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Rifting, subduction and collisional records from pluton petrogenesis and geochronology in the Hindu Kush, NW Pakistan

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ABSTRACT

New U-(Th)/Pb geochronology and geochemical analyses of plutonic bodies in the Hindu Kush range, NW Pakistan, provide insight on the crustal growth and tectonic evolution of the southern Eurasian margin. These new data outline a protracted magmatic history that spans the Cambrian to the Neogene (ca. 538 to 23 Ma) and record a variety of petrogenetic associations variably influenced by within plate, volcanic arc, and collision tectonic environments. The Kafiristan pluton (538 $\pm$ 4 to 487 $\pm$ 3 Ma) yields geochemical signatures consistent with extensional plutonism and rifting of the Hindu Kush terrane from Gondwana. The Tirich Mir (127 $\pm$ 1 to 123 $\pm$ 1 Ma) and Buni-Zom (110 $\pm$ 1 to 104 $\pm$ 1 Ma) plutons have geochemical signatures that can be attributed to a subduction related continental volcanic arc system that developed along the southern margin of Eurasia in the Mesozoic. The Garam Chasma pluton, the youngest body in the study area (27.3 $\pm$ 0.5 to 22.8 $\pm$ 0.4 Ma), yields a geochemical signature consistent with widespread anatexis during crustal thickening related to the development of the Himalaya. The present geochemical and geochronological analysis from the Hindu Kush have produced important new constraints on the timing of tectonic events and variable tectonic settings along the south Eurasian margin before and after the continued India–Asia collision.

1. Introduction

The NE–SW trending Hindu Kush range stretches for more than 600 km from northwestern Pakistan into adjacent Afghanistan (Figs. 1 and 2). The geology of the range records a complex history of magmatism, deformation, and metamorphism spanning the early Paleozoic to the present day (Debon et al., 1987; Hildebrand, 1998; Zanchi and Gaetani, 2011; Faisal et al., 2014). Because the Hindu Kush records evidence of the evolution of Eurasia prior to continental collision (Zanchi et al., 2000; Hildebrand et al., 2001; Zanchi and Gaetani, 2011; Faisal et al., 2014), which is not well preserved in other parts of the orogen, the geologic history of the Hindu Kush is important for our understanding of the tectonic, magmatic and metamorphic evolution of the southern Eurasian margin.

The Hindu Kush terrane, which comprises most of the study area, was detached from Gondwana in the Paleozoic (Zanchi and Gaetani, 2011; Angiolini et al., 2013) and accreted to the southern margin of Eurasia in the Late Triassic (Faisal et al., 2014). Its accretion was followed closely by the collision and accretion of the Karakoram terrane in the Early Jurassic (Zanchi et al., 2000; Faisal et al., 2014). Continued northward subduction of the Paleotethys from the Middle Jurassic to the Early Cretaceous along the southern margin of Eurasia resulted in the intrusion of plutonic bodies in the Tirich Mir-Wakhan and Karakoram belts in an Andean-style margin (Searle et al., 1989; Hildebrand et al., 2001; Searle et al., 2010). The Kohistan island arc is interpreted to have developed within the Paleotethys sometime in the Mesozoic above a northward-dipping subduction zone (Tahirkheli et al., 1979) and was accreted to Eurasia in the Late Cretaceous (Petterson et al., 1991; Fraser et al., 2001; Faisal et al., 2014). Continued subduction thereafter resulted in the development of a second Andean-style margin marked by the intrusion of the Kohistan Batholith (Petterson and Windley, 1991). Ultimately, the Kohistan island arc was sandwiched between India and Eurasia during the Cenozoic initiation of their collision (Beck et al., 1995).

While timing constraints on accretion events and metamorphism now exist for the Hindu Kush (Zanchi et al., 2000; Hildebrand et al., 2001; Heuberger et al., 2007; Faisal et al., 2014) relatively little is known about the various plutonic bodies that intrude the region. There have been no systematic geochemical studies of the plutons of the Pakistani Hindu Kush, and therefore, the geochemical characteristics, potential sources, and the tectonic evolution of the Kafiristan, Tirich Mir, Buni-Zom (exposed along Golen Gol) and Garam Chasma plutonic bodies (Fig. 2) remain poorly constrained. Their occurrence has been variably attributed to subduction and/or collision-related crustal

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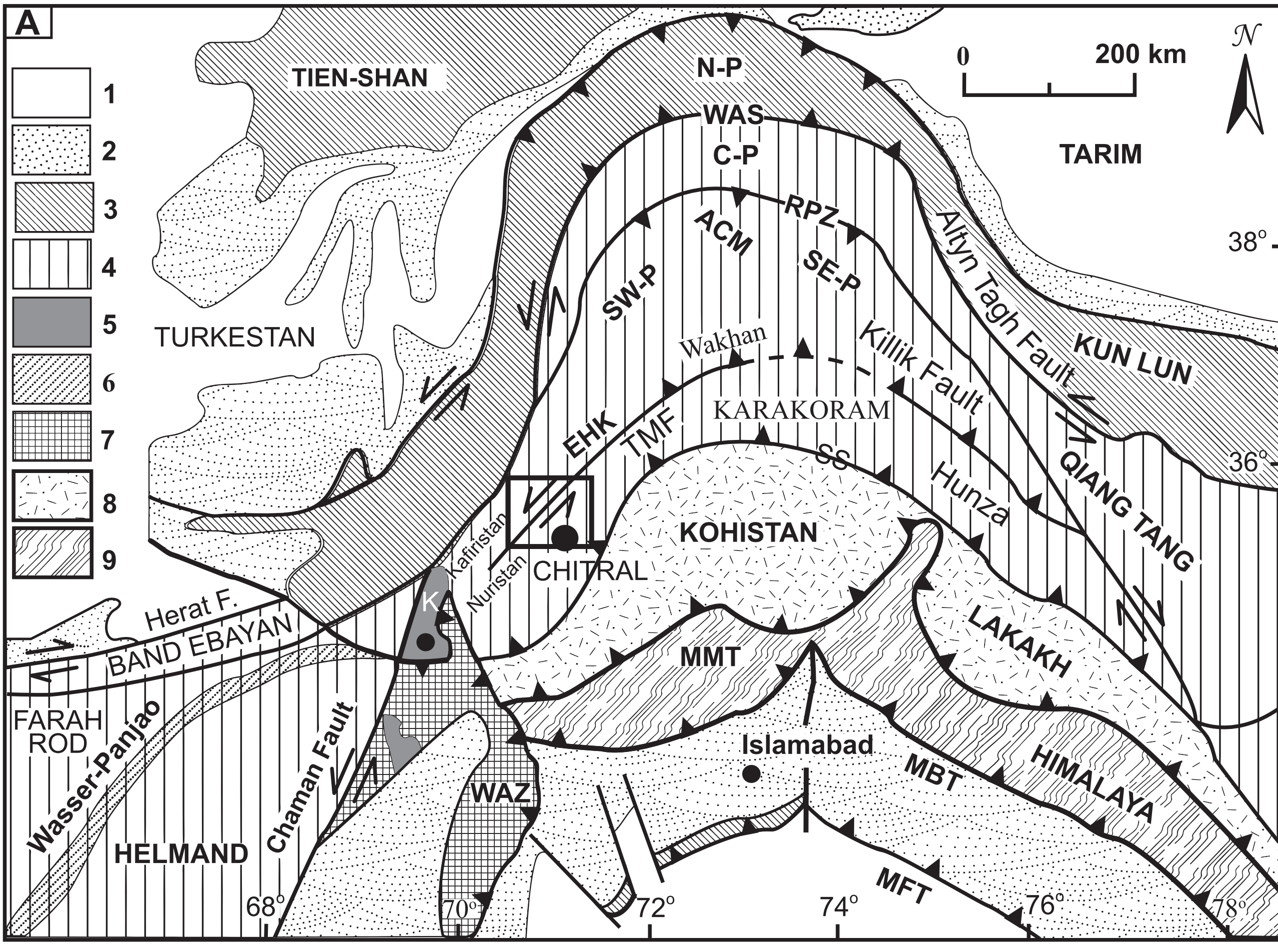

Fig. 1. Tectonic map of Northern Pakistan and surrounding regions. MFT, Main Frontal Thrust; MBT, Main Boundary Thrust; MMT, Main Mantle Thrust; SS, Shyok Suture; TMF, Tirich Mir Fault Zone; EHK, East Hindu Kush; ACM, Alitchur mountains; RPZ, Rushan–Pshart Zone; WAS, Wanch-Ak Baital Suture; N-P, North Pamir; C-P, Central Pamir; SE-P, SE-Pamir; SW-P, SW-Pamir; WAZ, Waziristan; K, Kabul. 1, Quaternary; 2, Tertiary foredeeps; 3, Palaeozoic belts; 4, Terranes of Gondwanan affinity; 5, Kabul Block; 6, Wasser-Panjao Suture; 7, Waziristan ophiolitic complex; 8, Kohistan–Ladakh arc terranes; 9, Himalaya. Heavy lines represent main sutures (Redrawn after Gaetani et al., 1996; Zanchi et al., 2000). Insert rectangle shows the location of Fig. 2.

thickening processes (e.g. Desio, 1964; Debon et al., 1987; Hildebrand, 1998; Hildebrand et al., 2000; Zafar et al., 2000; Zanchi et al., 2000; Hildebrand et al., 2001; Heuberger et al., 2007). This study examines the petrogenesis and tectonic significance of the Kafiristan, Tirich Mir, Buni-Zom and Garam Chasma plutons based on new major, trace and rare earth element (REE) data and integrated U(Th)–Pb (zircon/monazite) geochronology. This work contributes to the record of major tectonic events in the Hindu Kush and helps improve our understanding of the evolution of the southern margin of Eurasia, subduction dynamics of the Tethys, and the evolution of the Himalaya–Karakoram–Tibetan orogenic system.

1.1. Background geology and existing chronology

The present work is focused on the Hindu Kush in the Chitral region, NW Pakistan (Fig. 1). The geology of the area is characterized by multiply deformed, variably metamorphosed, Paleozoic to Mesozoic sedimentary rocks intruded by the elongate Kafiristan, Tirich Mir, Buni-Zom, Kesu-Kohuzi and Garam Chasma plutons (Calkins et al., 1981; Hildebrand et al., 2000; Fig. 2). The plutonic bodies typically form physiographic peaks in the region, which reach elevations of 7700 + m locally.

Published constraints on the age of plutonic rocks in the Hindu Kush vary considerably. Existing whole rock Rb–Sr data from the Kafiristan and Tirich Mir plutons outline ages of 483 ± 21 Ma (Debon et al., 1987) and 115 ± 4 Ma (Desio, 1964) respectively. U–Pb Isotope Dilution Thermal Ionization Mass Spectrometry (ID-TIMS) analysis on monazite and uraninite grains from a pegmatite dyke in the Tirich Mir fault zone, thought to be related to the main Tirich Mir plutonic body, yielded a discordant, interpreted intrusion age of 114 ± 2 Ma (Hildebrand et al., 2000). More recently, zircon grains analyzed from a different specimen of the Tirich Mir body yielded two concordant analyses interpreted to comprise an age of 121 ± 1 Ma (Heuberger et al., 2007). Both U–Pb age estimates for the Tirich Mir pluton are consistent with a 110.6 ± 3.2 Ma post-magmatic ^{39}Ar–^{40}Ar (muscovite) date (Heuberger et al., 2007). A specimen of the Buni-Zom plutonic body collected to the north-east of study area yielded a U–Pb (zircon; ID-TIMS) age of 103.79 ± 0.27 Ma defined by two concordant data points (Heuberger et al., 2007). Finally, U–Pb ID-TIMS analyses on monazite and xenotime grains from a specimen collected from the Garam Chasma pluton yielded a discordant age of 24 ± 0.5 Ma (Hildebrand et al., 1998). This is consistent with 18–20 Ma K–Ar (biotite) dates from the same body if they are interpreted to represent cooling and not crystallization (Zafar et al., 2000).

2. Pluton descriptions

Plutonic rocks are a major constituent of the eastern Hindu Kush comprising ~35% of the bedrock in the region (Fig. 1). The grayish white (fresh) Kafiristan pluton exposed along the Bomborate and Rumboor valleys (Fig. 1) is locally foliated and is characterized by a porphyritic texture with K-feldspar megacrysts ranging in size from 3–4 cm. The matrix minerals consist of Qz + Kfs + Pl + Bt ± Hbl and accessory Zrn + Tur + Ap + Ep (Fig. 3A and B). The alkali feldspar and plagioclase