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Hydrogeochemical study in Azores volcanic lakes: implications for volcano surveillance

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The Azores archipelago is located in the North Atlantic Ocean, between the latitudes of 37º-40º N and the longitudes of 25º-31º W. The archipelago is made of nine volcanic islands, divided in three groups according to their geographical distribution.

The islands of the Azores represent the emerged portion of the Azores Plateau, limited by the bathymetric line of -2000 meters. The Azores is located near the junction between the North American, Eurasian African Plates, according to a complex geodynamic setting, reflected by several tectonic structures, which explains the observable seismovolcanic activity.

With the goal of understand lake environments in active volcanic regions a study was developed at the Azores archipelago, in order to: (1) characterize water composition on lakes, (2) establishing a relation between water composition and volcanic fluids and (3) propose a monitoring plan for this aquatic systems,

This study was made in lakes located at São Miguel, Pico, Flores, Terceira and Graciosa islands. The studied lakes present a surface area range of 0.01 to 3.6 km^2, a maximum volume of 0.5 km^3 and depths between 3.5 m and 120 m. Volcanological setting is diverse, with sampled lakes located in large calderas, volcanic craters and maars.

At São Miguel, located in the eastern group of islands and the largest in area and population, several hydrogeochemical profiles were made at 3 caldera lakes and 2 maars lakes, all emplaced in the three active central volcanoes that dominates the island geology. At Pico island 5 crater lakes were studied and at Flores sampling was made in 3 lakes in maars and 2 crater lakes. At Terceira and Graciosa islands samples were collected in lakes located inside volcanic caves.

The studied waters are cold, with temperatures range between 11ºC and 23.8˚C, and are mainly alkaline, as shown by pH values, that range between 5.93 and 9.84. The higher pH values, near 10, are observed at the water surface, due to the eutrophication of the systems, while the slightly acid measurements were made in the bottom of the deepest lakes Two types of lake waters can be recognized: (1) one is characterized by Na/Cl ratio close to the seawater value, that evolves mainly by marine contribution, due to atmospheric input by precipitation and (2) Na–HCO_3 type waters that, in addition to sea-salt input, have been influenced by other processes, as water-rock interaction and hydrothermal seepage into the lake bottom. The higher total CO_2 content (average=344 mg/L) and SiO_2 content (average=49.9 mg/L) observed at Furna do Enxofre lake (Graciosa), compared to samples collected in the majority of the studied lakes, shown the effects of volcanic contribution to lake water chemical composition. The water samples from Furnas lake (São Miguel) also present a slight concentration enrichment of the same species, when compared with other lakes (except Furna do Enxofre) and is suggested that the fumarolic ground located near the north margin of the lake contributes to lake water chemistry.

Vertical profiles reveal that major-ion content shows a limited variation with depth, largely independent of the summer occurrence of thermally driven density stratification for the deeper lakes. During winter homogenization occurs due water circulation, enhanced by the absence of water stratification, and major-ion content is constant along the water column.

The stable isotopes δ^2H and δ^{18}O range respectively between -4.33‰ and -0.87‰ and -2.66‰ to -19.58‰ showing a meteoric origin for these waters, despite a shift to the right of the World Meteoric Water line due to evaporation

in the lakes with larger surface areas and higher volume.

For δ^{13}C data is possible to show that water from Furna do Enxofre lake is equal to 1.9‰ suggesting the loss of carbon dioxide by boiling. On other systems results for δ^{13}C suggests that carbon dioxide is mainly originated from the decomposition of organic matter in the bottom of the systems. Eutrophication enhances the accumulation of organic matter at the bottom of the majority of the studied lakes.