

ANALYTICAL METHODS

Mineral chemistry

Mineral compositions in rocks from the successive magmatic events were determined using a CAMECA SX 50 electron microprobe at BRGM Orléans, equipped with five wavelength-dispersive spectrometers (two PET, two TAP and one LIF) with an accelerating voltage of 15 kV and a beam current of 12 nA. PAP correction was applied to all data ([Pouchou & Pichoir 1984](#)). Formulae of minerals are calculated of the basis of 5 cations and 16 charges for feldspars, 4 cations and 12 charges for pyroxene, 15+Na+K (i.e. no Na ion M4 site) cations for amphibole and 8 cations, 11 O and 2 OH-sites for biotite.

U–Th–Pb zircon and monazite ages

The U–Th–Pb zircon and monazite ages were determined by laser ablation inductively coupled plasma spectrometry (LA-ICP MS) at the Laboratoire Magmas et Volcans, Clermont-Ferrand (France). The analyses involved the ablation of minerals with a Resonetics Resolution M-50 powered by an ultra-short pulse (<4 ns) ATL Atlex Excimer laser system operating at a wavelength of 193 nm (detailed description in [Müller *et al.* 2009](#)). A spot diameter of 26 µm associated with 3 Hz repetition rates and a laser energy of 4 mJ producing a fluence of 9.5 J/cm² were used for zircon dating, and a spot diameter of 7 µm associated with 3 Hz repetition rates and a laser energy of 6 mJ for monazite dating. The ablated material was carried into helium, and then mixed with nitrogen and argon, before injection into a plasma source of an Agilent 7500 cs ICP-MS equipped with a dual pumping system to enhance the sensitivity.

Data were corrected for U–Th–Pb fractionation occurring during laser sampling and for instrumental mass discrimination (mass bias) by standard bracketing with repeated measurements of a GJ-1 zircon standard ([Jackson *et al.* 2004](#)). At the beginning and end of

every run, repeated analyses of a 91500 zircon standard (1066 ± 3 Ma; Wiedenbeck *et al.* 1995), treated as unknowns, independently controlled the reproducibility and accuracy of the corrections (detailed were described in Hurai *et al.* 2012). Data reduction was carried out with the GLITTER® software package from Macquarie Research Ltd (van Achterbergh *et al.* 2001; Jackson *et al.* 2004). For each analysis, the time-resolved signal of single isotopes and isotope ratios was monitored to verify the presence of perturbations related to inclusions, fractures, mixing of different age domains, or common Pb. Calculated ratios were exported and Concordia ages and diagrams were generated using the Isoplot/Ex v. 2.49 software package (Ludwig 2001). The concentrations of U–Th–Pb were calibrated relative to the certified contents of a GJ-1 zircon standard (Jackson *et al.* 2004). The zircon analyses were projected on $^{207}\text{Pb}/^{206}\text{Pb}$ vs. $^{238}\text{U}/^{206}\text{Pb}$ diagrams (Tera & Wasserburg 1972), where the analytical points plot along a mixing line between the common Pb composition and the zircon age (at the lower intercept). This method is commonly used to date Phanerozoic zircons using *in situ* methods (Claoué-Long *et al.* 1995; Jackson *et al.* 2004). Unless stated otherwise, all errors are reported at 95 % (2σ) confidence level. Tables of zircon and monazite analyses are in *Supplementary Data*.

Major- and trace-elements whole-rock geochemistry

About 140 samples (5 to 10 kg of fresh material) with a maximum spacing of about 2 km were taken (40 CVMg–K, 30 SVMg–K and 70 CVG). The size of the samples was adapted to account for the presence of K-feldspar megacrysts. After crushing and splitting, rocks were ground in agate mills to fine powder. Major- and most trace-element analyses (Tables are in *Supplementary Data*) were carried out in AcmeLabs™, Vancouver, by ICP-ES following lithium metaborate/tetraborate fusion and dilute nitric digestion of a 0.2 g sample. The rare

earth elements (REE) were determined by the same laboratory by ICP-MS. The geochemical data were plotted with the R software package *GCDkit* ([Janoušek et al. 2006a](#)).

Sr–Nd isotopic compositions

The Sr and Nd isotope data for 13 samples of Mg–K associations (7 for SVMg–K and 6 for CVMg–K) and 10 CVG samples (6 for E-CVG and 4 for W-CVG) were determined at BRGM Orléans. Strontium and REE were separated by ion exchange chromatography on a cationic resin. The Nd was then stripped of the other REE and Ba using the HDEHP reverse chromatography adapted from [Richard et al. \(1976\)](#).

The Sr was loaded on single W filaments and isotopic ratios were measured on a thermal-ionization mass spectrometer (TIMS) Finnigan MAT 262 in double-double dynamic mode. Mass discrimination was corrected for by adjusting the $^{86}\text{Sr}/^{88}\text{Sr}$ ratio to 0.1194. An average internal precision of ± 10 ppm ($2\sigma_m$) was obtained and reproducibility of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio measurements was tested through repeated analyses of the NBS 987 standard for which we obtained, during the period of analysis, a mean value of 0.710246 ± 0.000011 (2σ , $n = 28$). Sample ratios were normalized to the certified value of the NBS 987 (0.710240).

The Nd isotopic ratios were also measured using the same TIMS but in static mode, with samples loaded on double Re filaments. The $^{143}\text{Nd}/^{144}\text{Nd}$ ratios were normalized to a $^{146}\text{Nd}/^{144}\text{Nd}$ of 0.7219 and then adjusted to the 0.511860 value of the La Jolla international standard. Repeated measurements of the La Jolla standard during the period of analyses yielded a mean $^{143}\text{Nd}/^{144}\text{Nd}$ of 0.511874 ± 14 (2σ ; $n = 10$). The present-day CHUR parameters used in the ε_{Nd} values calculation are from [De Paolo & Wasserburg \(1976\)](#): $(^{143}\text{Nd}/^{144}\text{Nd})_{\text{CHUR}} = 0.51264$ when normalised to $^{146}\text{Nd}/^{144}\text{Nd} = 0.7219$ ([Jacobsen & Wasserburg 1980](#)) and $(^{147}\text{Sm}/^{144}\text{Nd})_{\text{CHUR}} = 0.1967$. The two-stage depleted-mantle Nd model ages were calculated following [Liew & Hofmann \(1988\)](#).

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