High radiogenic heat–producing granites and metamorphism—An example from the western Mount Isa inlier, Australia: Comment and Reply

COMMENT

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We welcome the paper of McLaren et al. (1999) because it makes an important contribution to our understanding of the source of thermal anomalies in low-pressure metamorphic belts. However, we argue that high radiogenic heat–producing granites such as the Sybella batholith, although locally important in the overall thermal budget, were not the primary cause of low-pressure metamorphism in the Mount Isa inlier, and that synmetamorphic intrusions were a significant additional factor.

A simplified isograd map for the inlier shows amphibolite facies rocks are concentrated in four major belts that show a close spatial relationship with the occurrence of granites (Fig.1). The isograds relate to the Isan orogeny (1610–1490 Ma), which incorporates a number of metamorphic events. However the M_1 and M_2 metamorphic events are not restricted to the Mount Isa inlier, being widespread in Proterozoic areas in eastern and central Australia (e.g., Oliver et al., 1998). The peak of metamorphism was in most areas in the Mount Isa inlier synchronous with M_2 (1530–1550 Ma; Rubenach, 1992; Reinhardt, 1992; Connors and Page, 1995; Rubenach and Barker, 1998). The ages of pre-Isan granites differ markedly between the four belts, predating M_2 by between 120 and 330 Ma. It is unlikely that such a constant age for the metamorphic peak resulted solely from older high radiogenic heat–producing granites. Such granites nevertheless may have been important in the overall thermal budget in that they probably produced long-lived elevated thermal gradients, requiring less heat to be supplied from additional sources for amphibolite facies metamorphism during the Isan orogeny.

The occurrence in the Cloncurry belt of multiple low-pressure metamorphic events (M_1, M_2, and several post-M_2 events; Rubenach and Barker, 1998) poses additional problems for the model of McLaren et al. (1999),

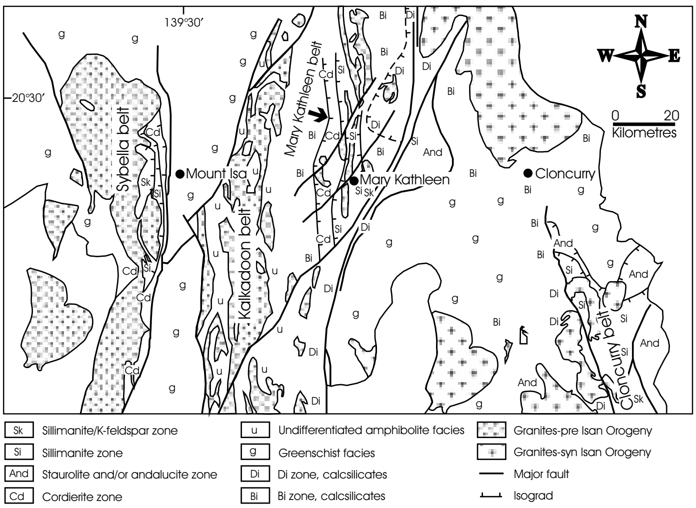

Figure 1. Isograd map for part of Mount Isa inlier, northeastern Australia, showing four amphibolite facies metamorphic belts. Pelitic isograds are given priority, but in absence of pelites, calsilicate zones are shown. Diopside isograd approximates to sillimanite isograd, whereas biotite zone for calcsilicate rocks extends from greenschist facies to sillimanite isograd. Amphibolite facies for Kalkadoon belt is based solely on mafic lithologies.

TABLE 1. SUMMARY OF METAMORPHIC EVENTS AND GRANITE AGES FOR AMPHIBOLITE FACIES BELTS, MOUNT ISA INLIER

Belt	Events and ages	Pre-Isan granites	Syn-Isan intrusives	Metamorphic characteristics
Sybella	M_2, 1532 Ma* (metamorphic peak)	Sybella granite 1655–1670 Ma*	Mica Creek pegmatites 1532, 1480 Ma*	Low *P*, anti-clockwise
Kalkadoon	M_2	Kalkadoon batholith 1850–1860 Ma§	Not known	Not known
Mary Kathleen	M_2, 1550 Ma† (Ar) Post-M_2 event	Wonga batholith 1730–1740 Ma§	Minor syn-M_2 pegmatites	Low *P*, anti-clockwise
Cloncurry	M_1, 1584 Ma§ M_2, 1530–1540 Ma# (Ar) Multiple post-M_2 events	Relatively rare 1740–1746 Ma§	Syn-M_1 pegmatites Syn-M_2 granites, 1528–1547 Ma§ Post-M_2 granites, 1493–1508 Ma§	Multiple low-*P*, anti-clockwise events

Note: Ages are U-Pb zircon dates (largely SHRIMP [sensitive high-resolution ion microprobe] determined), unless designated "Ar" where they are hornblende Ar-Ar dates.
*Connors and Page, 1995.
†Green, 1975.
§Page and Sun, 1998.
#Perkins and Wyborn, 1998; P. Pollard, personal communication.

which suggests a continuous cooling history. Pressure-temperature-time paths for these events were essentially anticlockwise, as shown by early growth of kyanite followed by andalusite in several events, suggestive of a number of transient thermal spikes. Abundant granites suggest a magmatic control for M_2 and subsequent events in the Cloncurry belt, and synmetamorphic pegmatites are locally abundant in sillimanite zones throughout the inlier (Table 1). Syn-M_2 granites have not been identified in the other belts, but syn-M_2 metasomatic rocks (including albitites, sodic-calcic alteration, calcite pods, tremolite-actinolite pods, and skarns) are quite abundant, and stable isotope data indicate that the fluid compositions are consistent with a magmatic derivation (Oliver et al., 1993), suggesting the presence of synmetamorphic granites below the level of erosion.

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REPLY

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Foster and Rubenach agree with our analysis that burial of the high heat–producing Sybella granite in the Western fold belt, Mount Isa, is capable of generating the metamorphic signature associated with the Isan orogeny. However, they dispute the general applicability of our model, arguing that the metamorphic signature in the Eastern fold belt must also reflect transient thermal spikes associated with synmetamorphic intrusions. In this way, their comment is slightly disingenuous, because our paper (McLaren et al., 1999) did not set out to explain the origins of the metamorphic signature across the entire Mount Isa region. Nor do we believe that internal heat production is the only factor governing metamorphic style in this or other settings. Our intention was simply to present a model for high temperature–low pressure metamorphism in the Western fold belt, and, through some simple physical models, to highlight the importance of internal heat sources in the overall crustal thermal budget. We believe we have illustrated these ideas adequately; in some ways, Foster and Rubenach avoid the importance of this general result by concentrating on the application of our model to another region. Despite this, Foster and Rubenach raise some intriguing issues relating to the involvement of granites during metamorphism in the Cloncurry belt, and we comment on these points here.

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We agree that examples from the Cloncurry fold belt suggest that magmatism played some role during Isan metamorphism in this region. Like granites of the Western fold belt, the granites in the Cloncurry region, such as the Williams and Naraku batholiths, are also enriched in heat-producing elements. In order to evaluate their role during thermal evolution, we first consider the primary thermal consequences of their generation. Geochemical and isotopic data (e.g., Wyborn, 1998; Mark, 1999) suggest both the Williams and Naraku batholiths are derived from dominantly lower crustal sources. Using this information and constraints on the geometry and geochemistry of the granites, we can model the distribution of crustal heat sources both prior to and after granite emplacement (Fig. 1). We also show the crustal geotherm in each case, calculated assuming average depth independent thermal conductivity of ~2.5 $Wm^{-1}K^{-1}$, and a basal mantle heat flow of ~20 mWm^{-2}.

It is clear from this simple calculation that crustal thermal regimes are sensitive not only to the abundance of crustal heat sources, but also to their distribution. Wyborn (1998) suggests that the young granites at Cloncurry are products of high temperature (>1000 °C) anhydrous melting, and, while the presence of a Williams–Naraku-like source alone is unlikely to have caused such melting, the predicted Moho temperatures are sufficiently high (~850 °C) so that such melting could have occurred as a result of either a minor additional contribution from the mantle or an increase in lower crustal temperatures due to crustal thickening. Both hypotheses are consistent with known geological constraints and indeed the former is supported by isotopic data suggesting a minor mantle component to young syn- and post- M_2 granites in the Cloncurry fold belt (Mark, 1999). A third, more remote possibility is that lower crustal temperatures were further elevated due to the deposition of an insulating sedimentary package, however this model is difficult to evaluate without more detailed information on the timing of both metamorphism and magmatism on the regional scale. So, while it is likely that the metamorphic signature in the Cloncurry fold belt is, at the outcrop scale, controlled by advective heat carried during the intrusion of these synmetamorphic granites and pegmatites, the overall metamorphic and magmatic signature reflects the broader first-order thermal consequences of the presence of anomalous heat sources in the crust.

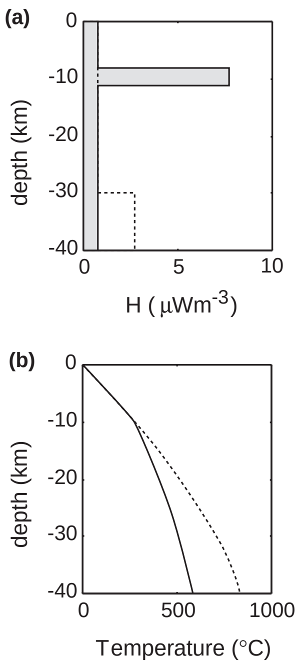

Figure 1. Thermal consequences of generation of younger granites in Eastern fold belt. A: Distribution of heat sources prior to (dashed line) and after (shaded section) extraction of a radiogenic melt from lower crust. Model granite is ~3–4 km thick based on seismic estimates of thickness of sill-like Williams and Naraku batholiths (McCready, 1997). Heat production is based on average of geochemical analyses of all 1530–1500 Ma granites in Cloncurry fold belt (Wyborn et al., 1998). Total crustal contribution to surface heat flow is taken ~50 mWm^{-2}, based on estimates of crustal heat flow in Western and Kalkadoon fold belts. During magma extraction, we assume no net loss of heat-producing elements. B: Crustal geotherm associated with each distribution, illustrating dependence of crustal thermal regime on distribution of heat-producing elements within crust. Temperatures are calculated using mantle heat flux of ~20 mWm^{-2}.

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CORRECTION

The correct e-mail address for Andrew Jacobson (Ca/Sr and $^{87}Sr/^{86}Sr$ geochemistry of disseminated calcite in Himalayan silicate rocks from Nanga Parbat: Influence on river-water chemistry, by Andrew D. Jacobson and Joel D. Blum, *Geology*, v. 28, no. 5, p. 463–466) is andrewdj@umich.edu.