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A LREE-depleted component in the Afar plume: Further evidence from Quaternary Djibouti basalts

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ABSTRACT

Major, trace element and isotopic (Sr, Nd, Pb) data and unspiked K–Ar ages are presented for Quaternary (0.90–0.95 Ma old) basalts from the Hayyabley volcano, Djibouti. These basalts are LREE-depleted (La_n/Sm_n = 0.76–0.83), with $^{87}Sr/^{86}Sr$ ratios ranging from 0.70369 to 0.70376, and rather homogeneous $^{143}Nd/^{144}Nd$ (ε_{Nd} = +5.9–+7.3) and Pb isotopic compositions ($^{206}Pb/^{204}Pb$ = 18.47–18.55, $^{207}Pb/^{204}Pb$ = 15.52–15.57, $^{208}Pb/^{204}Pb$ = 38.62–38.77). They are very different from the underlying enriched Tadjoura Gulf basalts, and from the N-MORB erupted from the nascent oceanic ridges of the Red Sea and Gulf of Aden. Their compositions closely resemble those of (1) depleted Quaternary Manda Hararo basalts from the Afar depression in Ethiopia and (2) one Oligocene basalt from the Ethiopian Plateau trap series. Their trace element and Sr, Nd, Pb isotope systematics suggest the involvement of a discrete but minor LREE-depleted component, which is probably an intrinsic part of the Afar plume.

1. Introduction

The study of basalts from intra-oceanic islands and plateaus as well as from traps and rifts has shown the considerable chemical heterogeneity of plume materials (Hart, 1988). This heterogeneity might indicate very complex plume structures and dynamics (Lin and van Keken, 2006). However, it may not only result from the initial chemical heterogeneity of mantle plumes at depth but also from the entrainment of surrounding mantle materials (Hart et al., 1992; Furman et al., 2006). In addition, a lithospheric component is clearly recognized in some intracontinental basalts, e.g. in the Afar province, but its origin is still debated (Rogers, 2006). Some authors have suggested that melting of the Afar lithospheric mantle explains a significant proportion of the erupted lavas (Hart et al., 1989; Vidal et al., 1991; Deniel et al., 1994) whilst others point out that continental crust contamination can also contribute to the isotopic signature of these basalts (Barrat et al., 1993; Baker et al., 1996; Pik et al., 1999).

The vast majority of plume-related basalts, including the Afar ones (Furman et al., 2006; Beccaluva et al., 2009) are dominated by a component that is chemically and isotopically enriched. However, the occurrence of subordinate components characterized by a light rare earth element (LREE) depletion has been suggested from the study of basalts from major mantle plumes in: (1) Iceland (Zindler et al., 1979; Hémond et al., 1993; Taylor et al., 1997; Chauvel and Hémond, 2000; Skovgaard et al., 2001; Fitton et al., 2003; Thirlwall et al., 2004; Kokfelt et al., 2006); (2) Hawaii (Chen and Frey, 1985; Yang et al., 2003; Frey et al., 2005); (3) the Galapagos (White et al., 1993; Hoernle et al., 2000; Blichert-Toft and White, 2001; Saal et al., 2007); and (4) the Kerguelen Archipelago (Doucet et al., 2002). However, the characterization of this reservoir is difficult because its signature may be overprinted by either the dominant enriched plume component or the lithospheric reservoirs. Therefore, the presence of an intrinsic depleted component in plumes is still an open question.

LREE-depleted basalts associated to the Afar mantle plume have long been recognized in the Quaternary Manda Hararo volcanic chain, Ethiopia (Treuil and Joron, 1975; Joron et al., 1980; Barrat et al., 2003). A single LREE-depleted Oligocene Ethiopian Plateau basalt has also been so far analysed (sample E88: Pik et al., 1998, 1999). The purpose of this paper is: (1) to describe another newly discovered occurrence of such basalts in the SE part of the Afar triangle, i.e. the rather large Hayyabley Quaternary volcano in Djibouti (Fig. 1), and (2) to discuss its bearing on the composition and heterogeneity of the Afar mantle plume.

2. Analytical techniques

Ar isotopic compositions and K contents (Table 1) were measured at Gif-sur-Yvette and IUEM (Institut Universitaire Européen de la

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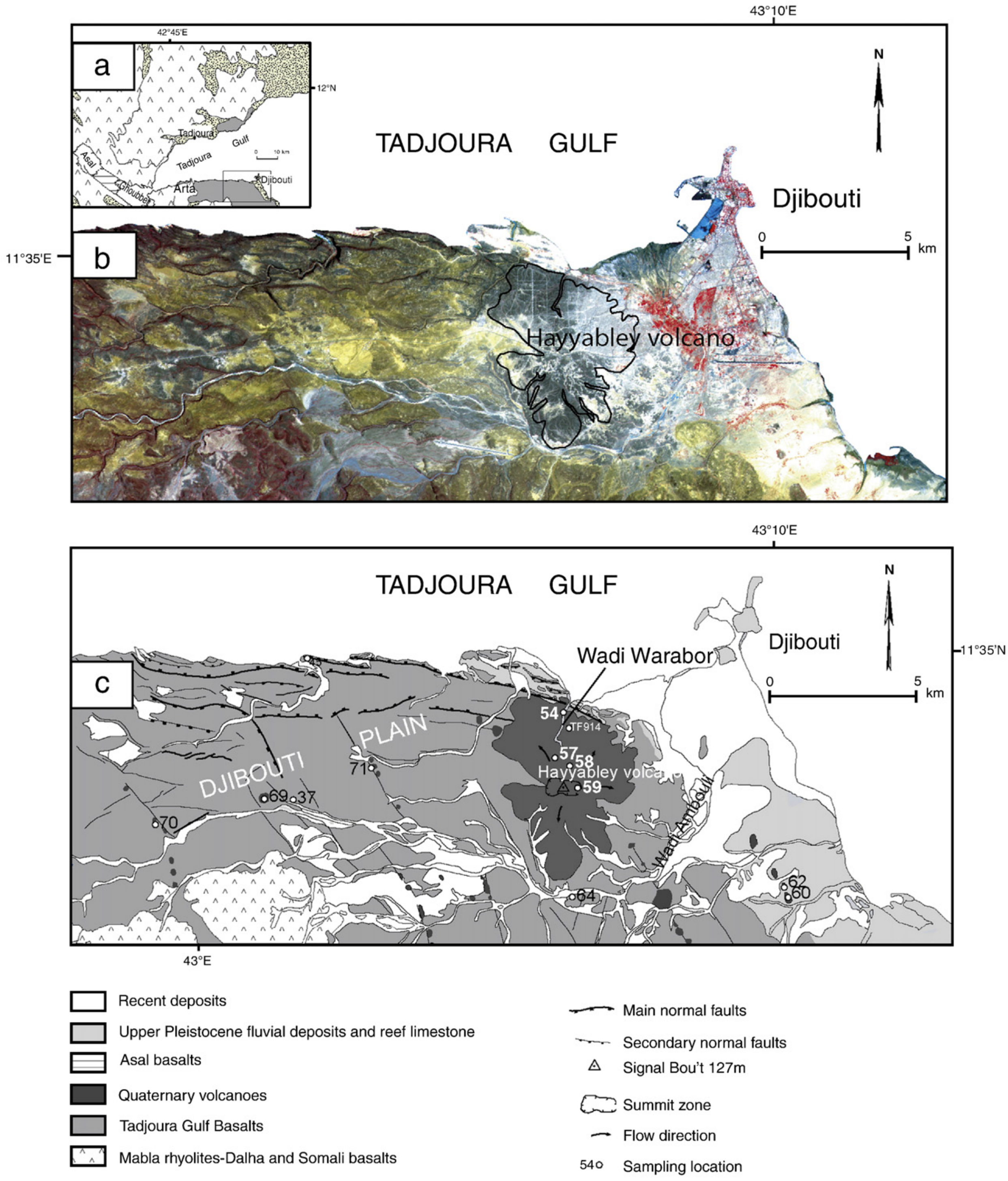

Fig. 1. Geological setting of the Djibouti Plain. (a) Location of the study area in the Tadjoura Gulf context. (b) ASTER satellite image showing the Hayyabley volcano post-dating the coastal fault belt related to the Tadjoura rift. (c) Geological interpretation of panel b.

Mer), respectively. The samples were crushed, sieved to 0.25–0.125 mm size fraction and ultrasonically washed in acetic acid. Potassium and argon were measured on the microcrystalline groundmass, after removal of phenocrysts using heavy liquids of appropriate densities and magnetic separations. This process improves the K yield as well as the percentage of radiogenic argon, and removes at least some potential sources of systematic error due to the presence of excess ^{40}Ar in olivine and feldspar phenocrysts (Laughlin et al., 1994). Ar analyses were performed using the procedures detailed in Yurtmen et al. (2002) and Guillou et al. (2004). The unspiked technique differs from the conventional isotope dilution method in that argon extracted from the sample is measured in sequence with purified aliquots of atmospheric argon at the same working gas pressure in the mass-spectrometer. This suppresses mass discrimination effects between the atmospheric reference and the unknown, and allows quantities of radiogenic $^{40}Ar^*$ as small as 0.14% to be detected on a single-run basis (Scaillet and Guillou, 2004). Argon was extracted by radio frequency heating of 2.0–3.0 g of sample, then transferred to an ultra-high-vacuum glass line and purified with titanium sponge and Zr–Ar getters. Isotopic analyses were performed on total ^{40}Ar contents ranging between 2.4