The « Salinelle of Mt. Etna » Geosite: thermo-physical and geochemical monitoring of hydrothermal fluids, aimed at understanding both their geothermal potential and their possible correlations with Mt. Etna activity

« Possibilities and limitations of geothermal energy use for heating and production of electricity at volcanic islands »

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Main objective of the work

Monitoring of hydrothermal fluid emissions in a volcanic area
- Analysis of daily temperatures
- Geothermal fluids upwelling (convective heat transfer)
- Geochemical characteristics

Analysis of the magnitude and frequency of seismic events
- Tectonic stress or deeper gas input
- Relationship between hydrothermal vents and volcanic activity

Evaluation of geothermal potential of the secondary hydrothermal system of Mt. Etna
Geological and geographical background

Salinelle dei Cappuccini

Salinelle del Fiume

Salinelle di San Biagio

Hydrothermal vents (mud volcanoes) on the SW flank of the Mt. Etna volcano, with greatly different features

Fluids emitted made up of a mixture of gases (mostly CO$_2$ of magmatic origin) and muddy hypersaline waters

Mt. Etna volcano lavas rises about 3300 m above sea level, forming a central cone gradually reducing his thickness.

Salinelle formed over the accretionary wedge developing in front of the Apennine-Maghrebian fold and thrust belt
Salinelle dei Cappuccini

The most active site, on the extinct volcanic hill “Conetto dei Cappuccini” (Capuchin monastery)

Outcropping sub-alkali to alkali-sodic lavas (pre-Etna volcano $\rightarrow 42.1\pm10.4$ to $28.7\pm12.6$ ka)

3 surveys over 1 year monitoring, for a total of a 7 sampling sites

Fluid temperatures and gas emissions change according to volcanic activity

field measurements water sampling for lab analyses
Salinelle di San Biagio

They extended over an area of several thousand square meters on a substrate of sandy clays dated to Lower Pleistocene

field measurements water sampling for lab analyses

2 survey over 1 year monitoring, for a total of a only 1 most interesting sampling sites

Hydrothermal vents changed their shape or location

Limited choice for a meaningful monitoring
Salinelle del Fiume

Located in the flat area composed of alluvial terraced deposits of the nearby Simeto River

field measurements water sampling for lab analyses

1 survey over 1 year monitoring, for a total of a only 1 most interesting sampling sites

Hydrothermal vents changed their shape or location

Limited choice for a meaningful monitoring
Methodology

Field observations and measurements
- Thermo-physical and geochemical monitoring of the hydrothermal fluid emissions

Laboratory analysis
- Mineralogical determinations of solid materials around hydrothermal vents
- Major ionic species

Evaluation of seismic parameters
- Seismological and volcanological data from INGV weekly reports
Field observations

Temporal changes in style and intensity of fluid emissions

Changes in morphological features of hydrothermal vents and muddy pools
Field observations

Higher gas or water emissions were not always correlated with higher water temperature values of fluids.
Field surveys:

**Thermal properties**

Thermal sensors and data loggers directly immersed in the most active and stable water pools

Continuous real-time monitoring with a sampling frequency every 15 minutes

→ 34,675 valid measurements at each site!

Thermal Property Analyzer based on the Transient Line Source method

Thermal conductivity and temperature of the mud continuously emitted from pools

→ A total of 50 measures for each test site!
Field surveys: Electrical and Geochemical properties

Hypersaline waters: Electrical Conductivity, pH and Electrical Potential through a waterproof handled meter

Bubbling gas phase: CO2 determinations through an inverted funnel, connected to the inlet port of a portable battery powered CO2 meters and a silicon pipe.
Laboratory analysis: Electrical, Geochemical Analysis and mineralogical determinations

1. Filtration from the muddy fraction in suspension. Residual liquid phase: volumetric analysis through automatic trititation → hydrocarbon (HCO3-) ions concentration

2. Measures of bicarbonate ions in the water, using HCl 0.1 N titrant solution

3. Direct Ion Chromatography → major and minor cations (Na+, K+, Ca2+, Mg2+, Li+ and NH4+)
   Ion Chromatography with chemical suppression → major anions (Cl-, Br-, NO3-, SO42-)
   XRD → mineralogical determinations
Field and laboratory results

- Most parameters show comparable values, among the sampled pools.
- Negative correlations between pH and thermal conductivity.
- Negative correlations between pH and Eh.
- Positive correlations between Eh and thermal conductivity.

Water temperatures: significantly higher than the typical values in Etna’s groundwater.

Hydrothermal origin of the emitted fluids.
Laboratory results: Geothermometric analysis

Hypersaline waters with a marked prevalence of sodium (Na+) and chloride (Cl-) on the other elements.

All samples fall within the partially equilibrated waters, very close to the full equilibrium curve, along isotherms between 100 and 140 °C

mixing of a full-equilibrated geothermal waters with a solution with low ionic strength

Origin of the local fluids from condensation of high-enthalpy gases, originally released from magma, into the Salinelle hydrothermal system.
Results and Discussions

Changes in temperatures anticipate of about three months paroxistic Etna events

Why temperatures decrease when a volcanic activity increases
Different trends of water temperatures probably linked to:

- strong variations in crustal permeability due to the earthquakes, changing gas/water ascent in the mud volcanoes
- increase of fluid pressure inside the geothermal reservoir and hence in the flux of hot fluids released at surface
- This affects the hydrothermal fluids feeding the Salinelle mud volcanoes
- This may have been combined with strong decrease in the magmatic gas flux at depth below Mt. Etna

Increase in water temperature at the surface vents due to:

- greater heat flux due to higher fluid pressure in the Salinelle hydrothermal reservoir
- greater input of high enthalpy magmatic fluids from new magma accumulating at depth
- Stored magma moves upward, the pressure drops due to the empty magma chamber
- Magmatic fluids released through shallower faults and volcanic conduits.
- Temperature variations at Salinelle linked to the ascent and accumulation of gas-rich magma which rules deep heat fluxes towards the Salinelle geothermal system
The study highlights that the geothermal potential of the Salinelle Geosite is related to a resource of about 120°C in the sedimentary bedrock, and this occasionally fed by fluids coming from the Etna magma chambers.

Geologic sketch of the Mt. Etna volcano illustrating the main hydro-geologic features of the layers forming the lithologic sequence (modified by Panzera et al., 2016, from Aiuppa et al. 2004)
Thank you!