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Comment on: "Evidence for shear heating, Musgrave Block, central Australia" by A. Camacho, I. McDonald, R. Armstrong, and J. Braun

M. Bjørnerud[a,*], H. Austrheim[b]

[a]Geology Department, Lawrence University, Appleton, WI 54912, USA
[b]Geologisk Museum, Postboks 1172, Blindern, 0318 Oslo, Norway

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Camacho et al. (2001) have presented fascinating evidence for highly localized resetting of Ar and Rb/Sr isotopic systems in eclogite shear zones within granulites of the Musgrave Block of central Australia. While it is all too easy to offer glib interpretations of complex rocks one has never seen, we would like to suggest an alternative explanation for these interesting data and discuss the broader significance of such observations for thermochronometry.

The shear zones described by Camacho et al. contain eclogite–facies mineral assemblages formed at ca. 550 Ma, and they transect granulite–facies rocks that record a high-temperature metamorphic event at ca. 1180 Ma. The authors document convincingly the localized manner in which the Ar and Rb/Sr systems in various minerals were reset in the eclogite shear zones. Biotite grains within the shear zones, for example, give ages of 500–600 Ma, while biotites from adjacent granulites yield ages greater than 800 Ma. Analyses of potassium feldspar from the shear zones and country rock give similar results.

Although it is possible that elevated temperatures resulting from localized shear heating are responsible for the reset ages, as argued by Camacho et al., there is no mechanism that could cause sustained, localized elevated pressures (ΔP ca. 4 kbar) to produce eclogite facies assemblages only within the shear zones. Since the zones with reset ages coincide with the areas of eclogite–facies recrystallization, a simpler interpretation of the data is that this part of the Musgrave Block equilibrated only locally to eclogite conditions at 550 Ma, along zones of high strain that became open to chemical and isotopic diffusion. The rest of the rocks, while experiencing the same temperature and pressure conditions, survived metastably owing to slower diffusion rates, and they retained their older isotopic signatures.

* Corresponding author. Tel.: +1-920-832-7015; fax: +1-920-832-6962.
E-mail address: bjornerm@lawrence.edu (M. Bjørnerud).

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Camacho et al. acknowledge that isotopic closure is a polyvariate function not only of temperature but also cooling rate, fluid circulation, deformation, grain size, etc. Yet they seem not to consider the possibility that a variable other than temperature could explain the observed pattern of reset ages. The authors suggest that the shear zone deformation took place under dry conditions, which would argue against fluid-assisted diffusion and/or advection as the cause of the isotopic age variations. However, the presence of biotite both inside and outside the shear zones indicates that conditions were not entirely anhydrous. Furthermore, Ellis and Maboko (1992) documented the occurrence of zoisite in the eclogite shear zones and concluded that "It is only where shearing and fluid access occur that mafic rocks convert to eclogite". In any case, a metamorphic fluid, particularly one rich in CO_2, may not necessarily form hydrous phases at eclogite–facies temperatures.

Camacho and co-authors emphasize that strain rates and finite strains were both very high within the shear zones. We suggest that high strain energies and intense grain size reduction in the shear zones would have greatly facilitated local recrystallization and reequilibration to eclogite facies conditions (e.g. Dunlap, 2000) even in the absence of a significant fluid phase. The reduction in volume (density increase) associated with the granulite to eclogite–facies transition, in turn, may also have contributed to opening the isotope system, through the development of microfractures (Jamtveit et al., 2000). In areas outside the shear zones, the kinetics of recrystallization may simply have been too sluggish for mineralogic and isotopic reorganization to occur prior to exhumation.

It also seems possible that isotopic closure temperatures may be asymmetric with respect to heating and cooling. Reopening a closed isotopic system in the absence of fluids may require reheating to higher temperatures than those at which the system first closed during cooling owing, for example, to the larger grain size of the mature rock, and the consumption of heat by endothermic metamorphic reactions. This too would help to preserve isotope values in unrecrystallized rocks at temperatures higher than the nominal closure temperatures for the constituent minerals.

In the Bergen arcs region of western Norway, in a geologic complex very similar to the rocks of the Musgrave Block, Austrheim and coworkers (Austrheim and Griffin, 1985; Austrheim, 1998; Jamtveit et al., 2000; Kuehn et al., 2000) have documented localized eclogitization of anhydrous granulite along fractures and shear zones. In these rocks, feedbacks between deformation, metamorphic reactions, volume changes and the influx of a comparatively small amount of fluid dictated where eclogite–facies mineral assemblages developed. Kuehn et al. (2000) have shown that the reopening of the Rb–Sr system in biotites in these rocks at dry static high-pressure conditions required temperatures of at least 650 °C. While isotopic age data for these rocks are not as complete as those presented by Camacho et al., the occurrence of pristine 945 Ma granulite–facies assemblages in close juxtaposition with ca. 460 Ma eclogites is most easily explained by metastable survival of the granulites under eclogite–facies conditions, with only localized re-equilibration at sites of fluid infiltration and/or deformation. In these rocks, eclogites are found not only in shear zones but also along fractures and other fluid pathways that show no evidence of offset, which argues against shear heating as a factor in their genesis.

There is growing evidence from other high pressure terranes for similar survival of metastable phases and limited, fluid- and deformation-controlled re-equilibration. In the Sulu ultra-high pressure belt of eastern China, for example, where metamorphic pressures in excess of 30 kbars have been estimated, Zhang and Liou (1997) report partial preservation of gabbroic textures and mineral assemblages with heterogeneous conversion of the rock to coesite-bearing eclogites along structurally controlled zones.

Such observations suggest that we must not only reconsider the conception of regional metamorphism as thermodynamically inevitable but also use great caution in interpreting isotopic ages strictly as thermal records, especially in cases where recrystallization may have been catalyzed largely by deformation and/or fluid infiltration. While thermochronometry is a potentially powerful technique, much remains to be learned about the physical and chemical factors that govern isotopic closure (e.g. Villa, 1998). In reading 'cooling' ages too literally, we may miss critical information about other aspects of a rock's history.

References

Austrheim, H., 1998. Influence of fluid and deformation on metamorphism of the deep crust and consequences for the geodynamics of collision zones. In: Hacker, B., Liou, J. (Eds.). When Continents Collide: Geodynamics and Geochemistry of Ultrahigh-Pressure Rocks. Kluwer Publishers, Dordrecht, pp. 297–323.

Austrheim, H., Griffin, W., 1985. Shear deformation and eclogite formation within granulite facies anorthosites of the Bergen Arcs, western Norway. Chemical Geology 50, 267–281.

Camacho, A., McDonald, I., Armstrong, R., Braun, J., 2001. Evidence for shear heating, Musgrave Block, central Australia. Journal of Structural Geology 23, 1007–1013.

Dunlap, W., 2000. Neocrystallization or cooling? $^{40}Ar/^{39}Ar$ ages of white micas from low-grade mylonites. Chemical Geology 143, 181–203.

Ellis, D., Maboko, M., 1992. Precambrian tectonics and the physicochemical evolution of the continental crust; I: the gabbro–eclogite transition revisited. Precambrian Research 55, 491–506.

Jamtveit, B., Austrheim, H., Malthe-Sørensen, A., 2000. Accelerated hydration of the Earth's deep crust induced by stress perturbations. Nature 408, 75–78.

Kuehn, A., Glodny, J., Iden, K., Austrheim, H., 2000. Retention of Precambrian Rb/Sr phlogopite ages through Caledonian eclogite facies metamorphism, Bergen Arc Complex, W. Norway. Lithos 51, 305–330.

Villa, I., 1998. Isotopic closure. Terra Nova 10, 42–47.

Zhang, R., Liou, J., 1997. Partial transformation of gabbro to coesite-bearing eclogite from Yangkou, the Sulu Terrane, eastern China. Journal of Metamorphic Geology 15, 183–202.