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Isotopic approach of rainfall and groundwater circulation in the volcanic structure of Tahiti-Nui (French Polynesia)

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Abstract

A chemical and isotopic study was conducted on rainfall, river and spring waters from the northern half of Tahiti-Nui tropical oceanic island, in order to constrain a conceptual model of groundwater circulation within a discontinuous volcanic structure. Tahiti-Nui comprises a main shield cut by a huge landslide to the north. This major flank collapse yielded the formation of a northern depression, in which rapidly grew a second shield. Additional volcanic activity occurred along the rims of the depression, as revealed by local concentrations of dykes. The island is now volcanically inactive and is strongly dissected by erosion. Rainfall collected during a complete hydrological year at different altitudes are characterized by seasonal and altitude gradients in δ^{18}O. Some of them have a deuterium excess upto +20‰, likely due to inland vapour recycling. Over the hydrological year, non-evaporated precipitation defines a mean annual δ-altitude gradient of −0.7‰/km. The mineralization and isotopic contents in river waters vary according to the geology. Rivers incising the main shield have low total mineral charges and are relatively enriched in stable isotopes (δ^{18}O around-3‰ vs. VSMOW), whereas rivers in the northern post-collapse in-fill exhibit greater electrical conductivity and lower δ^{18}O due to the contribution of more mineralized spring water. Springs sampled at different elevations along the NW rim of the N landslide depression have homogeneous stable isotopic compositions corresponding to signature of elevated rainfall. Recharge of these springs thus occurs on a localized area, upto 1500 m above their altitude of emergence. Dominant infiltration occurs at or above the geological discontinuity between the thick impermeable base of the second shield and the late overlying fractured volcanic flows. Dykes from the peripheral part of the system are poorly active in terms of infiltration and water storage, but likely connect the underground circulations. The huge geological discontinuity between the main shield and the post-collapse edifice may also concentrate the groundwater circulation. This main resurgence likely occurs at a deep level of the northern submarine slope of Tahiti-Nui.

Keywords: Tahiti-Nui; Stable isotopes; Infiltration; Groundwater; Rainfall

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1. Introduction

The hydrogeology of volcanic oceanic islands is poorly documented in the litterature and most studies concern Hawaii (e.g. Stearns and Macdonald, 1946; Peterson, 1972; Macdonald et al., 1983; Oki et al., 1999). The hawaiian model classically distinguishes three main types of groundwater: (1) Basal groundwater occurs as a low-gradient water table, the outflow of which being at or below the sea level. The extension of the regional water table toward the centre of the volcanic systems is not well known but it would have the geometry of a lens of fresh water floating on seawater that saturates the interior of the islands (e.g. Scholl et al., 1995). (2) Perched volume-restricted groundwater discharges inland and corresponds to superficial water circulation within the upper part of the volcanic structures (e.g. Join and Coudray, 1993; Scholl et al., 2002). These localized aquifers are isolated from the main basal water body by low-permeability layers such as compacted cinders or massive lava-flows (Violette et al., 1997). (3) Dike aquifers may exist where volcanic intrusions compartmentalize the islands. In such systems, the dikes act as impermeable surfaces impounding the groundwater flow (Mink, 1963; Takasaki and Mink, 1983; Jackson and Lénat, 1989).

For a given volcanic island, the identification of aquifer units requires an accurate geological knowledge of the volcanic structure. For instance, rift-zones and huge landslides are common features of many volcanic oceanic islands (e.g. the Canary Islands, Carracedo (1994) and Hildenbrand et al. (2003b); Reunion Island, Gillot et al. (1994); Hawaii, Moore et al. (1989)), which may strongly influence water infiltration and circulation. In the case of Tahiti-Nui Island (French Polynesia) which is composed of two nested volcanic edifices, the recent works of Gillot et al. (1993) and Hildenbrand et al. (2004) have demonstrated that those types of discontinuities exist. This has important implications in terms of groundwater resources since the previous hydrogeological works were based on the geological concept of a main single conical shield (Petit, 1969). In the present study, we re-evaluate the hydrogeology of Tahiti Island, taking into account these recent geological data and considering new chemical and isotopic data (^{18}O, ^{2}H, ^{13}C, ^{14}C) obtained on samples of rainfall water, coastal river water and spring water. This work is focused on the northern half of the island, and more particularly in the surrounding of Papeete (Fig. 1), where groundwater is used as drinking water supply.

2. General setting

2.1. Geography and climate

Tahiti Island is located at the southeastern end of the Society archipelago (Fig. 1), one of the five linear volcanic chains of the South Central Pacific Ocean. Tahiti is the largest island of French Polynesia: area of 1042 km^2 and total height of about 5000 m above the surrounding oceanic floor. Tahiti and Moorea constitute the 'Winwards Islands': the dominant winds are indeed mainly from east to west. Consequently, the rainfall amount is two times greater on the eastern coast than on the western coast (Fig. 1). The climate of Tahiti-Nui is tropical, and characterized by a wet summer period from November to February alternating with a relative dry period during winter (Fig. 1). The average annual rainfall amount is quite high and varies from 2000 mm at the sea level upto 11,000 mm at high altitudes (Ferry, 1988). At Papeete, the average rainfall amount on the period 1957–1986 is 2824 mm per year. The climatic conditions have induced a spectacular erosion of Tahiti volcanic structure, although the island was edified recently, during the last two million years (Le Roy, 1994; Duncan et al., 1994; Hildenbrand et al., 2004). The precipitation regime also explains the violent episodic behaviour of rivers especially during the heavy rainfall events of the rainy period (Danloux and Ferry, 1985; Lafforgue, 1987; Ferry, 1988; Wotling, 1999).

The average yearly temperature is 25.8 °C at the Tahiti-Faaa coastal station (1957–1986). The variations of monthly and yearly temperatures over the period 1957–1986 are rather small (average of 24.3 °C during July–August and average of 27.0 °C during March–April; Pasturel, 1993). Average values for evaporation during 1957–1986 are high (1682 mm at Tahiti-Faaa coastal station, Pasturel, 1993).

2.2. Geology and hydrogeology

Tahiti is composed of two coalescent eruptive systems defining the main island of Tahiti-Nui to