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Structure of an active volcano associated with a resurgent block inferred from thermal mapping: The Yasur–Yenkahe volcanic complex (Vanuatu)

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ABSTRACT

Subsurface thermal measurements provide a valuable tool to map hydrothermal-fluid release zones in active volcanic areas. On the Yasur–Yenkahe volcanic complex (Tanna Island, Vanuatu archipelago), fumaroles and hot springs abound, signs of upraising heat fluxes associated to a well-developed hydrothermal activity. Combination of high resolution mapping of ground thermal anomalies with geomorphological analysis allows the characterization of the structural relationships between the active Yasur volcano and the Yenkahe resurgent block.

A complex system of heat release and hydrothermal fluid circulation below the Yasur–Yenkahe complex is evidenced. Circulation, though propagating vertically as a whole, is funneled by stratification. Thus, the main thermal fluid released is almost exclusively concentrated along structural limits that break the seals induced by the stratified nature of the ground. Three types of medium/high temperature anomalies have been evidenced: (1) broad hydrothermalized areas linked with planar stratification that favor lateral spreading, (2) linear segments that represent active faults, and (3) arcuate segments related to paleo-crater rims. The limit between the Yasur volcano and the Yenkahe resurgent block is characterized by an active fault system accommodating both the rapid uplift of the Yenkahe block and the overloading induced by the volcano weight. In such a setting, faults converge below the cone of Yasur, which acts as a focus for the faults. Evidence of such structures, sometimes hidden in the landscape but detected by thermal measurements, is critical for risk assessment of flank landslides.

1. Introduction

On active volcanoes, magma bodies at shallow depth may generate important heat fluxes by conduction and convection. At the surface, ground thermal anomalies coincide with permeable zones, where uprising hot fluids are preferentially released (Aubert and Baubron, 1988; Finizola et al., 2003; Lewicki et al., 2003; Chiodini et al., 2005; Aubert et al., 2007; Barde-Cabusson et al., 2009; Schöpa et al., 2011). Such areas can thus be mapped and monitored by aerial or ground thermal infrared pictures (Harris et al., 2000; Pergola et al., 2004; Harris and Ripepe, 2007; Lagios et al., 2007; Antoine et al., 2009; Delle Donne et al., 2010; Staudacher, 2010; Murphy et al., 2011) and/or by direct ground temperature measurements (Finizola et al., 2003; Lewicki et al., 2003; Aubert et al., 2007; Barde-Cabusson et al., 2009). Indirect thermal infrared measurements are subject to errors due to the distance between the object and the measurement point and thus need to be corrected; they depend upon surface emissivity of the object, background mixing of the signal, and atmospheric effects (Harris and Maciejewski, 2000). On the other hand, temperatures measured directly at the surface depend only upon the physical properties of the ground and the surface cover, and are affected by the climate (air temperature, wind, solar radiation, air humidity and rainfall). Surface temperatures thus fluctuate seasonally and daily and the surface heat is transferred in depth by conduction, though diurnal cycles generally vanish at one-meter depth. On Stromboli volcano, a diurnal amplitude of 1.1 °C has been measured at 30 cm depth in an area outside the thermal anomalies (Finizola et al., 2003). Thermal measurements carried out at several tens of centimeters below the surface thus minimize the effects of daily variations. In active volcanic areas, mapping the distribution and intensity of ground temperature anomalies allows to evaluate the extent of hydrothermal activity (Revil et al., 2004, 2008; Finizola et al., 2006; Lagios et al., 2007; Staudacher, 2010). Hydrothermal fluid circulation being the most efficient way to transfer heat from depth to the surface, subsurface thermal measurements provide a valuable tool to map fluid release

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zones, which are controlled by ground permeability and structural limits acting as preferential circulation paths.

The Yasur–Yenkahe volcanic complex (Tanna island, Vanuatu archipelago; Fig. 1A, B, C) exhibits consequent fumarolic activity as well as hot springs, signs of upraising heat fluxes associated to a well-developed hydrothermal activity (Gauthier et al., 2001). This volcanic complex is among the rare and most active association between (1) a volcanic cone with a persistent strombolian–vulcanian explosive activity, Yasur, to the west and (2) a rapidly uprising resurgent block, Yenkahe, to the east.

Even if the two structures (Yasur–Yenkahe) seem closely linked in regard to their location, the limits and the structural relationships between the two edifices remain poorly constrained. This study combines high resolution mapping of ground thermal anomalies with geomorphological analysis in order to characterize the structural relationships between the active Yasur volcano and the Yenkahe resurgent block.

2. Geological settings

The Yasur–Yenkahe volcanic complex is hosted within the Siwi caldera in the south-eastern part of the island of Tanna, which is part of the central chain of Vanuatu, related to the subduction of the Australian plate below the Pacific plate (Fig. 1A, B, C; Louat et al., 1988).

The Siwi caldera (9×4 km) hosting the Yasur–Yenkahe complex is delimited by the "Siwi Ring Fracture" on land (Fig. 1C; Carnay and Macfarlane, 1979), and extends offshore between Sulphur Bay and Port Resolution. The Yenkahe block, (6×3 km), is a resurgent block elongated N65 in the axis of the Siwi caldera. It is interpreted as formed

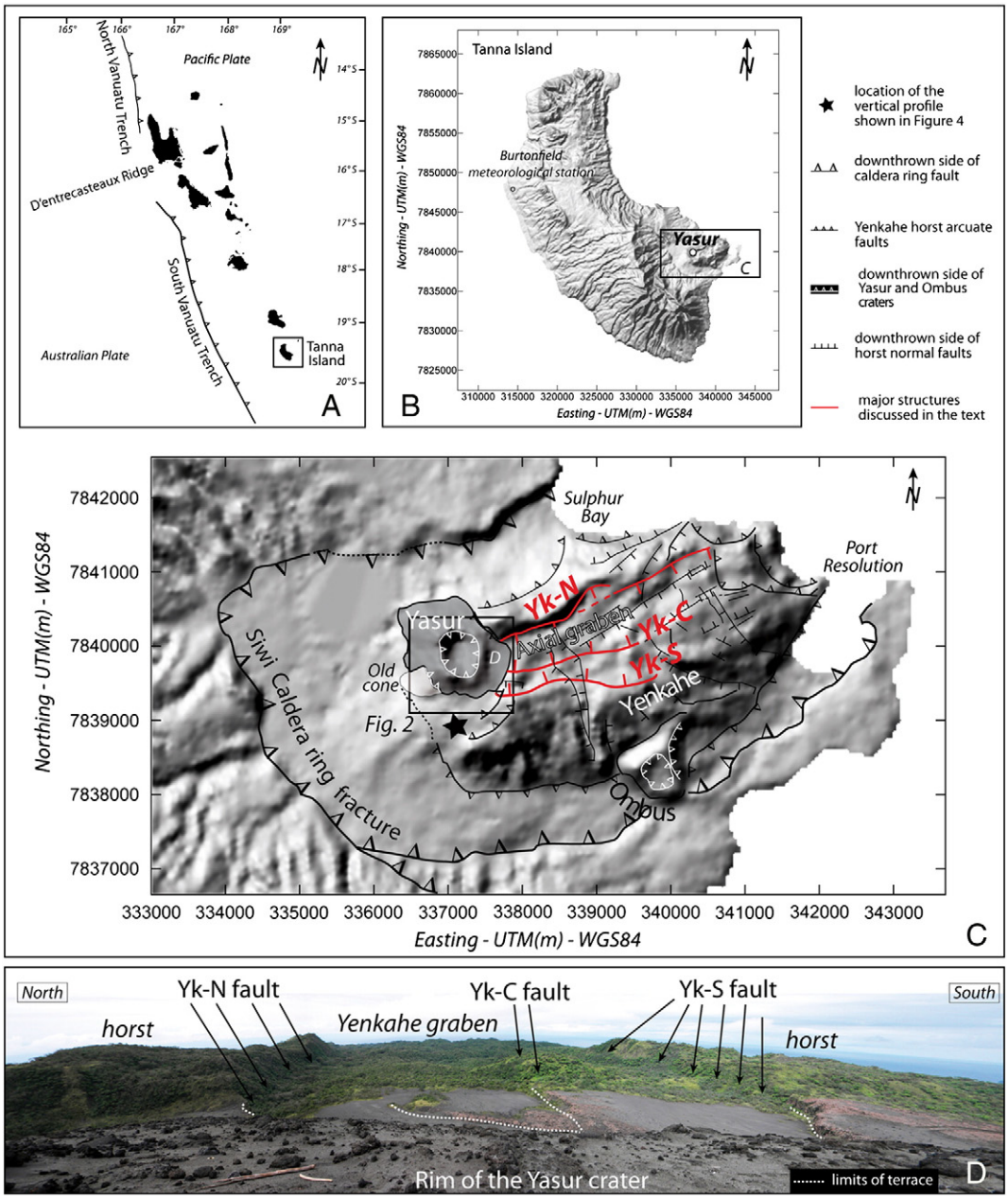

Fig. 1. A) Map of the Vanuatu archipelago and associated tectonic. B) Location of the Yasur–Yenkahe complex on the south-eastern part of the Tanna Island (SRTM digital elevation model). C) Structural map of the south-eastern Tanna including the Yasur–Yenkahe complex. D) Picture from the summit of Yasur to the east showing the main structures of the Yenkahe and the terraces at the junction between the two edifices.