Geology, Geochemistry, and Mineralogy of the Worthington Offset Dike: A Genetic Model for Offset Dike Mineralization in the Sudbury Igneous Complex

PETER C. LIGHTFOOT† AND CATHARINE E.G. FARROW

Inco Technical Services Limited, Copper Cliff, Ontario P0M 1N0, Canada

Abstract

The Worthington offset dike extends for approximately 15 km away from the southwestern margin of the 1.85 Ga Sudbury Igneous Complex. The dike is zoned with respect to inclusion and sulfide contents. Marginal chilled quartz diorite is transitional into medium-grained quartz diorite. These rocks are sulfide undersaturated, contain small inclusions from the wall rocks, and are preserved along much of the dike. Locally, the dike contains a core of inclusion-rich quartz diorite, which can be choked with inclusions surrounded by semimassive to massive sulfide. The more heavily mineralized inclusion-rich quartz diorite contains 10 to 75 percent amphibolite inclusions, which are petrologically and geochemically similar to the immediately adjacent country-rock amphibolites, locally termed "Sudbury gabbros." The semimassive to massive sulfide zones form subvertical pipes, much like the deposits of the Copper Cliff offset dike, and these are associated with locations where the Worthington dike widens from 20 to 30 m to 50 to 80 m. The average metal tenors of the sulfide with > = 5% sulfur are calculated to be 7 percent Ni and 13 percent Cu. Thus the dike ores have a much higher Cu/Ni ratio than orebodies within the contact sublayer (Cu/Ni ~ 1).

The medium-grained inclusion-poor quartz diorite and inclusion-rich quartz diorite differ in Ni, Cu, Pt, and Pd abundances, but they have similar major and lithophile trace element abundance levels despite having different inclusion and sulfide contents. Assimilation of inclusions has therefore not significantly changed the composition of the silicate matrix of the inclusion-rich quartz diorite. The composition of the inclusion-poor quartz diorite is a close approximation to average crust and also to the bulk composition of the Sudbury Igneous Complex rocks. Regional differences in offset geochemistry exist between the North and South Range offset dikes, but we believe that the formation of the inclusion-poor quartz diorite and inclusion-rich quartz diorite silicate magmas predated significant silicate differentiation or silicate gravitational segregation of the melt sheet and that the differences may record primary silicate heterogeneity of the melt sheet. These differences may have developed in response to the different proportions of Archean granitoids relative to Proterozoic sediments and volcanics that contributed to the melt sheet on the North and South Ranges of the Sudbury Igneous Complex.

The first quartz diorite melt was sulfide undersaturated and devoid of amphibolite inclusions. The introduction of this melt took place during or shortly after the generation of the melt sheet and represented a very rapid introduction of quartz diorite magma into radial and concentric dikes with local incorporation of metasedimentary inclusions. The second phase of activity involved the introduction of a sulfide-bearing melt into portions of the quartz diorite melt that were not completely crystallized at the center of the offset dike; this produced the inclusion-rich quartz diorite. The main control on the location of injection of the sulfide-bearing melt appears to be widened domains of the partially crystallized quartz diorite dike that often correspond to contacts between different country-rock types and sulfides, especially where there are Sudbury gabbro country rocks and/or local development of Sudbury breccia. The injection of sulfide-enriched melt is interpreted to have taken place along steeply oriented pipes through these heavily brecciated country rocks; this appears to explain why there is a contact relationship between inclusion-rich quartz diorite and inclusion-poor quartz diorite, and also explains the presence of fragments of inclusion-poor quartz diorite and country-rock amphibolites in the inclusion-rich quartz diorite. The introduction of sulfides into these pipes is interpreted to have taken place from the overlying melt sheet and it is suggested that the high Cu/Ni ratios and platinum-group element tenors of these sulfides, compared to contact-style sulfides, indicate that these were some of the earliest sulfides to segregate from the overlying melt sheet.

The type and style of brecciation developed in the country rocks along different offset dikes controlled the continuity of the quartz diorite and the location of the orebodies. Intersections of the quartz diorite with domains of Sudbury breccia appear to have been important in the Copper Cliff offset dike and the development of mineralization may be a response to the presence of favorable channels through which magmatic sulfides were introduced into the dike from the overlying melt sheet. We propose that the quantity of sulfide in a dike is related to the thickness of the overlying melt sheet. The melt sheet thickness was presumably greatest at the Copper Cliff and Frood-Stobie offset dikes, the Worthington offset dike is located below a thinner melt sheet, and the Manchester and Foy offset dikes developed beneath very thin portions of the melt sheet.

† Corresponding author: e-mail, lightfootpc@inco.com