MESO-ARCHAEAN AND PALAEO-PROTEROZOIC SEDIMENTARY SEQUENCE STRATIGRAPHY OF THE KAAPVAAL CRATON.

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ABSTRACT:

The Kaapvaal Craton hosts a number of Precambrian sedimentary successions which were deposited between 3105 Ma (Dominion Group) and 1700 Ma (Waterberg Group). Although younger Precambrian sedimentary sequences outcrop within southern Africa, they are restricted either to the margins of the Kaapvaal craton, or are underlain by orogenic belts off the edge of the craton. The basins considered in this work are those which host the Witwatersrand and Pongola, Ventersdorp, Transvaal and Waterberg strata. Many of these basins can be considered to have formed as a response to reactivation along lineaments, which had initially formed by accretion processes during the amalgamation of the craton during the Mid-Archaean. Faulting along these lineaments controlled sedimentation either directly by controlling the basin margins, or indirectly by controlling the sediment source areas. Other basins are likely to be more controlled by thermal effects associated with mantle plumes. Accommodation in all these basins may have been generated primarily by flexural tectonics, in the case of the Witwatersrand, or by a combination of extensional and thermal subsidence in the case of the Ventersdorp, Transvaal and

Waterberg. Wheeler diagrams are constructed to demonstrate stratigraphic relationships within these basins at the first- and second-order levels of cyclicity, and can be used to demonstrate the development of accommodation space on the craton through the Precambrian.

KEY WORDS: Kaapvaal, Witwatersrand, Ventersdorp, Transvaal, Waterberg, Wheeler diagrams

1. INTRODUCTION:

The Kaapvaal Craton underlies most of the northern part of South Africa and Swaziland, and a small part of eastern Botswana. As one of the most stable and long-lived examples of continental crust, the Kaapvaal Craton hosts a number of well-preserved Precambrian-aged sedimentary basins, which are the focus of this review. This paper presents Wheeler diagrams of the major Precambrian-aged basins that have been preserved on the Kaapvaal Craton, and focuses on the Witwatersrand, Ventersdorp, Transvaal and Waterberg Basins. Minor, poorly preserved basins such as the Dominion Group, and those developed only along the margins of the craton (e.g. the Soutpansberg Group), are not fully represented here. This paper forms part of a set of manuscripts documenting accommodation change with the aim of examining possible Precambrian global correlations.

2. THE DEVELOPMENT OF THE KAAPVAAL CRATON AND LIMPOPO BELT PRIOR TO LARGE-SCALE BASIN DEVELOPMENT, AND GENERAL TEMPORAL FRAMEWORK:

The Kaapvaal Craton is broadly divisible into an older and generally poorly exposed granite-greenstone basement, formed between 3.6 and 2.9 Ga, and unconformably overlying volcano-sedimentary cover sequences mostly deposited between 3.1 and 2.6 Ga. The ages that have been determined across the Kaapvaal Craton have been reviewed by Eglington and Armstrong (2004), though details are also provided here, in order to provide a timeframe into which the development of accommodation space of Kaapvaal basins fits.

The nucleus of the Kaapvaal Craton had formed by 3.1 Ga and has been ascribed to magmatic accretion of blocks (from 3547 to 3225 Ma) that were subsequently

amalgamated to form a larger continental block (Lowe and Byerly, 2007), or alternatively to initial (c. 3.6-3.4 Ga) thin-skin thrusting within ocean and arc settings, and subsequent (c. 3.3-3.2 Ga) amalgamation of displaced oceanic and arc terranes, accompanied by significant granitoid magmatism (de Wit et al., 1992). The bulk of the terrane accretion, which formed the Kaapvaal Craton, occurred along two prominent ENE-WSW suture zones, the Barberton lineament (BL) and the Thabazimbi-Murchison lineament (TML) (Fig. 1) between 3.23 and 2.9 Ga (Poujol et al., 2003; Anhaeusser, 2006; Robb et al., 2006), which had a strong control over subsequent basin development. The NNW-SSW trending Colesburg lineament accommodated the accretion of the Kimberley Block at c. 2.88 Ga (e.g. Eglington and Armstrong, 2004).

The eastern part of the Kaapvaal Craton is exposed as the Barberton, Murchison, Sutherland and Pietersburg granite-greenstone belts. The Barberton Greenstone Belt of the eastern Mpumalanga Province consists of ultramafic to felsic volcanic and sedimentary rocks, at generally low metamorphic grade, which are in contact with a range of trondhjemitic, tonalitic and granodioritic plutons. The oldest reliable date from the craton has been obtained from the Ancient Gneiss Complex, a high-grade gneiss terrane in fault contact with the south-eastern margin of the Barberton Greenstone Belt. Compston and Kröner (1988) reported an igneous crystallization date of 3644 ± 4 Ma for a gneissic tonalite from the Ancient Gneiss Complex. Precise U-Pb zircon dates reported by Kamo and Davis (1994) for 23 granitic, subvolcanic and felsic volcanic samples from the Barberton region defined magmatic episodes at 3470 to 3440 Ma, 3230 to 3200 Ma and at c. 3110 Ma. These results were generally consistent with earlier but less precise dates documented by Tegtmeier and Kröner (1987), Armstrong et al. (1990) and Barton et al. (1983). Recently, Zeh et al. (2009) used precise U-Pb and Lu-Hf isotope data from zircons in granitoids to subdivide the Kaapvaal Craton into at least four distinct terranes, namely: Barberton-North [BN] and Barberton-South [BS] either side of the Barberton lineament [BL]; Murchison-Northern Kaapvaal [MNK], north of the Thabazimbi-Murchison lineament [TML], and Central Zone [CZ] of the Limpopo Belt (Fig. 1); these underwent different crustal evolutions, and were successively accreted at c.3.23 (BN and BS), 2.9 (assembled BN-BS and MNK) and 2.65-2.7 Ga (three existing terranes and CZ). A date of 2687 ± 6 Ma determined by Layer et al. (1989) for the Mbabane Pluton, was

considered to represent the time of the last major Archaean magmatic intrusive event in the Kaapvaal Craton.

Volcanic and sedimentary units within the Barberton Greenstone Belt range in age from c. 3550 Ma to 3160 Ma. The oldest date of c. 3548 Ma was obtained by Kröner et al. (1996) for a schistose tuffaceous unit from the Theespruit Formation, near the base of the Onverwacht Group, whereas Byerly et al. (1996) determined a date of c. 3300 Ma for felsic tuffaceous units from the Mendon Formation, near the top of the Upper Onverwacht Group. The Fig Tree Group was deposited unconformably on the Upper Onverwacht Group between 3260 and 3225 Ma (Byerly et al., 1996), and was overlain by sedimentary rocks, assigned to the Moodies Group, which may be as young as 3164 Ma (Armstrong et al., 1990).

Within the Murchison belt further to the north of Barberton, three main magmatic events at c. 2970, 2820 and 2680 Ma have been documented (Poujol et al., 1997). In the Mafikeng-Vryburg region, the western margin of the Kaapvaal Craton basement is, in part, exposed in the Kraaipan granite-greenstone belt. A date of $3031 \pm 11/-10$ Ma was reported by Robb et al. (1992) for granitic rocks from about 90 km southeast of Mafikeng. Zircon Pb-evaporation dates of 2846 ± 22 Ma for the Kraaipan granodiorite and 2749 ± 3 Ma for the Mosita adamellite were obtained by Anhaeusser and Walraven (1997).

2.1 Chronology of basins on the Kaapvaal Craton

The granite-greenstone basement of the Kaapvaal Craton was subject to extensive erosion prior to and during deposition of the thick sedimentary and volcanic rock successions of the Dominion Group and Witwatersrand and Ventersdorp Supergroups (sections 3 and 4); these three units are informally known as the Witwatersrand triad. The youngest emplacement age so far determined for basement rocks that are unconformably overlain by supracrustal rocks of the triad, 3120 ± 5 Ma (Armstrong et al., 1991), provides a minimum date for the time of uplift and the onset of widespread erosion that preceded deposition of the Witwatersrand triad cover sequences. Robb et al. (1990) dated detrital zircons within Dominion Group sedimentary rocks and demonstrated that parts of the Dominion Group were deposited later than 3105 ± 3

Ma, whereas a date of 3074 ± 6 Ma obtained by Armstrong et al. (1991) for a quartz-feldspar porphyry indicated that deposition of at least part of the Dominion Group pre-dates this time. Dates obtained from detrital zircons in sedimentary rocks of the overlying West Rand Group (Witwatersrand Supergroup) were interpreted to indicate that these strata were deposited later than 3060 ± 2 Ma; this inference is in broad agreement with the conclusions drawn by Barton et al. (1989) in a similar study of detrital zircons within the Orange Grove Quartzite. Robb et al. (1990) also showed that the Turffontein Subgroup of the Central Rand Group was deposited later than 2909 ± 3 Ma. The likely time of onset of widespread erosion of the Kaapvaal basement and onset of deposition of the overlying Witwatersrand triad sediments is therefore within the interval 3125 to 3068 Ma.

Volcanic and sedimentary rocks of the Pongola Supergroup were deposited over the south-eastern edge of the Kaapvaal Craton at 2985 ± 1 Ma (Hegner et al., 1994). This succession was intruded by gabbroic rocks from the Usushawana intrusive suite at 2871 ± 30 Ma (Hegner et al., 1994). The Gaborone Granitic Complex, Plantation Porphyry, Kanye volcanics and Derdepoort basalts were also emplaced at c. 2782 Ma (Grobler and Walraven, 1983; Moore et al., 1993; Walraven et al., 1996; Wingate 1997).

The Ventersdorp Supergroup, a sequence up to 8km thick predominantly of basaltic lavas, overlies the sedimentary rocks of the Dominion Group and Witwatersrand Supergroup. The onset of deposition of the Ventersdorp volcanics has been constrained by dates of 2714 ± 16 and 2709 ± 8 Ma determined for samples from the Klipriviersberg Group, near the base of the supergroup, and of porphyry from the overlying Makwassie Formation of the Platberg Group (Armstrong et al., 1991) respectively. These dates are within uncertainty of the date of 2714 ± 3 Ma determined for the Kareefontein Quartz Porphyry from the south-western Kaapvaal by Walraven et al. (1991).

Contemporaneously, or just prior to the deposition of the Transvaal Supergroup, the northernmost section of the Kaapvaal Craton was involved in an orogenic event, traditionally known as the 'Limpopo Orogeny' (see Rigby et al., 2008a and references therein). Rocks from the Southern Marginal Zone of the Limpopo Mobile Belt

represent high-grade metamorphic equivalents of the adjacent granite-greenstone terranes that comprised the Kaapvaal Craton (e.g. Du Toit et al., 1983; van Reenen et al., 1987). Isotope and geochemical comparisons of the rocks from the Southern Marginal Zone and Kaapvaal Craton provide evidence to suggest that these rocks were derived from a common crustal source, which was formed between 3.05 and 2.9 Ga (Kreissig et al., 2000). Conversely, the Central Zone of the Limpopo Mobile Belt is composed of a lithologically and chemically diverse suite of rocks, which suggest that it is a separate and exotic terrane that bears no common history with the Kaapvaal Craton prior to its accretion.

The tectonic evolution of the Limpopo Mobile Belt has been the subject of considerable controversy over the years. Traditionally one camp argues that the Limpopo Mobile Belt formed during a single Palaeoproterozoic collision at c. 2.0 Ga (Kamber et al., 1995; Holzer et al., 1998; Kröner et al., 1999; Schaller et al., 1999; Zeh et al., 2004; Zeh et al., 2005; Eriksson et al., 2009). On the other hand, van Reenen et al. (1987), McCourt & Vearncombe (1992), Roering et al. (1992), McCourt & Armstrong (1998), Bumby et al. (2001) and Bumby and van der Merwe (2004), advocated that the Limpopo Mobile Belt formed during a single, Neoarchean, high-grade event that was initiated by the collision of the Kaapvaal and Zimbabwe cratons. However, recent studies (Boshoff et al., 2006; Zeh et al., 2007; Perchuk et al., 2008; Van Reenen et al., 2008; Gerdes & Zeh, 2008; Millonig et al., 2008) have unequivocally elucidated that these two opposing views are an oversimplification. Demonstrably, parts of the Central Zone have undergone a series of complex and temporally-discrete events, which included the formation and subsequent anatexis of the Sand River Gneiss at 3.24-3.12 Ga (Zeh et al., 2007; Gerdes & Zeh, 2008), structural, metamorphic and magmatic events at 2.65-2.51 Ga (e.g. Boshoff et al. 2006; van Reenen et al., 2008; Millonig et al., 2008) and a final ~2.03 Ga metamorphic overprint (e.g. Boshoff et al., 2006; Zeh et al., 2007; Perchuk et al., 2008; Rigby et al., 2008b; van Reenen et al., 2008; Gerdes & Zeh, 2009; Rigby, 2009; Rigby & Armstrong, 2010). Conversely, the Southern Marginal Zone appears to have an Archaean-only history, with no evidence of 2.0 Ga metamorphism (Eriksson et al., in press). The SMZ is undisputedly characterized by a single P-T path (Stevens and van Reenen, 1992) whose age is directly constrained by U-Pb dating of monazite and zircon dating of melt leucosomes to be 2691 $\pm$ 7 Ma and 2643 $\pm$ 1 Ma, respectively

(Kreissig et al., 2001). Moreover, the granulite facies rocks of the Southern Marginal Zone were thrust onto the adjacent Kaapvaal Craton along the mylonitic oblique-slip Hout River Shear Zone (e.g. Smit et al., 1992). The timing of this major thrust is constrained by zircon dates from the syn-kinematic Matok Intrusive Complex to be between ca. 2671 and 2664 Ma (Barton and van Reenen, 1992; Barton et al., 1992) and by Ar-Ar dating of amphiboles from the Hout River Shear Zone, which yield maximum ages ranging from 2650-2620 Ma (Kreissig et al., 2001). Collectively, this evidence supports a Kaapvaal Craton-Central Zone amalgamation during the Neoarchean, which is consistent with recent U-Pb and Lu-Hf data from zircons in granitoids that indicate the exotic Central Zone accreted onto the Kaapvaal Craton at 2.67-2.61 Ga (Zeh et al., 2009).

Unconformably overlying the Ventersdorp Supergroup are shales, sandstones, carbonates, banded-iron formations and minor volcanic rocks of the Transvaal Supergroup (section 5), deposited within 2 main preservational basins (Knoll and Beukes, 2009)– the Transvaal basin in the northern Kaapvaal region and the Griqualand West basin in the Northern Cape region. The Griqualand West basin may also be subdivided into the Prieska and Ghaap Plateau sub-basins that have different sedimentological histories (Altermann and Nelson, 1998). The Vryburg Formation of the Ghaap Group is the lowest stratigraphic unit above the unconformity over the Ventersdorp Supergroup lavas in the Griqualand West basin and consists of shales, quartzites, siltstones and volcanic rocks. A date of 2642 ± 3 Ma was obtained for a lava from the Vryburg Formation (Walraven and Martini, 1995; Altermann, 1996; Walraven et al., in press).

In the Griqualand West basin, tuff beds within mainly carbonate-facies units within the Nauga Formation have yielded dates ranging between 2590 and 2550 Ma (Barton et al., 1994; Altermann and Nelson, 1998), whereas dates ranging between 2560 and 2520 Ma have been obtained for the upper Monteville and Gamohaam Formations (Sumner and Bowring, 1996; Altermann and Nelson, 1998). Altermann and Nelson (1998) argued that carbonates of the southwestern part of the Griqualand West basin were in part correlatives of the Oak Tree Formation of the Transvaal basin and of parts of the Monteville Formation in the Ghaap Plateau sub-basin. Overlying the carbonates of the Campbellrand Subgroup in the Griqualand West basin are shales

and banded iron-formation of the Kuruman and Griquatown Formations. These have been dated at between 2490 and 2430 Ma (Pickard, 2003; Nelson et al., 1999).

The deposition of the Transvaal Supergroup predates the c. 2050 Ma Bushveld igneous event (Buick et al., 2001) within the Kaapvaal Craton, where a series of initial rhyolitic extrusives were followed by large-scale mafic and then felsic intrusions. Approximately co-eval with the Bushveld Complex, basin development associated with the Waterberg Group began (section 6). The Waterberg Group was generally deposited in a broad rift, controlled by reactivation along the TML and the Palala Shear Zone of the Limpopo Belt. Dykes which have cross-cut the Waterberg Group suggest that deposition in this youngest of the well-preserved Precambrian Kaapvaal basins was accomplished by 1.87 Ga (Hanson et al., 2004).

Details of the sedimentary history of each of the four major Precambrian basins preserved on the Kaapvaal Craton are discussed below, and Wheeler diagrams are presented for each of these basins. The criteria involved in the definition of hierarchical orders used during the presentation of each basin are discussed in detail by Catuneanu et al. (this volume). The classic hierarchy system based on the duration of cycles (e.g., Vail et al., 1977, 1991) fails to work in the case of Precambrian basins which typically lack the necessary time control that is required to constrain the frequency of occurrence of sequence boundaries. Instead, hierarchical orders are defined here on the basis of physical features, related to the magnitude of base-level changes, that can be observed in the field (Miall, 1997; Catuneanu et al., 2005; Catuneanu, 2006; Catuneanu et al., 2009; Catuneanu et al., this volume).

The first-order sequences represent the largest units in sequence stratigraphy and relate to a specific tectonic setting in the evolution of a sedimentary basin. The major subdivisions of these first-order sequences form second-order sequences. A stratigraphic hierarchy system therefore emerges from larger to smaller scales, is based on the relative importance of cycles, and is often basin-specific (Catuneanu et al., 2005; Catuneanu, 2006; Catuneanu et al., this volume). As the resolution of stratigraphic analysis increases with time as more data are collected, first-order sequences represent the starting (or the reference) point in the process of definition of a hierarchy framework for a specific sedimentary basin.

3. THE WITWATERSRAND AND PONGOLA SUPERGROUPS:

The Witwatersrand Supergroup has generally been interpreted as having been formed in a foreland basin on the cratonward side of the Limpopo Belt. (e.g. Burke et al., 1986). Despite a possible overlap in ages between the lower Witwatersrand strata and the upper Pongola strata, the relationship in terms of tectonic setting between the Witwatersrand and Pongola supergroups remains unclear. Although there are considerable differences in strata between the two basins, Catuneanu (2001) has suggested that the two basins form parts of a unitary retroarc foreland system, with the Witwatersrand Supergroup filling the proximal flexural foredeep (i.e., the Witwatersrand Basin *sensu stricto*)(Figs 2a and 2b), and the Pongola Supergroup occupying the distal back-bulge area (Catuneanu, 2001). The development of this foreland system is interpreted, in part, to relate to the ongoing Limpopo Orogeny to the north (Catuneanu, 2001) (Fig. 2b). Within this "greater Witwatersrand Basin", the Witwatersrand and the Pongola supergroups are separated by an area of non-deposition and erosion that corresponds to the forebulge flexural province of the foreland system.

The Witwatersrand Basin (Fig. 2c) is underlain by the Middle Archaean granitoids and greenstone belts of the Kaapvaal Craton (Barton et al., 1986; Myers et al., 1990; Hartzer et al., 1998). The chronology of the Witwatersrand Supergroup is constrained with dates obtained from the underlying (c. 3074 Ma) Dominion Group and the overlying (c. 2714 Ma) Ventersdorp Supergroup. In addition, one date has been recorded from the upper part of the West Rand Group (2914 ± 8 Ma; Armstrong et al., 1991; Hartzer et al., 1998) (Fig. 3).

The Witwatersrand Supergroup is subdivided into the West Rand and Central Rand groups (Fig.3). The West Rand Group is finer grained and represented by approximately equal proportions of shale and quartzite, with minor conglomerate. The Central Rand Group is dominated by quartzites, with frequent conglomerate layers and only minor amounts of shale. Therefore, the Witwatersrand Supergroup displays an overall coarsening-upward trend, which is interpreted to reflect an increase in tectonic activity in the source areas (Pretorius, 1979; Myers et al., 1990), most likely

related to the progradation of a thrust-fold belt towards its associated retroarc foreland system (Winter and Brink, 1991; Catuneanu, 2001).

The facies transition between the West Rand and the Central Rand groups is gradual and diachronous, becoming younger in a downdip (southeast) direction. As the depositional systems prograded through time, the uppermost West Rand facies represent the distal equivalent of the lowermost Central Rand facies (Tankard et al., 1982; Fig. 3). Beyond the flexural forebulge, the distal back-bulge sedimentary strata of the Pongola Supergroup correlate generally with the West Rand Group of the Witwatersrand Basin *sensu stricto* (Fig 2a). No Central Rand Group equivalents are recorded within the Pongola Supergroup, which probably reflects the lesser amount of accommodation that is typically generated in the back-bulge setting of a foreland system.

Sedimentation within the Witwatersrand Basin *sensu stricto* took place in a variety of clastic depositional environments, ranging from shallow marine to alluvial. The West Rand Group is dominated by shallow marine systems, with additional fluvial and alluvial facies preserved mainly along the proximal margin of the basin. The Central Rand Group records an increasingly nonmarine affinity, and is the product of deposition in alluvial fan, fluvial and shallow marine environments. The balance between marine and nonmarine sedimentation gradually changed in favour of the latter as the basin evolved from an early underfilled phase (represented by the West Rand Group) to a late overfilled phase (represented by the Central Rand Group) (Catuneanu, 2001, 2004). At the same time, the interior seaway of the Witwatersrand Basin became progressively shallower and more restricted to the distal region of the basin as the proximal nonmarine systems prograded and replaced the marine systems through time (Tankard et al., 1982; Karpeta et al., 1991; Els and Mayer, 1992, 1998).

The amount of accommodation generated by flexural subsidence in the foredeep was significantly greater than the amount of space created in the back-bulge area. For this reason, the back-bulge (Pongola) sub-basin may have become overfilled much sooner than the foredeep, resulting in a shortened stratigraphic succession (i.e., the Pongola Supergroup) that misses the equivalent of the Central Rand Group (Catuneanu, 2001).

3.1 Witwatersrand Wheeler diagram

The Witwatersrand Supergroup corresponds to a first-order depositional sequence that relates to the tectonic setting of a retroarc foreland system. The first-order sequence boundaries mark changes in the tectonic setting and the dominant subsidence mechanism, from extensional to flexural (the lower sequence boundary) and from flexural to extensional (the upper sequence boundary) (Catuneanu, 2001; Catuneanu et al., 2005; Fig. 3). The Wheeler diagram presented in Figure 3 (based upon the model of Catuneanu, 2001) is representative for all three flexural provinces of the foreland system (i.e., foredeep, forebulge and back-bulge), considering that the West Rand Group of the Witwatersrand Basin *sensu stricto* (foredeep) is age-equivalent to the Pongola Supergroup that accumulated in the back-bulge setting.

The internal stratigraphic architecture of the Witwatersrand first-order sequence includes an initial stage of transgression, which established the West Rand seaway across the basin, followed by the highstand progradation of the Central Rand fluvial systems. These major stages in the evolution of the Witwatersrand Basin define first-order transgressive and highstand systems tracts, separated by a first-order maximum flooding surface (Fig. 3).

The basal sequence boundary of the Witwatersrand first-order sequence is interpreted as a subaerial unconformity reworked subsequently by a transgressive ravinement surface during the transgression of the West Rand seaway. It is possible that remnants of a lowstand systems tract may also be preserved beneath the transgressive facies, filling topographic lows at the level of the basal unconformity, including incised valleys, but evidence of lowstand deposits requires further research. The upper sequence boundary of the Witwatersrand first-order sequence is a subaerial unconformity that formed during post-depositional rebound and erosion.

No significant stratigraphic hiatuses have been found within the Witwatersrand first-order sequence, although numerous unconformities are present and may be used to define higher-frequency (lower rank) sequence stratigraphic frameworks. Preliminary work indicates that the sedimentary fill of the Witwatersrand Basin may consist of 25 depositional sequences (Winter and Brink, 1991; Fig. 4), interpreted by Catuneanu

(2001) as of third order. However, the definition of second- and third-order frameworks requires further research, and so far it has been done in detail only in selected areas of economic interest (e.g. Catuneanu and Biddulph, 2001).

4. THE VENTERSDORP SUPERGROUP:

The Ventersdorp is a predominantly volcanic succession, which unconformably overlies the Witwatersrand basin as well as surrounding cratonic lithologies, particularly to the NW, W and SW thereof (Fig. 5). It was most recently reviewed by Eriksson et al. (2002) who provided details of lithostratigraphy, as well as a model of the inferred geodynamic evolution of this supergroup. The supergroup comprises three basic parts, each unconformably-based: (1) a basal, c. 1.5-2 km thick locally komatiitic flood basalt, the Klipriviersberg Group; (2) the medial graben-fills of the mixed clastic sedimentary-volcanic Platberg Group, totaling a maximum of ~1800 m in thickness; (3) succeeding c. 400 m thick Bothaville Formation clastic sedimentary rocks, and the uppermost, c. 750 m thick Allanridge flood basalts, which include minor komatiites (Fig. 6) (van der Westhuizen et al., 1991). The Klipriviersberg is accurately dated at 2714 ± 8 Ma, and the Platberg lavas at 2709 ± 4 Ma, by ion probe U-Pb zircon method (Armstrong et al., 1991).

The Ventersdorp Supergroup is separated from the underlying Witwatersrand Supergroup by a c. 100 My lacuna (Maphalala and Kröner, 1993; Beukes and Nelson, 1995) during which extensive tectonic shortening and erosive removal (up to ~1.5 km of stratigraphy in places) of the earlier basin-fill occurred (Hall, 1996). A mantle plume model has been applied to the Ventersdorp (e.g., Hatton, 1995). This hypothesis is compatible not only with the preserved flood basalts, but also with the subordinate komatiites within this supergroup and with the limited age range of the lower two groups of the Ventersdorp succession (Eriksson et al., 2002). The latter authors suggest that the plume head may have been marginal to the Kaapvaal Craton. Limited fluvial incision at the base of the lowermost clastic sedimentary – ultramafic-volcanic Venterspost Formation (Fig. 6), estimated to be a maximum of 44 m (Hall, 1996) suggests rapid ascent of Klipriviersberg lavas from magma ponded beneath the thinned crust underlying the Witwatersrand basin (Fig. 7) (Eriksson et al., 2002).

Crustal extension due to thermal elevation of the crust, concomitant with the envisaged plume model setting, allowed formation of a set of graben and half-graben depositories within the Klipriviersberg volcanics, which accommodated the commonly wedge-shaped clastic sedimentary and bimodal volcanic rocks of the Platberg Group (van der Westhuizen et al., 1991, and references therein). Sediment deposition occurred within graben-marginal alluvial, fluvial and medial lacustrine palaeoenvironments, with minor marls associated with the latter (van der Westhuizen et al., 1991). The uppermost sheetlike continental sedimentary rocks of the Bothaville Formation and the Allanridge Formation flood basalts (Fig. 6) suggest thermal subsidence following plume abatement, although minor komatiites within the flood basalts point to a continued, subordinate plume influence (Fig. 7) (Eriksson et al., 2002). These uppermost two formations of the Ventersdorp Supergroup are undated, though Olsson et al. (in press) suggest that the Allanridge volcanics may be coeval with a dyke swarm in the northeastern Kaapvaal craton, which they have dated to 2.66-2.68 Ga. They relate this swarm to a possible plume and also to development of rift-bound Transvaal basin “protobasinal” units, discussed below.

4.1 Ventersdorp Wheeler diagram

The Wheeler diagram for the Ventersdorp Supergroup is shown in Figure 8. The basal unconformity of the Ventersdorp Supergroup only reflects some tens of metres of fluvial incision associated with early plume ascent and Venterspost Formation lavas (Fig. 6), and there does thus not appear to have been any significant thermal uplift and extension of the crust until eruption of Klipriviersberg lavas was already well established, with these extensional processes reaching their apogee only in the Platberg Group. Basal Klipriviersberg flood basalts are absent in the SW of the preserved basin and basal Platberg graben-fills occur both atop weathered (with local palaeosols) basalts in the NE and within faulted older basement (granite-greenstone-gneiss and Witwatersrand Supergroup) rocks to the SW and W. The uppermost Bothaville and Allanridge formations’ more sheetlike geometry contrasts with the lenticular geometry of the Platberg units, and the former two formations are undated; the extent of the hiatus below the Bothaville Formation is thus unknown.

5. THE TRANSVAAL SUPERGROUP:

The Transvaal Supergroup occurs in three preservational basins on the Kaapvaal Craton: the Transvaal itself in the north-central part thereof (Fig. 9), and Griqualand West in the SW of the craton; both are in South Africa, with the third and minor basin, Kanye, being in Botswana, and situated to the W of the main Transvaal depository. This supergroup unconformably succeeds the Ventersdorp as well as overlying older basement rocks directly. Recent reviews of the lithostratigraphy and views on basin evolution are provided in Eriksson et al. (2001, 2006), with sequence stratigraphic interpretations being provided by Catuneanu and Eriksson (1999, 2002). The supergroup attains its maximum thickness and complexity within the Transvaal preservational basin where four subdivisions are recognized: (1) basal “protobasinal” (a descriptive term) rocks; (2) Black Reef Formation; (3) Chuniespoort Group carbonate-banded iron formation (BIF) platform succession; (4) Pretoria Group clastic sedimentary-subordinate volcanic succession (Fig. 10). The protobasinal rocks occur only in the Transvaal basin (Fig. 11), with the succeeding Black Reef Formation found in both the Kanye and the Transvaal depositories; the carbonate-BIF platform succession is the most widely developed, occurring in all three basins (Ghaap Group in Griqualand West and Taupone Group in Kanye), as does the Pretoria and equivalents: Segwagwa Group of the Kanye basin and the somewhat truncated Postmasburg Group in Griqualand West (e.g., Eriksson et al., 2006).

5.1 Protobasinal rocks

Figure 11 illustrates the large-scale geometry of the discrete, fault-bounded basins in which protobasinal rocks occur and also summarises the facies associations and their inferred depositional conditions (Eriksson et al., 2001 and references therein). The two eastern basins, Wolkberg and Godwan have very comparable basin-fill stratigraphies and particularly the former possesses a “steer’s head” geometry (initial localised mechanical subsidence, followed by thermal subsidence over a wider area) marked by restricted lower volcanic and immature clastic sedimentary rocks, succeeded by widespread basin marginal facies (Fig. 11). In the central part of the preserved Transvaal depository, thick successions of protobasinal rocks are known from boreholes only for the Wachteenbeetje Formation, and from restricted outcrops within a fragment of Transvaal rocks surrounded by younger Bushveld Complex

intrusives at Dennilton. In both these cases, predominantly more mature basin-margin and basin-central facies associations predominate, suggesting that these might reflect portions of a larger thermal sag type depository in contrast to the eastern fault-bounded Wolkberg and Godwan basins. To the west, lie the Buffelsfontein Group and Tshwene-Tshwene belt basins, dominated by bimodal volcanic rocks and immature clastic sedimentary rocks, in concert with their narrow, fault-bounded geometry (Fig. 11) (Eriksson et al., 2006 and references therein).

Taken as a whole, the protobasinal depository-fills suggest a broad zone of rifting, with marginal sub-basins subject to strong fault-control on both geometry and facies, and with a central more widespread thermal sag basin (post-rift thermally-driven subsidence) characterized by coastal and central basin facies associations (Eriksson et al., 2001, 2006). Hartzler (1994, 1995), who studied these rocks in detail, supports a single unitary basin for all of these occurrences based largely on lithostratigraphic correlations. The protobasinal successions have much in common with the Platberg Group of the preceding Ventersdorp Supergroup, especially as regards their inferred geodynamic setting and their overall lithologies and geometries. This has led to a model wherein the two are seen as lateral and chronological equivalents (e.g., Eriksson et al., 2005 and several earlier references). However, the only date determined for protobasinal rocks, 2657-2659 Ma (U-Pb ion probe; unpublished report, SACS, 1993; 2664 Ma, Barton et al., 1995) for the upper volcanic rocks of the Buffelsfontein Group does not support this viewpoint. As an alternative, Olsson et al. (in press) precisely date a dyke swarm within basement rocks to the east of the Transvaal basin at 2.66-2.68 Ga, which they suggest might be coeval with both protobasinal depository evolution and the Allanridge Formation lavas of the Ventersdorp Supergroup. A plume model (plume-related uplift, followed by mechanical extension and thermal sagging as the plume subsides) provides a logical interpretation to the dyke swarm, Allanridge lavas and protobasinal deposits.

5.1.1 Transvaal- protobasinal Wheeler diagram

This Wheeler diagram (Fig. 12) is drawn only for one of the discrete protobasinal rift-bound successions, namely that for the Wolkberg Group – the reason for choosing this specific basin-fill is that it is the best-studied and also because it shows the maximum

variability in terms of both facies and inferred geodynamic history. However, it should be borne in mind that it reflects the eastern group of protobasinal successions as discussed in the previous section, and will thus have more in common with the western group in its lower part (Sekororo Formation to Schelem Formation) and with the central group in its upper portion (Selati to “The Downs” Formations). Note also that the “Main Quartzite” and “The Downs” units are not yet fully formalized stratigraphic units.

5.2 Black Reef Formation (Vryburg Formation)

The undated Black Reef Formation, comprising thin (30-60 m thick) sheet sandstones overlies all the protobasinal successions unconformably, and also forms the base of the Transvaal Supergroup in the Kanye basin, Botswana; it is ascribed to initial fluvial deposition, followed by transgressive epeiric marine sedimentation for its upper portion (e.g., Button, 1973; Key, 1983; Henry et al., 1990; Els et al., 1995) (Fig. 13). Above the Wachteenbeetje and Bloempoort protobasinal successions, Hartzer (1994, 1995) records up to 200 m of Black Reef sandstones, suggesting a thermal sag basin setting for this formation, as shown in the isopach map in Figure 13. The Godwan basin was subjected to northward-directed tectonic shortening and this also affected the southern-central part of the Black Reef Formation (around the Johannesburg dome and to the west thereof; Fig. 13), during and after sedimentation (Eriksson et al., 2006 and references therein).

Some earlier workers include the “Main Quartzite” and “The Downs” units of the protobasinal succession in the Wolkberg basin as a basal part of the Black Reef Formation. In this sense, such a significantly thicker Black Reef succession in the Wolkberg basin area would be approximately equivalent to the much thicker Black Reef above the Wachteenbeetje and Bloempoort protobasinal successions discussed below. This might imply that the lower and major part of the Black Reef sandstones is in fact part of a preceding protobasinal unit (cf. The Downs and Main Quartzite units). It is commonly accepted that the Vryburg Formation, which forms the base of the Transvaal succession in the Griqualand West basin, where it unconformably overlies Ventersdorp basement, is approximately coeval with the Black Reef Formation of the other two Transvaal basins. The Vryburg comprises c. 100-300 m of mainly clastic

and lesser carbonate sedimentary lithologies as well as basaltic-andesitic lavas (dated at 2642 ± 3 Ma) (Walraven and Martini, 1995), and genesis of the sediments has been ascribed to a set of environments varying from fluvial to marginal or even deeper marine settings (Beukes, 1979; Altermann and Siegfried, 1997). However, in the absence of any age data for the Black Reef, and the different lithology of the Vryburg Formation, this assumed correlation needs to be treated with caution. The Black Reef Formation is included in the Wheeler diagram for other Transvaal protobasinal rocks.

5.3 Chuniespoort-Ghaap-Taupone Groups

This thick package of stromatolitic carbonate rocks (about 1200m thick in the Transvaal basin and >2500m in the Griqualand West depository), succeeding BIF (about 640m thick in the Transvaal basin) and uppermost mixed chemical and clastic sedimentary rocks (c. 1100 m thick Deutschland Formation of Transvaal; Koegas Subgroup of Griqualand West) overlies a regional unconformity related to tilting and base level fall (Altermann and Siegfried, 1997; Eriksson et al., 2001, 2006) (Fig. 14). Available age data indicate that this shallow epeiric palaeoenvironment accommodated chemical sedimentation from $<2642\pm3$ Ma until $\leq 2432\pm31$ Ma (Trendall et al., 1990; Barton et al., 1994; Knoll and Beukes, 2009). Spatial arrangements of sedimentary facies of the lower carbonates (summarized within chronological framework in the Wheeler diagram) show that the carbonate platform began in the area now preserved as the Prieska sub-basin in the SW of the Griqualand West basin, with an east-northeastward deepening of the platform towards the Ghaap Plateau sub-basin, and that with time shallower subtidal to peritidal settings migrated from WSW (Prieska sub-basin) towards the ENE (Ghaap Plateau sub-basin). At about 2550 Ma a major transgression occurred which drowned the SW peritidal carbonate flats and replaced those facies with subtidal muds (Prieska sub-basin), while shallow water subtidal-intertidal carbonate facies became established over both Ghaap Plateau sub-basin and the Transvaal depository (e.g., Eriksson and Altermann 1998) (Fig 14). A second major transgression followed at c. 2500 Ma, which drowned the entire carbonate platform and ushered in BIF deposition across all three preserved basins (Altermann and Nelson, 1998; Sumner and Beukes, 2006).

The final mixed clastic-chemical deposits of this thick carbonate-BIF platform succession have generally been seen as reflecting final withdrawal of the epeiric sea off the craton, essentially from NE to SW (e.g., Eriksson et al., 2005 and references therein). However it is possible that the Duitschland Formation, which is very localized in preservation in the far NE of the Transvaal basin (Fig. 15), may have formed within a different setting. A hiatus of possibly 80 My (or even as much as 200 My, Mapeo et al., 2006) separates the Chuniespoort chemical succession from the succeeding Pretoria Group in the Transvaal basin, and the Duitschland may well have been laid down during this time period, deriving much of its sediment from uplifted and eroded Chuniespoort carbonate beds lying to the south along the palaeo-Rand anticline (at the southern-central margin of the preserved Transvaal basin), but also apparently with some localized glacial or periglacial influences (Eriksson et al., 2001 and references therein).

5.3.1 Chuniespoort-Ghaap Wheeler diagram

The Wheeler diagram for the Chuniespoort Group is shown in Figure 16. Stratal patterns reflect initial sedimentation in the SW of the basin (Prieska sub-basin) with subsequent transgressive expansion over the Ghaap platform and further NE to the Transvaal basin portion. A second major transgression ushered-in BIF deposition that drowned shallow peritidal carbonates in the Prieska sub-basin, and deposited muds below wave-base, followed by development and expansion of the iron-formation platform from SW to NE. The stratal patterns of carbonate and BIF across the set of preserved basins are thus analogous. While the Griqualand West carbonate succession has the basal Schmidtsdrif Subgroup of clastic to chemical sediments dated at 2642 Ma, the undated Black Reef Formation beneath the Transvaal basin carbonate succession cannot be accepted as an unequivocal correlate.

5.4 Pretoria-Segwagwa-Postmasburg Groups

The Pretoria Group of the Transvaal basin and its close correlate in the Kanye basin, the Segwagwa, encompass up to 6-7 km of mainly argillaceous sedimentary rocks, lesser interbedded sandstones, and two major volcanic intervals (Fig. 17). These stacked formations have a predominantly sheetlike geometry (Eriksson et al., 2001).

Palaeoenvironments are thought to have comprised two major epeiric seas, characterized by mudrocks with marginal arenites (Timeball Hill Formation; Daspoort-Silverton-Magaliesberg Formations), and fluvially-deposited quartzitic sandstones (Boshoek, Dwaalheuwel Formations), with andesitic-basaltic volcanic lithologies (Hekpoort Formation, Machadodorp Member of the Silverton Formation) and evidence for minor glaciation (upper Timeball Hill Formation) (Eriksson et al., 2006, and references therein) (Fig. 17).

Catuneanu and Eriksson (1999) have identified two second-order, unconformity-bounded depositional sequences within the Pretoria Group, which they interpret as reflecting two episodes of (thermal?) uplift – rifting – thermal subsidence; uplift and rifting is related to essentially volcanic and immature sandy fluvial deposition, with thermal subsidence being inferred to have accommodated the two major epeiric marine (argillaceous) successions (Eriksson et al., 2001 and references therein). Age data on the Pretoria-Segwagwa succession is limited: (1) 2316 ± 7 Ma (Re-Os; Hannah et al., 2004) at the base of the groups; (2) detrital zircons within the Timeball Hill sandstones, Daspoort and Magaliesberg arenites, respectively, at $2250 \pm 14/15$ Ma, 2236 ± 13 Ma and 2193 ± 20 Ma, provide maximum ages for those units (Mapeo et al., 2006; similar data given by Dorland et al., 2004); (3) emplacement date for the Bushveld Complex (2058 ± 0.8 Ma; Buick et al., 2001), which intrudes largely above the Magaliesberg Formation, provides a minimum age for the groups, although a deformational event separates temporally the underlying sedimentary from the intrusive igneous rocks (Bumby et al., 1998) (Fig. 17).

The Hekpoort (Tsatsu Formation in Kanye basin; Ongeluk Formation in Griqualand West basin) flood basalt is common to all three preserved depositories and is dated in the latter basin at 2222 ± 13 Ma (Pb-Pb; Cornell et al., 1996). A much less complete basin-fill succession occurs in the Griqualand West basin, with a major glacigenic deposit below the basalts as well as a more chemical sedimentary succession above. This interval is, like the Pretoria-Segwagwa Groups, poorly dated and there have been divergent views on correlation between these two closely analogous basin-fills and that of the Griqualand West basin (e.g., discussion in Moore et al., 2001).

5.4.1 Pretoria Group Wheeler diagram

A Wheeler diagram (Fig. 18) is only presented for the Pretoria Group succession of the Transvaal basin, as this is the thickest and most complete basin-fill of the three preserved depositories. It must be noted that the post BIF development of the Griqualand West basin is very different from that of the Transvaal basin (Moore et al., 2001), and thus the Pretoria Group Wheeler diagram cannot be considered to be appropriate for the Postmasburg Group. The chronological extent of the basal hiatus separating this unit from the underlying Chuniespoort carbonate-BIF platform succession cannot be accurately constrained due to lack of precise age data, but is significant as in many parts of the basin (and particularly along its southern parts) the entire BIF unit and about one and a half formations of carbonate have been removed prior to Pretoria sedimentation (Eriksson et al., 2001). A second hiatus, of much more limited duration (but again not quantifiable due to lack of age data) occurs after the first thermal uplift-rifting-thermal subsidence cycle. There is an inferred weathering event (cf. hiatus) associated with Strubenkop Formation deposition (Figs. 17 and 18), which appears to have encompassed much more distant sediment source areas and a greatly peneplaned geomorphology, as derived from palaeohydrological data. The second epeiric sea, related to the second thermal uplift-rifting-thermal subsidence cycle advanced onto the craton from the ESE towards the WNW and retreated in the reverse direction, as suggested by diachronous facies associations observed in the Daspoort-Silverton-Magaliesberg Formations. Finally, a significant denudation/deformation event post-dated Pretoria Group deposition within the Transvaal basin, prior to intrusion of the Bushveld Complex, between a Pretoria Group floor and a Rooiberg Felsite Group roof succession; the latter was an immediate precursor of the main Bushveld magmas, and overlaps them in age (e.g. Hatton, 1995).

6. THE WATERBERG GROUP:

These strata were laid down on or along the northern margin of the Kaapvaal Craton between 2.06 and 1.7 Ga (Barker et al., 2006; Hanson et al., 2004), and outcrop across much of the northern-most portion of the craton (Fig. 19). Sedimentation of the lowermost parts of the Waterberg Group was either synchronous or immediately after the final (granitic) stages of intrusion of the Bushveld Complex (Dorland et al., 2006).

Of particular importance to the history of sedimentation of these units is an understanding of the timing of tectonic activity in the Limpopo Belt, which seems to have directly controlled the creation of these Late Palaeoproterozoic depositories and provided clastic source material for the basin fill. The Limpopo Belt is characterised by three separate zones, each at amphibolite to granulite grade, which trend ENE-WSW across the northern edge of the Kaapvaal and southern edge of the neighbouring Zimbabwe Craton. These zones are the Southern Marginal Zone, Central Zone and Northern Marginal Zone (from S to N respectively). The Palala Shear Zone separates the Southern Marginal Zone from the Central Zone (Fig. 1), and is considered as the northern edge of the Kaapvaal Craton. These terranes are thought to be the exhumed root of an orogen, which accommodated collision between the Kaapvaal and Zimbabwe cratons at either 2.6 or 2.0 Ga, incorporating a separate exotic terrane (the Central Zone) into the collision. Whether the array of dates determined from the Limpopo Belt represents a collision and subsequent reactivation, or a polyphase collision is still a matter of conjecture (discussion in section 2.1).

The Blouberg Formation is the oldest of the Palaeoproterozoic units discussed here, and outcrops only rarely, directly along the strike of the Palala Shear Zone (Figs. 1 and 19) (Bumby et al., 2001). Whilst sedimentation in the Blouberg Formation appears to be syn-tectonic, it has not been significantly metamorphosed, and rests nonconformably on the granulite-grade Limpopo basement, and therefore must post-date collision and exhumation of the Limpopo event. The lower part of the c. 1400m-thick Blouberg Formation is composed of coarse, immature sedimentary breccias, which grade upwards into granulestones in the upper half of the formation. The Blouberg sedimentary strata are steeply dipping and overturned in places, suggesting southwards-vergent reactivation along the Palala Shear Zone (Bumby et al., 2001). The southernmost outcrops of the Waterberg Group are those of the Wilge River Formation, which are preserved in the Middelburg basin in the central parts of the Kaapvaal Craton (Fig. 19). These were laid down approximately contemporaneously with the Swaershoek strata to the north, though are isolated from other strata of the Waterberg Group (Fig. 19). The Wilge River strata have a maximum thickness of 2500m, and are composed of granulestone with conglomeratic interbeds, containing clasts of Transvaal Supergroup and Bushveld Complex rocks, which have been interpreted as having been deposited within alluvial plains (van der Neut et al.,

1991). Palaeocurrent directions suggest sediment influx from alluvial plains was generally from the west. In contrast to the steeply-dipping Blouberg Formation, the Wilgeriver strata only rarely dip at angles greater than 10°.

The majority of the Waterberg Group rocks are preserved in the 'Main' and 'Nylstroom' basins, which are in north westerly parts of the craton (Fig. 20). The Main basin onlaps against the Palala Shear Zone at the northern cratonic margin, and both the southern edge of the Main basin and northern edge of the Nylstroom basin are marked by the WSW-ENE trending Thabazimbi Murchison lineament (TML), which similarly appears to have a strong influence over the development of the Waterberg basin (Callaghan et al., 1991). The lowermost unit in these basins is the Swaershoek Formation (Fig. 21), which thickens considerably in the Nylstroom basin, suggesting that it onlaps northwards over the TML (Fig. 22). In contrast, the overlying Alma Formation, which similarly outcrops in both the southern parts of the Main basin and in the Nylstroom basin, is characterised by an absence of strata along the TML, suggesting that the TML acted as a horst during Alma times, shedding sediment both to the N and S. The volcano-sedimentary Swaershoek Formation is characterised by intensely sheared and jointed arenites and intercalated basalts, thought to have been deposited in a fan-deltaic palaeo-environment, whereas the Alma Formation is conglomeratic close to the TML, grading into arkoses and arenites in more distal areas to the north. An alluvial fan setting, reflecting deposition adjacent to the TML fault scarps, is inferred for the Alma Formation.

The relationship between reactivation along the TML and deposition in the Main basin appears to be less complex in younger units of the Waterberg Group, where the strata can be interpreted to retrograde then prograde both along the northern (Palala) and southern (TML) boundaries during the medial and upper parts of the Waterberg strata respectively (Fig. 22). However, the Main basin is characterised by facies differences between southerly and northerly strata, which are reflected by different stratigraphic names for laterally equivalent strata, as detailed below.

Retrogradational medial units of the Waterberg Group comprise the Skilpadkop and Setlaole formations in the S and N respectively (generally fluvial arenites and arkoses), followed by the Aäsvolkop and Makgabeng formations (lacustrine and

aeolian deposits respectively in the S and N). Prograding upper units comprise the fluvial Sandriviersberg (S) and alluvial-fluvial Mogalakwena (N) formations, reflecting braided rivers flowing from the north east. The uppermost Cleremont and Vaalwater Formations are only preserved in central parts of the basin (Figs. 20 and 22), and the Cleremont is interpreted as being deposited in a high energy tidal environment (Callaghan et al., 1991). The Vaalwater Formation is similarly more mature than lower Waterberg strata, and is thought to have been deposited in a littoral palaeoenvironment.

6.1 Waterberg Group Wheeler diagram

The Wheeler diagram for the Waterberg Group is shown in Figure 22, which more clearly indicates the complex control of the TML over Waterberg sedimentation in the Main and Nylstroom basins. Figure 22 shows lower Waterberg units (Blouberg, Wilgerivier, Alma and Swaershoek) are either localised, fault bounded basins and/or have strong spatial and geodynamic relationships to the major bounding lineaments, i.e. the Palala Shear Zone in the north and the Thabazimbi-Murchison lineament in the south. Higher stratigraphic units in the Waterberg Group fill the entire accommodation space created by subsidence between these two major lineaments (Setloale-Skilpadkop, Makgabeng-Aasvoëlkop Formations) (Fig. 22). Following an inferred short-lived lacuna, subsequent Mogolokwena-Sandriviersberg formations onlapped onto and over both bounding lineaments. Lastly the more restricted spatial and geometrical character of the Cleremont and Vaalwater formations most likely reflects depositional, rather than tectonic controls.

7. DISCUSSION:

The evolution of the Kaapvaal Craton between 3.0 and 1.8 Ga can be interpreted from the stratigraphic record of four sedimentary basins, namely the Witwatersrand, Ventersdorp, Transvaal and Waterberg. The broad stratigraphic framework of these basins is summarized in generalized Wheeler diagrams (Figs. 3, 8, 12, 15, 18 and 22) which are constructed to illustrate mainly the first- and second-order levels of cyclicity.

The sedimentary fill of each of the four studied sedimentary basins corresponds to a first-order depositional sequence, the boundaries of which mark changes in the tectonic setting. The Witwatersrand Basin evolved during an initial transgressive phase, which established the West Rand seaway of the underfilled basin, followed by gradual highstand progradation and the transition to a filled and overfilled basin (Fig. 3). Accommodation was created primarily by flexural subsidence (Catuneanu, 2001), and multiple third-order depositional sequences are recognized (Fig. 4). Additional work is required to group these third-order sequences into second-order systems tracts and sequences.

Sedimentation in the Ventersdorp Basin is due to a combination of extensional and thermal subsidence. Two major unconformities partition the Ventersdorp first-order sequence into three second-order sequences (Fig. 8). Additional research is required to identify the second-order systems tracts of these depositional sequences, and to look into their possible subdivision into third-order sequences.

The Transvaal Basin hosts the first-order sequence that has been studied in most sequence stratigraphic detail within the confines of the Kaapvaal Craton (e.g., Catuneanu and Eriksson, 1999, 2002; Eriksson and Catuneanu, 2004; Fig. 10). The Transvaal first-order sequence has been subdivided into five second-order depositional sequences separated by major unconformities. Each of these second-order sequence boundaries can be related to a significant tectonic event in the evolution of the Kaapvaal Craton (Fig. 10). Overall, accommodation in the Transvaal Basin was provided by a combination of extensional and thermal subsidence mechanisms (Fig. 10).

The second-order sequence stratigraphic framework of the Transvaal succession (Fig. 10) is further detailed in the Wheeler diagrams presented in Figures 12, 15 and 18. These diagrams provide additional information on the low versus high accommodation setting (Fig. 12), the long-term transgressive-regressive trends (Fig. 15), and the detailed depositional system relationships (Fig. 18). The second-order sequence stratigraphic framework summarized in Figure 10 and the associated Wheeler diagrams are sufficient for the purpose of this special issue; however,

additional research is required to extrapolate the degree of detail acquired for specific stratigraphic intervals to the entire Transvaal first-order sequence.

The sedimentary fill of the Waterberg Basin represents the youngest Precambrian first-order sequence of the Kaapvaal Craton. The summary of stratigraphic data presented in Figure 22 indicates that deposition within the Waterberg Basin took place dominantly in a continental setting, with the exception of the marine transgression recorded during the late stage in the evolution of the basin. A significant stratigraphic hiatus subdivides the Waterberg first-order sequence into two second-order sequences. The continental section of the Waterberg succession is best described in terms of second-order low- versus high-accommodation systems tracts, topped by a second-order marine transgressive systems tract (Fig. 22). This interpretation accounts for upstream controls (i.e., climate and/or tectonism) on the deposition of second-order low- and high-accommodation systems tracts. More research is required to investigate the possible role of downstream controls (i.e., marine base-level change) on the deposition of these systems tracts, as well as on the formation of third-order sequences.

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Figure Captions

Figure 1: Schematic geological map of the Archaean and Proterozoic structural elements within the Kaapvaal Craton and the locality of major Precambrian basins discussed in the text (after Eriksson et al., 2005).

Figure 2. Maps and sections illustrating the genesis (Figs 2a. and 2b.), location and geology (Fig 2c.) of the Witwatersrand Supergroup (after Catuneanu, 2001). The location of the Witwatersrand and Pongola basins, relative to two centres of orogenic loading (arrows 1 & 2) are indicated in (a.). A typical model of foredeep basin development relative to the Limpopo Belt (orogenic loading 1) is shown in (b.). Figure 2c. shows the distribution of the West Rand and Central Rand groups of the Witwatersrand Supergroup. The older Dominion Group, as well as the younger Ventersdorp, Transvaal, and Karoo supergroups are not represented.

Figure 3. Generalized dip-oriented Wheeler diagram for the Witwatersrand Supergroup (modified from Catuneanu, 2001). Age data: ⁽¹⁾ Armstrong et al. (1991), from the underlying Dominion Group; ⁽²⁾ Armstrong et al. (1991) from the overlying Ventersdorp Supergroup; ⁽³⁾ Armstrong et al. (1991) and Hartzler et al. (1998), from the upper West Rand Group (summarised in Robb and Meyer, 1995). Abbreviations: SU - subaerial unconformity; SU/TRS - subaerial unconformity reworked by a transgressive ravinement surface; MFS - maximum flooding surface; TST - transgressive systems tract; HST - highstand systems tract.

Figure 4. Lithostratigraphy and depositional sequences of the Witwatersrand Supergroup along the proximal rim of the basin (Tankard et al., 1982; Winter and Brink, 1991). These litho- and sequence stratigraphic units thin and fine gradually in a down dip direction in response to the subsidence patterns within the basin and the location of the sediment source areas (Tankard et al., 1982; Myers et al., 1990; Stanistreet and McCarthy, 1991; Winter and Brink, 1991; Catuneanu, 2001).

Figure 5. Maps showing the location and extent of the Ventersdorp Supergroup relative to the Witwatersrand basin and the Kaapvaal Craton (after Winter, 1976; Eriksson et al., 2002).

Figure 6. Lithostratigraphic subdivisions of the Ventersdorp Supergroup, ages, inferred palaeoenvironments and sequence stratigraphy (after van der Westhuizen et al., 1991).

Figure 7. Schematic evolutionary model for the Ventersdorp Supergroup (after Eriksson et al., 2002, 2005).

Figure 8. Generalized dip-oriented Wheeler diagram for the Ventersdorp Supergroup. Age data from Armstrong et al., 1991.

Figure 9. Map showing the location and extent of the Transvaal basin, Griqualand West basin, Bushveld Complex and Waterberg Group within the Kaapvaal Craton (after Eriksson et al., 2009).

Figure 10. Vertical section through the Transvaal Supergroup (Transvaal basin) first-order cycle, illustrating lithostratigraphy, chronology, inferred tectonic settings and depositional palaeoenvironments, base-level changes and sequences stratigraphy (modified after Catuneanu and Eriksson, 1999). FSST= falling stage systems tract; HST= highstand systems tract; TST= transgressive systems tract; LST= lowstand systems tract; LAST= low accommodation systems tract; HAST= high accommodation systems tract. Age dates from Armstrong et al. (1991); Eriksson and Reczko (1995); Walraven and Martini (1995); Harmer and von Gruenewaldt (1991).

Figure 11. Fence diagram illustrating geometry and inferred depositional facies for the protobasinal rocks of the Transvaal Supergroup (after Eriksson and Reczko, 1995).

Figure 12: Generalized dip-oriented Wheeler diagram for the protobasinal units of the Transvaal Supergroup.

Figure 13: (a) Isopach map of the Black Reef Formation with mean palaeocurrent vectors and inferred palaeodrainage divide. (b.) Typical Black reef profile from the east of the basin, showing upward-fining and upper upward coarsening succession.

(c.) Typical Black reef profile from the west of the basin. (d.) Typical Black reef profile from Transvaal fragments within the Bushveld Complex. (after Eriksson et al., 2001).

Figure 14: The stratigraphic subdivision and geochronology for the Transvaal and Griqualand West structural basins (Transvaal Supergroup) (after Eriksson and Altermann, 1998; Eriksson et al., 2001).

Figure 15: Fence diagram showing the geometry of the preserved Chuniespoort Group units (after Eriksson and Reczko, 1995).

Figure 16: Generalized dip-oriented Wheeler diagram for the Ghaap-Chuniespoort Group (Transvaal Supergroup). The Duitschland Formation (at the top of the Chuniespoort Group), is shown at the base of the Pretoria Group in Figure 18. Age data based on Walraven and Martini (1995).

Figure 17: Summary of the Pretoria Group stratigraphy, indicating lithostratigraphy, depositional environment and sequence stratigraphy (after Eriksson et al., 2001).

Figure 18: Generalized dip-oriented Wheeler diagram for the Pretoria Group (Transvaal Supergroup). FSST= falling stage systems tract; HST= highstand systems tract; TST= transgressive systems tract; LST= lowstand systems tract.

Figure 19: Maps showing the location of the Waterberg Group Main, Nylstroom and Middelberg basins of the Waterberg Group, relative to major structural lineaments of the Kaapvaal Craton (after Bumby et al., 2001).

Figure 20: Geological map showing the distribution of strata in the Main basins of the Waterberg Group. Note gradational contacts marking facies changes between northern and southern parts of the basin (after Bumby et al., 2001).

Figure 21: The stratigraphic subdivision of the Waterberg Group in the different basins (after Callaghan et al., 1991).

Figure 22: Generalized dip-oriented Wheeler diagram for the Waterberg Group.

TST= transgressive systems tract; LAST= low accommodation systems tract; HAST= high accommodation systems tract.

Figure 1.

Figure 2.

Figure 3.

Group	Subgroup	Formation	Sequence
Central Rand	Turffontein	Elsburg	25
			24
		Kimberley	23
			22
			21
	Johannesburg	Krugersdorp	20
			19
		Randfontein	18
			17
			16
			15
West Rand	Jeppestown	Roodepoort	14
			13
		Crown	
		Florida	12
	Government	Witpoortjie	11
			10
			9
			8
		Coronation	7
		Promise	6
			5
	Hospital Hill	Brixton	4
			3
		Parktown	2
		Orange Grove	1

Figure 4.

Figure 5.

Figure 6.

Figure 7.

1. Klipriviersberg flood basalts

2. Platberg Group - elevation & brittle fracture of upper crust - sea level around Kaapvaal lowered

3. Plume abates - thermal subsidence of central Kaapvaal craton, deposition of Bothaville alluvial plain sediments and Allanridge plateau andesites followed by Transvaal transgression

Figure 8.

Figure 9.

Figure 10.

Figure 11.

Figure 12.

Figure 13.

Figure 14.

Figure 15.

Figure 16.

Figure 17.

Figure 18.

Figure 19.

Figure 20.

Figure 21.

GROUP	SUBGROUP	North / northeast & central parts	Southeast & central parts	South / southwest & central parts	Nylstroom area	Middelburg area
WATERBERG GROUP	KRANSBERG		Vaalwater Formation (475m)			
			Cleremont Formation (125m)			
		Mogalakwena Formation (1250-1500m)	Sandriversberg/ Mogalakwena Formations	Sandriversberg Formation (1250m)		
	MATLABAS	Makgabeng Formation (380-1000m)	Aasvoelkop/ Makgabeng Formations	Aasvoelkop Formation (300-600m)		
		Setlaole Formation (450m)	Skilpadkop Formation (450-600m)	Skilpadkop Formation (450-600m)		
	NYLSTROOM		Sterk River Formation (500-1500m)	Alma Formation (3000m)	Alma Formation	Wilge River Formation
				Swaershoek Formation	Swaershoek Formation (2500m)	
			Blouberg Formation (1400m)			

Figure 22.