PALEOPROTEROZOIC LATERITES AND IRON ORES

BEUKES, N.J., GUTZMER, J., DORLAND, H. and SZABO, A. Department of Geology, Rand Afrikaans University, Auckland Park 2006, South Africa.

Introduction

In this paper we report on the discovery of widespread 2,2 – 2,45 Ga laterites in the Transvaal Supergroup in southern Africa and how that change our understanding of soil forming environments, the origin and distribution of supergene iron and manganese deposits, and the history of atmospheric oxygen in the early Paleoproterozoic. The latter is a very contentious issue at present with two opposing models; one by Rye and Holland (1998) suggesting that earth had an essentially anoxic atmosphere with $pO_2 \leq 0,4\%$ of present atmospheric level (PAL) prior to 2,25 Ga followed by a rapid rise in pO_2 levels to at least 15% PAL in the period 2,05 - 2,25. The other advocated by Ohmoto (1996) defines an oxic atmosphere with minimum pO_2 of 1,5% PAL but most probably equal to PAL as far back as 3 Ga. These estimates are largely based on the behaviour of iron in paleosol profiles and the conflicting results depend on models of soil formation applied and whether terrestrial organic matter was involved or not.

Our findings have implications for both models of atmospheric oxygen development but impacts most dramatically on the first. The concept of a sudden change from an anoxic to oxic atmosphere shortly after 2.25 Ga is based on a comparison of the iron-depleted reduced Hekpoort paleosol of the Pretoria Group, as it appears in the south-eastern Transvaal between Pretoria and Waterval Onder, with the iron-enriched Drakenstein paleoweathering profile (Wiggering and Beukes,1990) in the Griqualand West area of the Transvaal basin, and the assumption that the Hekpoort paleosol is older than that of Drakenstein and Wolhaarkop (Rye and Holland,1998). However, our regional studies indicated that none of these assumptions may be valid and that in actual fact the Hekpoort paleosol forms part of a laterite profile which is time equivalent to the ferruginous Drakenstein paleoweathering profile with associated giant supergene iron ore deposits at Sishen and Beeshoek and Postmasburg manganese deposits (Gutzmer and Beukes, 1996). This implies highly oxygenated atmospheric conditions at time of formation of the deposits. We also discovered older ferricretes and groundwater laterites in the Pretoria Group of the Transvaal Supergroup indicating that oxidized terrestrial environments were present to at least as far back as 2,45 Ga.

Drakenstein Laterite Profile and Iron Ore Deposits

Giant iron and large manganese ore deposits occur on the Maremane dome in the area between Sishen and Postmasburg in Griqualand West, South Africa (Gutzmer and Beukes, 1998). These deposits are all associated with the lateritic Drakenstein paleoweathering profile developed along the unconformity that seperates late Neoarchean to very early Paleoproterozoic Transvaal strata from middle Paleoproterozoic red beds of the Gamagara/Mapedi Formation. Two types of paleoweathering profiles are preserved in Griqualand West namely ferruginous saprolite and karstic laterite. The latter is developed where the erosion surface transects Campbellrand dolomite and comprises ancient manganese earth deposits and giant Sishen-type hematite ore deposits derived from supergene leaching of manganiferous dolomite beds (Gutzmer and Beukes,1996) and Asbesheuwels iron-formation (Van Schalkwyk and Beukes,1986) respectively. In areas outside of the karstic environment virtually all of the Drakenstein paleoweathering profiles lack preservation of upper paleosol zones and only highly oxidized hematite-enriched saprolites, between 5 and 250 m thick and retaining original textures of parent rock, are preserved below the Gamagara/Mapedi red beds. Examples of these ferruginous saprolites are described by Holland and Beukes (1990) and Wiggering and Beukes (1990).

The largest of the karstic iron ore deposits is preserved at Sishen Iron Ore Mine (Van Schalkwyk and Beukes, 1986). The mine produces about 24 Mt of high-grade hematite ore per annum, with a potential open cast ore reserve of 1000 Mt. Between 80 and 90 percent of the ore reserve is situated in the Manganore Iron Formation as part of the Drakenstein paleoweathering profile below the Gamagara Formation. The Manganore Iron Formation is a correlative of the Kuruman and Griquatown Iron Formations that slumped into sinkhole depressions in the undelying Campbellrand dolomites during development of the lateritic Drakenstein paleoweathering profile. During this process, silica was leached from the iron-formation by alkaline ground water solutions and ferrous minerals oxidized to hematite. Subsequently these ore bodies were eroded and hematite pebble conglomerates accumulated in alluvial fan environments at the base of the overlying Gamagara red bed succession to form conglomeratic ore representing 10 - 20 percent of the ore reserve at Sishen. The conglomerates are interbedded with highly aluminous claystones that were derived from the underlying lateritized and bauxitized Drakenstein paleoweathering profile. Excellent examples of pisolitic laterites are also developed in the lower part of the Gamagara red bed succession (Gutzmer and Beukes, 1998).

Correlation and Composition of Hekpoort Paleosol

Recently we have traced the unconformity on top of the ferruginous lateritic Drakenstein paleoweathering profile from Griqualand West into the Transvaal area and realized that it is laterally equivalent to the unconformity on top of the Hekpoort paleosol. However, in contrast to all earlier descriptions of the Hekpoort paleosol, which suggest that it is a reduced paleosol formed under essentially anoxic atmospheric conditions (Rye and Holland, 1998), we discovered that it has all the features of a laterite profile that could only have formed under highly oxidizing atmospheric conditions.

The lateritic nature of the Hekpoort paleosol becomes apparent as it is traced north-westward in deep drill core intersections below the unconformity at base of red beds of the Dwaalheuwel Formation from near Potchefstroom in South Africa to near Gaborone in Botswana. In this area the paleosol is between 4 and 10 m thick and composed of a red banded and mottled ferruginous upper zone successively grading down through an iron-depleted bleached pallid zone and a grey-green saprolite into parent Hekpoort basalt . It used to be classified as a reduced paleosol (Rye and Holland, 1998) simply because the upper ferruginous zone of the laterite profile had been removed by erosion prior to deposition of the Dwaalheuwel Formation in the Pretoria - Waterval Onder area where previous studies took place.

The Hekpoort laterite profile is capped with sharp contact by a reworked laterite composed of red lateritic clay clasts derived from the underlying paleosol. It is intensely indurated with hematite present as matrix and cement between clay clasts and as pisolitic coatings on clay clasts. As such the reworked laterite is best described as a ferricrete that draped the erosion surface before deposition of the overlying Dwaalheuwel Formation. Iron-retaining environmental conditions must have remained in place during formation of the overlying Dwaalheuwel beds which we now know to represent a very extensive succession of fluvial red beds; thickening and coarsening north-westwards from the Carletonville-Pretoria area into Botswana. Towards the east and southeast the red beds interfinger with marine quartz arenite which directly overlies the Hekpoort paleosol at Waterval Onder.

Implications for Paleoproterozoic Soil Forming Environments, Atmospheric Conditions and Supergene Iron Ore Formation

The revised correlation between the Hekpoort and Drakenstein paleoweathering profiles, with their associated supergene iron and manganese ores and aluminous claystone deposits, indicates that virtually the entire Kaapvaal craton, an area in excess of 500 000 km^2, was covered by a single ferruginized lateritic erosion surface in early Paleoproterozoic times. The absolute timing of the laterization event is somewhat uncertain. Previously it was thought that the Hekpoort paleosol formed shortly after outflow of the Hekpoort lavas at 2,22 Ga. However, recent geochronological data suggests that the Hekpoort-Ongeluk succession has an age of between 2,39 and 2,41 Ga (Romer and Bau, 1998) and thus that the Hekpoort-Drakentein paleoweathering profile may have developed as far back as 2,35 – 2,39 Ga.

Vast amounts of ferric iron and alumina-rich clays thus accumulated along the Hekpoort-Drakenstein laterite profile, a situation typical of modern soils formed under oxidizing atmospheric conditions in humid tropical climates, with a long dry season. A tropical setting is supported by paleomagnetic data indicating that the Ongeluk lavas below and the Gamagara/Mapedi red beds above the Hekpoort-Wolhaarkop erosion surface formed within 11° ± 5° of the equator (Evans et al, 1997). In this near equatorial environment, lateral variation in the composition of paleoweathering profiles was apparently controlled by the nature of parent rock and tectonic setting.

Although common in modern tropical environments, the origin of laterite profiles with reduced pallid zones, like like that of the Hekpoort paleosol, is poorly understood. However, under oxidizing atmospheric conditions the leaching of iron from pallid zones of laterite profiles can be explained by lateral flow of reducing groundwaters with organic acids as reducing agents. Soil-forming environments and processes along the Hekpoort-Drakenstein erosion surface were thus highly variable and complex, similar to modern soils. Extreme care should therefore be taken before any attempt is made to link the composition of the paleosol with ancient atmospheric conditions. Certainly our new insights invalidate any earlier estimates of atmospheric oxygen concentrations by Rye and Holland (1998) that were based on the composition of the pallid zone of the Hekpoort paleosol, without consideration of the overlying hematite-indurated laterite zone and possible effects of terrestrial organic matter and reduced groundwater. However, in well-drained paleoweathering profiles, like that of Drakenstein, rain- and groundwater may have been in equillibrium, and could provide clues on atmospheric composition. Published results from a deep drill core intersection of the Drakenstein paleoweathering profile at Wolhaarkop indicate that atmospheric oxygen levels must have been at least 15 – 20 percent PAL (Holland and Beukes,1990) to have retained iron in saprolite derived from carbonate-oxide facies iron-formation. These are absolute minimum levels permitted by the data and for carbonate-facies iron-formation, oxygen levels equal to or slightly above PAL are required to explain the retention of ferric iron in the saprolite of the Drakenstein paleoweathering profile at Wolhaarkop. Most important these oxygen concentrations were calculated at pCO_2 levels of 1 – 10 PAL and if higher CO_2 values are used, oxygen levels required for iron retention are considerably above PAL.

Highly oxygenated tropical lateritic environments were thus present on the Kaapvaal craton some time after extrusion of the Ongeluk/Hekpoort lavas at about 2,4 Ga. However, such conditions may have developed even earlier in earth history as indicated by the presence of 2,41 – 2,45 Ga hematite oolite ironstones in the Timeball Hill Formation of the Pretoria Group. The ironstones, which underly the Hekpoort lava, cover an area of about 100 000 km^2 on the Kaapvaal craton and are associated with delta front and delta ditributary channel sands in two major delta lobe successions of the Timeball Hill Formation. The ironstones are composed of hematite oolites mixed with hematite-coated quartz grains set in a hematite-rich matrix. Centimetred sized *in-situ* hematite-coated pisoliths, similar to that of modern groundwater laterites, are abundant in some of the oolitic channel sand deposits. In addition a lateritic mud-clast conglomerate cemented by large hematite pisoliths overlies delta plain muds with a sharp erosional contact in the Pretoria area. It is thought to represent a pisolitic ferricrete that developed on an abandoned delta plain and together with the oolitic and pisolitic hematite ironstones could only have formed under oxygenated terrestrial environments in the period 2,41 – 2,45 Ga.

The above findings seriously question Rye and Holland's (1998) conclusion that the early Paleoproterozoic atmosphere contained extremely low oxygen levels. It also has important implications for iron ore exploration models. Rock successions as old as 2,5 Ga that were previously thought to be too old to contain supergene hematite ore deposits because of the assumption of reducing atmospheric conditions, may now be considered prospective if unconformities are present and paleogeographic settings were favourable.

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