Introduction: If a late heavy bombardment during the period from about 3.8 to 4 billion years ago occurred on the Moon, the Earth must have been subjected to an impact flux more intense than that recorded on the Moon. The consequences for the Earth must have been devastating, and may have included partial or total remelting of the crust. So far, no unequivocal record of a late heavy bombardment on the early Earth has been found. The earliest rocks on Earth date back to slightly after the end of the heavy bombardment, although there are relict zircons up to 4.4 Ga old (in which no unambiguous impact-characteristic shock features have yet been found). In terms of evidence for impact on Earth, the first solid evidence exists in the form of various spherule layers found in South Africa and Australia with ages between about 3.2-3.4 and 2.5 Ga; these layers represent several (the exact number is still unknown) large-scale impact events. The oldest documented (and preserved) impact structures on Earth have ages of 2.02 and 1.86 billion years. Thus, the impact record for more than half of the geological history of the Earth is extremely poor, and there is little information about the impact record and its effects during the first 2.5 billion years of Earth history.

Impact structures or ejecta are commonly identified from specific characteristics, including either the presence of evidence for shock metamorphism, and/or geochemical indications of the presence of an extraterrestrial component. Only elements that have high abundances in meteorites, but low abundances in terrestrial crustal and mantle-derived rocks are useful for such studies (such as the PGEs). Elevated abundances of siderophile elements in impact melt rocks or breccias (and impact ejecta), compared to target rock abundances, can be indicative of the presence of either a chondritic or an iron meteoritic component. There are, however, cases in which the PGE interelement abundances might be fractionated.

These problems can, in part, be overcome by the use of isotopic tracers for extraterrestrial components. Most prominent among these are the Os and Cr isotopic methods. The Os isotopic method, which is based on the decay of Re-187 to Os-187, is very sensitive and can detect sub-percent levels of extraterrestrial component in impact breccias and melt rocks, but it is not possible to determine a meteorite type.

In contrast, the Cr isotopic method relies on the fact that all terrestrial rocks have a uniform Cr isotopic composition, whereas different meteorite types have different isotopic anomalies. The Cr isotopic method is, thus, selective not only regarding the Cr source (terrestrial vs. extraterrestrial), but also regarding the meteorite type.

Barberton Greenstone Belt Spherule Layers:

Four distinct spherule horizons in the Barberton Greenstone Belt (BGB), South Africa (designated S1 to S4), with ages between about 3.5 and 3.2 Ga, have been proposed as being of impact origin (e.g., [1]). The spherules are mostly spherical to ovoid particles, up to a few mm across, of quenched melt droplets that supposedly formed by condensation from vapor clouds. The spherule layers are coarse-grained and have been interpreted to reflect high-energy depositional events in otherwise low-energy, quiet water environments. The original mineralogical and chemical composition of the spherules has been almost completely changed by alteration. The stratigraphic positions of these layers at different geographic locations are difficult to correlate and the possibility exists that some of the layers represent tectonic duplication. Some samples in these spherule layers show extreme enrichments in the PGEs (in some cases far exceeding the PGE abundances found in chondritic meteorites), unlike modern impact ejecta.
deposits. The correlation between the abundances of iridium and arsenic, a very mobile element, in samples from the Barberton spherule layers, all of which have been subject to pervasive transformation into secondary mineral assemblages, indicates remobilization of both elements; this means that the PGE signature in these samples is not primary (e.g., [2]). On the other hand, chromium isotopic anomalies in samples from several of these layers support the presence of an extraterrestrial component [3]. A comprehensive study of sedimentary, petrographic, mineralogical, and geochemical characteristics from a set of new samples of spherule layers between 510 and 512 m depth in the 760-m-long ICDP drill core BARB 5 from the Barite Valley Syncline [4], as well as samples from the CT3 location [5] of the northern Barberton Greenstone Belt has been carried out.

At BARB5, four new spherule layers, each about 4 cm thick, were identified in the core interval between 511.29 and 511.51 m depth, all separated by shale and chert within the 3.26 to 3.23 Ga old middle Mapepe Formation of the Fig Tree Group [6]. Stratigraphically these spherule layers may belong to the same interval as the previously studied S3 and/or S4 layers. Present day 185Os/188Os ratios are in part subchondritic for the spherule horizons (~0.106 to ~0.116) but back-calculated values are indistinguishable from the chondritic 187Os/188Os evolution line (~0.105 to ~0.112, compared to ~0.105 for chondrites at ~3.4 Ga). Possible Re loss during hydrothermal or other alteration may obscure the real initial values in these samples, which may also explain the subchondritic 166Re/188Os ratios in some samples.

The CT3 drill core contains some 17 spherule layers over a stratigraphic interval of 150 m, occurring along the transition zone between the Onverwacht and Fig Tree groups [6]). Some of these layers might represent tectonic duplication. It is possible, but not yet confirmed, that (some of?) the CT3 layers are correlated to the S2 layer, which occurs in the same stratigraphic unit. Ir and Os contents are comparably low in the country rocks, ranging from ~0.12 to 0.97 ppb for Ir and ~0.25 to 1.3 ppb for Os (which is still higher than average modern continental crust), and are elevated in the spherule horizons (between ~6 and 2068 ppb Ir and ~3 ppb and 4312 ppb Os); similarly, Cr concentrations are low in the spherule-free shale and chert intercalations. The isotopic ratios of 187Os/188Os and 187Re/188Os vary between the country rocks and spherule horizons (from 0.21 to 1.13 for 187Os/188Os and ~4.5 to 99.6 for 187Re/188Os ratios in country rocks compared to 0.11 to 0.17 for 187Os/188Os and ~0.06 to ~0.33 for 187Re/188Os ratios in the spherule horizons).

**Conclusions:** Our petrographic and geochemical data indicate strong hydrothermal overprint for all lithologies in the studied section of the BARB 5 core. Sulfide mineralization is of secondary origin and may be related to chemical alteration and metamorphism. High Zn concentrations frequently observed along cataclased spinel grains could relate to late secondary overprint. High abundances of the siderophile elements (Ni, Co, Ir, Os, Cr, and Au) are thought to reflect extraterrestrial components. Some high-PGE phases, maybe representing the PGE carriers, have been identified in some samples [7]. Mechanical or chemical concentration of such phases may account for the extreme enrichments in the PGEs that are observed in some samples. Osmium data reveal a trend between the spherule-free horizons (intercalating the spherule layers) and spherule-matrix aggregates. Whereas the former typically exhibit elevated 185Os/188Os ratios of up to ~1.2 and low Os and Ir concentrations below several hundred ppt, spherule-matrix aggregates tend to be less radiogenic (down to subchondritic present day 185Os/188Os ratios) with Os and Ir concentrations as high as in chondrites. Chromium-Ir correlations for CT3 and BARB5 samples mirror earlier results on S1 to S4 layers and can be interpreted in favor of an impact origin of the investigated spherule horizons. Our ongoing studies provide additional constraints on the early terrestrial impact record.