GEOCHEMICAL CORRELATION OF TWO LATE ARCHEAN IMPACT SPHERULE LAYERS BETWEEN SOUTH AFRICA AND WESTERN AUSTRALIA: THE PARABURDOO-REIVILO LINK. S. Goderis[1,5], B. M. Simonson[2], I. McDonald[3], S. W. Hassler[2,4], A. Izmer[5], F. Vanhaecke[5], and Ph. Claeys[1], [1]Earth System Science, Dept. of Geology, Vrije Universiteit Brussel, Pleinlaan 2, B-1050 Brussels, Belgium (Steven.Goderis@vub.ac.be), [2]Geology Dept., Oberlin College, Oberlin, OH 44074, USA, [3]School of Earth & Ocean Sciences, Cardiff University, Cardiff CF10 3YE, UK, [4]The Wilderness Society, San Francisco, CA 94111, USA, [5]Dept. of Analytical Chemistry, Ghent University, Krijgslaan 281 – S12, B-9000 Gent, Belgium.

Introduction: Several Late Archean to Early Proterozoic spherule layers (SL) have been recognized in thick successions of exceptionally well preserved sedimentary and volcanic strata on the Pilbara craton in the Hamersley Basin (Western Australia, WA) and on the Kaapvaal craton in the Griqualand West Basin (South Africa, SA). These Archean-Proterozoic Boundary (APB) spherules appear to represent 4 discrete impact events over a time span of about 140 Ma, from ca. 2.63 to 2.49 Ga [1,2]. The discovery of the Paraburdoo (PB) SL (Hamersley) and its proposed connection to the Reivilo (RV) SL (Griqualand West) provides an additional impact-related high-resolution stratigraphic correlation between WA and SA strata deposited near the APB [3].

Stratigraphic and petrographic correlation: In addition to comparable stratigraphic positions in the Hamersley and Griqualand West basins and similar interpolated U-Pb ages of ca. 2.57 and 2.56 Ga respectively, the RV and PB SL share numerous characteristics not seen in any of the other APB SL [3]. Both layers consist of highly crystallized microkrystites with abundant plagioclase and skeletal ferromagnesian crystals that have been replaced by K-feldspar and a phlogopite-like phyllosilicate, respectively. The skeletal texture is indicative of rapid cooling of a melt with mafic to ultramafic composition and suggests oceanic target rocks. In both layers, internal bubble cavities or replaced cores of impact glass rarely occur. The PB SL is ~2 cm thick, normally graded, and probably deposited by suspension settling. The RV SL is similar in some locations, but was reworked by waves and/or currents in others [1,3].

Geochemical data: The geochemical compositions of the PB and RV SL are strikingly similar, both in terms of major and trace element abundances, including the platinum group elements (PGE). The low Fe_2O_3 (0.53-1.83 wt%), moderate MgO (0.97-2.61 wt%), and high CaO (7.93-10.92 wt%) and K_2O (9.10-11.28 wt%) contents combined with the very high Cr (830-1076 ppm) and PGE concentrations (Ir_{avg} = 176-247 ppb) are unique for PB-RV in comparison to the other APB SL (Cr_{max} = 418 ppm, Ir_{max} = 17.9 ppb; [2]). In addition, spidergrams of upper continental crust (UCC) or CI carbonaceous chondrite-normalized trace elements and REE are very similar, with distinct positive Ti and negative Eu anomalies. These observations strongly suggest the formation of the PB-RV SL from a single impact event.

The unusual high levels of PGE are equivalent to ~40% of meteoritic component (nominal CI chondrite) in the RV SL [2], and up to 70% (Ir = 131-357 ppb) in the PB SL. Only the significantly older, Early Archean S3 and S4 SL from Barberton (SA) match these very high levels of PGE [4,5]. As noted by [2], the relative proportions of PGE analyzed are very similar when comparing PB-RV SL to the Early Archean S4 SL, suggesting these formed through similar processes. Considering the geographical extent over which the PB layer was sampled (~150 km), a mechanism in which local effects concentrated PGE-rich meteoritic material is unlikely.

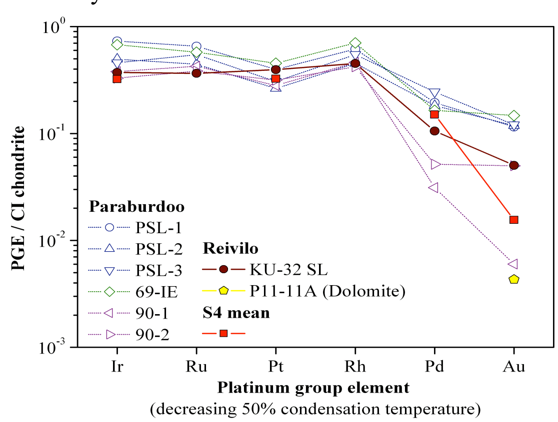

Fig. 1. CI chondrite-normalized PGE pattern of the Paraburdoo SL outcrops PSL, 69-IE, and 90 compared to the South African Reivilo SL and Early Archean S4 SL (data from [2] and [4]).

On a double-logarithmic plot of Cr versus Ir, the PGE-enriched PB-RL SL follows the mixing lines typical for the admixture of chondritic projectile material to terrestrial crustal rocks. This agrees with a relatively flat (i.e. chondritic) PGE pattern on a CI-normalized, logarithmic scale (Fig. 1). The variable depletion of Pd and Au compared to the other PGE for the PB SL is similar to that observed for the RV and Early Archean S4 SL, reflecting repeated hydrothermal overprinting or volatile PGE depletion during spherule condensation [2,4]. Compared to the RV SL, the PB SL is systematically depleted in Co (41.2 ppm) and Ni (279 ppm) compared to the RV SL (Co = 189 ppm, Ni = 3931 ppm). Previous work has shown that Co and Ni are more susceptible to chemical diffusion than less mobile Cr [6]. Based on PGE inter-element ratio plots (e.g., Rh/Ir versus Ru/Rh), the RV (and by inference PB) impactor was likely an ordinary (type L or LL) chondrite [2]. A stronger remobilization at PB could also explain the small discrepancies observed between PB-RV in terms of PGE (e.g., slight relative depletion of Pt at PB; Fig. 1). This may reflect the fact that all of the RV samples are from drill cores, whereas all the PB samples are from weathered surface exposures in an area with more tectonic deformation.

The unique characteristics of the PB-RV SL allow element distribution mapping (XRF and LA-ICP-MS) of meteoritic components (or proxies) and could provide unique insights into their formation processes [7]. Major, trace, and PGE elements are not evenly distributed in the PB SL. While Cr appears more homogeneously spread, Fe and Ni are concentrated in the bottom and top of the layer. Individual spherules can be depleted, show enriched rims or be elevated in these elements entirely. On higher spatially resolved LA-ICP-MS maps, PGE, Ni, and Co are predominantly confined to the spherule interiors, either as discrete nuggets or along the rims of individual spherules (Fig. 2). However, Ni and Co are much more chemically diffused than PGE. This distribution combined with the observation that the PB-RV SL are almost entirely composed of spherules with limited admixed detritus or interstitial cement could imply that higher spherule to matrix ratios more likely result in higher bulk PGE contents. Cr and Fe occur both inside and outside the spherules. None of the PGE systematically follow any of the sulfide phase-representative, moderately siderophile elements (e.g., Fe, Co, Ni, Cu). Mg, Mn, and possibly Fe and Cr appear more concentrated in the spherule matrix, although exceptions occur. These spherule characteristics are comparable to those previously observed for RV [7], although it remains unclear if the concentration of siderophile elements along spherule rims in PB is a primary condensation effect (accretionary growth?) or the result of recrystallization and/or chemical diffusion.

Implications: The PB-RV correlation has important stratigraphic and paleogeographic implications outlined in [3]. Moreover, the existence of the PB-RV SL shows that four large impact events took place in a span of 140 Ma around the APB. This is equivalent to a recurrence interval of ~47 Ma; an elevated rate relative to the Phanerozoic. A minimum rate of 77 Ma has been documented for the Early Archean [9], suggested to reflect the last vestiges of the Late Heavy Bombardment (LHB). More recently, dynamical modeling has been used to predict the presence of 3 ± 2 SL in the 2.63-2.49 Ga time interval based on late giant planet migration (the Nice model) in the presence of a hypothesized extention of the primordial asteroid belt between 1.7-2.1 AU (the so-called E-belt) [10]. The PB-RV SL are unique among the APB SL in that they represent one of the highest concentrations of PGE analyzed for any SL to date, only equaled by Early Archean S3 and S4 SL [4,5]. Although the proportion of meteoritic component is comparable, Cr isotope and PGE abundance analyses indicate that the impactors responsible for the Early Archean SL had carbonaceous chondritic compositions [5], while the APB SL likely were formed by ordinary chondrites [2]. This is an important constraint on the impactor source through time that will need to be accounted for in the proposed link to the primordial E-belt [10].

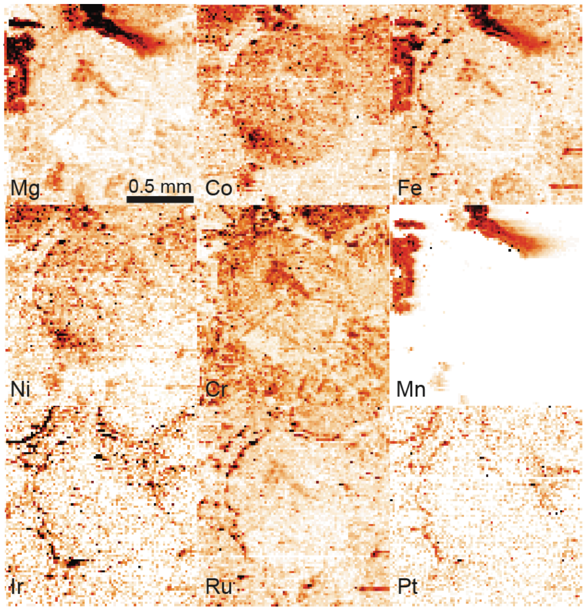

Fig. 2. LA-ICP-MS distribution map of selected elements. Darkest spots represent highest relative concentrations. Images were optimized for visual contrast and do not represent absolute abundances.

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References: [1] Simonson B. et al. (2009) *Precamb. Res., 169,* 100-111. [2] Simonson B. et al. (2009) *Precambr. Res., 175,* 51-76. [3] Hassler S. W. et al. (2011) *Geology, 39,* 307-310. [4] Kyte F. T. et al. (1992) *GCA, 56,* 1365-1372. [5] Kyte F. T. et al. (2003) *Geology, 31,* 283-286. [6] Sauvage J. et al. (2010) *42nd GSA Annual Meeting,* Abst. #180696. [7] McDonald I. et al. (2011) *74th MetSoc Meeting,* Abst. #5139. [8] de Kock M.O. et al. (2009) *Precamb. Res., 174,* 145–154. [9] Lowe D. R. and Byerly G. R. (2010) *LPS XLI,* Abst. #2563. [10] Bottke W. F. et al. (2012) *Early Solar System Impact Bomb. II,* Abst. #4036.