PALAEONTOLOGICAL HERITAGE BASIC ASSESSMENT: COMBINED DESKTOP & FIELD-BASED STUDY

Proposed 132 kV power lines between the ACWA Power SolarReserve Redstone Solar Thermal Energy Plant Site and Olien Main Transmission Substation near Lime Acres, Northern Cape Province

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EXECUTIVE SUMMARY

Several 132 kV overhead transmission line options are under consideration to connect the authorised ACWA Power SolarReserve Redstone Solar Thermal Energy Plant, located on the Remainder of Farm Nr. 469, *c*. 30-40 km east of Postmasburg, with the national grid at Olien Main Transmission Substation (MTS), situated approximately 16.5 km ENE of Lime Acres, Northern Cape Province.

The study area from ACWA Power SolarReserve Redstone Solar Thermal Energy Plant Project Site in the west to the Olien Substation in the east is underlain by largely undeformed Precambrian sediments and lavas of the Transvaal Supergroup that are Late Archaean to Early Proterozoic in age (*c*. 2.25 to 2.22 billion years old). These principally comprise shallow marine carbonates (limestones / dolomites) of the Campbell Rand Subgroup in the east that are successively overlain towards the west by banded iron formations (BIF) of the Asbestos Hills Subgroup and then glacial diamictites (tillites) and lavas of the Postmasburg Group. The Precambrian bedrocks are overlain by a range of late Caenozoic superficial sediments including aeolian sands of the Gordonia Formation (Kalahari Group), calcrete hardpans, colluvium (*e.g.* surface rubble, scree, downwasted gravels), river alluvium and pan deposits.

Well-preserved domical and columnar stromatolites (fossil reef-like microbial mounds) as well as associated microfossil biotas are recorded from the upper formations of the Campbell Rand Subgroup (esp. Kogelbeen Formation) to the north of Lime Acres, close to the R385 tar road, as well as within the PPC Lime quarry at Lime Acres. The stromatolitic limestone beds also occur beneath the central and eastern portions of several of the 132 kV transmission line corridor options. However, surface exposure of bedrocks here is poor due to extensive superficial sediment cover (calcrete, gravels). Significant impacts on well-preserved near-surface stromatolites are therefore not anticipated. Extensive karst weathered solution hollows are observed within the Campbell Rand carbonate rocks in the region and these might have served as fossil traps in the recent geological past (Tertiary / Quaternary). However, no fossil remains were observed within solution hollow infills during the recent field study by Almond (2014).

The finely-laminated Asbestos Hills BIFs overlying the Transvaal carbonate rocks are only known to contain microfossils. Presumed warm-water stromatolitic carbonates closely associated with glacial sediments are reported from the overlying Makganyene Formation (Postmasburg Group) in the Northern Cape. However, field studies confirm that stromatolites do not occur in the eastern outcrop area of this formation on or near the Remainder of the Farm Nr 469. No fossils are recorded from the overlying Ongeluk Formation succession that consists entirely of basaltic andesite lavas and is usually

deeply-weathered in this area. Sparse to locally common trace fossils (*e.g.* calcified termitaria and other invertebrate burrows, plant root casts), molluscs, and rare vertebrate remains (mammalian teeth, bones) are known from diverse Late Caenozoic superficial sediments in the broader Kalahari region but were not recorded during the recent field assessment by Almond (2014).

Power line corridor **Option 1 Route 1** traverses weathered Ongeluk Formation lavas and surface gravels on the western borders of the Remainder of the Farm Nr 469. The north-western sector of the corridor, close to the R385 tar road, overlies Makganyene Formation diamictites and Gordonia Formation aeolian sands. The next sector to the east crosses the Rooiberg hills where it is underlain by Asbestos Hills Subgroup BIF (Kuruman and Daniëlskuil Formations); the outcrop here is largely mantled by BIF colluvium (platy ironstone scree, soils). In the region to the north of Lime Acres settlement and limestone mine as far as Silverstreams Substation and further east the corridor traverses Campbell Rand carbonates. The bedrocks here are extensively mantled by superficial sediments (calcrete hardpan, soil, gravels, pan sediments). This applies particularly to the stretch between Silverstreams and Olien Substations where the Precambrian carbonate bedrocks are mantled by a well-developed calcrete hardpan and perhaps locally by pan sediments. Power line corridor **Option 1 Route 2** has a very similar underlying geology to Route 1, but with marginally less impact on surface exposures of Campbell Rand carbonate rocks to the north of Silverstreams Substation. The geology underlying power line corridor **Option 1 Route 3** does not differ significantly from that described for Route 1. The geology underlying power line corridor **Option 1 Route 4** is also similar to that described for Route 1 with the exception of comparatively shorter sectors traversing the banded ironstones of the Asbestos Hills Subgroup and corresponding longer sectors underlain by Gordonia Formation aeolian sands along the north-eastern edge of the Rooiberge. The geology and topography within the power line corridors for **Option 2 Route 2A** and **Option 2 Route 2B** are very similar. In both cases, flat-lying terrain underlain by Campbell Rand carbonates is largely covered by Late Caenozoic superficial deposits, notably calcrete hardpans and possibly also pan sediments.

On the basis of both desktop analysis and fieldwork within the broader power line study area (Almond 2013a, 2014) the palaeontological sensitivity of all power line corridors under consideration is assessed as low. This also applies to the area to the north of Lime Acres where stromatolites occur within the underlying bedrock but are rarely well-exposed at surface and are therefore unlikely to be significantly impacted by the proposed transmission lines. The Makganyene Formation outcrop area in the north-western corner of the Remainder of the Farm Nr 469, close to the R385 tar road, is of considerable scientific interest as an accessible part of the limited rock record for an Early Proterozoic (*c.* 2.3 billion years-old) "snowball earth" glacial event, when ice sheets may have covered much of the planet. However, fossil stromatolites do not occur within the succession here and significant palaeontological impacts are therefore not anticipated. Potential impacts on local palaeontological heritage are assessed for all power line corridor options as being of *low negative significance*. There is no preference on palaeontological heritage grounds for any particular power line corridor, or for either of the two main options for connecting the ACWA Power SolarReserve Redstone Thermal Energy Plant to the national grid.

No further specialist palaeontological studies, monitoring or mitigation are recommended for the proposed 132 kV power line projects near Postmasburg, including the associated substation and switchyard infrastructural developments, pending the discovery of significant new fossils within the development footprint (*e.g.* well-preserved fossil stromatolites). It is recommended that:

- The Environmental Control Officer (ECO) responsible for the electrical infrastructure developments should be aware of the possibility of important fossils (*e.g.* well-preserved stromatolites, mammalian bones, teeth) being present or unearthed on site and should regularly monitor all substantial excavations into superficial sediments as well as fresh (*i.e.* unweathered) sedimentary bedrock for fossil remains;

- In the case of any significant fossil finds made during construction, these should be safeguarded - preferably *in situ* - and reported by the ECO as soon as possible to the relevant heritage management authority (South African Heritage Resources Agency. Contact details: 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. Web : www.sahra.org.za) so that appropriate mitigation (*i.e.* recording, sampling or collection) by a palaeontological specialist can be considered and implemented, at the developer's expense; and

- These recommendations should be incorporated into the Environmental Management Programme (EMPr) for the electrical infrastructure projects associated with the ACWA Power SolarReserve Redstone Solar Thermal Power Plant.

The palaeontologist concerned with mitigation work will need a valid collection permit from SAHRA. All work should conform to international best practice for palaeontological fieldwork and the study (*e.g.* data recording fossil collection and curation, final report) should adhere to the minimum standards for Phase 2 palaeontological studies recently published by SAHRA (2013).

1. INTRODUCTION & BRIEF

Several 132 kV overhead transmission line options are under consideration to connect the authorised ACWA Power SolarReserve Redstone Solar Thermal Energy Plant, located on the Remainder of Farm Nr. 469 that lies *c*. 30-40 km east of Postmasburg, with the national grid at Olien Main Transmission Substation (MTS), situated approximately 16.5 km ENE of Lime Acres (Figures 1 & 2). The proposed developments lie partly within the Tsantsabane Local Municipality and partly within the Kgatelopele Local Municipality, both of which form part of the ZF Mgcawu District Municipality (previously Siyanda District Municipality), Northern Cape.

The power lines will consist of a series of towers spaced approximately 100-200 m apart, depending on the terrain and soil conditions. The exact tower type to be used will be determined (based on load and other calculations) during the final design stages of the power lines. It is likely that the bird friendly mono-pole self-supporting intermediate suspension (single steel pole) structure will be employed. The precise location of the power line towers will be determined during the final design stages of the power line.

Approximately 1 km - wide corridors have been proposed for each route alternative to allow flexibility when determining the final route alignments. However, only 31 m-wide servitudes would be required for each proposed 132 kV power line. As such, the 31 m wide servitudes would be positioned within the approved 1 km wide corridor.

1.1. Option 1 – ACWA Power SolarReserve Redstone Solar Thermal Energy Plant to Olien MTS

This option involves the construction of two 132 kV power lines *c*. 35 km in length that will run more or less directly ESE from the ACWA Power SolarReserve Redstone Solar Thermal Energy Plant to Olien MTS. Additional infrastructure developments include:

- Installation of two 132 kV feeder bays at Olien MTS;
- Construction of a 3x4 0MVA 11/132 kV step-up substation with 2x 132 kV feeder bays at the proposed ACWA Power SolarReserve Redstone Solar Thermal Power Plant site (located outside the solar field);
- Construction of two switchyards at the proposed Redstone Solar Thermal Energy Plant site (located outside the solar field); and

- Possible restringing of the existing power line and construction of a temporary bypass line.

Four *c*. 1 km –wide route corridor alternatives are being assessed for the two proposed 132 kV power lines. These are as follows:

- **Alternative 1** – approximately 35km (purple in Figure 2)
- **Alternative 2** – approximately 34km (lilac in Figure 2)
- **Alternative 3** – approximately 36km (dark blue in Figure 3)
- **Alternative 4** – approximately 36km (pale blue in Figure 3)

1.2. Option 2 – Silverstreams Distribution Substation to Olien MTS

This option involves the construction of two 132 kV power lines *c*. 11-12 km in length that will run within the already-authorised power line corridor from Silverstreams Distribution Substation (DS) near Lime Acres eastwards to Olien MTS. Additional infrastructural developments include:

- Installation of two 132 kV feeder bays at Olien MTS;
- Construction of a 3x40 MVA 11/132 kV step-up substation with 2x 132kV feeder bays at the proposed ACWA Power SolarReserve Redstone Solar Thermal Power Plant site (located outside the solar field);
- Construction of a switchyard at the proposed ACWA Power SolarReserve Redstone Solar Thermal Power Plant site (located outside the solar field); and
- Possible restringing of the existing power line and construction of a temporary bypass line.

Two route corridor alternatives, each approximately 1 km wide, will be evaluated during the Basic Assessment for the two proposed 132 kV power lines. These are as follows:

- **Alternative 2A** – approximately 11km (red in Fig. 4);
- **Alternative 2B** – approximately 12km (orange in Fig. 4).

The study area for the proposed electrical infrastructure projects overlies potentially fossiliferous sediments of the Precambrian Transvaal Supergroup and Late Caenozoic Kalahari Group (Fig. 7). Legally-protected fossil heritage resources preserved within the bedrock or superficial deposits may be disturbed, damaged or destroyed during the construction phase of the development. The extent of the proposed linear developments 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).

A short palaeontological basic assessment for the Remainder of the Farm Nr 469 was submitted by Almond (2011a). A palaeontological desktop study as well as a follow-up field assessment covering previously proposed 132 kV transmission line route options between the ACWA Power SolarReserve Redstone Thermal Energy Plant on Remainer of Farm Nr 469 and Silverstreams Substation near Lime Acres were prepared by Almond (2013b) and Almond (2014) respectively.

The present palaeontological heritage basic assessment for the revised power line and switchyard developments associated with the ACWA Power SolarReserve Redstone Solar Thermal Power Plant has been commissioned on behalf of the Project Company by PGS Heritage (Contact details: 906 Bergarend Street, Waverley, Pretoria, 0186. PO Box 32542, Totiusdal, 0134. Tel: (012) 332 5305 Fax: (012) 332 2625. Email: wouter@gravesolutionas.co.za). This document is largely based on the previous palaeontological assessment reports by the author listed earlier.

1.1. Legislative context of this palaeontological study

The various categories of heritage resources recognised as part of the National Estate in Section 3 of the National Heritage Resources Act (1999) 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 the palaeontological component of heritage impact assessment reports have been developed by SAHRA (2013).

2. APPROACH TO THE PALAEONTOLOGICAL HERITAGE ASSESSMENT

The information used in this combined desktop and field-based study was based on the following:

1. A project outline and kmz files provided by PGS Heritage.

2. A review of the relevant scientific literature, including published geological maps, satellite images, and several earlier desktop and field-based fossil heritage assessments in the broader region (Almond 2010b, 2011a, 2011b, 2012a, 2012b, 2013a). Previous palaeontological heritage assessment reports for the ACWA Power SolarReserve Redstone Solar Thermal Power Plant project include Almond (2011a, 2013b, 2014; see also Orton 2015).

3. The author's database on the formations concerned and their palaeontological heritage.

In preparing a palaeontological desktop study the potentially fossiliferous rock units (groups, formations *etc*) represented within the study area are determined from geological maps and satellite images. 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 following field assessment during the compilation of the final report). This data is then used to assess the palaeontological sensitivity of each rock unit to development. The potential 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 and scale of the development itself, most significantly the extent of fresh bedrock excavation envisaged. When rock units of moderate to high palaeontological sensitivity are present within the development footprint, a Phase 1 field assessment study by a professional palaeontologist is usually warranted to identify any palaeontological hotspots and make specific recommendations for any mitigation required before or during the construction phase of the development.

On the basis of the desktop and Phase 1 field assessment studies, the likely impact of the proposed development on local fossil heritage and any need for specialist mitigation are then determined. Adverse palaeontological impacts normally occur during the construction rather than the operational or decommissioning phase. Phase 2 mitigation by a professional palaeontologist – normally involving the recording and sampling of fossil material and associated geological information (*e.g.* sedimentological data) may be required (a) in the pre-construction phase where important fossils are already exposed at or near the land surface and / or (b) during the construction phase when fresh fossiliferous bedrock has been exposed by excavations. To carry out mitigation, the palaeontologist involved will need to apply for a palaeontological collection permit from the relevant heritage management authority, *i.e.* SAHRA for the Northern Cape (Contact details: Mrs Colette Scheermeyer, P.O. Box 4637, Cape Town 8000. Tel: 021 462 4502. Email: cscheermeyer@sahra.org.za). It should be emphasized that, *providing appropriate mitigation is carried out*, the majority of developments involving bedrock excavation can make a *positive* contribution to our understanding of local palaeontological heritage.

2.1. Assumptions & limitations

The accuracy and reliability of palaeontological specialist studies as components of heritage impact assessments are generally limited by the following constraints:

1. Inadequate database for fossil heritage for much of the RSA, given the large size of the country and the small number of professional palaeontologists carrying out fieldwork here. Most development study areas have never been surveyed by a palaeontologist.

2. Variable accuracy of geological maps which underpin these desktop studies. For large areas of terrain these maps are largely based on aerial photographs alone, without ground-truthing. The maps generally depict only significant ("mappable") bedrock units as well as major areas

of superficial “drift” deposits (alluvium, colluvium) but for most regions give little or no idea of the level of bedrock outcrop, depth of superficial cover (soil *etc*), degree of bedrock weathering or levels of small-scale tectonic deformation, such as cleavage. All of these factors may have a major influence on the impact significance of a given development on fossil heritage and can only be reliably assessed in the field.

3. Inadequate sheet explanations for geological maps, with little or no attention paid to palaeontological issues in many cases, including poor locality information;

4. The extensive relevant palaeontological “grey literature” - in the form of unpublished university theses, impact studies and other reports (*e.g*. of commercial mining companies) - that is not readily available for desktop studies;

5. Absence of a comprehensive computerized database of fossil collections in major RSA institutions which can be consulted for impact studies. A Karoo fossil vertebrate database is now accessible for impact study work.

In the case of palaeontological desktop studies without supporting Phase 1 field assessments these limitations may variously lead to either:

a. *underestimation* of the palaeontological significance of a given study area due to ignorance of significant recorded or unrecorded fossils preserved there, or

b. *overestimation* of the palaeontological sensitivity of a study area, for example when originally rich fossil assemblages inferred from geological maps have in fact been destroyed by tectonism or weathering, or are buried beneath a thick mantle of unfossiliferous “drift” (soil, alluvium *etc*).

Since most areas of the RSA have not been studied palaeontologically, a palaeontological desktop study usually entails *inferring* the presence of buried fossil heritage within the study area from relevant fossil data collected from similar or the same rock units elsewhere, sometimes at localities far away. Where substantial exposures of bedrocks or potentially fossiliferous superficial sediments are present in the study area, the reliability of a palaeontological impact assessment may be significantly enhanced through field assessment by a professional palaeontologist.

In the case of the ACWA Power SolarReserve Redstone Solar Thermal Power Plant and associated electrical infrastructure the major limitation for fossil heritage assessments is the paucity of previous specialist palaeontological field studies on Precambrian sedimentary rocks in this region of the Northern Cape (*cf* Almond 2012a, 2013b, 2014) as well as the often low levels of bedrock exposure in this topographically subdued region. The relevant geological explanation for 1: 250 000 sheet 2822 is printed on the map itself and is very brief, with almost no palaeontological data provided.

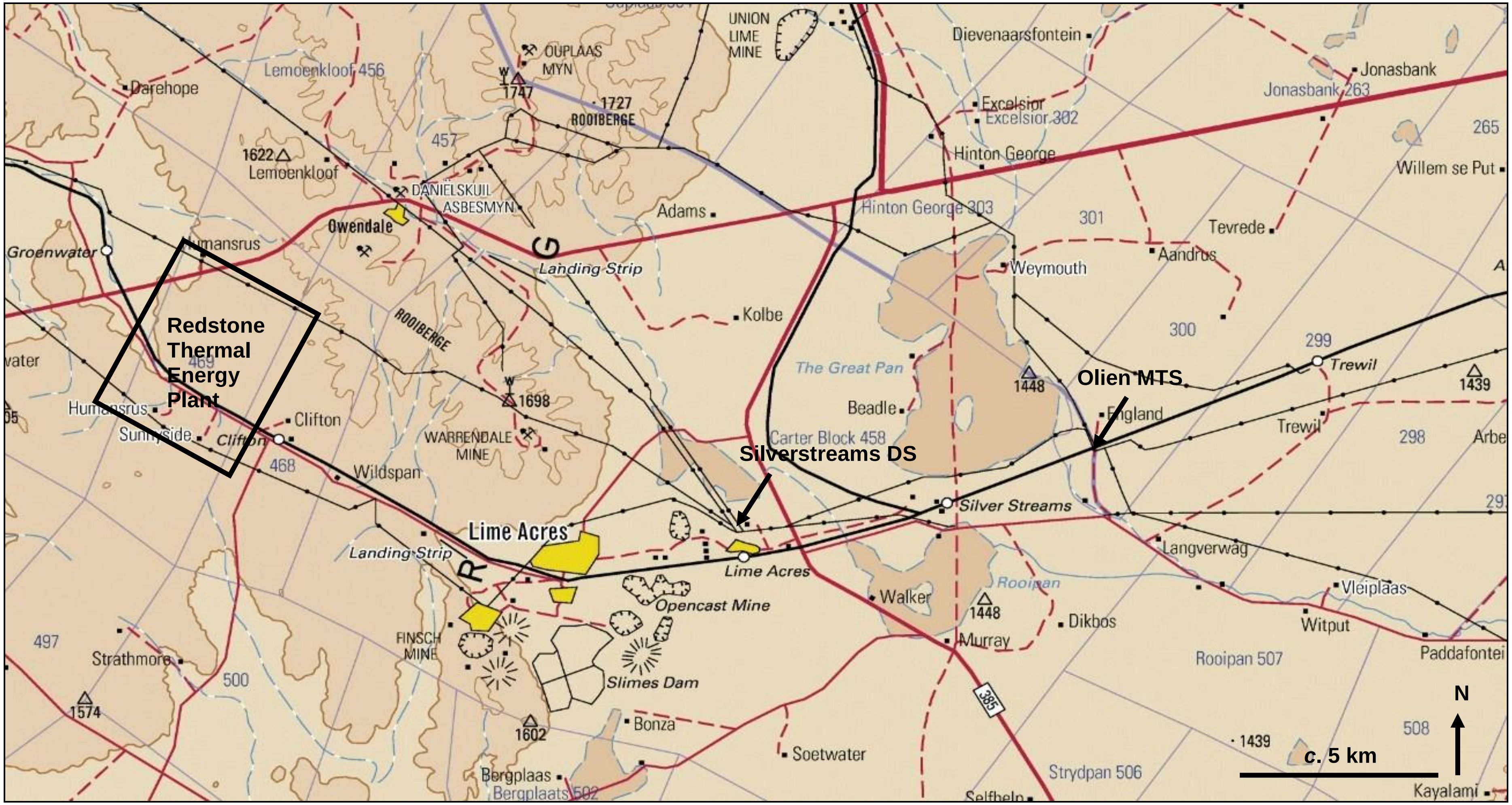

Fig. 1. Extract from 1: 250 000 topographical map 2822 Postmasburg (courtesy of the Chief Directorate: National Geo-spatial Information, Mowbray) showing the broader study area some 30 km east of Postmasburg (Tsantasbane and Kgatelopele Local Municipalities, Northern Cape). The ACWA Power SolarReserve Redstone Thermal Energy Plant lies on remainder of the Farm 469 in the Asbesberge mountain range. Silversteams Distribution Substation (DS) and Olien Main Transmission Substation (MTS) are situated to the east of Lime Acres.

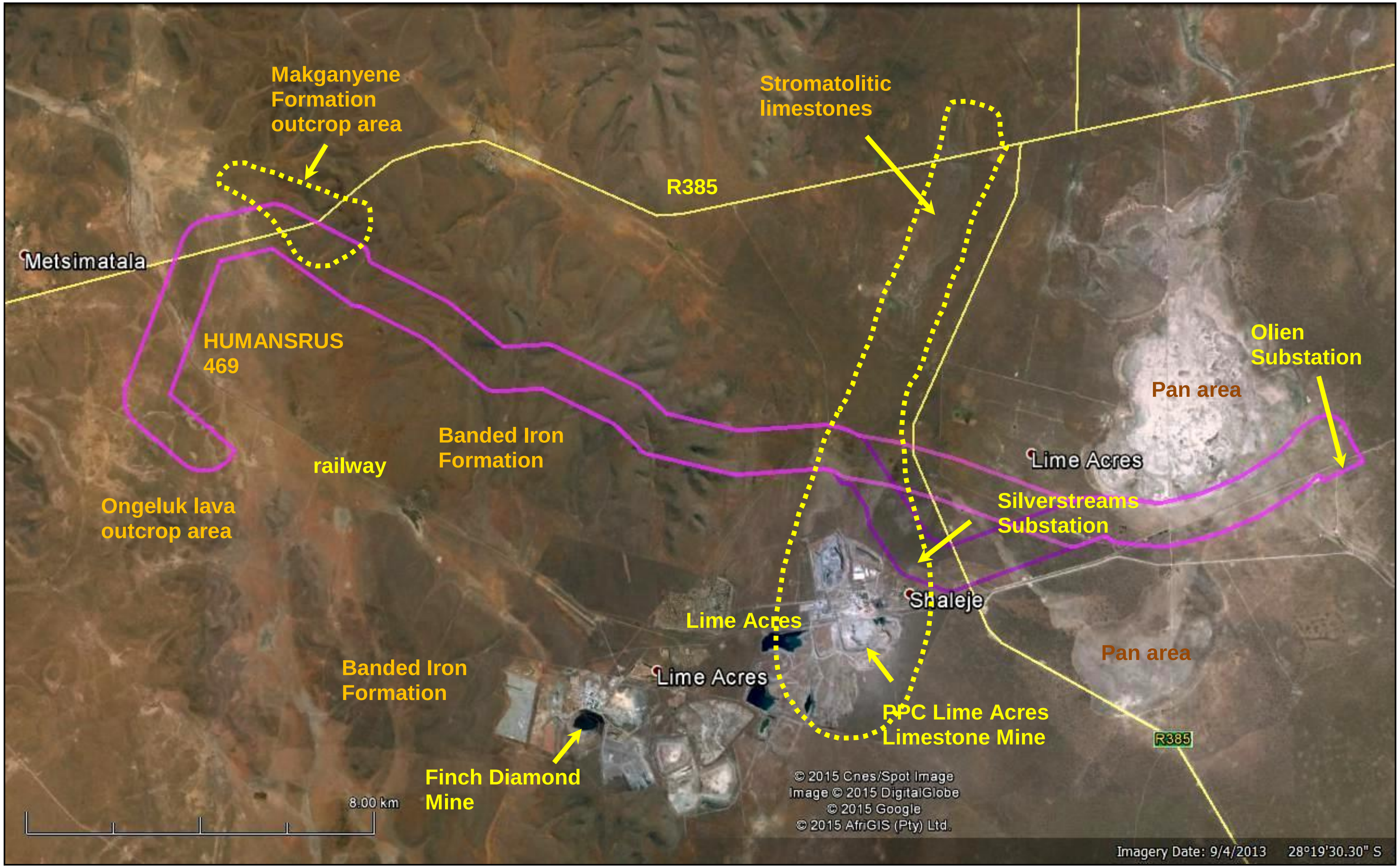

Fig. 2. Google earth© Satellite image of the study area from the remainder of the Farm Nr 469 in the west to Olien MTS in the east. The largely overlapping purple and lilac zones indicate the proposed corridors for Option 1 Routes 1 and 2 respectively. Two potentially palaeontologically sensitive areas are indicated by the yellow dotted lines. However, only the eastern area is known to contain fossil stromatolites.

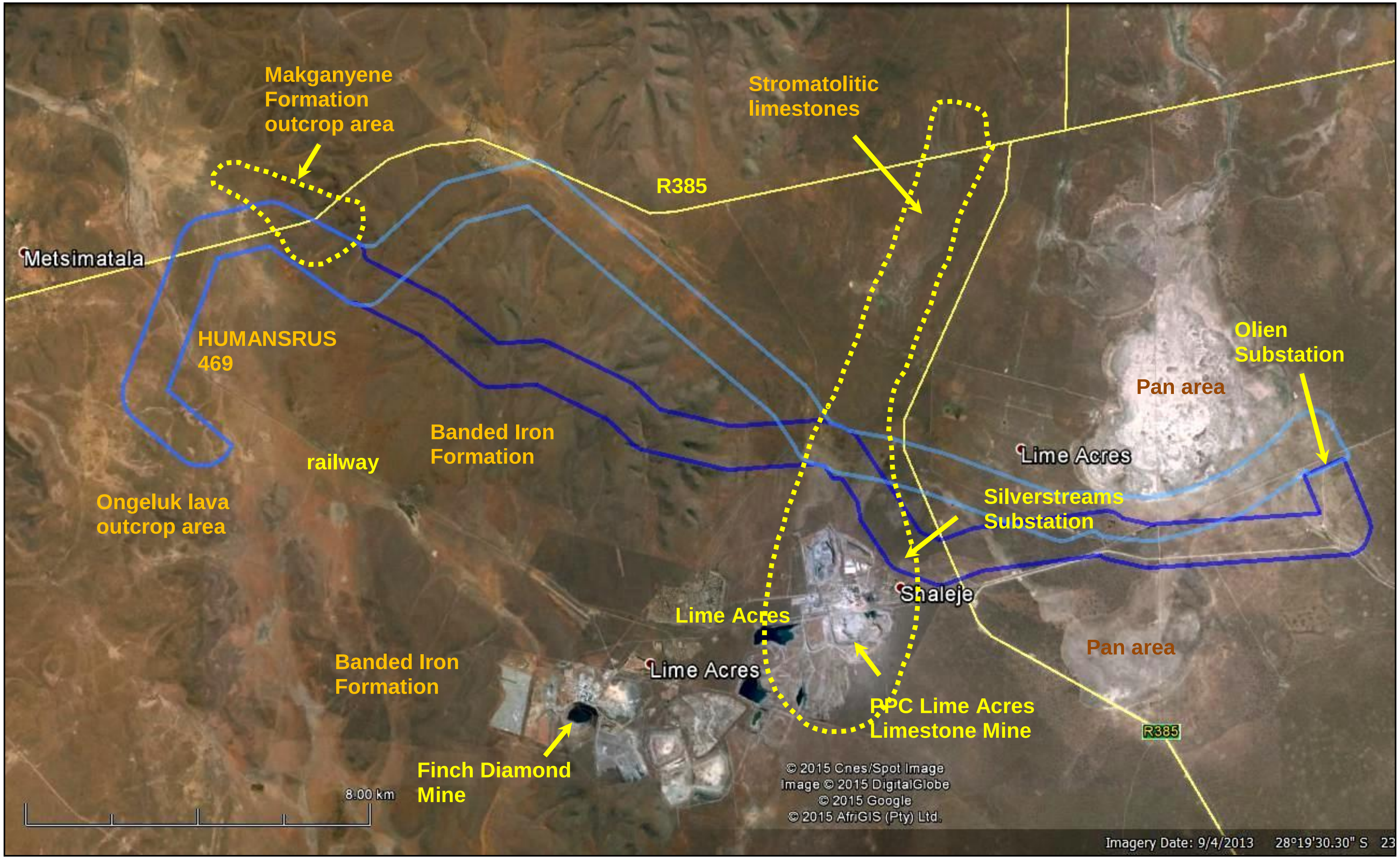

Fig. 3. Google earth© Satellite image of the study area from remainder of the Farm Nr 469 in the west to Olien MTS in the east. The partially overlapping dark blue and pale blue zones indicate the proposed corridors for Option 1 Routes 3 and 4 respectively. Two potentially palaeontologically sensitive areas are indicated by the yellow dotted lines. However, only the eastern area is known to contain fossil stromatolites.

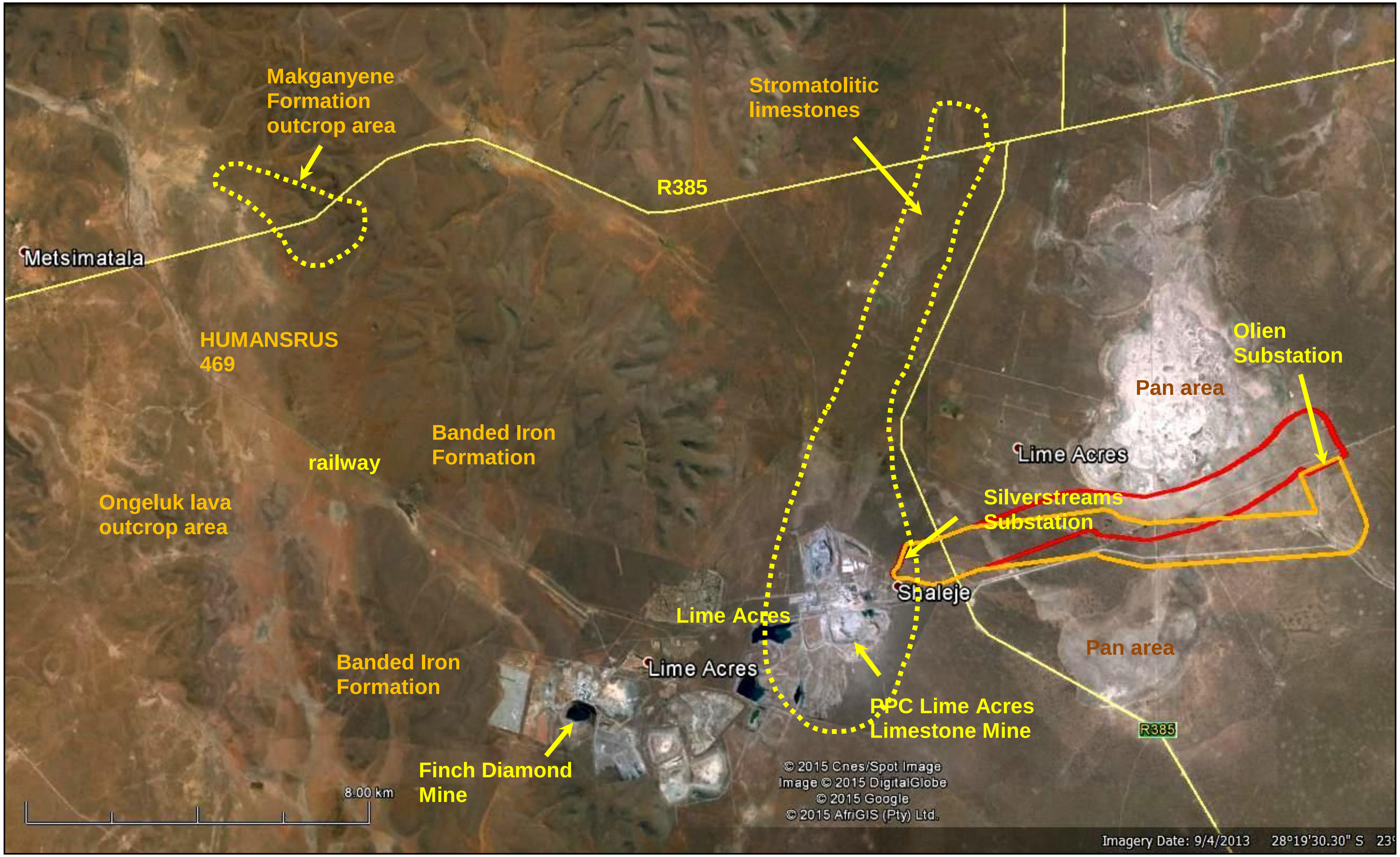

Fig. 4. Google earth© Satellite image of the study area from the remainder of the Farm 469 in the west to Olien MTS in the east. The partially overlapping red and orange zones indicate the proposed corridors for Option 2 Routes 2A and 2B respectively. Two potentially palaeontologically sensitive areas are indicated by the yellow dotted lines. However, only the eastern area is known to contain fossil stromatolites.

3. GEOLOGICAL BACKGROUND

The study area for the proposed ACWA Power SolarReserve Redstone Solar Thermal Power Plant electrical infrastructure developments on and between Humansrus 469 and Lime Acres lies largely within the gently hilly region of the Asbesheuwels, some 30 km east of Postmasburg, Northern Cape. The study area is situated on the southern side of the R385 tar road between Postmasburg and Kimberley, on either side of the Transnet manganese ore railway line linking Sishen and the port of Ngqura (Fig. 1). The Concentrated Solar Power Facility Project Site is situated the on Remainder of Farm Nr 469 is flat to gently sloping, semi-arid terrain at *c*. 1500-1560 m amsl. The proposed alternative 132 kV power line corridors linking the Project Site with Lime Acres traverse the eastern portion of the Asbesheuwels range, here known as the Rooiberge, which reaches elevations of *c*. 1700 m amsl.

The geology of the study area is shown on 1: 250 000 geological map 2822 Postmasburg (Council for Geoscience, Pretoria) (Fig. 7). Brief explanatory notes are printed on the published map, but a comprehensive geological explanation for this sheet has not yet been written. The following geological notes have been largely abstracted from previous palaeontological heritage assessments in the region by the author (*e.g.* Almond 2010b, 2011a, 2011b, 2012a, 2012b, 2013a, 2013b). Additional geological and palaeontological field data was obtained during the recent field assessment by the author (Almond 2014). GPS details of numbered sites mentioned in the text are given in the Appendix A.

The study area is entirely underlain by relatively undeformed sediments and subordinate lavas of the **Ghaap Group** and **Postmasburg Group** (**Transvaal Supergroup**) that are of Late Archaean to Early Proterozoic age. They form part of the thick Ghaap Plateau Sub-basin succession within the Griqualand West Basin, dipping and younging gradually towards the west. The stratigraphy of the relevant formations is shown in Fig. 5 below (Modified from Eriksson *et al.* 2006).

Useful reviews of the stratigraphy and sedimentology of the **Transvaal Supergroup** rocks have been given by Moore *et al.* (2001), Eriksson and Altermann (1998) as well as Eriksson *et al.* (1993, 1995, 2006), Sumner and Beukes (2006). The Ghaap Group represents some 200 Ma (million years) of chemical sedimentation - notably iron and manganese ores, cherts, carbonates and minor siliciclastics - within the Griqualand West Basin that was situated towards the western edge of the Kaapvaal Craton (See also fig. 4.19 in McCarthy & Rubidge 2005).

3.1. Campbell Rand Subgroup

The **Campbell Rand Subgroup** (previously included within the Ghaapplato Formation) of the Ghaap Group is a very thick (1.6 - 2.5 km) carbonate platform succession of dolostones, dolomitic limestones and cherts with minor tuffs and siliciclastic rocks that was deposited on the shallow submerged shelf of the Kaapvaal Craton roughly 2.6 to 2.5 Ga (billion years ago; see the readable general account by McCarthy & Rubidge, pp. 112-118 and Fig. 4.10 therein). A range of shallow water facies, often forming depositional cycles reflecting sea level changes, are represented here, including stromatolitic limestones and dolostones, oolites, oncolites, laminated calcilutites, cherts and marls, with subordinate siliclastics (shales, siltstones) and minor tuffs (Beukes 1980, Beukes 1986, Sumner 2002, Eriksson *et al.* 2006, Sumner & Beukes 2006).

Carbonates (*i.e.* limestones, dolostones) of the "Ghaapplato Formation" ("**Lime Acres Member**", Vgl in geological map Fig. 7) underlie the eastern portions of the present study area, east of the Asbesheuwels foothills, in the vicinity of Lime Acres settlement and the PPC limestone mine. Here they form part of a NNE-SSW trending zone of stromatolite-rich rocks extending from Daniëlskuil to Lime Acres and further southwards. Note that since the current 1: 250 000 geological maps were produced, the Campbell Rand succession has been subdivided into a series of formations, some of which were previously included within the older Schmidtsdrift Formation or Subgroup (Beukes 1980, 1986, Eriksson *et al.* 2006). Formations represented within the study area near Lime Acres, but not fully differentiated on the geological map, include the **Kogelbeen Formation** (with the **Lime Acres Member** at the top), the **Gamohaan Formation** and the **Tsineng Formation** (See stratigraphic table, Fig. 5). Short descriptions of these rock units are given by Altermann and Wotherspoon (1995) as well as Eriksson *et al.* (2006, p. 247), summarized as follows:

- **Kogelbeen Formation** (*c*. 450 m thick) – varied succession of dolomite, limestone and chert, with important horizons of stromatolites and microbial laminites; secondary chert replacement common.
- **Gamohaan Formation** (< 100 m thick) – microbial laminites (crinkly "algal mats") and stromatolites with minor dolarenite, tuff.
- **Tsineng Formation** (*c*. 30 m thick) – microbial laminites with abundant cherts, showing a transitional contact with the overlying deeper-water banded iron formations of the Asbestos Hills Subgroup.

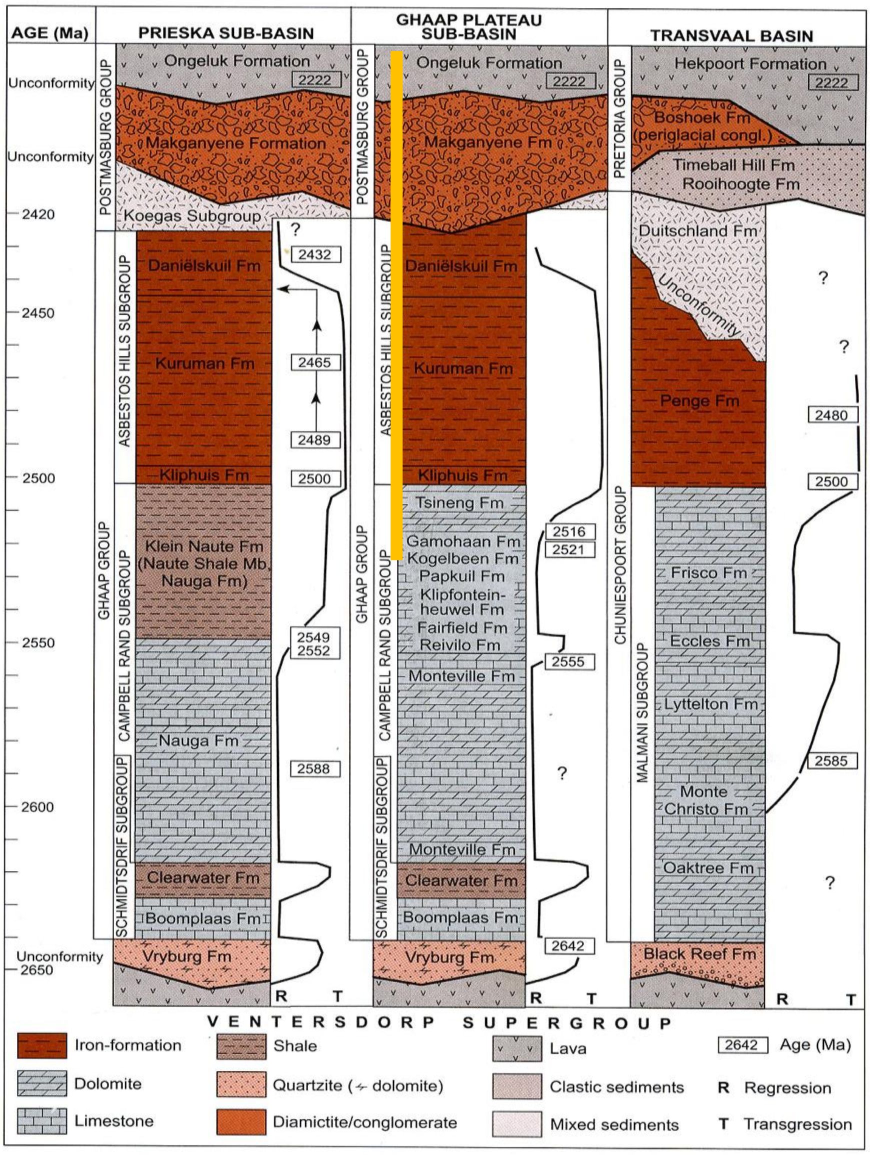

Fig. 5. Stratigraphy of the Transvaal Supergroup of the Ghaap Plateau Sub-basin (central column) showing rock units represented in the Project Site to Lime Acres study area (thick

orange line) (Modified from Eriksson *et al.* 2006). Figures in boxes indicate radiometric ages in millions of years (Ma).

Due to their solubility and low resistance to weathering, exposure levels of the Campbell Rand carbonate sediments are often very low. Many flatter-lying areas are mantled with thick Caenozoic calcrete hardpans, notably here in the area to the north and east of Lime Acres mine where pans are seen on satellite images (Figs. 2 to 4; *cf* Almond 2013a). The outcrop area of chert-rich subunits is often locally covered in downwasted, siliceous rock rubble in the Postmasburg sheet area (*ibid.*).

Limestones of the Lime Acres Member (Kogelbeen Formation) with a very high calcium carbonate content (≥ 96%) are mined for lime at the PPC Lime Ltd quarry at Lime Acres. These stromatolitic carbonates build a prominent, low, east-facing scarp (*c*. 1460-1480 m amsl) that extends from the R385 tar road southwards towards, but not as far as, Lime Acres mine (Figs. 8 and 10). In the lower-lying terrain just north of the mine, which will be traversed by the eastern end of the proposed 132 kV transmission line, the limestone bedrocks are largely obscured by calcrete and other superficial sediments (Fig. 9). Excellent vertical sections through grey-weathering limestones of the Lime Acres Member, dipping gently towards the west, are exposed in the cut faces of the presently active as well as abandoned quarries at Lime Acres (Fig. 32). A distinctive, darker-hued stromatolitic marker bed some 30 cm thick can be traced throughout the various quarries at Lime Acres and is also well-exposed on naturally weathered surfaces along the R385 (Locs. 095 to 097) and on the low limestone plateau to the south (Locs. 100 to 110, see Section 5.1). In addition to several horizons of discrete domical or columnar stromatolites here, most of the beds are built of crinkled microbial laminites showing a distinctive fenestrate or vuggy fabric. There are also occasional beds of brown-weathering sandy dolomite / dolomitic limestone and minor, prominent-weathering, irregular secondary black chert bodies. The Campbell Rand carbonates here show extensive, well-developed karstic weathering features, such as limestone pavements, panholes or solution pans, solution hollows, flutes and elephant skin weathering, as well as joint-controlled *karren* (clints and grikes) (*e.g.* egg box topography Fig. 11).

An unrelated geological feature exposed in one of the abandoned quarries at Lime Acres is an unexploited Cretaceous **kimberlite pipe**. A larger (18 ha) Group II kimberlite intrusion of Middle Cretaceous age that intrudes younger Transvaal Supergroup rocks (Asbestos Hills Group) is exploited at the Finsch Mine just southwest of Lime Acres village

3.2. Asbestos Hills Subgroup

The Campbell Rand carbonates are overlain with a gradational contact by the thick Early Proterozoic banded iron formations of the **Asbestos Hills Subgroup** (Ghaap Group) that build the low-lying, highly-dissected hills of the Rooiberge and associated ranges of the Asbesheuwels in the Postmasburg – Daniëlskuil study area. The Asbestos Hills Group rocks are often poorly exposed due to extensive colluvial gravel cover.

The basal **Kuruman Formation** of the Asbestos Hills Subgroup, cropping out along the eastern foothills of the Rooiberg near Lime Acres (Vak in Fig. 7), consists predominantly of banded iron formations (BIF). These comprise rhythmically bedded, thinly composition- and colour-banded cycles of fine-grained mudrock, chert and iron minerals (siderite, magnetite, haematite). These fine-grained chemical sediments were laid down in an offshore, intermittently anoxic depository, the Griqualand West Basin. In the Ghaap Plateau Sub-basin to the north of the Griquatown Fault Zone the Kuruman BIF reaches thicknesses of up to 250 m (Eriksson *et al.* 2006, their fig. 2). BIF deposition characterizes the Late Archaean – Early Proterozoic interval (2600-2400 Ma), before the onset of well-oxygenated atmosphere and seas on planet Earth.

The overlying iron–rich succession of the **Daniëlskuil Formation** (Vad in Fig. 7), up to 200 m-thick, is interpreted as a current- or wave-reworked banded iron formation, as suggested by the abundance of BIF intraclasts and sedimentary structures (Beukes 1983, Klein & Beukes 1989, Beukes & Klein 1990). The base of the Daniëlskuil Formation has been radiometrically dated to 2.43-2.49 Ga, *i.e.* Early Proterozoic (Eriksson *et al.* 2006). The Daniëlskuil Formation BIF tends to be more prominent weathering than the underlying finer-grained Kuruman BIF rocks. It builds the greater part of the Rooiberg range, especially the higher-lying terrain, in the present study area but bedrock exposure here is generally poor. Good cliff exposures of Daniëlskuil Formation rocks are seen on the Farm Groenwater that borders the Project Site on the north-western side (Almond 2012b). The fine-grained siliciclastics are brown to ochreous weathering, very tabular in geometry, laminated to thin-bedded (≤ 10-20 cm), cherty (*e.g.* showing conchoidal fracture) with bands of iron minerals (reddish haematite, dark magnetite *etc*). Jointing is well developed. Sedimentary structures indicating current reworking of BIF intraclasts were not observed in the Groenwater area by the author.

Almost all of the Asbestos Hills Subgroup outcrop in the Project Site area is mantled with several meter-thick colluvial to alluvial deposits (Fig. 14). Good surface exposures of these banded ironstones are seen on hillslopes near Metsimatala some ten kilometres to the northwest, however (Almond 2012b) (Fig. 15).

3.3. Makganyene Formation

The western portion of the study area - approximately the western half of the remainder of the Farm Nr. 469 - is underlain by glacial and volcanic rocks of the 2.4-2.2 Ga **Postmasburg Group** (uppermost Transvaal Supergroup). The Postmasburg succession overlies the older Ghaap Group rocks in the core of a broad NNE-SSW trending synclinal structure (Fig. 7) (Moore *et al.* 2012). Two contrasting rock units are mapped here. Basal diamictites of the **Makganyene Formation** (Vm in Fig. 7), which reaches a thickness of 500 m near Postmasburg, reflect a *c.* 250 million year - long glacial event of Palaeoproterozoic age (*c*. 2.3-2.2 Ga in Evans *et al.* 1997; *c*. 2.4 Ga in Polteau *et al.* 2006). This has been interpreted by some authors as a global "Snowball Earth" event of Early Proterozoic age triggered by the destruction of preceding methane-rich greenhouse atmospheres by oxygenic cyanobacterial photosynthesis (Kopp *et al.* 2005; but see also Coetzee *et al.* 2006). Sedimentary facies include massive to coarsely-bedded diamictites, sandstones, shales, BIF and even manganese-rich carbonates with stromatolitic bioherms (reefs) (Fig. 6). The bioherms are often up to 5 m long and 3 m thick and are associated with a period of regression (lowered sea levels) within the basin (Visser 1999, Kopp *et al.* 2005, Polteau 2000, 2005, Polteau *et al*. 2006). Most of the diamictite clasts are derived from the older Transvaal Supergroup succession (*e.g.* BIF, carbonates). Abundant striated clasts within the more proximal Makganyene facies support a glacial origin for the diamictites.

Good exposures of Makganyene Formation rocks are seen on either side of the R385 tar road, southeast of Humansrus farmstead (outcrop area approximately indicated by the yellow dotted line in Fig. 3) (Locs. 181 to 191). Here lenticular bodies up to 2 m-thick of massive, resistant-weathering diamictite containing small dispersed to clast-supported angular clasts of dark chert, BIF and carbonate are interbedded with laminated to thin-bedded mudrocks and fine sandstones (Almond 2012b). The wide range of sedimentary facies represented in the local Makganyene succession, mostly highly ferruginous, can be well seen in heaps of fresh blocks excavated from the R385 road cuttings (Locs. 085 to 087) while informative *in situ* exposures occur on the hill slopes and in shallow stream sections to the south of the R385 (Locs. 088 to 090). Meter- to several meter-scale lenticular beds of prominent-weathering, well-cemented, ferruginous silicified diamictite are packed with angular cherty clasts and may represent debris flows interbedded with more recessive-weathering, thin-bedded, pinkish to orange-brown, ferruginous siltstones and sandstones (Figs. 15 to 18). Thicker diamictite bodies higher in the Makganyene succession are dissected by steep polygonal joints (rather like columnar jointing in lavas) with well-developed, concentric Liesegang rings along the margins of the joint blocks as a result of secondary ferruginisation during diagenesis (Figs. 35 & 36) (Locs. 089 & 090). The rhythmically-banded portions of rock bear a superficial similarity with laminated stromatolites but contain dispersed angular cherty gravels. The cores of the joint blocks are of massive, liver-coloured ferruginous diamictite with suspended angular cherty clasts. No lenticles of ferruginous carbonate or indubitable true stromatolites were observed in the Makganyene succession here.

The Makganyene succession near Daniëlskuil has been discussed by Polteau *et al*. (2006). Here the glacial diamictites overlie a volcanic ash (tuff) and contain lenticular sandstone bodies but seemingly no carbonate lenticles with stromatolitic bioherms. These last are apparently confined to the more offshore parts of the basin preserved further to the southwest (= Prieska Sub-basin), but this requires further confirmation.

The Makganyene outcrop area comprises low, rolling hill slopes incised by shallow streams along the north-eastern edge of the Redstone study area. Most of this outcrop area is mantled by poorly-sorted surface gravels that consist predominantly of angular to subangular chert clasts weathered out of the underlying diamictite as well as admixed BIF and jasper, well-seen in road cuttings (Fig. 19). Locally these surface gravels have been cemented to form ferriginous silcrete-like colluvial breccias (Fig. 20).

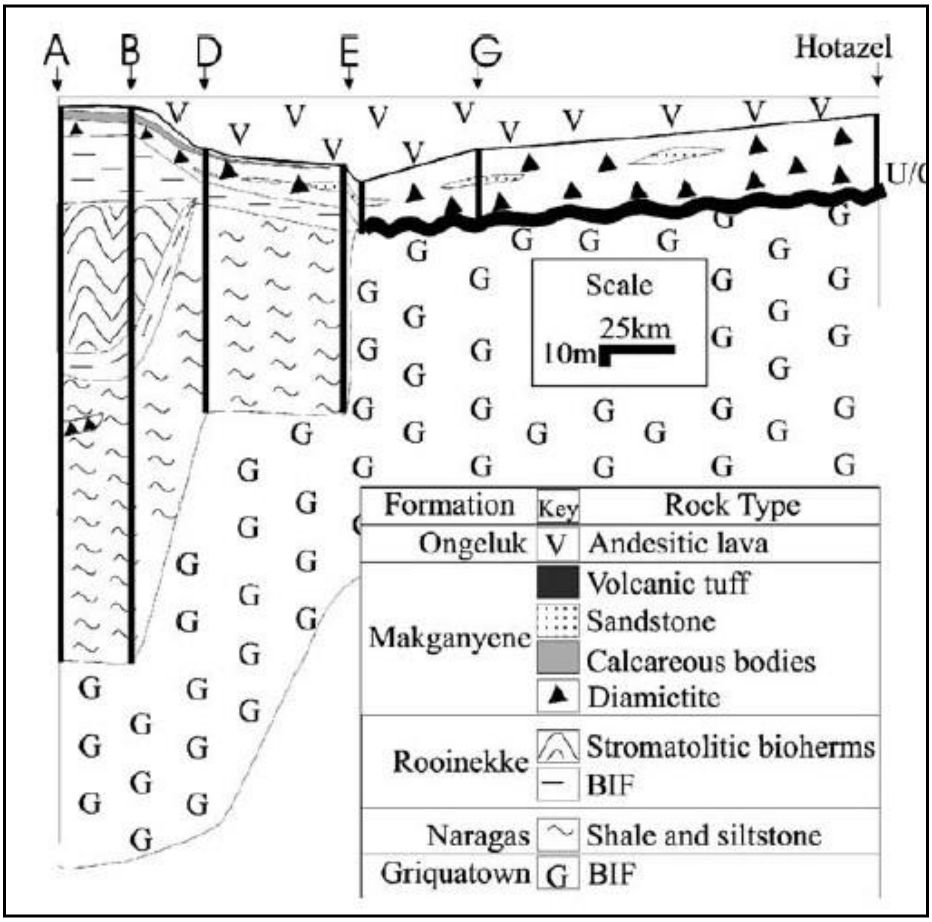

Fig. 6. Series of profiles through the Makganyene Formation (Postmasburg Group), roughly from SW to NE across the Griqualand Basin, Northern Province (From Polteau *et al.* 2006). Profile G, to the SW of Daniëlskuil, corresponds most closely to the Project study area. Here, on the platform area to the NE of the major Griquatown Fault Zone (Ghaap Plateau Sub-basin), the Makganyene glacial diamictites overlie a volcanic ash (tuff) and contain lenticular sandstone bodies but apparently no carbonate lenticles with stromatolitic bioherms. These

last are confined to the more offshore parts of the basin preserved further to the southwest (= Prieska Sub-basin).

3.4. Ongeluk Formation

The glacially-related Makganyene rocks are overlain in the south-western portion of remainder of the Farm Nr. 469 and further to the SW by basaltic to andesitic lavas of the **Ongeluk Formation** (Vo in Fig. 7) dated to 2.2 Ga. The first part of this major flood basalt succession was extruded sub-aerially, but later lava flows show evidence of sub-aqueous extrusion (*e.g.* pillow lavas; Cornell *et al.* 1996, Eriksson *et al.* 2006). Up to 27 successive lava flows can be picked up within the succession from stepped hill slopes on satellite images. Subordinate diamictites are found within the Ongeluk succession. Well-jointed, resistant-weathering Ongeluk Formation lavas seen just to the east of Metsimetala Village (Farm Groenwater 453) are massive, buff- to brown-weathering, fine-grained and speckled with occasional vugs / gas cavities (Almond 2012b).

Fresh exposures of the Ongeluk lavas are not seen within the Project study area but are seen in occasional road cuttings along the R385 to the west where this formation builds a landscape of low, rounded, well-grassed hills (*e.g.* Loc. 084). The blocky-jointed basaltic andesite lavas here are dark grey-green, medium-grained and speckled when fresh but weather with a pale brown patina (Fig. 21). Close to the land surface they are generally deeply weathered with subrounded corestones embedded in a *sabunga*-like, friable saprolite with onionskin-type weathering (exfoliation), in this respect resembling many Karoo dolerites (Fig. 22). No sedimentary interbeds were observed here.

A couple of borrow pits (one currently active) have been excavated into the weathered Ongeluk Formation and overlying superficial deposits close to the R385 tar road. Deeply-weathered, greenish-yellow to brown, crumbly Ongeluk lava saprolite at Loc. 092 is overlain by about a meter of orange-brown gravelly to sandy soils with occasional discrete lenticular gravel horizons (mainly angular to subrounded pebbles of vein quartz, chert) (Fig. 23).

3.5. Kalahari Group

In the flatter, low-lying areas in the central portion of remainder of the Farm Nr 469, as well as the gap through the Rooiberg to Lime Acres that is followed by the railway line, the Precambrian bedrocks are mantled by wind-blown (aeolian) sands of the **Gordonia Formation** (Qs, Kalahari Group). The geology of the Late Cretaceous to Recent **Kalahari Group** is reviewed by Thomas (1981), Dingle *et al.* (1983), Thomas & Shaw 1991, Haddon (2000) and Partridge *et al.* (2006). According to Bosch (1993) the Gordonia sands in the Kimberley area reach thicknesses of up to eight meters and consist of up to 85% quartz associated with minor feldspar, mica and a range of heavy minerals. The Gordonia Formation aeolian sands are considered to range in age from the Late Pliocene / Early Pleistocene to Recent, dated in part from enclosed Middle to Later Stone Age stone tools (Dingle *et al*., 1983, p. 291). Note that the recent extension of the Pliocene - Pleistocene boundary from 1.8 Ma back to 2.588 Ma would place the older Gordonia Formation almost entirely within the Pleistocene Epoch.

Other superficial sediments whose outcrop areas are often not indicated on 1: 250 000 scale geological maps include colluvial or slope deposits (scree, hillwash, debris flows *etc*), sandy, gravelly and bouldery river alluvium (*e.g.* small patch in SE corner of Humansrus), surface gravels of various origins (*e.g.* cherty "rubble" overlying Campbell Rand carbonates near Daniëlskuil), as well as spring and pan sediments (*e.g.* large pans to the NE of Lime Acres seen in satellite images, Fig. 2). The colluvial and alluvial deposits may be extensively calcretised (*i.e.* cemented with pedogenic limestone), especially in the neighbourhood of dolerite intrusions or overlying Ghaap Group carbonate rocks (Almond 2013a).

Good sections through mixed colluvial to alluvial deposits overlying the Asbestos Hills Subgroup (Kuruma Formation) are seen in borrow pits just north of the airstrip and railway line some 2.4 km NW of Lime Acres (Loc. 094). Here a several meter thick succession of crudely-bedded, semi-consolidated, clast-supported breccio-conglomerates consist almost entirely of subangular to platy BIF clasts, locally showing imbrication (Fig. 14). Satellite images as well as fieldwork suggest that most of the BIF outcrop area is mantled with similar thick colluvial to alluvial deposits.

Mappable exposures of **calcrete** or **surface limestone** (Ql, dark yellow, in Fig. 7) cover large portions of the Ghaap Group carbonates of the Ghaap Plateau in the Daniëlskuil – Lime Acres region (Almond 2013a). These pedogenic limestone deposits reflect seasonally arid climates in the region over the last five or so million years and are briefly described by Truter *et al.* (1938) as well as Visser (1958) and Bosch (1993). The surface limestones may reach thicknesses of over 20 m, but are often much thinner, and are locally conglomeratic with clasts of reworked calcrete as well as exotic pebbles. The limestones may be secondarily silicified and incorporate blocks of the underlying Precambrian carbonate rocks. The older, Pliocene - Pleistocene calcretes in the broader Kalahari region, including sandy limestones and calcretised conglomerates, have been assigned to the **Mokalanen Formation** of the **Kalahari Group** and are possibly related to a globally arid time period between 2.8 and 2.6 million years ago, *i.e.* late Pliocene (Partridge *et al.* 2006). Thick deposits of calc-tufa ("*kranskalk*") occur along the margins of the Ghaap Plateau, as at Ulco, where lime-rich groundwaters reach the ground surface (Bosch 1993).

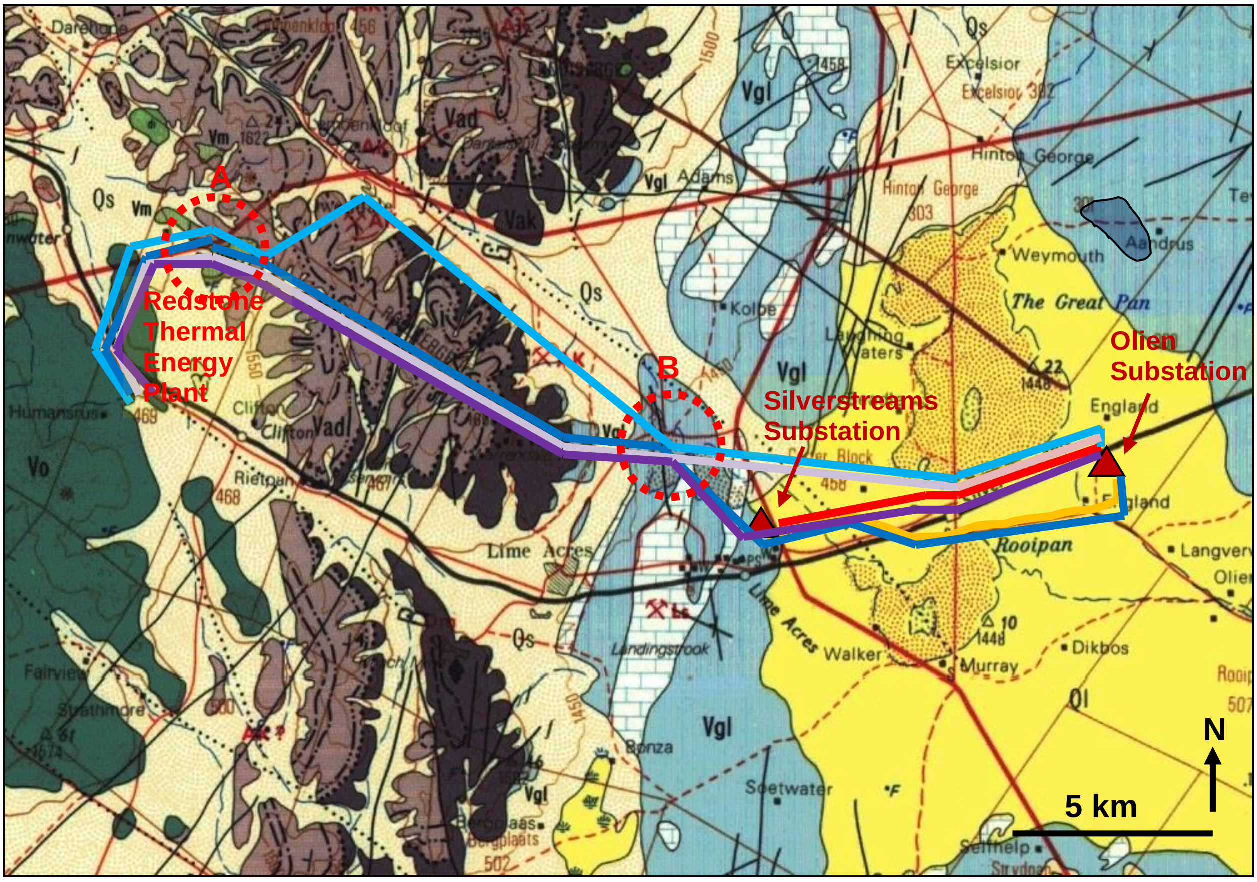

Fig. 7. Extract from 1: 250 000 geological map 2822 Postmasburg (Council for Geoscience, Pretoria) showing the geology of the remainder of the Farm 469 – Olien Substation study area near Postmasburg, Northern Cape. The coloured lines indicate - albeit schematically - the various proposed 132 kV power line route options connecting the ACWA Power SolarReserve Redstone Thermal Energy Plant, Silverstreams Substation and Olien Substation. These

include Option 1 Route 1 (purple), Route 2 (lilac), Route 3 (dark blue) and Route 4 (pale blue); Option 2 Route 2A (red) and Route 2b (orange). Two areas of potentially higher palaeontological sensitivity in the western and central portions of the study area are indicated by red dotted circles: area A with possible Makganyene stromatolites and area B with possible Campbell Rand stromatolites (See text for discussion). Geological units mapped within the study area include:
TRANSVAAL SUPERGROUP

Ghaap Group (CAMPBELL RAND SUBGROUP)
Vgl (pale blue) = Kogelbeen, Gamohaan & Tsineng Formations (undifferentiated) (*c*. 2.5 Ga)
Ghaap Group (ASBESTOS HILLS SUBGROUP):
Vak (dark purple) = Kuruman Formation
Vad (purplish-grey) = Daniëlskuil Formation (banded iron formation, 2.4 Ga)

POSTMASBURG GROUP
Vm (pale green) = Makganyene Formation (glacial diamictite) (*c.* 2.3 Ga)
Vo (dark green) = Ongeluk Formation (lavas, 2.2 Ga)

LATE CAENOZOIC DRIFT
Qs (pale yellow) = aeolian sand of the Gordonia Formation (Kalahari Group, Quaternary)
Ql (dark yellow) = calcrete hardpans or "surface limestone"
Middle yellow with flying bird symbol = alluvium
Red stippled areas = pan sediments

4. GEOLOGY UNDERLYING THE ELECTRICAL INFRASTRUCTURE FOOTPRINT

The geological units underlying each of the 132 kV power line corridors under consideration is briefly outlined here (See geological map in Fig. 7 as well as relevant satellite images in Figs. 2 to 4).

4.1. Geology underlying Option 1 power line corridors

Power line corridor **Option 1 Route 1** (purple zone in Fig. 2; purple line in Fig. 7) traverses weathered Ongeluk Formation lavas and surface gravels on the western borders of remainder of the Farm Nr. 469. The north-western sector of the corridor, close to the R385 tar road, overlies Makganyene Formation diamictites and Gordonia Formation aeolian sands. The next sector to the east crosses the Rooiberg hills where it is underlain by Asbestos Hills Subgroup BIF (Kuruman and Daniëlskuil Formations); the outcrop here is largely mantled by BIF colluvium (platy ironstone scree, soils). In the region to the north of Lime Acres settlement and limestone mine as far as Silverstreams Substation and beyond the corridor traverses Campbell Rand carbonates. The bedrocks here are extensively mantled by superficial sediments (calcrete hardpan, soil, gravels, pan sediments, aeolian sands). This applies particularly to the stretch between Silverstreams and Olien Substations where the Precambrian carbonate bedrocks are largely covered by a well-developed calcrete hardpan, and perhaps locally by pan sediments.

Power line corridor **Option 1 Route 2** (pink zone in Fig. 2 and pale blue line in Fig. 7) has a very similar underlying geology to Route 1, but with marginally less impact on surface exposures of Campbell Rand carbonate rocks to the north of Silverstreams Substation.

The geology underlying power line corridor **Option 1 Route 3** (dark blue zone in Fig. 3 and dark blue line in Fig. 7) does not differ significantly from that described for Route 1 above.

The geology underlying power line corridor **Option 1 Route 4** (pale blue zone in Fig. 3 and pale blue line in Fig. 7) is also similar to that described for Route 1 with the exception of comparatively shorter sectors traversing the banded ironstones of the Asbestos Hills Subgroup and corresponding longer sectors underlain by Gordonia Formation aeolian sands along the north-eastern edge of the Rooiberge.

4.2. Geology underlying Option 2 power line corridors

As shown on the geological map and satellite images (Figs. 7 and 4 respectively) the geology and topography within the corridors for **Option 2 Route 2A** and **Option 2 Route 2B** are very similar. In both cases, flat-lying terrain underlain by Campbell Rand carbonates is largely covered by Late Caenozoic superficial deposits, notably calcrete hardpans, and possibly also pan sediments.

Fig. 8. View southwards from the R385 near Loc. 096 showing extensive exposure of grey limestones of the Kogelbeen Formation along a low east-facing escarpment.

Fig. 9. View southwards towards Lime Acres mine from the limestone escarpment seen in the previous figure (viewpoint is Loc 108). Note lack of limestone bedrock exposure in lower-lying areas here.

Fig. 10. View south-westwards across the low limestone escarpment seen in Fig. 7 (Loc. 104). The large domal stromatolite horizon is in the foreground and the upper stromatolite marker bed a few meters higher in the succession is on the horizon (arrowed).

Fig. 11. Well-developed karstic weathering features (eggbox topography) in Campbell Rand carbonates just north of the R385 (Loc. 098). These dome-shaped structures are *not* stromatolites.

Fig. 12. Karst solution hollow within grey Campbell Rand carbonate (Scale in cm). The hollow is partially infilled with indurated chert gravels. Solution hollows might have acted as important traps for small mammal remains and snails in many karstified landscapes, though no fossils were seen in this case.

Fig. 13. Steep hillslope exposure of tabular-bedded banded iron formation of the Daniëlskuil Formation (Asbestos Hills Subgroup) near Metsimetala, northwest of the Project study area (*cf* Almond 2012b).

Fig. 14. Crudely-bedded banded ironstone colluvial / fluvial gravels that mantle most of the Asbestos Hills BIF outcrop area (Loc. 094) (Hammer = 30 cm).

Fig. 15. Prominent-weathering beds of silicified, ferruginised diamictite (possibly debris flows), hillslope exposure of the Makganyene Formation (Loc. 088) (Hammer = 30 cm).

Fig. 16. Close-up of clast-rich, ferruginous cherty breccias seen in the previous figure (Hammer = 30 cm).

Fig. 17. Road cutting through the Makganyene Formation showing prominent-weathering, lenticular bed of cherty diamictite interbedded with thin-bedded, ferruginous sandstones (Loc. 082).

Fig. 18. Close-up of silicified bed within the Makganyene Formation showing angular chert clasts towards the base of the unit – possibly a sediment gravity flow (Scale in cm).

Fig. 19. Poorly-consolidated, ferruginous cherty gravels mantling the Makganyene Formation outcrop area (Loc. 083) (Hammer = 30 cm).

Fig. 20. Poorly-sorted gravelly pedocrete composed of well-cemented, angular chert clasts overlying the Makganyene Formation (Loc. 086) (Hammer = 30 cm).

Fig. 21. Roadside exposure of fresh Ongeluk Formation basaltic andesite lavas along the R385 to the west of the Redstone study area (Loc. 084).

Fig. 22. Close-up of Ongeluk Formation lava exposure seen in the previous figure showing distinctive corestone weathering pattern (Hammer = 30 cm).

Fig. 23. Deeply-weathered Ongeluk Formation lava saprolite at level of hammer overlain by gravelly soils and orange-brown Kalahari sands (Loc.092) (Hammer = 30 cm).

5. PALAEONTOLOGICAL HERITAGE

The fossil record of the Precambrian sediments of the Northern Cape has been briefly reviewed by Almond & Pether (2008). An outline of the palaeontological heritage recorded from the major rock units represented in the Project Site – Lime Acres study area is given here, based largely on Almond (2012b, 2013a) as well as on new field data from the field-based assessment by Almond (2014).

5.1. Fossils within the Campbell Rand Subgroup

The shallow shelf and intertidal sediments of the carbonate-dominated lower part of the **Ghaap Group** (*i.e.* **Schmidtsdrif** and **Campbell Rand Subgroups**) are well known for their rich fossil biota of *stromatolites* or microbially-generated, finely-laminated sheets, mounds, columns and branching structures. Some stromatolite occurrences on the Ghaap Plateau of the Northern Cape are spectacularly well-preserved (*e.g.* Boetsap locality northeast of Daniëlskuil figured by McCarthy & Rubidge 2005, Eriksson *et al.* 2006). 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). Horizons of microbial mats as well as domal and columnar stromatolites are reported from the **Kogelbeen Formation**. Some of the oldest known (2.6 Ga) fossil microbial assemblages with filaments and coccoids have been recorded from stromatolitic cherty limestones of the **Lime Acres Member** (Kogelbeen Formation) at Lime Acres (Altermann & Schopf 1995, Altermann & Wotherspoon 1995). The **Gamohaan Formation** also features horizons of microbial mats, domal and columnar stromatolites (Eriksson *et al.* 2006). The **Tsineng Formation** at the top of the Campbell Rand carbonate succession has yielded stromatolites (previously assigned to the Tsineng Member of the Gamohaan Formation), microbial mats as well as filamentous microfossils named *Siphonophycus* that are thought to have developed in shallow waters of the photic zone that were no more than a few tens of meters deep (Klein *et al.* 1987, Altermann & Schopf 1995, Eriksson *et al*. 2006).

Richly stromatolitic limestones of the Kogelbeen Formation (Lime Acres Member) are exposed in road cuttings along both sides of the R385 tar road (Locs. 095 to 097) as well as on the low limestone plateau to the north and south. Well-preserved stromatolites were not seen at surface within the transmission line study area north and east of Lime Acres where the Lime Acres Member is not well-exposed at surface. The darker-hued stromatolitic marker bed that is prominent in the Lime Acres mine some 10 km to the SSW (Fig. 32) is well-seen along the R385 as well as on the low limestone plateau to the south (*e.g.* Locs. 106-107) (Figs. 27 to 31). It is clearly laterally persistent, at least on the scale of several kilometers. The individual, closely-spaced columnar columns making up the bed are much more clearly seen in surface outcrop than in quarry faces as a result of natural weathering, but detailed substructure is also well seen in prospecting core material from the mine (Fig. 33). The dark brown-weathering (possibly ferruginous or carbonaceous) stromatolitic columns within the bed are mostly unbranched, some 20 to 40 cm high, and 5 to 20 cm wide. The irregular, frequently truncated, convex-upward lamination indicates growth by trapping and binding of loose sediment (Sumner 2002). The tightly-packed columns are subrounded to plate-like / subrectangular or irregular and convex (domical) in plan view (Fig. 29). The narrow intervening columns or sheets of laminated clastic sediment (grainstones) are often preferentially dolomitised. The stromatolitic beds also contain dispersed, irregular bodies of secondary black chert. Above and below the marker bed are grey, horizontally-laminated microbialites (Fig. 31). The constituent laminae are commonly disrupted, with isolated small domical stromatolites, and display a well-developed fenestrate fabric, with impersistent, sparry calcite-infilled spaces between the microbiliates.

Several meters below the dark, upper stromatolite marker bed is another laterally persistent zone, this time characterised by medium- to large scale domal stromatolites with rounded to oval plan views (Figs. 10, 24 & 25) (*e.g.* Locs. 101-102, 104. Locally this planed-off stromatolitic bed bears small pecked rock engravings; *e.g.* Locs 103, 105). The domes reach diameters of up to a meter or more, with a relief of a few dm, and often form nested sets. Most of the dome structure is built of crinkled or cuspidate / peaked rather than smooth laminae (commonly seen in peritidal domal stromatolites) while the core region may show fenestrate fabrics or lack clear lamination (Fig. 25). Highly regular, concentric layers of isopachous (evenly thick) laminae infilling the spaces between the stromatolitic domes are probably the consequence of aragonite precipitation (possibly abiogenic) rather than carbonate sediment trapping and binding (Sumner 2000). In fact, a grainstone infill between the stromatolites is typically absent. The original aragonite precipitate has subsequently been replaced by calcite but retains an aragonitic high-strontium signature. Crystal fringes of fibrous aragonite pseudomorphs that precipitated directly onto the flanks of stromatolites were a common phenomenon in shallow subtidal and platform margin settings (Sumner 2002) (cf also Fig. 26). Domical and columnar stromatolites as well as carbonate microfabrics seen near Lime Acres suggest shallow, reef-like settings towards the seaward edge of the Campbell Rand carbonate platform. Similar stromatolite morphologies have already been described from Transvaal Supergroup carbonates elsewhere. Important fossil localities are situated in the Griqualand West Basin, for example on the edge of the Ghaap Plateau near Boetsap, Northern Cape, some 100 km to the NE of Lime Acres (See several pioneering papers by R.B. Young in the reference list, also Eriksson & Truswell 1975, Bertrand-Sarfati & Eriksson 1977, Eriksson & Altermann 1998, Sumner 2002) as well in the Transvaal Basin further east on the Kaapvaal Craton (*e.g.* Truswell & Eriksson (1972).

Gravel-infilled karstic solution hollows within the Campbell Rand exposures (Fig. 12) were inspected for micromammalian remains and gastropod molluscs, without success. Downwasted surface gravels overlying the limestone outcrop area are dominated by cherty clasts, including many fragments of buff, secondarily silicified stromatolitic carbonate. It appears that diagenetic silicification often preferentially affected stromatolitic beds.

Fig. 24. Oblique plan view of a portion of the large domal stromatolite horizon, Kogelbeen Formation, seen in Fig. 10 above (Loc. 104) (Hammer = 30 cm). Note grouping of smaller domes into nested sets.

Fig. 25. Detail of the same surface seen in the previous figure showing cuspidate or peaked laminae composing the stromatolites and the isopachous bands of precipitated carbonate infilling the spaces between the domes.

Fig. 26. Close-up of stromatolite-like, complex banded limestone. The layers here show no evidence of sediment trapping and binding and were probably precipitated abiogenically as aragonite crystal overgrowths, subsequently converted to calcite (Loc. 109) (Hammer = 30 cm).

Fig. 27. Laterally-extensive, brown-weathering upper stromatolite marker bed within the Kogelbeen Formation (Loc. 106).

Fig. 28. Detail of the upper *c*. 30 cm-thick stromatolite marker bed showing close-packed columnar stromatolites (near Loc. 097) (Hammer = 30 cm).

Fig. 29. Plan view of the upper stromatolite marker bed showing irregular cross-section and very close packing of the columns (near Loc. 097) (Hammer = 30 cm). Resistant-weathering irregular black patches are secondary chert.

Fig. 30. Close-up of narrow columnar stromatolites from the upper marker bed, Kogelbeen Formation (Loc. 097). The specimen is *c*. 20 cm high. The convex-upward laminae were built up by trapping and binding of carbonate sediment by microbial mats and show frequent erosional episodes. The inter-column spaces were infilled by clastic sediment (carbonate grainstone) and shows convex-downward lamination. Resistant-weathering irregular black patches are secondary chert.

Fig. 31. Overturned block of Kogelbeen Formation showing the grey fenestrate limestone under- and overlying the brown-weathering stromatolite marker bed (near Loc. 097) (Hammer = 30 cm).

Fig. 32. View of cut face on the western side of the active northern pit at Lime Acres Quarry showing vertical section through the tabular-bedded Kogelbeen Formation limestones (Lime Acres Member) including the dark, *c*. 30 cm thick upper stromatolite marker bed (arrowed).

Fig. 33. Borehole cores through a stromatolitic horizon within the Kogelbeen Formation, Lime Acres, showing fine carbonaceous lamination building up towards the left (Scale in cm).

Fig. 34. Upper bedding surface of stromatolitic limestone showing small-scale, onion-like nested domes preserved in positive relief (Hammer = 30 cm). This block is displayed at the PPC Lime Acres Mine.

5.2. Fossils within the Asbestos Hills Subgroup

The deep water BIF facies of the Asbestos Hills Subgroup (**Kuruman** and **Daniëlskuil Formations**) have not yielded stromatolites which are normally restricted to the shallow water photic zone since they are constructed primarily by photosynthetic microbes. No convincing trace fossils, attributable to sizeable metazoans (multi-cellular animals), have been reported from BIF facies. However, there are several reports of microfossils from cherty sediments within the Kuruman Formation according to MacRae (1999) and Tankard *et al.* (1982 – see refs. therein by Fockema 1967, Cloud & Licari 1968, La Berge 1973. *N.B.* the stratigraphic position of these older records may require confirmation). It is likely that cherts within the Daniëlskuil Formation also contain scientifically interesting Early Proterozoic microfossil assemblages. The supposed fossil medusoid or jellyfish *Gakarusia* reported from the Asbestos Hills Subgroup by Haughton (1963) is almost certainly a pseudofossil (*cf* Haughton 1969, Haentzschel 1975).

No fossil remains were recorded in the banded ironstone outcrop area during the present field study.

5.3. Fossils within the Postmasburg Group

The fossil record of the Postmasburg Group of the Transvaal Supergroup is still poorly known. Stromatolitic bioherms up to 5 m long and 3 m thick that are made up of manganese-rich laminated carbonates and contain chert clasts (presumably glacial dropstones) are reported from the glacially-influenced **Makganyene Formation** by Polteau *et al.* (2006). These carbonate rocks are interbedded with glacial diamictites in the Prieska Subbasin (Visser 1999). The intimate association of supposed warm-water carbonates and cold-water glacial deposits at low palaeolatitudes is of considerable palaeoclimatic and palaeobiological significance (See also Polteau 2000, 2005). An alternative view is that these Early Proterozoic stromatolites actually developed within cold, glacial waters, rather than in tropical Bahamas-like settings as previously assumed. Large conical stromatolites generated by cyanobacteria ("blue-green algae") have recently been discovered growing at depths of up to 100 m beneath permanent ice cover in an Antarctic alkaline freshwater lake, a possible modern analogue for the Makganyene fossils (Andersen *et al.* 2011). Any fossil occurrences of Makganyene stromatolites in association with glacial rocks are therefore of special research and conservation significance. There are contested records of possible trace fossils from contemporary 2.2 Ga sediments of the Postmasburg Group in the Transvaal Basin (Pretoria Group; Almond & Pether 2008).

According to Polteau *et al.* (2006) the stromatolitic carbonate bodies within the Makganyene Formation are restricted to the more distal Prieska Sub-basin, southwest of the Griquatown Fault Zone (Fig. 6). They have not been recorded from the more proximal, platform area that is represented in the study area to the southwest of Daniëlskuil, and this is supported by the present field study. Concentrically-patterned zones of diagenetic Liesegang rings seen around the margins of joint blocks might be easily mistaken for stromatolites but they contain dispersed, angular cherty clasts and the core region is of ferruginous diamictite (Figs. 35 & 36).

No fossils are recorded from the volcanic **Ongeluk Formation**, although the middle and upper parts of the lava succession was probably extruded subaqueously. Subaerial eruptions are inferred for the basal lava flows overlying the Makganyene diamictites (Eriksson *et al.* 2006). Stromatolitic dolomites are recorded from the **Mooidraai Formation** at the top of the Postmasburg Group succession (Beukes 1986, Eriksson *et al.* 2006), but these younger rocks are not represented within the present study area.

No fossil remains were recorded in the Ongeluk Formation outcrop area during the present field study.

Fig. 35. Polygonal-jointed, ferruginised Makganyene diamictite showing well-developed concentric Liesegang rings round the margins of the joint blocks (Loc. 090) (Hammer = 30 cm).

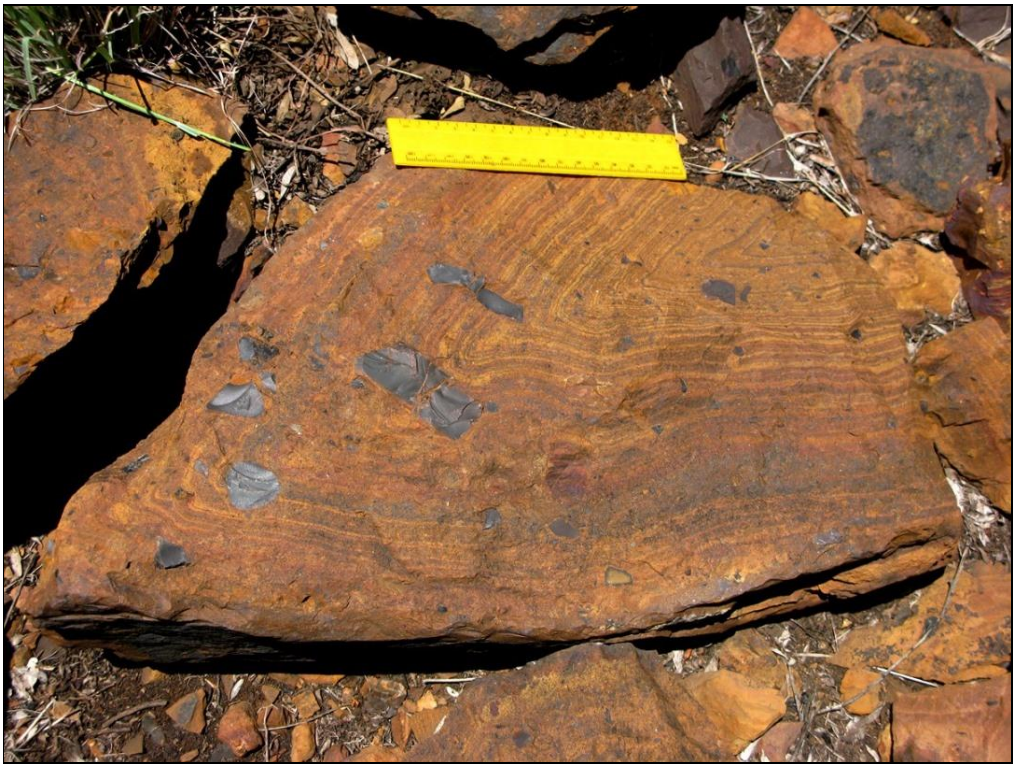

Fig. 36. Loose block of ferruginised Makganyene diamictite showing *Conophyton*-like conical Liesegang lamination and embedded clasts of black chert (Scale in cm) (Loc. 085).

5.4. Fossils within the Kalahari Group

The fossil record of the Kalahari Group is generally sparse and low in diversity. The **Gordonia Formation** dune sands were mainly active during cold, drier intervals of the Pleistocene Epoch that were inimical to most forms of life, apart from hardy, desert-adapted species. Porous dune sands are not generally conducive to fossil preservation. However, mummification of soft tissues may play a role here and migrating lime-rich groundwaters derived from underlying lime-rich bedrocks may lead to the rapid calcretisation of organic structures such as burrows and root casts. Occasional terrestrial fossil remains that might be expected within this unit include calcretized rhizoliths (root casts) and termitaria (*e.g. Hodotermes*, the harvester termite), ostrich egg shells (*Struthio*), tortoise remains and shells of land snails (*e.g. Trigonephrus*) (Almond 2008, Almond & Pether 2008). Other fossil groups such as freshwater bivalves and gastropods (*e.g. Corbula, Unio*) and snails, ostracods (seed shrimps), charophytes (stonewort algae), diatoms (microscopic algae within siliceous shells) and stromatolites (laminated microbial limestones) are associated with local watercourses and pans. Microfossils such as diatoms may be blown by wind into nearby dune sands (Du Toit 1954, Dingle *et al*., 1983). These Kalahari fossils (or subfossils) can be expected to occur sporadically but widely, and the overall palaeontological sensitivity of the Gordonia Formation is therefore considered to be low. Underlying **calcretes** might also contain trace fossils such as rhizoliths, termite and other insect burrows, or even mammalian trackways. Mammalian bones, teeth and horn cores (also tortoise remains, and fish, amphibian or even crocodiles in wetter depositional settings) may be expected occasionally expected within Kalahari Group sediments and calcretes, notably those associated with ancient alluvial gravels. Young (Quaternary to Recent) surface gravels and colluvium are probably unfossiliferous.

Surface limestones (calcrete hardpans) overlying Campbell Rand carbonates to the east of Lime Acres contain occasional horizons showing a porous, bioturbated fabric with dense networks of tubular hollows that may be attributed to insect burrowing, probably termites (Almond 2013a). Downwasted and reworked blocks of black to dark grey Campbell Rand cherts and grey karst-weathered dolostone / limestone frequently contain small-scale domical stromatolites (*ibid*). Calcretised alluvial conglomerates overlying Campbell Rand bedrocks near Postmasburg also contain reworked clasts of stromatolitic dolomite or limestone (*ibid*.).

No fossil remains were recorded from the Late Caenozoic superficial sediments in the Redstone transmission line study area during the previous field study by Almond (2014). Apart from blocks of Precambrian stromatolitic dolostone and chert (small-scale domical stromatolites), as well as low diversity trace fossil assemblages within the overlying Kalahari calcretes, neither of which is high palaeontological significance, no other fossil remains were observed during fieldwork in the Trewil area some 5 km ENE of Olien Substation by Almond (2013a).

6. EVALUATION OF POTENTIAL IMPACTS ON FOSSIL HERITAGE

Potential impacts on local fossil heritage as a result of the proposed 132 kV power line developments are briefly evaluated below in Table 1. Please note that this assessment refers to the Construction Phase of the development and applies equally to all the power line route options under consideration.

Significant further impacts on fossil heritage are not anticipated for the operational and decommissioning phases of the electrical infrastructure network.

Table 1: Evaluation of potential impacts on local fossil heritage resources due to the proposed 132 kV power line connections of the ACWA Power SolarReserve Redstone Thermal Energy Plant to the national grid (Construction Phase, all power line corridor routes)

IMPACTS ON FOSSIL HERITAGE RESOURCES		
Environmental Parameter	*Fossils preserved at or beneath the surface of the ground within the study area (*e.g. *stromatolites).*	
Issue/Impact/Environmental Effect/Nature	*Disturbance, damage or destruction of fossils preserved at or beneath the ground surface as a result of ground clearance and excavations for power line tower footings.*	
Extent	*Restricted to development footprint (site)*	
Probability	*Possible (but significant impacts on* well-preserved *fossil sites are considered to be unlikely)*	
Reversibility	*Irreversible*	
Irreplaceable loss of resources	*Marginal (fossils concerned are probably of widespread occurrence within the broader region).*	
Duration	*Permanent*	
Cumulative effect	*Negligible (given low palaeontological sensitivity of bedrocks and superficial sediments in the region)*	
Intensity/magnitude	*Low*	
Significance Rating	*Negative low impact*	
	Pre-mitigation impact rating	Post mitigation impact rating
Extent	1	1
Probability	2	2
Reversibility	4	4
Irreplaceable loss	2	2
Duration	4	4
Cumulative effect	1	1
Intensity/magnitude	1	1
Significance rating	- 15 (low negative)	- 15 (low negative)
Mitigation measures	*ECO to monitor all substantial excavations for fossil material. Any chance fossil finds (*e.g. *well-preserved stromatolites, mammalian bones & teeth) to be safeguarded and reported to SAHRA for possible recording and sampling by a professional palaeontologist.*	

7. CONCLUSIONS & RECOMMENDATIONS

The study area from the Remainder of Farm Nr 469 in the west to Olien Substation in the east is underlain by largely undeformed Precambrian sediments and lavas of the Transvaal Supergroup that are Late Archaean to Early Proterozoic in age (*c*. 2.25 to 2.22 billion years old). These principally comprise shallow marine carbonates (limestones / dolomites) of the Campbell Rand Subgroup in the east that are successively overlain towards the west by banded iron formations (BIF) of the Asbestos Hills Subgroup and then glacial diamictites (tillites) and lavas of the Postmasburg Group. The Precambrian bedrocks are overlain by a range of late Caenozoic superficial sediments including aeolian sands of the Gordonia Formation (Kalahari Group), calcrete hardpans, colluvium (*e.g.* surface rubble, scree, downwasted gravels), river alluvium and pan deposits.

Well-preserved domical and columnar stromatolites (fossil reef-like microbial mounds) as well as associated microfossil biotas are recorded from the upper formations of the Campbell Rand Subgroup (esp. Kogelbeen Formation) to the north of Lime Acres, close to the R385 tar road, as well as within the PPC Lime quarry at Lime Acres. The stromatolitic limestone beds also occur beneath the central and eastern portions of several of the 132 kV transmission line corridor options. However, surface exposure of bedrocks here is poor due to extensive superficial sediment cover (calcrete, gravels). Significant impacts on well-preserved near-surface stromatolites are therefore not anticipated. Extensive karst weathered solution hollows are observed within the Campbell Rand carbonate rocks in the region and these might have served as fossil traps in the recent geological past (Tertiary / Quaternary). However, no fossil remains were observed within solution hollow infills during the recent field study by Almond (2014).

The finely-laminated Asbestos Hills BIFs overlying the Transvaal carbonate rocks are only known to contain microfossils. Presumed warm-water stromatolitic carbonates closely associated with glacial sediments are reported from the overlying Makganyene Formation (Postmasburg Group) in the Northern Cape. However, field studies confirm that stromatolites do not occur in the eastern outcrop area of this formation on or near Humansrus 469. No fossils are recorded from the overlying Ongeluk Formation succession that consists entirely of basaltic andesite lavas and is usually deeply-weathered in this area. Sparse to locally common trace fossils (*e.g.* calcified termitaria and other invertebrate burrows, plant root casts), molluscs, and rare vertebrate remains (mammalian teeth, bones) are known from diverse Late Caenozoic superficial sediments in the broader Kalahari region but were not recorded during the recent field assessment by Almond (2014).

Power line corridor **Option 1 Route 1** traverses weathered Ongeluk Formation lavas and surface gravels on the western borders of the remainder of the Farm Nr 469. The north-western sector of the corridor, close to the R385 tar road, overlies Makganyene Formation diamictites and Gordonia Formation aeolian sands. The next sector to the east crosses the Rooiberg hills where it is underlain by Asbestos Hills Subgroup BIF (Kuruman and Daniëlskuil Formations); the outcrop here is largely mantled by BIF colluvium (platy ironstone scree, soils). In the region to the north of Lime Acres settlement and limestone mine as far as Silverstreams Substation and further east the corridor traverses Campbell Rand carbonates. The bedrocks here are extensively mantled by superficial sediments (calcrete hardpan, soil, gravels, pan sediments). This applies particularly to the stretch between Silverstreams and Olien Substations where the Precambrian carbonate bedrocks are mantled by a well-developed calcrete hardpan and perhaps locally by pan sediments. Power line corridor **Option 1 Route 2** has a very similar underlying geology to Route 1, but with marginally less impact on surface exposures of Campbell Rand carbonate rocks to the north of Silverstreams Substation. The geology underlying power line corridor **Option 1 Route 3** does not differ significantly from that described for Route 1. The geology underlying power line corridor **Option 1 Route 4** is also similar to that described for Route 1 with the exception of comparatively shorter sectors traversing the banded ironstones of the Asbestos Hills Subgroup and corresponding longer sectors underlain by Gordonia Formation aeolian sands along the north-eastern edge of the Rooiberge. The geology and topography within the power line corridors for **Option 2 Route 2A** and **Option 2 Route 2B** are very similar. In both cases, flat-lying terrain underlain by Campbell Rand carbonates is largely covered by Late Caenozoic superficial deposits, notably calcrete hardpans and possibly also pan sediments.

On the basis of both desktop analysis and fieldwork within the broader power line study area (Almond 2013a, 2014) the palaeontological sensitivity of all power line corridors under consideration is assessed as low. This also applies to the area to the north of Lime Acres where stromatolites occur within the underlying bedrock but are rarely well-exposed at surface and are therefore unlikely to be significantly impacted by the proposed transmission lines. The Makganyene Formation outcrop area in the north-western corner of the remainder of the Farm Nr. 469, close to the R385 tar road, is of considerable scientific interest as an accessible part of the limited rock record for an Early Proterozoic (*c.* 2.3 billion years-old) "snowball earth" glacial event, when ice sheets may have covered much of the planet. However, fossil stromatolites do not occur within the succession here and significant palaeontological impacts are therefore not anticipated. Potential impacts on local palaeontological heritage are assessed for all power line corridor options as being of *low negative significance*. There is no preference on palaeontological heritage grounds for any particular power line corridor, or for either of the two main options for connecting the ACWA Power SolarReserve Redstone Thermal Energy Plant to the national grid.

No further specialist palaeontological studies, monitoring or mitigation are recommended for the proposed 132 kV power line projects near Postmasburg, including the associated substation and switchyard infrastructural developments, pending the discovery of significant new fossils within the development footprint (*e.g.* well-preserved fossil stromatolites). It is recommended that:

- The Environmental Control Officer (ECO) responsible for the electrical infrastructure developments should be aware of the possibility of important fossils (*e.g.* well-preserved stromatolites, mammalian bones, teeth) being present or unearthed on site and should regularly monitor all substantial excavations into superficial sediments as well as fresh (*i.e.* unweathered) sedimentary bedrock for fossil remains;

- In the case of any significant fossil finds made during construction, these should be safeguarded **-** preferably *in situ* **-** and reported by the ECO as soon as possible to the relevant heritage management authority (South African Heritage Resources Agency. Contact details: 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. Web : www.sahra.org.za) so that appropriate mitigation (*i.e.* recording, sampling or collection) by a palaeontological specialist can be considered and implemented, at the developer's expense; and

- These recommendations should be incorporated into the Environmental Management Programme (EMPr) for the electrical infrastructure projects associated with the ACWA Power SolarReserve Redstone Solar Thermal Power Plant.

The palaeontologist concerned with mitigation work will need a valid collection permit from SAHRA. All work should conform to international best practice for palaeontological fieldwork and the study (*e.g.* data recording fossil collection and curation, final report) should adhere to the minimum standards for Phase 2 palaeontological studies recently published by SAHRA (2013).

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10. 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, Free State, Mpumalanga and Northwest Province under the aegis of his Cape Town-based company *Natura Viva* cc. He has been 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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APPENDIX A: GPS LOCALITY DATA FOR NUMBERED SITES MENTIONED IN TEXT

All GPS readings were taken in the field using a hand-held Garmin GPSmap 62sc instrument. The datum used is WGS 84. Only those localities mentioned by number in the text are listed here.

Locality number	Co-ordinates	Comments
081	28 16 40.2 S 23 23 12.6 E	R385 road cuttings in Makganyene Formation, stromatolite-like Liesegang rings
082	28 16 38.8 S 23 23 14.3 E	R385 roadcuttings in Makganyene Formation, prominent-weathering lenticular debris flows interbedded with ferruginous sandstones
083	28 16 37.0 S 23 23 16.6 E	Cherty surface gravels overlying Makganyene Formation
084	28 18 22.4 S 23 16 16.6 E	R385 road cutting through fresh and weathered Ongeluk Formation lavas
085	28 16 05.7 S 23 22 36.4 E	Roadside rubble excavated from R385 road cuttings into the Makganyene Formation, stromatolite-like Liesegang rings, cherty breccias and diamictites
086	28 16 56.0 S 23 22 39.3 E	Colluvial cemented breccias from above Makganyene Formation
087	28 16 57.4 S 23 22 35.9 E	R385 roadcuttings in Makganyene Formation, prominent-weathering lenticular debris flows interbedded with ferruginous sandstones / siltstones
088	28 16 56.7 S 23 22 41.1 E	Prominent-weathering cherty breccia beds of Makganyene Formation, hill slope exposure
089	28 16 58.0 S 23 22 42.4 E	Massive Makganyene diamictites with polygonal jointing, stromatolite-like Liesegang rings
090	28 16 58.8 S 23 22 45.3 E	Massive Makganyene diamictites with polygonal jointing, stromatolite-like Liesegang rings
091	28 16 54.8 S 23 22 46.3 E	R385 roadcuttings in Makganyene Formation, prominent-weathering lenticular debris flows interbedded with ferruginous sandstones / siltstones
092	28 17 28.9 S 23 20 21.0 E	Borrow pit into weathered Ongeluk lava bedrock overlain by gravelly sands
094	28 21 18.9 S 23 26 16.1 E	Thick, crudely-bedded gravels of BIF in abandoned borrow pit adjacent to railway line
095	28 16 04.4 S 23 31 49.8 E	R385 road cutting through Kogelbeen Formation stromatolitic limestones, north of Lime Acres
096	28 16 03.4 S 23 31 55.1 E	Columnar stromatolites of upper marker bed, Kogelbeen Formation in R385 road cutting (north)
097	28 16 03.2 S 23 31 55.2 E	Columnar stromatolites of upper marker bed, Kogelbeen Formation in R385 road cutting (north)
098	28 16 01.9 S 23 31 52.9 E	Karst weathering phenomena (karren *etc*) in Kogelbeen Formation limestones, just N of R385
099	28 16 02.3 S 23 31 55.1 E	Pseudo-stromatolites of isopachous precipitated carbonate bands, just N of R385
100	28 16 04.8 S 23 31 56.5 E	Large domical stromatolites with intervening space infilled by banded carbonate precipitates, S of R385
101	28 16 04.9 S 23 31 56.3 E	Ditto

102	28 16 05.7 S 23 31 54.9 E	Ditto
103	28 16 05.7 S 23 31 54.5 E	Ditto, with rock engraving (ostrich)
104	28 16 09.2 S 23 31 54.3 E	Ditto, excellent exposure of planed-off stromatolitic domes
105	28 16 05.7 S 23 31 54.9 E	Ditto, with sinuous pecked rock engravings
106	28 16 10.3 S 23 31 54.4 E	Good exposures of columnar stromatolites of upper marker zone, Kogelbeen Formation, S of R385
107	28 16 12.5 S 23 31 55.8 E	Exposure of convex tops of stromatolite columns
108	28 16 12.9 S 23 31 56.2 E	Viewpoint from limestone plateau towards Lime Acres showing poor bedrock exposure in eastern portion of study area
109	28 16 13.2 S 23 31 56.7 E	Good horizontal sections through complex nested pseudostromatolites built from laminated carbonate precipitates
110	28 16 13.1 S 23 31 57.5 E	Small convex stromatolitic microdomes in plan view