A brief retrospective of Bill Carlson's work on metamorphic disequilibrium and kinetics

DAVID M. HIRSCH

516 High St., Geology Dept., Western Washington University, Bellingham, WA 98229, USA (hirsch@cc.wwu.edu)

Bill Carlson's work has spanned a wide range of metamorphic and mineralogic topics. One overarching theme has been the extension of metamorphic petrology to occurrences dominated by disequilibrium, rather than equilibrium textures. Beginning with his graduate work on calcite-aragonite transition kinetics, continuing with coronal reaction textures, and, for the past 15 years, focusing on the quantitative analysis of porphyroblast textures, Bill has driven the field forward. His advances have been both in the theoretical realm, building on the work of folks like Ralph Kretz, and in the technical realm, in which he pioneered the use of high-resolution computed tomography for the analysis of porphyroblast textures in three-dimensions. While he has not been alone in this effort, his work, along with that of his students and colleagues, has been instrumental in advancing our science from the clean ideality of equilibrium towards the messy but more accurate world of disequilibrium.

Oxygen isotope speedometry in the Biwabik iron-formation

ELIZABETH P VALAAS AND JOHN W VALLEY

Dept. of Geology, University of Wisconsin, Madison, USA (epvalaas@wisc.edu, valley@geology.wisc.edu)

The Biwabik banded iron-formation (BIF) of northern Minnesota (1.9 Ga), underwent contact metamorphism by intrusion of the Duluth Complex (1.1 Ga). The igneous contact is sub-parallel and intersects the BIF at Dunka Pit.

Apparent temperatures, calculated from Δ^{18}O (Quartz-Magnetite) (Clayton and Kieffer, 1991), are precise and decrease smoothly from 700ºC at the contact to 375ºC at greater than 2.6 km (3-D, normal to the contact). However, measured temperatures are similar to closure temperatures (T_c; Dodson, 1973) for oxygen diffusion in magnetite at a cooling rate of ~2000°C/Ma over a gradient in observed grain size of magnetite of 2 mm at the contact to 10 µm at 2.6 km. In the absence of recrystallization, resetting of Δ^{18}O (Qt-Mt) is limited by diffusion in magnetite inside the grunerite isograd (2.6 km from the contact). At 1.25 km from the contact, the measured "temperature" is 490ºC and T_c is 468ºC; at 2.6 km from the contact the temperatures are 375ºC and 404ºC respectively. If T_c at the contact equals the measured apparent temperature, the cooling rate is defined.

To test whether Δ^{18}O (Qt-Mt) is a thermometer or a speedometer in these rocks, additional quartz magnetite pairs were analyzed from two outcrops in Dunka Pit within 10 m of the contact for two grain sizes: 500-350 µm and 150-105 µm diameter. The apparent temperatures are: 669°C, 702°C, and 716°C for 03BIW43B and 601°C, 644°C, and 732°C for 03BIW18C; for 150-105 µm, bulk, and 500-350 µm diameter magnetite grains respectively. Thus magnetites have been reset in δ^{18}O as a function of grain size and presumably are zoned in δ^{18}O due to diffusion. Inverted pigeonite in BIF at Dunka Pit indicates temperature > 775°C which further supports the interpretation that Δ^{18}O (Qt-Mt) records retrograde exchange.

Thus, measured Δ^{18}O (Qt-Mt) values record the rate of retrograde exchange. This suggests that the Biwabik iron-formation at Dunka Pit cooled from ~800°C to T_c (700°C) in 50 kyr. Measured apparent Δ^{18}O temperatures are lower than peak temperatures and should not be used to estimate depths of intrusion or peak metamorphic temperatures.

References

Clayton and Kieffer (1991) The Geochemical Society Special Publication. **3,** 3-10.

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