Migmitization of fertile lower crust driven by mafic magmatism, Athabasca Granulite Terrane, northern Saskatchewan

G. Christopher Koteas
Department of Geosciences, University of Massachusetts, Amherst, Ma.
ckoteas@geo.umass.edu

and
Michael L. Williams
Department of Geosciences, University of Massachusetts, Amherst, Ma.

and
Sheila J. Seaman
Department of Geosciences, University of Massachusetts, Amherst, Ma.

Summary

The Fehr granite, within the Athabasca granulite terrane in northern Saskatchewan, preserves evidence for substantial felsic melt generation and subsequent mixing and mingling with mantle-derived mafic magmas at depths of ~40km. The presence of fertile rocks in this deep crustal environment emphasizes the heterogeneity that may characterize the deep crust in many regions. Field relations and geochemical data suggest that dynamic processes of partial melt production, during a major episode of mafic magma input, led to rheological weakening and chemical modification of both mafic and felsic magmas. The record of mingling and mixing within the Athabasca granulite terrane promotes a new mechanism of crustal contamination (or assimilation) for mantle derived mafic magmas in the deep crust.

Introduction

Migimitization of the ca. 2.6 Ga K-feldspar megacryst-rich Fehr granite (Hanmer, 1994), Mesoarchean Chipman tonalite, and mafic dikes associated with the Chipman dike swarm occurred during a major episode of mafic magma intrusion along the axis of the Snowbird Tectonic Zone at ca. 1.9 Ga (Flowers et al., 2006). Significant volumes of leucocratic partial melt were produced. Evidence for mechanical and chemical hybridization of mantle-derived mafic magmas and partial melts produced from granites at depths of approximately 40 km or 1.0-1.2 GPa (Williams et al., 1995; Williams and Hanmer, 2006) is ubiquitous. Field relations and geochemistry suggest that 1) felsic partial melts may influence deep crustal rheology, 2) contamination of mafic magmas may occur quite close to the crust-mantle interface, and 3) mafic-felsic magma interaction, widely documented in the mid and shallow crust, may occur in the deep crust as a natural result of mafic magma intrusion into a compositionally heterogeneous environment.

Partial melting and magma mingling

A combination of heating, from underplating/intraplating and diking of mafic magmas of the Chipman dike swarm, and elevated volatile availability, derived from Bt-dehydration melting of the Fehr granite and Hbl-dehydration melting of older Chipman dikes, drove migmitization of the Fehr granite. These processes collectively stimulated eutectic melting of the Fehr granite. Granitic leucosome, produced from migmitization of the Fehr granite, and more volumetrically limited tonalitic leucosome, produced from migmitization of older Chipman mafic dikes, both appear to have migrated only locally (centimeters to meters) along a subhorizontal S_1 cleavage in the Fehr granite until a mechanical threshold was reached. At this rheological limit, the S_1

fabric drastically weakened, initially forming broad open folds that subsequently tightened to form a relatively steeply-dipping, northeast-striking S_2 fabric (here called “mega-crenulation cleavage”). The S_2 fabric became a conduit for partial melt transport, ascent, and diffusive interaction between melts. In some areas, 2-6 meter wide aplitic leucosome dikes are now parallel to the S_2 fabric.

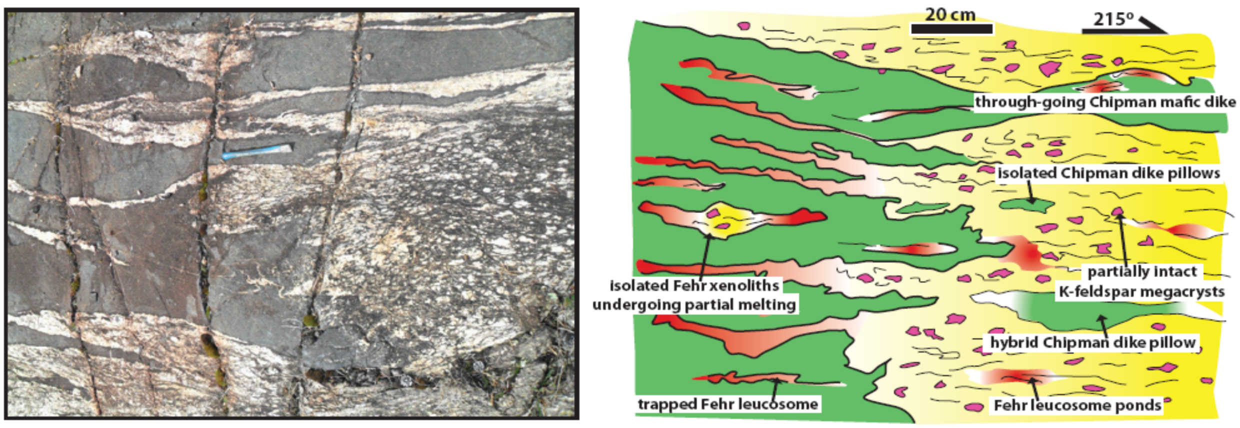

Figure1: Field photo on right (with chisel for scale) is a zone of mechanical mafic dike interaction with granitic leucosome-rich Fehr granite migmatite. Cartoon depiction illustrates the multiple components of Fehr partial melt – mafic magma interaction: green color is Chipman mafic magma, yellow color is migmatitic Fehr granite, red color represents transported Fehr-related granitic leucosome.

Chipman mafic dikes are typically straight and parallel sided where they intruded non-migmatitic Fehr Granite. However, in migmatitic Fehr granite, dikes commonly branch into small, anastomosing, discontinuous dikes and veins (Fig. 1) or end as rounded, pillow-like terminations. In these areas, Chipman dikes commonly have delicately scalloped margins that are rarely parallel on both sides of the same dike. K-feldspar megacrysts are locally present in Chipman dikes and have apparently migrated from Fehr granite into the mafic magma. In addition, leucosomes from migmatitic Fehr granite commonly project into mafic dikes and become progressively more diffuse along strike (Fig. 1). In areas where higher densities of migmatitic Chipman mafic dikes (dikes from the earliest pulses of ca. 1.9 Ga mafic magmatism) are also present, back-injections of tonalitic leucosome or hybridized granitic ± tonalitic leucosome into Chipman mafic dikes are common. Observations indicate that Chipman dikes were less able to cross-cut migmatitic Fehr granite, especially in areas where “mega-crenulation cleavage” is present. This suggests that migmatitic Fehr granite, and Fehr granite hosting ponds of collected leucosome, may have served as a mechanical impediment to dike emplacement. In addition, pooling of mafic magma in migmatitic Fehr granite is interpreted to promote mechanical and chemical interaction of the two magmas.

Compositional data indicate that extensive chemical interaction between Chipman mafic magmas and partial melt of the Fehr granite occurred in addition to mechanical interactions between mafic magmas, partial melt, and restitic Fehr granite. Bulk-rock geochemistry and in-situ analysis of individual minerals were utilized to: 1) delineate compositional end members of partial melting, 2) assist in identifying melt-producing reactions, 3) describe hybrid magmas (Fig. 2), and 4) chemically characterize migmatite microstructures (Fig. 3). Trends of partial melt production and subsequent chemical and mechanical interaction between the products of migmitization and mafic magmas are reflected in multiple bi-variant element plots of bulk geochemistry. These patterns, as illustrated in figure 2, suggest that the prolonged periods of elevated temperatures and, potentially, elevated concentrations of volatiles, were ideal for extensive mafic and felsic magma modification. Compositional evolution of mafic magmas and partial melts led to the growth of new igneous phases within the Fehr migmatite, as illustrated by

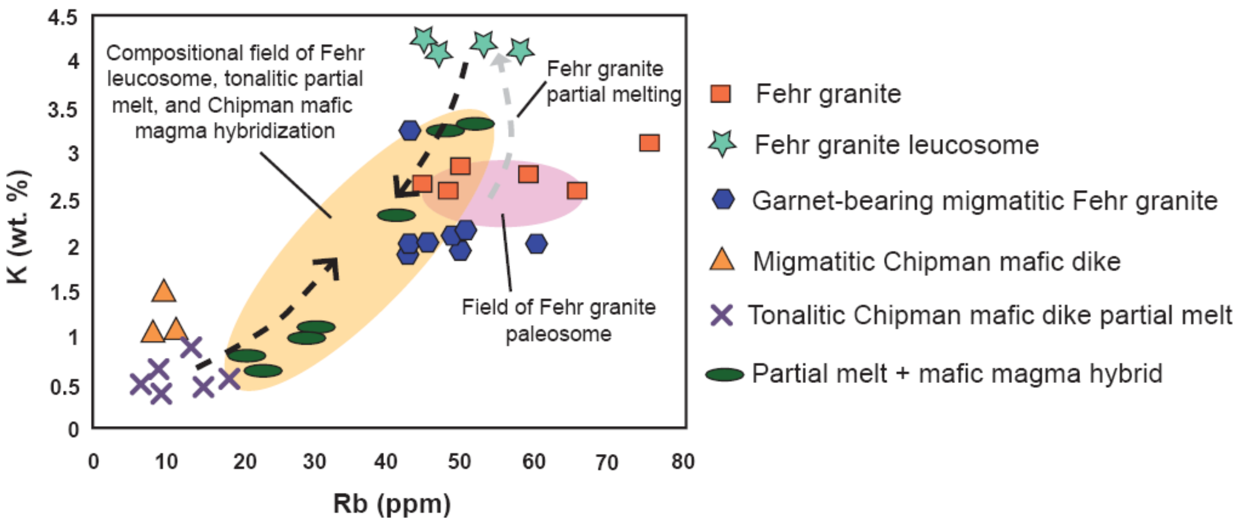

Figure 2: Plot of Rb (ppm) versus K (wt. %) for end-member partial melts and compositional hybrids (after Janoušek et al., 2004). The trend of increasing K relative to Rb is associated with generation of Fehr-related granitic leucosome, and the trend of decreasing K relative to Rb is related to growth of garnet as a peritectic phase in Fehr granite melanosome. The broad tan-colored field with positive slope is the region of mechanical and chemical interaction between granitic leucosome, tonalitic leucosome and mafic magmas during the ca. 1.9 Ga magmatic event.

the growth of K-rich alkali feldspar on the margins of inclusion-riddled plagioclase (Fig. 3). These geochemical observations are in agreement with field evidence and microstructural features, both of which suggest that mechanical and chemical interaction between mantle-derived mafic magmas and partial melts of fertile granitoids lead to extensive contamination.

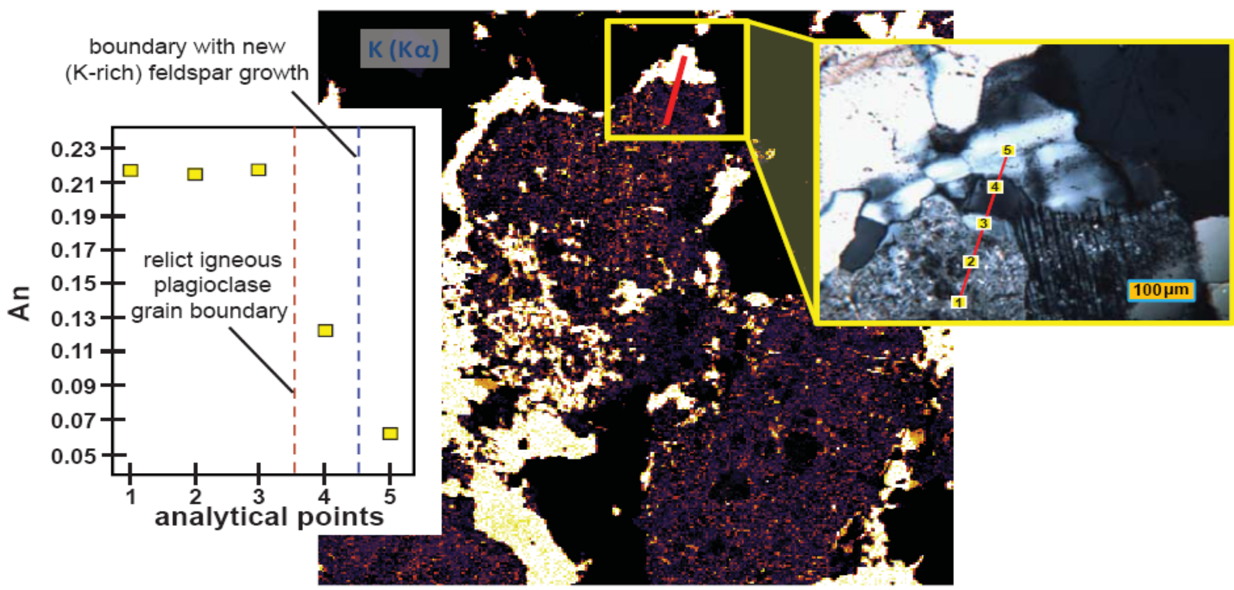

Figure 3: Photomicrograph and X-ray compositional map of feldspar from migmatitic Fehr granite. Textures and compositions are indicative of diffusive interaction with partial melt components and generation of new igneous feldspar. Analytical points were generated using a 30 nA, 5 µm diameter beam on the Cameca SX-50 electron microprobe at the University of Massachusetts after the work of Jercinovic and others (2008). Progressive K > Ca+Na (anti-rapikivi texture) from grain interiors to rims within Fehr granite that hosts leucosome is indicative of eutectic K-feldspar megacryst melting and migration of associated components.

Conclusions

Field relations, microstructures, and geochemical trends observed in the Fehr granite, Chipman mafic dikes, and tonalitic and granitic leucosomes suggest that 1) extensive partial melting in a fertile deep crustal orthogneiss can lead to significant amounts of felsic melt (i.e. granite genesis), 2) generation, migration, and ponding of locally derived felsic partial melts in the deep crust has important implications for the composition and through-put of mafic magmas, 3) heating, addition of volatiles from dehydration melting, and the insulating effects of deep structural levels in the crust appear to allow extensive mechanical and diffusive interaction between mantle-derived mafic magmas and partial melts generated during migmitization. The major implication of this work is that the crust-mantle interface can be a very dynamic environment for the production of partial melt and magma mixing and mingling that does not fit with models of a dry, restitic deep crust.

Acknowledgements

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