Lithos 125 (2011) 463–481

Contents lists available at ScienceDirect

Lithos

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

Geochemistry and petrogenesis of Mesoproterozoic (~1.1 Ga) magmatic enclaves in granites of the eastern Llano Uplift, central Texas, USA

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ARTICLE INFO

Article history:
Received 8 July 2010
Accepted 3 March 2011
Available online 10 March 2011

Keywords:
Mesoproterozoic
Grenville
Llano Uplift
Geochemistry
Enclaves
Granite

ABSTRACT

Mesoproterozoic (~1.1 Ga) plutons of the eastern Llano Uplift, central Texas, USA contain two types of magmatic enclaves (<1% by vol.). Although volumetrically insignificant, the enclaves contain important petrogenetic information. Type I enclaves are felsic in composition (70–75 wt.% SiO_2), with mineral assemblages and chemical compositions comparable with the host granites, but typically display a finer grained texture. They are interpreted as partly chilled disrupted material from the margins and roof of the plutons. Type II enclaves are intermediate in composition (~56–69 wt.% SiO_2), with many elements defining trends continuous with the host granites. Both types of enclaves display sharp borders in contact with the host granite suggesting magma quenching with little or no physical exchange between host granite and enclave magma.

Type II enclaves contained within the Marble Falls (MF) and Lone Grove (LG) plutons exhibit enrichments in Y, Nb, and Zr relative to their respective host granites. Enrichments in these incompatible trace elements at low SiO_2, renders unlikely the possibility that the MF and LG Type II enclaves are the result of partial melting (anatexis) of mafic crustal rocks. Numerical modeling of fractional crystallization and simple mixing fails to explain the observed trace element trends.

Because no coeval mafic to intermediate rocks are exposed in the uplift, characteristics of Type II enclave source magma(s) is uncertain. However, assuming source magmas similar to primitive continental arc basaltic andesite, trace-element trends (i.e., incompatible element enrichment and compatible element depletion) can be adequately replicated by a replenishment fractional crystallization (RFC) model. Chemistry of the MF and LG Type II enclaves suggest repeated replenishment of primitive magmas with only limited interaction with the host granitic magmas; the more primitive enclave magmas evolving in near chemical isolation by RFC processes. However, evidence from Type II enclaves in two other plutons in the Llano Uplift (Kingsland and Enchanted Rock) suggest that the isolation was non-ideal; i.e., some limited mixing may have occurred. Rapid quenching likely limited the potential for physical and chemical exchange between Type II enclaves and their host granite magmas.

1. Introduction

The Llano Uplift (see Fig. 1 in Smith et al., 2010) forms part of a discontinuous band of Grenville-aged rocks (ca. 1370–1070 Ma) extending some 4000 km from the Grenville Province of Canada to the Oaxaca complex of southern Mexico (Garrison and Mohr, 1983). It is believed to have formed along a major collisional reentrant associated with the Grenville orogeny (locally the Llano orogeny), and contains remnants of both island-arc and continental margin blocks. Today, the Llano Uplift is a gentle structural dome exposing ca.1360 ± 3 Ma to 1232 ± 4 Ma metavolcanic, metaplutonic, and metasedimentary rocks that have been polydeformed synchronous with a moderate- to high-pressure, upper amphibolite to lower granulite facies regional metamorphism (Carlson, 1998; Mosher, 1993, 1998; Reese, 1995; Reese et al., 2000; Roback, 1996; Walker, 1992). These rocks represent the core of a collisional orogen along the southern margin of Laurentia (Mosher, 1998; Mosher et al., 2008). Subsequently, the high-pressure metamorphic rocks were intruded by 1119 + 6/−3 Ma to 1070 ± 2 Ma late syn- to post-tectonic granites. These plutons form a mappable unit collectively known as the Town Mountain Granite (TMG), a pink, K_2O-rich, very coarse- to coarse-grained, generally porphyritic granite with associated fine- to medium-grained, gray to pink granites. They have been classified as syeno- to monzogranites with A-type affinities. More specifically they are high-K, metaluminous to marginally peraluminous, ferroan, biotite-calcic amphibole granites with large-ion lithophile (LIL) element (e.g., K, Rb, and Ba) enrichment. The central and easternmost of these granite bodies (Fig. 1) consist of the Enchanted Rock (ER), Marble Falls (MF), Kingsland (KL), and Lone Grove (LG) plutons. The plutons are zoned and generally circular to elliptical in areal exposure

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0024-4937/$ – see front matter
doi:10.1016/j.lithos.2011.03.005

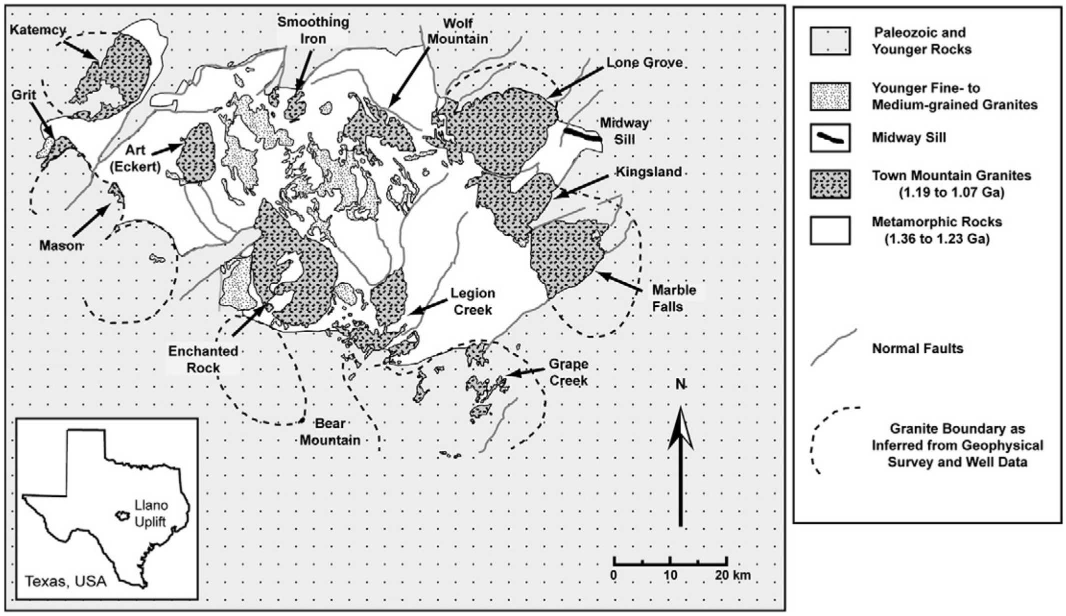

Fig. 1. Location of the eastern Granite plutons of the Llano Uplift, central Texas, USA (modified after Mosher, 1996).

(see Fig. 3 in Smith et al., 2010). Gravity and magnetic surveys indicate that the intrusive contacts are nearly vertical in the upper 2 to 3 km of the preserved crust (Muehlberger et al., 1963). Detailed descriptions and characteristics of these plutons are provided in Muehlberger et al. (1963), Smith et al. (1997), Barker and Reed (2010), and Smith et al. (2010).

Prior to this study, knowledge of the mineral chemistry, petrology, geochemistry, and petrogenetic characteristics of magmatic enclaves contained within the MF, KL, and LG plutons was sparse. In this paper, we document the petrologic and geochemical characteristics of these enclaves and compare them to enclaves from the ER pluton and the well-studied Cadillac Mountain intrusive complex of Maine. We then hypothesize as to their petrogenesis and relationship to the tectonic setting of the Llano Uplift.

Magmatic enclaves of intermediate to mafic composition are common in granitoid plutons, varying in size, shape, degree of cooling, and chemical composition (Barbarin and Didier, 1991; Didier, 1973; Vernon, 1983). Enclaves tend to have rounded, scalloped, or lenticular shapes with fine-grained igneous microstructures. Mineral assemblages are generally similar to the host granitoid, differing only in their proportions. Typically the mineral compositions indicate that they are igneous in origin and not host-rock xenoliths (Vernon, 1984). Vernon (1984) restricted the term enclave to fine-grained, ellipsoidal types of inclusions. Enclave distribution may be locally uniform and concentrated in swarms, but more commonly irregular. Enclave orientations may be aligned in those areas of the granitoid intrusion showing a prominent flow foliation, especially near the margins of the pluton (Vernon, 1984).

Field, geochemical, and experimental evidence suggest that most mafic magmatic enclaves form as globules of high-alumina basaltic or other mafic magma that are quenched in and become dispersed throughout the more felsic host granitoid magma as a result of magma mingling early in the crystallization history of the pluton (Frost and Mahood, 1987; Vernon, 1990). Enclave compositions range from mafic to felsic, suggesting that enclave magmas may have been a product of spatially limited magma-mixing (hybridization) between mafic and host granitoid magmas near the base of plutons, followed by mingling of the hybrid magma as globules (enclaves) into the more felsic host at a later stage within the upper levels of plutons. Microstructural features suggestive of mineral–melt disequilibrium and magma-mixing (hybridism) include; 1) xenocrysts of quartz (ocelli) rimmed with fine-grained aggregates of early-formed minerals, 2) K-feldspar megacrysts (often rimmed with plagioclase, i.e., rapakivi texture) identical to those occurring in the host granitoid, 3) zoned plagioclase phenocrysts, 4) plagioclase with resorbed or dendritic cores, and 5) Ca “spikes” in plagioclase (Vernon, 1984, 1990). K-feldspar megacrysts are often found partially to completely enclosed in the mafic enclaves, suggesting that they are xenocrysts with an igneous origin. However, the composition of mafic enclaves renders them unlikely to have precipitated K-feldspar. Instead K-feldspar xenocrysts are most likely the result of a partly crystallized granitoid melt that was incorporated into the more mafic magma during hybridization. The finer grained nature of the more mafic enclaves is likely the result of magma quenching [e.g., acicular apatite, chilled margins, and complexly zoned plagioclase (Barbarin, 1990), with mineral alignment reflecting magmatic strain (Paterson et al., 2003)] resulting from the temperature contrast between mafic and granitoid magmas at the time of mingling; i.e., the hotter more mafic magma is quenched to the temperature of the granitoid magma resulting in an undercooled mafic magma producing finer grained enclaves (Vernon, 1984, 1990).

2. Geologic and tectonic setting

Precambrian basement rocks of Texas are bisected by the Llano Front (see Fig. 1 in Smith et al., 2010), separating undeformed rocks to the north from rocks to the south that were deformed and metamorphosed during Grenville time (~1100 to1350 Ma). North of the Front, Precambrian basement rocks are dominated by granitic and rhyolitic rocks of the 1340–1500 Ma Granite–Rhyolite Province (Thomas et al., 1984) located adjacent to older rocks of the Yavapai–Mazatzal Province (Nelson and DePaolo, 1985; Van Schmus et al., 1993). In the Llano Uplift, central Texas, the Grenville Province consists predominantly of polydeformed gneiss, schist, and amphibolite, with minimal migmatite (Barker and Reed, 2010; Morris, 2006), sparse metaserpentinite, and local eclogite occurrences (Mosher, 1993). On the basis of lithology, field relations, geochemistry, and U/Pb ages these metamorphic rocks have been subdivided into three lithotectonic