Available online at www.sciencedirect.com
ScienceDirect
Journal of Volcanology and Geothermal Research 165 (2007) 46 – 63
Journal of volcanology and geothermal research
www.elsevier.com/locate/jvolgeores

Focused and diffuse effluxes of CO_2 from mud volcanoes and mofettes south of Mt. Etna (Italy)

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Received 13 June 2006; accepted 23 April 2007
Available online 17 May 2007

Abstract

Several sites with anomalous emissions of carbon dioxide were investigated in the region south of Mt. Etna volcano in order to assess the types of emission (focused and/or diffuse), their surface extension and the total output of CO_2. Most of the studied emissions are located on the southwest boundary of Mt. Etna, near the town of Paternò. They consist of three mud volcanoes (known as Salinelle), one spring with bubbling gas (Acqua Grassa) and one area of diffuse degassing (Peschería). Another site (Naftía Lake) with remarkable gas emissions (bubbling gas into a lake as well as adjacent areas of diffuse soil degassing) is located further southwest of Mt. Etna in an area of extinct Quaternary volcanism on the northwest margin of Hyblean Mts. In all of these areas the origin of the highest CO_2 emissions is clearly magmatic, and degassing to the atmosphere occurs mostly through tectonic structures, probably at a regional scale. The magmatic source that feeds anomalous degassing in the above areas is likely to be the same that feeds volcanic activity at Mt. Etna.

Focused degassing was measured at each emission vent using devices that measure the air speed, whereas diffuse soil degassing was measured using the accumulation chamber method. In total, 712 measurements were carried out (146 in focused degassing vents, 566 on diffuse degassing areas). Single CO_2 output values ranged from 1.8 10^{-5} to 1.68 kg s^{-1}. In the case of diffuse degassing areas, statistical analyses allowed to discriminate between biogenic CO_2 and CO_2 deriving from a magmatic-hydrothermal source. Only the efflux values from the latter source were considered in the output estimates. The total estimated output thus obtained was about 2.61 kg s^{-1}, relevant to a total surface of about 146,500 m^2 (which includes only the magmatic CO_2 emissions). This value is comparable with that of most non-volcanic emissions from geothermal and/or faulted areas of central-southern Italy, as well with the CO_2 output from some of the volcanic areas of Italy.

Keywords: carbon dioxide; Mt. Etna; mud volcanoes; soil CO_2 effluxes; magmatic degassing

1. Introduction

Since the early work of Irwin and Barnes (1980), it has become clear that a close relationship exists between active tectonic areas and anomalous crustal emissions of carbon dioxide. Due to their high crustal permeability, faults act as preferential pathways for the upward migration and eventual release of deep gases to the atmosphere. The central part of eastern Sicily (Italy) is characterized by several sites with remarkable natural emissions of gases. Their occurrence is likely due to

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doi:10.1016/j.jvolgeores.2007.04.010

intense local geodynamic activity, which produced magmatic activity in the northern part of the Hyblean Mts. area (southeast Sicily), feeds the eruptive activity of Mt. Etna volcano and triggers seismic activity in both of those areas. Five major destructive earthquakes (Intensity ≥ IX on the Mercalli – Cancani – Sieberg scale) occurred there in the last 1000 years (Feb. 4, 1169: Intensity = XI; Dec. 10, 1542: Intensity ≤ X; Oct. 3, 1624: Intensity = IX; Jan. 11, 1693: Intensity = XI; Aug. 6, 1757: Intensity = IX, AA.VV., 1983). The estimated magnitude of the Jan. 11, 1693 earthquake (Magnitude > 7.5, Richter scale, according to Mulargia et al. (1985)) makes it the largest event in the Mediterranean basin. The last significant earthquake in this area occurred on December 13, 1990 (M = 5.4, Adam et al., 2000), causing serious damage over a large area south of Catania as well as 19 casualties.

Huge summit and flank emissions of CO_2 take place at Mt. Etna volcano. The magnitude of the emissions has recently been assessed (Allard et al., 1991; Giammanco et al., 1995, 1997; D'Alessandro et al., 1997b; Giammanco et al., 1998b) and temporal variations were found to be associated to the present volcanic activity. Moreover, low temperature (<100 °C) gas manifestations occur at the southern foot of Mt. Etna and along the highly faulted northern boundary of Hyblean Mts. These include bubbling gases, mud volcanoes and CO_2-rich soil gases. In recent years, these manifestations were analyzed repeatedly for chemical and isotopic characterization (Allard et al., 1991; Giammanco et al., 1995; D'Alessandro et al., 1996; Allard, 1997; D'Alessandro et al., 1997a; Giammanco et al., 1998b). The work presented here is the first attempt to estimate the output of CO_2 from these features, which is important for the assessment of potential gas hazards.

2. Analytical and survey methods

The gas emissions surveyed in this study include gases bubbling in mud or water pools as well as diffuse emissions through soil (Fig. 1). The gas mass efflux over pools and mud pots was measured using a wind speed meter (detection limit of 0.1 m s^{-1}) placed inside an open syringe connected to an inverted funnel. The surface area of the syringe inlet equaled 5 10^{-5} m^2, and this value was used in the calculation of the mass efflux from each sampling point. The utility of this method was tested and confirmed using a solid state flowmeter calibrated for CO_2 (Cambridge Scientific Instruments Ltd, mod. CSi 6000, detection limit 1.7 10^{-9} m^3 s^{-1}, upper scale limit of 5 10^{-6} m^3 s^{-1}). In each of the surveyed areas, efflux measurements at individual sites were summed to obtain the total mass efflux. This efflux was then multiplied by the density (1.84 kg/m^3 at 1.013 bar and 20 °C) and the average molar fraction of CO_2, in order to obtain the CO_2 efflux values. Carbon dioxide contents were measured in the same bubbling gases by gas-chromatography on samples collected in glass samplers connected to an inverted funnel placed on the gas emission.

Diffuse CO_2 emissions were measured using the accumulation chamber method, which consists of measuring the rate of increase of the CO_2 concentration inside a cylindrical chamber opened at its bottom placed on the ground surface. The chamber is provided with an internal fan to achieve an efficient gas mixing and is connected with a portable NDIR (nondispersive infrared) spectrophotometer (PP Systems, UK, mod. EGM4). The change in concentration during the initial measurement is proportional to the efflux of CO_2 (Tonani and Miele, 1991; Chiodini et al., 1998). This is an absolute method that does not require corrections linked to the physical characteristics of the soil. We tested the method in the laboratory with a series of replicate measurements of known CO_2 effluxes. The average error was about ±5%, which is assumed as a random error in the natural emission rates. The reproducibility in the range 200–1600 g m^{-2} d^{-1} was 5%.

In order to assess the anomaly threshold for soil CO_2 effluxes, logarithmic probability plots were used for soil CO_2 sample points in each area studied, assuming a log-normal distribution of values. Sinclair (1974) discussed that in such plots, changes in slope are indicative of separate populations of data. For each population the arithmetic mean (M_i) and their respective standard deviation (σ_i) were calculated. Because the populations of efflux values individuated with the log probability plots have log-normal distributions, the mean values of CO_2 efflux (ϕ_{CO2}) that were used for the CO_2 output calculations and the central 95% confidence interval of the mean were estimated with the Sichel's t-estimator (David, 1977). The CO_2 output from each source recognised by means of the statistical estimations was calculated multiplying its average CO_2 efflux by the respective surface (S_i) obtained from a contour map computed using a kriging spherical model, and the results are shown in Table 1. We used Ordinary Kriging as interpolation method to compute the CO_2 output from the studied areas. Although the Kriging algorithm is the most used for this purpose, we are aware that it can provide an incomplete measure of local accuracy, and that assuming a Gaussian model for errors normally gives more reliable results (Goovaerts, 1997). Stochastic simulations, such as the sequential Gaussian simulation,