PALAEONTOLOGICAL HERITAGE: PHASE 2 MITIGATION REPORT

RECORDING & SURFACE SAMPLING OF PRECAMBRIAN STROMATOLITES FROM THE BOOMPLAAS FORMATION (GHAAP GROUP) ON A PORTION OF THE FARM WATERLOO 992 NEAR VRYBURG, NALEDI LOCAL MUNICIPALITY, NORTH-WEST PROVINCE

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EXECUTIVE SUMMARY

Stromatolites (fossil microbial mounds) within 2.6 billion-year-old shallow marine sediments of the Boomplaas Formation (Ghaap Group, Transvaal Group) are known from several localities to the south of Vryburg, Northwest Province. A range of partially silicified stromatolites was recently recorded within and just outside the project area for a solar energy facility on Farm Waterloo 992 (Almond 2013). Following authorisation of the development, the present Phase 2 palaeontological mitigation has involved (1) recording of stromatolites within or close to the development footprint as well as (2) judicious sampling of representative stromatolite material. The stromatolite samples are to be curated in the palaeontological collections of the Council for Geoscience, Bellville.

Several traverses across the main solar facility project area on Farm Waterloo 992 indicate that stromatolites occur widely within bedrocks here, although no clear pattern of distribution (*e.g.* discrete raised bioherms or fossil reefs) could be detected. It is likely that numerous stromatolites are hidden beneath the thin surface mantle of sandy soils and gravels here. However, on Waterloo 992 the best-exposed large-scale (1-2 m) stromatolite domes, as well as good representatives of other smaller forms, are concentrated outside and just east of the project area where the first examples were found and where most of the recent sampling occurred. The smaller (dm-scale), asymmetric stromatolitic domes or short columns and cones recorded from the Boomplaas Formation are better represented on neighbouring farms such as Champions Kloof 731 and Hartsboom 734, as reported in recent palaeontological impact studies by Almond (2016a, 2016b) and Groenewald (2016). It is likely that comparable stromatolite concentrations occur widely within hitherto unstudied parts of the Boomplaas Formation outcrop area near Vryburg. However, pending the discovery and documentation of further and better-preserved material, the designated areas featuring well-exposed stromatolites on the farms listed here are considered to be of high palaeontological research and conservation significance.

Two access road options for the solar energy facility on Waterloo 992 are presently under consideration, traversing the outcrop areas of the Vryburg and Boomplaas Formations. No sensitive fossil sites have been recorded either along the westernmost (Alternative 2) route that runs on the western side of a pan. In contrast, the Alternative 1 (preferred) access route passes through at least two areas where numerous stromatolites are exposed outside the main solar facility project area. A mitigated version of Alternative 1 that avoids the palaeontologically-sensitive areas is acceptable from the palaeontological heritage viewpoint (See Fig. 40 herein).

Following the recent Phase 2 recording and collection of stromatolites on Farm Waterloo 992 covered by this report, it is considered that a representative, scientifically-useful sample of the various stromatolite types known to be present in the Boomplaas Formation in the Vryburg region would be conserved within

the following areas once the solar facility is constructed: (a) the area just outside and to the east of the main solar facility project area on Waterloo 992 and (b) protected areas proposed on neighbouring farms Champions Kloof 731 and Hartsboom 734 (See Almond 2016a, 2016b, Groenewald 2016 and Fig. 2 herein). This would apply *with the proviso that all* the *palaeontological mitigation measures outlined in these specialist reports as well as the present report are followed through*. In the case of Farm Waterloo 992, these mitigation measures include: (1) protection of that portion of the area encircled in red in Fig. 39 that lies outside the defined solar facility project area by security tape or a fence during construction, and (2) exclusion of the sensitive stromatolite-rich area from the route of the access road or selection of an alternative road option.

These specialist palaeontological recommendations should be included within the Environmental Management Programme (EMPr) for the proposed solar energy facility on Farm Waterloo 992. *Provided that* these recommendations are followed through, the authorised solar facility development is unlikely to compromise a significant fraction of the *in situ* fossil stromatolite occurrences within the northern outcrop area of the Boomplaas Formation and there are no objections to its construction. Note that, since fossils will undoubtedly be destroyed, the developer will need to apply on the basis of this report for a Fossil Destruction Permit from the South African Heritage Resources Agency, SAHRA (Contact details: Dr Ragna Redelstorff. SAHRA, 111 Harrington Street, Cape Town. PO Box 4637, Cape Town 8000, South Africa. Phone: +27 (0)21 462 4502. Fax: +27 (0)21 462 4509. E-mail: rredelstorff@sahra.org.za. Web: www.sahra.org.za) before construction starts.

1. PROJECT BACKGROUND

Well-preserved stromatolites (fossil microbial mounds) of early Precambrian age have been recorded at surface within the footprint of an authorized solar PV facility on Farm Waterloo 992, situated some 10 km southeast of Vryburg, North West Province (Almond 2013). The truncated stromatolitic domes here reach up to 2 m in diameter (though usually less) but also occur at various smaller scales. The laminated biomats are frequently replaced by secondary silica and might conceivably also contain well-preserved microbial fossils (*cf* Wright & Altermann 2000). The stromatolites occur within the Boomplaas Formation, a carbonate-dominated succession that lies towards the base of the Ghaap Group (Transvaal Supergroup) and is estimated to be approximately 2.6 Ga / billion years old (Late Archaean) (See geological map Fig. 3 and stratigraphic column Fig. 4). The Boomplaas Formation occurrences are among the oldest well-preserved stromatolites known from the RSA palaeontological record (Older stromatolites are known, for example, from the 2.9 Ga Pongola Supergroup and the 2.7 Ga Ventersdorp Group of the RSA as well as in Zimbabwe; *cf* Schopf 2006). In addition to the large domes seen on Farm Waterloo 992, further occurrences of well-preserved stromatolitic horizons within the Boomplaas Formation - including possible patchy reefal structures or bioherms, short columnar stromatolites and conical forms - have been reported just to the south of Waterloo Farm 992 on the farm Champions Kloof 731 as well as to the southwest on Farm Hartsboom 734. In all these cases it was recommended that concentrations of especially well-preserved stromatolites be excluded from the proposed development footprints (Almond 2016a, 2016b, Groenewald 2016).

On following-up on an initial alert by Van Schalkwyk (2012), silicified stromatolites - fossil microbial mounds - were recorded from Precambrian rocks of the Boomplaas Formation (Ghaap Group) within the study area for a proposed solar energy facility on Farm Waterloo 992 near Vryburg, Northwest Province during a Phase 1 field-based palaeontological assessment by Almond (2013) (Please see Figs. 1 & 2 for location of project area). The original recommendations for palaeontological heritage mitigation for the solar facility development were as follows:

> *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.

Following subsequent discussions with the developer, SunEdison Energy Southern Africa (Pty) Ltd (Contact details: Ms Monique Jordaan, SunEdison Energy Southern Africa (Pty) Ltd. Mobile: +27 81 038 2443. Tel : +27 10 595 7015. E- mail: mjordaan@sunedison.com. Web: www.sunedison.com) and the responsible heritage management authority, SAHRA, it was agreed that the palaeontological mitigation work should rather be undertaken at an earlier stage, *before* vegetation clearance, since:

- The process of vegetation clearance is itself likely to damage surface-exposed stromatolite material that is the primary target for the proposed fossil sampling;

- It would prove difficult and time-consuming to integrate the proposed palaeontological mitigation work with phased vegetation clearance and construction work.

In response to a reasoned application (Almond 2017), a fossil collection permit for the proposed Phase 2 palaeontological mitigation work was issued by SAHRA (Case ID: 10938, dated Thursday May 04, 2017). The present report provides feedback from the two-day Phase 2 palaeontological mitigation fieldwork carried out by the author and an experienced heritage assistant in May 2017.

1.1. Legislative context

The present Phase 2 palaeontological heritage report falls under Sections 35 and 38 (Heritage Resources Management) of the South African Heritage Resources Act (Act No. 25 of 1999), and it will also inform the Environmental Management Programme (EMPr) for this project.

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

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

According to Section 35 of the National Heritage Resources Act, dealing with archaeology, palaeontology and meteorites:
(1) The protection of archaeological and palaeontological sites and material and meteorites is the responsibility of a provincial heritage resources authority.
(2) All archaeological objects, palaeontological material and meteorites are the property of the State.
(3) Any person who discovers archaeological or palaeontological objects or material or a meteorite in the course of development or agricultural activity must immediately report the find to the responsible heritage resources authority, or to the nearest local authority offices or museum, which must immediately notify such heritage resources authority.
(4) No person may, without a permit issued by the responsible heritage resources authority—
(a) destroy, damage, excavate, alter, deface or otherwise disturb any archaeological or palaeontological site or any meteorite;
(b) destroy, damage, excavate, remove from its original position, collect or own any archaeological or palaeontological material or object or any meteorite;
(c) trade in, sell for private gain, export or attempt to export from the Republic any category of archaeological or palaeontological material or object, or any meteorite; or
(d) bring onto or use at an archaeological or palaeontological site any excavation equipment or any equipment which assist in the detection or recovery of metals or archaeological and palaeontological material or objects, or use such equipment for the recovery of meteorites.
(5) When the responsible heritage resources authority has reasonable cause to believe that any activity or development which will destroy, damage or alter any archaeological or palaeontological site is under way, and where no application for a permit has been submitted and no heritage resources management procedure in terms of section 38 has been followed, it may—

(a) serve on the owner or occupier of the site or on the person undertaking such development an order for the development to cease immediately for such period as is specified in the order;
(b) carry out an investigation for the purpose of obtaining information on whether or not an archaeological or palaeontological site exists and whether mitigation is necessary;
(c) if mitigation is deemed by the heritage resources authority to be necessary, assist the person on whom the order has been served under paragraph *(a)* to apply for a permit as required in subsection (4); and
(d) recover the costs of such investigation from the owner or occupier of the land on which it is believed an archaeological or palaeontological site is located or from the person proposing to undertake the development if no application for a permit is received within two weeks of the order being served.

Minimum standards for palaeontological mitigation reports (Phase 2 PIAs) have been published by SAHRA (2013).

1.2. Methodology

The main focus of the proposed Phase 2 palaeontological mitigation was (1) to record (photographs, gps data, brief description) stromatolites exposed at surface within the solar facility development footprint, as well as (2) to collect a representative sample of the range of well-preserved stromatolitic structures from the Boomplaas Formation, such as those illustrated previously by Almond (2013, 2017). Fieldwork took place over two days (11-12 May 2017) with visibility on the ground only moderately good due to tall grass cover, scattered shrubs and small trees (Ghaap Plateau Vaalbosveld; Figs. 5 & 6).

Several WNW-ESE traverses across the solar development study area were undertaken by the author and an experienced field assistant (See tracks and waypoints shown in Figs. 38 & 39). Stromatolite occurrences and any geological features of interest were noted (See brief locality descriptions and gps data tabulated in the Appendix 1).

A modest number of blocks of silicified stromatolitic rock were collected at surface (See collection data provided in Appendix 2. The great majority specimens were collected from the area encircled in red in satellite image Figure 39. Large-scale (1-2 m diam.) stromatolitic domes at this site have largely been truncated by erosion and are usually poorly-exposed (Almond 2013) (Figs. 15 to 25); it is therefore not practicable to collect entire specimens. Collection methods employed included hand-picking of loose material from the surface (the majority of specimens) as well as prising-out of modest-sized blocks (dm - scale) using crowbars, hammer and chisels (only a few specimens) (*e.g.* Figs. 22 & 23). In practice, most of the silicified surface material proved to be extremely well-cemented to the underlying bedrocks and it was therefore not feasible to prise- or hammer-off sample blocks without destroying the fossils themselves.

1.2. Curation of fossil material

Stromatolitic material from Farm Waterloo 992, together with relevant collection data (Appendix 2), is to be curated in the Precambrian fossil collections at the offices of the Council for Geoscience, Bellville (Curator: Ms Claire Browning. 03 Oos Street BELLVILLE 7535, RSA. Tel: +27 (0)21 943 6700. Fax +27 (0)21 946 4190. Internet:http://www.geoscience.org.za).

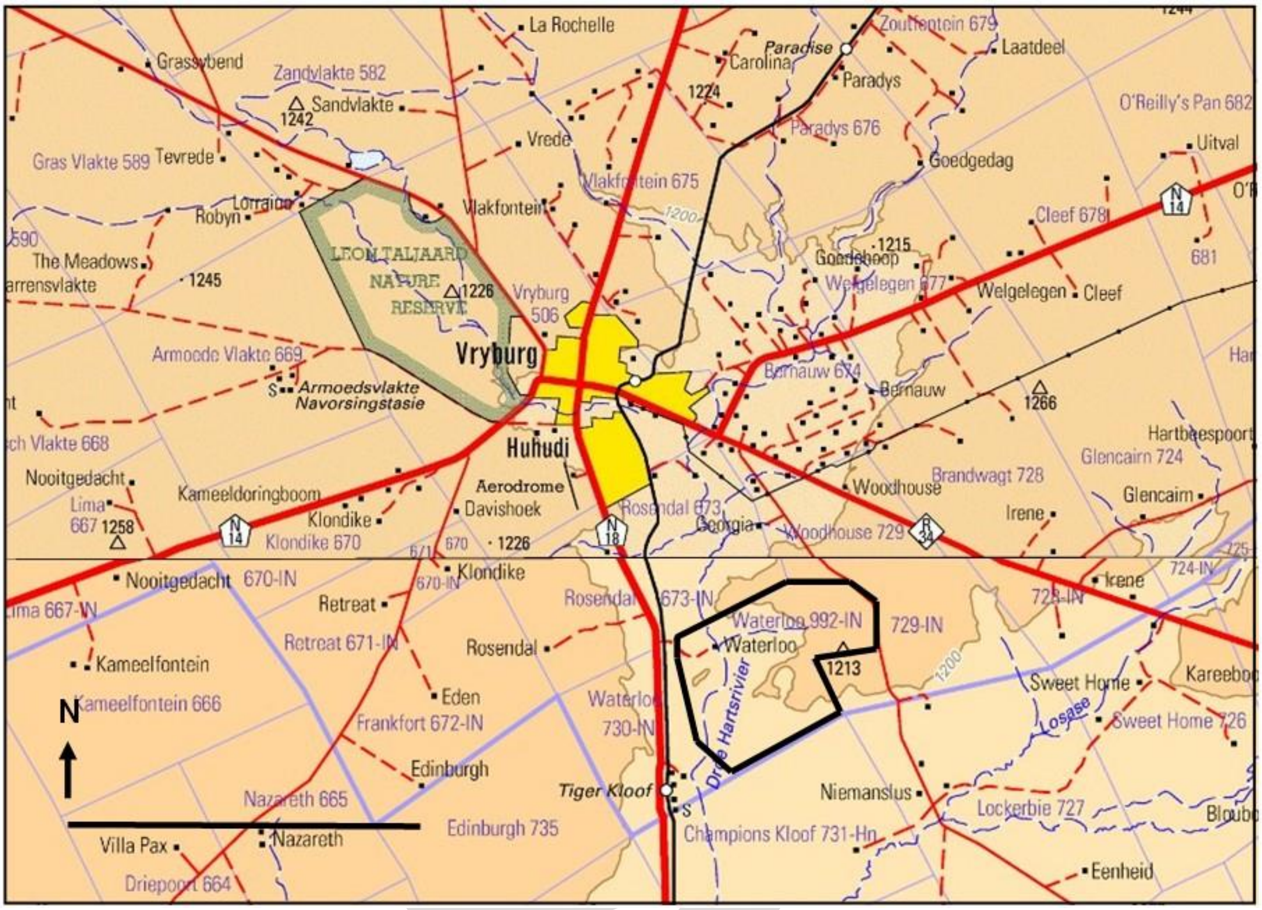

Fig. 1. Extracts from adjoining 1: 250 000 topographical maps 2624 Vryburg and 2724 Christiana (Courtesy of the Chief Directorate of Surveys & Mapping, Mowbray) showing location of the farm Waterloo 992 study area some 10 km southeast of Vryburg, North-West Province (black polygon). Scale bar is *c*. 10 km. Important Precambrian stromatolite occurrences are also known on the farm Champions Kloof 731 immediately to the south.

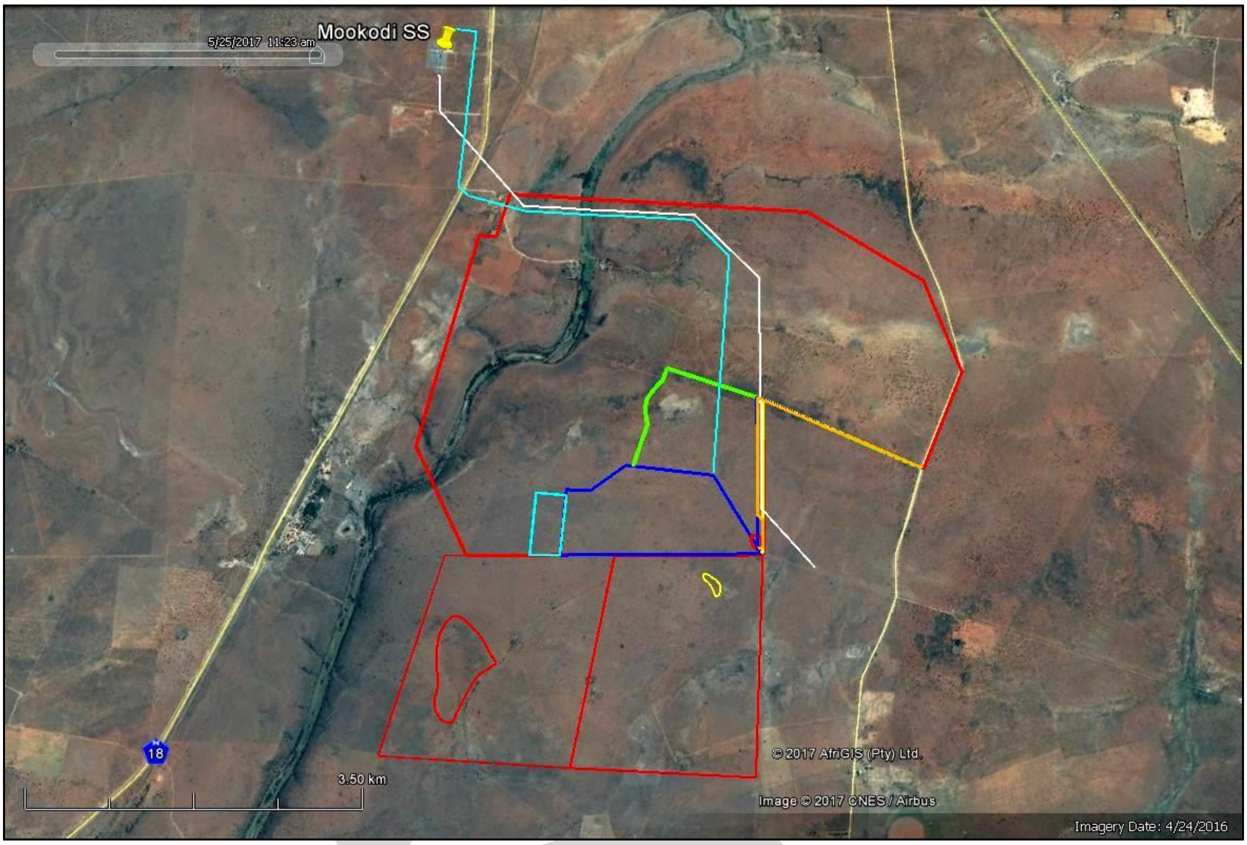

Fig. 2. Google earth© satellite image of the broader study region to the south of Vryburg, Northwest Province. Note N is towards the top right in this view.

KEY:

Red polygons: outline of Farm Waterloo 992 (north) and Champions Kloof 731 (2 southern polygons)
Dark blue *plus* pale blue polygons: expanded development area for the authorised 75 MW Waterloo Solar Power Park
Pale blue line: revised grid connection to Mookodi Substation on Rosendal 673
White line: existing Eskom transmission line
Small red and yellow shapes on Champion's Kloof 731: areas with well-preserved stromatolites (Almond 2016a, 2016b)
Green, orange & yellow lines: access road options (Please see Fig. 40 for more detail)

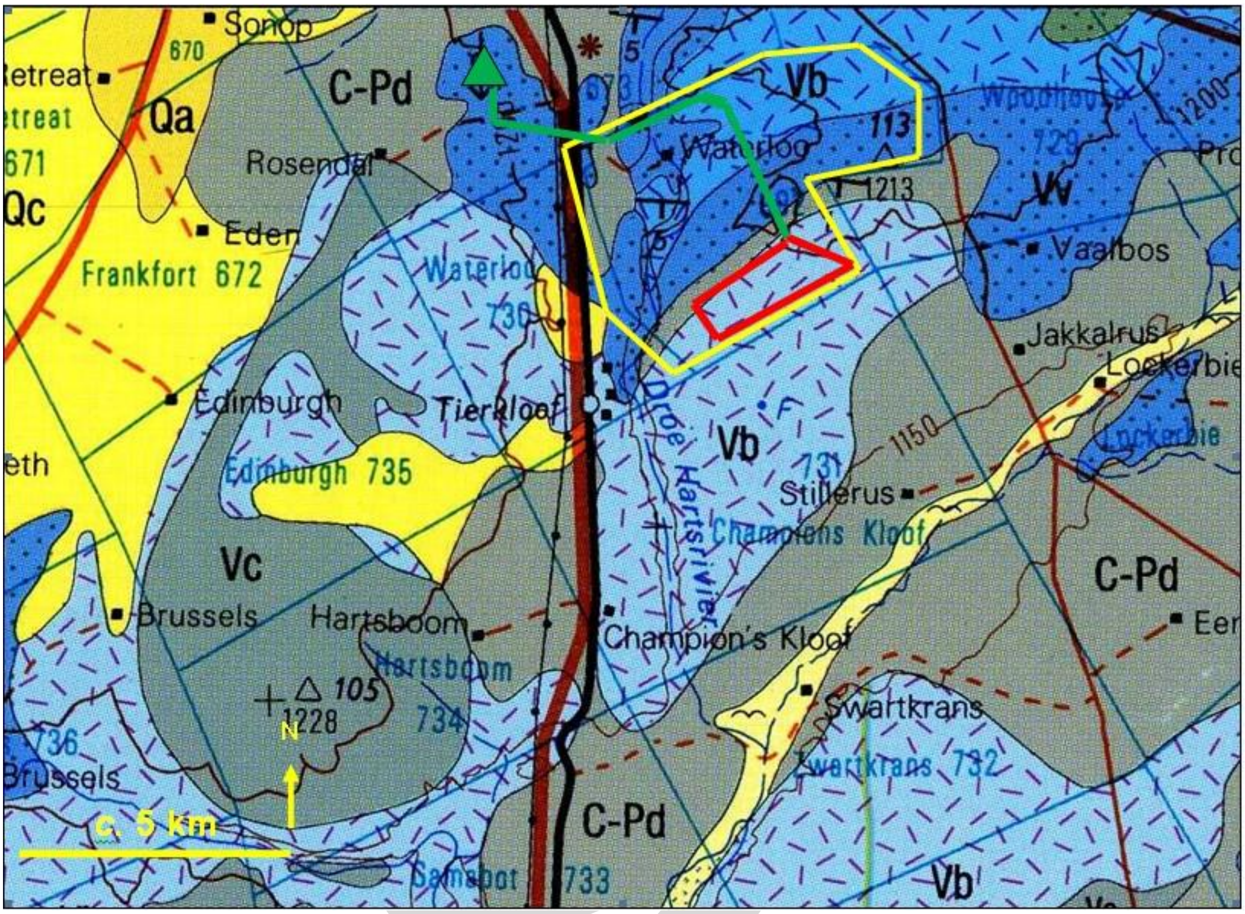

Fig. 3. Extract from the 1: 250 000 geological map 2724 Christiana (Council for Geoscience, Pretoria) showing location of the broader study area on the farm Waterloo 992, located some 10 km southeast of Vryburg (yellow polygon). The red polygon shows the expanded solar development area and the green line indicates the *approximate* power line route to Mookodi Substation (green triangle).

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)

Clearwater Formation (Vc, dark grey) – late Archaean mudrocks with interbedded dolomites, flagstones, tuffites, cherts

KAROO SUPERGROUP

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

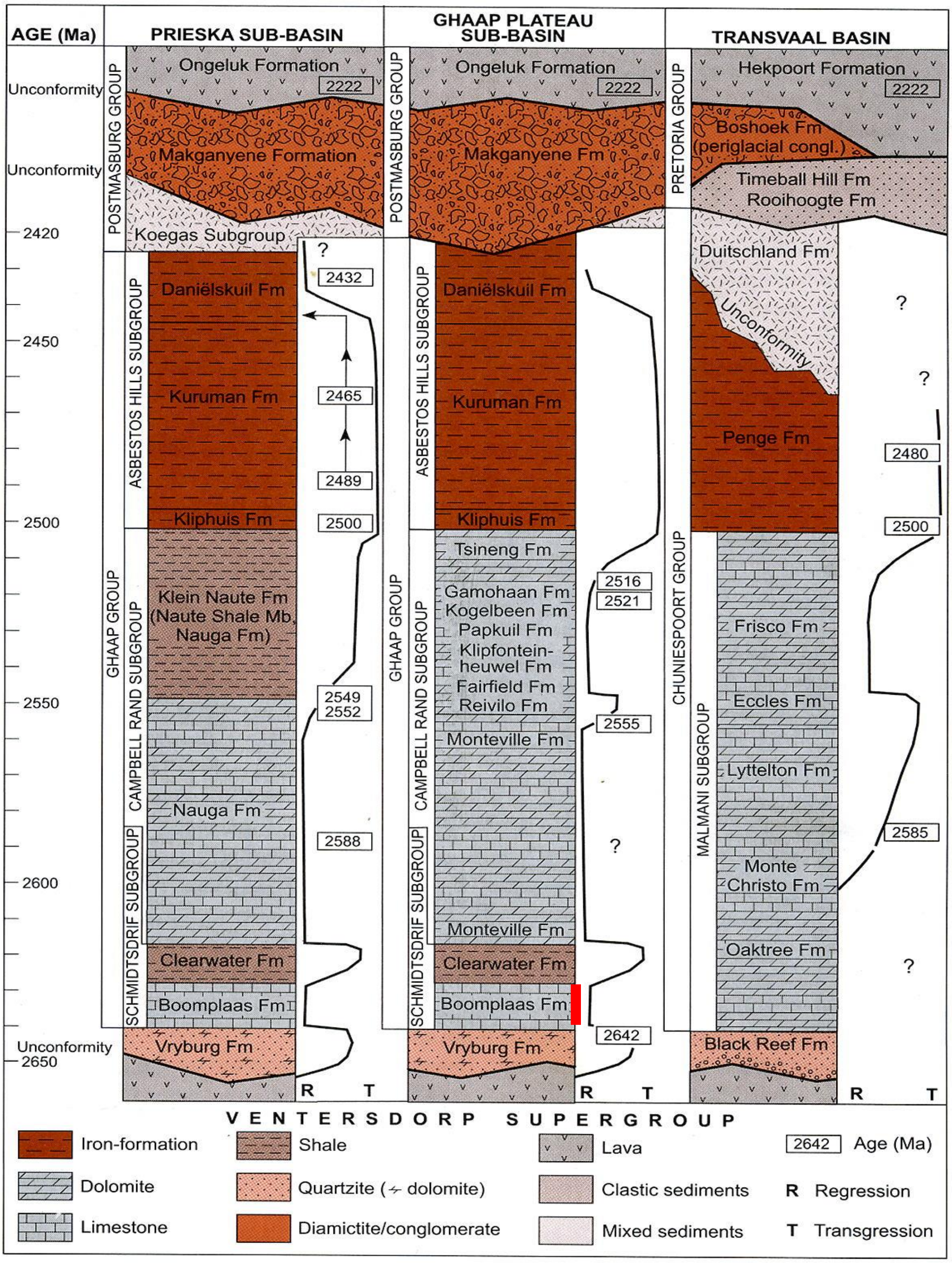

Fig. 4. Stratigraphy of the Transvaal Supergroup of the Ghaap Plateau Basin (central column) showing the position of the carbonate-dominated Boomplaas Formation that underlies the Waterloo Farm 992 solar energy facility main project area (red line) (From Eriksson *et al.* 2006). The proposed access road to the solar facility will in addition traverse the outcrop area of quartzites and lavas of the underlying Vryburg Formation (also included within the Schmidtsdrif Subgroup by some recent authors.

2. GEOLOGICAL & PALAEONTOLOGICAL CONTEXT

The shallow shelf and intertidal sediments of the carbonate-dominated lower part of the Ghaap Group (*i.e.* Schmidtsdrif and Campbell Rand Subgroups; Fig. 4) are well known for their rich fossil biota of *stromatolites* or microbially-generated, finely-laminated sheets, mounds, columns and branching structures. Detailed studies of these 2.6-2.5 Ga carbonate sediments and their stromatolitic biotas have been presented by Young (1932 and several subsequent papers), Beukes (1980, 1983), Eriksson & Truswell (1974), Eriksson & Altermann (1998), Eriksson *et al* (2006), Altermann and Herbig (1991), Altermann and Wotherspoon (1995), and Sumner (2002). The oldest, Archaean stromatolite occurrences from the Ghaap Group have been reviewed by Schopf (2006, with full references therein. Stromatolites within the Late Archaean (*c*. 2.6 Ga) Boomplaas Formation within the Schmidtsdrif Subgroup represent some of the oldest assemblages of these microbially-generated organo-sedimentary structures recorded in South Africa (Older stromatolites are known, for example, from the 2.9 Ga Pongola Supergroup and the 2.7 Ga Ventersdorp Group of the RSA as well as in Zimbabwe; *cf* Schopf 2006). Various forms of stromatolite have been recorded from the northern outcrop area of the Boomplaas Formation near Vryburg in recent palaeontological assessments by the author and others (*e.g.* Almond 2013, Almond 2016a, 2016b, Groenewald 2016), including those on Farm Waterloo 992 that are the subject of the present report. The laminated biomats were frequently replaced by secondary silica and might conceivably also contain well-preserved microbial fossils (*cf* Wright & Altermann 2000).

The Precambrian bedrocks on Farm Waterloo 992 are assigned to the Late Archean Vryburg and Boomplaas Formations (Ghaap Group), as outlined in the previous PIA report by Almond (2013) (Figs. 3 & 4). Low rounded exposures of grey-green Vryburg andesitic lavas, locally vesicular or blocky and accompanied by veins or lenses of chert, crop out on Farm Waterloo 992 to the north of the main solar energy facility project area, underlying the various access road route options (Fig. 14). Good exposures of the associated quartzites do not occur here and the bedrocks appear to be entirely unfossiliferous (*cf* Almond 2013). Occasional quartzitic float blocks contain abundant cubical pseudomorphs after pyrite. The land surface is mantled by sandy soils with abundant angular surface gravels of chert (some flaked) of many different hues that have downwasted from the Vryburg bedrocks. The narrow SW-NE band of Dwyka Group sediments (C-Pd, grey in Fig. 3) mapped along the southern edge of the Vryburg Formation outcrop area is not obvious in the field and may be an artefact.

The terrain in the main solar energy facility project area, which is entirely underlain by the Boomplaas Formation, shows very low topographic relief with no prominent outcrops of bedrock, and no extensive areas of fresh, unaltered limestone or dolomite. The bedrocks are largely obscured by orange-brown sandy soils and colluvial to alluvial cherty gravels as well as by grassy vegetation with scattered small trees and shrubs (Ghaap Plateau Vaalbosveld; Figs. 1 & 2). The surface gravels are mainly composed of angular chert clasts of different hues (esp. black, dark grey, brownish), occasional pale grey to brown quartzites and ferruginised carbonate. Some of the surface gravel clasts are flaked, especially in the vicinity of cherty lenses or layers in the bedrocks. Higher concentrations of surface gravels are encountered in the western portion of the study area where occasional pebbles are well-rounded, indicating stream transport. Occasional boulder-sized relict surface blocks of Boomplaas bedrocks comprise thin-bedded to laminated, greyish to pale yellow, sandy carbonate that is occasionally stromatolitic and shows prominent-weathering cherty lenses or bands (Figs. 8 & 9). *In situ* tougher interbeds of brown, medium- to fine-grained quartzite and lenses or layers of massive, black to dark grey stratiform chert are encountered (the latter often showing signed of Stone Age knapping) (Figs 10 to 12). Both facies may contain cubical pseudomorphs or moulds after pyrite, probably a product of anoxic decomposition of buried organic material during diagenesis (*cf* Wright & Altermann 2000). Curious preservational features within some grey quartzites suggest microbial binding of wave-rippled sandstone laminae (Fig. 13).

Only small, patchy *in situ* exposures of Boomplaas carbonate bedrocks are seen within the study area with little clear evidence of bedding orientation (Fig. 6). The Schmidtsdrift Subgroup succession in the study area broadly youngs towards the south, with the Vryburg, Boomplaas and Clearwater Formations cropping out successively from north to south on farms Waterloo 992 and Champions Kloof 731 (Fig. 3). It is inferred that bedding dips are low and towards the south. Given the extensive secondary ferruginisation of the surface carbonates as well as the ubiquitous horizontal truncation of larger stromatolitic domes, the terrain is interpreted as an ancient (perhaps Late Tertiary) peneplanated land surface at an elevation of *c*. 50 m above the current bed of the Droë Hartsrivier. This relict land surface has been worn flat through surface weathering (including solution weathering of carbonates) and erosion, secondarily ferruginised (with additionally some blackish manganese mineralisation) and mantled with down-wasted gravels and aeolian sands. Vertical denudation has led to the horizontal truncation of large-scale stromatolite domes, no intact examples of which are now seen at surface (There may be buried examples). Solution weathering of more soluble carbonate rocks has led to the preferential weathering-out of resistant silicified horizons and lenses including stratiform chert bands, occasional quartzite interbeds as well as silicified portions of stromatolitic beds.

Dense, cryptocrystalline chert lenses, veins and thin (dm-scale) horizons occur within the Vryburg Formation, especially in association with andesitic lavas, as well as in the overlying carbonate-dominated Boomplaas Formation. It seems likely that partial secondary silicification of the Boomplaas stromatolites occurred as an early and / or late diagenetic effect in Late Archaean times, *i.e.* long-antedating and unrelated to land surface development, with the underlying volcanic rocks as a possible source of dissolved silica. On-going igneous activity in Boomplaas times might also have played a role here (*N.B.* Many Ghaap Group carbonate successions show secondary cherty lenses, pods and layers which were sometimes concentrated into surface gravel breccias by erosional downwasting in Precambrian times). Silicification has often been confined to the periphery of the large stromatolite domes, which consequently weather-out as rings, the softer core having been weathered away (Figs. 15 & 16). The detailed pattern of silicification may have been related to the preservational status of the microbial organic remains at the time (*e.g.* level of decomposition). The cherty peripheral zones of the large stromatolites are variously massive and black or dark grey (when they often show signs of *in situ* Stone Age knapping; Fig. 17) or preserve the original fine-scale, flat or crinkly organic lamination. Several examples of silicified cores and surrounding inner laminated zones are also encountered, however (Figs. 18 to 25).

Major occurrences of stromatolites within the lower, Late Archaean portions of the Ghaap Group of South Africa reflect colonisation of extensive shallow marine platform carbonate settings in Late Archaean and Proterozoic times by sediment-binding microbes (cyanobacteria and others). According to some workers microbially-mediated carbonate precipitation was a more important process in stromatolite build-up and diagenetic mineralisation than sediment trapping and binding in the Archaean – Proterozoic interval (*e.g.* Altermann 2008, Wright & Altermann 2000). However, since some of the cyanobateria involved probably generated sticky surfaces, it is likely that *both* sediment-binding and carbonate precipitation processes were often involved. The large domal stromatolites seen in the Boomplaas Formation were built-up from smooth or (more commonly) wavy- to pustular or crinkly ("laterally-linked") layers showing only a moderate degree of inheritance through successive laminae (Fig. 20). The end result was a broadly dome-shaped "lithoherm" with an onion-like internal structure of numerous concentric laminae rather than discrete stromatolitic columns. Stromatolitic domes with a circular base have been associated by various authors with quiet water settings in the photic zone, for example offshore below fair-weather wave-base or in sheltered lagoons (Altermann 2008 and refs. therein). The large (m-scale) hemispherical, low –relief (few dm) domal stromatolites with internal, small-scale wavy or crinkly lamination observed in the Boomplaas Formation may have formed under the influence of waves but in the absence of dominant currents. Under the influence of prevailing currents, some of the domes or steeper-sided cushions grew in an asymmetrical fashion with an elliptical base (Figs. 24 & 25); the long axis of the domes is taken to be subparallel to the predominant current direction. Larger domes as well as flat-laminated, stratiform microbial mats probably formed in deeper, persistently-quiet waters in offshore areas on the carbonate platform.

Medium-scale (1-2 dm diameter) stromatolites in the Boomplaas Formation comprise small domes as well as short, stubby columns (Figs. 26 to 30); these probably form an ontogenetic series. More energetic, unstable conditions nearer shore in the subtidal zone favoured smaller, probably less longlived stromatolites with current or wave scour maintaining spaces between adjacent lithoherms. The medium-sized (dm-scale) forms seen here typically show a strongly asymmetrical growth pattern with accretion consistently towards the west or northwest and smooth to crinkly, upward-convex internal lamination. Medium-scale stromatolites are locally associated with thin platy intraclast breccias (Fig. 7), with clasts of reworked carbonate or mudrock (usually preserved as moulds), suggesting they were exposed to turbulent conditions, at least intermittently. Asymmetrical growth probably reflects local or regional current patterns that may have caused preferential accretion of fine clastic material on the up-current face of the domes (*N.B.* local asymmetrical growth may be caused by other factors such as uneven illumination). In Boomplaas Formation times the Kaapvaal Craton shoreline probably lay towards the east in the Vryburg area and the epicontinental / epeiric sea deepened towards the west. Stromatolitic growth may have been influenced by east-west, tidally-driven onshore and offshore currents.

Several widely-spaced WSW-ENE traverses across the solar project study area (See tracks in satellite images in Figs. 37 to 39) show that stromatolites on various scales, ranging from large m-scale domes to medium-sized (1-2 dm scale) domes / short columns and small (cm-scale) microdomes or "buttons", occur sporadically at surface throughout the area. They are extensively silicified and undoubtedly occur in the subsurface as well. While a wide range of intergrading stromatolite morphology is observed among the Boomplaas stromatolites, the microbial organo-sedimentary structures found can be conveniently grouped into three main types:

- **Large stromatolitic domes** with diameters of the order of 75 cm – 200 cm and a low original relief (estimated to be of the order of a few dm) (Figs. 15 to 20). These domes are generally round in plan view but occasionally ellipsoid (NW-SE elongation) and may form nested sets. Where very occasionally preserved the core of the dome is a convex-up hemisphere, either smooth or covered with small button-like protuberances reflecting early growth stages of the dome (Figs. 21 to 23). The surrounding concentric laminae of the dome may be smooth or – more often - crinkled. In most cases only the outer rim of the dome was silicified (possibly because it was richer in coherent, less decomposed organic material) while the core and other inner portions are lost. No examples of 3D intact large domes or specimens preserved in the original carbonate were recorded.

- **Medium-scale domes and/or short columnar stromatolites** with diameters of one to two dm and well-developed, smooth or crinkly, concentric internal lamination. They are typically preserved in rusty-brown ferruginous carbonate or silicified carbonate (Figs. 26 to 30); occasional less diagenetically-modified examples preserved in greyish carbonate are also occur (Fig. 9). Most of these medium-sized stromatolites are closely-spaced to adjoining, or form nested sets, but occasional well-spaced examples are observed (Fig. 29). In horizontal section the internal lamination characteristically displays clear evidence of highly-asymmetrical accretion, with lateral growth consistently towards the W or NW in the study area, giving the appearance of a coherent "mass migration" of small domes or short columns through time. Asymmetrical growth is probably attributable to current influence (*cf* Altermann 2008). Good vertical sections through these structures were not seen on the Waterloo 992 and would be of great interest. At least some some of them may represent the tips of stumpy asymmetrical columns rather than simple hermispherical domes, depending on the relative proportions of vertical *versus* lateral accretion. This interpretation is supported by clumps of short, stubby stromatolitic columns observed surmounting well-spaced, rounded, low-relief mounds in the Boomplaas Formation on Farm Hartsboom 736, located only a few km to the southwest of the present study area (Groenewald 2016) (Fig. 30).

- **Small-scale stromatolitic "buttons"** with diameters up to 5 cm (and often less) (Fig. 31 to 33). These small-scale convex-up features - technically termed laterally-linked hemisphaeroids or LL-H - are rounded to irregular in plan and connect sideways with one another within a given lamina. Where preserved in vertical section they show irregular, low-inheritance vertical accretion, without the formation of discrete, well-defined micro-columns (Figs. 34 to 36). Buttons are occasionally seen in preserved cores of large domes (Figs. 21 & 22) as well as covering convex steep-sided stromatolitic cushions and undulose to irregularly-ridged bedding surfaces. They may be responsible for the wavy or crinkly appearance of interior or peripheral lamination in large domes but this is often at a smaller scale and might also reflect hydrodynamic modelling (*e.g.* by wave action).

It is noted that examples of the distinctive medium-sized, conical microbial mounds that were recorded in the Boomplaas Formation on Champion's Kloof 731 have not been identified on Waterloo 992. These conical stromatolites show a coarse or poorly-defined internal lamination, a characteristic rugose (rough) surface texture and tendency to coalesce laterally (Almond 2016b).

Fig. 5. Typical flat terrain within the main solar facility project area on Farm Waterloo 992 with grasses, scattered trees and shrubs (Ghaap Plateau Vaalbosveld). The bedrock here are largely mantled by orange sandy soils and sparse to locally concentrated cherty gravels.

Fig. 6. Patchy, low-relief exposure of Boomplaas Formation ferruginous carbonates in the western portion of the solar facility project area (Loc. 214).

Fig. 7. Lens of fine intraclast breccias within ferruginous Boomplaas Formation sandy carbonates witnessing occasional high-energy events such as storms in the depository (Scale is 15 cm long). Original platy carbonate or mudrock clasts have weathered out as hollows (Loc. 196).

Fig. 8. Relict block of pale grey, thin-bedded Boomplaas Formation carbonates with prominent-weathering lens of grey chert containing cubical moulds of pyrite crystals (Hammer = 30 cm) (Loc. 160).

Fig. 9. Overturned float block of pale, sandy Boomplaas Formation carbonate containing inverted medium-scale stromatolitic domes (or tips of short columns) showing a strongly asymmetric growth pattern (Scale = 15 cm) (Loc. 139).

Fig. 10. Extensive stratiform horizon or lens of dark grey diagenetic chert (Hammer = 30 cm) (Loc. 140).

Fig. 11. Thicker beds and lenses of resistant-weathering chert have often been exploited by Stone Age tool-makers, as shown by evidence of *in situ* knapping and concentrations of chert flakes in the vicinity (Scale in cm and mm) (Loc. 200).

Fig. 12. Rare exposure of tough, well-jointed, brown, fine- to medium-grained quartzite interbeds within the Boomplaas Formation (Hammer = 30 cm) (Loc. 177).

Fig. 13. Pale grey quartzite float block showing vague wave rippling and fine sedimentary lamination. Accentuation of ripple crests by microbial binding has generated sinuous, linear, borrow–like features (Scale in cm) (Loc. 151).

Fig. 14. Low, rounded exposure of brown-weathering andesites within the Vryburg Formation with pale and dark grey chert veins or lenses in the background (Hammer = 30 cm). Note carpet of brown cherty gravels mantling much of the outcrop area (Loc. 112).

Fig. 15. Typical preservation of a horizontally-truncated large stromatolitic dome (*c*. 1 m diameter) showing prominent weathering of preferentially-silicified peripheral zone and loss of the core zone (Hammer = 30 cm) (Loc. 129).

Fig. 16. Detail of silicified periphery of the stromatolitic dome seen in the previous figure showing preservation of thin, concentric, smooth to finely-crinkly laminae in dark chert (Scale in cm and mm) (Loc. 129).

Fig. 17. Portion of the silicified periphery of a large stromatolitic dome showing areas of well-defined crinkly lamination contrasting with others showing replacement by massive black chert. The latter has been knapped *in situ* for stone tools (Scale is 15 cm long) (Loc. 126).

Fig. 18. Truncated large stromatolitic dome (r = *c*. 40 cm) showing contrasting secondary silicification of the smooth core *plus* inner concentric laminae as well as the separate peripheral zone (Loc. 131).

Fig. 19. Truncated large stromatolitic dome showing the low convexity of the inner lamination (Hammer = 30 cm) (Loc. 133).

Fig. 20. Interior portion of a large stromatolitic dome showing fine-scale crinkly lamination which may reflect wave action during growth (Scale in cm and mm) (Loc. 118).

Fig. 21. Silicified central or primordial portion of a large stromatolitic dome. The paler, highly-convex core region is covered with smooth, button-like mini-stromatolites (Loc. 116).

Fig. 22. As above, also clearly showing the small, internally-laminated micro-stromatolite buttons in the paler core region (Diameter of core is *c*. 10 cm). The blackish-brown surrounding region has been secondarily impregnated by ferro-manganese minerals, possibly in Late Caenozoic times (Loc. 117).

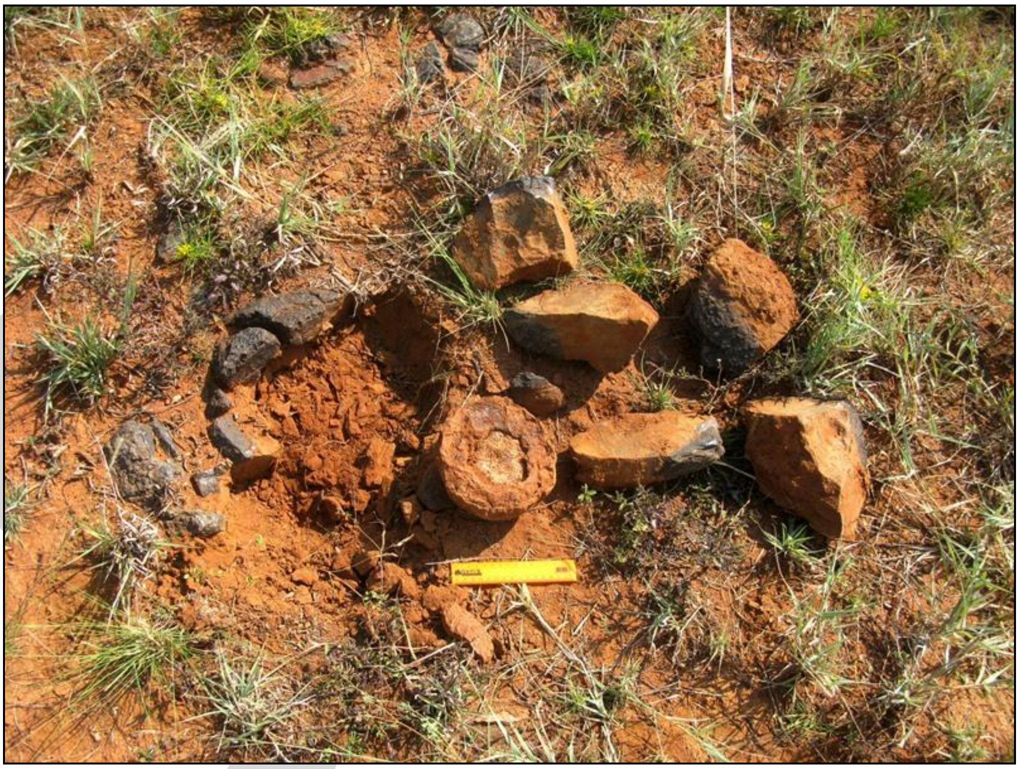

Fig. 23. Partially-excavated fragments of the specimen seen in the previous figure (Scale is *c.* 15 cm long). The blocks here had already become separated from the bedrock by weathering, but in most other cases stromatolite structures exposed at the surface are strongly welded to the silicified substratum (Loc. 117).

Fig. 24. Elliptical, silicified core of a large stromatolitic dome (Scale in cm) (Loc. 131). Centripetally- as well as centrifugally-dipping laminae imply an asymmetrical, cushion-like form.

Fig. 25. Silicified cushion-like stromatolite or stromatolite core with steep to undercut sides (Scale in cm) (Loc. 158).

Fig. 26. Ferruginised carbonate stromatolite horizon (partially silicified) composed of a densely-packed array of medium-sized stromatolites – short column or domes - showing strong, consistent asymmetrical growth away from the observer (westwards) (Hammer = 30 cm) (Loc. 144).

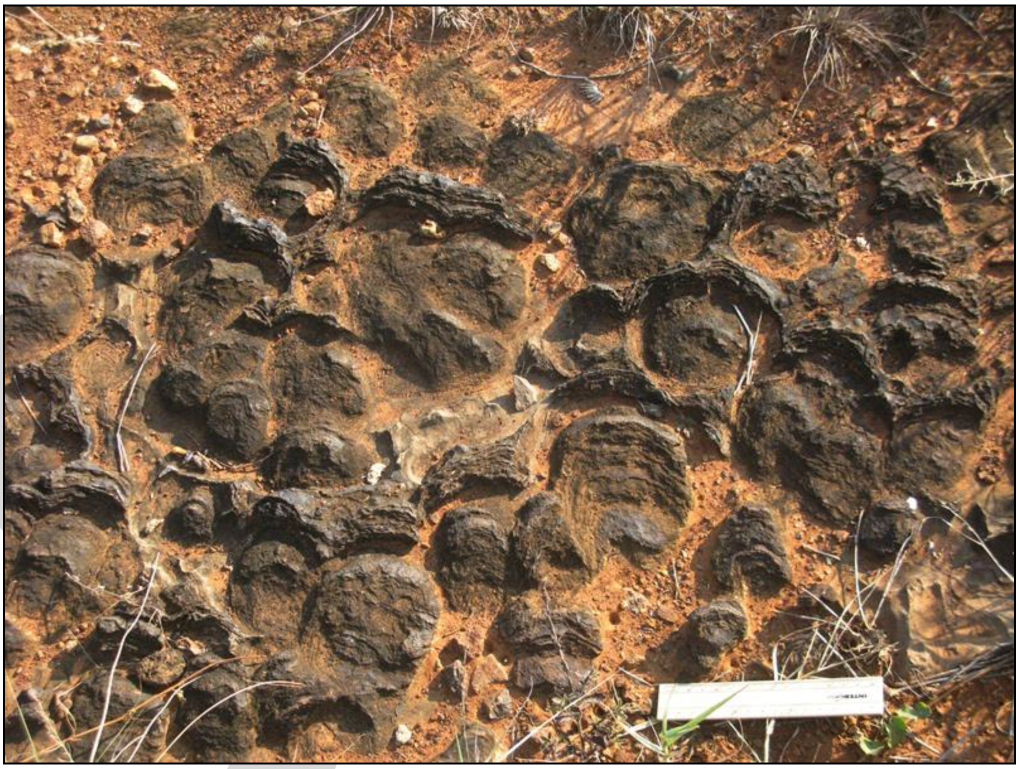

Fig. 27. Same as above (Scale in cm). Irregular dark grey cherty ridges appear to represent silicification of the leading edge of some stromatolites (Loc. 153).

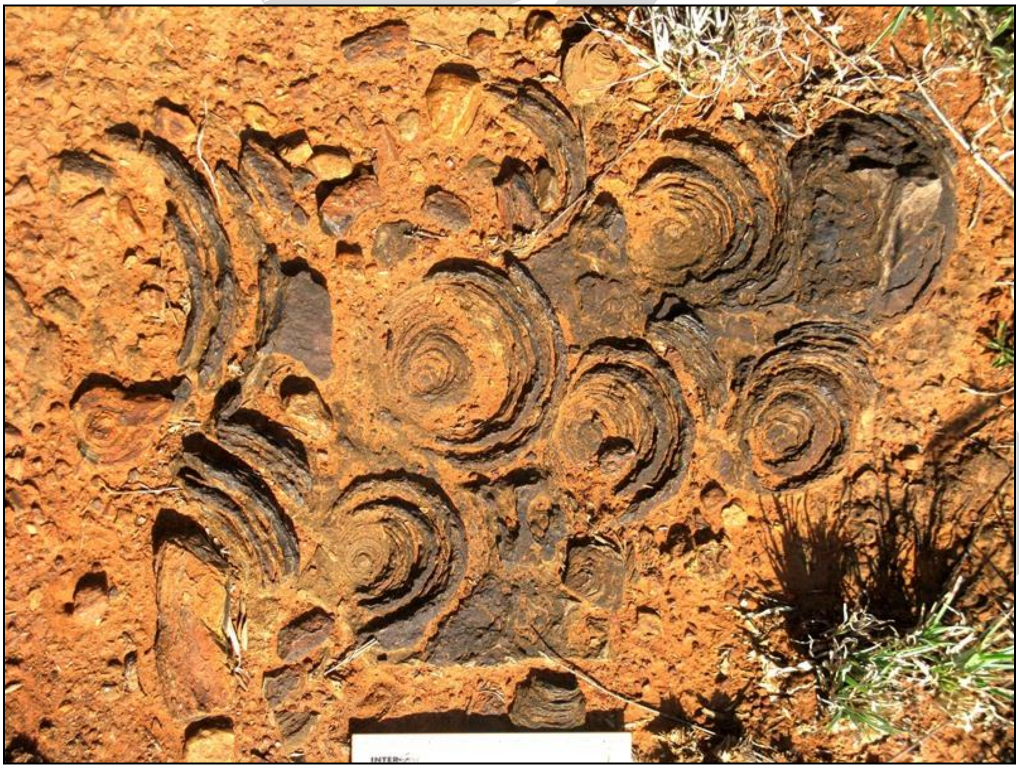

Fig. 28. Subcircular horizontal sections through a set of closely-spaced, silicified and ferruginised, medium-scale stromatolites (Scale is 15 cm long). Growth is highly asymmetrical, towards the top right, *i.e.* westerly (Loc. 194). These may represent sections through short, stubby, leaning columns rather than domes (*cf* Fig. 30 below).

Fig. 29. Well-spaced, concentrically-laminated stromatolites with an ellipsoidal plan showing asymmetric growth towards the observer (Scale is 15 cm long). Note smooth lamination surfaces here (Loc. 196).

Fig. 30. Spaced subcircular, low-relief, meter-scale mounds or patch reefs (estimated *c.* 60-100 cm across), each with an array of short, stubby columnar stromatolites on the upper surface, Boomplaas Formation, Farm Hartsbooom 734 (Photo abstracted from the PIA report by Groenewald 2016). These columns are probably equivalent to at least some of the medium-sized stromatolites seen in horizontal section in Figs. 26 to 29 above.

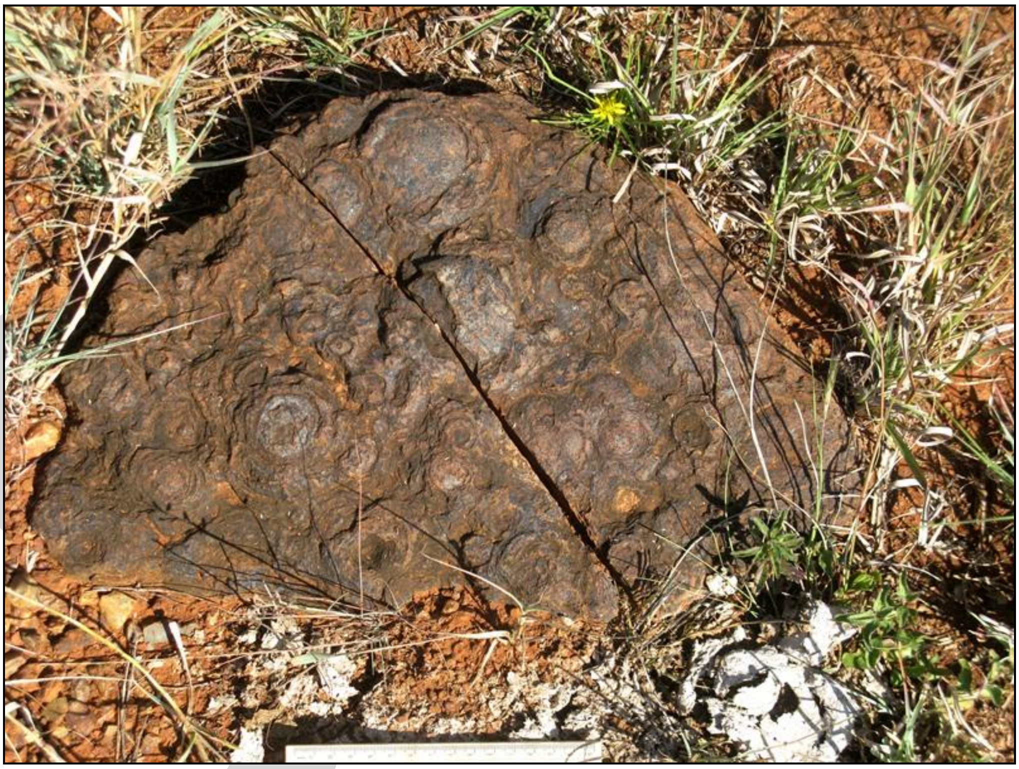

Fig. 31. Bedding plane of ferruginous carbonate covered with small-scale stromatolitic microdomes of various diameters (Scale in cm) (Loc. 210).

Fig. 32. Low ridges and rounded, cushion-like elevations covered with a carpet of silicified stromatolitic buttons or microdomes (Scale = 15 cm) (Loc. 125).

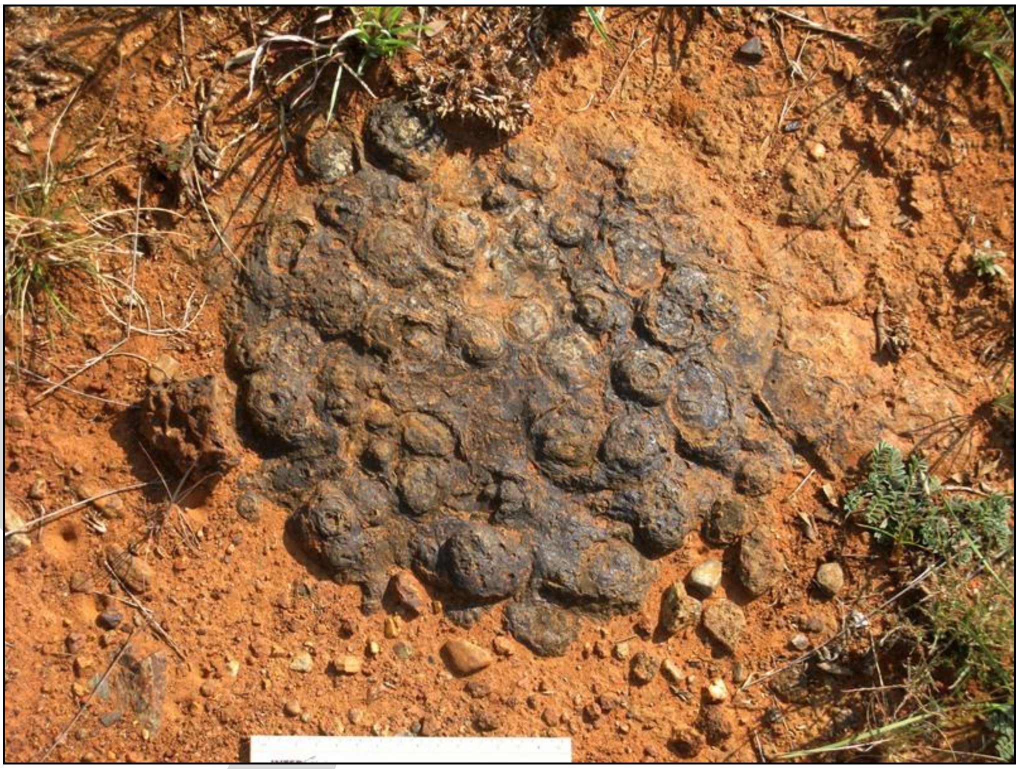

Fig. 33. Low dome-like elevation showing dense cover by small silicified stromatolitic microdomes or “buttons” with convex-upwards internal lamination (Scale is *c.* 15 cm long) (Loc. 125).

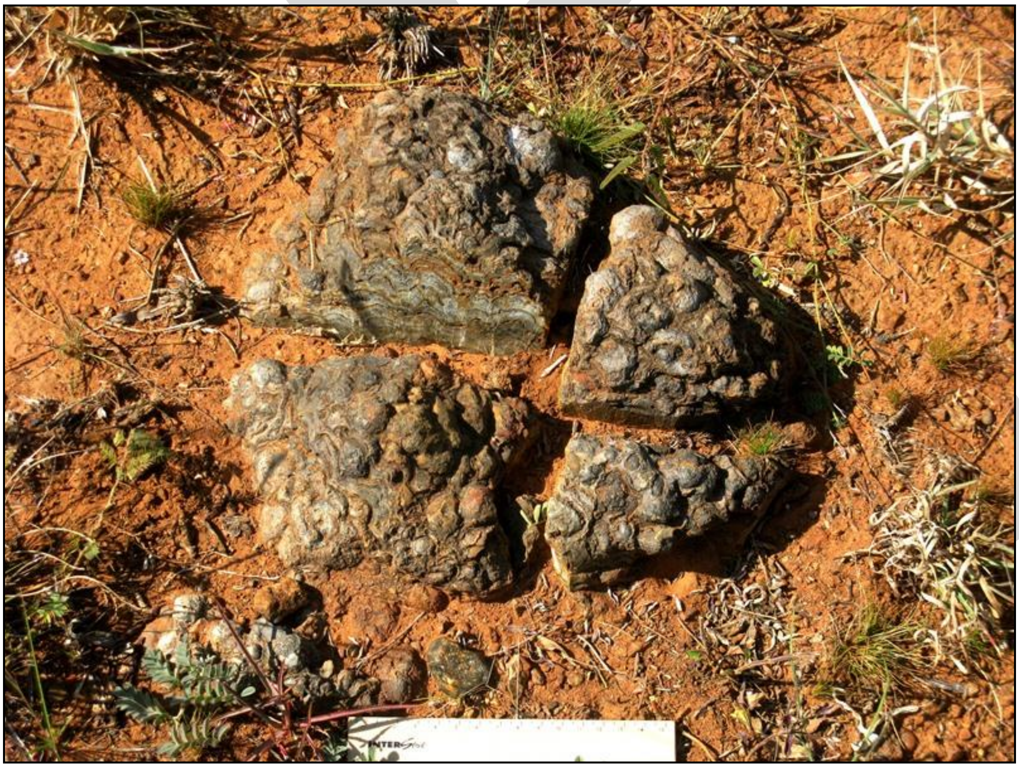

Fig. 34. Silicified steep-sided, cushion-like stromatolitic cushion or head composed of stromatolitic microdomes generating a rough, warty or pustular outer surface (Loc. 217).

Fig. 35. Vertical section through the stromatolitic cushion seen in the previous figure showing how it is made up of small-scale, convex-up buttons (so-called "laterally-linked hemisphaeroids" of LL-H). Due to the low level of shape inheritance between successive laminae the stromatolite builds-up to form a dome-like structure rather forming discrete, well-defined columns (Loc. 217).

Fig. 36. Wavy lamination in vertical section through a stromatolite cushion generated by small-scale laterally-linked hemisphaeroids (1 to few cm wide) (Loc. 128).

3. RESULTS & CONCLUSIONS

Tracks and waypoints recorded during the May 2017 fieldwork are shown on satellite images in Figures 37 and 38 below, with gps data and short descriptions provided in the Appendix 1 (Please note that the absence of fossil data for many areas does *not* imply that there are no stromatolites present here; they may be buried in the subsurface or simply not have been recorded). Occurrences of large domal stromatolites and medium-sized domal / columnar stromatolites are distinguished on the satellite maps in yellow and green respectively.

No clear patterns of stromatolite distribution within the study area could be discerned, nor were discrete fossil bioherms (*i.e.* prominent, wave-resistant stromatolitic build-ups or reefs) identified here. These larger-scale features are not recognisable on satellite images either. It is likely that stromatolites occur widely in the subsurface across most of the area and their recorded distribution to a large extent may well be a function of low, patchy levels of bedrock exposure through the thin mantle of sandy soils and gravels. The densest concentration of well-exposed large stromatolitic domes, as well as many of the best examples of small-scale stromatolitic buttons, were recorded just outside and to the east of the study area (red encircled area in Fig. 39), with numerous additional occurrences inside the area itself. None of the latter are considered sufficiently exceptional as to warrant special mitigation measures; good representative examples of these stromatolite morphologies recognised are found within the red circled area and were sampled here. It is recommended that during construction of the solar facility the stromatolites exposed at surface within the portion of the red circled area in Figure 39 that lies outside the main development area be protected from damage or disturbance by fencing or security tape. Medium-scale stromatolites of domal or possibly short columnar shape are best represented within the solar facility study area (green locality numbers in Fig. 38), although there are also occurrences outside this too.

A list of stromatolite specimens collected from Farm Waterloo 992 and curated by the Council for Geosciences, Bellville, is provided in Appendix 2. The great majority of the sampled fossil material was collected in the stromatolite-rich area outside and east of the main solar facility project area (encircled in red on Fig. 39). The specimens mainly comprise loose float blocks but also include material prised-out by hammers, chisels and crowbars (Fig. 23). The medium-scale, laterally-accreting stromatolite populations were *not* sampled because they occur on more extensive bedding surfaces which it was not practicable to break-up or remove intact in the field. Fortunately, this stromatolite type is well represented on Champions Kloof 731 just to the south (Almond 2016a. 2016b; see small red and yellow areas marked in Fig. 2) as well as on Hartsboom 736 to the southwest (Groenewald 2016). On these other farms large (m-scale) stromatolite domes have not yet been recorded. There is as yet insufficient field data to determine if their absence here is due to different palaeoecological settings and / or is related to different stratigraphic levels within the broadly south-dipping Boomplaas Formation. It is likely that comparable stromatolite concentrations occur widely within hitherto unstudied parts of the Boomplaas Formation outcrop area near Vryburg. However, pending the discovery and documentation of further and better-preserved material, the designated areas featuring well-exposed stromatolites on the farms listed here are considered to be of high palaeontological research and conservation significance.

Following the recent Phase 2 recording and collection of stromatolites on Farm Waterloo 992 covered by this report, it is considered that a representative, scientifically-useful sample of the various stromatolite types known to be present in the Boomplaas Formation in the Vryburg region would be conserved within the following areas once the solar facility is constructed: (a) the area just outside and to the east of the main solar facility project area on Waterloo 992 and (b) protected areas proposed on neighbouring farms Champions Kloof 731 and Hartsboom 734 (See Almond 2016a, 2016b, Groenewald 2016 and Fig. 2 herein). This would apply *with the proviso that all* the *palaeontological mitigation measures outlined in these specialist reports as well as the present report are followed through*. In the case of Farm Waterloo 992, these mitigation measures include: (1) protection of that portion of the area encircled in red in Fig. 39 that lies outside the defined solar facility project area by security tape or a fence during construction, and (2) exclusion of sensitive stromatolite area from the route of the access road or selection of an alternative road option.

These specialist palaeontological recommendations should be included within the Environmental Management Programme (EMPr) for the proposed solar energy facility on Farm Waterloo 992. *Provided that* these recommendations are followed through, the authorised solar facility development is unlikely to compromise a significant fraction of the *in situ* fossil stromatolite occurrences within the northern outcrop area of the Boomplaas Formation and there are no objections to its construction. Note that, since fossils will undoubtedly be destroyed, the developer will need to apply on the basis of this report for a Fossil Destruction Permit from the South African Heritage Resources Agency, SAHRA (Contact details: Dr Ragna Redelstorff. SAHRA, 111 Harrington Street, Cape Town. PO Box 4637, Cape Town 8000, South Africa. Phone: +27 (0)21 462 4502. Fax: +27 (0)21 462 4509. E-mail: rredelstorff@sahra.org.za. Web: www.sahra.org.za) before construction starts.

To the author's knowledge, the Late Archaean stromatolite occurrences within the northern outcrop area of the Boomplaas Formation near Vryburg have not yet been comprehensively described, illustrated or interpreted in any detail. It may well prove worthwhile to search for better exposures of the Boomplaas Formation in the Vryburg area in the hope of finding good vertical sections through stromatolitic horizons and perhaps mappable, 3D weathered-out bioherms and intact stromatolites that have not been truncated by erosion. It may possible in future to relate stromatolite morphology and stromatolite bioherm build-ups to palaeo-environmental factures such as water depth, exposure, sediment supply as well as wave and current action. If some of the secondary chert within the stromatolitic horizons is early diagenetic in origin, it might show well-preserved Archaean microfossils in thin section (*cf* Schopf 2006); filamentous microfossils have been recorded from Ghaap Group stromatolitic carbonates by Wright and Altermann (2000), for example.

3.1. Access road options

Two access road options are presently under consideration (Fig. 40). The west-east, northern limbs of the proposed access road route options traverse the Vryburg Formation outcrop area and are not palaeontologically sensitive (*cf* Almond 2013). The north-south limbs pass from the Vryburg Formation in the north onto potentially-fossiliferous Boomplaas Formation bedrocks in the south. There are no highly sensitive fossil sites recorded along the western (land owner/Alternative 2) route along the western side of the pan (green in Fig. 40) or along the existing farm track that runs along the fenced edge of the property (yellow in Fig. 40). In contrast, the Alternative 1 (preferred) access route (dark blue in Fig. 40) which runs inside and parallel to the farm boundary passes through at least two areas where numerous stromatolite occurrences outside the main project area are recorded at surface (Figs. 38 & 39). A mitigated version of the Alternative 1 route that is designed to avoid the palaeontologically-sensitive area has therefore been proposed (orange in Fig. 40). This last mitigation version of Alternative 1 is acceptable from a palaeontological heritage viewpoint. It is noted that the existing access road (approved) is also still being considered, pending approval by Eskom for it to be widened to 6m.

4. ACKNOWLEDGEMENTS

This Phase 2 palaeontological project has been ably facilitated by Ms Monique Jordaan (SunEdison Energy Southern Africa (Pty) Ltd) and her colleagues. Dr Ragna Redelstorff and her colleagues Philip Hine and Clinton Jackson are thanked for assistance with the fossil collection permit application to SAHRA. Ms Claire Phutieagae of Subsolar was very helpful with arranging access to the study area. I am especially grateful to Madelon Tusenius for unflagging assistance with the fieldwork as well as companionship and logistical backup during the fieldtrip to Vryburg. Dr Gideon Groenewald of Metsi Metseng Geological Services cc, Bethlehem is thanked for the use of his impressive photo of columnar stromatolites from Hartsboom 734 (Fig. 30 herein).

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6. 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, Limpopo, Northwest, KwaZulu-Natal and the Free State under the aegis of his Cape Town-based company *Natura Viva* cc. He has served as 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 APHP (Association of Professional Heritage 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.

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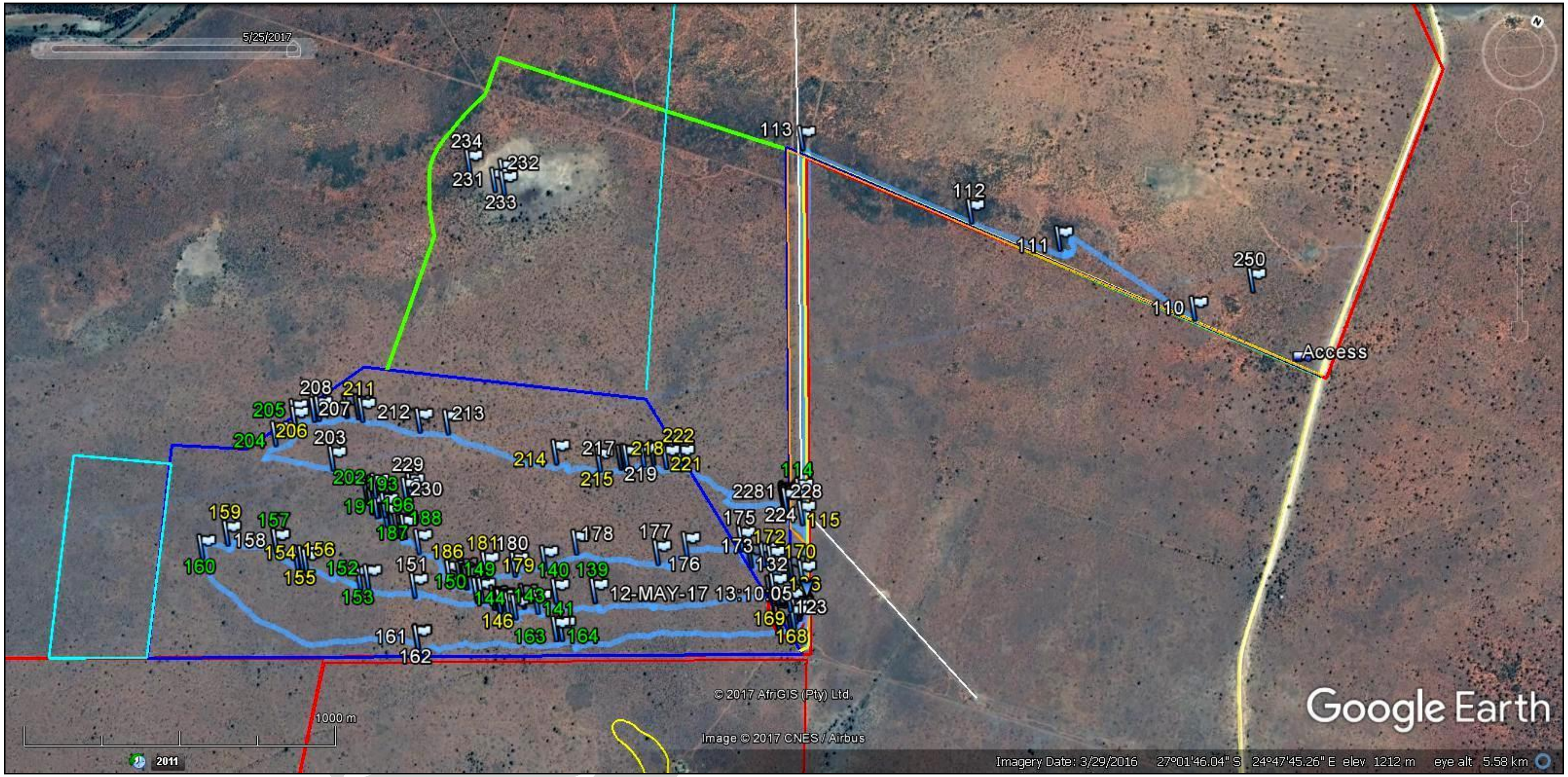

Fig. 37. Google earth© satellite image showing the outline of adjoining Farms Waterloo 992 and Champions Kloof 731 near Vryburg (red), the expanded solar facility study area (dark blue *plus* light blue polygons). Close-up images showing tracks and waypoints in more detail are provided in Figs. 38 & 39 while access road options are shown in Fig. 40. *N.B.* North is towards the top right of the image.

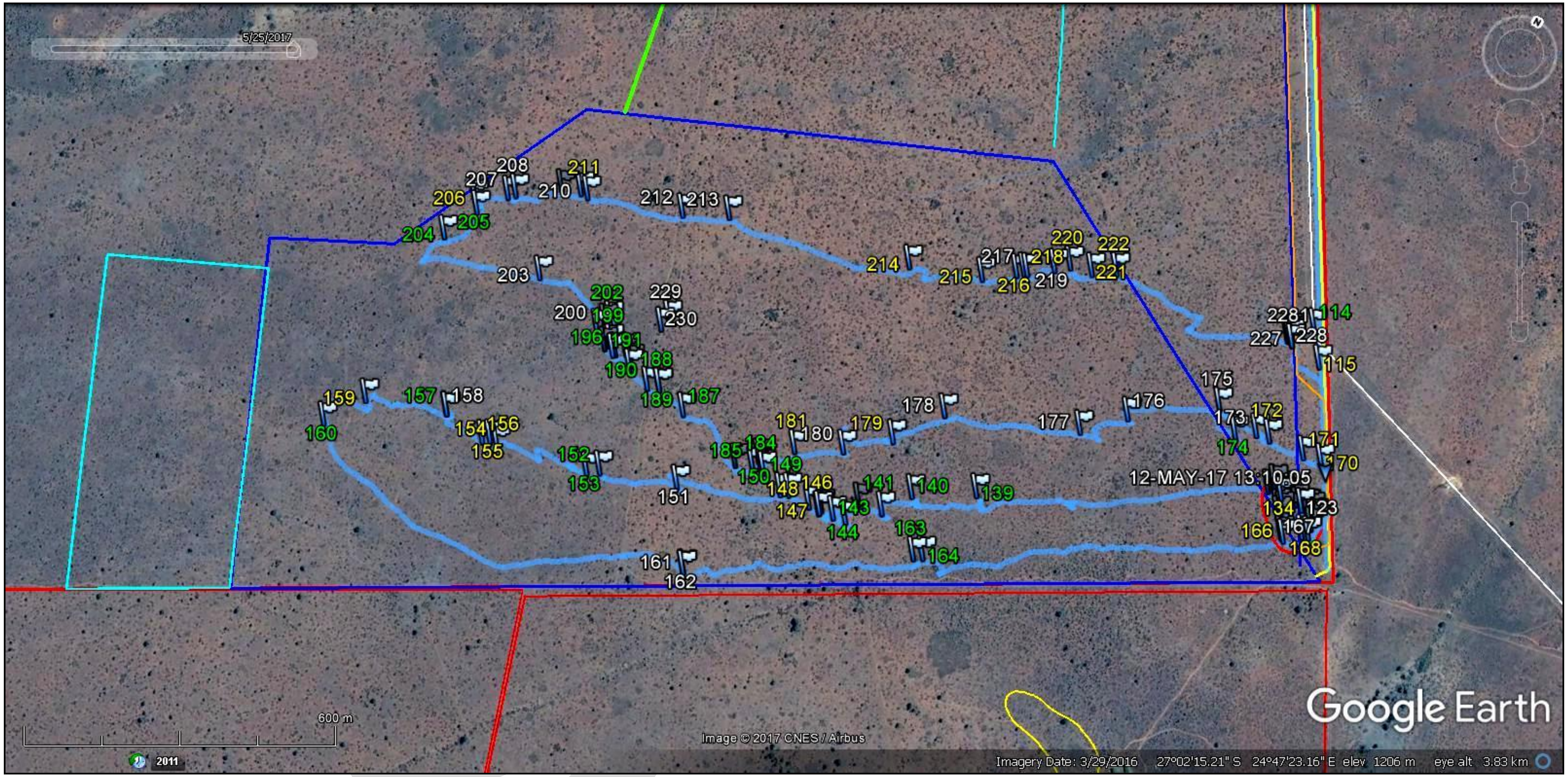

Fig. 38. Google earth© satellite image of the main solar facility study area on Waterloo 992 (dark blue *plus* pale blue) showing gps tracks and numbered waypoints recorded during fieldwork in May 2017 (Note N is towards the *top right* of the image). Most of the waypoints refer to stromatolite occurrences within the Boomplaas Formation which clearly occur widely across the area. Their apparent distribution is probably largely governed by low levels of bedrock exposure rather than being an original feature (*e.g.* patch reefs). Yellow waypoints = large domal stromatolites. Green waypoints = medium-sized stromatolites (domes / short columns). White waypoints = other features (*e.g.* stromatolite buttons, geological phenomena) (Please see Appendix 1 for details).

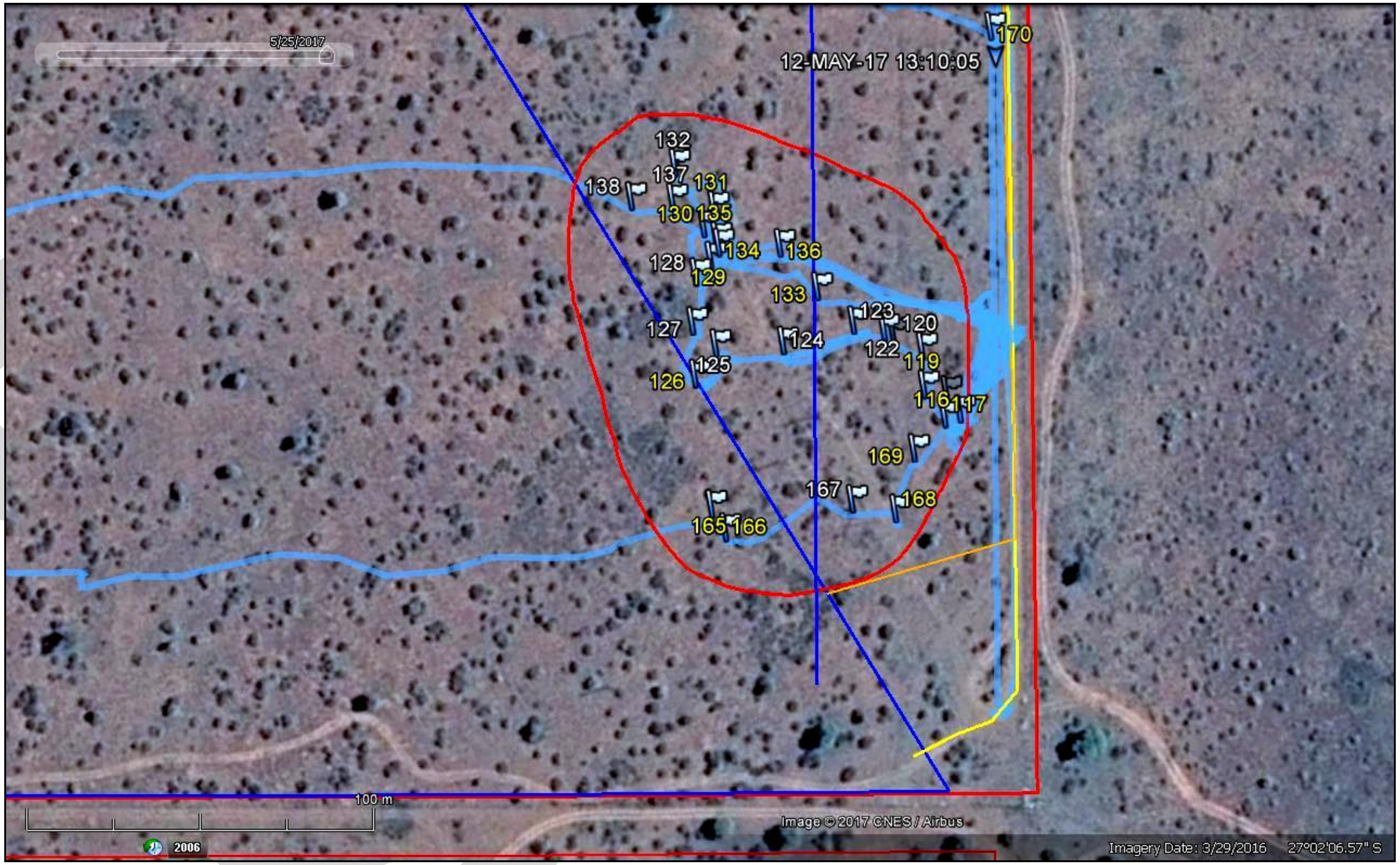

Fig. 39. Satellite image of eastern corner of the study area (N towards top right). The area outlined in red includes a high concentration of large domal stromatolites (yellow waypoints) that lies largely outside and to the east of the main solar facility development area (dark blue polygon shown in previous figure). Access road Alternative 1 (unmitigated) is shown in dark blue and the existing farm track in yellow . The yellow access road is preferred from a fossil heritage point of view. However, a mitigated version of the Alternative 1 route (orange in this and the following figure) is also acceptable since it avoids the palaeontologically-sensitive area outlined in red. During construction the protection - *e.g.* by fencing or security tape - of stromatolites exposed at surface within the portion of the red area that lies outside the main solar facility development area is recommended. Most of the stromatolite sampling took place within this red-outlined area.

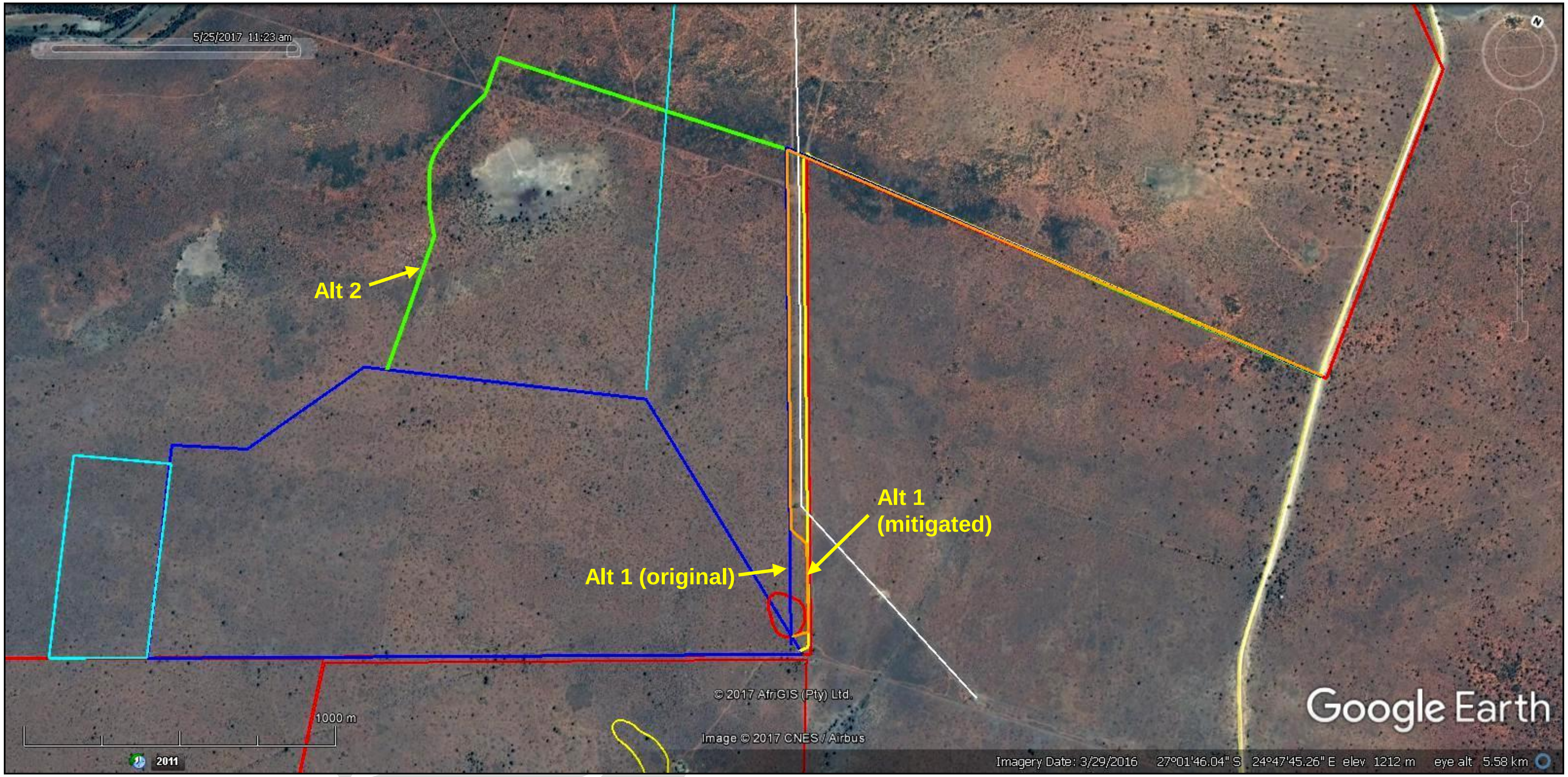

Fig. 40. Google earth© satellite image of the solar facility study area on Waterloo Farm 992 showing the two access route options under consideration. Alternative 1 runs parallel to and slightly west of the farm boundary (blue). Alternative 2 (green) skirts a pan to the north of the main solar project area. A mitigated version of Alternative 1 (orange) has been proposed in order to avoid the sensitive stromatolite-rich area (red circle). This last is the preferred option from a palaeontological heritage viewpoint. An existing farm track (yellow) runs along the eastern boundary of the property.

APPENDIX 1: LOCALITY DATA

All GPS readings were taken in the field using a hand-held Garmin GPSmap 60CSx instrument. The datum used is WGS 84. Please see also satellite images Figs 38 and 39 (*N.B.* Buried stromatolites may be present in many areas where no fossil data is shown).

Loc.	GPS data	Comments
110	27° 1'18.39"S 24°48'23.86"E	Low exposure of *in situ* Vryburg Formation cherty facies adjacent to access road. Orange-brown sandy soils with angular cherty surface gravels (some flaked). Various cherty facies – pale brown, grey, cream, pinkish, orange, reddish-brown *etc*. Some cherts laminated. Occasional quartzite gravel clasts and float blocks of ferruginous gritty brown sandstone with abundant cubical pyrite pseudomorphs.
111	27° 1'18.89"S 24°48'6.01"E	Low exposure of brownish-weathering, grey-green Vryburg Formation andesitic lavas in vicinity of Trig. beacon, locally vesicular and with cherty veins. Mantled in sandy soils and cherty gravels. Occasional shallow-dipping beds of brownish quartzites.
112	27° 1'21.00"S 24°47'55.38"E	Low rounded exposure of Vryburg Formation andesitic lavas just N of farm track. Associated veins of dark to pale greyish or pinkish or creamy chert, massive to finely-laminated.
113	27° 1'23.01"S 24°47'33.62"E	Good exposures of highly vesicular andesitic lavas of Vryburg Formation. Rounded open or silica-infilled amygdales of grey chert in reddish-brown weathering matrix (up to > 1 cm diam.). Local development of vuggy, rubbly textures. Float blocks of finely-lamianted to cream-and-reddish banded chert.
114	27° 1'55.53"S 24°47'54.09"E	Patchy exposures of greyish Boomplaas Fm limestones, locally ferruginised and brownish-weathering, near electrical pylons. Medium-scale stromatolites. Cherty surface gravels much sparser than in Vryburg Fm outcrop area.
115	27° 1'57.40"S 24°47'55.64"E	Displaced blocks of laminated to thin-bedded, greyish to brownish and ferruginised Boomplaas Fm carbonates close to access road. Local development of blackish to dark brown ferro-manganese patina (possibly ferruginised palaeosurface). Microbial mat textures, ferruginised medium-sized laterally accreting stromatolites and occasional large domical stromatolites truncated by erosion.
116	27° 2'6.07"S 24°48'0.85"E	Large stromatolitic dome with silicified core that shows small, button-like micro-stromatolites (sampled). Numerous float blocks comprising well-silicified fragments of large domes as well as vertically-accreting small microdomes / buttons (sample area).
117	27° 2'6.18"S 24°48'0.74"E	Well-preserved silicified core of large stromatolitic dome showing pale early developmental phase with buttons, darker cherty outer zones (sampled).
118	27° 2'5.97"S 24°48'0.63"E	Core of large stromatolitic dome, finer greyish chert towards centre, browner-weathering, coarser-grained towards periphery.
119	27° 2'6.04"S 24°48'0.40"E	Poorly-preserved peripheral part of large stromatolitic dome.
120	27° 2'5.73"S 24°48'0.18"E	*In situ* flattish horizon of silicified closely-packed / adjoining (3 cm or less diam.), small scale stromatolitic buttons, locally with ferruginous patina.
121	27° 2'5.74"S 24°47'59.83"E	In situ flattish horizon of silicified closely-packed / adjoining (3 cm or less diam.), small scale stromatolitic buttons, locally with ferruginous patina.
122	27° 2'5.76"S 24°47'59.73"E	In situ flattish horizon of silicified closely-packed / adjoining (3 cm or less diam.), small scale stromatolitic buttons, locally with ferruginous patina.
123	27° 2'5.84"S 24°47'59.42"E	In situ flattish horizon of silicified closely-packed / adjoining (3 cm or less diam.), small scale stromatolitic buttons, locally with ferruginous patina.
124	27° 2'6.33"S 24°47'58.88"E	In situ flattish horizon of silicified closely-packed / adjoining (3 cm or less diam.), small scale stromatolitic buttons, locally with ferruginous patina.
125	27° 2'6.67"S 24°47'58.28"E	Low elongate ridges or bedding undulations covered with small-scale stromatolitic buttons, with occasional discrete, projecting cushions constructed of buttons (LL-H).

126	27° 2'7.01"S 24°47'58.25"E	Laminated to massive black cherty replacement of periphery of large stromatolitic domes (showing anthropogenic flaking).
127	27° 2'6.60"S 24°47'57.96"E	Undulating to subdued domed silicified bedding plave covered with button stromatolites.
128	27° 2'6.18"S 24°47'57.72"E	Vertical sections through silicified, superimposed small-scale, button-like stromatolites (LL-H) building a convex cushion (sampled).
129	27° 2'5.98"S 24°47'57.78"E	Well-preserved cherty peripheral zone of large domal stromatolite (*c*. 1 m across). Core area not preserved (possibly not silicified).
130	27° 2'5.75"S 24°47'57.54"E	Partial cherty, laminated periphery of large stromatolitic dome (*c*. 80 cm diameter).
131	27° 2'5.55"S 24°47'57.54"E	Cluster of large-scale domical to cushion-shaped stromatolites with preferentially silicified peripheral zones. Occasionally massive to laminated cherty core zone also preserved (may be double, nested).
132	27° 2'5.39"S 24°47'56.96"E	Rounded to elongate elevated surfaces covered with small-scale, button-like stromatolites (LL-H). Vertical sections show superposition of small domes in successive laminae.
133	27° 2'5.73"S 24°47'58.91"E	Well-preserved, laminated core zone of large domical stromatolite, truncated horizontally by erosion. Several large domes in vicinity.
134	27° 2'5.83"S 24°47'57.78"E	Cluster of planed-off large stromatolitic domes.
135	27° 2'5.79"S 24°47'57.72"E	Part of same cluster of planed-off large stromatolitic domes.
136	27° 2'5.55"S 24°47'58.34"E	Large stromatolitic domes, black secondary chert, sparse scatter of associated black cherty stone artefacts.
137	27° 2'5.68"S 24°47'57.12"E	Large stromatolitic domes and small buttons.
138	27° 2'5.86"S 24°47'56.73"E	Small-scale stromatolitic buttons. Orange-brown sandy soils, dispersed chert artefacts, with rare brownish quartzite artefacts. Occasional patches of ferruginous Boomplas Fm carbonate (also seen in material excavated from test pits).
139	27° 2'15.15"S 24°47'39.08"E	Large float block of greyish laminated Boomplaas Fm carbonates with spaced, non-silicified but sl. ferruginised, medium-scale (1-few dm diameter), laterally-accreting stromatolites.
140	27° 2'17.20"S 24°47'35.15"E	Stratiform chert or extensive black cherty lens showing evidence of anthropogenic flaking, Chert here associated with brownish-weathering quartzites and is non-stromatolitic. Float blocks of medium-scale stromatoliites.
141	27° 2'19.07"S 24°47'33.92"E	Low surface exposures of dark brown, ferruginised Boomplaas Fm carbonates, closely-spaced, medium-sized, laterally-accreting stromatolites (current-orientation).
142	27° 2'19.31"S 24°47'32.20"E	Dense assemblages of medium-sized, current-orientated stromatolites in brown ferruginous carbonates, growth towards WNW.
143	27° 2'20.82"S 24°47'31.09"E	Dense assemblages of medium-sized, current-orientated stromatolites in brown ferruginous carbonates, growth towards WNW.
144	27° 2'20.68"S 24°47'32.00"E	Dense assemblages of medium-size, current-orientated stromatolites in brown ferruginous carbonates, growth towards W. High level of secondary silicification.
145	27° 2'20.80"S 24°47'30.13"E	Large adjoining domical stromatolites.
146	27° 2'20.99"S 24°47'30.09"E	Core of large stromatolitic dome. Zone just outside smooth core with crinkly lamination (possibly sections through small, irregular microbial buttons). Nearby test pit material comprises brownish-weathering ferruginous thin-bedded carbonate.
147	27° 2'21.04"S 24°47'30.05"E	Large domical stromatolite.
148	27° 2'20.98"S 24°47'29.25"E	Large domical stromatolite.
149	27° 2'20.95"S 24°47'27.59"E	Medium-sized stromatolites and buttons.
150	27° 2'21.21"S	Medium-sized stromatolites and buttons.

	24°47'27.06"E	
151	27° 2'24.00"S 24°47'20.46"E	Small exposure of pale grey quartzite bedding plane showing subdued rippling. Preferential preservation of linear ripple crests within laminated quartzite – probably due to microbial binding - gives superficial impression of horizontal burrows.
152	27° 2'25.63"S 24°47'15.23"E	Bed of ferruginous carbonate, partially silicified, preserving tightly-packed medium-sized, laterally-accreting stromatolites.
153	27° 2'26.10"S 24°47'14.48"E	Bed of ferruginous carbonate, partially silicified, preserving tightly-packed medium-sized, laterally-accreting stromatolites. Preferential growth towards the west.
154	27° 2'27.45"S 24°47'8.01"E	Tight cluster of large, coalescent large stromatolitic domes showing good preservation of core as well as surrounding laminae.
155	27° 2'27.37"S 24°47'7.40"E	Irregular-shaped to elongate, medium-sized stromatolitic domes, partially silicified, within brown ferruginous carbonate.
156	27° 2'27.63"S 24°47'6.94"E	Large stromatolitic dome.
157	27° 2'27.22"S 24°47'3.74"E	Extensive cherty zone with well-silicified small- to medium-sized stromatolites, including several with irregular to elongate growth forms. Preferential accretion towards the west.
158	27° 2'27.21"S 24°47'3.72"E	Silicified asymmetrical stromatolitic cushion. Core zones of stromatolite locally well-preserved.
159	27° 2'29.03"S 24°46'58.27"E	Zone of stratiform dark chert (non-stromatolitic).
160	27° 2'31.59"S 24°46'56.52"E	Boulder-sized relict block of pale grey, thin-bedded Boomplaas carbonate with thin, prominent-, ochreous-weathering horizon (few cm) of dark grey chert showing numerous cubical voids representing weathered-out pyrite crystals (suggests transient bottom anoxia / rotting microbial mats). Cryptic embedded medium-scale stromatolites within grey limestone.
161	27° 2'28.44"S 24°47'23.84"E	Float block of Boomplaas Fm thin-bedded greyish-brown sandy carbonate.
162	27° 2'28.40"S 24°47'23.81"E	As above.
163	27° 2'20.55"S 24°47'37.39"E	Medium-sized stromatolites.
164	27° 2'20.23"S 24°47'37.95"E	Medium-sized stromatolites.
165	27° 2'7.99"S 24°47'59.09"E	Large stromatolitic dome.
166	27° 2'8.11"S 24°47'59.34"E	Large stromatolitic dome, secondarily silicified periphery.
167	27° 2'7.30"S 24°48'0.34"E	Small stromatolitic buttons.
168	27° 2'7.18"S 24°48'0.78"E	Silicified, laminated periphery of large stromatolitic dome.
170	27° 2'2.78"S 24°47'59.13"E	Silicified periphery of large stromatolitic domes, small buttons.
171	27° 2'2.92"S 24°47'57.75"E	Silicified periphery of large stromatolitic domes, small buttons, ferruginous carbonate.
172	27° 2'3.05"S 24°47'55.11"E	Large stromatolitic dome.
173	27° 2'3.15"S 24°47'54.13"E	Patchy low exposure of ferruginous carbonate.
174	27° 2'3.91"S 24°47'52.91"E	Ferruginous carbonate with laterally-accreting medium-sized stromatolites.
175	27° 2'2.85"S 24°47'51.00"E	Quartzite float blocks with stromatolite-like small scale convolute lamination (possible microbial binding).
176	27° 2'6.24"S 24°47'45.70"E	Dense, angular surface gravels of brown ferruginous and locally stromatolitic carbonate, cherts

177	27° 2'8.45"S 24°47'43.24"E	Low exposures of dark brown, fine-grained quartzite, chert, associated with stone artefacts.
178	27° 2'11.76"S 24°47'34.36"E	Thin surface gravels, mainly angular cherts and quartzites but also including occasional well-rounded, water-worn reworked greyish quartzite pebbles.
179	27° 2'14.79"S 24°47'32.10"E	Periphery of large stromatolitic dome.
180	27° 2'16.92"S 24°47'29.43"E	Stratiform chert lens or layer associated with fine-grained brown quartzites.
181	27° 2'18.41"S 24°47'26.42"E	Float block fragments of large stromatolitic dome.
182	27° 2'20.04"S 24°47'24.55"E	Concentration of medium to large stromatolitic domes within ferruginous, partly-silicified carbonate. Include NW-SE elongated domes as well as small buttons.
183	27° 2'20.54"S 24°47'25.07"E	Silicified cores of domical stromatolites weathered out as pedestals.
184	27° 2'20.58"S 24°47'25.28"E	Extensive outcrop area of brown ferruginous carbonate, locally stromatolitic.
185	27° 2'20.66"S 24°47'24.45"E	Small- to medium-sized stromatolites within ferruginous brown carbonate (locally leached).
186	27° 2'21.02"S 24°47'23.29"E	Elliptical core of large stromatolitic dome.
187	27° 2'19.85"S 24°47'18.28"E	Extensive patchy exposure of brown ferruginous Boomplaas carbonate, often non-stromatolitic but with occasional medium-sized stromatolites.
188	27° 2'19.27"S 24°47'15.96"E	Extensive patchy exposure of brown ferruginous Boomplaas carbonate, often non-stromatolitic but with occasional medium-sized stromatolites.
190	27° 2'19.55"S 24°47'15.17"E	Medium-sized stromatollte in ferruginous carbonate.
191	27° 2'19.14"S 24°47'13.46"E	Brown-weathering ferruginous carbonate exposures with closely-spaced, laterally-accreting medium-sized stromatolites (migration towards the west).
192	27° 2'18.84"S 24°47'13.37"E	Brown-weathering ferruginous carbonate exposures with closely-spaced, laterally-accreting medium-sized stromatolites (migration towards the west).
193	27° 2'18.36"S 24°47'12.65"E	Brown-weathering ferruginous carbonate exposures with well-spaced to closely-spaced, laterally-accreting medium-sized stromatolites (migration towards the west).
194	27° 2'18.72"S 24°47'12.00"E	Good horizontal sections through closely-spaced, laterally-accreting, medium-sized stromatolites.
195	27° 2'18.74"S 24°47'11.95"E	Good horizontal sections through closely-spaced, laterally-accreting, medium-sized stromatolites.
196	27° 2'18.82"S 24°47'11.86"E	Well-spaced medium-sized stromatolites migrating towards the NW. Local development of platy limestone breccias (poorly-sorted, subangular to rounded clasts preserved as moulds – possibly composed of mudrock or carbonate).
197	27° 2'18.73"S 24°47'11.13"E	Large stromatolitic dome.
198	27° 2'18.46"S 24°47'11.24"E	Medium-sized, laterally-accreting stromatolites.
199	27° 2'18.39"S 24°47'11.39"E	Medium-sized, laterally-accreting stromatolites.
200	27° 2'17.98"S 24°47'9.99"E	Low exposures of brown, fine-grained quartzite (surface with low ridges and rounded projections; locally with cubical pyrite moulds) associated with stratiform or lenticular black massive chert (showing signs of extensive *in situ* anthropogenic knapping), numerous chert artefacts.
201	27° 2'17.45"S 24°47'10.30"E	Low exposures of brown, fine-grained quartzite (locally with pyrite moulds) associated with stratiform or lenticular black massive chert (showing signs of extensive *in situ* anthropogenic knapping), numerous chert artefacts.
202	27° 2'17.13"S	Large, low, chertified domal structure (*c*. 75 cm diameter) within fine-

	24°47'10.53"E	grained quartzites, associated with stone artefacts. Stromatolitic nature uncertain. Some medium-sized stromatolites in ferruginous carbonate.
203	27° 2'16.84"S 24°47'4.58"E	Abundant surface gravels composed of small angular to subangular pebbles and cobbles of brownish and dark grey cherty material, quartzites (some flaked).
204	27° 2'17.61"S 24°46'57.22"E	Ferruginous carbonate with medium-sized, laterally-accreting stromatolites.
205	27° 2'15.23"S 24°46'58.34"E	Medium-sized stromatolites.
206	27° 2'14.63"S 24°46'57.80"E	Large ferruginous stromatolitic domes.
207	27° 2'13.43"S 24°46'59.72"E	Brown-weathering bedding plane exposures covered with small-sized, button-like silicified stromatolitic domes.
208	27° 2'13.07"S 24°47'0.13"E	Brown-weathering bedding plane exposures covered with small-sized, button-like silicified stromatolitic domes.
209	27° 2'11.39"S 24°47'2.82"E	Large stromatolitic dome.
210	27° 2'10.91"S 24°47'4.10"E	Small stromatolitic buttons.
211	27° 2'10.93"S 24°47'4.66"E	Prominent-weathering, silicified periphery of large stromatolitic dome.
212	27° 2'8.92"S 24°47'11.18"E	Ferruginous carbonate exposure.
213	27° 2'7.59"S 24°47'14.14"E	Scattered coarse (cobble to boulder-sized) angular float blocks of pale brown quartzite.
214	27° 2'4.67"S 24°47'27.00"E	Scattered exposures of dark brown ferruginous carbonate with scattered large domical stromatolites.
215	27° 2'3.08"S 24°47'31.92"E	Silicified periphery of large stromatolitic dome; dark grey chert possibly knapped.
216	27° 2'1.80"S 24°47'33.93"E	Large stromatolitic dome.
217	27° 2'1.50"S 24°47'34.33"E	Convex domical protuberances or cushions of silicified grey carbonate covered with small, button-like stromatolites (LL-H), also visible in vertical section (sampled).
218	27° 2'1.43"S 24°47'34.55"E	Large stromatolitic dome showing extensive silicification of concentric wrinkly-laminated interior, apart from core.
219	27° 2'0.34"S 24°47'36.09"E	Test pit showing brownish excavated rock – mainly ferruginous and silicified carbonate.
220	27° 1'59.69"S 24°47'36.97"E	Large silicified stromatolitic domes.
221	27° 1'59.38"S 24°47'38.52"E	Large domical stromatolites and small buttons.
222	27° 1'58.60"S 24°47'40.03"E	Large domical stromatolites and small buttons.
223	27° 1'56.96"S 24°47'52.83"E	Ferruginous carbonate with closely-spaced medium-sized stromatolites showing westwards lateral accretion.
229	27° 2'15.24"S 24°47'14.14"E	Extensive exposure of dark grey cherty lens or stratiform chert horizon near farm track, well-jointed, probably knapped.
230	27° 2'15.87"S 24°47'13.92"E	Quarried cores of black chert associated with brown, fine-grained pyritic quartzite.
231	27° 1'43.06"S 24°47'4.37"E	Coarse gravels, float blocks and low exposures of fine-grained, brown to greyish quartzite in pan area, including occasional brown-weathering or pale greyish, fine-grained quartzite bifaces (ESA handaxes). Interbeds of oolitic Boomplaas Formation carbonate.
233	27° 1'42.85"S 24°47'5.49"E	Oolitic grey carbonates, sparse ESA artefacts, pan area.
234	27° 1'42.69"S 24°47'0.65"E	Low, well-jointed, rough-surfaced exposure of brown-weathering, grey-green Vryburg Formation andesites along western edge of pan. Associated varicoloured cherty gravels (reddish jaspers, pink, brown cherts *etc*).