

# Massive Volcanism in the Altiplano-Puna Volcanic Plateau and Formation of the Huge Atacama Desert Nitrate Deposits: A Case for Thermal and Electric Fixation of Atmospheric Nitrogen

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## Abstract

The origin of the giant nitrate deposits of the Atacama Desert (Chile) is a controversial issue. At a global scale, the Atacama Desert nitrates constitute a rare singularity because no equivalent deposits are found anywhere else. Previous hypotheses for origin of the Chilean nitrates have failed to recognize the importance of the 70,000 km<sup>2</sup> Late Miocene to present Altiplano-Puna volcanic plateau (APVP), only 50–200 km eastward from the nitrate deposits. We argue that the extrusion of a volume of over 10<sup>4</sup> km<sup>3</sup> of pyroclastic rocks at the APVP may have created the conditions to induce thermal and electric fixation of an estimate of 2800 Mt of atmospheric nitrogen in the form of NO<sub>3</sub>. This figure exceeds the amount of nitrogen required to account for the Atacama Desert nitrate deposits. Thus, the origin of the nitrate deposits may be found in an unusual combination of hyper-arid conditions (vital for the final stabilization and preservation of the NaNO<sub>3</sub> mineral phase) and massive volcanism (key to fixation of large amounts of atmospheric nitrogen). Volcanic eruptions have far more environmental implications than usually assumed, decisively contributing to the global cycles of many chemical elements and compounds. For example, nitrogen fixation by volcanic activity could also explain the current excess of NO<sub>x</sub> compounds in the pristine marine atmosphere of the mid-Pacific, a realm conspicuously surrounded by the world's largest concentration of active volcanoes.

## Introduction

THE ORIGIN OF THE extensive natural nitrate (NaNO<sub>3</sub>) deposits of Chile's Atacama Desert poses one of the most intriguing, unresolved problems in the Earth sciences. The nitrate deposits (e.g., Erickson, 1981, 1983, 1993) are emplaced along a narrow, N-S, ~700 km long belt at an altitude of ~1000 m, hosting some 250 Mt of nitrates (Fig. 1). Despite the abundance of the components (Na, N, O), only minor occurrences of natural nitrate have been reported elsewhere. Thus, the Chilean nitrates constitute a world-class geological singularity lacking, despite several attempts, a definitive explanation.

From a geological and physiographic point of view, the region can be divided into five main N-S-trending structural blocks (Fig. 2): (1) the Coastal Ranges, formed by Mesozoic andesitic volcanic

rocks and granitoids; (2) the Western Depression, where the nitrate districts are present; (3) the Domeyko Mountains, with Mesozoic to Cenozoic sedimentary, volcanic, and intrusive rocks; (4) the pre-Andean depressions, including the large Atacama Salar; and (5) the giant Altiplano-Puna volcanic plateau (APVP). The APVP outcrop area in the Andean segment of the study area (Fig. 1) is about 70,000 km<sup>2</sup>, with over 10<sup>4</sup> km<sup>3</sup> of erupted volume, which makes the plateau the largest young ignimbrite province on Earth (e.g., Allmendinger et al., 1997; Babeyko et al., 2002). Ignimbrite activity in the APVP started at about 10 Ma and continued strongly until ~1 Ma (Babeyko et al., 2002; Schmitt et al., 2002). Single ignimbrite eruptions of silicic andesitic to dacitic composition (63–68% SiO<sub>2</sub>) exceeded 1000 km<sup>3</sup> in volume, erupted from caldera systems, and constitute the dominant late Miocene–Pliocene volcanic deposits on the plateau (De Silva,

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