TOWARDS A NOVEL HYPOTHESIS FOR ORIGIN OF MASSIVE CHROMITITES IN THE BUSHVELD IGNEOUS COMPLEX

***Latypov R.M.*[1], Chistyakova S.Yu.[1], Mukherjee R.[1]**
[1]*School of Geosciences, University of the Witwatersrand, Johannesburg, South Africa, rais.latypov@wits.ac.za*

Abstract
The origin of stratiform layers of massive chromitite (60-90 vol.% chromite) is a long-standing puzzle in petrology mafic-ultramafic sills and layered intrusions (e.g. Alapieti et al., 1989; Marques & Ferreira Filho, 2003; Naldrett *et al.*, 2012, Maier *et al.* 2013, Mungall, 2014; Cawthorn, 2015). The origin of chromitites in the Bushveld Complex has been attributed to two principal mechanisms: (1) gravity-controlled settling of chromite onto the chamber floor from magma that was saturated in chromite, either initially or due to some internal process; or (2) gravity- and size-controlled separation of chromite from co-existing olivine and orthopyroxene within crystal-rich slurries, either formed directly within the chamber or brought into the chamber from some deep staging reservoirs. Here we present field observations from potholes, roughly circular structures in which footwall rocks were removed by magmatic erosion, that rules out both approaches. A key observation is that UG1/UG2 chromitites drape the irregular margins of potholes, even where they are vertical or overhanging (Fig. 1). These relationships eliminate both early settling of chromite from the overlying magma and late mechanical segregation of chromite within cumulates as viable hypotheses. In addition, thick chromitites commonly consist of several texturally and compositionally distinct sublayers that are locally separated by thin partings of silicate rocks. The absence of thick sequences of intervening silicate rocks from which chromite may have been separated to form these sublayers refutes an origin from crystal slurries. Transgression of chromitite-orthopyroxenite units by hanging wall rocks excludes the origin of chromitites from crystal slurries that intrude as late-stage sills into pre-existing cumulates. The field relationships appear to be compatible only with the emplacement of superheated, dense magma along the temporary base of the chamber that led to intense melting and dissolution of the pre-existing floor cumulates, followed by the *in situ* crystallization of chromite directly on the irregular chamber floor.

Based on the above premises, we advance a novel hypothesis for origin of UG1/UG2 chromitites in the Bushveld Complex that involves the following sequence of events: (1) new dense and superheated magmas replenished the chamber with little to no mixing with the stratified melt in the chamber; (2) the magma spread out laterally along the floor of the chamber and caused intense thermochemical erosion of the floor cumulates, resulting in an igneous unconformity; on cooling, most of these magmas crystallized orthopyroxenite cumulates; (3) some batches of magma were, however, chromite-saturated and, after cooling, crystallized chromite directly on the chamber floor, draping all irregularities produced by the previous erosion; (4) chromite and sulphide droplets that grew directly at the crystal-liquid interface extracted PGE from a large volume of fresh magma delivered to the base of the chamber by vigorous flow/convection in the basal layer. (5) Formation of chromitite occurred through prolonged replenishment of the chamber by chromite-saturated magmas, which caused multiple cycles of thermochemical erosion of pre-existing cumulates followed by *in situ* crystallization of chromite on the chamber floor; this resulted in the formation of thick layers of PGE-rich chromitite that consist of several sublayers with distinct textural and compositional characteristics. (6) The formation of chromitites was commonly terminated by the emplacement of pulses of new magma that were not saturated in chromite and therefore resulted in local thermal/chemical erosion of chromitites with subsequent deposition of hanging wall orthopyroxenite. Thus, chromitites are both underlain and overlain by cumulate rocks produced from magmas that replenished the chamber. These rocks developed from magmas that were similar in composition and therefore lack cryptic variations in mineral composition above and below the chromitite layers.

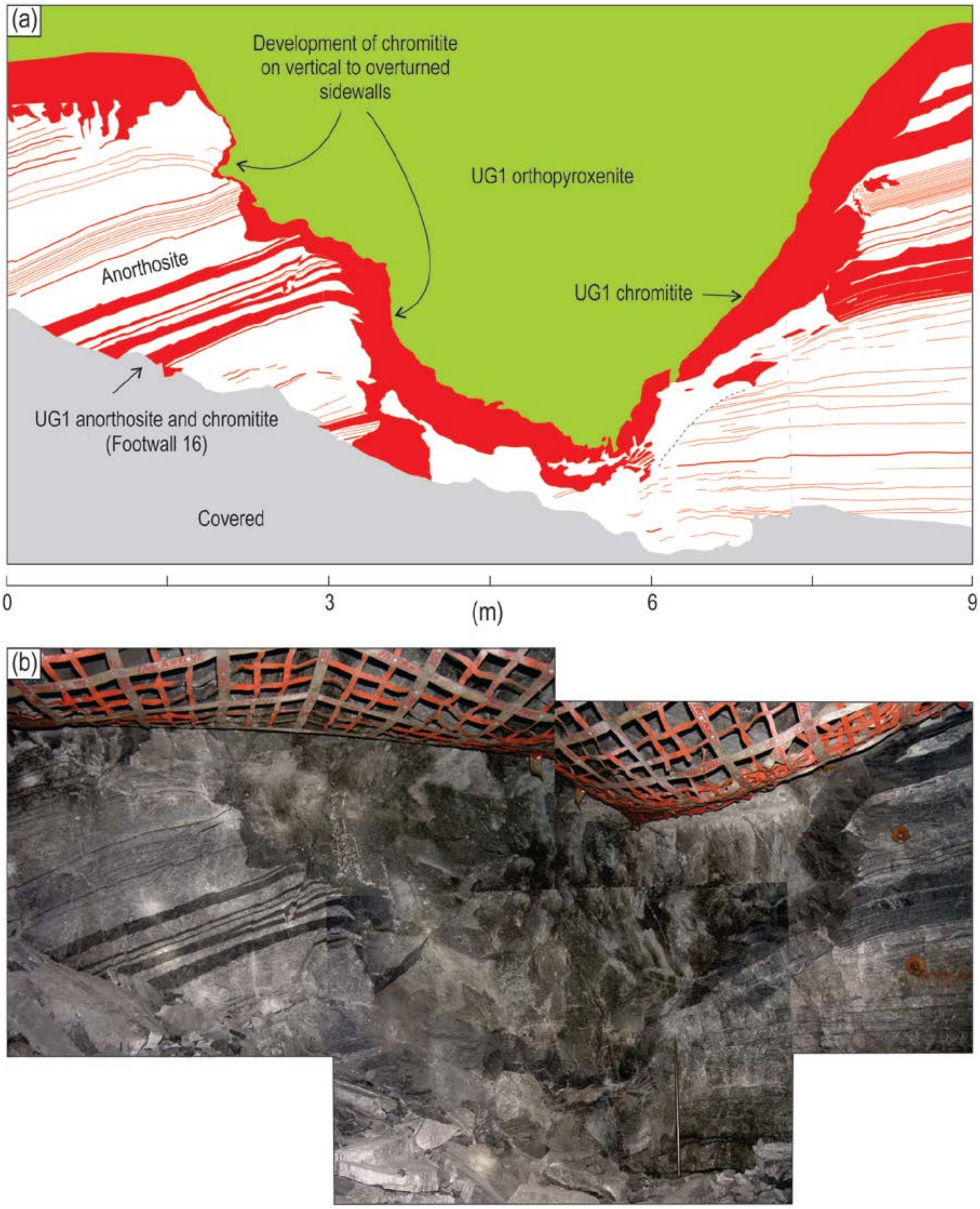

Fig. 1. Sketch (a) and photograph (b) of an oblique cross-section showing UG1 chromitite draping over steeply-inclined to overhanging walls of a pothole. Note crosscutting relationships of the UG1 chromitite with interlayered anorthosite and chromitite in the footwall rocks and disrupted layering on the right side of a pothole. Level 15, Shaft 10 of the Impala Platinum Mine, Western Bushveld.

It should be noted that the field relationships of UG1/UG2 chromitites with their footwall and hanging wall rocks are very similar to those of the Merensky Reef (Latypov *et al.*, 2015; 2017). This provides support for the opinion (e.g. Irvine & Sharpe, 1986) that the chromitite of the Merensky Reef can essentially be regarded as the UG4 chromitite. This also suggests that there are no substantial differences in the origin of the UG1/UG2 and Merensky Reef chromitites, i.e. they are essentially products of the same process – which we interpret to be basal replenishment of the chamber by chromite-saturated magmas. This scenario appears to be conceptually the simplest and physically most plausible explanation for origin of thick chromitites in the Bushveld Complex and we infer that these processes can be extrapolated to chromitites in other mafic-ultramafic layered intrusions.

Acknowledgements:
This work is based on the research supported by the National Research Foundation (NRF) of South Africa in the form of Research Grants 87677, 90834 and 91812 to Rais Latypov and the Innovation Postdoctoral Fellowship to Sofya Chistyakova. The DST-NRF Centre of Excellence (CoE) for Integrated Mineral and Resource Analysis (CIMERA) is acknowledged for providing funding for postdoctoral research to Ria Mukherjee. Any opinion, finding and conclusion or recommendation expressed in this material is that of the authors and the NRF and CoE do not accept any liability in this regard.

References:
Alapieti, T.T., Kujanpää, J., Lantinen, J.J. & Papunen, H. (1989). The Kemi stratiform chromitite deposit, Northern Finland // Economic Geology 84, 1057-1077.

Cawthorn, R.G. (2015). Bushveld Complex. In: Charlier B., Namur, O., Latypov R., Tegner, C. (eds) // Layered Intrusions, p. 517-587. Springer International Publishing. New York City: Springer.

Irvine, T.N. & Sharpe, M.R. (1986). Magma mixing and the origin of stratiform oxide ore zones in the Bushveld and Stillwater Complexes. In: Gallagher, M. J., Ixer, R. A., Neary, C. R. & Pritchard, H. M. (eds) // Metallogeny of Basic and Ultrabasic Rocks. Instit. Mining Metallurgy, London, 183-198.

Latypov, R.M., Chistyakova, S.Yu, Page, A. & Hornsey, R. (2015). Field evidence for the in situ crystallization of the Merensky Reef // Journal of Petrology 56, 2341–2372.

Latypov, R.M., Chistyakova, S.Yu., Barnes, S.J. & Hunt, M. (2017). Origin of platinum deposits in layered intrusions by in situ crystallization: evidence from undercutting Merensky Reef of the Bushveld Complex // Journal of Petrology (accepted manuscript).

Maier, W.D., Barnes, S.J. & Groves, D.I. (2013). The Bushveld Complex, South Africa: formation of platinum–palladium, chrome- and vanadium-rich layers via hydrodynamic sorting of a mobilized cumulate slurry in a large, relatively slowly cooling, subsiding magma chamber // Mineralium Deposita 48, 1-56.

Marques, J.C. & Ferreira Filho, C.F. (2003). The chromite deposits of the Ipueira-Medrado Sill, Bahia, Brazil' // Economic Geology 98, 87–108.

Mungall, J.E. (2014). Geochemistry of Magmatic ore deposits. In: Holland, H. D. & Turekian, K. K. (eds) // Treatise on Geochemistry. Volume 13, Pergamon, Oxford, pp. 195-218.

Naldrett, A., Kinnaird, J., Wilson, A., Yudovskaya, M. & Chunnett, G. (2012). The origin of chromitites and related PGE mineralization in the Bushveld Complex: new mineralogical and petrological constraints // Mineralium Deposita 47, 209-232.