

The Composition of the Stillwater and Bushveld Parental Magmas.

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The Bushveld and Stillwater Complexes contain most of the world's platinum-group element resources and it has long been recognized that their cumulate stratigraphies show similarities, which suggests that the magmas they formed from were similar with respect to major element compositions. At both localities a magma rich in SiO₂ and MgO is needed to produce the orthopyroxene rich lower parts of the intrusions. Chill margins with the composition of Mg-rich basaltic andesite are present at both localities (the B-1 and Gp-3 chills). To produce the gabbroic middle zones of the intrusions, melts close to tholeiitic basalt composition are required. Chills with these compositions are found at both intrusions (B-2 and Gp-1 chills). Recent studies on Bushveld have provided information on the trace element content of the Bushveld magmas and cumulates indicating that the magmas were strongly enriched in LILE and LREE (Fig. 1). We have determined the trace element content of the equivalent magmas from Stillwater and they are poorer in LILE and LREE. The Mg-rich andesite (Gp-3) are closer to boninite compositions than the Bushveld B-1 rocks. The tholeiitic basalt (Gp-1) show some similarities to arc tholeiites.

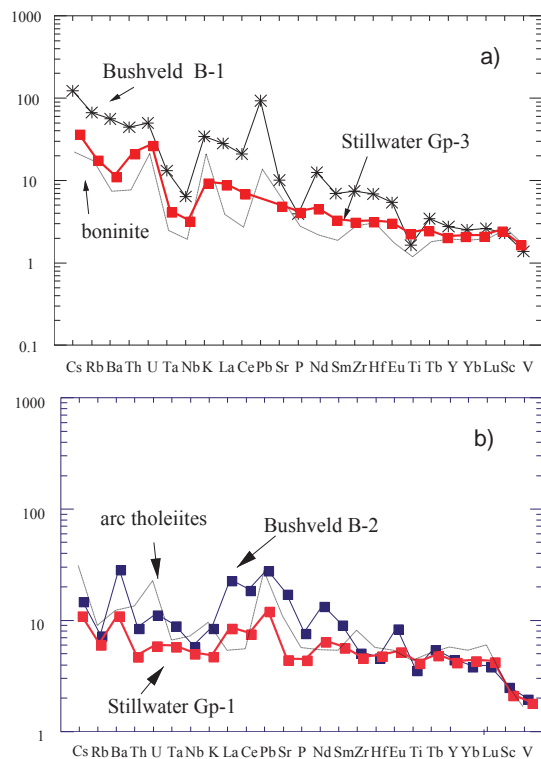


Fig. 1 Mantle normalized incompatible element plot of the marginal rocks of the Bushveld and Stillwater compared with modern magmas

Lead Isotopic bias during the *Chaîne Opératoire* of Non Ferrous metal: Implications for Provenance Studies

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Introduction

The rise of the high resolution mass spectrometers (MC-ICP-MS) during the last ten years allows the analyses of traditional and non traditional isotopes to be more accurate, precise, relevant and consequently subtly interpretable [e.g. 1, 2]. The lead isotopic tracing, from mines/ore bodies to archaeological materials, constitutes the main tool of metal provenance studies. Despite the use of high-resolution isotopic measurements, the identification of the geographical ores source is difficult because of several factors. The most important factor is inherent to the ores themselves: *i*) the ores could have lead isotopic heterogeneity in a same ore body and *ii*) numerous different geographical mining districts could have same lead isotopic compositions. Furthermore, the ores are disconnected of any geological, archaeological and historical significance in respect with the metal provenance study. When the archaeological materials are well documented by mining archaeology and history, the provenance studies (coupled with high resolution measurements) are improved [3]. Another factor, rarely taken into account, is the possible lead isotopic bias during the metallurgical processes. Because the isotopic tracing is directly operated from ores to object at global scale, the consequence is that the *chaîne opératoire* is not taken into account. But, during the *chaîne opératoire*, numerous human operations occurred. Some archaeological experiments conducted on ores reduction have measured isotopic bias between ores / metal of slags and metal of slags / slags silicated matrix at furnace scale [4]. Through two regional studies, conducted on materials well documented by mining archaeology and history, we found isotopic bias due to the local *chaîne opératoire*. These results corroborate the previous experimental ones.

Results and discussions

We will present here the results from two *chaîne opératoire* well documented by mining archaeology: *i*) the lead-silver one in France for medieval time and *ii*) the gold-silver one in Romania for roman time. We will demonstrate here that the additions during the metallurgical processes produce lead isotopic bias. According the high-resolution isotopic measurement available today, it is necessary to take into account these biases in order to refine the tracing and understand the *chaîne opératoire* in its historical context. This approach will allow the understanding of regional management of ore sources in ancient times. It constitutes the first step before the beginning of a metal diffusion at global scale.

[1] Klein et al. (2010) *Archaeol. Anthropol. Sci.* **2**, 45-56. [2] Desaulty et al., (2011) *PNAS* **108**, 9002-9007. [3] Baron et al., **submitted** in *Archaeometry*. [4] Baron et al. (2009) *Appl. Geochem.* **24**, 2093-2101.