A case study of microbial mat-related features in coastal epeiric sandstones from the Palaeoproterozoic Pretoria Group (Transvaal Supergroup, Kaapvaal craton, South Africa); The effect of preservation (reflecting sequence stratigraphic models) on the relationship between mat features and inferred palaeoenvironment

P.G. Eriksson[1], R. Bartman[1], O. Catuneanu[2], R. Mazumder[3] and N. Lenhardt[1]

[1]Department of Geology, University of Pretoria, Pretoria 0002, South Africa

[2]Department of Earth and Atmospheric Sciences, University of Alberta, 1-26
 Earth Sciences Building, Edmonton, Alberta, T6G 2E3, Canada

[3]Geological Studies Unit and Fluvial Mechanics Laboratory, Indian Statistical Institute,
 203 B.T. Road, Kolkata 700 108, India

ABSTRACT

The Magaliesberg Formation sandstones within the upper part of the Pretoria Group are interpreted as a second-order highstand systems tract within an overall clastic epeiric marine setting, where episodic braided fluvial systems fed sediment directly into a tidally dominated coastline setting. Mat-related features are abundantly preserved within the inferred tidal flat and supratidal deposits. The Daspoort Formation sandstones at a lower stratigraphic level are ascribed to a closely analogous palaeoenvironmental setting, yet have hardly any preserved mat features at all; they are ascribed to a second-order transgressive systems tract in a sequence stratigraphic framework. During highstand the depositional systems are inferred to have aggraded, thus preserving the mat-related features formed in Magaliesberg intertidal-supratidal environments. During second-order transgression, the formation of the wave/tidal ravinement surface in the

subtidal/intertidal environments largely obliterated the features of the Daspoort intertidal and supratidal environments, leading to a paucity of mat-related structures in the preserved Daspoort succession. This case study thus supports the application of mat-related features to integrated palaeoenvironmental and sequence stratigraphic analysis, while emphasizing the role of preservation.

Keywords: microbial mats; mat-related features; palaeoenvironments; systems tracts; preservation; Pretoria Group

_____

1. Introduction

Cyanobacteria are readily adaptable and thus comprise the most successful mat-builders within clastic sedimentary realms; essentially, they are able to grow on any moist clastic sedimentary surface where their nutritional and energy requirements are met, within settings where metazoan grazers and burrowers are either absent or ineffective (Schieber et al., 2007a, c). Various classification schemes have been proposed for preserved mat features in the clastic rock record (e.g., Noffke et al., 2001a; Schieber, 2004; Sarkar et al., 2008; Noffke, 2010); we here use that of Schieber (op. cit.; see also Eriksson et al., 2007).

Studies attempting to relate different microbial mat features (the "MISS" - microbially-induced sedimentary structures - of Noffke et al., 2001a; cf., "MRS", a broader acronym for mat-related structures including those not directly induced by microbes, Eriksson et al., 2010) preserved in clastic sedimentary rocks to specific (palaeo)environments or even

to parts of identified depositional settings have been limited (e.g., Schieber et al., 2007c). Environmental variation can also often result in different groups of mat-building bacteria becoming established under the different conditions (Schieber et al., 2007c). As many studies of microbial mat features have been carried out in modern and ancient presumed analogues of shallow marine tidal-supratidal as well as hypersaline lagoon environments (e.g., Gerdes et al., 1985a, b and c), there is a body of opinion that suggests they might be partially diagnostic of such settings, and that they might also even have sequence stratigraphic connotations, specifically as marking transgression-regression cycles (e.g., Noffke et al., 2006; Noffke, 2007, 2010). Mats have been seen as contributing at a range of scales, to clastic sediment stacking patterns and concomitant architecture within the sequence stratigraphic context (Sarkar et al., 2005; Catuneanu, 2007). Cultivation of extant mats suggests that a well developed, tough, leathery mat requires several weeks of non-burial to form (however thin films may develop within tidal cycles; Eriksson et al., 2010, their Fig. 1) and mat features should thus presumably be associated with episodic clastic sedimentation patterns (Eriksson et al., 2009).

In contrast to the possible shallow marine coastal bias in inferred mat-forming environments discussed above, many other workers perceive them to be non – facies specific (e.g., Schieber et al., 2007a, c). In this paper we examine two well preserved and exposed Palaeoproterozoic sandstone formations from the Pretoria Group (Transvaal Supergroup, Kaapvaal craton, South Africa), both ascribed to a shallow marine coastal origin (e.g., Eriksson et al., 2001, 2006) wherein microbial mat features have been found, in abundance in the one case (Magaliesberg Formation) and parsimoniously in the other (Daspoort Formation). We thus use these two examples (deliberately chosen to have

analogous inferred genetic settings) to examine the possible ties between preserved mat features and the depositional environments of their associated clastic sediments, and to argue for the importance of preservation potential within a broader sequence stratigraphic framework when evaluating mat feature – palaeoenvironmental relationships. The paper is thus a case study and is not intended to constitute a generalized examination of the MRS-palaeoenvironment-sequence stratigraphic model relationships.

2. Environmental affinities of microbial mats

A brief examination of this complex topic provides necessary background for the case study presented in this paper. For modern mats growing on clastic substrates, the most commonly observed environments are, firstly, the shallow marine tidal-supratidal-sabkha continuum (Schieber et al., 2007a; Gerdes, 2007; Bose and Chafetz, 2009), and secondly, hypersaline lagoons (e.g., Gerdes and Krumbein, 1987; Noffke et al., 2001b; Noffke, 2010) or analogues thereof (viz. salt works and laboratory models; Schneider, 1995; Gerdes and Klenke, 2003). Gerdes et al. (2000) and Noffke et al. (2001b) provide further examples of the perceived shallow marine – coastal bias in clastic mat studies in Pleistocene-modern tidal flats, as do Parizot et al. (2005) for Palaeoproterozoic equivalents where they related MRS to inferred water depths and wave heights. In the Precambrian record, where the absence of grazers enhanced preservation and abundance of MRS, most marginal shallow marine settings formed part of preserved epeiric seas (e.g., Eriksson et al., 2008); as an example, Schieber (1998) relates MRS in the c. 1450-850 Ma Belt Supergroup of North America to a palaeoenvironmental spectrum ranging

from calm offshore - shallow nearshore - sea-marginal sandflats - shallow nearshore lagoons.

However, many researchers view microbial mat features in clastic sedimentary rocks as essentially non - facies-specific, a viewpoint reinforced by the common occurrence of "opportunistic mats" (Schieber et al., 2007a and c). Krumbein et al. (2003) and Schieber et al. (2007a) stress the highly divergent facies (i.e., sediment lithofacies) relationships observed for modern and interpreted for rock record MRS occurrences; the range of depositional settings is underlined by the occurrence of MRS in some of the oldest known large desert (erg) deposits (c. 1.8 Ga; Eriksson et al., 2000). Compounding this point of view, is the fact that formation of a specific mat feature within a particular setting does not necessarily equate with final deposition within the same setting; two examples are provided by photosynthetic oxygen bubbles allowing mat fragments to float and become transported (Fagerstrom, 1967) and physical mat destruction through high energy transporting processes can readily transport MRS like mat chips (Schieber, 1999; Gerdes, 2007). Schieber (2007) has carried out flume experiments on the nature of mat fragment transport.

Schieber et al. (2007c) found a generally weak facies-specific relationship for MRS studied within 10 separate stratigraphic units varying in age from Archaean to Eocene and containing significant suites of mat features, necessitating a rather robust environmental classification for the mat features. They identified coastal (above mean sea/lake level); shallow marine/lacustrine (below mean sea/lake level with agitated

shallow waters); deep sea or lake (quiet water settings); fluvial; and aeolian environments. However, some interesting patterns did emerge from this study, for sandstone-hosted MRS (Schieber et al., 2007c, their table 9(a)-1): the coastal setting exhibited the largest abundance and variety of MRS; although much reduced in number, both shallow and deep water MRS were rather similar in type; the mat features in the fluvial setting resembled those of the coastal environment although lacking the latter's numbers and variety. For the Daspoort and Magaliesberg sandstones studied in this paper, the inferred palaeoenvironment reflects an interface of both fluvial and coastal influences, with mat features dominantly reflecting the imprint of the latter setting. Bathymetry and energy level ranges may have been similar amongst the fluvial and coastal examples studied to explain these observations, and the analogous MRS were dominated by surface ornamentation features such as wrinkles, petees/petee ridges, sand cracks and sand chips (Schieber et al., 2007c). Despite the impact of the advent of grazing metazoans in the Phanerozoic on the relative abundance of MRS in many clastic settings, this had little effect on the broad environmental adaptability of microbial mats (Schieber et al., 2007b).

3. Pretoria Group geology

The c. 2.66-2.05 Ga Transvaal Supergroup supracrustal succession is preserved in three basins across the Kaapvaal craton of Southern Africa: Transvaal, Griqualand West and Kanye depositories (Fig. 1) (Catuneanu and Eriksson 1999, 2002; Eriksson et al., 2001, 2006). The most complete Transvaal succession is that in the Transvaal basin (TB; Fig. 2), which begins with a set of "protobasinal" (a purely descriptive appellation) rift

depositories filled with immature sedimentary as well as volcanic rocks which mature stratigraphically upwards as thermal subsidence replaced mechanical subsidence (Eriksson et al., 2006 and references therein). A recent 2.66-2.68 Ga age on a dyke swarm to the east of the preserved basin-fills suggests that these protobasinal rifts may have been related to late Ventersdorp Supergroup volcanism (Olsson et al., 2010), as the c. 2.7 Ga Ventersdorp mantle plume event came to an end (van der Westhuizen et al., 1991; Eriksson et al., 2002a). Thin, undated fluvial sheet sandstones of the Black Reef unconformably succeed the protobasinal rifts (e.g., Els et al., 1995) and grade up into a thick chemical sedimentary, epeiric seaway platform succession (dated at ca. 2.65-2.40 Ga; Knoll and Beukes, 2009), which occurs in all three preservational basins; lowermost carbonates pass up into medial iron formations and uppermost mixed clastic-chemical deposits (~1200 m, ~640 m, ≤1100 m thick Duitschland Fm., respectively, in TB; Fig. 2) (e.g., Altermann and Siegfried 1997; Eriksson et al. 2001, 2005, 2006). The latter deposits include a thin glacigenic diamictite (Bekker et al., 2001; Frauenstein et al., 2009).

Following a significant time gap (possibly 80 my; Eriksson et al., 2001), the Pretoria Group (an essentially clastic sedimentary-lesser volcanic succession) unconformably succeeded the chemical platform deposits (e.g., Eriksson et al. 2006). Palaeokarst-fill sediments of the basal Rooihoogte Formation of the Pretoria Group formed initially during the hiatus separating this group from the underlying chemical sedimentary deposits and may also have been related to genesis of the Duitschland Formation at the latter's top (Eriksson et al., 2001). Pretoria Group lithostratigraphy, interpreted

depositional environments and inferred sequence stratigraphy are well reported in the literature (e.g., Eriksson et al., 1991, 2001, 2005, 2006; Eriksson and Reczko, 1995; Catuneanu and Eriksson, 1999; Moore et al., 2001). The 6-7 km thick succession comprises essentially sheet-like thick (1-2 km) epeiric marine argillaceous units, several thinner yet prominent fluvial sandstones (sheet- or wedge-type geometry), and two major volcanic horizons; this overall succession is ascribed to two major rifting events with subsequent thermal subsidence, with two concomitant major epeiric transgressive to highstand unconformity-bound second-order depositional sequences (Fig. 2) (Catuneanu and Eriksson, 1999; Eriksson et al., 2006 and references therein). Widespread, yet thin and lenticular glacigenic beds are found within the uppermost Timeball Hill Formation epeiric marine succession, which are ascribed to reworked glacial moraines within an overall periglacial palaeoenvironment (Visser, 1971; Coetzee et al., 2006; Eriksson et al., 2006). The Pretoria Group succession is sparsely dated: 2316±7 Ma (Re-Os; Hannah et al., 2004) basal black shales; 2222±13 Ma (Pb-Pb; Cornell et al., 1996) flood basalts in the Griqualand West basin which correlate with the Hekpoort Formation in the TB; within the Kanye basin, detrital zircons within successively higher sandstone units correlated, respectively, with the Timeball Hill, Daspoort and Magaliesberg sandstones (see Fig. 2 for stratigraphy of the Pretoria group in the TB) date at 2250±14/15 Ma, 2236±13 Ma, and 2193±20 Ma (Mapeo et al., 2006; comparable data in Dorland et al., 2004). Pretoria Group formations were affected by a regional compressive deformation event (Bumby et al., 1998; Eriksson et al., 1998) before emplacement of the major layered mafic intrusion of the Bushveld Complex at 2058±0.8 Ma (Buick et al., 2001).

The younger epeiric, transgressive to highstand unconformity-bound second-order depositional sequence inferred in the Pretoria Group succession comprises the Daspoort (base), Silverton and Magaliesberg (top) formations (Fig. 2).

3.1. Daspoort Formation

This unit has an overall sheet-like geometry with a thickening trend from north to south, and the basal and upper contacts are sharp and, on the regional scale, approximately conformable (Eriksson and Catuneanu, 2004). The formation is dominated by fine- to medium-grained quartzose sandstones (which are commonly recrystallised) with subordinate coarse pebbly and arkosic sandstone facies, and minor conglomerate, mudrock and ironstone facies (Eriksson et al., 1993); three facies associations are recognized – sandstones (mainly fine – to medium-grained arenites and wackes); mudrocks-ironstones; pebbly sandstones (coarse quartzose and arkosic sandstones, conglomerates) (Eriksson and Catuneanu, 2004) (Fig. 3). The latter association exhibits a locally erosive basal contact with the other facies associations.

Palaeoenvironmental interpretation of these facies suggests braided fluvial deposition for the predominant sandstone facies association, basinal sedimentation for the mudrock-ironstone association which is restricted to the east of the basin, with the pebbly lithologies being seen as a younger, less mature fluvial deposit which incised into the other two facies associations (Eriksson et al., 1993; Eriksson and Catuneanu, 2004). Tidal reworking of the finer sandstone facies association appears to have occurred across the

basin, and these arenitic deposits generally fine from west to east, and become pyritic in the east where the marine influence was strongest; fluvial incision of the coarser and younger river deposits is greater in the east (Eriksson and Catuneanu, 2004). Polymodal palaeocurrent patterns in the east contrast with unimodal patterns in the west (Eriksson et al., 1993).

Based on the above observations, inferred Daspoort fluvial systems from the west passed into a shallow eastern-southeastern basin; where fluvial and shallow marine systems interacted at the coastline itself, the two facies associations become difficult to separate due to their inherently complex temporal and spatial associations in the extant coastal environment. Transgression of the Silverton epeiric sea whose advance was coeval with Daspoort tidally-influenced fluvial sedimentation, advanced in the reverse direction, from E-SE to W, and was followed by highstand conditions, during which mainly substorm wave-base argillaceous deposits accumulated in the basin (Catuneanu and Eriksson, 1999; Eriksson et al., 2002b; Eriksson and Catuneanu, 2004). The observed widespread tidal influences on the Daspoort fluvial deposits across the preserved basin can thus be ascribed to the latter being overcome by the coeval second-order Silverton transgression, while the incision at the base of the upper, immature pebbly sandstone facies association reflects a third-order change in accommodation conditions during Daspoort deposition (Eriksson and Catuneanu, 2004). The latter authors thus recognize third-order high accommodation and low accommodation fluvial systems tracts in this formation.

3.2. Magaliesberg Formation

The Magaliesberg Formation is underlain by the thick muddy deposits of the Silverton Formation with which it has a gradational contact. Basal braid-delta sandstones of the latter formation in the far west of the Pretoria Group basin were approximate time equivalents of the eastern shallow marine upper Daspoort deposits; these sediments were drowned as Silverton transgression took place, passing up into initial turbidity current sediments and then the pelagic mudrocks that predominated in the Silverton epeiric sea (Catuneanu and Eriksson, 1999; Eriksson et al., 2002b). This fine detritus was sourced from fine fluvial sediment of the Magaliesberg Formation coastline which had bypassed high energy sand belts along this littoral when fluvial flood stages resulted in high proportions of suspended load sediments (Fig. 4) (Eriksson et al., 2008).

Eriksson et al. (1995) identified three architectural elements (AE; cf. Allen, 1983; Miall, 1985, 1988) within the Magaliesberg Formation: (1) medium- to coarse-grained sandstone sheets characterized by horizontal lamination and planar cross-bedding, with less prevalent trough cross-strata, channel-fills, wave, current and wind ripples, and minor desiccated mudrock partings, double-crested and flat-topped ripple marks; (2) fine- to medium-grained sandstone sheets with analogous sedimentary structures; (3) mudrocks: alternating mudstone, siltstone and lesser very fine-grained sandstone laminae, displaying soft sediment deformation structures, and minor flaser structures, ripple cross-lamination, wave ripples, mudcracks and channel-fills. Predominantly unimodal palaeocurrent patterns found within the coarser sandstone sheets (AE#1) are ascribed to

ephemeral braid-delta deposits subject to minor shallow marine (tidal) reworking (this interpretation is based on the combination of facies characteristics and palaeocurrent data); the predominantly bimodal patterns observed within finer sheet sandstone elements (AE#2) support macrotidal energy with more complete reworking of braid-deltaic sands; the mudrock elements reflect either braid-delta channel abandonment or uppermost tidal flat deposition (Eriksson et al., 1995). Overall, thus, a set of braid-deltaic systems are thought to have debouched directly into high energy peritidal flats around the margins of the Silverton-Magaliesberg epeiric sea, with similar channel dynamics (braided pattern; predominant bedload sedimentation) inferred for both braid-delta and tidal channel systems (Eriksson et al., 1995, 2002b, 2008) (Fig. 4).

4. Mat features in the Pretoria Group

4.1. Magaliesberg Formation

The predominant sandstone sheets discussed in the previous section for this formation crop out as thin (few cm to several dm thick on average) sandstone beds, and these are commonly covered with pervasive and perfectly preserved ripple marks, mainly of wave type and with bifurcation and varying crest alignments (Parizot et al., 2005), forming ripple fields of enormous lateral extent (Fig. 5) (Eriksson et al., 2010). The resultant repeated rippled sandstone bed surfaces are analogous to palimpsest ripples, where a microbial mat is inferred to have protected ripples from erosion preceding or

accompanying deposition of the succeeding arenaceous bed (cf., Pflüger, 1999; Schieber, 2004; Bottjer and Hagadorn, 2007; Eriksson et al., 2007).

A wide range of other MRS occur on Magaliesberg sandstone sheet upper surfaces, including reasonably common (but not pervasive like the palimpsest ripples) cracked sand layers and petee ridges (e.g., Bosch and Eriksson, 2008), as well as only localized occurrences of ripple-crest cracks, "elephant skin textures", wrinkle structures and *Manchuriophycus* (sinuous ripple trough sand cracks) (Eriksson et al., 2010) (Fig. 6). Parizot et al. (2005) used the dimensions of the pervasive ripples to estimate water depths and wave heights (using the Tanner 1967, 1971 formulae) along the epeiric sea coastline for the other MRS, with the assumption that relatively more distal deeper water conditions were indicated by greater values for both water depth and wave height. Within this context, Parizot et al. (2005) were able to postulate (based on spatial relations between mat features and other sedimentary structures) a lateral arrangement of *Manchuriophycus* – petee ridges – ripple-crest cracks, respectively ordered from more proximal to more distal; Eriksson et al. (2010) noted a caveat in this regard that time differences implicit in the periods required for mat growth (at least several weeks; cf. Gerdes and Klenke, 2003, 2007) would impinge on the postulated arrangement. The genesis of these various MRS along the Magaliesberg littoral are discussed in detail by Parizot et al. (2005), Bosch and Eriksson (2008) and Eriksson et al. (2010).

4.2. Daspoort Formation

In an ongoing study of the sedimentology of this formation (MSc thesis of second author), based on 15 measured profiles along an E-W transect across the preserved Daspoort basin, MRS were only identified at two field localities, one in the far east of the basin, at its southern extremity, and a second to the east of Pretoria (localities shown on Fig. 3). These MRS comprise petee ridges and cracked sand layers at the SE locality, and sand cracks superimposed on ripples east of Pretoria. In both cases, the MRS appear to be limited in occurrence. The pervasive palimpsest ripples typical of the Magaliesberg Formation and the rich variety of MRS to be found at many localities in this unit apart from these ripples are not observed in the Daspoort outcrops.

5. Discussion and conclusions

Both Daspoort and Magaliesberg formations are interpreted as reflecting the interplay of braided fluvial deposition and shallow epeiric reworking taking place largely through tidal processes. Relatively thin (cm to dm) sheets of mostly mature quartzose sandstones, which have been extensively recrystallised locally, characterise both formations (section 3). The Daspoort fluvial sandstones exhibit evidence for tidal reworking across the basin from east to west, as the Silverton epeiric sea advanced onto the craton from a shallow eastern Daspoort basin; a high rate of transgression may be inferred from the predominant fluvial facies preserved in the Daspoort rather than voluminous epeiric marine facies (on the basinal scale) (Eriksson and Catuneanu, 2004). In contrast, the Magaliesberg

Formation, where essentially aggradational fluvial facies advanced predominantly from west to east, is characterized by a much greater degree of epeiric marine (tidal) influence, as inferred from the predominantly littoral facies preserved in this unit (Parizot et al., 2005). This suggests that Magaliesberg highstand aggradation was relatively slow compared to Daspoort transgression, allowing more thorough reworking. A distinctly episodic clastic sedimentation regime is argued for the Magaliesberg palaeoenvironment (summarized in Fig. 4) by Eriksson et al. (2009), on various grounds, including the need to accommodate non-burial of mats implicit in the formation of MRS (cf., Gerdes and Klenke, 2003, 2007).

Microbial mats are expected to flourish in any moist clastic system where their nutritional and energy requirements can be met (e.g., Schieber et al., 2007 a, c), and the braided fluvial – epeiric littoral setting envisaged for both Daspoort and Magaliesberg formations would seem to meet this requirement. However, the pervasive large palimpsest ripple fields complemented by a rich variety of associated MRS observed at most extensive outcrops of the latter unit (Parizot et al., 2005; Bosch and Eriksson, 2008; Eriksson et al., 2010), contrast strongly with the near-absence of MRS in the Daspoort outcrops. As has been discussed in section 2 of this paper, for both modern and ancient mats (including Precambrian examples) growing on clastic substrates, a school of thought supports a bias in the occurrence of MRS in the shallow marine – tidal flat- supratidal setting-sabkha environmental continuum (e.g., Schieber, 1998; Gerdes et al., 2000; Noffke et al., 2001b; Schieber et al., 2007a; Gerdes, 2007; Bose and Chafetz, 2009; Noffke, 2010). The widespread occurrence of MRS in the Magaliesberg Formation supports the view that

these mat-related features might be partially diagnostic of such coastal palaeoenvironmental settings, but the paucity of Daspoort MRS does not. However, the Daspoort Formation (as preserved across the basin) is dominated by fluvial deposits, and this could be argued to be the reason for the poor MRS development in this unit; the littoral-supralittoral palaeoenvironmental bias is thus possibly still relevant for this formation also, but affected by preservation potential.

The inference that MRS might also have sequence stratigraphic connotations, notably denoting transgression-regression cycles (e.g., Noffke et al., 2006; Noffke, 2007, 2010) seems to be supported by the combination of the Daspoort-Silverton-Magaliesberg succession, which together mark such a second-order sequence stratigraphic cycle. As a caveat however, it should be noted that Noffke (op. cit.) might be referring to higher order cyclicity than second-order. The observed prevalence of Magaliesberg MRS from an inferred coastal (-fluvial) setting compared to their paucity in the analogous Daspoort fluvial (-coastal) palaeoenvironment, can be taken as indicating support for the viewpoint that MRS might more often be facies-specific. This relationship might however owe much to preservation potential; preservation of coastal facies within a second-order transgresive systems tract will be low due to the transgressive ravinement erosion (Daspoort case), while preservation of coastal facies within the highstand systems tract, where progradation and aggradation occur (Magaliesberg case), will be high (e.g., Catuneanu, 2006). Quite apart from the possible veracity of any environmental bias (or lack thereof) of MRS, detailed genetic processes which can be read through careful study of MRS, can well complement standard clastic sedimentary facies analysis (e.g., Schieber

et al., 2007a). This point is reinforced by the seminal work of Noffke (2001a), wherein she coined the term MISS (microbially-induced sedimentary structures), and wherein she suggested they be added as a new group to the existing classification schemes for the physically formed sedimentary structures (see also, Noffke, 2010).

Clastic sedimentary structures, as well as MISS/MRS are amongst the building blocks for palaeoenvironmental modeling in classic sedimentological technique; equally, the palaeoenvironmental modeling helps in defining stratigraphic architecture and systems tract arrangements in three-dimensional space. However, the caveat must be made, that the binding properties of microbial mats, operating on clastic sediment particles, can still lead to certain apparently anomalous stratigraphic architecture being preserved, including a poor development or even near-absence of transgressive deposits as shown by some Indian case studies (e.g., Banerjee and Jeevankumar, 2005; Sarkar et al., 2005; Catuneanu et al., 2005; Catuneanu and Eriksson, 2007; Eriksson et al., 2010). Noffke (2010) notes that microbial mats thrive particularly during transgressions, but this inference is made on the basis of this situation creating large areas of shallow water habitat amenable to mat colonization, and the argument is not made on the basis of a sequence stratigraphic understanding of a transgression.

In a general sequence stratigraphic framework, the transgressive systems tract generally comprises transgressive fluvial to coastal facies which are commonly scoured at their top by transgressive (wave and tidal) ravinement surfaces. In turn, these scour surfaces are onlapped by transgressive shallow-marine strata (Catuneanu, 2006). Thus, the poor

development or even absence of the coastal portion of Precambrian transgressive systems tracts can be ascribed to strong wave/tidal-scouring into the upper shoreface to intertidal areas during transgression; this could have eroded all or a large part of the underlying coastal section during shoreline backstepping (Catuneanu, 2006; Eriksson et al., 2010). This scenario can be applied directly to the Daspoort Formation and the coeval onset of lowermost Silverton Formation transgression, hence explaining the paucity of MRS observed in field studies of the Daspoort outcrops. Erosional downcutting related to transgressive ravinement surfaces is generally of the order of 20 m for Phanerozoic deposits (Demarest and Kraft, 1987), but exceptionally high values ≤40 m have been reported for the extant Canterbury Plains coastline (Leckie, 1994). If such enhanced erosion applied to the Precambrian era (Eriksson et al., 2010), this provides a reasonable explanation for what is observed in the Daspoort Formation in the present study. Exposure of the Daspoort-Silverton contact in the field is poor and we have yet to identify such postulated scour features. However, our hypothesis for the poorly preserved Daspoort MRS also accords with the essence of the findings of the Indian case studies alluded to above (Banerjee and Jeevankumar, 2005; Sarkar et al., 2005; Catuneanu et al., 2005; Catuneanu and Eriksson, 2007; Eriksson et al., 2010).

In conclusion thus, we surmise that microbial mats and their resultant MRS were not absent in the Palaeoproterozoic Daspoort Formation depositional environment itself, but that they rather had a very low preservation potential at the larger systems tract scale, within the overall second-order transgressive systems tract that characterized the Daspoort-Silverton transition, due to excessive erosion beneath the transgressive

ravinement surface that accompanied advance of the Silverton epeiric sea onto the Kaapvaal craton. This sequence stratigraphic situation did not apply to the interpreted second-order highstand systems tract and braided fluvial – epeiric marine palaeoenvironment inferred for the Magaliesberg Formation. In this scenario, our data suggest that the MRS might have both an environmental bias and a sequence stratigraphic connotation, thus providing an additional tool for integrated sedimentologic and sequence stratigraphic analysis. It should be noted however, that our inferences are based on second-order sequence stratigraphic modeling; higher-order modeling of the Daspoort and Magaliesberg successions, which has not yet been done (there is a lack of laterally extensive outcrops and seismic data are as yet unavailable for the typical narrow outcrops belts surrounding the Bushveld Complex intrusion in the centre of the Transvaal basin) might support a different conclusion.

Acknowledgements

References

Allen, J.R.L., 1983. Studies in fluviatile sedimentation: bars, bar-complexes and sandstone sheets (low sinuosity braided streams) in the Brownstones (L. Devonian), Welsh Borders. Sedimentary Geology 33, 237-293.

Altermann, W., Siegfried, H.P., 1997. Sedimentology, facies development and type-section of an Archaean shelf-carbonate platform transition, Kaapvaal Craton, as deduced from a deep borehole core at Kathu, South Africa. Journal of African Earth Sciences 24, 391-410.

Banerjee, S., Jeevankumar, S., 2005. Microbially originated wrinkle structures on sandstone and their stratigraphic context: Palaeoproterozoic Koldaha Shale, central India. Sedimentary Geology 176, 211-224.

Bekker, A., Kaufman, A.J., Karhu, J.A., Beukes, N.J., Swart, Q.D., Coetzee, L.L., Eriksson, K.A., 2001. Chemostratigraphy of the Paleoproterozoic Duitschland Formation, South Africa: implications for coupled climate change and carbon cycling. American Journal of Science 301, 261-285.

Bosch, P.J.A., Eriksson, P.G., 2008. A note on two occurrences of inferred microbial mat features preserved in the c. 2.1 Ga Magaliesberg Formation (Pretoria Group, Transvaal

Supergroup) sandstones, near Pretoria, South Africa. South African Journal of Geology 111, 251-262.

Bose, P.K., Eriksson, P.G., Sarkar, S., Wright, D.T., Samanta, P., Mukhopadhyay, S., Mandal, S., Banerjee, S., Altermann, W., in press. Sedimentation patterns during the Precambrian: a unique record? Marine and Petroleum Geology. doi.10.1016/j.marpetgeo.2010.11.002.

Bose, S., Chafetz, H.S., 2009. Topographic control on distribution of modern microbially induced sedimentary structures (MISS): A case study from Texas coast. Sedimentary Geology 213, 136-149.

Bottjer, D., Hagadorn, J.W., 2007. Mat growth features. In: Schieber, J., Bose, P.K., Eriksson, P.G., Banerjee, S., Sarkar, S., Altermann, W., Catuneanu, O. (Eds.), Atlas of Microbial Mat Features Preserved within the Siliciclastic Rock Record. Atlases in Geoscience 2, Elsevier, Amsterdam, pp. 53-71.

Buick, I.S., Maas, R., Gibson, R., 2001. Precise U-Pb titanite age constraints on the emplacement of the Bushveld Complex, South Africa. Journal of the Geological Society, London 158, 3-6.

Bumby, A.J., Eriksson, P.G., van der Merwe, R., 1998. Compressive deformation in the floor rocks to the Bushveld Complex (South Africa): evidence from the Rustenburg Fault Zone. Journal of African Earth Sciences 27, 307-330.

Catuneanu, O., 2006. Principles of Sequence Stratigraphy, 1st ed. Elsevier, Amsterdam, 375 pp.

Catuneanu, O., 2007. Sequence stratigraphic context of microbial mat features. In: Schieber, J., Bose, P.K., Eriksson, P.G., Banerjee, S., Sarkar, S., Altermann, W., Catuneanu, O. (Eds.), Atlas of Microbial Mat Features Preserved within the Siliciclastic Rock Record. Atlases in Geoscience 2, Elsevier, Amsterdam, pp. 276-283.

Catuneanu, O., Eriksson, P.G., 1999. The sequence stratigraphic concept and the Precambrian rock record: an example from the 2.7-2.1 Ga Transvaal Supergroup, Kaapvaal craton. Precambrian Research 97, 215-251.

Catuneanu, O., Eriksson, P.G., 2002. Sequence stratigraphy of the Precambrian Rooihoogte-Timeball Hill rift succession, Transvaal Basin, South Africa. Sedimentary Geology 147, 71-88.

Catuneanu, O., Eriksson, P.G., 2007. Sequence stratigraphy of the Precambrian. Gondwana Research 12(4), 560-565.

Catuneanu, C., Martins-Neto, M.A., Eriksson, P.G., 2005. Precambrian sequence stratigraphy. Sedimentary Geology 176, 67-95.

Coetzee, L.L., Beukes, N.J., Gutzmer, J., Kakegawa, T., 2006. Links of organic carbon cycling and burial to depositional depth gradients and establishment of a snowball Earth at 2.3 Ga. Evidence from the Timeball Hill Formation, Transvaal Supergroup, South Africa. South African Journal of Geology 109, 109-122.

Cornell, D.H., Schütte, S.S., Eglington, B.L., 1996. The Ongeluk basaltic andesite formation in Griqualand West, South Africa: submarine alteration in a 2222 Ma Proterozoic sea. Precambrian Research 79, 101-123.

Demarest, J.M., Kraft, J.C., 1987. Stratigraphic record of Quaternary sea levels: implications for more ancient strata. In: Nummedal, D., Pilkey, O.H., Howard, J.D. (Eds.), Sea Level Fluctuation and Coastal Evolution. Special Publication 41, Society for Economic Paleontologists and Mineralogists, Tulsa, OK, pp. 223-239.

Dorland, H.C., Beukes, N.J., Gutzmer, J., Evans, D.A.D., Armstrong, R.A., 2004. Trends in detrital zircon provenance from Neoarchaean-Palaeoproterozoic sedimentary successions on the Kaapvaal craton: Abstract volume, Geoscience Africa 2004 Congress, Geological Society of South Africa, Johannesburg, pp. 176-177.

Els, B.G., van den Berg, W.A., Mayer, J.J., 1995. The Black Reef Quartzite Formation in the western Transvaal: sedimentological and economic aspects, and significance for basin evolution. Mineralium Deposita 30, 112-123.

Eriksson, P.G., Catuneanu, O., 2004. Third-order sequence stratigraphy in the Palaeoproterozoic Daspoort Formation (Pretoria Group, Transvaal Supergroup), Kaapvaal craton. In: Eriksson, P.G., Altermann, W., Nelson, D.R., Mueller, W.U., Catuneanu, O. (Eds.), The Precambrian Earth: tempos and events. Elsevier, Amsterdam, pp. 724-735.

Eriksson, P.G., Reczko, B.F.F., 1995. The sedimentary and tectonic setting of the Transvaal Supergroup floor rocks to the Bushveld complex. Journal of African Earth Sciences 21, 487-504.

Eriksson, P.G., Schreiber, U.M., Van der Neut, M., 1991. A review of the sedimentology of the Early Proterozoic Pretoria Group, Transvaal Sequence, South Africa. Implications for tectonic setting. Journal of African Earth Sciences 13, 107-119.

Eriksson, P.G., Schreiber, U.M., Van der Neut, M., Labuschagne, H., van der Schyff, W., 1993. Alternative marine and fluvial models for the non-fossiliferous quartzitic sandstones of the Early Proterozoic Daspoort Formation, Transvaal Sequence of Southern Africa. Journal of African Earth Sciences 16, 344-366.

Eriksson, P.G., Reczko, B.F.F., Boshoff, A.J., Schreiber, U.M., Van der Neut, M., Snyman, C.P., 1995. Architectural elements from Lower Proterozoic braid-delta and high-energy tidal flat deposits in the Magaliesberg Formation, Transvaal Supergroup, South Africa. Sedimentary Geology 97, 99-117.

Eriksson, P.G., van der Merwe, R., Bumby, A.J., 1998. The Palaeoproterozoic Woodlands Formation of eastern Botswana - northwestern South Africa: lithostratigraphy and relationship with Transvaal basin inversion structures. Journal of African Earth Sciences 27(3-4), 349-358.

Eriksson, P.G., Simpson, E.L., Eriksson, K.A., Bumby, A.J., Steyn, G.L., Sarkar, S., 2000. Muddy roll-up structures in siliciclastic interdune beds of the ca. 1.8 Ga Waterberg Group, South Africa. Palaios 15, 177-183.

Eriksson, P.G., Altermann, W., Catuneanu, O., van der Merwe, R., Bumby, A.J., 2001. Major influences on the evolution of the 2.67-2.1 Ga Transvaal basin, Kaapvaal craton. Sedimentary Geology 141-142, 205-231.

Eriksson, P.G., Condie, K.CA., Westhuizen, W.V.D., Merwe, R.V.D., Bruiyn, H.D., Nelson, D.R., Altermann, W., Cunningham, M.J., 2002a. Late Archaean superplume events: A Kaapvaal-Pilbara perspective. Journal of Geodynamics 34, 207-247.

Eriksson, P.G., Altermann, W., Eberhardt, L., Ahrend-Heidbrinck, S., Bumby, A.J., 2002b. Palaeoproterozoic epeiric sea palaeoenvironments: the Silverton Formation (Pretoria Group, Transvaal Supergroup), South Africa. In: Altermann, W., Corcoran, P.L. (Eds.), Precambrian Sedimentary Environments: a modern approach to ancient depositional systems. Special Publication 33, International Association of Sedimentologists, Blackwell, Oxford, pp. 351-367.

Eriksson, P.G., Catuneanu, O., Els, B.G., Bumby, A.J., Van Rooy, J.L., Popa, M., 2005. Kaapvaal Craton: Changing first- and second-order controls on sea level from 3.0 Ga to 2.0 Ga. Sedimentary Geology 176, 121-148.

Eriksson, P.G., Altermann, W., Hartzer, F.J., 2006. The Transvaal Supergroup and its precursors, In: Johnson, M.R., Anhaeusser, C.R., Thomas, R.J. (Eds.) The Geology of South Africa. Geological Society of South Africa, Johannesburg and Council for Geoscience, Pretoria, pp. 237-260.

Eriksson, P.G., Schieber, J., Bouougri, E., Gerdes, G., Porada, H., Banerjee, S., Bose, P.K., Sarkar, S., 2007. Classification of structures left by microbial mats in their host sediments. In: Schieber, J., Bose, P.K., Eriksson, P.G., Banerjee, S., Sarkar, S., Altermann, W., Catuneanu, O. (Eds.), Atlas of Microbial Mat Features Preserved within the Siliciclastic Rock Record. Atlases in Geoscience 2, Elsevier, Amsterdam, pp. 39-52.

Eriksson, P.G., Bose, P.K., Catuneanu, O., Sarkar, S., Banerjee, S., 2008. Precambrian clastic epeiric embayments: examples from South Africa and India. In: Pratt, B.R., Holmden, C. (Eds.) Dynamics of epeiric seas. Special Paper 48, Geological Association of Canada, St. Johns, Newfoundland, pp. 119-136.

Eriksson, P.G., Rautenbach, C.J.deW., Wright, D.T., Bumby, A.J., Catuneanu, O., Mostert, P., van der Neut, M., 2009. Possible evidence for episodic epeiric marine and fluvial sedimentation (and implications for palaeoclimatic conditions), c. 2.3-1.8 Ga, Kaapvaal craton, South Africa. Palaeogeography, Palaeoclimatology, Palaeoecology 273, 153-173.

Eriksson, P.G., Sarkar, S., Banerjee, S., Porada, H., Catuneanu, O., Samanta, P., 2010. Paleoenvironmental context of microbial mat-related structures in siliciclastic rocks – examples from the Proterozoic of India and South Africa. In: Seckbach, J., Oren, A. (Eds.) Microbial Mats: Modern and Ancient Microorganisms in Stratified Systems. Springer, Berlin, pp. 73-108.

Fagerstrom, J.A., 1967. Development, flotation and transportation of mud crusts-neglected factors in sedimentology. Journal of Sedimentary Petrology 37, 73-79.

Frauenstein, F., Veizer, J., Beukes, N., van Niekerk, H.S., Coetzee, L.L., 2009. Transvaal Supergroup carbonates: Implications for Paleoproterozoic δ^{18}O and δ^{13}C records. Precambrian Research 175, 149-160.

Gerdes, G., 2007. Structures left by modern microbial mats in their host sediments. In: Schieber, J., Bose, P.K., Eriksson, P.G., Banerjee, S., Sarkar, S., Altermann, W., Catuneanu, O. (Eds.), Atlas of Microbial Mat Features Preserved within the Siliciclastic Rock Record. Atlases in Geoscience 2, Elsevier, Amsterdam, pp. 5-38.

Gerdes, G., Klenke, T., 2003. Geologische Bedeutung ökologischer Zeiträume in biogener Schichtung (Mikrobenmatten, potentielle Stromatolithe). Journal of Alpine Geology (Mitteilungen der Gesellschaft der Geologie- und Bergbaustudenten in Österreich) 46, 35-49.

Gerdes, G., Klenke, T., 2007. States of biogenic bedding as records of the interplay of ecologic time and environment (a case study of modern siliciclastic sediments, Mellum Island, southern North Sea). Senckenbergiana Maritima 37(2), 129-144.

Gerdes, G., Krumbein, W.E., 1987. Biolaminated Deposits. In: Bhattacharya, G.M., Friedmann, G.M., Neugebauer, H.J., Seilacher, A. (Eds.), Lecture Notes in Earth Sciences 9. Springer-Verlag, Berlin, pp. 1-183.

Gerdes, G., Krumbein, W.E., Holtkamp, E.M., 1985a. Salinity and water activity related zonation of microbial communities and potential stromatolites of the Gavish Sabkha. In: Friedman, G.M., Krumbein, W.E. (Eds.), Hypersaline Ecosystems: the Gavish Sabkha. Springer-Verlag, Berlin, pp. 238-266.

Gerdes, G., Krumbein, W.E., Reineck, H.E., 1985b. The depositional record of sandy, versicoloured tidal flats (Mellum Island, southern North Sea). Journal of Sedimentary Petrology 55, 265-278.

Gerdes, G., Krumbein, W.E., Reineck, H.E., 1985c. Verbreitung und aktuogeologische Bedeutung mariner mikrobieller Matten im Gezeitenbereich der Nordsee. Facies 12, 75-96.

Gerdes, G., Klenke, Th., Noffke, N., 2000. Microbial signatures in peritidal siliciclastic sediments: a catalogue. Sedimentology 47, 279-308.

Hannah, J.L., Bekker, A., Stein, H.J., Markey, R.J., Holland, H.D., 2004. Primitive Os and 2316 Ma age for marine shale: implications for Paleoproterozoic glacial events and the rise of atmospheric oxygen. Earth and Planetary Science Letters 225, 43-52.

Knoll, A.H., Beukes, N.J., 2009. Introduction: Initial investigations of a Neoarchean shelf margin-basin transition (Transvaal Supergroup, South Africa). Precambrian Research 169(1-4), 1-14.

Krumbein, W.E., Brehm, U., Gerdes, G., Gorbushina, A.A., Levit, G., Palinska, K.A., 2003. Biofilm, biodictyon, biomat, microbialites, oolites, stromatolites, geophysiology,

global mechanism, parahistology. In: Krumbein, W.E., Paterson, G.A., Zavarzin, G.A. (Eds.), Fossil and Recent Biofilms. Kluwer Academic Publishers, Dordrecht, pp. 1-27.

Leckie, D.A., 1994. Canterbury Plains, New Zealand - Implications for sequence stratigraphic models. American Association of Petroleum Geologists Bulletin 78, 1240-1256.

Mapeo, R.B.M., Armstrong, R.A., Kampunzu, A.B., Modisi, M.P., Ramokate, L.V., Modie, B.N.J., 2006. A ca. 200 Ma hiatus between the Lower and Upper Transvaal Groups of southern Africa: SHRIMP U-Pb detrital zircon evidence from the Segwagwa Group, Botswana: Implications for Palaeoproterozoic glaciations. Earth and Planetary Science Letters 244, 113-132.

Miall, A.D., 1985. Architectural-element analysis; a new method of facies analysis applied to fluvial deposits. Earth Science Reviews 22, 261-308.

Miall, A.D., 1988. Reservoir heterogeneities in fluvial sandstones: lessons from outcrop studies. Bull. American Association of Petroleum Geologists Bulletin 72, 682-697.

Moore, J.M., Tsikos, H., Polteau, S., 2001. Deconstructing the Transvaal Supergroup, South Africa: implications for Palaeoproterozoic palaeoclimate models. Journal of African Earth Sciences 33, 437-444.

Noffke, N., 2007. Microbially-induced sedimentary structures (MISS) of Early and Middle Archaean ages – Moodies Group, Pongola Supergroup, Witwatersrand Supergroup (South Africa). In: Schieber, J., Bose, P.K., Eriksson, P.G., Banerjee, S., Sarkar, S., Altermann, W., Catuneanu, O. (Eds.), Atlas of Microbial Mat Features Preserved within the Siliciclastic Rock Record. Atlases in Geoscience 2, Elsevier, Amsterdam, pp. 153-157.

Noffke, N., 2010. Geobiology: Microbial mats in sandy deposits from the Archean Era to today. Springer, Berlin, 194 pp.

Noffke, N., Gerdes, G., Klenke, T., Krumbein, W.E., 2001a. Microbially induced sedimentary structures - a new category within the classification of primary sedimentary structures. Journal of Sedimentary Research A71, 649-656.

Noffke, N., Gerdes, G., Klenke, T., Krumbein, W., 2001b. Microbially induced sedimentary structures indicating climatological, hydrological and depositional conditions within Recent and Pleistocene coastal facies zones (Southern Tunisia). Facies 44, 23-30.

Noffke, N., Eriksson, K.A., Hazen, R.M., Simpson, E. L., 2006. A new window into Early Archean life: microbial mats in Earth's oldest siliciclastic deposits (3.2 Ga Moodies Group, South Africa). Geology 34, 253-256.

Olsson, J.R., Söderlund, U., Klausen, M.B., Ernst, R.E., 2010. U–Pb baddeleyite ages linking major Archean dyke swarms to volcanic-rift forming events in the Kaapvaal craton (South Africa), and a precise age for the Bushveld Complex. Precambrian Research 183(3), 490-500.

Parizot, M., Eriksson, P.G., Aifa, T., Sarkar, S., Banerjee, S., Catuneanu, O., Altermann, W., Bumby, A.J., Bordy, E.M., Louis van Rooy, J., Boshoff, A.J., 2005. Suspected microbial mat-related crack-like sedimentary structures in the Palaeoproterozoic Magaliesberg Formation sandstones, South Africa. Precambrian Research 138, 274-296.

Pflüger, F., 1999. Matground structures and redox facies. Palaios 14, 25-39.

Sarkar, S., Banerjee, S., Eriksson, P.G., Catuneanu, O., 2005. Microbial mat control on siliciclastic Precambrian sequence stratigraphic architecture: examples from India. Sedimentary Geology 176, 195-209.

Sarkar, S., Bose, P.K., Samanta, P., Sengupta, P., Eriksson, P.G., 2008. Microbial mat-mediated structures in the Ediacaran Sonia sandstone, Rajasthan, India and their implications for Proterozoic sedimentation. Precambrian Research 162, 248-263.

Schieber, J., 1998. Possible indicators of microbial mat deposits in shales and sandstones: examples from the Mid-Proterozoic Belt Supergroup, Montana, USA. Sedimentary Geology 120, 105-124.

Schieber, J., 1999. Microbial mats in terrigenous clastics: the challenge of identification in the rock record. Palaios 14**,** 3-12.

Schieber, J., 2004. Microbial mats in the siliciclastic rock record: a summary of the diagnostic features. In: Eriksson, P.G., Altermann, W., Nelson, D.R., Mueller, W.U., Catuneanu, O. (Eds.), The Precambrian Earth: Tempos and Events. Developments in Precambrian Geology 12, Elsevier, Amsterdam, pp. 663-673.

Schieber, J., 2007. Flume experiments on the durability of sandy microbial mat fragments during transport. In: Schieber, J., Bose, P.K., Eriksson, P.G., Banerjee, S., Sarkar, S., Altermann, W., Catuneanu, O. (Eds.), Atlas of Microbial Mat Features Preserved within the Siliciclastic Rock Record. Atlases in Geoscience 2, Elsevier, Amsterdam, pp. 248-257.

Schieber, J., Bose, P.K., Eriksson, P.G., Banerjee, S., Sarkar, S., Altermann, W., Catuneanu, O., 2007a. Prologue: An introduction to microbial mats. In: Schieber, J., Bose, P.K., Eriksson, P.G., Banerjee, S., Sarkar, S., Altermann, W., Catuneanu, O., (Eds.) Atlas of Microbial Mat Features Preserved within the Siliciclastic Rock Record. Atlases in Geoscience 2, Elsevier, Amsterdam, pp. 1-3.

Schieber, J., Bose, P.K., Eriksson, P.G., Banerjee, S., Sarkar, S., Altermann, W., Catuneanu, O. (Eds.), 2007b. Atlas of Microbial Mat Features Preserved within the Siliciclastic Rock Record, Atlases in Geoscience 2, Elsevier, Amsterdam, 311 pp.

Schieber, J., Bose, P.K., Eriksson, P.G., Sarkar, S., 2007c. Palaeogeography of microbial mats in terrigenous clastics – environmental distribution of associated sedimentary features and the role of geologic time. In: Schieber, J., Bose, P.K., Eriksson, P.G., Banerjee, S., Sarkar, S., Altermann, W., Catuneanu, O. (Eds.), Atlas of Microbial Mat Features Preserved within the Siliciclastic Rock Record. Atlases in Geoscience 2, Elsevier, Amsterdam, pp. 267-275.

Schneider, J., 1995. Eindunstung von Meerwasser und Salzbildung in Salinen. Kali Steinsalz 11, 325-330.

Tanner, W.F., 1967. Ripple mark indices and their uses. Sedimentology 9, 89-104.

Tanner, W.F., 1971. Numerical estimates of ancient waves, water depths and fetch. Sedimentology 16, 71-88.

Van der Westhuizen, W.A., de Bruiyn, H., Meintjies, P.G., 1991. The Ventersdorp Supergroup: an overview. Journal of African Earth Sciences 13, 83-105.

Visser, J.N.J., 1971. The deposition of the Griquatown Glacial Member in the Transvaal Supergroup. Transactions of the Geological Society of South Africa 74, 187-199.

Figure captions:

Fig. 1. Sketch map showing the three preservational sub-basins of the Transvaal Supergroup: Transvaal itself, separated from the Griqualand West sub-basin by the Vryburg Rise palaeohigh, and the Kanye sub-basin in Botswana, north of the palaeohigh.

Fig. 2. Schematic geodynamic history chart proposed for the Transvaal Supergroup (first-order sequence) in the Transvaal basin: summarizes lithostratigraphy, chronology, inferred depositional paleoenvironments and tectonic settings, as well as interpreted second- and third-order sequence stratigraphy (modified after Catuneanu and Eriksson 1999; Eriksson et al., 2001). Age near base of Pretoria Group (lower Timeball Hill Formation) is from Hannah et al. (2004) with remaining age data from references in Eriksson et al. (2001). Note the Daspoort and Magaliesberg Formations, discussed in this paper, near the top of the uppermost Pretoria Group, in the middle of the youngest second-order sequence, concomitant with the base-level maximum.

Fig. 3. Schematic illustration of vertical and lateral arrangements of facies/facies associations, as identified at field sites across the preserved Daspoort basin (modified from Eriksson et al., 1993; Eriksson and Catuneanu, 2004). Note two field localities indicated, where mat-related features were found.

Fig. 4. Schematic sketch of palaeoenvironmental model postulated for the fine-clastic epeiric sea interpreted for the Silverton Formation, and its sandy coastal zone interpreted for the Magaliesberg Formation. Modified after Eriksson et al. (2008).

Fig. 5. Typical large exposed bed surface from the Magaliesberg Formation, covered by pervasive wave ripples (Enzelsburg Mountain, Marico area, western Pretoria Group basin); note perfectly preserved ripple crests, exhibiting slight sinuosity and bifurcation (open compass for scale in foreground). The preservation of stacked sets of thin sandstone beds with similar extensive rippled surfaces virtually throughout the succession and exposures of the Magaliesberg Formation supports an interpretation of individual rippled beds as palimpsest ripples related to microbial mat growth (see text). Photo: courtesy of Hermann Labuschagne.

Figure 6. Mat-related structures (MRS) from the Magaliesberg Formation collected from two study sites and typical of the MRS to be found associated with the ripple fields (Fig. 5) at most outcrops. (A) Polygonal petee ridges, showing two orders; (B) *Manchuriophycus*, sinuous sand cracks formed within ripple troughs (photo: Pieter Bosch); (C) reticulate crack pattern of "elephant skin texture", preserved as negative features on the sole of a sandstone bed; (D) ripple crest sand cracks; note secondary cracks cutting across ripple troughs, and main crack bifurcation; (E) sand cracks, localized within ripple troughs; in contrast to those shown in B (*Manchuriophycus*), these cracks are relatively straight and approximately parallel to ripple crests; (F) wrinkle structures (top left part of block near pen) passing into wedge-shaped petee ridges (bottom right of drilled quarry block). Modified from Eriksson et al. (2010).
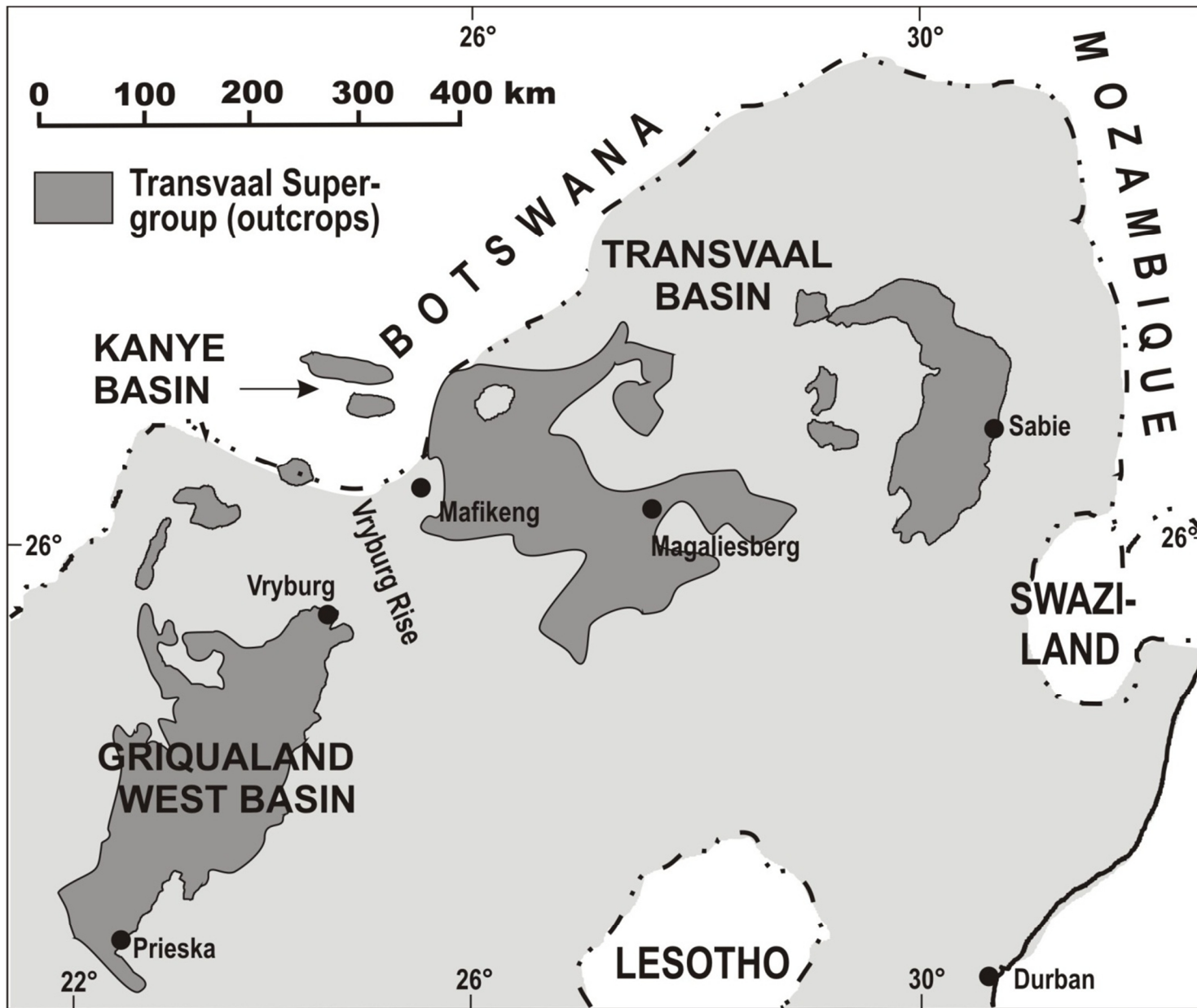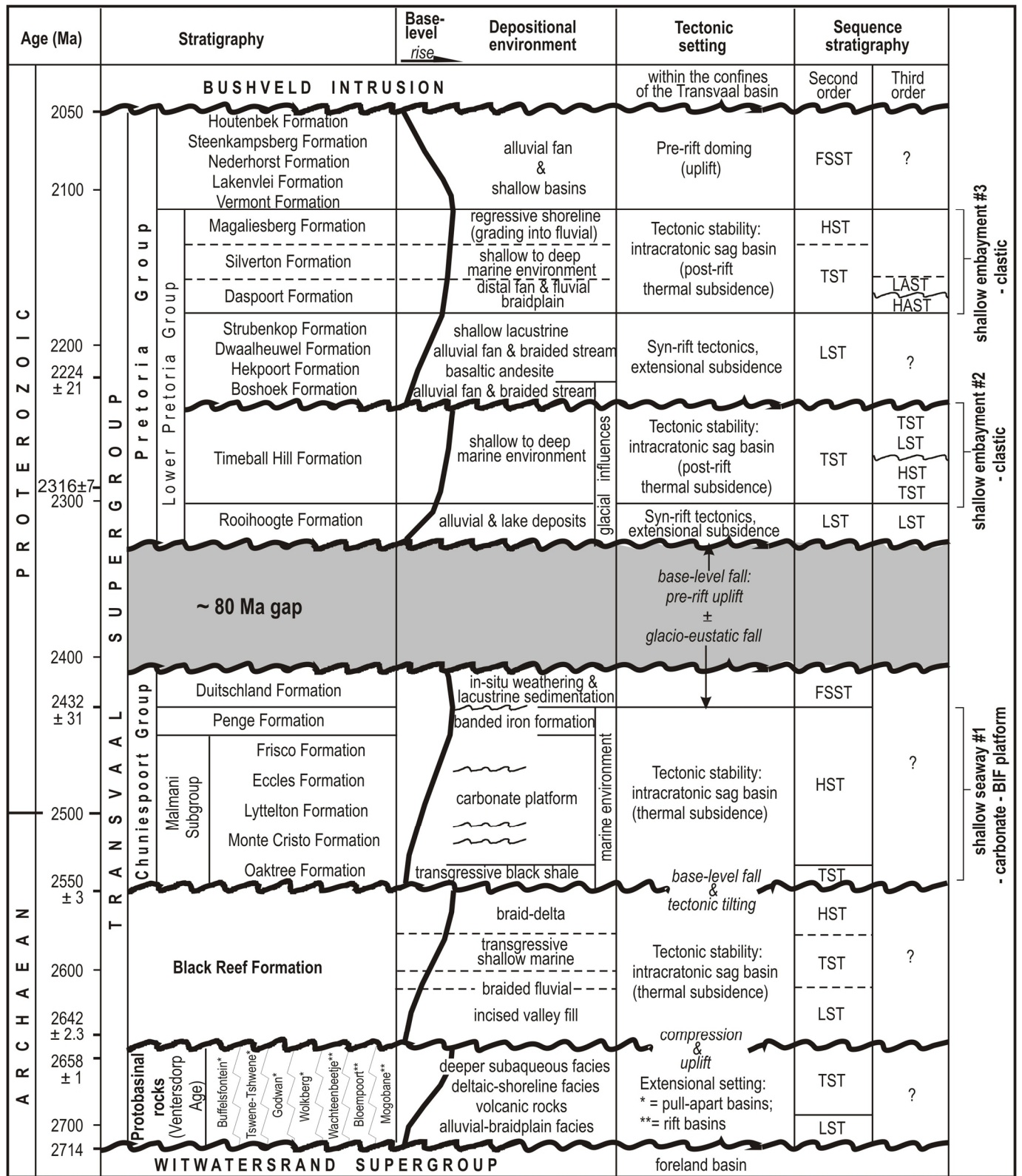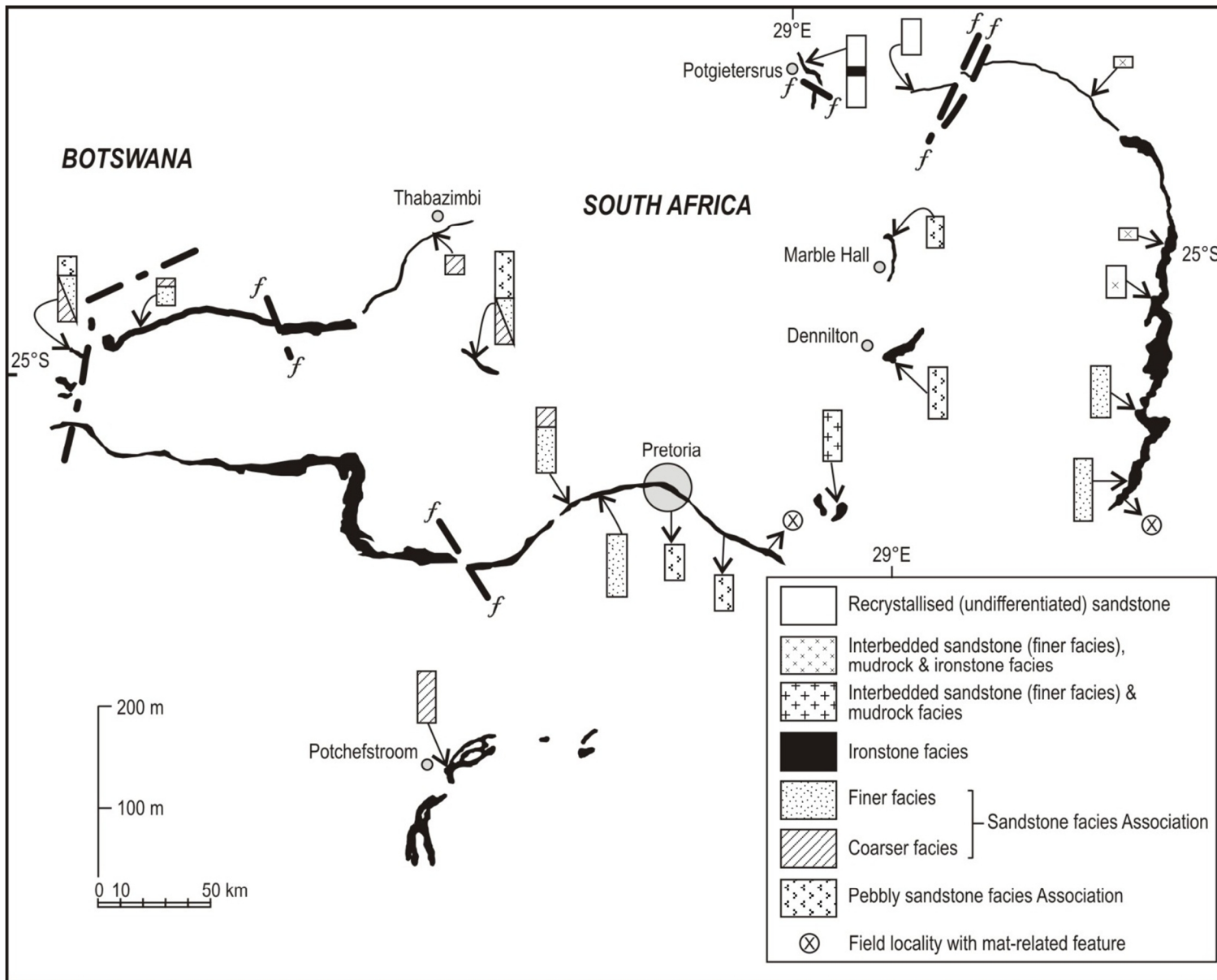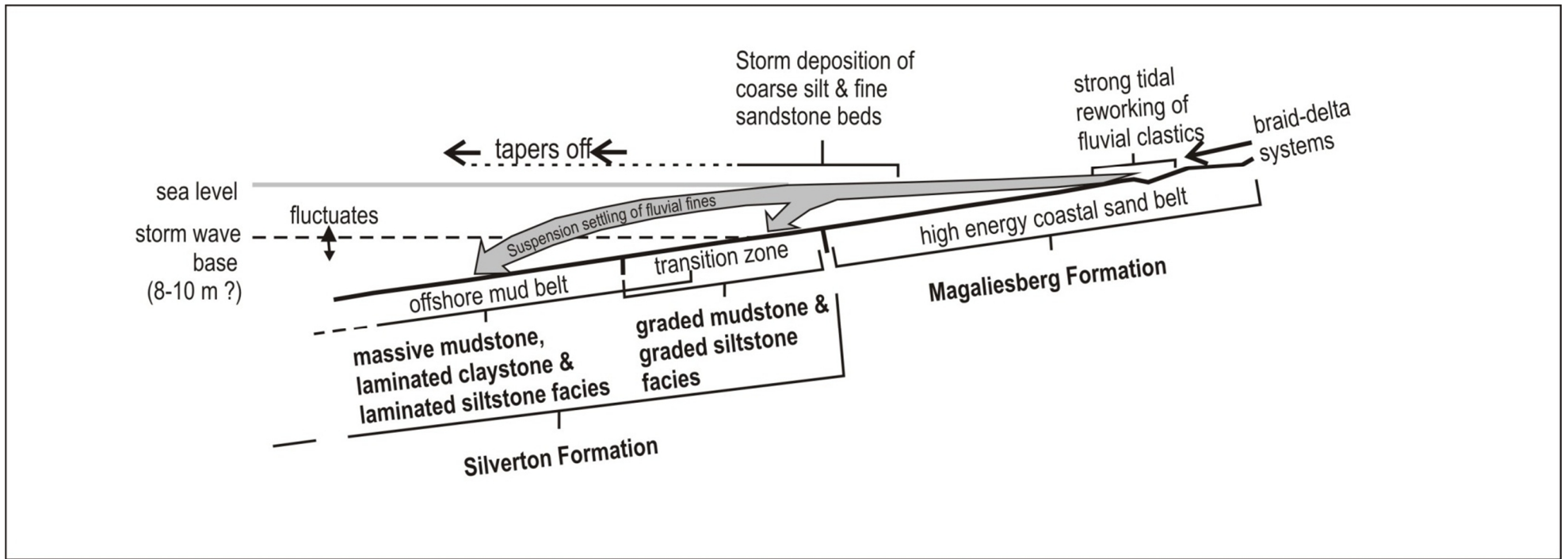
Figure 1

Figure 2

Age (Ma)	Stratigraphy	Base-level rise	Depositional environment	Tectonic setting	Sequence stratigraphy — Second order	Sequence stratigraphy — Third order	
2050	**BUSHVELD INTRUSION**			within the confines of the Transvaal basin	Second order	Third order	
2100	Houtenbek Formation / Steenkampsberg Formation / Nederhorst Formation / Lakenvlei Formation / Vermont Formation		alluvial fan & shallow basins	Pre-rift doming (uplift)	FSST	?	shallow embayment #3 - clastic
	Magaliesberg Formation		regressive shoreline (grading into fluvial)	Tectonic stability: intracratonic sag basin (post-rift thermal subsidence)	HST		
	Silverton Formation		shallow to deep marine environment		TST	LAST	
	Daspoort Formation		distal fan & fluvial braidplain			HAST	
2200	Strubenkop Formation / Dwaalheuwel Formation / Hekpoort Formation / Boshoek Formation		shallow lacustrine / alluvial fan & braided stream / basaltic andesite / alluvial fan & braided stream	Syn-rift tectonics, extensional subsidence	LST	?	shallow embayment #2 - clastic
2224 ± 21							
2316±7	Timeball Hill Formation		shallow to deep marine environment	Tectonic stability: intracratonic sag basin (post-rift thermal subsidence)	TST	TST / LST / HST / TST	
2300	Rooihoogte Formation		alluvial & lake deposits	Syn-rift tectonics, extensional subsidence	LST	LST	
	~ 80 Ma gap			base-level fall: pre-rift uplift ± glacio-eustatic fall			
2432 ± 31	Duitschland Formation		in-situ weathering & lacustrine sedimentation		FSST		shallow seaway #1 - carbonate - BIF platform
	Penge Formation		banded iron formation			?	
	Frisco Formation			Tectonic stability: intracratonic sag basin (thermal subsidence)	HST		
2500	Eccles Formation		carbonate platform				
	Lyttelton Formation						
	Monte Cristo Formation						
2550 ± 3	Oaktree Formation		transgressive black shale	base-level fall & tectonic tilting	TST		
	Black Reef Formation		braid-delta	HST			
2600			transgressive shallow marine	Tectonic stability: intracratonic sag basin (thermal subsidence)	TST	?	
			braided fluvial				
2642 ± 2.3			incised valley fill		LST		
2658 ± 1	Protobasinal rocks (Ventersdorp Age) — Buffelsfontein* / Tswene-Tswene* / Godwan* / Wolkberg / Wachteenbeetje** / Bloempoort** / Mogobane**		deeper subaqueous facies / deltaic-shoreline facies / volcanic rocks / alluvial-braidplain facies	compression & uplift; Extensional setting: * = pull-apart basins; ** = rift basins	TST	?	
2700					LST		
2714	**WITWATERSRAND SUPERGROUP**			foreland basin			

Left margin era column: PROTEROZOIC / ARCHAEAN
Supergroup column: SUPERGROUP / TRANSVAAL
Group columns: Pretoria Group / Lower Pretoria Group / Chuniespoort Group / Malmani Subgroup

Figure 3

Figure 4

Figure 5

Figure 6