Ground Stability Unit

A Dolomite Stability Investigation for a Proposed Photovoltaic Plant

Westonaria

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Contents

1 INTRODUCTION

Sibanye Gold Limited (SGL) intends developing a Photovoltaic (PV) Plant to supply solar energy to its mining operations in Westonaria, Gauteng Province. A site of 589ha has been identified, situated adjacent to the R510 Provincial Highway and 6.5km west of the town of Westonaria, Figure 1 .

As this is an area prone to dolomite related sinkhole (and ground settlement) formation, a dolomite stability investigation was undertaken, according to the requirements of the SANS 1936 (2012) Parts 1-4 national standards, to understand the nature of this hazard and the associated risk faced by this development.

2 NATURE OF THE PHOTO VOLTAIC PLANT

The PV Plant is expected to eventually supply 200MW. Approximately 750,000 solar panels will be placed in rows forming a large rectangular array. The array will consist of long rows of panels in blocks (20m long), approximately 4m apart with a total length of approximately 700km. The panels will be aligned north-south, rotating about their long axes to follow the daily path of the sun whose movement will be driven by long drive shafts connecting the rows of panels. The foundation structures of each panel will consist of short piles driven into the ground to anchor the panels or short concrete slabs/ rafts placed on surface, Figure 2, Figure 3. Optimum performance of the solar panels will require <1% settlement of these slabs/piles. The power generated by these panels will require only a few personnel for its operation who will be based in a small 'Operations Centre' structure situated close to either of the nearest ESKOM substations. No water bearing services will be placed on the site and the panels will be cleaned by a mobile unit using high energy water sprayers. There will thus be little disturbance of the existing surface. Additional panels can be added to the array.

This site thus consists of:

- The Main Site, where the array of solar panels will be placed and,
- two possible positions for a Control Centre. Two possible were required to be investigated which offered options for optimal operational configuration of the PV Plant. Site A is found near the south eastern corner and Site B is found near the south western corner. Additionally, available geological information indicated the existence of two small Karoo age shale/clay deposits in these positions, where a lower dolomitic hazard was expected. The Control Centre site chosen will consist of
    - a small substation containing an array of transformers (1ha) and
    - a rectangular building (100m² footprint), situated 30m to the south, to control the operation of the whole facility.

3 SITE SELECTION

This site has been chosen based on the following factors:

- The land is already owned by Sibanye Gold Limited/ Far West Rand Dolomitic Water Association (FWRDWA).
- It is essentially open land with no existing structures present and is currently only used for agriculture.
- It is close to the existing ESKOM power grid with a major ESKOM substation situated in its south eastern corner and another approximately 5km from the south western corner, allowing relatively easy transfer of the power generated onto either the national grid or to the various mining operations.
- It is a large uninterrupted site that will provide the required area (4MW/ha) for the proposed energy generation (200MW). It us not crossed by any major roads or water paths.
- It is relatively flat which is essential for the positioning of such a large number of solar panels.
- For environmental reasons when compared to two other sites immediately south of this site, this was the recommended option.

Based on the reasons above, this site was thus considered for a detail dolomitic investigation.

4 GENERAL SITE DESCRIPTION

In general this site is essentially flat, measuring 2.3km (north south) by 3.2km with a slight northwards gradient of 1600mamsl dropping to 1573mamsl on the northern boundary. A small drainage channel enters the site centrally from the R501 Highway crossing it diagonally and exiting it towards the west. The whole site has historically (and currently) been used for non-irrigated agriculture (maize). The Mean Annual Precipitation is in the range of 500-600mm pa.

5 AVAILABLE INFORMATION

- Council for Geoscience 1:250,000 West Rand 2626 Geological Sheet.
- Council for Geoscience Bank Groundwater Compartment gravity survey undertaken at a 90 yard grid spacing which was conducted in the 1960's.
- Existing boreholes (5) drilled by the Council for Geoscience during the 1960's. A number of these were drilled to calibrate the above gravity survey while the rest were drilled along the R501 to test the integrity of this road.

- LIDAR Survey of SGL property (SGL, April 2015).
- VGIConsult, 2008 (VGI 3176R). This report which was conducted as a *regional* dolomite hazard assessment for the Western District Regional Municipality (WRDM) was based on the existing groundwater compartment gravity surveys and available drilling information (both by the Council for Geoscience). It assessed all the dewatered dolomite groundwater compartments, including this one (Bank Compartment). This portion of that study was assessed as having a medium to high probability of any size sinkhole.
- Aurecon EIA Assessment of Alternative PV sites, 2015. Based on the low historical rate of occurrence and the absence of water bearing services they indicated that this site should have a low future rate of event occurrence.They qualify this further by stating they expect 0.001-0.01 15m events/20years/ha. Over this site (589ha) this could result in 0.6-6 events.

6 GEOLOGY

The proposed site is underlain by dolomite and interbedded chart, presumably of the Monte Christo formation, Malmani Subgroup, Transvaal Supergroup which is notorious for the occurrence of sinkhole and subsidence formation. This sequence dips to the south, Figure 1. It is also situated in the Bank Groundwater Compartment which has been dewatered since the early 1970's. The original water table (owt) was situated at an elevation of 1502mamsl and is currently many hundreds of metres below the original.

Small Karoo Supergroup outliers (younger deposits) of shale and sandstone are present along the southern and eastern edges of this site. These relatively small, and disconnected deposits represent scouring of the preexisting dolomite surface by glaciers to produce narrow steep sided valleys which were later filled by fine clayey materials of the Karoo Supergroup. Some of this material is currently being extracted in quarries approximately 1km west of this site.

7 GROUND MOVEMENT EVENTS

Only two sinkhole/subsidence events have been recorded directly on this site, and a third immediately to the north west, however the Far West Rand region has experienced many sinkholes and ground settlement particularly after dewatering that began in the 1960's, Figure 1.

The most significant sinkhole is situated in the south central portion of the main site and measures approximately 30m in diameter. Being greater than 15m it is classified as a 'very large sinkhole'. It is not known when this sinkhole developed however the presence of existing vegetation within the sinkhole, suggests it is greater than 20 years old (aerial photos indicate between 1988 and 2013). With no obvious source of ingress water in the vicinity its' formation is presumed to be related to dewatering of the Bank Groundwater Compartment. A second event, consisting of concentric cracks occurred in 1990 which are situated approximately 200m north of the previous event. A third sinkhole is situated approximately 350m west of the western boundary and has a diameter of approximately 9m. Again the date of origin is unknown but believed to be from a similar era.

8 DOLOMITE STABILITY ASSESSMENT

8.1 Ground investigation method

Dolomite ground is notorious for its subsurface variability over very short distances, varying from solid rock near surface to deep soil and valleys containing various weathered products and even cavities. These conditions affect the size and probability of the sinkhole/subsidence to be expected.

A residual gravity survey is used to develop a continuous subsurface picture of the site by measuring differences in the earth's gravitational field to provide a measure of differences in ground density which assists in assessing the ground profile's vulnerability to sinkhole/subsidence formation.

Ground profile information is generated by drilling percussion boreholes. Specific gravity features are targeted by the drilling to be able to be able to characterize areas of a site. The high cost of drilling unfortunately does limit its usage to a large extent. This approach is thus able to provide some indication of areas of lower density (such as cavities) and areas where dense rock could be expected from which zones of higher and lower probability are produced.

The SANS 1936-2(2012) national standard provides guidelines of how the dolomitic investigation must be conducted:

- Sec 4.2.2. A geophysical (normally gravity) survey is required which was undertaken by Engineering Environmental & Geophysical Services (EE&G) in December 2015. Due to the size of the site (589ha) a 50m grid was chosen, Appendix 1. A 15m survey was undertaken at each of the two 1ha sites for the Control Centre positions. Major gravity features were identified and the boreholes positioned accordingly.
- Sec 4.2.3 stipulates the following:
    - Boreholes must be drilled 6m into dolomite bedrock and up to a 100m in dewatered groundwater compartments.
    - Accurate GPS positions of the boreholes must be recorded.
    - Detailed drilling logs must be kept.

- The boreholes must be suitably backfilled. This was undertaken here by returning the spoils and completely filling the hole, mixing with cement to create a soilcrete mixture and then sealing with a small concrete plug (Figure 7).

- The drilling was supplied by JK Developments over the period 11/12/2015 to 19/1/2016. Borehole profiles, indicating the nature of the ground profile, drilling rates and air/sample losses were produced, see Appendix 2. Chip samples were taken for every metre of borehole drilled and both a gross and a washed sample (fines removed) were saved in the chip trays (Appendix 2).

As investigation specifications for solar panel arrays are not provided for in the above SANS standards, an 'investigation requirements' proposal was submitted to the Council for Geoscience in 2015. It was proposed that due to the size of this site (589ha), with the estimated 750,000 potential panels, that drilling of each panel footprint would not be prohibitive and that the whole site should be treated as 'the footprint'. Along with the nine existing boreholes it was proposed that an additional 20 boreholes be drilled on the main site and additional holes for the detailed investigations of Site A and Site B be undertaken. This proposal was accepted (27/10/2015) by the Council for Geoscience, Appendix 3.

8.1.1 Gravity Survey

The regional Bank Compartment gravity survey indicates that this site is dominated by a major gravity 'high' with gravity 'low' features (1.8mgal lower) towards the south west corner and northwest border. The 'zero' gravity contour, which is taken as the line separating areas potentially affected by dewatering (gravity lows) and those not (gravity highs), runs on this site just inside and roughly parallel to the western and northern boundaries. According to Bezuidenhout and Enslin (1969), the major portion of this site then, should not be affected by dewatering.

Main Site

The detailed (50m spacing) conventional residual gravity survey (Figure 9) conducted for the main Site, as expected, shows a similar pattern to the Bank Compartment survey. The value range here is from 0.9 to -0.30mgal from the 'highs' to the 'lows', with a relative 'high' covering the major portion with deeper 'valley' features in between. There may be deeper local gravity features amongst the highs but not detectable on the scale of this grid, see opinion by R. Day (Appendix1). Deeper gravity features are found towards the south eastern corner and north western border.

Site A

This detailed gravity survey (Figure 10) indicated a gentle gravity gradient of 0.2mgal towards the south east. Borehole 5092 drilled on the 'high' intersected bedrock at

63m, and borehole 5094, drilled on the 'low', intersected bedrock much deeper at >100m.

Site B

This detailed gravity survey (Figure 11) indicated a gentle gravity gradient of 0.2mgal deepening towards the northwest with borehole 5097 drilled on the 'high' and borehole 5099 drilled on the 'low'.

8.1.2 Drilling results

The borehole profiles are summarized in Table 1 and discussed below.

Main Site

22 boreholes were drilled over the main site which along with six existing boreholes provided an indication of the general conditions to be expected. Borehole spacing varied on average from 250-750m over this 589ha site.

The drill encountered difficult drilling conditions in borehole 5089 at a depth of 41m (before dolomite bedrock was achieved) and thus an additional borehole (5117) was drilled nearby (75m away) which coincidentally also encountered similar conditions at a similar depth (34m) and could not be completed either.

The following general layers were encountered:

- Transported soils: The surface layer was generally < 6m thick across the site consisting of reddish silty clay with varying amounts of coarse to fine, weathered chert gravels. Exceptions could be found at borehole G909 (along the R501), 5089, 5117 and 5107 where this thickness reached up to 16m.
- Karoo clay. Underlying the surface layer, a Karoo age layer of light buff coloured clay was present in 13 of the 28 boreholes (46%). Its thickness varied from 10 to 33m with an average of 16m thick.
- Chert Residuum. Most of the boreholes indicated chert residuum, where thicknesses of this light to dark grey, coarse, chert rock, with varying proportions of white silty clay, were present. This material varied in thickness from 4-47m.
- Dolomite Residuum. Commonly a layer of varying amounts of dark silty clay was found with varying amounts of hard, chert rock, typically with moderately high penetration rates. This layer was typically 4-14m thick though at 5115 it did reach a thickness of 32m.

  More significantly, zones of very high penetration rates (<15s.m^{-1}), suggesting only very soft wad or cavities, occurred in eight (28%) of these holes indicating a relatively common occurrence throughout the site.[1] These zones were typically 10-23m thick with the most significant being 40m at borehole 5110. Most of these zones, as expected, were found immediately above hard rock dolomite.

- Dolomite Rock. In 75% of the boreholes a slightly 'softer' (penetration rates of 2-3min.m^{-1}) layer of dolomite rock was encountered just above dolomite bedrock with a general thickness of 4-20m, maximum 33m (as seen at borehole 5108). This dolomite layer typically consisted of coarse, fresh, angular dolomite chips or based on the penetration rates (where sample loss occurred) was interpreted as such.
- Dolomite bedrock. Coarse, fresh, hard rock dolomite (3min.m^{-1}.) was found commonly found with a depth range of 40-60mbs[2] with the shallowest being at 20mbs (5109) and the deepest at >100mbs (5086). The boreholes situated on the gravity highs had a bedrock depth in the range 20-75mbs and the only borehole drilled on a major low (5088) intersected it at 80mbs.

Five cross sections (C-C', D-D', E-E', F-F', G-G') for the Main Site (Figure 12) are provided, in rows of boreholes, each approximately 2,5km long, which provide an overview of the typical conditions to be expected across the site from north to south.

- The northernmost boreholes (C-C') show a consistent layer of clay, essentially 20m thick. The chert residuum is less well developed there and with a dolomite rock layer followed by dolomite bedrock, which was consistently deep (52-60mbs). Only borehole 5114 here shows poor a zone or poor material (wad etc.), depth 34mbs.
- The northern central line (D-D') shows less overlying clay and chert than to the north, with zones of wad and chert (dolomite residuum) commonly present. Borehole 5110 had a prominent zone of very poor material, possible cavity, from 24-64mbs (40m).
- The central cross section (E-E') shows a consistent layer of chert residuum, with some Karoo clay, across all seven boreholes, of at least 15m thickness followed by occasional layers of dolomite residuum. Zones of very poor material are found in three of these boreholes particularly at borehole 5102 (24m thick). As boreholes 5103 and 5117 were not drilled to bedrock it is unknown whether further poorer conditions exist at depth.
- The southernmost row (F-F'), nearest to the R501, shows a mixture of thick clay and some gravels in the upper part of their profiles but with very poor material zones (cavities) in the centre of the site (along this line).

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[1] The existing available boreholes unfortunately did not record this information at the time of drilling.

[2] mbs-metres below surface

- The southernmost section (G-G'), nearest the R501, and consisting of historical boreholes, shows consistent Karoo age clay and significant thicknesses of chert, 15-59m. Some dolomite residuum is present in most of these boreholes.

Due to the size of this site and the wide spacing between boreholes, and hence the varying conditions that could be present between boreholes, it was not thought possible to zone this site with any degree of confidence. The whole of the Main Site is thus treated as one dolomitic stability zone.

Site A

Four boreholes were drilled within the 1ha site (5092-5095), with a spacing of 50-60m, where the transformers will be placed and two (5090 and 5091) with a 40m spacing within the Control Centre footprint.

- Transported soils (0-7m): The surface layer here was uniformly thick (5-8m) across the site consisting of reddish silty clay with varying amounts of coarse to fine, weathered chert gravels.
- Karoo clay. Underlying the surface layer, a laterally consistent Karoo age layer of light buff coloured clay (average 16m thick) across this small site was present in all the boreholes except 5095.
- Chert Residuum. In all six boreholes here a thick layer (29-40m) of white silty clay and or light to dark grey coarse chert rock is present.
- Dolomite Residuum. Very little dark silty clay and chert was found in these profiles. This layer was typically 4-14m thick though at 5115 it did reach a thickness of 32m.

  In four of the boreholes a slightly softer (penetration rates of 2-3min.m^{-1}) thin layer 3-4m thick was encountered just above dolomite bedrock except for borehole 5094 where this layer extended from 71-100m depth. This dolomite layer typically consisted of coarse, fresh, angular dolomite chips.

  Total sample loss occurred in boreholes 5091, 5092 and 5095 at depths of 65-89m. Possible cavities (very high penetration rates) of approximately 8m thickness, or at least very soft waddy material is found in boreholes 5091 and 5095 though at great depth (>63m).
- Dolomite bedrock. Coarse hard rock dolomite (3min.m.) was found within a relatively narrow depth range of 59-80m except for borehole 5094 where dolomite of this hardness occurs was not reached within the prescribed drilling limit (>100m).

The cross section for Site A (A-A', Figure 13) provides an overview of the typical conditions to be expected where a thick sequence (always >60m) of clay (either Karoo age or chert derived) and chert rock is found overlying dolomite rock. Only boreholes 5091 and 5095 had a weak zone (depth 60-77m) of wad with high penetration rates.

Site B

Six boreholes were drilled within the 1ha site (5096-5100, 5119), with a spacing of 40-60m, where the transformers and Control Centre building will be placed.

- Transported soils: The surface layer here was uniformly thick (up to 3m) across the site consisting of reddish silty clay with varying amounts of coarse to fine, weathered chert gravels. Only borehole 5100 (north eastern corner) did not have this surficial cover but a thick very dark brown waddy surface layer (9m).
- Karoo clay. Underlying the surface layer, a laterally consistent Karoo age layer of light buff coloured clay (average 11m thick) was present across this small site as seen in all the boreholes.
- Chert Residuum. In all six boreholes here a moderately thick layer (11-22m) of white silty clay and or light to dark grey coarse chert rock was present.
- Dolomite Residuum. Commonly a layer of varying amounts of dark silty clay was found with varying amounts of hard, chert rock, typically with moderately high penetration rates across all the boreholes. This layer was typically 6-14m thick.

  Only borehole 5100 had a zone of very poor material (with very high penetration rates), indicating a possible cavity (only 2m thick though).

  In five of the boreholes a slightly softer dolomite layer typically consisting of coarse, fresh, angular dolomite chips and lowish penetration rates of 2-3min.m^{-1} was generally present. This layer was typically 9-19m thick.
- Dolomite bedrock. Coarse, fresh hard rock dolomite (3min.m^{-1}) was found within a relatively narrow depth range of 37-61m.

The cross section for Site B (B-B', Figure 13) provides an overview of the typical conditions to be expected where a moderately thick sequence, at least 15m of Karoo age clay is found. Underlying this is a consistent layer of chert rock and clay (10-15m thick) however a consistent layer of wad with chert though with moderate penetration rates is present in five of the six boreholes here. Only one borehole (5100) showed a small weak, cavernous zone (depth 27m).

9 HAZARD AND RISK ASSESSMENT

The SANS 1936-1 (2012) national standard utilizes a hazard classification method which classifies dolomitic hazard conditions into eight classes (Table 2, p9-11); ranging from low probability (Inherent Hazard Class 1) to highest probability

(Inherent Hazard Class 8) of sinkhole/subsidence formation. The probability of occurrence, as per SANS 1936-1 (Table 4) is shown here in Table 2 .These classes denote the probability of a sinkhole or subsidence (low to high) occurring as well as its likely size (diameter) ranging from small (<2m) to very large (>15m). The various soil and rock layers found in each borehole profile are used to predict the vulnerability of the ground to sinkhole formation (Table 3). Profiles consisting of hard rock layers are expected to impede the upwards migration of cavities while impermeable clay layers are similarly likely to impede the ingress of surface water. Profiles containing soft zones, recorded as high penetration rates, and/ or materials such as 'wad' [3] indicate a higher vulnerability. The thickness of these layers is used to predict the susceptibility to sinkhole formation. Along with the overlying materials the depth to dolomite bedrock (in general) determines the size of sinkhole that can be expected to develop.

Appropriate land uses are then assigned depending on the hazard expected with those land uses where a high concentration of people can be expected only allowed on the lowest hazard classes. This philosophy thus suggests a photo voltaic site, though not specifically stated, where there will be minimal personnel, can if necessary, be placed on the higher hazard classes as there will be no particular safety threat.

Each of the sites here was assessed according to their susceptibility to sinkhole/ subsidence formation

9.1 Hazard assessment of the Main site

Assessment of the boreholes considers two components:

- Sinkhole development space:
  Dolomite bedrock was encountered on average from 20-60mbs, indicating a very large *potential* development space for sinkhole development.

- Overlying materials:
  The materials overlying dolomite rock are assessed in terms of their nature (soil or rock?), bridging capability, thickness and ability to impede the inflow of ingress water (particularly clay or extensive rock layers), the known trigger of sinkholes.

  The presence of Karoo age clay is found across nearly half the boreholes (and by implication nearly half the site) which provides a significant impermeable barrier typically 10-20m thick. Additionally the clays and chert rock layers (chert residuum) are even more laterally extensive which provide an additional 10-20m of consistent, largely, impermeable material. The significant clay percentage in this layer is expected to impede the flow of water into the ground profile and the chert rock layer is expected to offer

[3] a black silty clay derived from the weathering of dolomite

reasonable resistance to upwards migration of voids. The presence of zones of weakness (high penetration rates, wad, and some cavities) is regularly present across the site indicating void development is present already. While the overlying layer should confine sinkhole size development over most of the site there were conditions (5106, 5087) where this protection may be absent and larger events develop. A wide range of loss of support is anticipated (5-15m).

Two boreholes (5086 and 5118) were drilled either side of the sinkhole (see position on F-F') on this site in order to try and understand the subsurface conditions that may have triggered this event. Both show a protective covering of Karoo age clay (10-18m) and chert and both show vulnerable zones at a depth of 30-40mbs. It is these vulnerable zones that contributed to the development of this very large sinkhole (30m diameter), despite the protective layers.

The original water table (64mbs) is uniformly situated well below dolomite bedrock (35-98mbs) and no additional affects due to dewatering are thought possible and a low probability of sinkhole formation due to dewatering is awarded.

9.2 Hazard assessment of Site A:

- Sinkhole development space:

  Dolomite bedrock was encountered at great depth, from 59mbs to greater than 100mbs, indicating a very large *potential* development space for sinkhole development.

- Overlying materials:

  The presence of Karoo age clay is found across all the boreholes (except 5095) here (thickness 5-23m) and is consistently underlain by thick chert rock and clay. These two layers are typically 55-65m thick which provide a significant hard and impermeable barrier. It is this material with such thickness that is expected to confine the final size event that manifests at surface. Only two zones of weakness (high penetration rates) and /or poorer materials (wad), were encountered here (5091 and 5095), which were 6m thick but at great depth (>66m) below the chert and clay.

With the great depth to bedrock there is a large space for a sinkhole to form however the thick impermeable overlying layers are considered likely to impede water ingress and the growth and upwards migration of any voids. A low, possibly medium, hazard rating of any size sinkhole is assigned (IHC1/4). A 5m loss of support should be allowed for.

Furthermore the original water table (93-95mbs) is uniformly situated well below dolomite bedrock (59-80mbs) and no additional negative affects due to dewatering are thought possible and a low probability due to dewatering is awarded.

9.3 Hazard assessment of Site B:

- Sinkhole development space:

  Dolomite bedrock was also encountered at great depth, from 37mbs to 61mbs, though slightly shallower than Site A, indicating a very large *potential* development space for sinkhole development. Note should be taken of the slightly softer dolomite rock commonly mantling this layer which could be considered to slightly reduce the development space.

- Overlying materials:

  The presence of Karoo age clay is also found here across all the boreholes on this site though slightly thinner (thickness range 9-16m) and is also consistently underlain by chert rock and clay but much thinner (thickness range 11-17m) than Site A. It is this material with such thickness that is expected to confine the final size event that manifests at surface. Poorer materials (wad) were encountered in most of the boreholes, except 5098, with a thin zone of high penetration rates (possible cavity) in borehole 5100. These zones were typically thicker (6-14m) and at shallower depths (15-42mbs) than Site A.

With the great depth to bedrock there is a large space for a sinkhole to form however the impermeable overlying layers are reasonably thick and considered likely to impede water ingress and the growth and upwards migration of any voids. A moderate hazard rating of any size sinkhole is also assigned (IHC 4) for Site B. A 5m loss of support should be allowed for.

The original water table (77-79mbs) is uniformly situated well below dolomite bedrock (37-61mbs) and no additional negative affects due to dewatering are thought possible and a low probability due to dewatering is awarded.

By comparison, Site A has thicker overlying, impermeable, protective layers than Site B and is thus the preferred option for the positioning of a Control Centre though Site B is considered suitable for this purpose as well.

9.3.1 Dolomite Designations

SANS 1936-1 (Table 1 and 2) assigns Dolomite Area Designations (*precautionary and mitigating measures*) to the various hazard classes in order to reduce the expected frequency of sinkhole events. With increasing hazard class standard (D2) plus additional measures (D3) are required. The *additional measures* usually take the form of i) design improvements and ii) water precautionary measures to be implemented during the operation of the structure.

Main Site: As vulnerable ground has been shown to be present across this site a D3 designation is assigned, with an expected loss of support of 15m. The foundation design should attempt to cater for this possibility. As ingress water is the cause of almost all sinkholes (96%), with only 4% occurring naturally, any additional water brought to this site (via a pipe network) is likely to generate sinkholes. A Dolomite Risk Management Plan (DRMP) must be developed which minimizes the possibility of water ingress (discussed under Section 12).

Site A: Even though this site has significant protective cover in its ground profile to prevent failure a D3 designation is assigned largely due to the importance of this building for the operations. The Control Centre building should thus incorporate a raft foundation, with a nominal 5m loss of support, and standard water precautionary measures.

Site B: Even though this site probably has sufficient protective cover in its ground profile to prevent failure a D3 designation is assigned. The Control Centre building should thus incorporate a raft foundation (nominal 5m loss of support) and standard water precautionary measures.

9.4 Hazard and Risk Discussion of the Main Site

Due to the size and cost of this planned project and the risk posed by the sinkhole hazard, some discussion is required:

- as stated earlier it would have been prohibitively expensive to drill each panel footprint as is required for footprints of other types of structures. Neither would the drilling of a much larger amount of boreholes have yielded an answer much different from that obtained here. The amount of drilling here, with the wide spacing between boreholes, should be treated then as a representative sample. It is possible that both worse and better conditions could have been missed but the 'sample' here does indicate though that some very poor (cavernous) conditions are present, though at depth (>30m) below consistent, significant protective cover.

- As the solar array, being infrastructure that has an almost 100% coverage of almost the whole site, it is thus not able to be positioned to avoid poorer ground profiles. A similar example is commonly seen in roads networks (linear features) which are obliged to traverse poorer ground.

- With only a few personnel on this property on a daily basis the threat to human safety is considered minimal.

- Table 2 indicates the expected number of events for the various hazard classes though this is based on an 'abuse' scenario i.e where there is no control over water ingress and leaking pipes are not timeously closed off nor repaired. In such scenarios, IHC 4 conditions (medium hazard) for a site of this size (589ha) could lead to approximately 60 events and theoretically 600 events in IHC 8 conditions (high hazard) over a 20 year period. Numbers of events of this range is seen in poorly maintained sub economic housing developments (Khutsong, Vosloorus etc) where dense networks of water bearing services are present and not maintained well. As no water bearing services will be installed on the Main Site, the number of events over the lifetime operation of this facility is expected to be a fraction[4] of that estimate as no water ingress over and above the normal annual rainfall will be present.

- The performance of this site, under a similar land use as the existing dry agriculture, has only resulted in the occurrence of only 2/3 historical events over a 60 year period. Even the nearby centre pivot irrigation systems, immediately to the north, despite receiving large amounts of water, seem to have also performed well in this area. This suggests that while the occurrence of a few sinkholes may well occur their frequency is expected to be only 'occasional' and as stated previously, provision may still be needed for the occasional replacement of panels.

10 CONCLUSIONS AND RECOMMENDATIONS

- Dolomite stability investigations were conducted, as per the national standards requirements of SANS 1936, for the Main Site and two possible positions for a Control Centre, for a proposed photovoltaic electricity generation project. The level of investigation required was conducted in agreement with the Council for Geoscience.
- In general, the ground profile of the Main Site, while containing reasonably thick, consistent protective layers, is considered variable and vulnerable to sinkhole formation and thus a moderate to high susceptibility (IHC 4-8) of any size sinkhole was awarded.

  Despite the presence of poor conditions in places at depth, this site has resulted in very few sinkholes over the last 60 years from a similar land use (agriculture) suggesting its fitness for purpose.
- For this large solar array; avoidance of poor conditions is largely not possible and foundation designs to overcome loss of support would be prohibitively expensive. Sinkhole prevention will thus be dependent on the management of surface water ingress via a Dolomite Risk Management Plan (DRMP).
- While Site A (IHC 1/4) and Site B (IHC 4) are considered suitable for the placing of an operations Control Centre, Site A is the preferred option with a slightly more favourable hazard rating.

[4] Aurecon expected 0,6-6 events over 20 years

11 DOLOMITE RISK MANAGEMENT PLAN

Operations

In general the Main Site will consist of long rows of solar panels operated by steel rods driving the rotation of the panels. A sinkhole could cause the loss of 1or 2 panels at a time, leading to small losses in power generation but also disrupt the connecting rods to the next panel(s). As the panels are expected to be damaged in such a scenario, replacement panels may be necessary (on an occasional basis).

Water Precautionary measures

The following general water precautionary measures are highlighted:

- No accumulation of surface water to be allowed and the entire area to be properly drained so that the natural rate of water ingress is maintained.
- No water supply network allowed on the Main Site where eventual leaking of pipes could trigger sinkholes.
- Cleaning of panels to be undertaken by mobile spray units.
- All trenches to be backfilled according to SABS 1200 DA (Sec. 5.2.4).
- All ponds and water course to be rendered impervious by suitable design.
- All storm water sewerage and water pipes and channels to be water tight.
- Control Centre, standard water precautionary measures are required including:
    - No water bearing services to run beneath the building
    - Water tight couplings to be used.
    - Flexi joints to be used where connecting to the main structure.
    - Reporting of water leaks to the relevant SGL maintenance officer to be undertaken immediately.
    - 1m concrete or paving apron to be placed around building.
    - Parking areas to be paved.

Monitoring

The Ground Stability Unit should initiate a program to monitor any ground movement on this site. This should involve the installation of levelling pegs and accurate readings by the SGL Survey Department.

12 REFERENCES

Bezuidenhout, C.,A, and Enslin, J.F.,(1969). Surface subsidence and sinkholes in the dolomite area on the Far West Rand, Transvaal, Republic of South Africa. International Symposium on Land Subsidence, Tokyo.

FIGURES

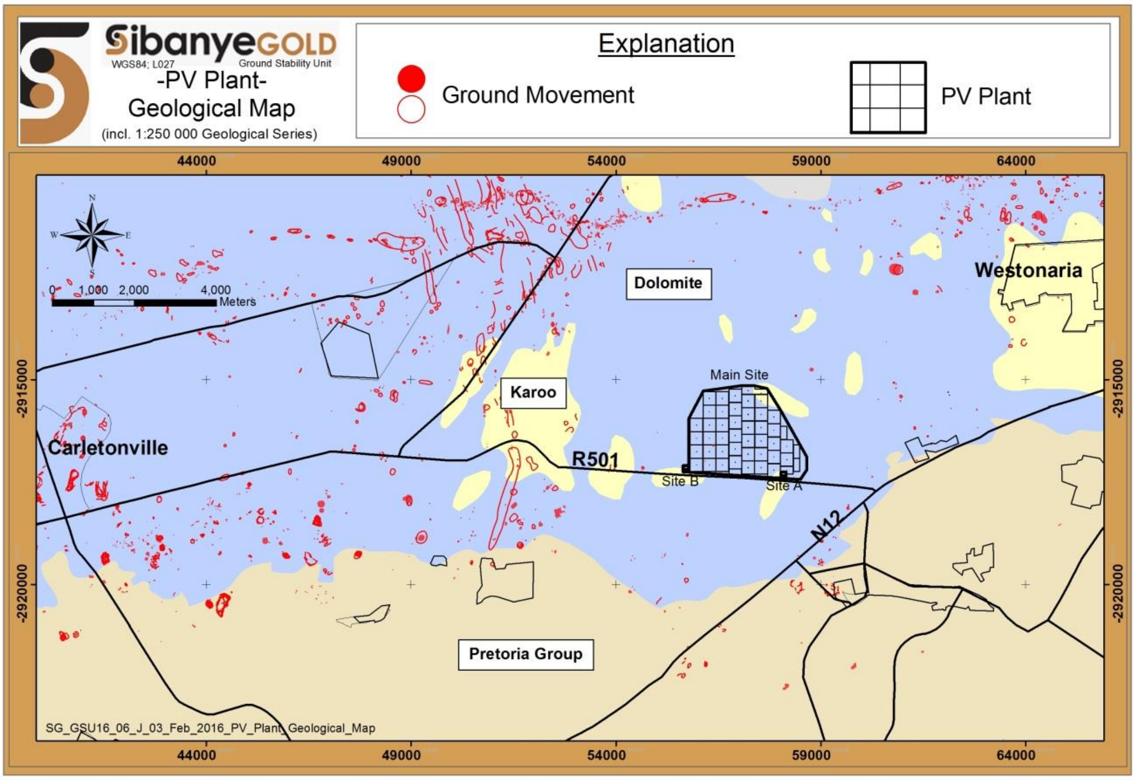

Figure 1. Locality map of the proposed photovoltaic site showing the geology and ground movements in the region, Westonaria

Figure 2. Example of solar panel (non rotating) placed on piles

Figure 3. Solar panel (non rotating) placed on strip footings

Figure 4. PV plant site looking southwards indicating flat topography,

Figure 5. Very large sinkhole situated in south central portion of site

Figure 6. Sinkhole in south central portion of the main PV Plant site (LIDAR, April 2015)

Figure 7. Concrete plug placed on top of backfilled borehole (Borehole 5106)

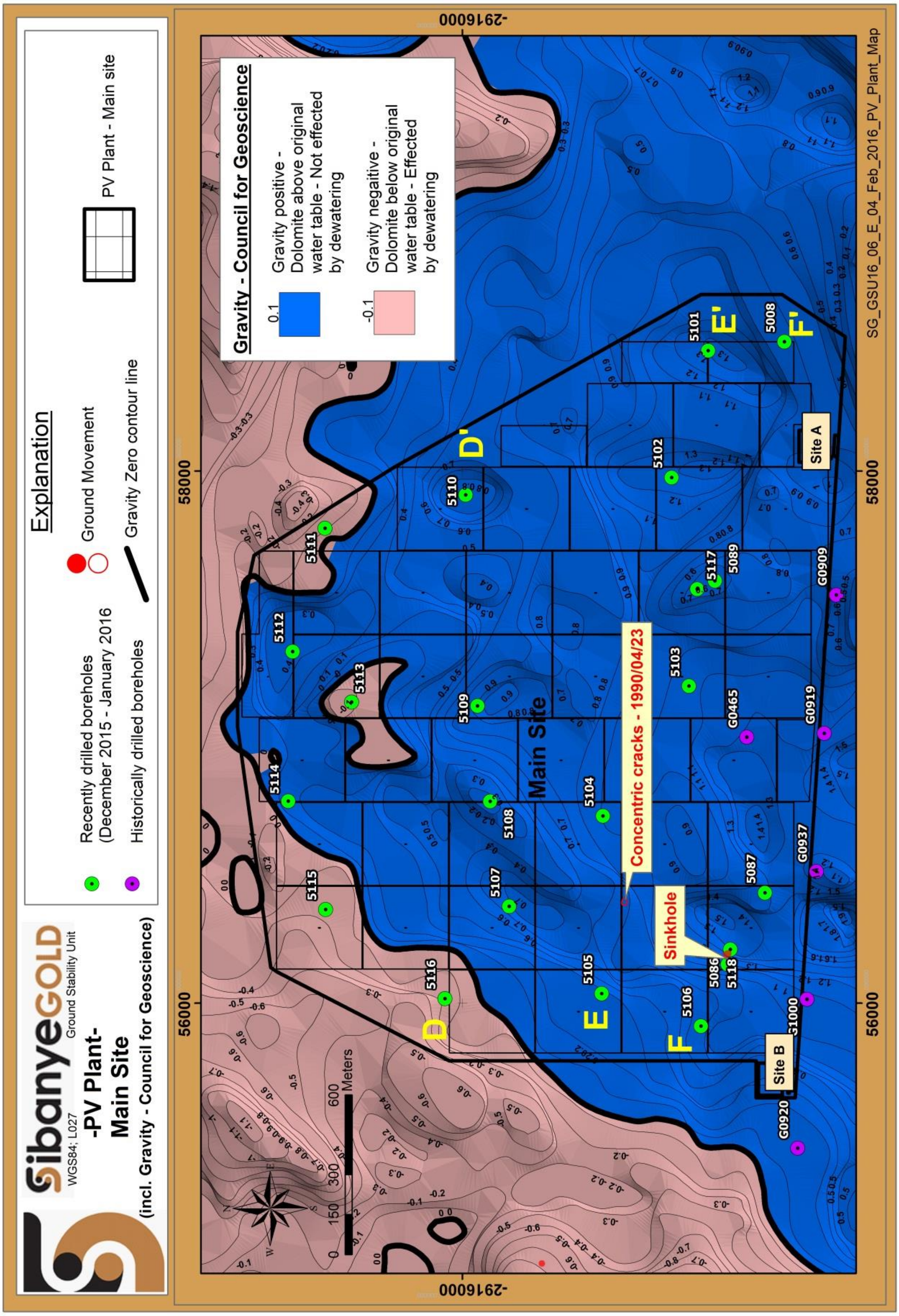

Figure 8. Bank Groundwater Compartment gravity survey (Council for Geoscience)

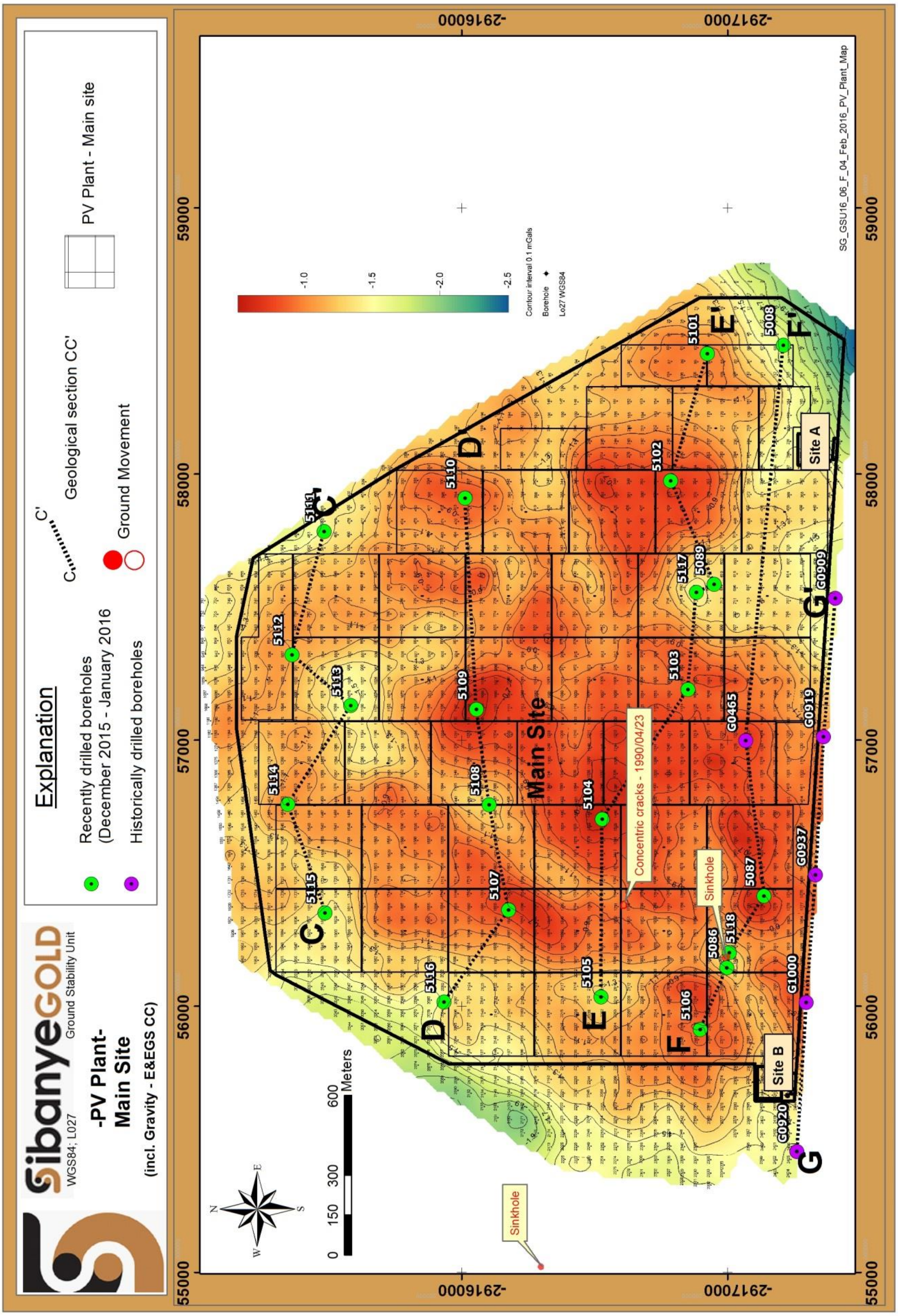

Figure 9. Residual gravity map showing borehole positions and cross sections

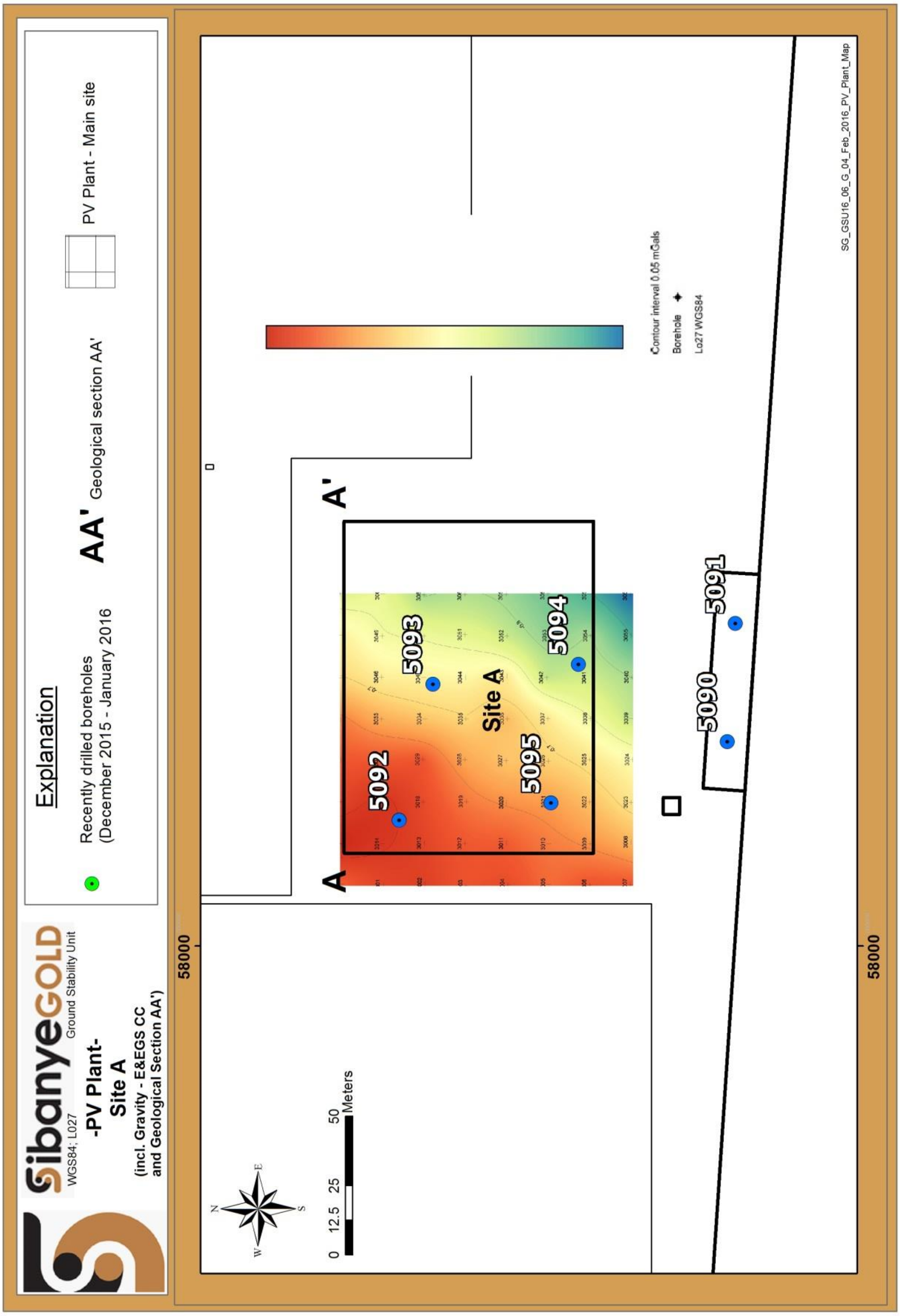

Figure 10. Residual gravity map of Site A.

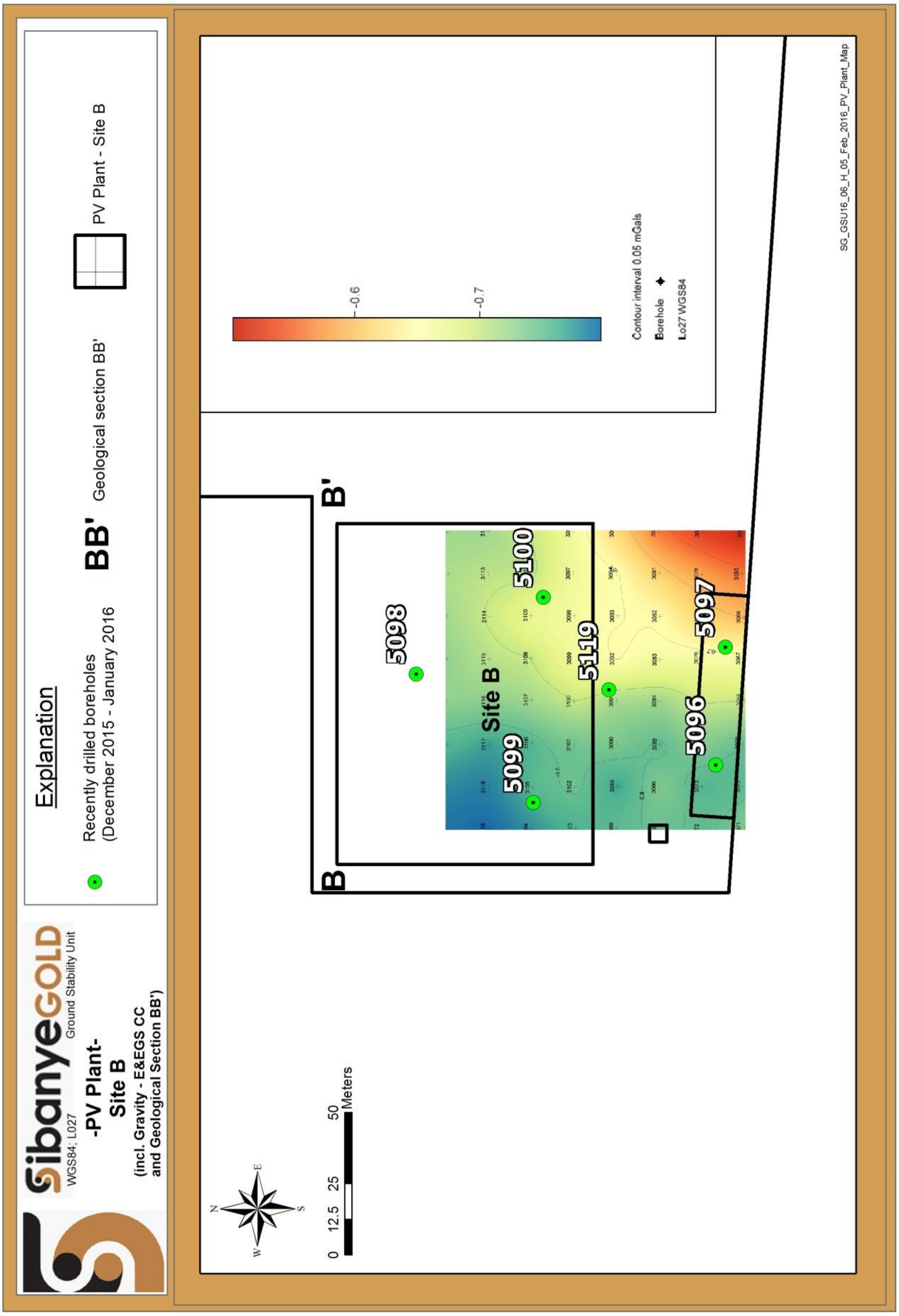

Figure 11. Residual gravity map of Site B

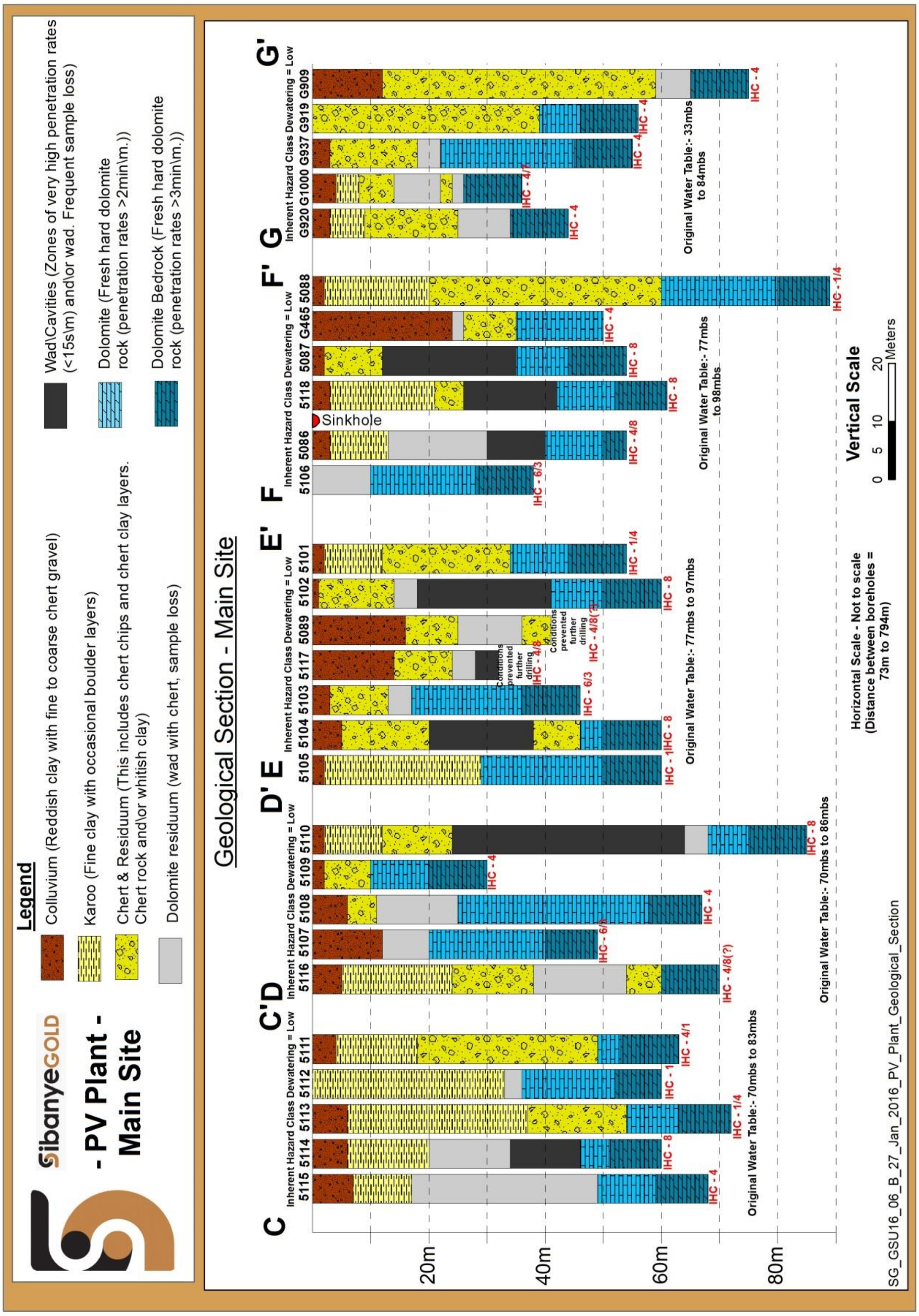

Figure 12. Cross sections through the Main site

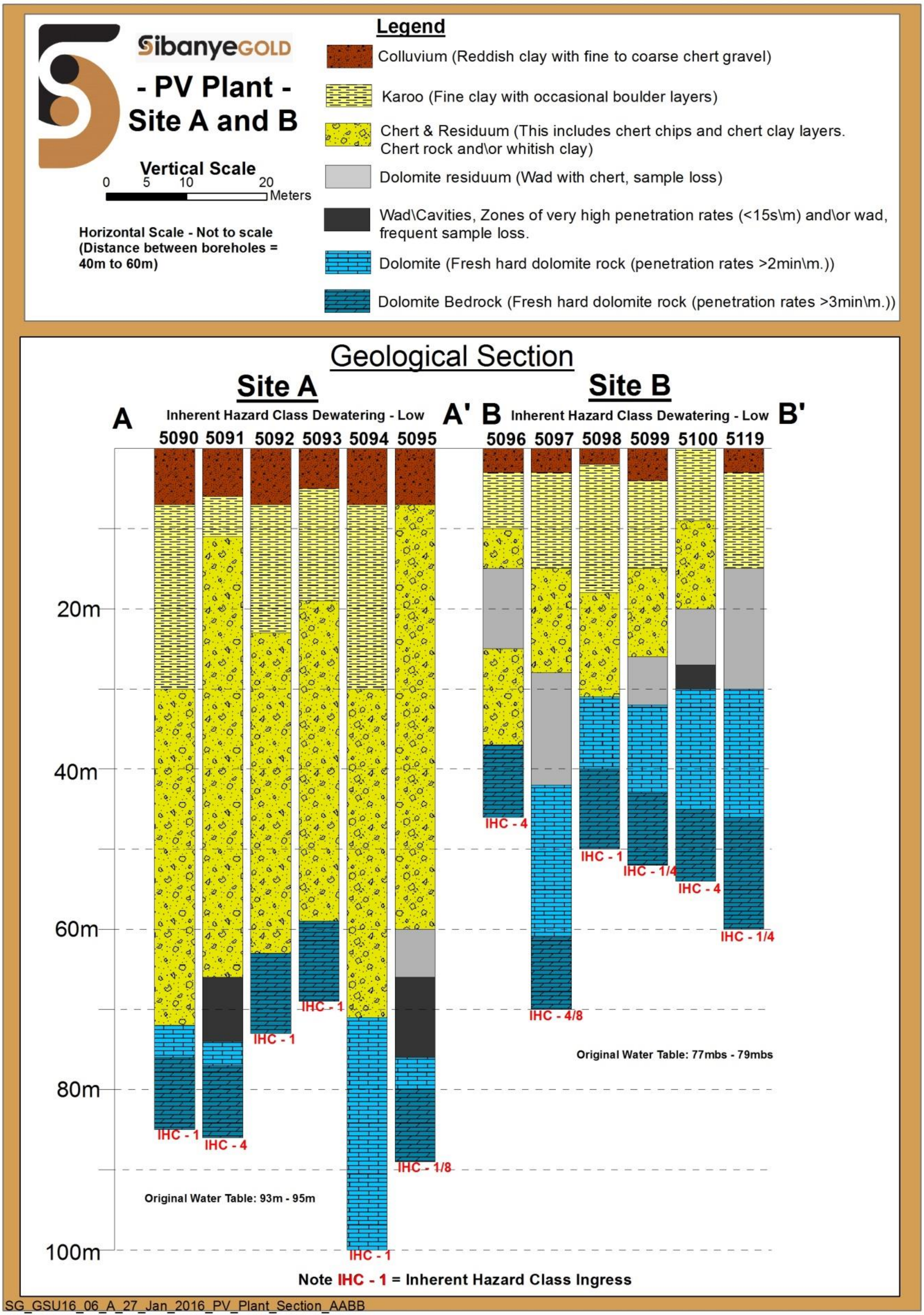

Figure 13. Cross sections through Site A and Site B

Table 1. Ground profile layers encountered at boreholes on this site

No.	BOREHOLE	DATE DRILLED	WG27 - Y	WG27 - X	Elevation (mamsl)	SOIL/ Transported (m-m)	KAROO/ IGNEOUS, PRETORIA GROUP (m-m)	CHERT & RESIDUUM (m-m)	DOLOMITE & RESIDUUM (m-m)[5]	AIR/ SAMPLE LOSS/ High Pen.Rates/ CAVITY (m-m)	DEPTH TO BEDROCK (m)	ORIGINAL WATER TABLE (mbs)[6]	IIHC (INGRESS)	IHC DEWATERING
Site A														
1	5090	11/12/2015	-58074.030	2917404.062	1597	0-7	7-30	30-72	72-76dr		76	95	1	Low
2	5091	11/12/2015	-58116.655	2917406.978	1597	0-6	6-11	11-66	74-77dr	66-86sl 66-74cav	77	95	1/4	Low
3	5092	14/12/2015	-58045.560	2917285.578	1595	0-7	7-23	23-63		54-73sl	63	93	1/4	Low
4	5093	6/01/2016	-58094.774	2917297.787	1596	0-5	5-19	19-59			59	94	1/4	Low
5	5094	05/01/2016	-58101.850	2917350.315	1596	0-7	7-30	30-71	71-100dr		>100	94	1	Low
6	5095	6/01/2016	-58051.798	2917340.468	1596	0-7		7-60	60-66wad 77-80dr	60-89sl 66-76cav hpr	80	94	1/4	Low
Site B														
1	5096	6/01/2016	-55689.229	2917246.776	1580	0-3	3-10	10-15 25-37	15-25wad		37	78	4	Low
2	5097	6/01/2016	-55730.788	2917250.166	1581	0-3	3-15	15-28	28-42wad 42-61dr	33-42sl	61	79	4/8 (?)	Low
3	5098	6/01/2016	-55 713	2917143	1580	0-2	2-18	18-31	31-40dr		40	78	4	Low
4	5099	6/01/2016	-55676.006	2917182.590	1579	0-4	4-15	15-26	26-32wad 32-43dr		43	77	4	Low
5	5100	6/01/2016	-55748.221	2917186.187	1580		0-9	9-20	21-27wad 30-45dr	27-30sl cav	45	78	4	Low
6	5119	19/01/2016	- 55715.730	2917209.086	1580	0-3	3-15		15-30 30-46dr		46	78	4	Low
Main Site														
1	5086	8/12/2015	-56146.31663	2916998.677	1582	0-3	3-13		13-30wad 40-50dr	30-40 hpr sl cav	50	80	4/8	Low
2	5087	8/12/2015	-56415.49738	2917137.911	1585	0-2		2-12	35-44dr	12-54sl 12-35 hpr cav	44	83	8	Low

[5] dr-'dolomite rock' (penetration rates (2-3min.m)

[6] Original Water Table for the Bank Compartment is 1502 mamsl

No.	BOREHOLE	DATE DRILLED	WG27 - Y	WG27 - X	Elevation (mamsl)	SOIL/ Transported (m-m)	KAROO/ IGNEOUS, PRETORIA GROUP (m-m)	CHERT & RESIDUUM (m-m)	DOLOMITE & RESIDUUM (m-m)[5]	AIR/ SAMPLE LOSS/ High Pen.Rates/ CAVITY (m-m)	DEPTH TO BEDROCK (m)	ORIGINAL WATER TABLE (mbs)[6]	IIHC (INGRESS)	IHC DEWATERING
3	5088	9/12/2015	-58487.14303	2917210.798	1600	0-2	2-20	20-60	60-80dr	60-70 sl	80	98	1/4	Low
4	5089	9/12/2015	-57588.29489	2916949.776	1590	0-16		16-25 36-41	25-36wad	36-41sl	Not achieved	88	4/8	Low
5	5101	8/01/2016	-58454.22037	2916924.135	1599	0-2	2-12	12-34	34-44dr	-	44	97	1/4	Low
6	5102	7/01/2016	-57976.92971	2916787.31	1592	0-1		1-14	14-18wad 41-50dr	18-41sl hpr cav	50	90	8	Low
7	5103	7/01/2016	-57192.81784	2916852.531	1587	0-3		3-13	13-17wad 17-36dr	13-17sl	36	85	6/3	Low
8	5104	7/01/2016	-56704.37884	2916529.351	1582	0-5		5-20 38-46	46-50dr	20-38sl hpr cav	50	80	8	Low
9	5105	7/01/2016	-56037.03628	2916524.296	1575	0-2	2-29		29-50dr		50	73	1	Low
10	5106	6/01/2016	-55914.46618	2916897.145	1579				0-10wad 10-28dr		28	77	6/3	Low
11	5107	18/01/2016	-56364.38632	2916176.333	1576	0-12			12-20wad 20-40dr	20-49sl	40	74	6/3	Low
12	5108	7/01/2016	-56759.43083	2916104.728	1580	0-6		6-11	11-25wad 25-58dr	18-25sl	58	78	4	Low
13	5109	7/01/2016	-57118.00441	2916057.131	1582	0-2		2-10	10-20dr		20	80	4	Low
14	5110	7/01/2016	-57911.64869	2916012.898	1588	0-2	2-12	12-24	24-68wad 68-75dr	31-85sl 24-64 hpr	75	86	8	Low
15	5111	8/01/2016	-57786.14674	2915483.675	1585	0-4	4-18	18-49	49-53dr		54	83	4/1	Low
16	5112	8/01/2016	-57322.52732	2915362.65	1580		0-33		33-36wad 36-52dr		52	78	1	Low
17	5113	7/01/2016	-57132.75796	2915583.649	1580	0-6	6-37	37-54	54-63dr	54-72sl	63	80	1/4	Low
18	5114	8/01/2065	-56760.25711	2915346	1575	0-6	6-20		20-34wad 46-51dr	34-46 hpr cav 37-60	51	73	8	Low
19	5115	8/01/2016	-56352.77224	2915486.45	1573	0-7	7-17		17-49wad 49-59dr		59	70	4	Low
20	5116	8/01/2016	-56017.36181	2915934.823	1572	0-5	5-24	24-38 54-60	38-54wad	42-70sl	60	70	4/8(?)	Low
21	5117	19/01/2016	-57557.323	2916882.941	1590	0-14		14-24	24-28wad	28-32cav hpr	Not achieved	88	4/8(?)	Low

No.	BOREHOLE	DATE DRILLED	WG27 - Y	WG27 - X	Elevation (mamsl)	SOIL/ Transported (m-m)	KAROO/ IGNEOUS, PRETORIA GROUP (m-m)	CHERT & RESIDUUM (m-m)	DOLOMITE & RESIDUUM (m-m) [5]	AIR/ SAMPLE LOSS/ High Pen.Rates/ CAVITY (m-m)	DEPTH TO BEDROCK (m)	ORIGINAL WATER TABLE (mbs) [6]	IIHC (INGRESS)	IHC DEWATERING
22	5118	18/01/2016	-56202.620	2917007.454	1582	0-3	3-21	21-26	26-42wad 42-52dr	26-42sl hpr	52	80	8	Low
25	G1000	?	-56015.33336	2917296.46	1585	0-4	4-8	8-14 22-24	14-22wad 24-26		26	83	4/7	Low
26	G919	9/12/1971	-57015.33014	2917361.46	1583			0-39	39-46dr		46	81	4	Low
27	G920	9/12/1971	-55455.33519	2917261.46	1567	0-3	3-9	9-25	25-34		34	65	4	Low
28	G465	17/6/1969	-57000.33017	2917069.461	?	0-24		24-33	22-24wad		50		4	Low
29	G937	18/1/1972	-56495.33184	2917331.46	1535	0-3		3-18	18-22 22-45dr		45	33	4	Low
30	G909	9/12/1971	-57535.32843	2917406.46	1586	0-12		12-59	59-65		65	84	4	Low

Table 2. Probability of sinkhole occurrence (SANS 1936-1)

Inherent Hazard	Anticipated events per hectare per 20 years
Low	Typically <0.1 events. Return period >200 years
Medium	Typically <0.1 to 1.0 events. Return period 20-200 years
High	Typically >0.1 events. Return period <20 years

Table 3. Assessing blanketing materials (SANS 1936:2012-2)

Table B.3 — Indicators for assessing the inherent susceptibility of the blanketing layer to mobilization

1	2
Inherent susceptibility	**Indicators**
Low	In this type of profile, the groundwater level can be a) above the bedrock and at a shallow depth, thereby reducing the likelihood of ingress of water eroding the blanket layer; b) in the dolomite bedrock, negating the effect of groundwater level drawdown; or c) in soil material with geotechnical characteristics reflecting a low susceptibility to consolidation settlement, i.e. material with a high density, low void ratio and a low compression index (e.g. Karoo mudrock) or stiff or dense blanketing material.
Medium	This type of profile is characterized by the absence of a substantial protective horizon and has a blanketing layer of materials potentially susceptible to mobilization by ingress of water. The groundwater level is within the dolomite bedrock or at a depth within the blanketing layer. Voids and disseminated voids might be present above the bedrock, indicating the susceptibility to subsidence formation. Areas of continuous, sub-outcropping or outcropping dolomite bedrock characterized by limited leaching or fissure development (or both).
High	Thin blanketing layer covering intensely leached and jointed or fractured outcropping and sub-outcropping dolomite bedrock Or The blanketing layer reflects a high susceptibility to mobilization. The groundwater level is above the dolomite bedrock in soil material with a low dry density, high void ratio, and a high compression index. Any lowering of the groundwater level will change the state of these materials thereby inducing consolidation. Residual dolomite soils, namely wad and ferroan soils, have a high potential for dramatic ground settlement. Or The blanketing layer is heterogeneous, not only vertically, but also from one borehole to the next, and is of a moderate to high permeability. Variable, often rapid, drilling penetration times through the overburden are encountered with substantial sample and air loss. Cavernous conditions, cavities, thick deposits of Quaternary material, especially wind-blown sands (suggesting the presence of palaeo-sinkhole conditions), steep gravity gradients, troughs within gravity plateaus, groundwater level within the dolomite residuum, and a lack of control of groundwater level drawdown are typically encountered.

26