Gondwana Research 22 (2012) 360–376

Contents lists available at SciVerse ScienceDirect

Gondwana Research

journal homepage: www.elsevier.com/locate/gr

The Himalayan leucogranites: Constraints on the nature of their crustal source region and geodynamic setting

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ARTICLE INFO

Article history:
Received 10 February 2011
Received in revised form 18 July 2011
Accepted 25 July 2011
Available online 11 August 2011

Keywords:
Leucogranites
Decompression melting
Himalayan orogen
Steepening of the subducted Indian slab

ABSTRACT

Late Oligocene–Miocene leucogranites within southern Tibet form part of an extensive intrusive igneous province within the Himalayan orogen. The main rock types are tourmaline leucogranites (Tg) and two-mica leucogranites (2 mg). They have high SiO_2 (70.56–75.32 wt.%), Al_2O_3 (13.55–15.67 wt.%) and $(^{87}Sr/^{86}Sr)_i$ (0.724001–0.797297), and low MgO (0.02–0.46 wt.%) and $(^{143}Nd/^{144}Nd)_i$ (0.511693–0.511906). Chondrite-normalized rare earth element (REE) patterns display strong negative Eu anomalies. Whole-rock major and trace element and Sr–Nd isotope data for the leucogranites suggest that their source region was a two-component mixture between a fluid derived from the Lesser Himalayan (LH) crustal sequence and the bulk crust of the Higher Himalayan (HH) sequence. Trace element and Sr–Nd isotope modeling indicate that the proportion of fluid derived from the LH sequence varied from 2% to 19% and the resulting metasomatised source experienced 7–16% melting. The amount of fluid derived from the LH sequence increases from north to south. Northward underthrusting of the Indian continent resulted in infiltration of the LH-derived fluid into the overlying HH sequence. Subsequent decompression melting of this metasomatised crust, mostly during the Miocene (25–9 Ma), generated the leucogranites. This may be linked to steepening of the subducted slab of Indian lithosphere beneath the orogenic belt.

1. Introduction

Late Oligocene–Miocene leucogranite bodies in southern Tibet form part of an E–W-striking, ~3000 km long igneous intrusive province in the Himalayan orogen (Fig. 1). These Himalayan leucogranites potentially provide an important tool to constrain the tectono-magmatic history of the orogen (Zhang et al., 2004, 2005; Yin, 2006; King et al., 2011); however, their geodynamic setting remains a subject for debate. Although there have been numerous studies of the leucogranites (e.g. Harrison et al., 1999; Visona and Lombardo, 2002; Searle et al., 2003; Zhang et al., 2004, 2005; King et al., 2011), their source region and petrogenesis remain highly controversial. The main arguments focus on two aspects: (1) What is the source composition of the Himalayan leucogranites? Some workers (e.g. Le Fort et al., 1987; Visona and Lombardo, 2002) have suggested that this involved two-component mixing between the Lesser Himalayan (LH) and Higher Himalayan (HH) sequences, whereas other workers (e.g. Harris and Massey, 1994; Guillot and Le Fort, 1995; Harrison et al., 1999; Zhang et al., 2004) proposed that the leucogranites resulted from melting of the HH sequence only. (2) What is the most likely petrogenetic model for the Himalayan leucogranites? This has been variously attributed to (a) fluid-present melting (e.g. Le Fort et al., 1987; Harris et al., 1993; Patino Douce and Harris, 1998), (b) decompression melting (e.g. Harris and Massey, 1994; Davidson et al., 1997) and (c) over-heating melting (e.g. Bird, 1978; Harrison et al., 1999; Visona and Lombardo, 2002). However, there is little geophysical evidence to support the over-heating melting model (e.g. Nelson et al., 1996). The lack of detailed sampling and of petrological and geochemical data has precluded further constraints on the source region and petrogenesis of the Himalayan leucogranites.

This study reports new geochemical and Sr–Nd isotope data for six leucogranite bodies from the Himalayas (Fig. 1). Whole-rock major and trace element and Sr–Nd isotope data are used to define the characteristics of the leucogranite bodies studied. These data complement those of previous studies (e.g. Harrison et al., 1997; Searle and Godin, 2003) that predominantly focused on the leucogranites of Nepal and Bhutan, and the most recent work of King et al. (2011) on the Sakya dome of southern Tibet. Based on the new data presented and previously published data, we explore the source region composition and petrogenesis of the Himalayan leucogranites.

2. Geological background

The Himalayan orogen is defined by the Indus-Tsangpo Suture (ITS) to the north and the Main Frontal Thrust (MFT) to the south (Fig. 1). From north to south the orogen comprises four roughly parallel, laterally continuous tectonostratigraphic units (e.g. Godin et al., 2001; Yin, 2006): (1) the Tethyan Himalayan (TH) sequence,

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1342-937X/$ – see front matter
doi:10.1016/j.gr.2011.07.027

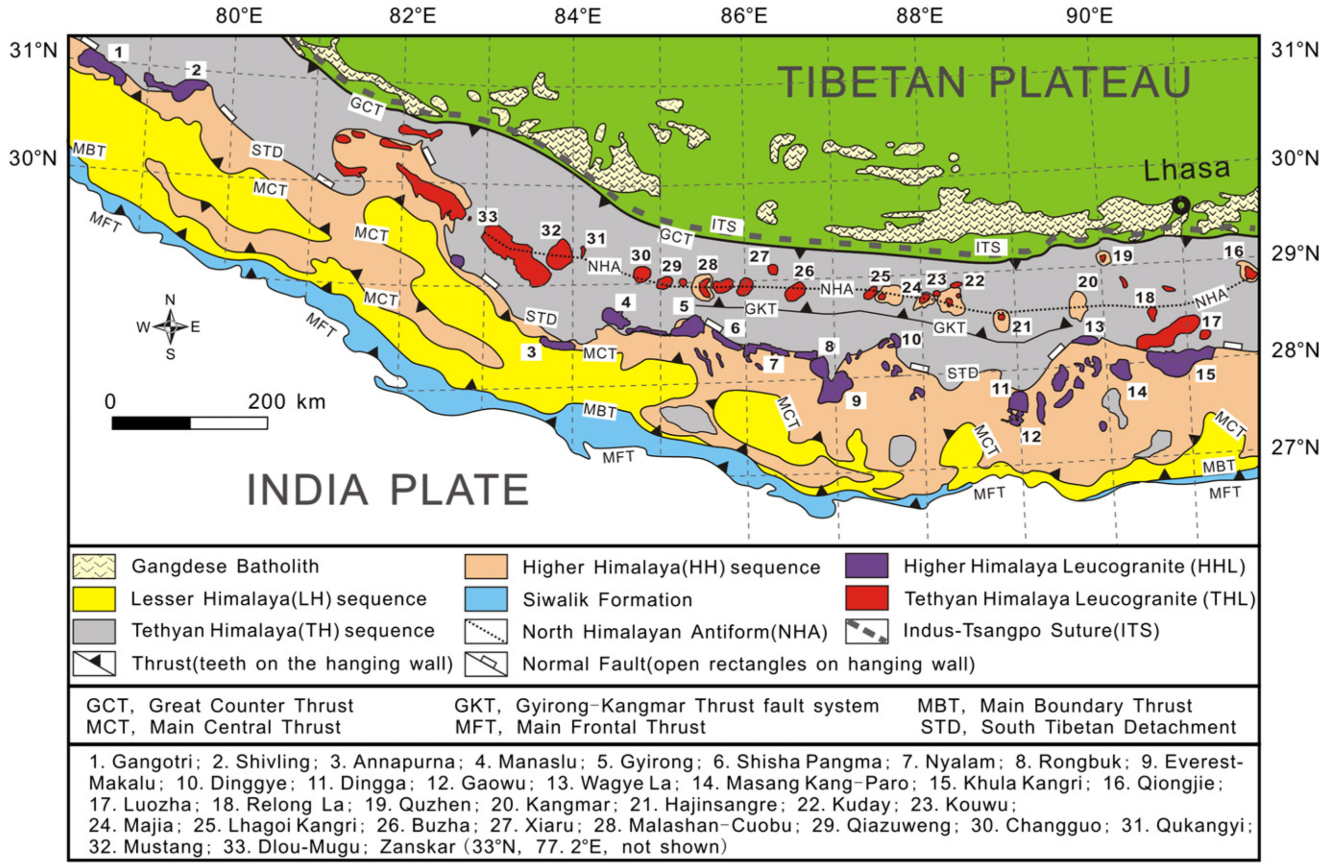

Fig. 1. Simplified map showing the distribution of leucogranites in the Himalayas (Modified from Harrison et al., 1999; Searle et al., 2003; Pan and Ding, 2004; Aoya et al., 2005; Yin, 2006). Abbreviations as follows: HH, Higher Himalayan Crystalline; LH, Lesser Himalayan Sequence; TH, Tethyan Himalayan Sequence; HHL, Higher Himalayan leucogranite; THL, Tethyan Himalayan leucogranite. Leucogranite bodies studied here are Numbers. 5, 7, 10, 12, 17 and 19.

composed of Proterozoic to Eocene siliciclastic and carbonate sedimentary and volcanic rocks; (2) the Higher Himalayan (HH) sequence, composed of Paleoproterozoic to Ordovician high-grade metamorphic rocks; (3) the Lesser Himalayan (LH) sequence, composed of Proterozoic–Cambrian low-grade metasedimentary rocks (Richards et al., 2005); and (4) the Neogene Siwalik Formation (Fig. 1). Previous studies (e.g. Guillot et al., 1994; Godin et al., 2001; Yin, 2006 and references therein) have identified three north-dipping tectonic boundaries between the tectonostratigraphic units from north to south (Fig. 1): (1) the South Tibetan Detachment (STD) system, which is a late Oligocene to Miocene (25–12 Ma) normal fault juxtaposing the TH sequence in the hanging wall against the HH sequence in the footwall; (2) the Main Central Thrust (MCT), which is interpreted as a shear zone along which the HH sequence was emplaced southward over the LH sequence; and (3) the Main Boundary Thrust (MBT), which is defined as a thrust placing the LH sequence over the Neogene Siwalik Formation (Fig. 1). The INDEPTH seismic reflection data of Nelson et al. (1996) indicate that the major Himalayan thrusts (MCT, MBT and MFT) sole into the low-angle Main Himalayan Thrust (MHT) beneath the TH sequence.

The Himalayan leucogranites comprise two roughly parallel, near E–W striking, intrusive belts; from north to south these are (Fig. 1): (1) the Tethyan Himalayan leucogranites (THL) and (2) the Higher Himalayan leucogranites (HHL) belts. King et al. (2011) refer to the THL as “North Himalayan granites”, but we do not adopt this terminology here. The THL are located in the axial zone of the North Himalayan Antiform (NHA) within the TH sequence, whereas the HHL are located within the HH sequence (Zhang et al., 2004, 2005). The NHA exposes a discontinuous series of gneiss domes, comprising Palaeozoic granite gneisses and Neoproterozoic to early Palaeozoic high grade metasediments, including migmatites (King et al., 2011); these represent tectonic windows into the underlying HH crustal sequence. The THL intrude both the gneiss domes and the overlying Tethyan sedimentary series (Fig. 1). The ages of the Himalayan leucogranites range from ca 9 to 25 Ma (Table 1).

Six leucogranite bodies from the Himalayas form the basis of this study; they are located in both the HHL (Gyirong, Nyalam, Dinggye and Gaowu) and the THL (Luozha and Quzhen) belts from south to north (Fig. 1 and Table 1). The leucogranite bodies analyzed (Fig. 1 and Table 1) include both plutons and dykes. The Gyirong, Nyalam, Dinggye, Gaowu and Quzhen samples are from plutons whereas those from Luozha include both plutons and dykes. In general, the exposed areas of the plutons are relatively small, ranging from 5 km^2 to 50 km^2. They intrude pre-Cambrian and Palaeozoic–Mesozoic gneisses and metasediments in the TH and HH sequences (Fig. 1).

3. Petrography

The leucogranites studied are ubiquitously leucocratic without mafic enclaves and have a relatively uniform mineralogy. To estimate their modal mineralogy, three perpendicular thin sections were cut for each sample. The main minerals include plagioclase, potassic feldspar (K-feldspar), biotite, muscovite, tourmaline and quartz; the accessory minerals are dominated by garnet, apatite, zircon, monazite and magnetite (Table 2). Plagioclase is euhedral to subhedral with weak zoning. Perthitic K-feldspar is subhedral to anhedral. Euhedral to subhedral biotite mostly grows together with muscovite, which is often euhedral. Tourmaline is euhedral to subhedral, and displays