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# New insight into the tectonic framework of the Vanuatu island arc from the distribution of helium isotopes in volcanic gases and thermal waters

Jean-Baptiste, P.[1] and Fourré, E.[1]

[1]LSCE, CEA-Saclay, 91191Gif-sur-Yvette, France (pjb@lsce.ipsl.fr)

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The Vanuatu volcanic archipelago is the subaerial part of a N-S intra-oceanic island arc that extends over 1200 km between 12° and 25°S in the southwestern Pacific. This island arc has developed in a complex tectonic setting through two distinct subduction stages: the first one, from the Late Oligocene to Middle Miocene (27-14 Ma), was associated with westward subduction of the Pacific plate under the Indian-Australian plate, whereas the second one, initiated 6 Ma ago and still ongoing, was marked by a reverse eastward subduction of the Indo-Australian plate beneath the North Fiji back-arc basin expanding at the margin of the Pacific plate. In the northern and southern parts of the Vanuatu arc, the subduction rate varies from 16 to 9 cm $yr^{-1}$ and a well-defined deep subduction trench run parallel to the chain of active volcanoes. Instead, the central part of the arc (14-17°S) was strongly disrupted since 2-3 Ma by its collision with the d'Entrecasteaux Ridge, a fossil arc system carried by the subducting plate. This collision resulted in a sharp reduction of the local subduction rate (~4.2 cm $yr^{-1}$), intense ground uplift and the disappearance of the arc trench. In this central area, three N-S chains of volcanic islands can be observed: the western chain (Espiritu Santo and Malakula islands), where the oldest (upper Oligocene to lower Miocene) rocks outcrop; (2) the eastern chain (Maewo, Pentecost, Epi and Efate islands), formed during a major tectonic rejuvenation stage of the arc in the Pliocene; and (3) the central chain, formed in the Pleistocene-Holocene period, along which subduction-related volcanism is currently active at the open air and under sea water.

Although most volcanic rocks from Vanuatu have geochemical feature typical of island arc volcanics, the Vanuatu subduction system shows considerable variation in major and trace elements as well as in Sr-Nd-Pb isotopic composition in relation with these complex tectonic conditions.

We report the first helium isotope survey of volcanic gases and hot springs along the Vanuatu island arc, from Tanna in the south to Vanua Lava in the north. Low $CO_2$ content and low $^3He/^4He$ ratios in thermal fluids of Epi ($4.0 \pm 0.1$ $R_a$), Efate ($4.5 \pm 0.1$ $R_a$) and Pentecost ($5.3 \pm 0.5$ $R_a$) islands coherently indicate reduced mantle gas leakage and crustal contamination by radiogenic helium on these extinct volcanic systems of the former (Pliocene) arc. Instead, presently active Vanuatu volcanoes display $^3He/^4He$ and $C/^3He$ ratios typical of subduction-related volcanic arcs: $^3He/^4He$ ratios range from $6.4 \pm 0.5$ $R_a$ in southernmost Tanna and $7.23 \pm 0.09$ $R_a$ in northernmost Vanua Lava to typical MORB values in the central islands of Gaua ($7.68 \pm 0.06$ $R_a$), Ambrym ($7.6 \pm 0.8$ $R_a$) and Ambae ($7 \pm 2$ $R_a$ in groundwaters and $8.0 \pm 0.1$ $R_a$ in summit fumaroles of Aoba volcano). On Ambrym, however, we discover that hydrothermal manifestations separated by only 10-15 km on both sides of a major E-W transverse fault zone crossing the island are fed by two distinct helium sources, with different $^3He/^4He$ signatures: while fluids in southwest Ambrym (Baiap and Sesivi areas) have typical arc ratios ($7.6 \pm 0.8$ $R_a$), fluids on the northwest coast (Buama Bay area) display both higher $^3He/^4He$ ratios ($9.8 \pm 0.2$ $R_a$ in waters to $10.21 \pm 0.08$ $R_a$ in bubbling gases) and lower $C/^3He$ ratios that evidence a hotspot influence. We thus

infer that the influx of Indian MORB mantle beneath the central Vanuatu arc, from which Ambrym magmas originate, also involves a $^{3}$He-rich hotspot component, possibly linked to a westward influx of Samoan hotspot material or another yet unknown local source. This duality in magmatic He source at Ambrym fits with the bimodal composition and geochemistry of the erupted basalts, implying two distinct magma sources and feeding systems.

More broadly, the wide He isotopic variations detected along the Vanuatu arc further verify the complex tectonic and magmatic framework of this intra-oceanic island arc.