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Mesozoic to Cenozoic magmatic history of the Pamir

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ABSTRACT

New geochronologic, geochemical, and isotopic data for Mesozoic to Cenozoic igneous rocks and detrital minerals from the Pamir Mountains help to distinguish major regional magmatic episodes and constrain the tectonic evolution of the Pamir orogenic system. After final accretion of the Central and South Pamir terranes during the Late Triassic to Early Jurassic, the Pamir was largely amagmatic until the emplacement of the intermediate ($SiO_2 > 60$ wt.%), calc-alkaline, and isotopically evolved (-13 to -5 zircon $\varepsilon\text{Hf}_{(t)}$) South Pamir batholith between 120–100 Ma, which is the most volumetrically significant magmatic complex in the Pamir and includes a high flux magmatic event at $\sim$105 Ma. The South Pamir batholith is interpreted as the northern (inboard) equivalent of the Cretaceous Karakoram batholith and the along-strike equivalent of an Early Cretaceous magmatic belt in the northern Lhasa terrane in Tibet. The northern Lhasa terrane is characterized by a similar high-flux event at $\sim$110 Ma. Migration of continental arc magmatism into the South Pamir terrane during the mid-Cretaceous is interpreted to reflect northward directed, low-angle to flat-slab subduction of the Neo-Tethyan oceanic lithosphere. Late Cretaceous magmatism (80–70 Ma) in the Pamir is scarce, but concentrated in the Central and northern South Pamir terranes where it is comparatively more mafic ($SiO_2 < 60$ wt.%), alkaline, and isotopically juvenile (-2 to $+2$ zircon $\varepsilon\text{Hf}_{(t)}$) than the South Pamir batholith. Late Cretaceous magmatism in the Pamir is interpreted here to be the result of extension associated with roll-back of the Neotethyan oceanic slab, which is consistent with similarly aged extension-related magmatism in the Karakoram terrane and Kohistan.

There is an additional pulse of magmatism in the Pamir at 42–36 Ma that is geographically restricted ($\sim$150 km diameter ellipsoidal area) and referred to as the Vanj magmatic complex. The Vanj complex comprises metaluminous, high-K calc-alkaline to shoshonitic monzonite, syenite, and granite that is adakitic ($\text{La/Yb}_N = 13$ to 57) with low Mg# (35–41). The Vanj complex displays a range of SiO_2 (54–75 wt.%) and isotopic compositions (-7 to -3 $\varepsilon\text{Nd}_{(i)}$, 0.706 to 0.710 $^{87}\text{Sr}/^{86}\text{Sr}_{(i)}$, -3 to $+1$ zircon $\varepsilon\text{Hf}_{(i)}$, 6.0 to 7.6‰ zircon $\delta^{18}\text{O}_{\text{VSMOW}}$), which reflects some juvenile mantle input and subsequent assimilation or mixing with the Central/South Pamir terrane lower crust. The Vanj complex is speculatively interpreted to be the consequence of a mantle drip or small delamination event that was induced by India–Asia collision. The age, geochemistry, outcrop pattern, and tectonic position of the Vanj magmatic complex suggest that it is part of a series of magmatic complexes that extend for >2500 km across the Pamir and northern Qiangtang terrane in Tibet. All of these complexes are located directly south of the Tanymas–Jinsha suture zone, an important lithospheric and rheological boundary that focused mantle lithosphere deformation after India–Asia collision. Miocene magmatism (20–10 Ma) in the Pamir includes: 1) isotopically evolved migmatite and leucogranite related to crustal anataxis and decompression melting within extensional gneiss domes, and; 2) localized intra-continental magmatism in the Dunkeldik/Taxkorgan complex.

1. Introduction

The Tibetan-Pamir orogen is the preeminent natural laboratory for studying continental collisional orogenesis and is also examined to understand Andean-style orogenesis and oceanic sub-

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duction that preceded India–Asia collision (Allégre et al., 1984; Yin and Harrison, 2000; Kapp et al., 2007). Magmatic, mostly subduction-related, rocks are a central component of this effort (Ding et al., 2003; Chung et al., 2005; Zhu et al., 2015); however, few syntheses of the magmatic history of the Pamir Mountains, at the western end of the Tibetan plateau exist (Schwab et al., 2004). We present new geochronologic, geochemical, and isotopic data from 14 Mesozoic (pre-collisional) to Cenozoic (syn-collisional) igneous rocks in the Pamir and combine these data with detrital geochronologic and isotopic data to identify and characterize the major magmatic events in the Pamir. Detrital analyses are a powerful tool to obtain an overview of the magmatic history of a region and combining detrital and bedrock analyses allows for more detailed interpretations that are tied to a specific area or magmatic complex. Future studies and additional data from the Pamir will help to improve upon the interpretations presented.

Several discrete magmatic episodes in the Pamir have along-strike equivalents in Tibet or across-strike equivalents in the Karakoram, which are interpreted to reflect orogen-scale geodynamic processes. The magmatic history of the Pamir is used to reconstruct the tectonic evolution of the Tibetan-Pamir orogen from the Cretaceous to the Miocene.

2. Geologic background

The Pamir and Tibet are part of a single contiguous orogenic plateau consisting of a series of allochthonous Gondwanan continental fragments that were accreted to Asia during the early Mesozoic (Allégre et al., 1984; Burtman and Molnar, 1993; Robinson et al., 2012). In Tibet, these fragments include the Qiangtang terrane and the Lhasa terrane, separated by the Bangong suture zone (Fig. 1) (Yin and Harrison, 2000). The Qiangtang terrane is laterally equivalent to (from north to south) the Central Pamir terrane, the South Pamir terrane, and the Karakoram terrane, whereas there is no direct equivalent of the Lhasa terrane in the Pamir (Figs. 1 and 2) (Robinson et al., 2012). The Central Pamir terrane was accreted to the Triassic Karakul–Mazar arc-accretionary complex along the Tanymas suture (Fig. 2) (Burtman and Molnar, 1993) and the Qiangtang terrane was accreted to the Triassic Songpan-Ganzi turbidite complex along the Jinsha suture in Tibet during Late Triassic-Early Jurassic time (Yin and Harrison, 2000). The Karakul–Mazar complex in the Pamir consists of relatively undeformed Late Triassic intermediate intrusive rocks that were emplaced into a Triassic accretionary complex (Schwab et al., 2004; Robinson et al., 2012). The Karakul–Mazar magmatic rocks are believed to have originated above a north-dipping subduction zone (Schwab et al., 2004). Structural relationships exposed in the Muztaghata extensional system (Fig. 2), however, show that the accretionary complex was underthrust southward beneath the Central Pamir terrane and possibly beneath the South Pamir terrane during the Early Jurassic (Robinson et al., 2012). The Central Pamir terrane is separated from the South Pamir terrane by the Rushan-Pshart suture zone (Fig. 2). Southward subduction and closure of the Rushan-Pshart ocean basin during the Jurassic resulted in emplacement of the Rushan-Pshart arc (Schwab et al., 2004). The Karakoram terrane was accreted to the South Pamir terrane along the Tirich–Kilik suture during the Jurassic to Early Cretaceous (Zanchi and Gaetani, 2011).

During the Cretaceous, an Andean-style continental arc associated with the northward subduction of oceanic lithosphere developed on the southern margin of Asia (Searle et al., 1987). The intrusive component of this arc has been called the Trans-Himalayan batholith and consists of the Gangdese batholith in Tibet and the Karakoram batholith in the Pamir (Allégre et al., 1984; Debon et al., 1987). Schwab et al. (2004) suggested that Cretaceous igneous rocks in the South Pamir terrane are part of a composite Tirich–Mir–Karakoram–Kohistan–Ladakh–Gangdese arc, however, we refer to these rocks as the South Pamir batholith to distinguish them from other magmatic complexes. A belt of Early Cretaceous magmatic rocks in the northern Lhasa terrane in Tibet (distinct from the Gangdese batholith in the southern Lhasa terrane) has been variably interpreted to be related to low-angle northward subduction of Neotethyan oceanic lithosphere (Ding et al., 2003; Kapp et al., 2007), southward subduction of an ocean basin separating the Lhasa and Qiangtang terranes (Zhu et al., 2009), doubly vergent subduction beneath both the Lhasa and Qiangtang terranes (Zhu et al., 2016), and oceanic slab foundering following suturing of the Lhasa and Qiangtang terranes (Chen et al., 2017). This magmatic belt experienced a high flux event at ∼110 Ma (Zhu et al., 2009; Sui et al., 2013; Chen et al., 2014).

The timing for the closure of the Neotethyan ocean basin and initial collision of India with Asia is debated. On the Tibetan (east) side of the orogen, estimates for the timing of collision between India and Asia along the Indus-Yarlung suture range from 70 Ma to 25 Ma, with most authors favoring an initial collision at 60–50 Ma (Hu et al., 2016, and references therein). India–Asia collision on the Pamir (west) side of the orogen is complicated by the presence of the Kohistan–Ladakh island arc, which is separated from the Karakoram terrane by the Shyok suture (Fig. 1). Traditionally, Kohistan has been interpreted to have been accreted to the Karakoram terrane in the middle Cretaceous (95–90 Ma) (Searle et al., 1987; Treloar et al., 1989; Borneman et al., 2015), however, other studies have suggested that Kohistan first accreted to India at ∼50 Ma and then accreted to the Karakoram terrane at or after ∼40 Ma (Bouilhol et al., 2013, and references therein).

Prograde metamorphism in the Karakoram and Pamir suggest that crustal thickening and burial associated with India–Asia collision was underway by the Middle to Late Eocene (Fraser et al., 2001; Smit et al., 2014; Stearns et al., 2013, 2015; Hacker et al., 2017). Structural relationships within the north Karakoram terrane (Zanchi and Gaetani, 2011) and the Central Pamir terrane (Rutte et al., 2017a) also record shortening and crustal thickening during this time. Metamorphism in the Karakoram and Pamir peaked during the Late Oligocene to Early Miocene (Searle et al., 2010; Stearns et al., 2015; Rutte et al., 2017b). Peak metamorphism was immediately followed by the exhumation of a series of extensional gneiss domes (north-south directed extension) in the South and Central Pamir terranes that lasted until the Late Miocene to Early Pliocene (Stübner et al., 2013; Stearns et al., 2013, 2015; Rutte et al., 2017b). These gneiss domes include the Shakdhara-Alichur dome in the South Pamir terrane and the Yazgulem, Sarez, Muskol, and Shatput domes in the Central Pamir terrane (Fig. 2).

2.1. *Cenozoic magmatism in the Pamir*

The most-well studied magmatic rocks in the Pamir are also the youngest; the 10 to 12 Ma potassic Taxkorgan intrusive complex (Robinson et al., 2007; Jiang et al., 2012) and the ultrapotassic Dunkeldik volcanic field (Ducea et al., 2003; Hacker et al., 2005). The Taxkorgan and the Dunkeldik suite magmas have been interpreted to be related to decompression melting and asthenosphere upwelling, which entrained near ultra-high lower crustal xenoliths prior to eruption (Hacker et al., 2005, 2017; Jiang et al., 2012).

The Pamir gneiss domes and the Karakoram metamorphic complex contain abundant early to middle Miocene leucogranite plutons, dikes, and sills as well as leucosomes of similar age in migmatitic regions (Robinson et al., 2007; Searle et al., 2010; Stearns et al., 2015). Previous studies have also identified Eocene igneous rocks in the Central and South Pamir terranes (Schwab et al., 2004; Stearns et al., 2015; Volkov et al., 2016), although there has been no effort to correlate this magmatism along strike