PALAEONTOLOGICAL HERITAGE ASSESSMENT: COMBINED DESKTOP & FIELD-BASED STUDY

Proposed PV Solar Facility on a portion of the farm Waterloo 992 near Vryburg, Naledi Local Municipality, North-West Province

John E. Almond PhD (Cantab.)
***Natura Viva* cc, PO Box 12410 Mill Street,**
Cape Town 8010, RSA
naturaviva@universe.co.za

January 2013

EXECUTIVE SUMMARY

The company DPS79 Solar Energy (Pty) Ltd. is proposing to construct a 75 MW photovoltaic solar facility on the southern portion of the farm Waterloo 992 some 10 km southeast of Vryburg (Naledi Local Municipality), North-West Province. The study area is largely underlain by late Archaean (*c*. 2.6 billion year-old) sedimentary and volcanic rocks of the Schmidtsdrif Subgroup (Ghaap Group, Transvaal Supergroup). These comprise fluvial quartzites, mudrocks and volcanic rocks of the Vryburg Formation as well as shallow marine carbonates and siliciclastic sediments of the slightly younger Boomplaas Formation. A stratotype section of the Vryburg Formation has been designated on Waterloo Farm by Smit *et al.* (1991) because of the exceptionally good exposure of the basal quartzitic and volcanic successions here, including the eponymous Waterloo Member lavas. The Vryburg rocks in this area are apparently unfossiliferous, however, although intertidal stromatolites (microbial mounds) are known from marine intercalations within this rock unit further to the south.

Poorly- to well-preserved, secondarily silicified stromatolite assemblages are recorded within the Boomplaas Formation carbonate rocks on the southern portion of Waterloo Farm, including within the proposed solar plant development area. A range of stromatolite growth types is represented here, from small cm-scale buttons to cauliflower-like heads and large domes up to two meters or more in width. Bedrock exposure is very poor and many of the stromatolites have been planed down by erosion. Due to high levels of gravelly soil cover and dense vegetation (including summer grasses) within the development area it was not possible to map the occurrence of stromatolites here. The Boomplaas Formation stromatolites represent some of the oldest examples of these microbially generated fossils in South Africa but they have yet to be comprehensively described while their stratigraphic and geographical distributions are poorly understood.

Given these uncertainties, the overall impact of the proposed solar plant development on the southern portion of Waterloo 992 is provisionally rated as of NEGATIVE MEDIUM SIGNIFICANCE in palaeontological heritage terms. Recommended mitigation of the inevitable damage and destruction of fossil stromatolites within the proposed development area involves the surveying, recording, description and judicious sampling of well-preserved fossil occurrences within the development footprint by a professional palaeontologist. This work should take place after initial vegetation clearance has taken place but *before* the ground is leveled for construction.The palaeontologist concerned would need to apply beforehand for a fossil collection permit from SAHRA. These recommendations should be incorporated into the Environmental Management Plan for the Waterloo solar plant project.

1. INTRODUCTION & BRIEF

The company DPS79 Solar Energy (Pty) Ltd. is proposing to construct a 75 MW photovoltaic solar facility on a portion of the farm Waterloo 992 situated approximately 10 km southeast of the town of Vryburg (Naledi Local Municipality), North-West Province (NEAS Reference: DEA/EIA/0001090/2012; DEA Reference: 14/12/16/3/3/2/308). The study site is situated on flat lying terrain in the southeastern portion of the farm, 1.3 km east of the Droë Harts River and 2.5 km east of the N18 tar road from Vryburg to Kimberley. The location of the study area is shown on the map Fig. 1 and a satellite image of the area is shown in Fig. 2.

The footprint of the proposed alternative energy project will be approximately 150 hectares (including supporting infrastructure). The main infrastructural components of the solar facility that are of relevance to the present fossil heritage study include:

- a photovoltaic (PV) panel array tilted at a fixed angle towards the north;
- building infrastructure including a new on-site control facility, security, office and warehouse with a total footprint of 400 m^2 or less;
- electrical infrastructure including an on-site 33/132 kV distribution substation (90 m x 120 m) located close to existing powerlines and connected to the new Mookodi Substation situated *c*. 5 km west of the site;
- new or upgraded gravels roads (4 m wide) forming an internal site road network (total area *c*. 40 000 $m^{2)}$;
- a laydown area (*c*. 13 400 m^2);
- fencing round the solar facility.

The proposed solar energy facility overlies potentially fossiliferous sediments of the Ghaap Group (Transvaal Supergroup). Fossils preserved within the bedrock or superficial deposits may be disturbed, damaged or destroyed during the construction phase of the proposed project. The extent of the proposed development (over 5000 m^2) falls within the requirements for a Heritage Impact Assessment (HIA) as required by Section 38 (Heritage Resources Management) of the South African Heritage Resources Act (Act No. 25 of 1999). Ancient stromatolites (microbial mounds) were identified within the study area during field assessment by a heritage consultant (Van Schalkwyk, Heritage Impact Assessment report for 2012).

SAHRA has therefore requested a palaeontological heritage assessment of the proposed development (SAHRA Ref. no. 9/2/103/0002). According to their letter of 8 November 2012:

> A Palaeontological Impact Assessment, inclusive of a site visit, should be compiled for the proposed project, with recommendations regarding the actions necessary to record or preserve the algal stromatolites identified in the field. This report must be submitted to SAHRA for comment before any development work occurs on site.

This combined desktop and field-based palaeontological study has accordingly been commissioned on behalf of the client DPS79 Solar Energy (Pty) Ltd by Mr Bennie J. Scheepers (Project Manager, Subsolar Energy (Pty) Ltd. Cell: +27 79 822 2455. Tel: +27 54 461 0293. Fax: 086 527 1258. Email: scheepers@subsolar.co.za).

The various categories of heritage resources recognised as part of the National Estate in Section 3 of the Heritage Resources Act include, among others:

- geological sites of scientific or cultural importance
- palaeontological sites
- palaeontological objects and material, meteorites and rare geological specimens

Minimum standards for the palaeontological component of heritage impact assessment reports are currently being developed by SAHRA. The latest version of the SAHRA guidelines is dated 2011.

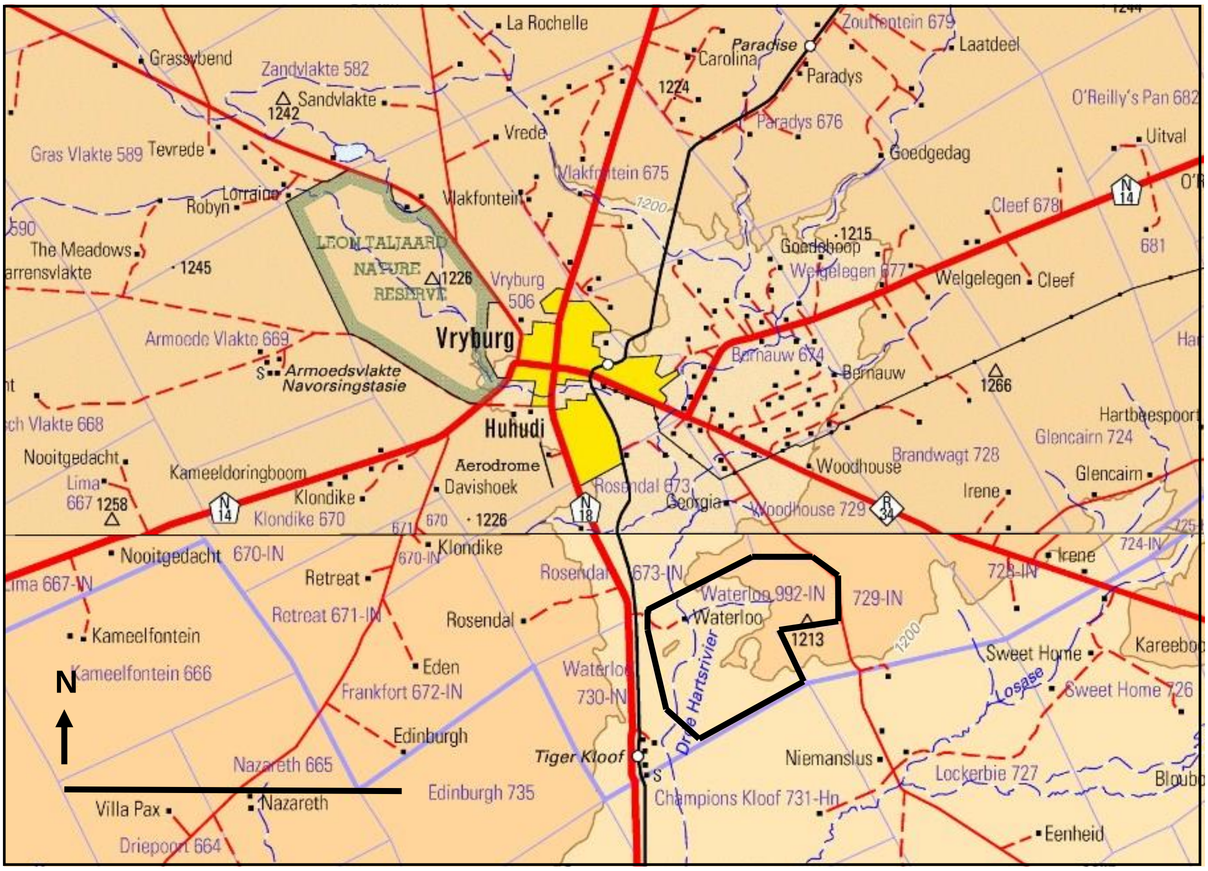

Fig. 1. Extracts from adjoining 1: 250 000 topographical maps 2624 Vryburg and 2724 Christiana (Courtesy of the Chief Directorate of Surveys & Mapping, Mowbray) showing approximate location of the farm Waterloo 992 study area some 10 km southeast of Vryburg, North-West Province (black polygon). Scale bar is *c*. 10 km.

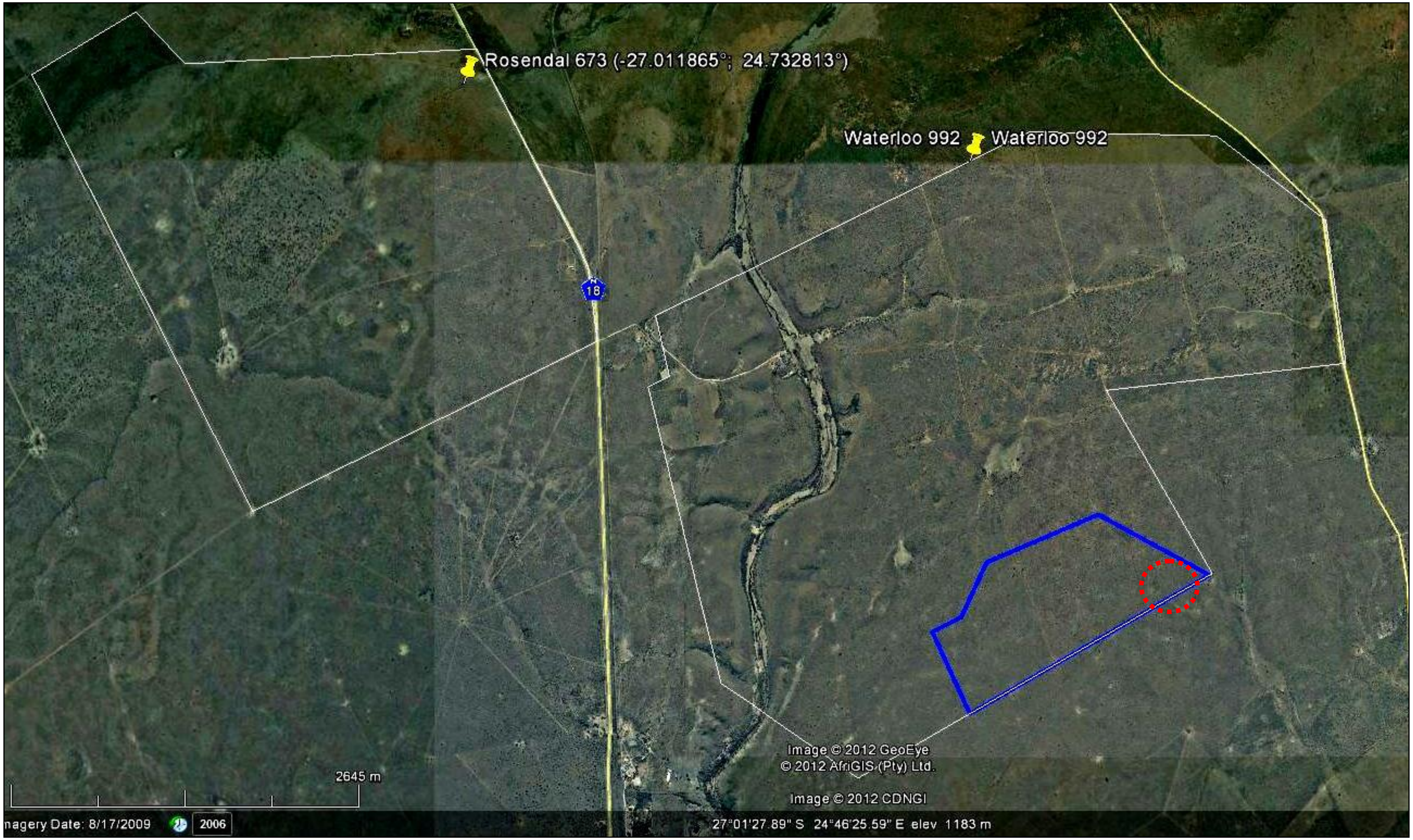

Fig. 2. Google earth© satellite image of the solar plant study area on farms Waterloo 992 and Rosendal 673 to the south of Vryburg, North-West Province (The solar project on Rosendal 673 is the subject of a separate palaeontological assessment). The red circle here indicates a concentration of fossil stromatolite occurrences at the eastern edge of the proposed development area. It is likely that many other occurrences are scattered through the area but are currently hidden by vegetation and soil cover (See Appendix).

1.1. General approach used for palaeontological assessment studies

In preparing a palaeontological desktop study the potentially fossiliferous rock units (groups, formations *etc*) represented within the study area are determined from geological maps. The known fossil heritage within each rock unit is inventoried from the published scientific literature, previous palaeontological impact studies in the same region, and the author's field experience (Consultation with professional colleagues as well as examination of institutional fossil collections may play a role here, or later during the compilation of the final report). This data is then used to assess the palaeontological sensitivity of each rock unit to development (Provisional tabulations of palaeontological sensitivity of all formations in the Western, Eastern and Northern Cape have already been compiled by J. Almond and colleagues; *e.g.* Almond & Pether 2008). The likely impact of the proposed development on local fossil heritage is then determined on the basis of (1) the palaeontological sensitivity of the rock units concerned and (2) the nature of the development itself, most notably the extent of fresh bedrock excavation envisaged.

When rock units of moderate to high palaeontological sensitivity are exposed within the development footprint, a Phase 1 field-based study by a professional palaeontologist is usually warranted. Most detrimental impacts on palaeontological heritage occur during the construction phase when fossils may be disturbed, destroyed or permanently sealed-in during excavations and subsequent construction activity. Where specialist palaeontological mitigation is recommended, this may take place before construction starts or, most effectively, during the construction phase while fresh, potentially fossiliferous bedrock is still exposed for study. Mitigation usually involves the judicious sampling, collection and recording of fossils as well as of relevant contextual data concerning the surrounding sedimentary matrix. The palaeontologist concerned would need to apply beforehand for a collection permit from SAHRA. It should be emphasised that, *provided* appropriate mitigation is carried out, many developments involving bedrock excavation actually have a *positive* impact on our understanding of local palaeontological heritage. Constructive collaboration between palaeontologists and developers should therefore be the expected norm

2. GEOLOGICAL & PALAEONTOLOGICAL BACKGROUND

The study area on farm Waterloo 992 near Vryburg consists of typical flat-lying terrain of the Ghaap Plateau region at *c*. 1150 – 1200m amsl that is currently used for agricultural purposes (principally cattle farming). The climate is semi-arid and the dense vegetation cover of grassy thornveld is mapped as Ghaap Plateau Vaalbosveld. The area is traversed north to south by the incised meandering course of the Droë Harts river. Bedrock exposure is generally poor apart from along the banks of the river and steeper adjacent hillslopes. The proposed solar plant development area in the south-eastern corner of the farm is especially flat (*c*. 1200m amsl) with only small, low and scattered bedrock exposures. The bedrocks here are mantled by reddish-brown sandy soils containing abundant gravel clasts, principally cherty material downwasted from the underlying Boomplaas Formation.

The geology of the study area south of Vryburg is shown on the 1: 250 000 geology map 2724 Christiana (Council for Geoscience, Pretoria; Fig. 3 herein). An explanation for the Christiana geological map has been published by Schutte (1994) and that the adjoining Vryburg sheet 2624 to the north is also very relevant (Keyser & Du Plessis 1993). The study area is almost entirely underlain by ancient sedimentary rocks of the **Schmidtsdrif Subgroup** that are almost flat-lying, with a gentle dip towards the south. This is the basal subdivision of the Late Archaean to Early Proterozoic **Ghaap Group** (**Transvaal Supergroup**) in the Griqualand West Basin, Ghaap Plateau Subbasin (Fig. 4). Useful reviews of the stratigraphy and sedimentology of these Transvaal Supergroup rocks have been given by Moore *et al.* (2001), Eriksson and Altermann (1998) as well as Eriksson *et al.*

(1993, 1995, 2006). The Ghaap Group represents some 200 Ma of chemical sedimentation - notably iron and manganese ores, cherts and carbonates with subordinate siliclastic rocks - within the Griqualand West Basin that was situated towards the western edge of the Kaapvaal Craton (See fig. 4.19 in McCarthy & Rubidge 2005).

The central and western portions of farm Waterloo 992, including exposures along the Droë Harts river and adjacent hillslopes, are underlain by siliclastic fluvial and shallow marine / lagoonal sediments as well as volcanic rocks of the **Vryburg Formation** (**Vv**). The Vryburg Formation is approximately 140 m thick in this area and unconformably overlies lavas of the Venterdorp Supergroup (Allanridge Formation). The holostratotype of the formation lies near Dry Harts Siding some 35 km to the south of Waterloo Farm. An important reference section (Stratotype G), including good examples of the two major volcanic packages known as the Rosendal and Waterloo Members, is located on Waterloo Farm itself (Smit *et al.* 1991). These last authors give a useful summary of the geology and sedimentology of the Vryburg succession, together with a detailed stratigraphic column for Waterloo Farm largely based on exposures along or close to the Droë Harts River. The lower portion of the Vryburg succession here comprises a basal conglomerate followed by a 20 m-thick, prominent-weathering package of cross-bedded feldspathic quartzites known as the Kobaga beds. This is overlain by *c*. 20 m of andesitic or basaltic lavas (the **Rosendal Member**) and pyroclastic sediments and then another 20 m package of varied siliciclastic rocks including conglomerates, quartzites, grits, flaggy sandstones (often ripple marked) and shales. These last are often pitch black and calcitic. The overlying **Waterloo Member** consists of c. 20-50 m of amydaloidal and non-amydaloidal basaltic / andesitic lavas and is overlain by 14 m of interbedded pyroclastic sediments and thin lenticular limestones. These last form the top of the Vryburg Formation and are followed by the carbonate-dominated beds of the Boomplaas Formation (see below). According to Schutte (1994), however, the uppermost Vryburg beds, especially well exposed on Waterloo 992, comprise thin-bedded flaggy sandstones, pale quartzites and interbedded dolomite.

Minor carbonate interbeds within the upper Vryburg Formation in its southern, more distal outcrop area (*e.g.* near Douglas) contain microbial stromatolites, and these are also recorded from the holostratotype section some 40 km south of Vryburg (Smit *et al.* 1991). The stromatolitic carbonates within the Vryburg succession interfinger with and pass up into siliclastic sediments and are interpreted as intertidal in setting (Altermann & Wotherspoon 1995). To the author's knowledge, a detailed description of the Vryburg stromatolite occurrences has not yet been published. Useful reviews of Archaean stromatolites and associated organic-walled microfossils from southern Africa and elsewhere are provided by Altermann (2001), Buick (2001), Brasier *et al.* (2006) and Schopf (2006). Bertrand-Sarfarti and Eriksson (1977) describe columnar stromatolites from the Schmidtsdrift Subgroup of the Northern Cape.

The northernmost and southernmost portions of farm Waterloo 992 are underlain by shallow marine carbonates (predominantly dolomites) and subordinate siliclastic sediments of the overlying **Boomplaas Formation** (**Vb**). This mixed carbonate and siliciclastic succession is 100 – 185 m in thickness and is transitional between the predominantly continental Vryburg beds and the fully marine Campbell Rand platform carbonates of the Kaapvaal Craton. The Boomplaas beds are dominated by grey dolomites (weathering reddish-brown) with subordinate interbeds of limestone (weathering blue-grey), quartzite, flaggy sandstone and shale. Packages of oolitic and stromatolitic dolomite alternate with intervals of carbonaceous mudrocks (possibly lagoonal) containing interbeds of calcareous sandstone and mudclast breccias. Nearshore oolitic and stromatolitic facies with cherty layers and inclusions (probably secondary replacement of carbonate) predominate in the northern outcrop area of the Boomplaas Formation, as at Vryburg, while offshore mudrock facies are found towards the south. The Boomplaas beds are overlain by the grey- to khaki-hued mudrocks and interbedded dolomites, flagstones, tuffites and BIF-like cherts of the **Clearwater Formation**

(= Lokamonna Formation), the uppermost subunit of the Schmidtsdrif Subgroup. The finer mudrocks are pitch black and locally pyritic and calcitic while the carbonates may show crinkly stromatolitic textures. This last unit does not crop out on Waterloo farm but is mapped on the western side of the N18 tar road.

A detailed, comprehensive account of the Neoarchaean stromatolites from the Boomplaas Formation of the Schmidtsdrif Subgroup has not been published, to the author's knowledge. Brief mention of large stromatolites from 50 cm up to 2 m across within the Boplaas Formation in the Vryburg area is made by Keyser and Du Plessis (1993). Preferential north-south elongation seen in some examples may reflect dominant onshore-offshore, wave-generated currents scouring sediment from between the domes. Wright and Altermann (2000) discuss slumping and contortion of partially decomposed, pyrite-rich stromatolitic laminae as well as preservation of organic-walled filamentous cyanobacterial microfossils within stromatolites of the Boomplaas Formation. A shallow subtidal setting for large stromatolitic domes in the Transvaal Supergroup is inferred by Truswell and Eriksson (1973), with oolites generated in higher energy inshore settings, although they may subsequently have been reworked into deeper waters offshore (See also Eriksson & Altermann 1998).

The Vryburg Formation is treated as the basal unit of the Schmidtsdrif Subgroup by several recent authors (*e.g.* Altermann & Wotherspoon 1995, Sumner & Beukes 2006) but was previously placed below the base of the Ghaap Group succession (See stratigraphic column in Fig. 4). The Vryburg siliciclastics and overlying carbonate-rich Boomplaas Formation of the Griqualand West Basin have classically been correlated with the Black Reef Formation and overlying basal Malmani dolomites of the Transvaal Basin (*e.g.* Eriksson *et al.* 1995, 2006). However, recent sequence stratigraphic studies of the Transvaal Supergroup have demonstrated that the Vryburg / Boomplaas / Clearwater sequence is in fact older than the Black Reef Formation (Sumner & Beukes 2006). Lavas from the Vryburg Formation have been radiometrically dated to 2.64 Ga (billion years old), *i.e.* Late Archaean in age (Eriksson *et al.* 2006), and the overlying Boomplaas stromatolitic carbonates are likewise assigned a Neoarchaean age (Fig. 4).

According to the 1: 250 000 geological map sheet 2724 Christiana the outcrop areas of the Vryburg and Boomplaas Formations on Waterloo 992 are separated by a narrow arcuate strip of **Dwyka Group** (**C-Pd**) rocks of Permo-carboniferous age (Fig. 3). These glacial-related sediments were not seen in the field and, if indeed present, are almost certainly unfossiliferous and so they will not be treated further here. Their mapped outcrop corresponds with a recessive weathering zone of thin-bedded oolitic and flaggy beds of the lowermost Boomplaas Formation, marked on satellite images by a row of pans (Fig. 2). This zone of softer-weathering Archaean bedrocks may have been preferentially scoured out by pre-Dwyka erosion.

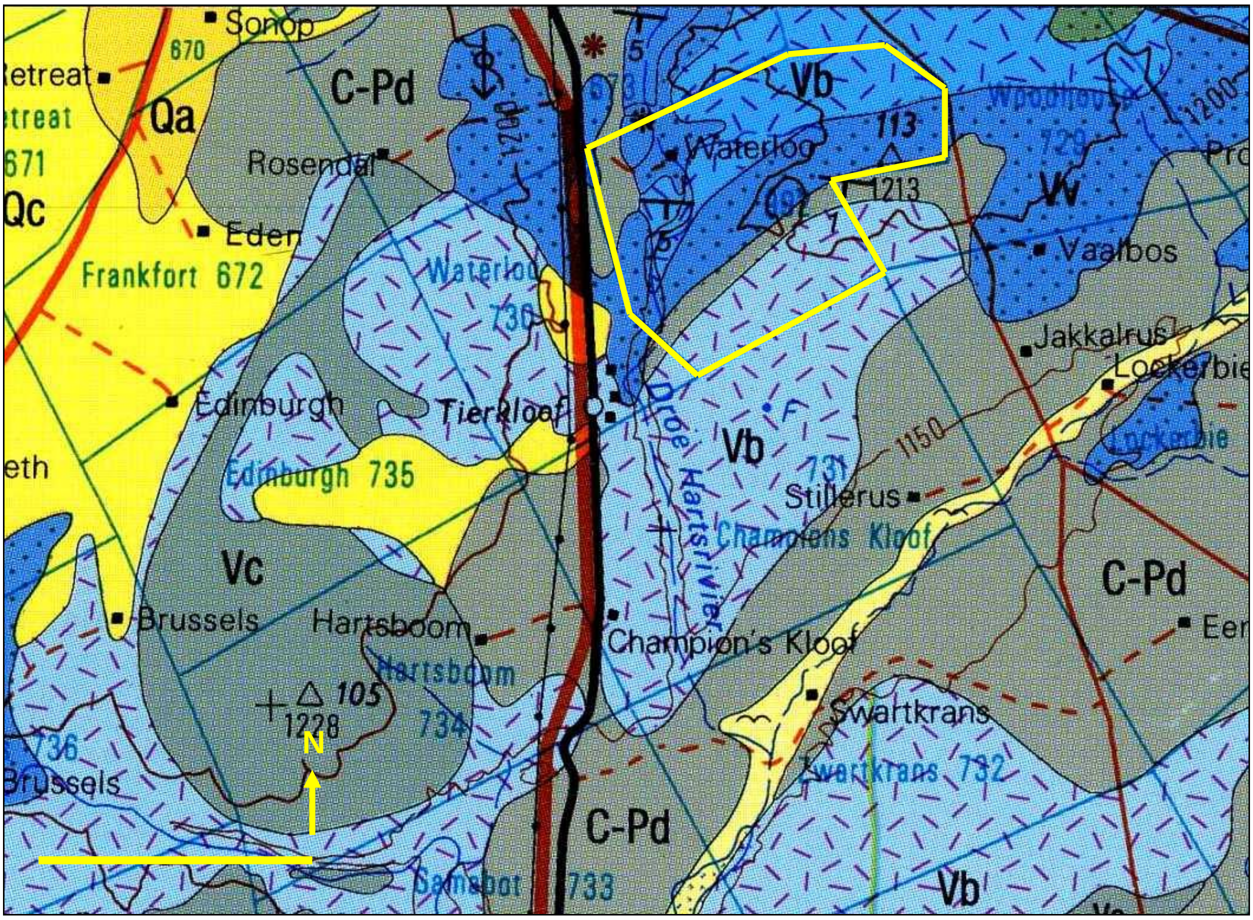

Fig. 3. Extract from the 1: 250 000 geological map 2724 Christiana (Council for Geoscience, Pretoria) showing the outline of the study area on the farm Waterloo 992 some 10 km southeast of Vryburg (yellow polygon). Scale bar = *c*. 5 km. The main geological units represented mapped the broader study region include:

GHAAP GROUP (SCHMIDTSDRIF SUBGROUP)

Vryburg Formation (Vv, dark blue with stipple) – late Archaean fluvial and shallow marine quartzites, mudrocks, conglomerates with two intervals of andesitic volcanics

Boomplaas Formation (Vb, pale & middle blue with dashes) – late Archaean dolomites (locally stromatolitic or oolitic) interbedded with siliciclastics (quartzite, shale, flagstone)

KAROO SUPERGROUP

Dwyka Group (C-Pd, middle grey) – Permocarboniferous glacial sediments

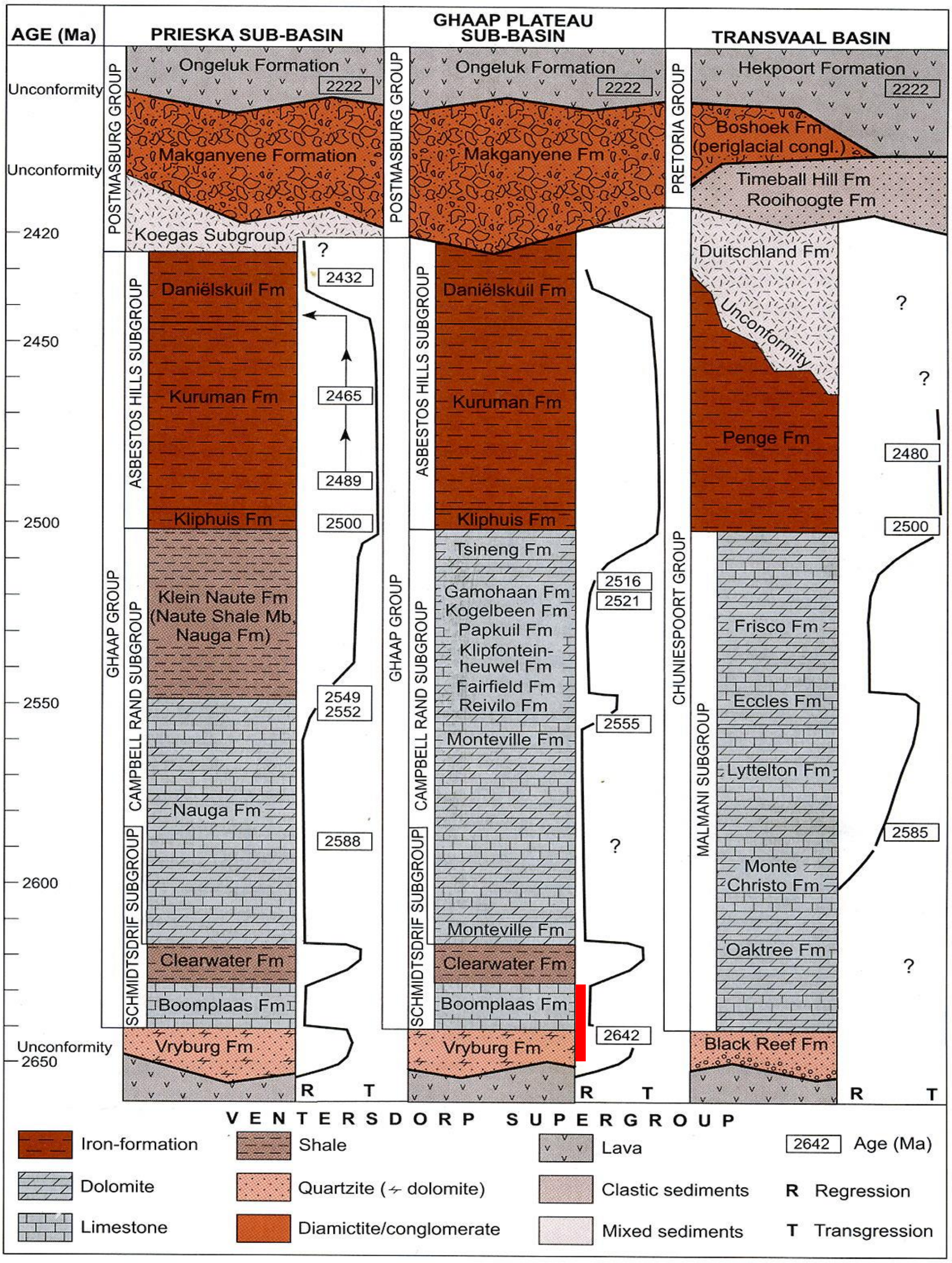

Fig. 4. Stratigraphy of the Transvaal Supergroup of the Ghaap Plateau Basin (central column) showing rock units represented in the study area (red line) (From Eriksson *et al.* 2006). Note that the Vryburg Formation is incorporated within the base of the Schmidtsdrif Subgroup by some recent authors and is no longer correlated with the Black Reef Formation of the Transvaal Basin as shown here (*e.g.* Altermann & Wotherspoon 1995, Sumner & Beukes 2006).

3. FIELD OBSERVATIONS ON FARM WATERLOO 922

Since Neoarchaean stromatolites have been reported from both the Vryburg and Boomplaas Formations in North-West Province (in the latter case from the proposed development site itself), the field assessment of farm Waterloo 992 concentrated on these two stratigraphic units. As mentioned earlier, exposures of the Dwyka Group were not encountered (and may be at least in part incorrectly mapped here), while superficial deposits such as river alluvium, colluvial rubble and downwasted surface gravels are generally unfossiliferous or at most sparsely fossiliferous in this region.

GPS locations of sites mentioned by number in the text are listed in the Appendix.

3.1. Vryburg Formation on Waterloo 922

The gently south-dipping **Vryburg Formation** succession on Waterloo Farm is well exposed along the Droë Harts River Valley (Stratotype G section of Smit *et al.* 1991) and to a lesser extent on the adjacent plateau and hillslopes in the central portion of Waterloo Farm. The basal prominent-weathering, cross-bedded quartzite package (Kobaga Beds) crops out along the western and eastern bank of the river valley in the neighbourhood of the farmstead (Locs. 971, 972, 973) and is also well seen in the small quarry adjacent to the railway line *c*. 1.5 km to the northwest (Loc. 982) (Figs. 5 & 7). These are typical sandy braided fluvial deposits characterised by medium- to coarse-grained, moderately well-sorted to sparsely pebbly quartzites and feldspathic quartzites of buff to pinkish or grey-green hue. Bedding is medium to thick, generally tabular but occasionally comprising erosive-based channels. The beds vary from massive to horizontally-laminated to cross-bedded, with both tabular and trough cross sets commonly developed. Small scale current ripple cross-lamination, rib-and-furrow, primary current lineations as well as scour-and-fill structures indicate a spread of palaeocurrent directions from south-southeast to southwest. Bedding planes occasionally preserve small scale current ripples. Thin lenticles and layers of coarse grit (granules) or poorly-sorted, fine to coarse polymict gravels of chert, vein quartz, quartzite, hornfels and volcanic lithologies, many derived from the underlying Ventersdorp Supergroup, occur frequently. Gravel clasts are subangular to rounded and outsized examples reach up to 15 cm in diameter. Intraclast breccias mainly feature moulds of mudclasts (Fig. 6). Moulds showing impressions of surface ripple structures may reflect reworked microbially-bound sediment, as also suggested by horizons of rounded, irregular sandy intraclasts. Finer-grained dm-scale interbeds of reddish-brown, wavy-laminated siltstone and fine-grained sandstone occur between the quartzites in the railway quarry but are usually absent (or poorly exposed) elsewhere.

Fig. 5. Horizontal-laminated and cross-bedded quartzites of the lower Vryburg Formation (Kobaga Beds) on the banks of the Droë Harts River Valley, near Waterloo farmstead (Hammer = 29 cm).

Fig. 6. Intraclast breccia with angular moulds of reworked mudrock on a quartzite sole, lower Vryburg Formation (Hammer = 29 cm).

Fig. 7. Tabular-bedded, horizontally laminated quartzites of the lower Vryburg Formation exposed in the small railway quarry NE of Waterloo farmstead.

At Loc. 974 at the plateau edge on the eastern side of the Droë Harts River dark grey to black, brownish-weathering micaceous mudrocks and interbedded fine-grained wackes are exposed besides a farm track (Fig. 8). Bedding is flaggy to irregular and occasionally undulose. These sediments underlie the Rosendal Member volcanics and may be baked (*i.e.* hornfels). The dark colour suggests a high organic carbon content but this may alternatively be due to baking and / or disseminated iron minerals. Sedimentary structures include cross-bedding in quartzite interbeds (possibly overturned locally), mudflake breccias and small scale wave rippled surfaces. These heterolithic, mudrock-dominated packages might be lagoonal in origin.

A range of volcanic facies can be seen within the Rosendal and Waterloo Members of the Vryburg Formation in the study area. Lavas vary from blocky and aphanitic to porphyritic and are commonly richly amydaloidal (Loc. 975) (Fig. 9). Fresh lava is grey-green but weathering surfaces are usually reddish-brown. Coarser volcanic facies include buff-coloured agglomerates with abundant dark, angular igneous inclusions in a pale cherty matrix (Fig. 10) as well as poorly-sorted rubbly or slaggy flow breccias (Loc. 978) (Fig. 11).

Fig. 8. Brown-weathering, thin-bedded dark mudrocks beneath the Rosendal Member, Vryburg Formation (Hammer = 29 cm).

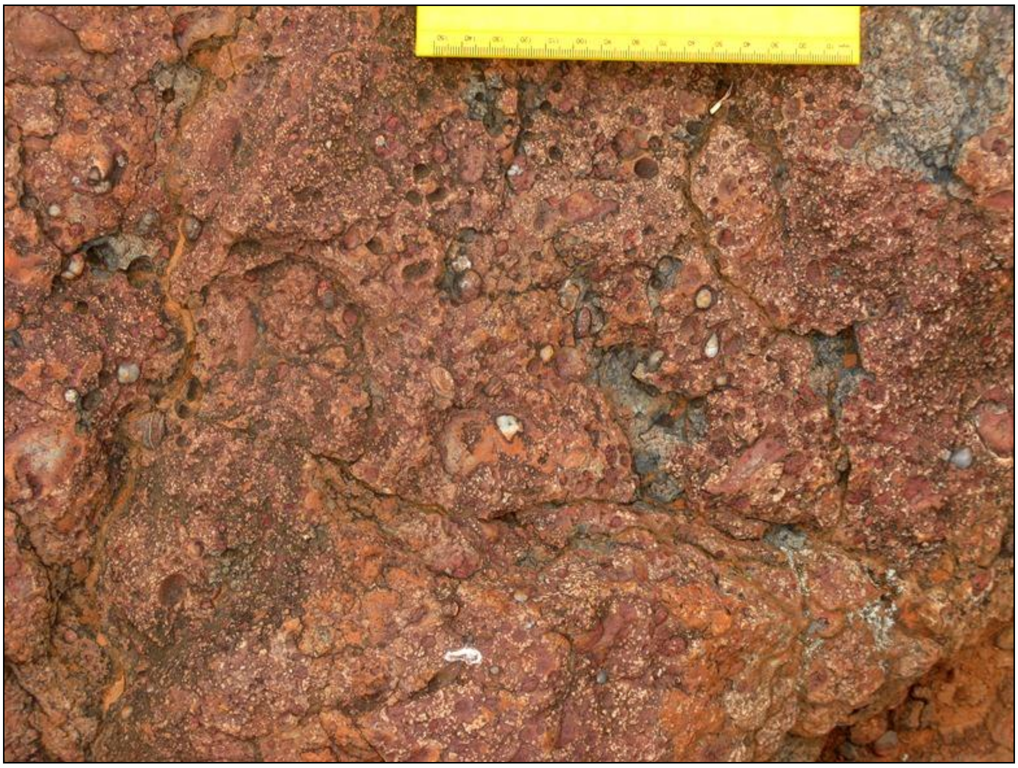

Fig. 9. Typical amydaloidal lava within the Waterloo Member of the Vryburg Formation (Scale in cm).

Fig. 10. Volcanic breccia or agglomerate within the Waterloo Member, Vryburg Formation (Hammer – 29 cm).

Fig. 11. Slaggy flow breccia within the upper part of the Waterloo Member, Vryberg Formation (Hammer = 29 cm).

Heterolithic siliclastic packages interbedded with or overlying the upper (Waterloo Member) lavas contain numerous flaggy sandstones with well-developed wave-rippled bedding planes and synaeresis cracks, possibly deposited on a tempestite-dominated shoreface (Fig. 12).

No carbonate interbeds or stromatolitic structures were observed within the Vryburg succession on farm Waterloo 992 and they are not recorded in the Stratotype G section for this rock unit on Waterloo farm (Smit *et al.* 1991). This may be because only terrestrial, lagoonal, volcanic or shallow nearshore settings are represented this far north within the Vryburg outcrop area (Note, however, that Archaean stromatolites are recorded from still older lacustrine facies in the Ventersdorp Group, while stromatolites are present in the Vryburg succession only 35 km to the south of the present study area; Smit *et al.* 1991).

Fig. 12. Wave rippled flaggy quartzite bedding plane within the upper part of the Vryburg Formation (Hammer = 29 cm).

3.2. Boomplaas Formation on Waterloo 922

In general exposure of the Boomplaas Formation is very poor in the flat-lying southern portion of Waterloo 992 (Fig. 13). The bedrock here has been reduced by erosion to small, scattered, low outcrops that are otherwise obscured by gravelly soil and thornveld vegetation. The basal beds of the Boomplas Formation comprise poorly-exposed sandy limestones and fine-grained flaggy sandstones with primary current lineation as well as grey oolitic limestones (Fig 14). They are represented, for example, as low *in situ* bedrock exposures and float blocks in the pan close to a windpump at Loc. 970.

Fig. 13. Typical flat landscape of the Ghaap Plateau underlain by carbonates of the Boplaas Formation and mantled by gravelly soils, study area on southern portion of Waterloo Farm.

Fig, 14. Pale grey oolitic carbonates within the lowermost part of the Boomplaas Formation (Scale in cm and mm).

A high proportion of the visible Boomplaas bedrock exposures comprise subhorizontal to gently south-dipping, rusty-brown weathering, sandy dolomites with subordinate flaggy sandstones and grits as well as very low relief (few dm) exposures of resistant-weathering, secondarily silicified stromatolitic carbonates. The stromatolites seen may form a series of isolated patch reefs or perhaps a single, laterally extensive stromatolite-rich horizon; this can only be determined by detailed mapping. The highest concentration seen of *in situ* large domical stromatolites as well as stromatolitic float blocks occurs adjacent to the powerline and either side of the farm track in the south-eastern corner portion of the property, on the eastern edge of the proposed development area (red dotted circle in Fig. 2; Locs. 960-963). This was the main fossil locality recorded in the earlier heritage impact study by Van Schalkwyk (2012). Further scattered occurrences of stromatolitic carbonates were recorded at several other sites close to the farm tracks in and around the proposed development area (See Appendix) but due to the dense vegetation cover no attempt was made to comprehensively map their distribution. This would only be feasible once the vegetation had been cleared and summer grasses were not present.

A fairly wide range of stromatolitic morphologies (but excluding elongate columns) are represented within the Boomplaas beds on farm Waterloo 992, some of which may intergrade or form overgrowths upon one another. These include:

- Large, low stromatolitic domes, from 20 cm up to 2 m or more across, with even, concentric, parallel to wavy or convolute lamination (*e.g.* Locs. 960, 961, 962, 968, 969) (Figs. 15 to 17). The large domes have generally been planed off by erosion so their remaining relief is less than 50 cm. In some areas the large domes are laterally coalescent (Fig. 16). Smaller smooth dm-scale domes are also seen (*e.g.* Loc 966, Loc 979).
- Small (< 50 cm) domes with subdued button-like microdomes, squat microcolumns or pustules on the surface on various scales (*c*. 2 cm to a few cm across) (*e.g.* Locs. 960, 961, 963, 964) (Figs. 18 to 20).
- Cauliflower-like heads of microcolumns or microdomes, often with a vuggy internal structure (*e.g.* Loc 967) (Fig. 21).
- Isolated irregular stromatolitic cushions, blobs or buttons (Fig. 22).

In most cases the original carbonate of the stromatolites has been secondarily replaced by resistant-weathering, pale or dark grey to buff, fine-grained silica. Lamination is often well preserved on the outer part of the microbial bioherm while the inner portions are converted to a massive, very dark cherty material with no apparent internal layering (Fig. 16). Convolute lamination suggests early deformation of soft, semi-decomposed microbially-bound sediment and may be unconformably overlain by more regular subsequent laminae. Regular cubical voids within some stromatolites are moulds of pyrite crystals indicating anoxia within the interior of decomposing stromatolite bioherms (Fig. 23).

Fig. 15. Large domical stromatolite planed down by erosion (Hammer = 29 cm).

Fig. 16. Laterally coalescent large domical stromatolites showing good preservation of laminae on the exterior and massive dark cherty replacement in the interior (Hammer = 29 cm).

Fig. 17. Closely-packed small domical stromatolites (Hammer – 29 cm).

Fig. 18. Small domical stromatolite showing subdued microdomes on the outer surface (width of specimen *c*. 16 cm).

Fig. 19. Small microdomes on the surface of a larger stromatolite (Scale in cm).

Fig. 20. Horizontal sections through microdomes showing concentric internal lamination (domes *c.* 2 to 3 cm across).

Fig. 21. Cauliflower-like stromatolitic crown of small coalescent microdomes overlying a larger-scale domical stromatolitic base (Specimen *c*. 18 cm wide).

Fig. 22. Irregular to ovoidal stromatolitic growths within ferruginous dolomite (Hammer = 29 cm).

Fig. 23. Silicified stromatolite showing numerous cuboidal moulds of pyrite crystals (Scale in cm and mm).

Fig. 24. Thinly interbedded pale grey limestone and ferruginous sandstone within the upper Boomplaas Formation (Hammer = 29 cm).

Sparse, scattered low exposures and isolated float blocks of the upper Boomplaas Formation observed along the southern edge of Waterloo farm comprise thinly bedded, rusty-brown sandy dolomites and sandstones with secondary chert and ferruginous lenses (Fig. 24). Sedimentary structures include horizontal and small scale ripple cross-lamination. No stromatolites were observed within these beds.

4. SIGNIFICANCE OF IMPACTS ON PALAEONTOLOGICAL HERITAGE

A brief assessment of the impact significance of the proposed photovoltaic solar facility development on local fossil heritage resources on Farm Waterloo 992 is presented here.

- **Nature of the impact**

Bedrock excavations and site clearance for the proposed PV panels, control building, any buried cables, the electrical substation as well as the internal site roads and powerline infrastructure may adversely affect potential fossil heritage within the study area – principally stromatolites (laminated microbial mounds) - by damaging, destroying, disturbing or permanently sealing-in fossils at or below the ground surface that are then no longer available for scientific research or other public good.

- **Geographical extent and duration of the impact**

Significant impacts on fossil heritage are limited to the development site and to the construction phase when site clearance and excavations into fresh, potentially fossiliferous bedrock may take place. No further significant impacts are anticipated during the operational or decommissioning phases of the solar facility. Impacts on fossil heritage are generally permanent.

- **Probability of the impact occurring**

Since concentrations of small to large stromatolites are recorded on the margins of, as well as within, the proposed development site, the probability of significant impacts on palaeontological heritage during the construction phase are high (definite).

- **Intensity / magnitude of impact**

The intensity of the impact on fossil heritage is rated as medium.

- **Degree to which the impact can be reversed**

Impacts on fossil heritage are generally irreversible. Well-documented new records and further palaeontological studies of any fossils revealed during construction would represent a positive impact from a scientific viewpoint.

- **Degree to which the impact may cause irreplaceable loss of resources**

Since little is known about the stratigraphic and geographical distribution of Late Archaean stromatolites within the Schmidtsdrift Subgroup, including the Boomplaas Formation, it is not yet possible to accurately assess the uniqueness of the stromatolite assemblages present on

Farm Waterloo 992. It is quite likely that better preserved examples are present within the extensive outcrop area of the Boomplaas Formation to the south and west.

Adopting a precautionary approach, a significant loss of fossil resources is anticipated.

- **Degree to which the impact can be mitigated**

Recommended mitigation of the inevitable damage and destruction of fossil stromatolites within the proposed development area would involve the surveying, recording, description and judicious sampling of well-preserved fossil occurrences within the development footprint by a professional palaeontologist. This work should take place after initial vegetation clearance has taken place but *before* the ground is leveled for construction.

- **Cumulative impacts**

According to the Draft Environmental Impact Report for this solar plant development (Environamics 2012) two other solar plants have been proposed in the vicinity. These are:

- A 19.5 MW solar plant on a northern portion of the farm Waterloo 992 (NEAS Reference: DEA/EIA/0001105/2012 & DEA Reference: 14/12/16/3/3/1/506) and
- A 75 MW solar plant on a portion of the Remaining Extent of the farm Rosendal 673 (NEAS Reference No: DEA/EIA/0001359/2012 & DEA Reference No.: 14/12/16/3/3/2/390).

Impacts on fossil stromatolite assemblages within the Boplaas Formation are likely in the first case but not in the second since the Boplaas Formation has only a very small outcrop area on the farm Rosendal. However, the Boplaas Formation is largely mapped in the subsurface in the first case. The cumulative effect of the three proposed solar plant developments is considered to be low.

The overall impact of the proposed southern Waterloo 992 solar plant development is provisionally rated as of **NEGATIVE MEDIUM SIGNIFICANCE** in palaeontological heritage terms.

5. CONCLUSIONS & RECOMMENDATIONS

The company DPS79 Solar Energy (Pty) Ltd. is proposing to construct a 75 MW photovoltaic solar facility on the southern portion of the farm Waterloo 992 some 10 km southeast of Vryburg (Naledi Local Municipality), North-West Province. The study area is largely underlain by late Archaean (*c*. 2.6 billion year-old) sedimentary and volcanic rocks of the Schmidtsdrif Subgroup (Ghaap Group, Transvaal Supergroup). These comprise fluvial quartzites, mudrocks and volcanic rocks of the Vryburg Formation as well as shallow marine carbonates and siliciclastic sediments of the slightly younger Boomplaas Formation. A stratotype section of the Vryburg Formation has been designated on Waterloo Farm by Smit *et al.* (1991) because of the exceptionally good exposure of the basal quartzitic and volcanic successions here, including the eponymous Waterloo Member lavas. The Vryburg rocks in this area are apparently unfossiliferous, however, although intertidal stromatolites (microbial mounds) are known from marine intercalations within this rock unit further to the south.

Poorly- to well-preserved, secondarily silicified stromatolite assemblages are recorded within the Boomplaas Formation carbonate rocks on the southern portion of Waterloo Farm, including within the proposed solar plant development area. A range of stromatolite growth types is represented here, from small cm-scale buttons to cauliflower-like heads and large domes up to two meters or more in width. Bedrock exposure is very poor and many of the stromatolites have been planed down by erosion. Due to high levels of gravelly soil cover and dense vegetation (including summer grasses) within the development area it was not possible to map the occurrence of stromatolites here. The Boomplaas Formation stromatolites represent some of the oldest examples of these microbially generated fossils in South Africa but they have yet to be comprehensively described while their stratigraphic and geographical distributions are poorly understood.

Given these uncertainties, the overall impact of the proposed solar plant development on the southern portion of Waterloo 992 is provisionally rated as of NEGATIVE MEDIUM SIGNIFICANCE in palaeontological heritage terms. Recommended mitigation of the inevitable damage and destruction of fossil stromatolites within the proposed development area involves the surveying, recording, description and judicious sampling of well-preserved fossil occurrences within the development footprint by a professional palaeontologist. This work should take place after initial vegetation clearance has taken place but *before* the ground is leveled for construction.The palaeontologist concerned would need to apply beforehand for a fossil collection permit from SAHRA. These recommendations should be incorporated into the Environmental Management Plan for the Waterloo solar plant project.

6. ACKNOWLEDGEMENTS

Mr Bennie J Scheepers (Project Manager, Subsolar Energy (Pty) Ltd.) is thanked for comissioning this study and for kindly providing all the necessary background information. I am also grateful to the owner of farm Waterloo 992, Dr Chris van Zyl, for facilitating access to his land.

7. REFERENCES

ALTERMANN, W. 2001. The oldest fossils of Africa – a brief reappraisal of reports from the Archaean. African Earth Sciences 33, 427-436.

ALTERMANN, J. & HERBIG 1991. Tidal flats deposits of the Lower Proterozoic Campbell Group along the southwestern margin of the Kaapvaal Craton, Northern Cape Province, South Africa. Journal of African Earth Science 13: 415-435.

ALTERMANN, W. & SCHOPF, J.W. 1995. Microfossils from the Neoarchaean Campbell Group, Griqualand West Sequence of the Transvaal Supergroup, and their paleoenvironmental and evolutionary implications. Precambrian Research 75, 65-90.

ALTERMANN, W. & WOTHERSPOON, J. McD. 1995. The carbonates of the Transvaal and Griqualand West sequences of the Kaapvaal craton, with special reference to the Lime Acres limestone deposit. Mineralium Deposita 30, 124-134.

AWRAMIK, S.M. 1991. Archaean and Proterozoic stromatolites. In Riding, R. (ed.) Calcareous algae and stromatolites, pp. 289-304. Springer, Berlin.

BERTRAND-SARFATI, J. & ERIKSSON, K. A. 1977. Columnar stromatolites from the Early Proterozoic Schmidtsdrift Formation, Northern Cape Province, South Africa--Part 1: Systematic and diagnostic features. Palaeontologia Africana 20, 1-26.

BEUKES, N. J. 1977. Transition from siliciclastic to carbonate sedimentation near the base of the Transvaal Supergroup, Northern Cape Province, South Africa. Sedimentary Geology 18, 201-221.

BEUKES, N. J. 1987. Facies relations, depositional environments and diagenesis in a major Early Proterozoic stromatolitic carbonate platform to basinal sequence, Campbellrand Subgroup, Transvaal Supergroup, southern Africa. Sedimentary Geology 54, 1-46.

BRASIER, M., MCLOUGHLIN, N., GREEN, O. & WACEY, D. 2006. A fresh look at the fossil evidence for early Archaean cellular life. Philosophical Transactions of the Royal Society B361, 887-902.

BUICK, K. 2001. Life in the Archaean. In: Briggs, D.E.G. & Crowther, P.R. (eds.) Palaeobiology II, 13-21. Blackwell Science, London.

ERIKSSON, K.A. & TRUSWELL, J.F. 1973. High inheritance elongate stromatolitic mounds from the Transvaal Dolomite. Palaeontologia Africana 15, 23-28.

ERIKSSON, K.A. & TRUSWELL, J.F. 1974. Tidal flat associations from a Lower Proterozoic carbonate sequence in South Africa. Sedimentology 21: 293-309.

ERIKSSON, K.A., TRUSWELL, J.F. & BUTTON, A. 1976. Paleoenvironmental and geochemical models from an Early Proterozoic carbonate succession in South Africa. In: Walter, M.R. (Ed.) Stromatolites, 635-643. Blackwell, Oxford.

ERIKSSON, K.A. & MCGREGOR, I.M. 1981. Precambrian palaeontology of southern Africa. In: Hunter, D.R. (ed.) Precambrian of the southern hemisphere, 813-833. Elsevier, Amsterdam.

ERIKSSON, P.G., SCHWEITZER, J.K., BOSCH, P.J.A., SCHREIBER, U.M., VAN DEVENTER, J.L. & HATTON, C. 1993. The Transvaal Sequence: an overview. Journal of African Earth Science 16, 25-51.

ERIKSSON, P.G., HATTINGH, P.J. & ALTERMANN, W. 1995. An overview of the geology of the Transvaal Sequence and the Bushveld Complex, South Africa. Mineralium Deposita 30, 98-111.

ERIKSSON, P.G. & ALTERMANN, W. 1998. An overview of the geology of the Transvaal Supergroup dolomites (South Africa). Environmental Geology 36, 179-188.

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, pp. 237-260. Geological Society of South Africa, Marshalltown.

KEYSER, N. & DU PLESSIS, C.P. 1993. The geology of the Vryburg area. Explanation to 1: 250 000 geology sheet 2624 Vryburg, 28 pp. Council for Geoscience, Pretoria.

KNOLL, A.H. & BEUKES, N.J. 2009. Introduction: Initial investigations of a Neoarchean shelf margin – basin transition (Transvaal Supergroup, South Africa). Precambrian Research 2009. doi:10.1016/j.precamres.2008.10.2009

MACRAE , C. 1999. Life etched in stone. Fossils of South Africa. 305 pp. The Geological Society of South Africa, Johannesburg.

MCCARTHY, T. & RUBIDGE, B. 2005. The story of Earth and life: a southern African perspective on a 4.6-billion-year journey. 334pp. Struik, Cape Town.

MOORE, J.M., TSIKOS, H. & POLTEAU, S. 2001. Deconstructing the Transvaal Supergroup, South Africa: implications for Palaeoproterozoic palaeoclimate models. African Earth Sciences 33, 437-444.

SCHOPF, J.W. 2006. Fossil evidence of Archaean life. Philosophical Transactions of the Royal Society B361, 869-885.

SCHUTTE, I.C. 1994. Die geologie van die gebied Christiana. Explanation to 1: 250 000 geology sheet 2724 Christiana, 58 pp. Council for Geoscience, Pretoria.

SMIT, P.J., BEUKES, N.J., JOHNSON, M.R., MALHERBE, S.J. & VISSER, J.N.J. 1991. Lithostratigraphy of the Vryburg Formation (including the Kalkput, Geelbeksdam, Rosendal, Waterloo and Oceola Members). South African Committee for Stratighraphy Lithostratigraphic Series No. 14, 1-10.

SUMNER, D.Y. & BEUKES, N.J. 2006. Sequence stratigraphic development of the Neoarchaean Transvaal carbonate platform, Kaapvaal Craton, South Africa. South African Journal of Geology 109, 11-22.

TANKARD, A.J., JACKSON, M.P.A., ERIKSSON, K.A., HOBDAY, D.K., HUNTER, D.R. & MINTER, W.E.L. 1982. Crustal evolution of southern Africa – 3.8 billion years of earth history, xv + 523pp. Springer Verlag, New York.

VAN SCHALKWYK, J. 2012. Heritage impact assessment for the proposed development of a photovoltaic power plant on a portion of the farm Waterloo 730, Vryburg region, North West Province, 16 pp.

WRIGHT, D.T. & ALTERMANN, W. 2000. Microfacies development in Late Archaean stromatolites and oolites of the Ghaap Group of South Africa. Geological Society, London, Special Publications 178, 51-70.

YOUNG, R.B. 1932. The occurrence of stromatolitic or algal limestones in the Campbell Rand Series, Griqualand West. Transactions of the Geological Society of South Africa 53: 29-36.

8. QUALIFICATIONS & EXPERIENCE OF THE AUTHOR

Dr John Almond has an Honours Degree in Natural Sciences (Zoology) as well as a PhD in Palaeontology from the University of Cambridge, UK. He has been awarded post-doctoral research fellowships at Cambridge University and in Germany, and has carried out palaeontological research in Europe, North America, the Middle East as well as North and South Africa. For eight years he was a scientific officer (palaeontologist) for the Geological Survey / Council for Geoscience in the RSA. His current palaeontological research focuses on fossil record of the Precambrian - Cambrian boundary and the Cape Supergroup of South Africa. He has recently written palaeontological reviews for several 1: 250 000 geological maps published by the Council for Geoscience and has contributed educational material on fossils and evolution for new school textbooks in the RSA.

Since 2002 Dr Almond has also carried out palaeontological impact assessments for developments and conservation areas in the Western, Eastern and Northern Cape under the aegis of his Cape Town-based company *Natura Viva* cc. He is a long-standing member of the Archaeology, Palaeontology and Meteorites Committee for Heritage Western Cape (HWC) and an advisor on palaeontological conservation and management issues for the Palaeontological Society of South Africa (PSSA), HWC and SAHRA. He is currently compiling technical reports on the provincial palaeontological heritage of Western, Northern and Eastern Cape for SAHRA and HWC. Dr Almond is an accredited member of PSSA and APHAP (Association of Professional Heritage Assessment Practitioners – Western Cape).

Declaration of Independence

I, John E. Almond, declare that I am an independent consultant and have no business, financial, personal or other interest in the proposed development project, application or appeal in respect of which I was appointed other than fair remuneration for work performed in connection with the activity, application or appeal. There are no circumstances that compromise the objectivity of my performing such work.

John E. Almond

Dr John E. Almond
Palaeontologist
***Natura Viva* cc**

APPENDIX: GPS LOCALITY DATA FOR NUMBERED SITES LISTED IN TEXT

All GPS readings were taken in the field using a hand-held Garmin GPSmap 60CSx instrument. The datum used is WGS 84.

Location number	South	East	Comments
959	S27 02 03.7	E24 47 54.2	Ferruginous dolomites
960	S27 02 05.9	E24 47 58.1	Large domical stromatolites, small stromatolite buttons
961	S27 02 06.6	E24 47 55.1	Large domical stromatolites, small stromatolite buttons
962	S27 02 04.8	E24 47 57.5	Coalescent large domical stromatolites
963	S27 02 04.8	E24 48 00.1	Pyritic cherty stromatolites
964	S27 02 06.7	E24 47 57.9	Abundant stromatolite buttons
965	S27 02 20.7	E24 47 16.0	Cherty stromatolites
966	S27 02 08.5	E24 47 10.7	Medium-sized stromatolitic domes
967	S27 02 00.6	E24 47 08.4	Cherty cauliflower head of microdomical stromatolites, large domes also
968	S27 01 45.9	E24 47 02.3	Siliclastic beds within Boplaas Fm
969	S27 01 45.2	E24 47 01.5	
970	S27 01 42.5	E24 47 05.8	Oolitic carbonates and flaggy sandstones of lowermost Boplaas Fm
971	S27 01 11.7	E24 46 04.7	Cross-bedded Vryburg Fm quartzites
972	S27 01 10.1	E24 46 09.8	Current-bedded Vryburg quartzites
973	S27 01 06.5	E24 46 01.7	Cross-bedded Vryburg Fm quartzites, intraclast breccias
974	S27 01 14.7	E24 46 22.5	Dark mudrocks of Vryburg Fm
975	S27 01 34.7	E24 46 56.9	Amygdaloidal Vryburg lavas
976	S27 01 40.3	E24 46 23.3	Wave rippled flagstones, upper Vryburg Fm
977	S27 01 39.9	E24 46 25.4	Heterolithic zone in upper Vryburg Fm
978	S27 01 59.0	E24 46 16.9	Rubbly flow breccia
979	S27 02 36.8	E24 46 22.5	Ferruginous carbonate plus stromatolites
980	S27 02 46.6	E24 46 49.9	Limestones and sandstones of upper Boomplaas Fm
981	S27 02 08.1	E24 47 10.1	Ferruginous Boomplaas carbonates
982	S27 00 51.5	E24 45 15.2	Quarry excavated into lower Vryburg quartzites near railway line