



Water chemistry of lakes related to active and inactive Mexican volcanoes

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ABSTRACT

Water chemistry of crater lakes, maars and water reservoirs linked to some Mexican volcanoes within and outside the Mexican Volcanic Belt has been determined for several years and examined regarding environmental and volcanic factors. All the analyzed lakes are relatively small with a maximum depth of 65 m, and are located in regions with different climates, from semi-arid to very humid, with altitudes ranging from 100 to more than 4000 m a.s.l. Crater lakes in active volcanoes (El Chichón, Popocatepetl) have very low pH, moderate to high temperatures and major ion concentrations varying with the level of volcanic unrest. Lakes in sub-arid and temperate-arid regions (like maars in Puebla and Guanajuato states) show high alkalinity and pH, with bicarbonate/carbonate, chloride, sodium and magnesium as predominant ions. Lakes located in humid climates (Central Michoacán and Veracruz state) have low mineralization and near-neutral pH values. In general, conservative dissolved ions and conductivity appear to be mostly controlled by precipitation/evaporation and by the ionic concentration of groundwater inputs. Calcium, magnesium, sulfate concentrations and pH are strongly influenced by volcanic-rock or volcanic gas interactions with water. The influence of low-level volcanic activity on crater lakes may be obscured by water-rock interactions, and climatic factors. One of the aims of this paper is to define the relative influence of these factors searching for a reference frame to recognize the early volcanic precursors in volcano-related lakes.

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1. Introduction

The chemical composition of crater lakes depends on factors related to the regional geology, climate, and the level of volcanic unrest evidenced mostly as magmatic heat and gas input. The first two factors depend on the lake location and are essentially stable, showing only seasonal variations or other climate-related changes. In contrast, the latter may provide an important role as one of the earliest precursors of increasing volcanic activity.

For example, an increase in sulfate and chloride concentrations was observed in the crater lake of Soufrière volcano in St Vincent, West Indies, during the 1972 eruption (Sigurdsson, 1977). Chemical variations in Kusatsu-Shirane crater lake in Japan took place about one year before the 1976 eruption (Ossaka et al., 1980). Takano and Watanuki (1990) observed a decrease in polythionate and an increase in sulfate concentrations at Yugama crater lake, Japan, before the 1982 eruption. The crater lake of Rincón de la Vieja volcano in Costa Rica, showed a significant increase in the SO_4/Cl , a few months prior to a phreatic eruption episode in March 2002 (Tassi et al., 2005). Enhanced magnesium flux was observed in the hydrothermal system of Copahue

volcano, located along the Chile–Argentina border, before the magmatic eruptions of July–October 2000 (Varekamp et al., 2001). Sulfate concentrations and Mg/Cl ratio increased between 1992 and 1994 in the Popocatepetl crater lake in México, preceding an eruption that occurred on December 21, 1994, after nearly 70 years of quiescence (Armienta et al., 2000). These changes were clear precursors of volcanic unrest in lakes.

The earliest precursors, or the precursors of low-level volcanic activity may however be obscured by water–rock interactions and climatic changes making the magmatic-induced chemical modifications difficult to recognize. One of the aims of this paper is to define the relative influence of these factors seeking a reference frame for the recognition of early volcanic precursors in the volcano-related lakes of Mexico.

Thousands of volcanic structures are widespread in the Mexican territory, many related to subduction of the Rivera and Cocos plates under the North American and Caribbean plates. Most subduction-related volcanoes are located in the Mexican Volcanic Belt (MVB; Fig. 1), crossing the country around latitudes 19–20°N. The MVB trends in a roughly E–W direction, oblique to the trench axis, revealing a complex subduction geometry. Some of the volcanoes, either active or inactive, within or outside the MVB, contain lakes. Crater lakes, maars, and water reservoirs formed by volcanic processes have been sampled along several years for this study. Most of the lakes are relatively small, with a maximum depth

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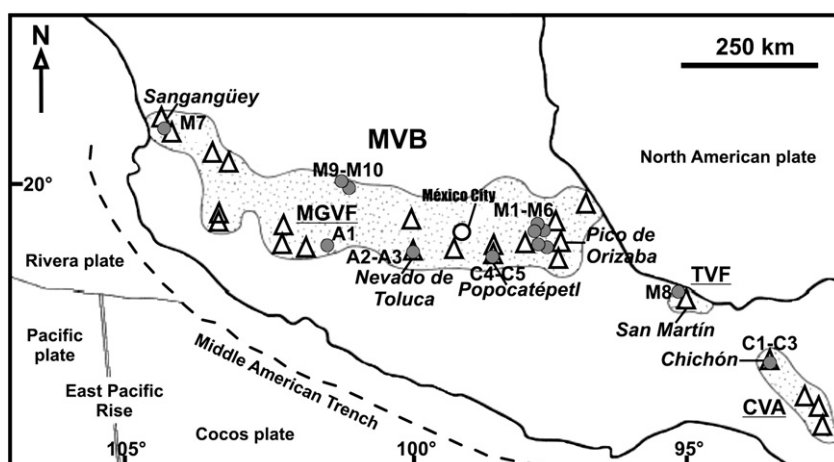


Fig. 1. Important Holocene volcanoes within the Mexican Volcanic Belt (MVB) and in other volcanic regions: the Tuxtlas Volcanic Field, TVF, and the Chiapas Volcanic Arc, CVA. Studied lakes are: M7 – Santa María del Oro; M9 – La Alberca; M10 – Rincón de Parangueo; A1 – Zirahuén; A2 – La Luna; A3 – El Sol; C4–C5 – Samples of the crater lake of Popocatepetl volcano; M8 – Lago Verde at one side of the San Martín volcano; M1–M6 – Alchichica, Atexcac, La Preciosa, Quechulac, Tecuitlapa and Aljojuca in North Oriental basin; and C1–C3 – Samples of the crater lake at El Chichón volcano.

of 65 m, and are located in different climate zones from semi-arid to very humid, at elevations from 100 to more than 4000 m a.s.l.

We expect that the identification of the specific hydrogeochemical parameters most sensitive to active volcanic processes may provide a better understanding of the magma–lake interactions to improve hydrogeochemical volcano monitoring.

2. Methods

Samples were obtained from lakes formed by different types of volcanic activity in various parts of México (Fig. 1). Sampling included maars (Quechulac, Aljojuca, La Preciosa, Atexcac, Alchichica, Santa María del Oro, La Alberca, Lago Verde, and Rincón de Parangueo), a quiescent active volcano (El Sol and La Luna lakes in Nevado de Toluca volcano), active volcanoes (El Chichón and Popocatepetl), and a lake formed by the closing of a small basin by a lava flow (Zirahuén). Waters from the surface and near the bottom at the deepest part were sampled in most of the lakes, except at Popocatepetl and El Chichón, where the

samples were obtained at the shores. Location, climate, precipitation and lake origin of the sampled sites are summarized in Table 1.

Our water sampling program at El Chichón began in 1985, three years after the eruptions of March 28 to April 4, 1982, which included a Plinian phase (Carey and Sigurdsson, 1986; Yokoyama et al., 1992). Samples obtained in January, 1983 (Casadevall et al., 1984), January, 1993, and April, 2003, have been selected here as representative of the post-eruptive crater lake composition.

The Popocatepetl crater lake disappeared shortly before the onset of eruptive activity in 1994, and the analysis of one sample from Popocatepetl crater lake, obtained in April, 1992 two years before the initial eruption of the current episode, is discussed here. La Alberca and Rincón de Parangueo lakes were sampled once, before they dried out during the dry season. The causes for the drying are briefly addressed below. Table 2 shows the most representative field parameters and water type of the sampled lakes.

Temperature and pH were measured in the field by potentiometry. The pH meter calibration was made with buffer solutions submerged in the lake in equilibrium with the lake water temperature. Sampling

Table 1

Location, dimensions, climate conditions, and type of the studied lakes. Area, depth, and water temperature data from: Vilaclara et al., 1993, 2005; Alcocer et al., 2000; Armienta et al., 2000; Serrano et al., 2002; Escolero and Alcocer, 2004; Alcocer et al., 2004b; Rouwet et al., 2004; Caballero et al., 2006. Climate, and precipitation data from: SMN, 2005. Aw = Tropical, dry winter. Cw = Temperate, dry winter. Ew = Polar, dry winter. Bs = Dry, semi-arid

Lakes	Location	Elevation (m a.s.l.)	Area (km ²)	Maximum depth (m)	Climate	Precipitation (mm/yr)	Water temperature range (°C)	Type of lake
Santa María del Oro	21°22'N 104°34'W	730	3.07	65	Aw	800–1200	22–30	Phreatic explosion maar (Pleistocene)
Zirahuén	19°21'N 101°46'W	2100	9.7	40	Cw	800–1200	16–22	Lava-dammed Endorheic Basin (Pleistocene)
La Alberca	20°23'N 101°12'W	1690	0.2	5	Cw	700–750	19–27	Phreatic explosion maar
Rincón de Parangueo	20°25'N 101°15'W	1700	0.7	2	Cw	600–800	19–30	Phreatic explosion maar
El Sol	19°10'N 99°45'W	4200	0.17–0.24	15	Ew	1244	5–12	Pluvial in Holocene magmatic explosion crater
La Luna	19°10'N 99°45'W	4200	0.02–0.03	10	Ew	1244	6–11	Pluvial in Holocene magmatic explosion crater
Popocatepetl	19°01'N 98°37'W	5452	0.12	<5	Ew	425	19–65	Mixed waters in active magmatic explosion crater (Lake Life Span, 1930–1994)
Aljojuca	19°05'N 97°32'W	2340	0.44	45	Cw	600	16–23	Phreatic explosion maar (Pleistocene)
Tecuitlapa	19°08'N 97°33'W	2380	0.26	4.5	Cw	600	16–24	Phreato-magmatic explosion maar (Pleistocene)
Atexcac	19°20'N 97°27'W	2340	0.29	39	Cw	500	16–22	Phreatic explosion maar (Pleistocene)
Quechulac	19°22'N 97°21'W	2350	0.5	40	Cw	500	16–23	Phreatic explosion maar (Pleistocene)
La Preciosa	19°22'N 97°23'W	2330	0.78	45	Cw	500	16–23	Triple Phreatic explosion maar (Pleistocene)
Alchichica	19°22'N 97°24'W	2320	1.8	63	Bs	400	14–22	Phreatic explosion maar (Pleistocene)
Lago Verde	18°36'N 95°20'W	150	0.12	4	Aw	2500	21–28	Phreatic explosion maar (Pleistocene–Holocene)
Chichón	17°24'N 93°12'W	2224	0.15 (April 2001)	3.5	Aw	2900	28–56	Mixed waters in active magmatic explosion crater (Lake Life Span, 1983 up to now)

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