Review of Brazilian Chromite Deposits Associated with Layered Complexes: Constraints for the Postulated Genetic Models

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Introduction

Chromitites represent a special case of cumulate rock where chromite is the only cumulus phase. Formation of chromitites thus requires that phase relations of the appropriate system be somehow changed to allow the system to fall into the chromite stability field. Several mechanisms for the formation of chromitite seams have been postulated. They include the contamination of the basic parental magma by sialic rocks, the change in total pressure, the influx of fresh magma into the magma chamber, and changes in oxygen fugacity. In order to test the postulated models, chromitites and hosting mafic and ultramafic rocks from three layered complexes in Brazil were investigated (Fig. 1). The main purpose of these studies was to provide an integrated understanding of the primary igneous evolution of chromitite seams and their host rocks, focusing on magma chamber processes leading to the formation of chomitites. In this paper we summarize the previous results and use them to review the genetic models.

The layered intrusions investigated: Bacuri Complex (Amapá), Niquelândia Complex (Goiás), and Ipueira-Medrado Sill (Bahia), have distinct geological settings and igneous stratigraphy, thus providing an opportunity to look at chromitites formed in different geological-petrological environments.

The Chromite Deposits of the Bacuri Complex

The tectonic setting, geology and chromite deposits of the Bacuri mafic-ultramafic layered complex (Fig. 1) were recently investigated (Spier and Ferreira Filho, 2001; Pimentel et al., 2002; Prichard et al., 2001). The chromite deposits of the Bacuri Mafic-Ultramafic Complex (BMUC) consist of 8.8 Mt. of ore grading 34% Cr_2O_3, representing the second largest reserves of chromite in Brazil. The BMUC is a major Paleoproterozoic (ca. 2.2 Ga) layered intrusion overprinted by ductile deformation and associated regional amphibolite facies metamorphism of the Transamazonian Cycle (ca. 2.0 Ga). The BMUC is intrusive into gneiss-migmatite terranes of the Guyana Shield.

The BMUC consists of a Lower Mafic Zone (> 500 meters-thick), an Ultramafic Zone (30-120 meters-thick) and an Upper Mafic Zone (> 300 meters-thick). The Ultramafic Zone consists of interlayered serpentinite (olivine cumulate) and chromitite (chromite cumulate). Most of the chromite is concentrated in a few meters-thick chromitite layer located at the base of the Ultramafic Zone in direct contact with the underlying Lower Mafic Zone (Fig. 2). Cryptic variation data (Fig. 2) are consistent with extensive fractionation within the UZ. The stratigraphic position of the main chromitite and cryptic variations in the UZ strongly supports a model for its origin associated with a major new influx of primitive magma, and mixing with more fractionated resident magma. The composition of chromite in massive chromitite of the BMUC is compared with other deposits in Table 1. The Mg ratio of chromite from the BMUC extends over a wide range (0.15-0.55), while the Cr ratios are very high (0.66 - 0.89) and vary through a smaller range.

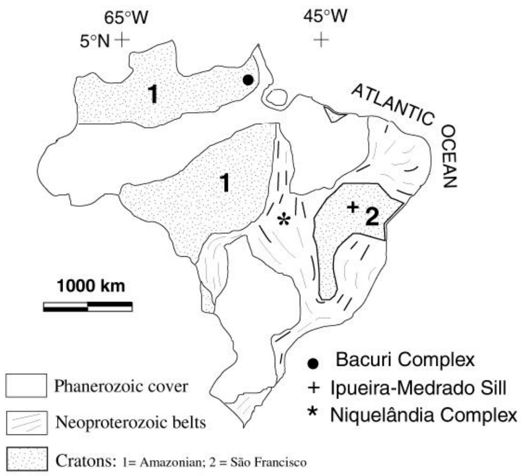

Figure 1. *Schmatic location of the chromite mineralizatied layered complexes in Brazil.*

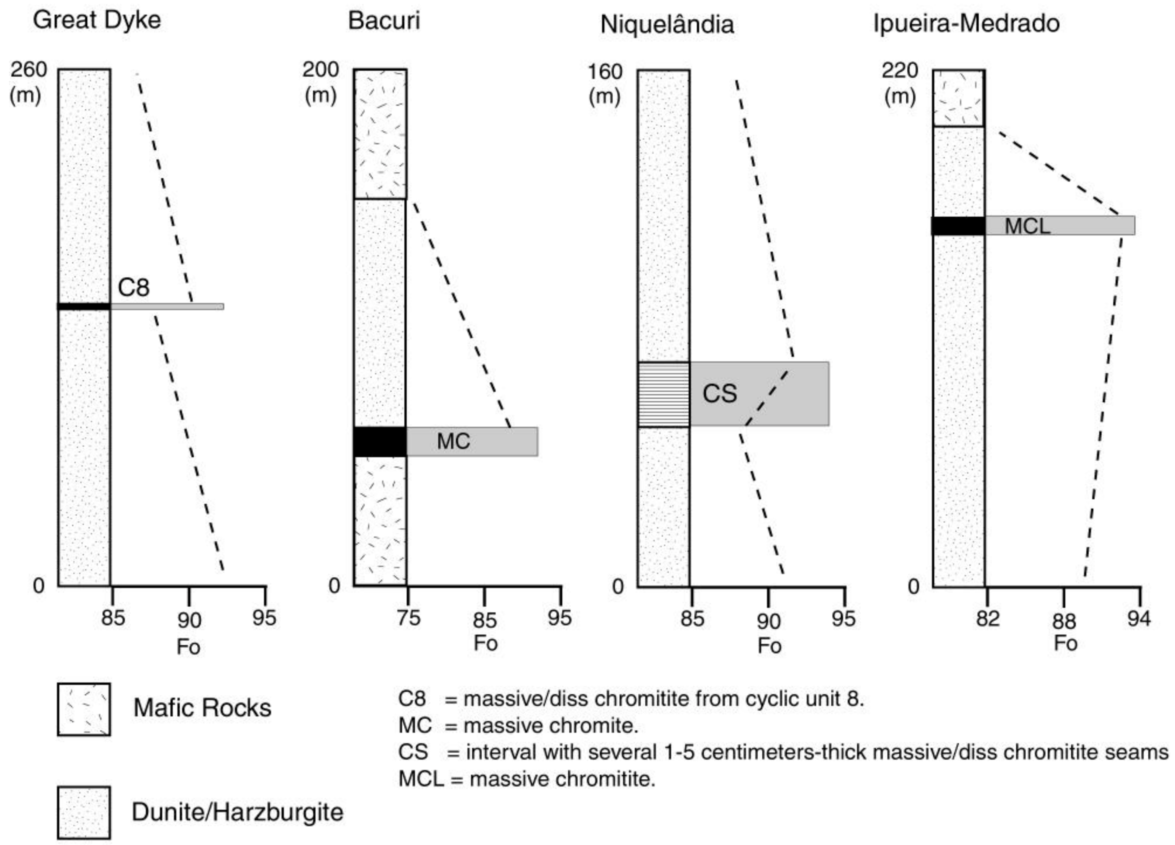

Figure 2. *Schematic sections of chromitites from different layered complexes. Olivine cryptic variations indicate the general fractionation trend closely associated to chromitites. Data from the great Dyke are from Wilson et al. (1982).*

The Chromitites of the Niquelândia Complex

The tectonic setting, geology and petrology of the Niquelândia Complex were considered in several papers and recently reviewed by Ferreira Filho et al. (1998; 2000). Previous investigations of the non-economic chromitite seams of the Niquelândia Complex were mainly focused on their anomalous PGE contents (Ferreira Filho et al., 1995). The Niquelândia Complex is a major layered intrusion that was affected by tectonic-metamorphic events during the Neoproterozoic. The estimated age for the Lower Layered Series (LS) of the Niquelândia Complex is Paleoproterozoic (ca. 2.0 Ga). The LS has an estimated thickness of several km, consisting of a Lower Mafic Zone (mainly gabbronorite), an Ultramafic Zone (interlayered dunite/pyroxenite) and an Upper Mafic Zone (mainly gabbronorite and pyroxenite).

The chromitite seams consist of several few centimeters-thick layers restricted to a 20 meters-thick interval of the estimated 3 km-thick Ultramafic Zone of the LS. Detailed study of the mineralized interval (Ferreira Filho et al., in prep) indicates that chromitites are interlayered with homogeneous dunite (olivine ± chromite adcumulate) of the Ultramafic Zone (Fig. 2). Cryptic variations indicate that the 20 meters-thick interval marks a slight reversal of the fractionation path (Fig. 2). The data support a model for its origin associated with new influx of primitive magma, and mixing with slightly more fractionated resident magma. The composition of chromite in massive chromitite of the Niquelândia Complex is compared with other deposits in Table 1. The Mg ratio of chromite from the Niquelândia Complex extends over a narrow range (0.48-0.57), while the Cr ratios extend over a wider range (0.58-0.71). The small range of Mg ratio is compatible with the very restricted variation of olivine (Fo 87-93) from interlayered dunites.

Table 1. *Compositional features of chromite and olivine from different chromite-mineralized layered complexes.*

Layered Complex	Crhomite in massive chromitite			Olivine		Age (Ga)
	Mg ratio	Cr ratio	Ti^{+4}	Fo	NiO	
Bushveld	0.24-0.58	0.60-0.75	0.13-1.06	77-88	na	2.05
Great Dyke	0.36-0.67	0.70-0.80	0.02-0.13	84-92	0.18-0.44	2.74
Stillwater	0.39-0.57	0.60-0.66	0.02-0.28	79-90	0.11-0.33	2.46
Bacuri	0.15-0.55	0.66-0.89	0.03-0.70	76-91	0.18-0.66	ca. 2.2
Ipueira-Medrado	0.45-0.72	0.58-0.68	0.09-0.44	84-93	0.18-0.47	ca. 2.0
Niquelândia	0.48-0.57	0.58-0.71	0.04-0.07	87-93	0.20-0.45	ca. 2.0

Adapted from Spier & Ferreira Filho (2001), Marques & Ferreira Filho (2002), and Stowe (1994)
na = systematic data not available.
Mg ratio = Mg/(Mg+Fe^{+2}); Cr ratio = Cr/(Cr+Al).

The Chromite Deposit of the Ipueira-Medrado Sill

The geology, petrology and chromite deposits of the Ipueira-Medrado sill, a Paleoproterozoic (ca. 2.0 Ga) mafic-ultramafic intrusion, were recently investigated (Marques and Ferreira Filho, 2002; Marques et al., 2002). The chromite deposit of the Ipueira-Medrado sill consists of 4.5 Mt. of ore grading 30-40 wt. % Cr_2O_3, representing one of several chromite-mineralized intrusions of the Jacurici Complex, the largest reserve of chromite in Brazil with over 30 Mt of ore. The Jacurici Complex consists of a NS trending (70 km-long to 20 km-wide) swarm of mafic-ultramafic chromite mineralized bodies hosted by granulite-gneiss terranes of the São Francisco Craton (Fig. 1).

At the Ipueira-Medrado Sill, a 5-8 meters-thick massive chromitite layer (MCL) is hosted by a 200-300 meters-thick layered intrusion. The sill is subdivided in a Marginal Zone, consisting of sheared gabbro and harzburgite; an Ultramafic Zone consisting of dunite, harzburgite, chromitite and minor orthopyroxenite; and an upper Mafic Zone consisting of leuco- to melanorites. The MCL is located at the upper part of the Ultramafic Zone. Cryptic variations of olivine and orthopyroxene throughout the stratigraphy indicate that the sill consists of two intervals with distinct magmatic evolution. The interval located below the MCL is characterized by slow evolution of mineral compositions toward more primitive compositions. The interval located above the MCL is characterized by fast upward evolution toward more fractionated compositions (Fig. 2). The data suggest that the interval below the MCL crystallized in a dynamic magma chamber undergoing frequent replenishment with primitive magma. The magmatic evolution above the MCL suggests that crystallization occurred in a mainly closed magma chamber. The MCL is located at the transition from dynamic open system to mainly closed system magma chamber. The most primitive compositions are observed just below or at the MCL. Cryptic variations are the opposite to what is expected as the result of mixing new influxes of primitive liquid with residual fractionated liquid in the magma chamber. Re-Os and Sm-Nd data indicate strong contamination of the magma at or above the MCL, suggesting that chromite crystallization was triggered by changes of physical-chemical conditions associated to crustal contamination. The composition of chromite in massive chromitite of the Ipueira-Medrado sill is compared with other deposits in Table 1. The Mg ratio of chromite from the Ipueira-Medrado sill extends over a wide range (0.45-0.72), while the Cr ratios (0.58 - 0.68) vary through a smaller range.

Conclusions

Chromitites occur at the base of cyclic units in several layered complex suggesting that chromitites are formed by mixing new influxes of primitive liquid with residual fractionated liquid in the magma chamber (Irvine 1977). Evidence for such model is suggested by changes in the cryptic variation and/or the sequence of cumulus phases illustrated at the Great Dyke, Bacuri and Niquelândia complexes (Fig. 2). However, cryptic variations at the Ipueira-Medrado chromite deposit do not support such model for the origin of the main chromitite layer. Isotope data suggest that chromite crystallization was triggered by changes of physical-chemical conditions associated to crustal contamination at the Ipueira-Medrado sill. The data indicate that chromitite layers are always associated with major changes in the magma chamber. This study also indicates that the specific mechanism responsible for appropriate phase changes leading to chromite crystallization may be different for each deposit. The compositions of chromite from massive chromitites investigated in our studies occupy a broader compositional field than previously stated for stratiform chromites (Stowe, 1994). Compositional fields currently considered to be typical of stratiform chromite should be reviewed.

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