393                   | 112                     | 194                     | 470                    | <0.1                                | 334                                  | 1150                                 | 2880       |
| 09/02         | 23.7   | 6.0  | -144    | 228                    | 389                   | 110                     | 198                     | 470                    | <0.1                                | 332                                  | 1090                                 | 2820       |
| 10/02         | 23.8   | 5.9  | -140    | 233                    | 398                   | 112                     | 201                     | 470                    | <0.1                                | 332                                  | 1140                                 | 2890       |
| 12/02         | 23.5   | 6.1  | -59     | 227                    | 381                   | 111                     | 198                     | 450                    | <0.1                                | 331                                  | 1140                                 | 2840       |
| 12/02         | 23.5   | 5.9  | 12      | 214                    | 378                   | 107                     | 195                     | 410                    | <0.1                                | 295                                  | 1130                                 | 2730       |
| 01/03         | 23.1   | 5.9  | -43     | 202                    | 343                   | 100                     | 208                     | 410                    | <0.1                                | 318                                  | 1120                                 | 2700       |
| 03/03         | 23.3   | 6.0  | -83     | 225                    | 356                   | 104                     | 203                     | 410                    | <0.1                                | 312                                  | 1110                                 | 2730       |
| 04/03         | 23.2   | 6.0  | -190    | 217                    | 351                   | 102                     | 207                     | 430                    | 7                                   | 318                                  | 1100                                 | 2730       |
| 05/03         | 23.7   | n.m. | -140    | 196                    | 360                   | 98                      | 212                     | 410                    | 4                                   | 306                                  | 1120                                 | 2700       |

Table A2 (continues on next page).

HYDROLOGY AND SEISMICITY ON MT. VESUVIUS

Site 13

| Date (mo./yr) | T (°C) | pH   | Eh (mV) | Na <sup>+</sup> (mg/l) | K <sup>+</sup> (mg/l) | Mg <sup>2+</sup> (mg/l) | Ca <sup>2+</sup> (mg/l) | Cl <sup>-</sup> (mg/l) | NO <sub>3</sub> <sup>-</sup> (mg/l) | SO <sub>4</sub> <sup>2-</sup> (mg/l) | HCO <sub>3</sub> <sup>-</sup> (mg/l) | TDS (mg/l) |
|---------------|--------|------|---------|------------------------|-----------------------|-------------------------|-------------------------|------------------------|-------------------------------------|--------------------------------------|--------------------------------------|------------|
| 08/03         | 24.1   | 6.1  | -110    | 205                    | 380                   | 104                     | 197                     | 430                    | 3                                   | 314                                  | 1110                                 | 2740       |
| 09/03         | 24     | 6.1  | -200    | 199                    | 367                   | 115                     | 202                     | 440                    | 6                                   | 310                                  | 1090                                 | 2720       |
| 10/03         | 23.8   | 6.1  | -93     | 203                    | 369                   | 108                     | 220                     | 480                    | 7                                   | 292                                  | 1120                                 | 2790       |
| 11/03         | 23.6   | 6.0  | -90     | 214                    | 387                   | 105                     | 198                     | 450                    | 6                                   | 320                                  | 1130                                 | 2800       |
| 12/03         | 23.7   | 6.0  | -62     | 208                    | 385                   | 100                     | 205                     | 420                    | 5                                   | 304                                  | 1140                                 | 2760       |
| 01/04         | 23.0   | 5.9  | -200    | 205                    | 373                   | 104                     | 205                     | 420                    | 5                                   | 299                                  | 1140                                 | 2740       |
| 03/04         | 23.3   | 5.8  | -30     | 184                    | 335                   | 95                      | 214                     | 390                    | 0                                   | 272                                  | 1090                                 | 2570       |
| 04/04         | 23.3   | 5.8  | -30     | 185                    | 330                   | 93                      | 212                     | 370                    | 6                                   | 276                                  | 1120                                 | 2580       |
| 05/04         | 23.7   | 6.0  | -27     | 180                    | 324                   | 89                      | 210                     | 340                    | 2                                   | 268                                  | 1090                                 | 2500       |
| 06/04         | 23.6   | n.m. | -82     | 184                    | 337                   | 94                      | 204                     | 370                    | 19                                  | 281                                  | 1090                                 | 2560       |
| 08/04         | n.m.   | n.m. | n.m.    | 203                    | 360                   | 97                      | 200                     | 400                    | 2                                   | 297                                  | 1100                                 | 2650       |
| 09/04         | 24.1   | 6.1  | -90     | 203                    | 368                   | 96                      | 191                     | 400                    | 2                                   | 300                                  | 1090                                 | 2640       |
| 10/04         | 23.9   | 6.0  | -70     | 171                    | 330                   | 75                      | 179                     | 290                    | 16                                  | 253                                  | 1040                                 | 2340       |
| 11/04         | 23.5   | 5.9  | -38     | 169                    | 310                   | 79                      | 180                     | 300                    | 12                                  | 232                                  | 1050                                 | 2320       |
| 12/04         | 23.5   | 5.9  | -18     | 177                    | 322                   | 86                      | 193                     | 340                    | 4                                   | 261                                  | 1050                                 | 2420       |
| 01/05         | 23.5   | n.m. | -37     | 181                    | 322                   | 86                      | 186                     | 340                    | 4                                   | 265                                  | 1020                                 | 2400       |
| 03/05         | 23.2   | 6.0  | -60     | 162                    | 316                   | 78                      | 179                     | 300                    | 7                                   | 234                                  | 980                                  | 2250       |
| 04/05         | 23.3   | 5.8  | 70      | 157                    | 288                   | 74                      | 169                     | 290                    | 9                                   | 214                                  | 990                                  | 2180       |
| 05/05         | 23.2   | 5.9  | -3.5    | 172                    | 314                   | 80                      | 181                     | 310                    | <0.1                                | 238                                  | 1010                                 | 2300       |
| 06/05         | 23.4   | 5.9  | -92     | 183                    | 330                   | 85                      | 186                     | 340                    | <0.1                                | 263                                  | 1020                                 | 2400       |
| 07/05         | 23.8   | 5.9  | -36     | 179                    | 326                   | 84                      | 179                     | 340                    | <0.1                                | 248                                  | 1010                                 | 2360       |
| 08/05         | 23.5   | n.m. | n.m.    | 193                    | 346                   | 91                      | 189                     | 360                    | <0.1                                | 271                                  | 1050                                 | 2500       |
| 10/05         | 23.7   | n.m. | n.m.    | 177                    | 320                   | 81                      | 177                     | 320                    | <0.1                                | 252                                  | 1020                                 | 2340       |
| 11/05         | 23     | n.m. | n.m.    | 182                    | 330                   | 86                      | 182                     | 330                    | <0.1                                | 254                                  | 1030                                 | 2390       |
| 12/05         | 23.1   | n.m. | n.m.    | 167                    | 293                   | 79                      | 177                     | 310                    | <0.1                                | 228                                  | 960                                  | 2210       |
| 01/06         | 22.4   | n.m. | n.m.    | 175                    | 305                   | 83                      | 183                     | 320                    | <0.1                                | 251                                  | 980                                  | 2300       |
| 03/06         | 22.5   | n.m. | n.m.    | 183                    | 319                   | 86                      | 184                     | 350                    | <0.1                                | 262                                  | 980                                  | 2370       |
| 06/06         | 22.7   | 5.9  | n.m.    | 161                    | 294                   | 80                      | 186                     | 310                    | <0.1                                | 228                                  | 980                                  | 2230       |
| 10/06         | 22.3   | 5.8  | -40     | 161                    | 294                   | 80                      | 186                     | 310                    | <0.1                                | 228                                  | 980                                  | 2230       |
| 02/07         | 21.5   | n.m. | n.m.    | 145                    | 259                   | 68                      | 166                     | 250                    | <0.1                                | 192                                  | 910                                  | 1990       |
| 06/07         | 22.0   | 5.9  | -20     | 136                    | 242                   | 63                      | 154                     | 220                    | <0.1                                | 165                                  | 890                                  | 1870       |
| 02/08         | 21.7   | 5.8  | -35     | 128                    | 230                   | 60                      | 138                     | 200                    | <0.1                                | 155                                  | 910                                  | 1824       |
| 05/08         | 21.2   | 6.8  | -150    | 116                    | 213                   | 52                      | 130                     | 190                    | <0.1                                | 137                                  | 770                                  | 1610       |
| 10/08         | 21.4   | 5.8  | -230    | 107                    | 190                   | 47                      | 118                     | 170                    | <0.1                                | 119                                  | 720                                  | 1470       |
| 07/09         | 20.7   | 5.9  | -200    | 88                     | 167                   | 41                      | 108                     | 130                    | <0.1                                | 97                                   | 660                                  | 1290       |
| 04/10         | 19.7   | 5.8  | n.m.    | 88                     | 163                   | 55                      | 154                     | 180                    | <0.1                                | 132                                  | 730                                  | 1500       |
| 07/10         | 20.0   | 5.6  | n.m.    | 103                    | 196                   | 59                      | 165                     | 220                    | <0.1                                | 164                                  | 780                                  | 1690       |
| 07/11         | 20.4   | 5.9  | 40      | 142                    | 247                   | 68                      | 181                     | 280                    | <0.1                                | 212                                  | 900                                  | 2020       |

Table A2 (continued from previous page).

Site 14

| Date (mo./yr) | T (°C) | pH  | Eh (mV) | Na <sup>+</sup> (mg/l) | K <sup>+</sup> (mg/l) | Mg <sup>2+</sup> (mg/l) | Ca <sup>2+</sup> (mg/l) | Cl <sup>-</sup> (mg/l) | NO <sub>3</sub> <sup>-</sup> (mg/l) | SO <sub>4</sub> <sup>2-</sup> (mg/l) | HCO <sub>3</sub> <sup>-</sup> (mg/l) | TDS (mg/l) | CH <sub>4</sub> cc/1STP | CO <sub>2</sub> cc/1STP |
|---------------|--------|-----|---------|------------------------|-----------------------|-------------------------|-------------------------|------------------------|-------------------------------------|--------------------------------------|--------------------------------------|------------|-------------------------|-------------------------|
| 5/98          | 23.3   | 6.3 | -170    | 530                    | 410                   | 760                     | 620                     | 2000                   | <0.1                                | 88                                   | 4060                                 | 8470       | 0.010                   | 500                     |
| 11/98         | 23.3   | 6.4 | -260    | 540                    | 415                   | 770                     | 620                     | 2200                   | 2.4                                 | 86                                   | 4340                                 | 8980       | 0.500                   | 890                     |
| 1/99          | 23.2   | 6.4 | -70     | 560                    | 413                   | 810                     | 590                     | 2020                   | 7.1                                 | 88                                   | 4340                                 | 8810       | 0.180                   | 740                     |
| 3/99          | 23.1   | 6.4 | -90     | 530                    | 433                   | 760                     | 610                     | 1970                   | 0.7                                 | 82                                   | 3910                                 | 8300       | 0.190                   | 1010                    |
| 5/99          | 23.5   | 6.4 | -260    | 530                    | 413                   | 720                     | 590                     | 1830                   | 5.9                                 | 87                                   | 4080                                 | 8470       | 0.080                   | 680                     |
| 10/99         | 23.2   | 6.4 | -150    | 510                    | 429                   | 830                     | 550                     | 1880                   | 1.7                                 | 82                                   | 4290                                 | 8550       | 0.130                   | 730                     |
| 3/00          | 22.6   | 6.5 | -200    | 520                    | 420                   | 790                     | 410                     | 2100                   | 21.0                                | 114                                  | 3820                                 | 8180       | 0.070                   | 900                     |
| 5/00          | 22.9   | 6.9 | -250    | 540                    | 414                   | 830                     | 400                     | 2080                   | 6.8                                 | 113                                  | 3770                                 | 7990       | 0.190                   | 1180                    |
| 7/00          | 23.4   | 6.4 | -200    | 530                    | 401                   | 770                     | 670                     | 1980                   | 17.0                                | 105                                  | 4590                                 | 9120       | 0.001                   | 660                     |
| 10/00         | 23.0   | 6.3 | -130    | 560                    | 422                   | 790                     | 510                     | 1880                   | <0.1                                | 77                                   | 4590                                 | 8970       | 0.230                   | 1030                    |
| 11/00         | 22.3   | 6.3 | -80     | 510                    | 387                   | 790                     | 550                     | 1980                   | <0.1                                | 77                                   | 4450                                 | 8860       | 0.450                   | 1090                    |
| 1/01          | 21.8   | 6.6 | n.m.    | 560                    | 352                   | 800                     | 730                     | 2110                   | 1.2                                 | 71                                   | 4290                                 | 8660       | 0.350                   | 860                     |
| 3/01          | 22.1   | 6.5 | n.m.    | 530                    | 406                   | 780                     | 570                     | 1810                   | 1.2                                 | 80                                   | 4300                                 | 8420       | 0.430                   | 820                     |
| 4/01          | 22.1   | 6.4 | -90     | 510                    | 392                   | 840                     | 610                     | 1860                   | 7.3                                 | 95                                   | 4340                                 | 8640       | 0.340                   | 800                     |
| 5/01          | 22.4   | 6.2 | -80     | 500                    | 392                   | 790                     | 570                     | 1910                   | 0.8                                 | 71                                   | 4620                                 | 8890       | 0.330                   | 960                     |
| 6/01          | 23.1   | 6.4 | -58     | 510                    | 381                   | 810                     | 680                     | 2040                   | 5.0                                 | 84                                   | 4620                                 | 9120       | 0.260                   | 1040                    |
| 7/01          | 23.7   | 6.3 | -90     | 540                    | 405                   | 800                     | 700                     | 2010                   | 32                                  | 95                                   | 4620                                 | 9180       | 0.090                   | 1120                    |
| 8/01          | 23.3   | 6.5 | -80     | 540                    | 408                   | 830                     | 730                     | 2020                   | 21                                  | 85                                   | 4610                                 | 9220       | 0.060                   | 1100                    |
| 9/01          | 22.9   | 6.3 | -60     | 550                    | 404                   | 820                     | 680                     | 2040                   | 20                                  | 84                                   | 4430                                 | 9000       | 0.640                   | 1060                    |
| 10/01         | 22.9   | 6.3 | -60     | 550                    | 398                   | 810                     | 640                     | 2050                   | 6.0                                 | 83                                   | 4410                                 | 8940       | n.m.                    | n.m.                    |
| 11/01         | 22.9   | 6.2 | -40     | 530                    | 383                   | 860                     | 470                     | 1860                   | <0.1                                | 93                                   | 4170                                 | 8370       | n.m.                    | n.m.                    |
| 12/01         | 23.1   | 6.1 | -80     | 550                    | 415                   | 810                     | 650                     | 2010                   | <0.1                                | 97                                   | 4440                                 | 8970       | n.m.                    | n.m.                    |
| 01/02         | 22.7   | 6.3 | -60     | 530                    | 400                   | 820                     | 650                     | 1970                   | <0.1                                | 98                                   | 4490                                 | 8960       | 0.052                   | 910                     |
| 02/02         | 22.6   | 6.0 | -50     | 550                    | 392                   | 810                     | 620                     | 1890                   | <0.1                                | 103                                  | 4580                                 | 8930       | 0.143                   | 910                     |
| 03/02         | 22.8   | 6.1 | n.m.    | 560                    | 396                   | 800                     | 580                     | 1950                   | <0.1                                | 94                                   | 4590                                 | 8970       | 0.099                   | 1180                    |
| 04/02         | 23.2   | 6.4 | -30     | 550                    | 394                   | 810                     | 680                     | 2000                   | 11.8                                | 92                                   | 4420                                 | 8940       | 0.061                   | 700                     |
| 05/02         | 23.3   | 6.4 | -150    | 560                    | 394                   | 800                     | 640                     | 1910                   | <0.1                                | 91                                   | 4830                                 | 9220       | 0.047                   | 650                     |
| 06/02         | 23.4   | 6.5 | -100    | 580                    | 419                   | 800                     | 720                     | 2010                   | <0.1                                | 85                                   | 4660                                 | 9270       | 0.069                   | 670                     |
| 07/02         | 23.4   | 6.5 | -150    | 530                    | 395                   | 750                     | 700                     | 1950                   | 24                                  | 83                                   | 4710                                 | 9110       | 0.051                   | 670                     |
| 08/02         | 23.8   | 6.7 | -110    | 540                    | 392                   | 780                     | 610                     | 1950                   | <0.1                                | 83                                   | 4690                                 | 9030       | 0.059                   | 690                     |
| 09/02         | 23.5   | 6.4 | -130    | 540                    | 396                   | 780                     | 620                     | 1940                   | <0.1                                | 89                                   | 4520                                 | 8880       | 0.170                   | 770                     |
| 10/02         | 23.3   | 6.4 | -150    | 550                    | 411                   | 770                     | 570                     | 1930                   | 22                                  | 88                                   | 4440                                 | 8760       | 0.164                   | 810                     |
| 12/02         | 20.8   | 6.4 | -70     | 540                    | 388                   | 790                     | 530                     | 1810                   | <0.1                                | 93                                   | 4380                                 | 8530       | 0.290                   | 670                     |
| 01/03         | 20.8   | 6.1 | -70     | 550                    | 392                   | 760                     | 530                     | 1840                   | 10                                  | 92                                   | 4440                                 | 8600       | 0.310                   | 680                     |

Table A3 (continues on next page).



HYDROLOGY AND SEISMICITY ON MT. VESUVIUS

Site 14

| Date (mo./yr) | T (°C) | pH   | Eh (mV) | Na <sup>+</sup> (mg/l) | K <sup>+</sup> (mg/l) | Mg <sup>2+</sup> (mg/l) | Ca <sup>2+</sup> (mg/l) | Cl <sup>-</sup> (mg/l) | NO <sub>3</sub> <sup>-</sup> (mg/l) | SO <sub>4</sub> <sup>2-</sup> (mg/l) | HCO <sub>3</sub> <sup>-</sup> (mg/l) | TDS (mg/l) | CH <sub>4</sub> cc/1STP | CO <sub>2</sub> cc/1STP |
|---------------|--------|------|---------|------------------------|-----------------------|-------------------------|-------------------------|------------------------|-------------------------------------|--------------------------------------|--------------------------------------|------------|-------------------------|-------------------------|
| 03/03         | n.m.   | n.m. | n.m.    | 540                    | 402                   | 730                     | 590                     | 1950                   | 12                                  | 92                                   | 4270                                 | 8580       | 0.391                   | 790                     |
| 04/03         | 23.4   | 6.5  | -180    | 590                    | 403                   | 790                     | 680                     | 2160                   | 117                                 | 95                                   | 4270                                 | 8980       | 0.046                   | 810                     |
| 06/03         | 23.5   | n.m. | -220    | 560                    | 431                   | 780                     | 720                     | 1880                   | <0.1                                | 88                                   | 4740                                 | 9200       | 0.165                   | 620                     |
| 07/03         | 23.1   | 6.3  | -150    | 540                    | 408                   | 770                     | 680                     | 1950                   | <0.1                                | 95                                   | 4710                                 | 9150       | n.m.                    | n.m.                    |
| 08/03         | 23.7   | 6.4  | -200    | 550                    | 421                   | 830                     | 670                     | 1950                   | <0.1                                | 99                                   | 4590                                 | 9120       | 0.117                   | 790                     |
| 09/03         | 22.8   | 6.5  | -110    | 550                    | 422                   | 790                     | 690                     | 2060                   | <0.1                                | 91                                   | 4620                                 | 9220       | 0.117                   | 770                     |
| 10/03         | 21.9   | 6.5  | -110    | 540                    | 417                   | 810                     | 630                     | 1930                   | 22.3                                | 121                                  | 4670                                 | 9120       | 0.6177                  | 830                     |
| 12/03         | 22.6   | 6.4  | -140    | 550                    | 418                   | 760                     | 670                     | 1930                   | <0.1                                | 108                                  | 4660                                 | 9100       | 0.160                   | 760                     |
| 01/04         | 22.2   | 6.3  | -180    | 530                    | 405                   | 760                     | 670                     | 1930                   | <0.1                                | 101                                  | 4560                                 | 8950       | n.m.                    | n.m.                    |
| 03/04         | 22.2   | 6.3  | -150    | 530                    | 413                   | 730                     | 670                     | 1850                   | <0.1                                | 124                                  | 4610                                 | 8930       | 0.671                   | 710                     |
| 04/04         | 21.4   | 6.3  | -170    | 510                    | 405                   | 740                     | 670                     | 1960                   | <0.1                                | 110                                  | 4510                                 | 8910       | 0.089                   | 890                     |
| 05/04         | 22.5   | 6.5  | -160    | 530                    | 405                   | 790                     | 720                     | 1930                   | <0.1                                | 113                                  | 4690                                 | 9190       | 0.092                   | 680                     |
| 06/04         | 23.0   | 6.7  | -120    | 540                    | 413                   | 780                     | 690                     | 1870                   | <0.1                                | 112                                  | 4740                                 | 9130       | n.m.                    | n.m.                    |
| 09/04         | 22.8   | 6.6  | -140    | 560                    | 428                   | 780                     | 620                     | 2050                   | <0.1                                | 101                                  | 4450                                 | 8980       | 0.050                   | 750                     |
| 10/04         | 22.4   | 6.4  | -150    | 560                    | 427                   | 830                     | 570                     | 1970                   | <0.1                                | 112                                  | 4340                                 | 8810       | 0.207                   | 760                     |
| 11/04         | 22.2   | 6.3  | -110    | 530                    | 409                   | 750                     | 550                     | 1940                   | <0.1                                | 96                                   | 4270                                 | 8540       | 0.235                   | 620                     |
| 12/04         | 22.0   | 6.4  | -110    | 530                    | 407                   | 780                     | 550                     | 1940                   | <0.1                                | 88                                   | 4290                                 | 8590       | 0.066                   | 650                     |
| 01/05         | 22.0   | n.m. | -80     | 530                    | 410                   | 780                     | 590                     | 1890                   | <0.1                                | 115                                  | 4270                                 | 8580       | n.m.                    | n.m.                    |
| 03/05         | 22.4   | 6.2  | -140    | 530                    | 408                   | 780                     | 490                     | 1830                   | <0.1                                | 106                                  | 4270                                 | 8400       | 0.481                   | 740                     |
| 04/05         | 22.3   | 6.2  | 2.0     | 520                    | 398                   | 750                     | 580                     | 1850                   | <0.1                                | 93                                   | 4320                                 | 8500       | 0.208                   | 610                     |
| 05/05         | 22.3   | 6.2  | -140    | 510                    | 397                   | 740                     | 550                     | 1850                   | <0.1                                | 89                                   | 4210                                 | 8340       | n.m.                    | n.m.                    |
| 06/05         | 22.6   | 6.4  | -130    | 550                    | 404                   | 790                     | 640                     | 1980                   | <0.1                                | 89                                   | 4460                                 | 8920       | 0.097                   | 520                     |
| 07/05         | 22.7   | 6.5  | -140    | 510                    | 387                   | 720                     | 620                     | 1980                   | <0.1                                | 89                                   | 4150                                 | 8460       | 0.137                   | 590                     |
| 08/05         | 22.6   | n.m. | n.m.    | 540                    | 416                   | 780                     | 660                     | 1990                   | <0.1                                | 87                                   | 4420                                 | 8900       | 0.430                   | 840                     |
| 10/05         | 22.7   | n.m. | n.m.    | 550                    | 418                   | 780                     | 570                     | 2060                   | <0.1                                | 95                                   | 4160                                 | 8620       | n.m.                    | n.m.                    |
| 11/05         | 21.4   | 6.3  | n.m.    | 540                    | 414                   | 780                     | 590                     | 1940                   | <0.1                                | 94                                   | 4270                                 | 8630       | 0.430                   | 700                     |
| 12/05         | 22.3   | 6.2  | n.m.    | 570                    | 422                   | 810                     | 590                     | 2060                   | <0.1                                | 85                                   | 4270                                 | 8810       | 0.184                   | 720                     |
| 01/06         | 21.8   | 6.3  | n.m.    | 520                    | 380                   | 730                     | 540                     | 1910                   | <0.1                                | 99                                   | 3990                                 | 8170       | 0.286                   | 740                     |
| 03/06         | 22.3   | 6.4  | n.m.    | 540                    | 397                   | 760                     | 550                     | 2000                   | <0.1                                | 106                                  | 4060                                 | 8400       | n.m.                    | n.m.                    |
| 10/06         | 22.8   | 6.4  | -80     | 540                    | 412                   | 790                     | 590                     | 1890                   | <0.1                                | 89                                   | 4460                                 | 8770       | 0.143                   | 770                     |
| 02/07         | 22.0   | n.m. | n.m.    | 540                    | 407                   | 780                     | 570                     | 1990                   | <0.1                                | 84                                   | 4280                                 | 8660       | n.m.                    | n.m.                    |
| 06/07         | 22.5   | 6.0  | -200    | 550                    | 410                   | 780                     | 670                     | 1960                   | <0.1                                | 91                                   | 4470                                 | 8930       | 0.307                   | 800                     |

Table A3 (continued from previous page).

Site 19

| Date<br>(mo./yr) | T<br>(°C) | pH   | Eh<br>(mV) | Na <sup>+</sup><br>(mg/l) | K <sup>+</sup><br>(mg/l) | Mg <sup>2+</sup><br>(mg/l) | Ca <sup>2+</sup><br>(mg/l) | Cl <sup>-</sup><br>(mg/l) | NO <sub>3</sub> <sup>-</sup><br>(mg/l) | SO <sub>4</sub> <sup>2-</sup><br>(mg/l) | HCO <sub>3</sub> <sup>-</sup><br>(mg/l) | TDS<br>(mg/l) |
|------------------|-----------|------|------------|---------------------------|--------------------------|----------------------------|----------------------------|---------------------------|--|---|---|---------------|
| 11/98            | 21.0      | 6.6  | 140        | 195                       | 361                      | 119                        | 136                        | 331                       | 74                                     | 196                                     | 1210                                    | 2500          |
| 1/99             | 20.9      | 6.6  | 130        | 212                       | 386                      | 130                        | 110                        | 326                       | 84                                     | 210                                     | 1130                                    | 2460          |
| 3/99             | 16.9      | 7.1  | 170        | 202                       | 354                      | 114                        | 93                         | 307                       | 72                                     | 183                                     | 1090                                    | 2300          |
| 5/99             | 21.1      | 6.7  | 90         | 193                       | 360                      | 106                        | 97                         | 266                       | 78                                     | 189                                     | 1020                                    | 2200          |
| 10/99            | 20.8      | 6.7  | 180        | 207                       | 368                      | 122                        | 99                         | 294                       | 112                                    | 195                                     | 1150                                    | 2440          |
| 11/99            | 20.7      | 6.6  | 230        | 203                       | 384                      | 128                        | 110                        | 299                       | 107                                    | 191                                     | 1140                                    | 2390          |
| 3/00             | 20.0      | 6.6  | 110        | 219                       | 381                      | 121                        | 97                         | 283                       | 77                                     | 191                                     | 1170                                    | 2440          |
| 5/00             | 20.9      | 6.7  | 140        | 217                       | 380                      | 118                        | 93                         | 284                       | 73                                     | 184                                     | 1170                                    | 2410          |
| 7/00             | 21.3      | 6.7  | 200        | 206                       | 364                      | 129                        | 107                        | 296                       | 74                                     | 191                                     | 1230                                    | 2470          |
| 10/00            | 20.8      | 6.7  | 160        | 216                       | 385                      | 132                        | 92                         | 300                       | 76                                     | 191                                     | 1240                                    | 2510          |
| 11/00            | 20.7      | 6.5  | 180        | 214                       | 371                      | 132                        | 97                         | 328                       | 79                                     | 208                                     | 1280                                    | 2590          |
| 1/01             | 19.2      | 6.8  | n.m.       | 203                       | 414                      | 131                        | 120                        | 323                       | 71                                     | 191                                     | 1240                                    | 2570          |
| 3/01             | 20.0      | 6.5  | n.m.       | 218                       | 371                      | 130                        | 112                        | 310                       | 76                                     | 201                                     | 1230                                    | 2560          |
| 4/01             | 20.8      | 6.5  | 150        | 215                       | 375                      | 129                        | 91                         | 300                       | 72                                     | 182                                     | 1230                                    | 2490          |
| 5/01             | 21.2      | 6.6  | 150        | 204                       | 362                      | 129                        | 110                        | 314                       | 98                                     | 193                                     | 1250                                    | 2520          |
| 6/01             | 21.0      | 6.5  | 260        | 220                       | 377                      | 137                        | 111                        | 327                       | 73                                     | 199                                     | 1250                                    | 2560          |
| 7/01             | 21.4      | 6.5  | 210        | 228                       | 396                      | 140                        | 103                        | 331                       | 80                                     | 201                                     | 1260                                    | 2600          |
| 8/01             | 22.5      | 6.6  | 190        | 225                       | 389                      | 133                        | 107                        | 320                       | 54                                     | 195                                     | 1290                                    | 2580          |
| 9/01             | 20.9      | 6.5  | 230        | 232                       | 396                      | 142                        | 122                        | 341                       | 60                                     | 205                                     | 1270                                    | 2630          |
| 10/01            | 20.9      | 6.5  | 180        | 242                       | 404                      | 148                        | 122                        | 341                       | 72                                     | 191                                     | 1280                                    | 2650          |
| 11/01            | 20.3      | 6.6  | 190        | 226                       | 397                      | 142                        | 114                        | 339                       | 77                                     | 216                                     | 1310                                    | 2680          |
| 12/01            | 20.2      | 6.6  | 110        | 221                       | 379                      | 130                        | 104                        | 322                       | 65                                     | 207                                     | 1280                                    | 2580          |
| 01/02            | 20.6      | 6.3  | 140        | 216                       | 379                      | 135                        | 111                        | 338                       | 77                                     | 222                                     | 1290                                    | 2630          |
| 02/02            | 20.1      | 6.5  | 240        | 229                       | 385                      | 128                        | 102                        | 308                       | 70                                     | 192                                     | 1240                                    | 2520          |
| 03/02            | 20.0      | 6.1  | n.m.       | 226                       | 396                      | 131                        | 107                        | 334                       | 61                                     | 217                                     | 1230                                    | 2570          |
| 04/02            | 20.4      | 6.5  | -60        | 227                       | 395                      | 130                        | 105                        | 330                       | 47                                     | 213                                     | 1250                                    | 2560          |
| 05/02            | 21.0      | 6.6  | 150        | 222                       | 379                      | 133                        | 100                        | 319                       | 73                                     | 195                                     | 1270                                    | 2550          |
| 06/02            | 21.3      | 6.6  | 170        | 231                       | 389                      | 131                        | 102                        | 320                       | 76                                     | 194                                     | 1250                                    | 2560          |
| 07/02            | 21.5      | 6.5  | 150        | 237                       | 400                      | 134                        | 106                        | 327                       | 75                                     | 196                                     | 1270                                    | 2610          |
| 08/02            | 21.1      | 6.6  | 160        | 235                       | 394                      | 130                        | 98                         | 329                       | 76                                     | 206                                     | 1270                                    | 2610          |
| 09/02            | 20.4      | 6.6  | 110        | 232                       | 391                      | 131                        | 98                         | 334                       | 74                                     | 206                                     | 1310                                    | 2640          |
| 10/02            | 20.8      | 6.5  | 140        | 235                       | 390                      | 128                        | 96                         | 317                       | 69                                     | 195                                     | 1320                                    | 2620          |
| 12/02            | 20.9      | 6.5  | n.m.       | 231                       | 365                      | 131                        | 117                        | 320                       | 72                                     | 204                                     | 1310                                    | 2620          |
| 12/02            | 19.8      | 6.5  | 120        | 227                       | 393                      | 130                        | 92                         | 291                       | 62                                     | 181                                     | 1280                                    | 2530          |
| 01/03            | 19.2      | 6.2  | 120        | 224                       | 375                      | 125                        | 93                         | 300                       | 71                                     | 199                                     | 1260                                    | 2520          |
| 03/03            | n.m.      | n.m. | n.m.       | 211                       | 335                      | 103                        | 93                         | 239                       | 122                                    | 210                                     | 1030                                    | 2240          |
| 04/03            | 20.8      | 6.7  | 150        | 192                       | 310                      | 101                        | 99                         | 245                       | 136                                    | 222                                     | 920                                     | 2120          |
| 05/03            | 20.8      | 6.5  | 160        | 164                       | 301                      | 87                         | 86                         | 189                       | 131                                    | 193                                     | 870                                     | 1940          |

Table A4 (continues on next page).

HYDROLOGY AND SEISMICITY ON MT. VESUVIUS

Site 19

| Date (mo./yr) | T (°C) | pH   | Eh (mV) | Na <sup>+</sup> (mg/l) | K <sup>+</sup> (mg/l) | Mg <sup>2+</sup> (mg/l) | Ca <sup>2+</sup> (mg/l) | Cl <sup>-</sup> (mg/l) | NO <sub>3</sub> <sup>-</sup> (mg/l) | SO <sub>4</sub> <sup>2-</sup> (mg/l) | HCO <sub>3</sub> <sup>-</sup> (mg/l) | TDS (mg/l) |
|---------------|--------|------|---------|------------------------|-----------------------|-------------------------|-------------------------|------------------------|-------------------------------------|--------------------------------------|--------------------------------------|------------|
| 06/03         | 20.9   | n.m. | 160     | 160                    | 287                   | 86                      | 94                      | 186                    | 136                                 | 190                                  | 850                                  | 1910       |
| 07/03         | 21.4   | 6.6  | 160     | 153                    | 278                   | 85                      | 103                     | 197                    | 128                                 | 192                                  | 850                                  | 1900       |
| 09/03         | 21     | 6.5  | n.m.    | 179                    | 326                   | 107                     | 111                     | 261                    | 104                                 | 206                                  | 1040                                 | 2230       |
| 10/03         | 20.3   | 6.6  | 130     | 190                    | 333                   | 118                     | 112                     | 246                    | 85                                  | 179                                  | 1130                                 | 2280       |
| 11/03         | 18.4   | 6.5  | 180     | 198                    | 351                   | 115                     | 119                     | 280                    | 93                                  | 202                                  | 1160                                 | 2400       |
| 12/03         | 18.4   | 6.5  | 120     | 200                    | 360                   | 110                     | 113                     | 268                    | 85                                  | 190                                  | 1150                                 | 2370       |
| 01/04         | 18.5   | 6.3  | 110     | 193                    | 350                   | 109                     | 110                     | 270                    | 82                                  | 190                                  | 1140                                 | 2340       |
| 02/04         | n.m.   | 6.8  | 140     | 192                    | 346                   | 111                     | 110                     | 268                    | 75                                  | 189                                  | 1150                                 | 2330       |
| 03/04         | 19.8   | 6.8  | 140     | 205                    | 363                   | 116                     | 112                     | 285                    | 68                                  | 190                                  | 1160                                 | 2380       |
| 04/04         | 17.6   | 6.6  | 120     | 210                    | 369                   | 118                     | 107                     | 296                    | 68                                  | 198                                  | 1200                                 | 2405       |
| 05/04         | 17.6   | 6.6  | 50      | 211                    | 373                   | 122                     | 108                     | 292                    | 73                                  | 196                                  | 1200                                 | 2450       |
| 06/04         | 21.8   | 6.5  | 90      | 213                    | 388                   | 124                     | 62                      | 300                    | 66                                  | 196                                  | 1190                                 | 2410       |
| 08/04         | n.m.   | n.m. | n.m.    | 219                    | 390                   | 130                     | 107                     | 317                    | 71                                  | 205                                  | 1230                                 | 2540       |
| 09/04         | 21.6   | 6.6  | 10      | 224                    | 401                   | 130                     | 108                     | 326                    | 80                                  | 212                                  | 1260                                 | 2610       |
| 10/04         | 21.3   | 6.5  | 90      | 229                    | 407                   | 139                     | 108                     | 322                    | 76                                  | 208                                  | 1270                                 | 2620       |
| 11/04         | 19.6   | 6.4  | 120     | 226                    | 400                   | 130                     | 108                     | 326                    | 78                                  | 206                                  | 1300                                 | 2640       |
| 12/04         | 19.6   | 6.5  | 120     | 226                    | 403                   | 134                     | 107                     | 327                    | 78                                  | 207                                  | 1300                                 | 2650       |
| 01/05         | 19.3   | n.m. | 70      | 224                    | 403                   | 130                     | 101                     | 308                    | 78                                  | 199                                  | 1270                                 | 2580       |
| 03/05         | 19.4   | 6.4  | 90      | 223                    | 404                   | 134                     | 89                      | 300                    | 74                                  | 195                                  | 1260                                 | 2540       |
| 04/05         | 19.8   | 6.4  | 120     | 224                    | 397                   | 130                     | 108                     | 309                    | 76                                  | 196                                  | 1260                                 | 2570       |
| 05/05         | 20.9   | 6.4  | 100     | 216                    | 385                   | 128                     | 104                     | 296                    | 74                                  | 191                                  | 1260                                 | 2530       |
| 06/05         | 21.6   | 6.4  | 140     | 222                    | 399                   | 132                     | 108                     | 326                    | 76                                  | 204                                  | 1260                                 | 2590       |
| 07/05         | 21.9   | 6.6  | 200     | 224                    | 401                   | 134                     | 111                     | 326                    | 71                                  | 204                                  | 1260                                 | 2600       |
| 08/05         | 22.5   | n.m. | n.m.    | 222                    | 397                   | 134                     | 117                     | 339                    | 81                                  | 212                                  | 1260                                 | 2630       |
| 10/05         | 20.8   | n.m. | n.m.    | 227                    | 404                   | 137                     | 113                     | 338                    | 81                                  | 215                                  | 1270                                 | 2650       |
| 11/05         | 20.1   | 6.4  | n.m.    | 231                    | 413                   | 140                     | 112                     | 339                    | 80                                  | 213                                  | 1280                                 | 2660       |
| 12/05         | 18.2   | 6.5  | n.m.    | 237                    | 404                   | 141                     | 113                     | 353                    | 79                                  | 212                                  | 1260                                 | 2660       |
| 03/06         | 19.4   | 6.5  | n.m.    | 230                    | 390                   | 136                     | 107                     | 336                    | 79                                  | 204                                  | 1260                                 | 2610       |
| 06/06         | 21.2   | 6.3  | n.m.    | 244                    | 433                   | 150                     | 123                     | 389                    | 100                                 | 246                                  | 1260                                 | 2790       |
| 10/06         | 20.8   | 6.5  | 100     | 240                    | 420                   | 150                     | 121                     | 369                    | 89                                  | 230                                  | 1340                                 | 2810       |
| 02/07         | 19.1   | n.m. | n.m.    | 236                    | 410                   | 143                     | 114                     | 339                    | 82                                  | 211                                  | 1320                                 | 2720       |
| 06/07         | 21.8   | 6.5  | 100     | 212                    | 363                   | 125                     | 108                     | 304                    | 62                                  | 197                                  | 1160                                 | 2410       |
| 02/08         | 19.7   | 6.8  | 130     | 213                    | 371                   | 123                     | 105                     | 298                    | 68                                  | 197                                  | 1170                                 | 2420       |
| 05/08         | 20.3   | 6.9  | 120     | 205                    | 355                   | 117                     | 99                      | 270                    | 57                                  | 185                                  | 1150                                 | 2320       |
| 10/08         | 20.7   | 7.0  | 120     | 203                    | 348                   | 113                     | 97                      | 277                    | 70                                  | 183                                  | 1140                                 | 2310       |
| 04/10         | 19.2   | 6.6  | 200     | 167                    | 290                   | 104                     | 93                      | 229                    | 68                                  | 168                                  | 980                                  | 2000       |
| 07/10         | 21.5   | 6.6  | n.m.    | 182                    | 326                   | 100                     | 83                      | 234                    | 69                                  | 170                                  | 1040                                 | 2100       |
| 07/11         | 22.3   | 7.0  | 210     | 194                    | 340                   | 109                     | 89                      | 256                    | 80                                  | 184                                  | 1080                                 | 2220       |

Table A4 (continued from previous page).

Site 29

| Date (mo./yr) | T (°C) | pH   | Eh (mV) | Na <sup>+</sup> (mg/l) | K <sup>+</sup> (mg/l) | Mg <sup>2+</sup> (mg/l) | Ca <sup>2+</sup> (mg/l) | Cl <sup>-</sup> (mg/l) | NO <sub>3</sub> <sup>-</sup> (mg/l) | SO <sub>4</sub> <sup>2-</sup> (mg/l) | HCO <sub>3</sub> <sup>-</sup> (mg/l) | TDS (mg/l) | CH <sub>4</sub> cc/ISTP | CO <sub>2</sub> cc/ISTP |
|---------------|--------|------|---------|------------------------|-----------------------|-------------------------|-------------------------|------------------------|-------------------------------------|--------------------------------------|--------------------------------------|------------|-------------------------|-------------------------|
| 5/98          | 21.7   | 7.0  | -30     | 163                    | 225                   | 68                      | 73                      | 153                    | 4.4                                 | 241                                  | 732                                  | 1660       | 2.2E-2                  | 56                      |
| 11/98         | 21.5   | 7.1  | -604    | 158                    | 229                   | 65                      | 68                      | 180                    | 2.2                                 | 248                                  | 738                                  | 1690       | 2.8E-2                  | 57                      |
| 1/99          | 21.4   | 7.3  | -15     | 162                    | 234                   | 73                      | 79                      | 191                    | 2.5                                 | 272                                  | 750                                  | 1760       | 4.8E-2                  | 44                      |
| 5/99          | 21.5   | 7.4  | -40     | 151                    | 213                   | 69                      | 58                      | 148                    | 1.4                                 | 230                                  | 628                                  | 1500       | 2.0E-1                  | 41                      |
| 10/99         | 20.9   | 7.0  | 120     | 162                    | 217                   | 63                      | 82                      | 149                    | 3.7                                 | 226                                  | 1007                                 | 1910       | 6.9E-2                  | 43                      |
| 11/99         | 21.8   | 6.8  | 120     | 150                    | 217                   | 74                      | 77                      | 163                    | 2.9                                 | 235                                  | 683                                  | 1700       | 2.7E-2                  | 60                      |
| 3/00          | 19.7   | 7.1  | 110     | 160                    | 220                   | 67                      | 75                      | 154                    | 8.5                                 | 232                                  | 702                                  | 1610       | 4.1E-2                  | 44                      |
| 5/00          | 21.2   | 7.5  | 70      | 166                    | 231                   | 68                      | 68                      | 161                    | 6.2                                 | 239                                  | 720                                  | 1570       | n.m.                    | n.m.                    |
| 7/00          | 21.4   | 7.2  | 55      | 151                    | 211                   | 70                      | 83                      | 164                    | 7.5                                 | 234                                  | 732                                  | 1660       | n.m.                    | n.m.                    |
| 10/00         | 21.2   | 7.1  | 70      | 168                    | 219                   | 68                      | 68                      | 146                    | 4.1                                 | 228                                  | 720                                  | 1610       | 2.2E-2                  | 67                      |
| 11/00         | 21.3   | 6.9  | 100     | 156                    | 232                   | 70                      | 72                      | 165                    | 3.8                                 | 247                                  | 744                                  | 1670       | 4.2E-2                  | 54                      |
| 1/01          | 20.3   | 6.9  | n.m.    | 155                    | 227                   | 65                      | 71                      | 166                    | 3.1                                 | 237                                  | 723                                  | 1730       | 3.8E-2                  | 83                      |
| 3/01          | 21.3   | 6.9  | n.m.    | 166                    | 226                   | 74                      | 83                      | 176                    | 3.8                                 | 251                                  | 781                                  | 1770       | n.m.                    | 78                      |
| 4/01          | 21.4   | 6.8  | 70      | 161                    | 229                   | 80                      | 80                      | 158                    | 3.8                                 | 227                                  | 787                                  | 1710       | 6.3E-2                  | 127                     |
| 5/01          | 21.5   | 7.0  | 90      | 152                    | 213                   | 74                      | 79                      | 169                    | 2.9                                 | 250                                  | 738                                  | 1680       | 6.4E-2                  | 76                      |
| 6/01          | 21.5   | 6.9  | 100     | 160                    | 218                   | 74                      | 72                      | 169                    | 5.5                                 | 247                                  | 702                                  | 1650       | n.m.                    | n.m.                    |
| 7/01          | 21.5   | 6.7  | 150     | 162                    | 223                   | 70                      | 73                      | 165                    | 9.2                                 | 241                                  | 720                                  | 1660       | n.m.                    | n.m.                    |
| 8/01          | 22.0   | 6.8  | 70      | 159                    | 222                   | 72                      | 73                      | 156                    | 0.6                                 | 230                                  | 726                                  | 1640       | n.m.                    | n.m.                    |
| 9/01          | 21.5   | 6.9  | 200     | 166                    | 223                   | 75                      | 78                      | 172                    | 4.3                                 | 245                                  | 741                                  | 1700       | n.m.                    | n.m.                    |
| 10/01         | 21.6   | 7.0  | 110     | 149                    | 217                   | 67                      | 70                      | 163                    | 10.4                                | 236                                  | 738                                  | 1650       | 9.6E-3                  | 70                      |
| 01/02         | 21.8   | 6.7  | 90      | 153                    | 211                   | 66                      | 74                      | 176                    | <0.1                                | 262                                  | 717                                  | 1660       | n.m.                    | n.m.                    |
| 02/02         | 20.6   | 6.7  | 110     | 159                    | 214                   | 65                      | 72                      | 148                    | 7                                   | 229                                  | 683                                  | 1580       | 5.4E-2                  | 61                      |
| 03/02         | 21.1   | 6.7  | n.m.    | 157                    | 232                   | 70                      | 69                      | 182                    | <0.1                                | 259                                  | 711                                  | 1680       | 2.3E-2                  | 62                      |
| 04/02         | 21.5   | 6.8  | 70      | 163                    | 229                   | 70                      | 81                      | 183                    | <0.1                                | 257                                  | 747                                  | 1730       | 3.4E-2                  | 165                     |
| 05/02         | 21.9   | 6.9  | 110     | 159                    | 211                   | 67                      | 65                      | 164                    | <0.1                                | 236                                  | 726                                  | 1630       | n.m.                    | n.m.                    |
| 06/02         | 21.8   | 6.9  | 60      | 162                    | 225                   | 68                      | 77                      | 174                    | <0.1                                | 236                                  | 723                                  | 1670       | 4.9E-2                  | 69                      |
| 07/02         | 21.5   | 6.9  | -5      | 164                    | 224                   | 66                      | 74                      | 154                    | <0.1                                | 230                                  | 717                                  | 1630       | 8.7E-2                  | 62                      |
| 09/02         | 21.4   | 6.9  | -25     | 154                    | 211                   | 60                      | 67                      | 159                    | <0.1                                | 234                                  | 705                                  | 1590       | 1.4E-1                  | 59                      |
| 09/02         | 21.1   | 7.3  | -50     | 151                    | 209                   | 60                      | 66                      | 155                    | <0.1                                | 231                                  | 702                                  | 1570       | 7.1E-2                  | 45                      |
| 10/02         | 21.2   | 7.0  | -30     | 163                    | 220                   | 65                      | 67                      | 159                    | <0.1                                | 239                                  | 708                                  | 1620       | 1.4E-1                  | 62                      |
| 12/02         | 21.0   | 7.0  | 40      | 155                    | 215                   | 63                      | 66                      | 138                    | <0.1                                | 221                                  | 781                                  | 1640       | 1.2E-1                  | 52                      |
| 12/02         | 20.9   | 6.9  | 50      | 158                    | 218                   | 64                      | 69                      | 142                    | <0.1                                | 220                                  | 732                                  | 1600       | 8.6E-2                  | 60                      |
| 01/03         | 21.7   | 6.8  | 20      | 166                    | 215                   | 65                      | 71                      | 156                    | 3                                   | 247                                  | 723                                  | 1650       | 1.2E-1                  | 61                      |
| 03/03         | 21.3   | 7.2  | 80      | 175                    | 213                   | 64                      | 63                      | 163                    | <0.1                                | 250                                  | 686                                  | 1620       | 8.5E-2                  | 58                      |
| 04/03         | 21.6   | 6.9  | -90     | 170                    | 211                   | 64                      | 69                      | 181                    | 1                                   | 269                                  | 672                                  | 1640       | 6.7E-2                  | 56                      |
| 05/03         | 21.5   | n.m. | 70      | 153                    | 216                   | 63                      | 69                      | 157                    | 1                                   | 249                                  | 653                                  | 1560       | 6.0E-2                  | 63                      |
| 07/03         | 21.8   | 7.0  | 60      | 152                    | 214                   | 61                      | 68                      | 153                    | <0.1                                | 243                                  | 641                                  | 1530       | n.m.                    | n.m.                    |

Table A5 (continues on next page).



HYDROLOGY AND SEISMICITY ON MT. VESUVIUS

Site 29

| Date (mo./yr) | T (°C) | pH   | Eh (mV) | Na <sup>+</sup> (mg/l) | K <sup>+</sup> (mg/l) | Mg <sup>2+</sup> (mg/l) | Ca <sup>2+</sup> (mg/l) | Cl <sup>-</sup> (mg/l) | NO <sub>3</sub> <sup>-</sup> (mg/l) | SO <sub>4</sub> <sup>2-</sup> (mg/l) | HCO <sub>3</sub> <sup>-</sup> (mg/l) | TDS (mg/l) | CH <sub>4</sub> cc/ISTP | CO <sub>2</sub> cc/ISTP |
|---------------|--------|------|---------|------------------------|-----------------------|-------------------------|-------------------------|------------------------|-------------------------------------|--------------------------------------|--------------------------------------|------------|-------------------------|-------------------------|
| 08/03         | 21.8   | 7.0  | 80      | 142                    | 204                   | 62                      | 72                      | 142                    | 0                                   | 235                                  | 653                                  | 1510       | 3.3E-2                  | 56                      |
| 09/03         | 21.3   | 6.8  | n.m.    | 140                    | 207                   | 63                      | 69                      | 133                    | 3                                   | 239                                  | 628                                  | 1480       | 1.9E-2                  | 66                      |
| 10/03         | 20.9   | 7.0  | 130     | 142                    | 207                   | 60                      | 64                      | 123                    | <0.1                                | 211                                  | 647                                  | 1450       | 1.9E-2                  | 63                      |
| 11/03         | 21.4   | 7.0  | 60      | 148                    | 215                   | 60                      | 67                      | 140                    | 3                                   | 241                                  | 637                                  | 1510       | 8.6E-3                  | 58                      |
| 12/03         | 21.1   | 7.0  | 30      | 146                    | 213                   | 59                      | 69                      | 134                    | <0.1                                | 231                                  | 671                                  | 1520       | <0.001                  | 54                      |
| 01/04         | 20.7   | 6.7  | 50      | 136                    | 205                   | 59                      | 69                      | 131                    | 4                                   | 231                                  | 634                                  | 1470       | n.m.                    | n.m.                    |
| 03/04         | 21.0   | 6.2  | -30     | 143                    | 207                   | 59                      | 69                      | 123                    | 4                                   | 242                                  | 637                                  | 1490       | 2.9E-2                  | 59                      |
| 04/04         | 20.8   | 7.0  | 30      | 144                    | 209                   | 59                      | 69                      | 146                    | 2                                   | 247                                  | 653                                  | 1530       | 2.9E-2                  | 60                      |
| 05/04         | 21.1   | 7.0  | 40      | 143                    | 204                   | 63                      | 75                      | 144                    | 0                                   | 239                                  | 647                                  | 1510       | 2.9E-2                  | 59                      |
| 06/04         | 21.3   | n.m. | 10      | 143                    | 211                   | 60                      | 68                      | 135                    | 0                                   | 230                                  | 647                                  | 1490       | 1.2E-2                  | 55                      |
| 09/04         | 20.9   | 7.0  | 40      | 143                    | 211                   | 60                      | 71                      | 148                    | 0                                   | 257                                  | 641                                  | 1530       | <0.001                  | 23                      |
| 10/04         | 20.7   | 7.1  | 30      | 130                    | 206                   | 50                      | 68                      | 108                    | 0                                   | 239                                  | 637                                  | 1440       | 3.3E-1                  | 33                      |
| 11/04         | 20.3   | 6.9  | 70      | 139                    | 206                   | 57                      | 67                      | 139                    | 4                                   | 238                                  | 637                                  | 1490       | <0.001                  | 29                      |
| 12/04         | 20.1   | 7.3  | 30      | 140                    | 207                   | 60                      | 69                      | 138                    | 2                                   | 245                                  | 631                                  | 1490       | 6.6E-1                  | 10                      |
| 03/05         | 20.3   | 6.9  | 70      | 140                    | 211                   | 60                      | 63                      | 132                    | 0                                   | 236                                  | 607                                  | 1450       | 3.8E-3                  | 39                      |
| 04/05         | 19.5   | 7.3  | 30      | 139                    | 214                   | 60                      | 73                      | 145                    | 0                                   | 240                                  | 607                                  | 1480       | <0.001                  | 17                      |
| 05/05         | 20.8   | 6.8  | -2      | 136                    | 204                   | 59                      | 70                      | 133                    | <0.1                                | 234                                  | 604                                  | 1440       | n.m.                    | n.m.                    |
| 06/05         | 21.1   | 7.3  | 80      | 143                    | 213                   | 58                      | 66                      | 136                    | <0.1                                | 240                                  | 607                                  | 1460       | 2.9E-3                  | 23                      |
| 07/05         | 21.1   | 6.7  | 90      | 134                    | 201                   | 58                      | 70                      | 136                    | <0.1                                | 241                                  | 580                                  | 1420       | 3.9E-3                  | 14                      |
| 08/05         | 20.5   | n.m. | n.m.    | 135                    | 203                   | 58                      | 69                      | 135                    | <0.1                                | 241                                  | 580                                  | 1420       | 4.9E-3                  | 10                      |
| 10/05         | 20.4   | n.m. | n.m.    | 135                    | 203                   | 58                      | 69                      | 135                    | <0.1                                | 241                                  | 580                                  | 1420       | n.m.                    | n.m.                    |
| 11/05         | 18.1   | 6.9  | n.m.    | 132                    | 200                   | 58                      | 69                      | 128                    | <0.1                                | 237                                  | 592                                  | 1420       | 9.3E-3                  | 30                      |
| 12/05         | 19.6   | 7.6  | n.m.    | 139                    | 204                   | 60                      | 71                      | 140                    | <0.1                                | 254                                  | 576                                  | 1440       | 3.6E-3                  | 10                      |
| 01/06         | 19.7   | 7.6  | n.m.    | 131                    | 195                   | 59                      | 73                      | 131                    | <0.1                                | 244                                  | 576                                  | 1410       | 2.8E-3                  | 12                      |
| 03/06         | 19.5   | 7.4  | n.m.    | 134                    | 195                   | 56                      | 67                      | 133                    | <0.1                                | 243                                  | 576                                  | 1410       | <0.001                  | 20                      |
| 06/06         | 20.2   | 7.0  | n.m.    | 135                    | 206                   | 61                      | 74                      | 135                    | <0.1                                | 252                                  | 598                                  | 1460       | 5.5E-3                  | 18                      |
| 10/06         | 19.7   | 6.9  | 150     | n.m.                   | n.m.                  | n.m.                    | n.m.                    | n.m.                   | n.m.                                | n.m.                                 | n.m.                                 | n.m.       | 2.3E-2                  | 42                      |
| 02/07         | 19.6   | n.m. | n.m.    | 135                    | 200                   | 58                      | 72                      | 136                    | <0.1                                | 248                                  | 570                                  | 1420       | 2.8E-3                  | 25                      |
| 06/07         | 20.4   | 7.6  | 30      | 132                    | 198                   | 59                      | 76                      | 155                    | <0.1                                | 233                                  | 570                                  | 1420       | 3.3E-3                  | 14                      |
| 02/08         | 19.6   | 7.6  | -10     | 128                    | 193                   | 58                      | 75                      | 161                    | <0.1                                | 228                                  | 564                                  | 1410       | 4.2E-3                  | 16                      |
| 05/08         | 19.7   | 7.6  | 100     | 124                    | 187                   | 52                      | 69                      | 124                    | <0.1                                | 228                                  | 525                                  | 1310       | 2.8E-3                  | 10                      |
| 10/08         | 19.5   | 7.4  | 70      | 120                    | 181                   | 50                      | 64                      | 120                    | <0.1                                | 220                                  | 512                                  | 1270       | 4.0E-3                  | 12                      |
| 07/09         | 19.8   | 7.4  | 80      | 112                    | 177                   | 48                      | 62                      | 112                    | <0.1                                | 204                                  | 506                                  | 1220       | n.m.                    | n.m.                    |
| 04/10         | 19.7   | 7.4  | 150     | 106                    | 166                   | 45                      | 54                      | 112                    | <0.1                                | 197                                  | 467                                  | 1150       | 5.9E-3                  | 16                      |
| 07/10         | 22.2   | 7.1  | 107     | 107                    | 173                   | 43                      | 55                      | 113                    | <0.1                                | 192                                  | 458                                  | 1140       | 7.8E-3                  | 24                      |
| 07/11         | 19.3   | 7.1  | 140     | 108                    | 170                   | 41                      | 51                      | 111                    | <0.1                                | 180                                  | 451                                  | 1110       | 4.0E-3                  | 20                      |

Table A5 (continued from previous page).

Site 31

| Date (mo/yr) | T (°C) | pH  | Eh (mV) | Na <sup>+</sup> (mg/l) | K <sup>+</sup> (mg/l) | Mg <sup>2+</sup> (mg/l) | Ca <sup>2+</sup> (mg/l) | Cl <sup>-</sup> (mg/l) | NO <sub>3</sub> <sup>-</sup> (mg/l) | SO <sub>4</sub> <sup>2-</sup> (mg/l) | HCO <sub>3</sub> <sup>-</sup> (mg/l) | TDS (mg/l) | CH <sub>4</sub> cc/1STP | CO <sub>2</sub> cc/1STP |
|--------------|--------|-----|---------|------------------------|-----------------------|-------------------------|-------------------------|------------------------|-------------------------------------|--------------------------------------|--------------------------------------|------------|-------------------------|-------------------------|
| 5/98         | 19.0   | 7.0 | -90     | 309                    | 285                   | 191                     | 141                     | 383                    | 5.8                                 | 173                                  | 1650                                 | 3140       | 0.0001                  | 130                     |
| 11/98        | 19.1   | 7.0 | -90     | 313                    | 281                   | 187                     | 133                     | 411                    | 2.7                                 | 167                                  | 1630                                 | 3120       | 0.0001                  | 170                     |
| 1/99         | 18.4   | 6.9 | -90     | 300                    | 269                   | 178                     | 124                     | 448                    | 0.0                                 | 183                                  | 1590                                 | 3100       | 0.3000                  | 140                     |
| 3/99         | 20.1   | 7.0 | -100    | 310                    | 282                   | 183                     | 141                     | 456                    | 1.2                                 | 178                                  | 1590                                 | 3140       | 0.0050                  | 80                      |
| 5/99         | 20.2   | 7.0 | -120    | 285                    | 270                   | 168                     | 134                     | 395                    | 0.2                                 | 185                                  | 1380                                 | 2830       | 0.0004                  | 130                     |
| 10/99        | 19.7   | 7.2 | -110    | 303                    | 277                   | 175                     | 128                     | 412                    | 0.3                                 | 177                                  | 1680                                 | 3150       | 0.0030                  | 120                     |
| 11/99        | 20.7   | 6.8 | -90     | 297                    | 275                   | 184                     | 154                     | 378                    | 0.2                                 | 164                                  | 1560                                 | 3070       | 0.0400                  | 230                     |
| 3/00         | 20.5   | 7.0 | -90     | 302                    | 277                   | 172                     | 135                     | 391                    | 8.7                                 | 177                                  | 1620                                 | 3150       | n.m.                    | n.m.                    |
| 5/00         | 20.4   | 6.9 | -80     | 318                    | 289                   | 182                     | 141                     | 403                    | 1.2                                 | 176                                  | 1650                                 | 3140       | <0.0001                 | 170                     |
| 7/00         | 19.8   | 6.8 | -90     | 290                    | 270                   | 186                     | 139                     | 382                    | 3.2                                 | 173                                  | 1540                                 | 2980       | <0.0001                 | 120                     |
| 10/00        | 18.8   | 6.7 | -110    | 301                    | 286                   | 190                     | 122                     | 383                    | <0.1                                | 176                                  | 1650                                 | 3110       | <0.0001                 | 170                     |
| 11/00        | 20.0   | 6.8 | -90     | 300                    | 262                   | 187                     | 137                     | 384                    | <0.1                                | 178                                  | 1700                                 | 3150       | n.m.                    | n.m.                    |
| 1/01         | 19.7   | 6.9 | n.m.    | 288                    | 256                   | 177                     | 132                     | 383                    | <0.1                                | 165                                  | 1630                                 | 3060       | n.m.                    | n.m.                    |
| 3/01         | 19.6   | 6.8 | n.m.    | 306                    | 271                   | 192                     | 159                     | 415                    | <0.1                                | 185                                  | 1650                                 | 3150       | <0.0001                 | 200                     |
| 4/01         | 20.6   | 7.0 | -90     | 298                    | 263                   | 187                     | 127                     | 414                    | 2.0                                 | 169                                  | 1710                                 | 3210       | 0.05                    | 180                     |
| 5/01         | 20.4   | 6.8 | -50     | 281                    | 266                   | 189                     | 134                     | 412                    | 0.8                                 | 208                                  | 1580                                 | 3070       | <0.0001                 | 180                     |
| 6/01         | 20.3   | 6.8 | -10     | 291                    | 278                   | 199                     | 151                     | 423                    | 1.8                                 | 211                                  | 1580                                 | 3140       | n.m.                    | n.m.                    |
| 7/01         | 20.5   | 6.7 | -110    | 309                    | 280                   | 200                     | 159                     | 432                    | 6.7                                 | 200                                  | 1690                                 | 3280       | n.m.                    | n.m.                    |
| 8/01         | 20.7   | 6.9 | -70     | 287                    | 286                   | 200                     | 130                     | 381                    | 7.3                                 | 240                                  | 1640                                 | 3170       | <0.0001                 | 120                     |
| 9/01         | 19.9   | 6.8 | -50     | 304                    | 271                   | 185                     | 148                     | 385                    | 4.3                                 | 175                                  | 1680                                 | 3150       | <0.0001                 | 120                     |
| 10/01        | 19.8   | 6.8 | -40     | 282                    | 291                   | 194                     | 148                     | 408                    | 4.3                                 | 234                                  | 1520                                 | 3080       | <0.0001                 | 130                     |
| 11/01        | 19.9   | 6.7 | -60     | 315                    | 281                   | 201                     | 141                     | 416                    | <0.1                                | 221                                  | 1690                                 | 3260       | <0.0001                 | 150                     |
| 12/01        | 20.0   | 6.9 | -70     | 292                    | 259                   | 181                     | 139                     | 387                    | <0.1                                | 186                                  | 1660                                 | 3100       | n.m.                    | n.m.                    |
| 1/02         | 20.3   | 6.7 | -70     | 285                    | 263                   | 179                     | 140                     | 373                    | <0.1                                | 174                                  | 1680                                 | 3090       | 0.01                    | 140                     |
| 2/02         | 19.9   | 6.8 | -30     | 320                    | 281                   | 195                     | 138                     | 407                    | <0.1                                | 190                                  | 1680                                 | 3210       | <0.0001                 | 130                     |
| 3/02         | 20.1   | 6.8 |         | 305                    | 269                   | 188                     | 138                     | 418                    | <0.1                                | 199                                  | 1680                                 | 3200       | 0.1                     | 200                     |
| 4/02         | 20.0   | 6.9 | -80     | 294                    | 277                   | 187                     | 145                     | 374                    | <0.1                                | 194                                  | 1650                                 | 3120       | 0.1                     | 210                     |
| 5/02         | 20.1   | 6.9 | -60     | 298                    | 273                   | 195                     | 136                     | 406                    | <0.1                                | 204                                  | 1710                                 | 3220       | <0.0001                 | 160                     |
| 6/02         | 20.1   | 6.8 | -30     | n.m.                   | n.m.                  | n.m.                    | n.m.                    | n.m.                   | n.m.                                | n.m.                                 | n.m.                                 | n.m.       | 0.01                    | 120                     |

Table A6 (continues on next page).

HYDROLOGY AND SEISMICITY ON MT. VESUVIUS

Site 31

| Date<br>(mo./yr) | T<br>(°C) | pH   | Eh<br>(mV) | Na <sup>+</sup><br>(mg/l) | K <sup>+</sup><br>(mg/l) | Mg <sup>2+</sup><br>(mg/l) | Ca <sup>2+</sup><br>(mg/l) | Cl <sup>-</sup><br>(mg/l) | NO <sub>3</sub> <sup>-</sup><br>(mg/l) | SO <sub>4</sub> <sup>2-</sup><br>(mg/l) | HCO <sub>3</sub> <sup>-</sup><br>(mg/l) | TDS<br>(mg/l) | CH <sub>4</sub><br>cc/1STP | CO <sub>2</sub><br>cc/1STP |
|------------------|-----------|------|------------|---------------------------|--------------------------|----------------------------|----------------------------|---------------------------|--|---|---|---------------|----------------------------|----------------------------|
| 7/02             | 19.9      | 6.9  | -80        | n.m.                      | n.m.                     | n.m.                       | n.m.                       | n.m.                      | n.m.                                   | n.m.                                    | n.m.                                    | n.m.          | 0.3                        | 130                        |
| 8/02             | 19.9      | 6.9  | -80        | n.m.                      | n.m.                     | n.m.                       | n.m.                       | n.m.                      | n.m.                                   | n.m.                                    | 1700                                    | n.m.          | 0.4                        | 130                        |
| 9/02             | 19.5      | 7.0  | -80        | 315                       | 264                      | 179                        | 121                        | 370                       | <0.1                                   | 166                                     | 1690                                    | 3100          | 0.5                        | 140                        |
| 10/02            | 19.8      | 6.9  | -110       | 305                       | 278                      | 182                        | 153                        | 413                       | <0.1                                   | 182                                     | 1690                                    | 3210          | 0.15                       | 170                        |
| 12/02            | 19.7      | 7.0  | -90        | 311                       | 267                      | 185                        | 125                        | 338                       | <0.1                                   | 149                                     | 1720                                    | 3100          | 0.5                        | 150                        |
| 12/02            | 19.6      | 7.0  | -110       | 306                       | 266                      | 181                        | 120                        | 355                       | <0.1                                   | 159                                     | 1750                                    | 3140          | 0.3                        | 110                        |
| 1/03             | 19.0      | 6.8  | -87        | 305                       | 256                      | 174                        | 118                        | 350                       | <0.1                                   | 160                                     | 1760                                    | 3130          | 0.4                        | 140                        |
| 2/03             | n.m.      | n.m. | n.m.       | n.m.                      | n.m.                     | n.m.                       | n.m.                       | n.m.                      | n.m.                                   | n.m.                                    | n.m.                                    | n.m.          | 0.4                        | 130                        |
| 3/03             | 19.4      | 7.0  | -40        | 325                       | 213                      | 177                        | 120                        | 359                       | <0.1                                   | 198                                     | 1640                                    | 3040          | 0.2                        | 140                        |
| 4/03             | 19.8      | 6.8  | -90        | 296                       | 275                      | 186                        | 129                        | 398                       | 3                                      | 215                                     | 1670                                    | 3170          | 0.2                        | 130                        |
| 5/03             | 19.6      | n.m. | -100       | 286                       | 285                      | 178                        | 105                        | 390                       | <0.1                                   | 198                                     | 1700                                    | 3140          | 0.0003                     | 110                        |
| 6/03             | 20.3      | n.m. | -90        | 283                       | 291                      | 176                        | 117                        | 390                       | <0.1                                   | 206                                     | 1700                                    | 3160          | <0.0001                    | 130                        |
| 7/03             | n.m.      | n.m. | n.m.       | 302                       | 294                      | 195                        | 121                        | 368                       | <0.1                                   | 195                                     | 1650                                    | 3120          | n.m.                       | n.m.                       |
| 8/03             | n.m.      | n.m. | n.m.       | 264                       | 271                      | 177                        | 103                        | 308                       | <0.1                                   | 190                                     | 1620                                    | 2930          | n.m.                       | n.m.                       |
| 9/03             | n.m.      | n.m. | n.m.       | 265                       | 267                      | 191                        | 110                        | 358                       | 2                                      | 173                                     | 1574                                    | 2940          | 0.5                        | 130                        |
| 10/03            | n.m.      | n.m. | n.m.       | 306                       | 277                      | 189                        | 115                        | 332                       | <0.1                                   | 141                                     | 1690                                    | 3050          | n.m.                       | n.m.                       |
| 11/03            | n.m.      | n.m. | n.m.       | 309                       | 276                      | 182                        | 140                        | 389                       | <0.1                                   | 171                                     | 1710                                    | 3180          | 0.4                        | 130                        |
| 12/03            | n.m.      | n.m. | n.m.       | 311                       | 286                      | 172                        | 125                        | 367                       | <0.1                                   | 163                                     | 1690                                    | 3120          | 0.7                        | 150                        |
| 1/04             | 18.6      | 7.10 | -170       | 296                       | 272                      | 168                        | 122                        | 345                       | <0.1                                   | 154                                     | 1650                                    | 3010          | 0.6                        | 150                        |
| 2/04             | n.m.      | n.m. | n.m.       | n.m.                      | n.m.                     | n.m.                       | n.m.                       | n.m.                      | n.m.                                   | n.m.                                    | n.m.                                    | n.m.          | 0.5                        | 150                        |
| 3/04             | 19.5      | 7.20 | -130       | 298                       | 279                      | 180                        | 129                        | 355                       | <0.1                                   | 177                                     | 1660                                    | 3080          | 0.4                        | 150                        |
| 4/04             | 19.6      | 6.80 | 7          | 294                       | 269                      | 173                        | 125                        | 366                       | 9                                      | 163                                     | 1600                                    | 3000          | 0.8                        | 140                        |
| 5/04             | 19.4      | 6.9  | -150       | 296                       | 269                      | 172                        | 119                        | 417                       | <0.1                                   | 24                                      | 1620                                    | 2910          | 0.6                        | 160                        |
| 6/04             | 19.9      | n.m. | -110       | 293                       | 272                      | 175                        | 119                        | 325                       | <0.1                                   | 143                                     | 1680                                    | 3000          | <0.0001                    | 150                        |
| 8/04             | n.m.      | n.m. | n.m.       | 290                       | 266                      | 171                        | 119                        | 356                       | <0.1                                   | 158                                     | 1600                                    | 2960          | 0.5                        | 120                        |
| 9/04             | 19.1      | 7.0  | -180       | 295                       | 273                      | 172                        | 115                        | 356                       | <0.1                                   | 160                                     | 1660                                    | 3030          | 0.6                        | 130                        |
| 10/04            | 19        | 6.9  | -100       | 299                       | 269                      | 189                        | 114                        | 365                       | <0.1                                   | 166                                     | 1640                                    | 3040          | 0.6                        | 140                        |
| 11/04            | 19.1      | 6.9  | -100       | 299                       | 272                      | 174                        | 123                        | 353                       | <0.1                                   | 167                                     | 1690                                    | 3070          | 0.5                        | 150                        |
| 1/05             | 19.1      | n.m. | -130       | 299                       | 278                      | 179                        | 116                        | 353                       | <0.1                                   | 158                                     | 1650                                    | 3030          | 0.6                        | 140                        |

Table A6 (continued from previous page).

Olivella

| Date (mo/yr) | T (°C) | pH   | Eh (mV) | Na <sup>+</sup> (mg/l) | K <sup>+</sup> (mg/l) | Mg <sup>2+</sup> (mg/l) | Ca <sup>2+</sup> (mg/l) | Cl <sup>-</sup> (mg/l) | NO <sub>3</sub> <sup>-</sup> (mg/l) | SO <sub>4</sub> <sup>2-</sup> (mg/l) | HCO <sub>3</sub> <sup>-</sup> (mg/l) | TDS (mg/l) | CO <sub>2</sub> cc/STP |
|--------------|--------|------|---------|------------------------|-----------------------|-------------------------|-------------------------|------------------------|-------------------------------------|--------------------------------------|--------------------------------------|------------|------------------------|
| 5/98         | 13.2   | 8.0  | 110     | 50                     | 72                    | 22                      | 78                      | 36                     | 56                                  | 52                                   | 400                                  | 730        | n.m.                   |
| 11/98        | 14.1   | 7.7  | 180     | 52                     | 75                    | 20                      | 70                      | 37                     | 60                                  | 57                                   | 400                                  | 740        | 8                      |
| 1/99         | 10.7   | 8.3  | 60      | 52                     | 74                    | 23                      | 65                      | 38                     | 61                                  | 60                                   | 350                                  | 690        | 7                      |
| 3/99         | 9.2    | 8.2  | 190     | 52                     | 75                    | 22                      | 63                      | 37                     | 60                                  | 63                                   | 320                                  | 660        | 4                      |
| 5/99         | 12.8   | 8.0  | 120     | 53                     | 73                    | 24                      | 79                      | 38                     | 58                                  | 60                                   | 340                                  | 690        | 7                      |
| 10/99        | 13.7   | 6.8  | -150    | 55                     | 78                    | 24                      | 81                      | 38                     | 64                                  | 64                                   | 410                                  | 770        | 19                     |
| 11/99        | 12.7   | 8.1  | 240     | 51                     | 80                    | 27                      | 68                      | 38                     | 64                                  | 62                                   | 370                                  | 720        | 3                      |
| 3/00         | 10.8   | 8.2  | 230     | 54                     | 70                    | 21                      | 60                      | 44                     | 52                                  | 57                                   | 310                                  | 620        | 4                      |
| 5/00         | 12.7   | 7.9  | 130     | 53                     | 76                    | 22                      | 78                      | 37                     | 57                                  | 60                                   | 320                                  | 640        | 3                      |
| 7/00         | 13.4   | 7.9  | 210     | 51                     | 73                    | 25                      | 76                      | 36                     | 60                                  | 62                                   | 430                                  | 770        | 7                      |
| 10/00        | 13.5   | 7.7  | 160     | 56                     | 78                    | 25                      | 72                      | 34                     | 56                                  | 61                                   | 410                                  | 760        | 7                      |
| 11/00        | 13.3   | 7.8  | 170     | 50                     | 72                    | 22                      | 66                      | 36                     | 51                                  | 60                                   | 390                                  | 700        | 9                      |
| 1/01         | 9.3    | 8.3  | n.m.    | 52                     | 60                    | 20                      | 61                      | 32                     | 42                                  | 48                                   | 350                                  | 670        | 2                      |
| 3/01         | 12.2   | 8.1  | n.m.    | 50                     | 72                    | 24                      | 71                      | 34                     | 51                                  | 50                                   | 370                                  | 680        | 3                      |
| 4/01         | 12.4   | 8.0  | 150     | 47                     | 69                    | 23                      | 69                      | 32                     | 40                                  | 46                                   | 400                                  | 690        | 8                      |
| 5/01         | 13.2   | 7.9  | 180     | 47                     | 69                    | 22                      | 67                      | 34                     | 42                                  | 53                                   | 400                                  | 700        | 7                      |
| 6/01         | 13.5   | 8.0  | 280     | 49                     | 72                    | 22                      | 74                      | 41                     | 44                                  | 59                                   | 410                                  | 730        | n.m.                   |
| 7/01         | 13.7   | 8.0  | 140     | 54                     | 76                    | 23                      | 75                      | 37                     | 46                                  | 53                                   | 430                                  | 750        | n.m.                   |
| 8/01         | 13.8   | 7.8  | 240     | 53                     | 76                    | 24                      | 75                      | 37                     | 45                                  | 53                                   | 430                                  | 750        | n.m.                   |
| 9/01         | 13.6   | 7.9  | 230     | 55                     | 76                    | 25                      | 74                      | 36                     | 49                                  | 53                                   | 430                                  | 770        | 5                      |
| 10/01        | 13.8   | 7.8  | 330     | 55                     | 75                    | 24                      | 67                      | 33                     | 45                                  | 51                                   | 410                                  | 730        | 4                      |
| 11/01        | 11.4   | 8.0  | 430     | 54                     | 73                    | 22                      | 68                      | 36                     | 45                                  | 53                                   | 380                                  | 700        | 5                      |
| 12/01        | 7.2    | 7.9  | 250     | 54                     | 68                    | 20                      | 68                      | 42                     | 47                                  | 60                                   | 370                                  | 680        | n.m.                   |
| 01/02        | 8.4    | 7.9  | 290     | 51                     | 68                    | 21                      | 69                      | 40                     | 49                                  | 60                                   | 370                                  | 690        | 4                      |
| 02/02        | 9.7    | 8.2  | 190     | 52                     | 69                    | 20                      | 64                      | 41                     | 43                                  | 57                                   | 380                                  | 690        | n.m.                   |
| 03/02        | 9.1    | 8.1  | 160     | 51                     | 71                    | 22                      | 66                      | 36                     | 38                                  | 54                                   | 360                                  | 660        | 3                      |
| 04/02        | 10.7   | 8.0  | 110     | 53                     | 70                    | 23                      | 66                      | 37                     | 36                                  | 54                                   | 380                                  | 680        | n.m.                   |
| 05/02        | 13.2   | 8.0  | 140     | 54                     | 71                    | 23                      | 64                      | 39                     | 42                                  | 57                                   | 380                                  | 700        | 5                      |
| 06/02        | 13.2   | 7.9  | 170     | 76                     | 76                    | 23                      | 74                      | 44                     | 43                                  | 56                                   | 380                                  | 710        | 4                      |
| 07/02        | 13.6   | 7.8  | 160     | 57                     | 76                    | 23                      | 73                      | 43                     | 43                                  | 61                                   | 380                                  | 720        | 4                      |
| 08/02        | 13.9   | 7.9  | 180     | 54                     | 75                    | 22                      | 69                      | 43                     | 46                                  | 62                                   | 390                                  | 720        | 6                      |
| 09/02        | 12.5   | 7.9  | 130     | 52                     | 72                    | 21                      | 63                      | 41                     | 38                                  | 59                                   | 380                                  | 680        | n.m.                   |
| 10/02        | 13.6   | 7.8  | 180     | 51                     | 71                    | 22                      | 69                      | 40                     | 38                                  | 55                                   | 390                                  | 700        | 3                      |
| 12/02        | 11.6   | 8.3  | 110     | 57                     | 67                    | 21                      | 65                      | 35                     | 38                                  | 52                                   | 370                                  | 670        | 5                      |
| 12/02        | 8.3    | 8.2  | 30      | 49                     | 67                    | 19                      | 59                      | 35                     | 34                                  | 52                                   | 350                                  | 630        | n.m.                   |
| 01/03        | 9.7    | 8.1  | 170     | 51                     | 67                    | 20                      | 62                      | 40                     | 35                                  | 55                                   | 360                                  | 650        | 4                      |
| 03/03        | 13.2   | 7.9  | 180     | 58                     | 73                    | 21                      | 58                      | 39                     | 58                                  | 60                                   | 430                                  | 760        | 9                      |
| 04/03        | 13.0   | 7.6  | 250     | 57                     | 73                    | 22                      | 84                      | 49                     | 49                                  | 73                                   | 390                                  | 750        | 4                      |
| 05/03        | 13.3   | n.m. | 210     | 55                     | 74                    | 22                      | 87                      | 39                     | 45                                  | 59                                   | 440                                  | 780        | 4                      |

Table A7 (continues on next page).

HYDROLOGY AND SEISMICITY ON MT. VESUVIUS

Olivella

| Date<br>(mo/yr) | T<br>(°C) | pH   | Eh<br>(mV) | Na <sup>+</sup><br>(mg/l) | K <sup>+</sup><br>(mg/l) | Mg <sup>2+</sup><br>(mg/l) | Ca <sup>2+</sup><br>(mg/l) | Cl <sup>-</sup><br>(mg/l) | NO <sub>3</sub> <sup>-</sup><br>(mg/l) | SO <sub>4</sub> <sup>2-</sup><br>(mg/l) | HCO <sub>3</sub> <sup>-</sup><br>(mg/l) | TDS<br>(mg/l) | CO <sub>2</sub><br>cc/1STP |
|-----------------|-----------|------|------------|---------------------------|--------------------------|----------------------------|----------------------------|---------------------------|--|---|---|---------------|----------------------------|
| 06/03           | 13.7      | n.m. | 190        | 55                        | 76                       | 23                         | 88                         | 39                        | 43                                     | 58                                      | 450                                     | 790           | 12                         |
| 07/03           | 14.7      | 7.9  | 170        | 55                        | 77                       | 22                         | 83                         | 41                        | 45                                     | 62                                      | 420                                     | 770           | n.m.                       |
| 08/03           | 14.3      | 7.6  | 100        | 52                        | 73                       | 23                         | 89                         | 38                        | 49                                     | 58                                      | 460                                     | 810           | 6                          |
| 09/03           | 14.0      | 7.7  | -50        | 53                        | 76                       | 23                         | 89                         | 39                        | 44                                     | 61                                      | 440                                     | 790           | 5                          |
| 10/03           | 13.8      | 7.8  | 170        | 51                        | 73                       | 22                         | 82                         | 36                        | 42                                     | 51                                      | 420                                     | 740           | 5                          |
| 11/03           | 13.4      | 7.9  | 210        | 52                        | 73                       | 22                         | 75                         | 36                        | 41                                     | 52                                      | 420                                     | 740           | 6                          |
| 12/03           | 11.2      | 7.8  | 90         | 53                        | 71                       | 23                         | 78                         | 35                        | 40                                     | 48                                      | 420                                     | 740           | 6                          |
| 01/04           | 8.80      | 7.9  | 200        | 49                        | 69                       | 23                         | 77                         | 37                        | 37                                     | 46                                      | 420                                     | 720           | n.m.                       |
| 02/04           | 7.90      | 7.8  | 190        | 47                        | 66                       | 22                         | 74                         | 35                        | 31                                     | 45                                      | 390                                     | 680           | 4                          |
| 03/04           | 8.6       | 7.9  | 140        | 54                        | 69                       | 22                         | 72                         | 35                        | 33                                     | 45                                      | 420                                     | 710           | 3                          |
| 4/04            | 11.9      | 7.7  | 150        | 47                        | 67                       | 21                         | 72                         | 34                        | 29                                     | 45                                      | 400                                     | 680           | 4                          |
| 5/04            | 12.8      | 7.9  | 80         | 50                        | 71                       | 22                         | 79                         | 36                        | 40                                     | 52                                      | 410                                     | 720           | 7                          |
| 06/04           | 13.4      | n.m. | 110        | 49                        | 72                       | 22                         | 85                         | 36                        | 37                                     | 55                                      | 420                                     | 740           | 5                          |
| 08/04           | n.m.      | n.m. | n.m.       | 50                        | 70                       | 23                         | 76                         | 35                        | 33                                     | 54                                      | 420                                     | 730           | 5                          |
| 09/04           | 13.7      | 7.6  | 70         | 54                        | 76                       | 23                         | 89                         | 44                        | 48                                     | 71                                      | 430                                     | 790           | 6                          |
| 10/04           | 13.8      | 7.7  | 70         | 55                        | 79                       | 26                         | 94                         | 39                        | 37                                     | 62                                      | 470                                     | 830           | 6                          |
| 11/04           | 12.9      | 7.9  | 20         | 53                        | 74                       | 24                         | 86                         | 36                        | 37                                     | 58                                      | 450                                     | 790           | 5                          |
| 12/04           | 12.5      | 7.8  | 150        | 49                        | 70                       | 21                         | 67                         | 33                        | 30                                     | 51                                      | 390                                     | 680           | 5                          |
| 01/05           | 12.5      | n.m. | 40         | 49                        | 69                       | 22                         | 84                         | 35                        | 38                                     | 52                                      | 430                                     | 740           | 3                          |
| 03/05           | 12.7      | n.m. | 80         | 44                        | 66                       | 23                         | 85                         | 29                        | 35                                     | 40                                      | 430                                     | 730           | 5                          |
| 04/05           | 13.0      | 7.9  | 80         | 49                        | 70                       | 23                         | 89                         | 33                        | 34                                     | 50                                      | 450                                     | 760           | 6                          |
| 05/05           | 13.4      | 7.7  | 40         | 51                        | 73                       | 23                         | 92                         | 35                        | 37                                     | 54                                      | 460                                     | 790           | n.m.                       |
| 06/05           | 13.6      | 7.7  | 130        | 55                        | 76                       | 23                         | 92                         | 37                        | 39                                     | 57                                      | 460                                     | 800           | 6                          |
| 07/05           | 13.8      | 7.7  | 220        | 53                        | 75                       | 23                         | 80                         | 40                        | 37                                     | 62                                      | 420                                     | 750           | 6                          |
| 08/05           | 13.8      | n.m. | n.m.       | 55                        | 77                       | 24                         | 89                         | 40                        | 38                                     | 63                                      | 440                                     | 790           | 4                          |
| 09/05           | 13.7      | n.m. | n.m.       | 54                        | 76                       | 24                         | 89                         | 39                        | 38                                     | 61                                      | 440                                     | 780           | n.m.                       |
| 10/05           | 13.7      | n.m. | n.m.       | 51                        | 72                       | 22                         | 80                         | 37                        | 31                                     | 56                                      | 410                                     | 720           | 6                          |
| 12/05           | 12.0      | 7.8  | n.m.       | 51                        | 71                       | 21                         | 69                         | 30                        | 24                                     | 44                                      | 420                                     | 700           | 2                          |
| 06/06           | 13.4      | 7.6  | n.m.       | 51                        | 73                       | 24                         | 94                         | 35                        | 33                                     | 57                                      | 460                                     | 790           | 7                          |
| 10/06           | 13.8      | 7.8  | 240        | 51                        | 73                       | 24                         | 94                         | 35                        | 33                                     | 56                                      | 460                                     | 790           | 7                          |
| 02/07           | 11.1      | n.m. | n.m.       | 52                        | 72                       | 23                         | 78                         | 38                        | 31                                     | 60                                      | 420                                     | 730           | 3                          |
| 06/07           | 13.3      | 7.7  | 200        | 52                        | 73                       | 24                         | 79                         | 36                        | 32                                     | 64                                      | 420                                     | 750           | 14                         |
| 02/08           | 10.6      | 8.0  | 120        | 52                        | 72                       | 24                         | 82                         | 38                        | 30                                     | 64                                      | 420                                     | 750           | 3                          |
| 05/08           | 12.3      | 7.5  | 200        | 51                        | 70                       | 23                         | 85                         | 32                        | 26                                     | 51                                      | 420                                     | 730           | 6                          |
| 10/08           | 13.4      | 7.7  | 20         | 54                        | 73                       | 24                         | 82                         | 34                        | 35                                     | 74                                      | 410                                     | 750           | 6                          |
| 04/10           | 12.9      | 8.1  | 260        | 45                        | 62                       | 21                         | 81                         | 28                        | 25                                     | 56                                      | 400                                     | 690           | 5                          |
| 07/10           | 13.4      | 7.8  | 100        | 50                        | 72                       | 22                         | 82                         | 35                        | 30                                     | 66                                      | 420                                     | 740           | 7                          |
| 07/11           | 13.3      | 7.8  | 100        | 54                        | 71                       | 22                         | 81                         | 32                        | 24                                     | 64                                      | 440                                     | 760           | 8                          |

Table A7 (continued from previous page).