EGU General Assembly 2020

Geochronology and Lu-Hf isotopic study of the granodioritic pulse in the Qaradagh batholith (NW Iran)

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Introduction

The Qaradagh batholith is located in northwest Iran, south of the Iran–Armenia international border, about 80 km north of Tabriz (aerial distance), between the latitudes of 46°14′ and 46°31′40′′ E and longitudes of 38° 49′53′′ and 38° 56′17′′ N (Fig. 1).

It is formed by several intrusive pulses of Eocene–Oligocene age, intruding the Upper Cretaceous and early Cenozoic sedimentary and magmatic rocks.

This batholith is mainly comprised of granodioritic rocks, which form the first intrusive pulse within this batholith and the oldest Tertiary magmatism in the region, though other younger pulses of granite, diorite, quartz-diorite, syenite, quartz-syenite, monzonite, quartz-monzonite, quartz-monzodiorite, monzogranite and gabbro intruded the main body.

Therefore, granodiorite to quartz-monzonite is the dominant constituent of the Qaradagh batholith (Mokhtari et al. 2013), which makes more than 50% of the batholith.

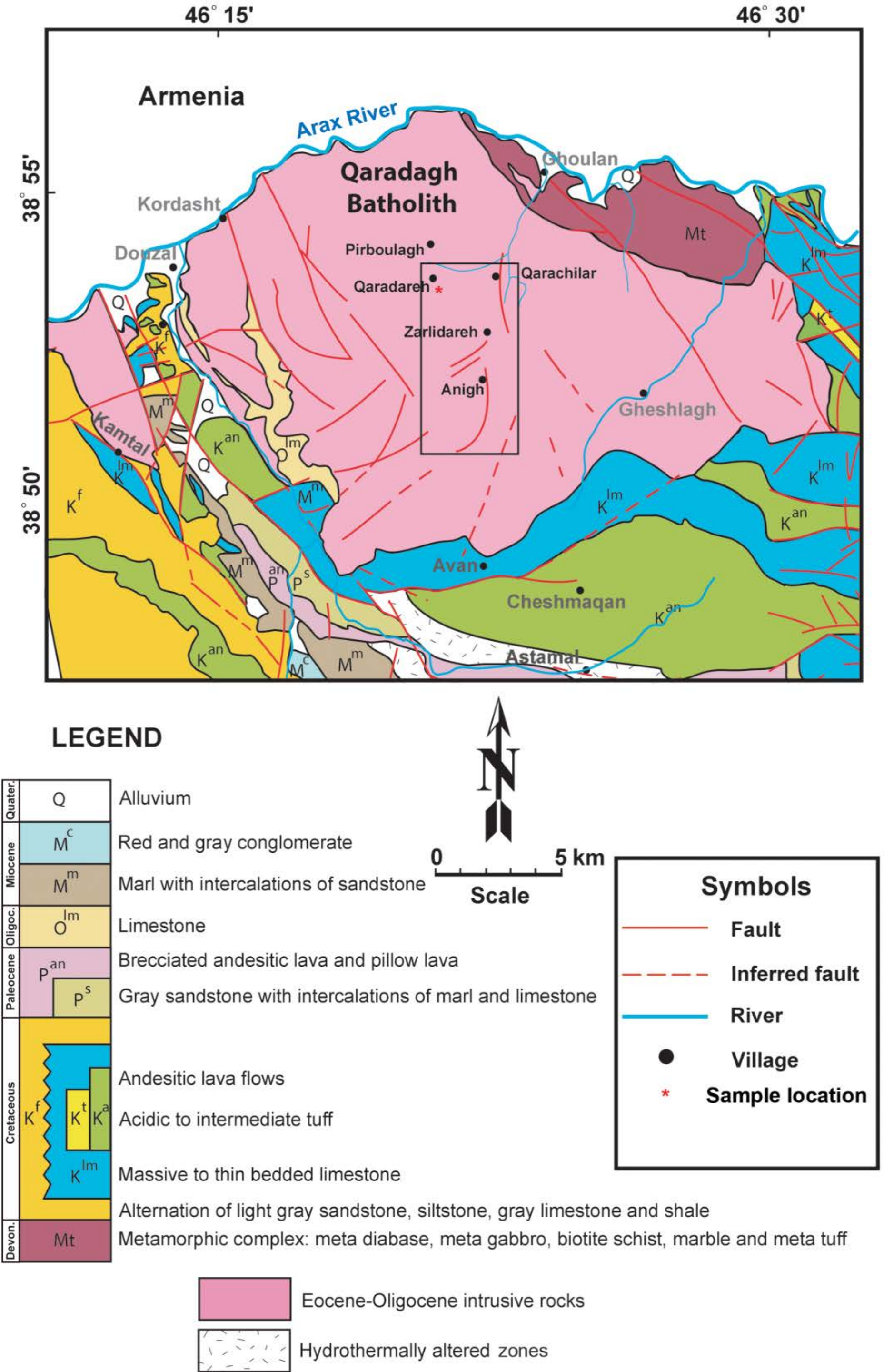

Fig. 1 Geologic map of the Qaradagh batholith and the surrounding areas (simplified and modified after Mehrpartou et al. 1997).

This batholith hosts vein-type and some local stock-work type Cu–Au–Mo mineralization, especially in its central parts, while skarn-type deposits have been formed at its contacts with peripheral carbonate rocks.

Its extension towards the north into the neighboring south Armenia (which is part of the South Armenian Block) is known as the Meghri–Ordubad pluton (MOP), which hosts several large porphyry Cu–Mo deposits and other precious and base metal mineralizations (Fig. 2).

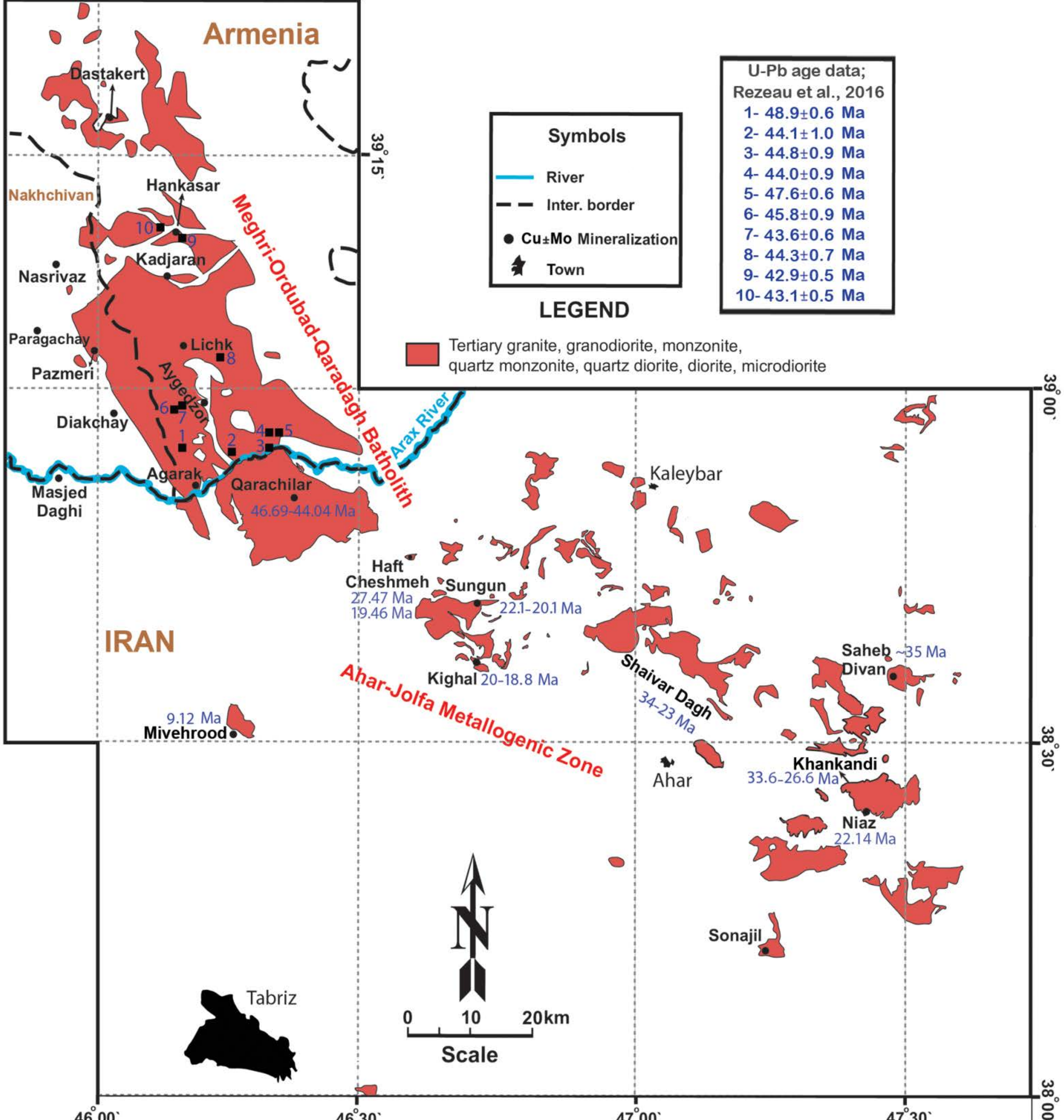

Fig. 2 Cenozoic (Eocene–Miocene) granitoids in NW Iran and South Armenian Block, including the Meghri–Ordubad–Qaradagh batholith, Shaivar Dagh plutonic complex and other smaller intrusives, along with the main porphyry Cu–Mo, base and precious metal deposits in the region.

Presented ages are from Rezeau et al. (2016) for the Meghri–Ordubad pluton, Simmonds et al. (2019) for Siah Kamar, Aghazadeh et al. (2015) for Sungun, Hassanpour et al. (2015) for Haft Cheshmeh and Niaz, Aghazadeh et al. (2011) for Shaivar Dagh, Aghazadeh et al. (2010) for Khankandi, Hassanpour (2010) for Saheb Divan, Alirezaei et al. (2016) for Mivehrood and Simmonds (2019) for Kighal.

Petrography and Petrology

Granodioritic rocks are composed of plagioclase (oligoclase with an andesine core; 50–70 vol.%), K-feldspar (orthoclase; 5–15 vol.%) and quartz (anhedral; 15–25 vol.%) with subordinate amounts of amphibole (magnesian hornblende; 5–15 vol.%), biotite (5–10 vol.%), pyroxene (augite; <5 vol.%) and opaque minerals (1–5 vol.%), and display hetero-granular texture (Fig.3).

Petrologically, they have medium to high-K calc-alkaline affinity and metaluminous characteristics, being classified as I-type Cordilleran, active continental margin calc-alkaline granitoids (ACG).

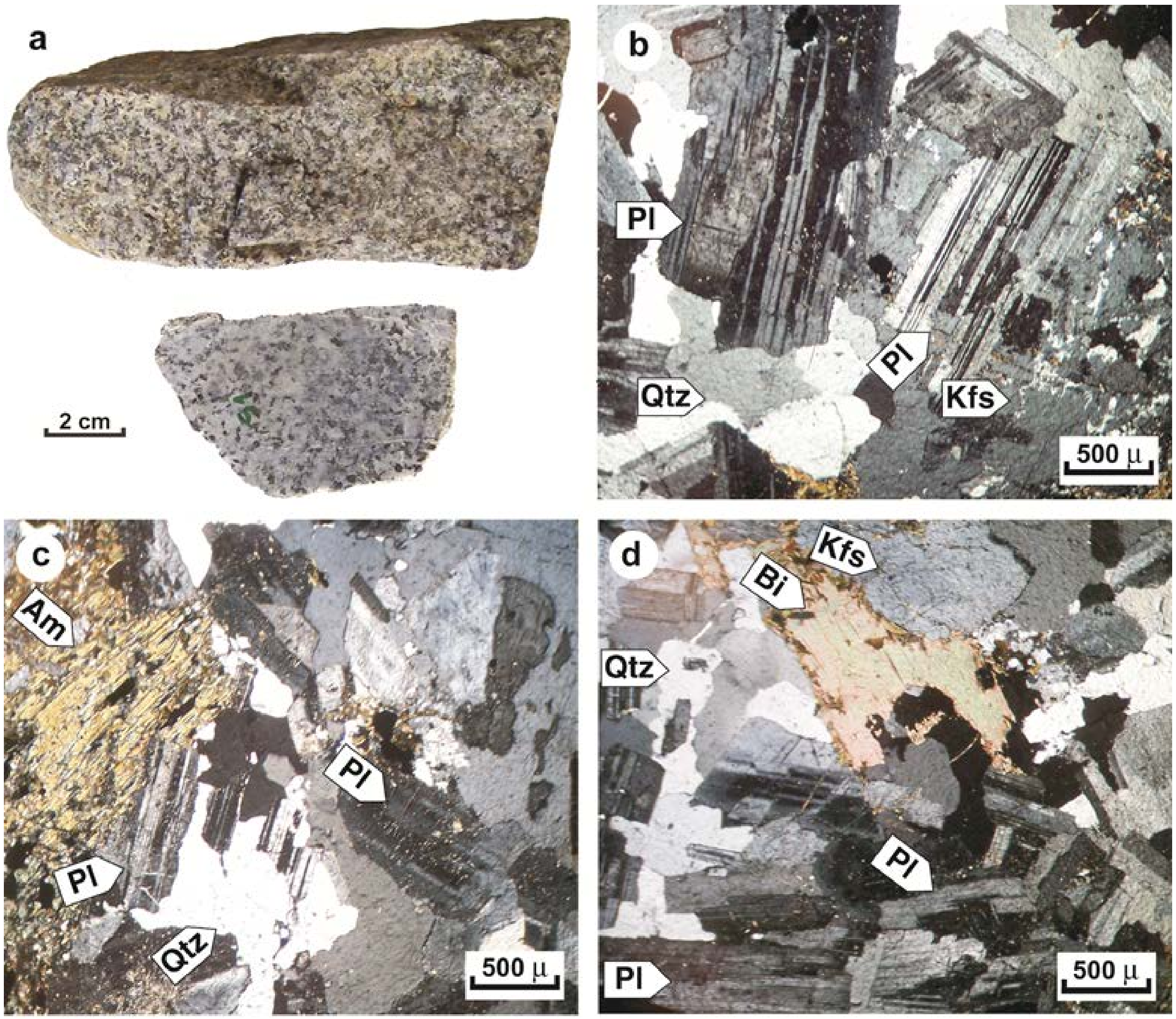

Fig. 3 (a) Granodioritic rocks in hand specimen, (b–d) microphotographs illustrating the main rock-forming minerals of the granodioritic rocks, including tabular plagioclase with poly-synthetic twinning, subhedral amphibole and biotite, and anhedral alkali feldspar and quartz, portraying granular texture.

Mineralization

The hypogene mineralization in the Qaradagh batholith includes Cu–Mo±(Au–Ag) sulphides, which have mainly occurred as parallel swarms of mono-mineralic and quartz±carbonate veins and veinlets and silicified zones, as well as disseminations within the host rocks, while stock-work mineralization is also evident in the environs of the Qarachilar area. The main sulphide minerals are pyrite, chalcopyrite and molybdenite, with lesser amounts of bornite and digenite.

The reported grades of Mo and Cu from surficial samples range from 20 ppm to 3.6 wt.% and 0.7 to 5 wt.%, respectively (Sohrabi 2003; Rezai Aghdam and Sohrabi 2010; Zakeri 2013).

The genesis of mineralization in Qaradagh batholith is controversial. Mokhtari et al. (2013) introduce it as intrusion-related gold mineralization, while Rezai Aghdam and Sohrabi (2010) propose vein-type Cu–Mo–Au mineralization. However, evidence like the presence of mineralized dikes, hydrothermal alteration zones and stock-work mineralization in the Qarachilar area suggest that a porphyry mineralization system is most likely present beneath the surface (e.g., Amini Fazl 1994; Zakeri et al. 2011; Zakeri 2013).

Material and Methods

A representative sample from the Qaradagh granodiorite was chosen for U–Pb zircon dating. Zircon separation was performed in the Eurasia Institute of Earth Sciences in Istanbul Technical University by conventional techniques. Representative zircon grains were handpicked under binocular and mounted in epoxy resin. The mounts were ground down to expose the zircon cores and polished to a flat surface for analyses.

Ten spots on the separated zircons were dated using U–Pb method at the Microgeochemistry lab at the Department of Earth Sciences, University of Gothenburg on a New Wave NWR213 laser ablation system coupled to an Agilent 8800 ICP-MS/MS. The zircon standards GJ-1 (Jackson et al. 2004) and 91500 (Wiedenbeck et al. 1995) were also analyzed for testing the age accuracy. U–Pb zircon ages were calculated using an in-house spreadsheet. As a whole, a conservative lower limit of 1.5% error on overall accuracy of the method is assumed.

The mounted zircons were later used for Hf isotope analysis at ETH Zurich for which, further U–Pb dating was also performed. The U–Pb analysis was performed on 50 spots using a 193 nm Resonetics Resolution 155 laser ablation system coupled to a Thermo Element XR Sector-field ICP-MS at ETH Zurich (Guillong et al. 2014).

Six In-situ Hf isotope analysis was performed on a Nu plasma MC-ICP-MS (Nu instrument Ltd) attached to a 193 nm UV ArF Excimer laser, at the ETH Zurich on the same zircon grains.

Results

The concordia age calculated for the analyzed zircons is about 44.04 ± 1.00 Ma (at 2σ level) (MSWD= 24), which corresponds to the Middle Eocene (Fig. 4).

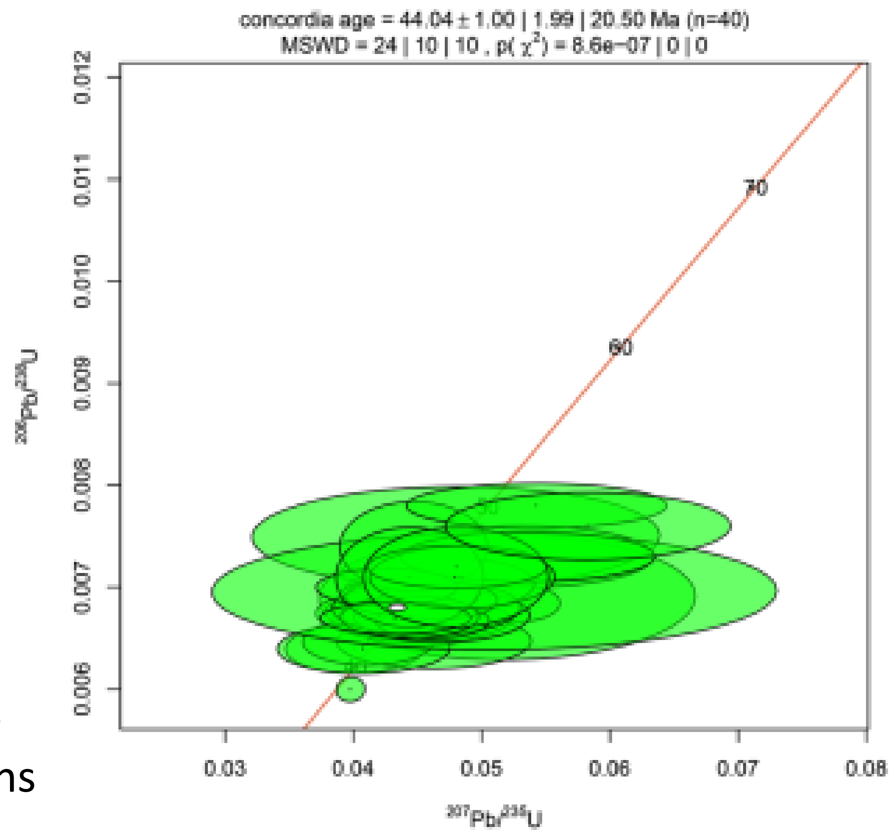

Fig. 4 Pb*/U concordia age of the analyzed zircon grains from granodiorite.

Six laser-ablation Lu–Hf measurements were performed on the dated zircon grains. The analyzed zircons have almost similar $^{176}Lu/^{177}Hf$ ratios of 0.000721–0.001876 and $^{176}Hf/^{177}Hf$ ratios between 0.283003 and 0.283072, with positive $\varepsilon Hf_{(t)}$ values (at the time of zircon crystallization) of 8.7 to 11.1 with the mean of 9.5, that are plotted between the CHUR (Chondritic Uniform Reservoir model; Blichert-Toft and Albarède 1997) and the Depleted Mantle evolution (DM; Griffin et al. 2000) lines.

Discussion and Conclusion

According to the obtained results, the granodioritic lithology which forms the main framework of the Qaradagh batholith has Middle Eocene age.

Since the Qaradagh batholith and especially its earlier magmatic phases are considered as the oldest plutonic event of the Cenozoic age in northwest Iran, thus this investigation testifies to the fact that intrusive activities of Tertiary in this region has commenced in Middle Eocene, contrary to the opinion of the majority of authors who believe that plutonism in this region occurred during Oligocene, with some suggesting Upper Eocene age for this pluton.

Albeit, reconstruction of the history of this batholith regarding its younger magmatic pulses needs more geochronological datings on younger intrusive stocks within it. For example, Re–Os ages published by Simmonds and Moazzen (2015) on the molybdenite separates from the quartz veins immediately hosted by the studied granodioritic rocks in the Qarachilar area (central part of the batholith) range from 25.19 ± 0.19 to 31.22 ± 0.28 Ma (Upper Oligocene), which are considerably younger than the host granodiorites and indicate that mineralization in this batholith is related to another much younger intrusive phase.

Comparing the zircon U–Pb ages of the main lithology of the Qaradagh pluton with intrusive pulses of the MOP showed that the southern part of the MOP is almost coeval with the emplacement of the granodioritic rocks in Qaradagh batholith (Fig. 2) (Moritz et al., 2013; Rezeau et al., 2016).

The positive $\varepsilon Hf_{(t)}$ values of the analyzed zircons (8.7 to 11.1) indicate a juvenile and homogeneous magmatic source and the predominance of mantle-derived magmas with limited crustal assimilation.

These data are thoroughly in the range of those from the neighboring MOP (median initial εHf values between 8.0 and 11.3) reported by Rezeau et al. (2016), who explain the deduced predominance of mantle-derived magmas with little crustal contribution by considering a long-lived homogeneous deep reservoir in the lower crust or lithospheric mantle. They have also proposed progressive cannibalization of young and juvenile lower crust, formed by mantle-derived magmas.

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