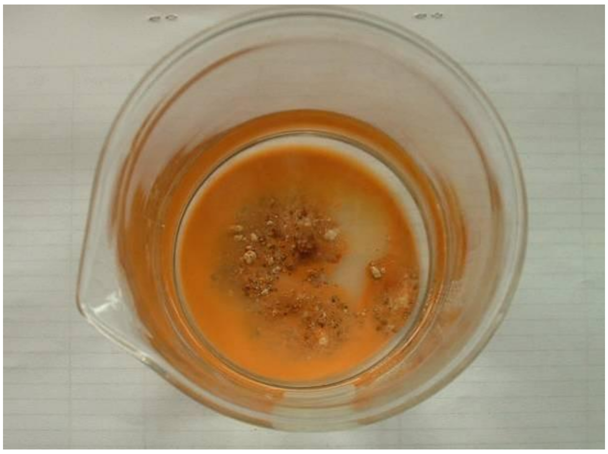
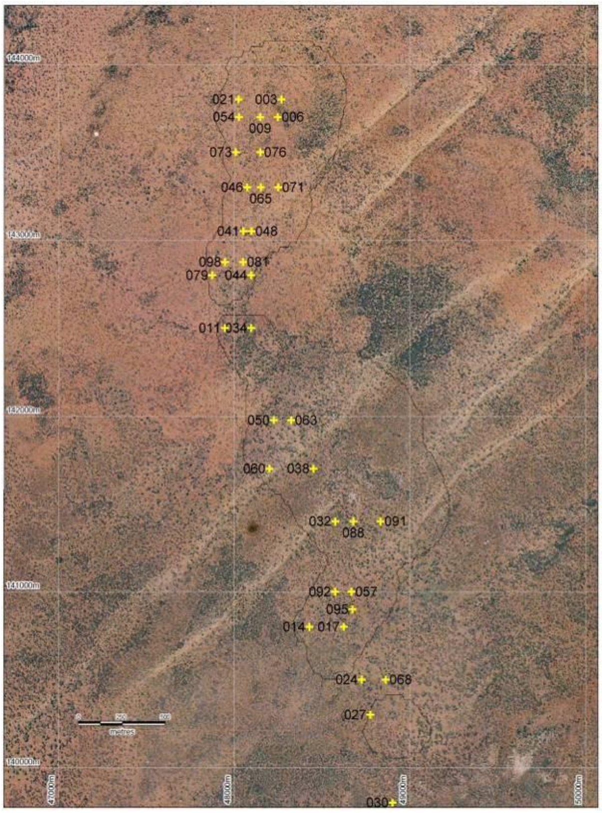


Characterisation of Weathered Zone Materials from RC Drilling



Tropicana Gold Project

AngloGold Ashanti Ltd
and
Independence Group NL

July 2009

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Tropicana Gold Project (TGP) is situated in the Great Victoria Desert Bioregion, 340 km north-east of Kalgoorlie and 220 km south east of Laverton, Western Australia. Two mineralised zones have been indentified on the Tropicana Gold Project – Tropicana and Havana. Mining these zones will create an open pit and large volumes of overburden that will be stored in permanent surface waste landforms. These landforms must be demonstrably safe, stable, and able to support a functional ecosystem. The characteristics of the weathered material and (more importantly) how it is managed once disturbed will impact the ability (favourably or not) of the Tropicana Joint Venture (JV) to achieve this goal.

Landloch Pty Ltd was engaged by AngloGold Ashanti Ltd on behalf of the JV to:

1) Characterise weathered zone materials for their potential impact on material stability and plant growth.
2) Highlight those characteristics that will limit or advantage the ability of AngloGold Ashanti to achieve successful rehabilitation.
3) Provide recommendations on minimising or ameliorating potential negative impacts caused by the characteristics of the weathered material.
4) Provide guidance on the final waste landform design as impacted by the properties of the weathered material.

The weathered zone materials can be categorised into 3 classes – Upper Saprolite (USAP), Lower Saprolite (LSAP), and Saprock (SAPRK). A range of major rock types exist within each class. USAP and LSAP materials are comprised predominantly of saprolite clay, with smaller proportions of Permian sediments, and some gneiss, schist, and tertiary materials. The vast majority of SAPRK materials are gneisses or schists. Little variability occurs between materials found at Tropicana and Havana.

Broadly, all weathered zone materials are characterised by:

1. Appreciable clay contents; saprolites are likely to have clays contents of 40-50%.
2. Very high Na base saturation.
3. Significant tendency to disperse (as illustrated by the modified Emerson dispersion test).
4. Generally acceptable salinity
5. Low fertility
6. Total metal concentrations below health based suitability criteria.
7. Mean total metal concentrations below ecological suitability criteria, with a few samples having values that exceed these criteria.

The current mine plan involves burying the weathered zone materials below the growth media layer and a fresh rock layer. Materials with high Na base saturation and significant tendency to disperse can be effectively managed using this approach. However, careful management of the growth media and rock layers will be crucial to ensure the material is sufficiently buried. Placement of sufficient growth media and fresh rock material over the weathered zone materials will:

1. Reduce the risk of saturated flows infiltrating through the weathered zone materials; and
2. Ensure that water that may pond on them cannot preferentially flow to the outer batters of the waste landform, creating tunnels and possible causing landform failure.
3. Ensure that materials with elevated metal concentrations when compared to background levels (these materials exist in localised areas) do not adversely impact vegetation.

Establishment of deep rooted vegetation is recommended as extraction of water from the soil will reduce the potential for deep drainage and reduce the risk of tunnel erosion. As well, increasing root growth through the surface soils will act to stabilise the surface against water erosion and the above-ground proportion of vegetation will be crucial in reducing the risk of excessive wind erosion.

The saprolitic materials are likely to be impermeable and dispersive. At depth in a waste landform, these properties are useful in limiting the movement of water and air. Therefore, these materials may be useful in encapsulating any potentially acid forming materials. Some of the weathered zone materials may be acid-forming themselves, and should be isolated and managed in a similar manner to other identified potentially acid forming materials.

1. INTRODUCTION

The Tropicana Gold Project (TGP) is situated in the Great Victoria Desert Bioregion, 330 km east north-east of Kalgoorlie and 220 km south east of Laverton, Western Australia (Figure 1). The TGP is a joint venture between AngloGold Ashanti Australia Limited (70%; manager) and Independence Group (30%) The site is characterised by linear aeolian dunes and swales. The climate is arid, receiving approximately 230 mm of rain annually. It is warm to extremely hot in summer and mild to warm in winters. Rainfall is typically more common during the summer and autumn, though still very low.

Figure 1: *Location of the Tropicana Gold Project relative to the Great Victoria Desert Bioregion (bounded in blue), and selected localities.*

Two mineralised zones have been indentified on the Tropicana Gold Project – Tropicana and Havana. Mining these zones will create an open pit and large volumes of overburden that will be stored in permanent surface waste landforms. The overburden represents the weathered state of the underlying competent parent material.

According to the mine plan, waste landforms will remain post-lease relinquishment. As a result, they must be demonstrably safe, stable, and able to support a functional ecosystem. The characteristics of the weathered material and (more importantly) how it is managed once disturbed will impact the ability (favourably or not) of JV to achieve this goal.

1.1. Regulatory expectations

The Western Australian EPA lists the following objectives for rehabilitation of waste landforms (EPA, 2006):

- Safe, stable and resilient landforms and soils;
- Appropriate hydrology;
- Providing visual amenity, retaining heritage values and suitable for agreed land uses;
- Resilient and self sustaining vegetation comprised of local provenance species;
- Reaching agreed numeric targets for vegetation recovery; and
- Comprising habitats capable of supporting all types of biodiversity.

Safe, stable and resilient landforms are the basis on which functional ecosystems can be developed. To achieve these objectives stated by the EPA, adequate characterisation of all materials impacted by mining is required. Failure to adequately characterise the weathered zone materials not only jeopardises AngloGold's ability to meet these required objectives, but also limits the ability of the site to:

- Identify the inherent risk associated with disturbing these materials (in one case that Landloch is aware of, modifying the site to an underground operation was more cost effective than managing the overburden materials); and
- Make informed and cost-effective decisions regarding managing these materials.

1.2. Project objectives

Landloch Pty Ltd was engaged by AngloGold Ashanti Australia Ltd on behalf of the Tropicana Joint Venture (JV) to provide characterisation of materials found in the weathered zone and within the conceptual pit outline supplied.

This information will form part of the approvals documentation and will be useful for development of site-level waste material management procedures.

The intent of this report is to:

1) Provide characterisation data for the weathered zone materials. Materials were characterised for properties that impact on material stability and plant growth. Properties associated with soil contamination (heavy metals) were also considered.
2) Highlight those characteristics that will limit or advantage the ability of AngloGold Ashanti to achieve successful rehabilitation.
3) Provide recommendations on minimising or ameliorating potential negative impacts caused by the characteristics of the weathered material.
4) Provide guidance on the final waste landform design as impacted by the properties of the weathered material.

2. MATERIALS AND ANALYSIS METHODS

2.1. Weathered zone materials

For the purposes of this characterisation, the weathered zone was assumed to be all material positioned above fresh rock, but below any transported and superficial deposits or lateritic residuum. Therefore, weathered zone materials can be categorised into 3 classes. These classes are defined as Regolith Classes within the Project drilling database. The weathered zone materials can be categorised, in order of the depth at which they occur, as:

1) Upper saprolite (USAP),
2) Lower saprolite (LSAP), and
3) Saprock (SAPRK)

The codes in brackets are Regolith Class codes as listed in the drilling database.

A range of major rock types exist within each weathered zone material. (It is noted that the weathered materials are largely not competent rock materials.) Based on material classification found in the drilling database, USAP and LSAP materials are comprised predominantly of saprolite clay. A small proportion is Permian sediment, and some gneiss, schist, and tertiary materials are also present in small quantities. The vast majority of SAPRK materials are gneisses or schists.

Saprolite clays are highly weathered (not competent), fine grained materials with little or no discernable structure. The degree of oxidisation and weathering decreases as depth increases. Therefore, LSAP materials are likely to contain a larger proportion of rocky coarse fragments than USAP materials. SAPRK is less weathered than both USAP and LSAP materials.

Weathering of the SAPRK materials tends to be variable and is largely contained to areas surrounding failure planes within the rock. SAPRK tends to be underlain by fresh rock (though this is not always the case).

Gneiss and schist materials are similar metamorphic rocks though schists are notable for higher proportions of platy minerals. Both are likely to weather to granular (sandy, gritty) materials where the parent material is sedimentary in nature. Permian sediments are typically sandy sediment materials. Tertiary materials consist of cemented sand and gravels. In particular, Tertiary ferricrete (sampled in this characterisation) is cemented by iron oxides.

2.2. Sample selection

Samples of the weathered zone materials were sourced from RC drilling material. A total of 100 samples were taken across both the Tropicana (52 samples) and Havana (48 samples) mineralisation zones. Within each mineralisation zone, samples of the major rock types were selected. A small selection of those materials that occur infrequently was also taken. Table 1 lists the weathered zone materials found on the Tropicana Gold Project, and the number of samples of each major rock type sampled.

Table 1: *Material types and the number of samples taken within each broad regolith class.*

Regolith class	Major rock type	No. of samples
Upper saprolite	Saprolite clay	24
	Permian sediments	5
	Tertiary (ferricrete)	1
	Gneiss	4
	Schist	1
Lower saprolite	Saprolite clay	25
	Gneiss	7
	Schist	1
Saprock	Gneiss	30
	Schist	2

Samples were sourced from RC drilling materials located within the conceptual pit outlines, and as such, sampling locations were limited by the:

1) Location of RC drilling holes,
2) Availability of physical sample from the RC drilling holes, and
3) The conceptual pit outlines provided to Landloch by AngloGold Ashanti.

A sample list encompassing the conceptual pit areas, all three regolith classes, and the major rock types found within each regolith class was generated by Landloch Pty Ltd. The sample list was used by AngloGold to source the required samples and supply them to Landloch Pty Ltd for analysis. Figures 2-4 show the sample locations of the USAP, LSAP, and SAPRK materials. The conceptual put outlines are shown in black. Further information regarding the sample location – drill hole ID, "down-hole" depth, approximate GPS coordinates of the drill hole collar, and the associated major rock type for each sample – can be found in Appendix A.

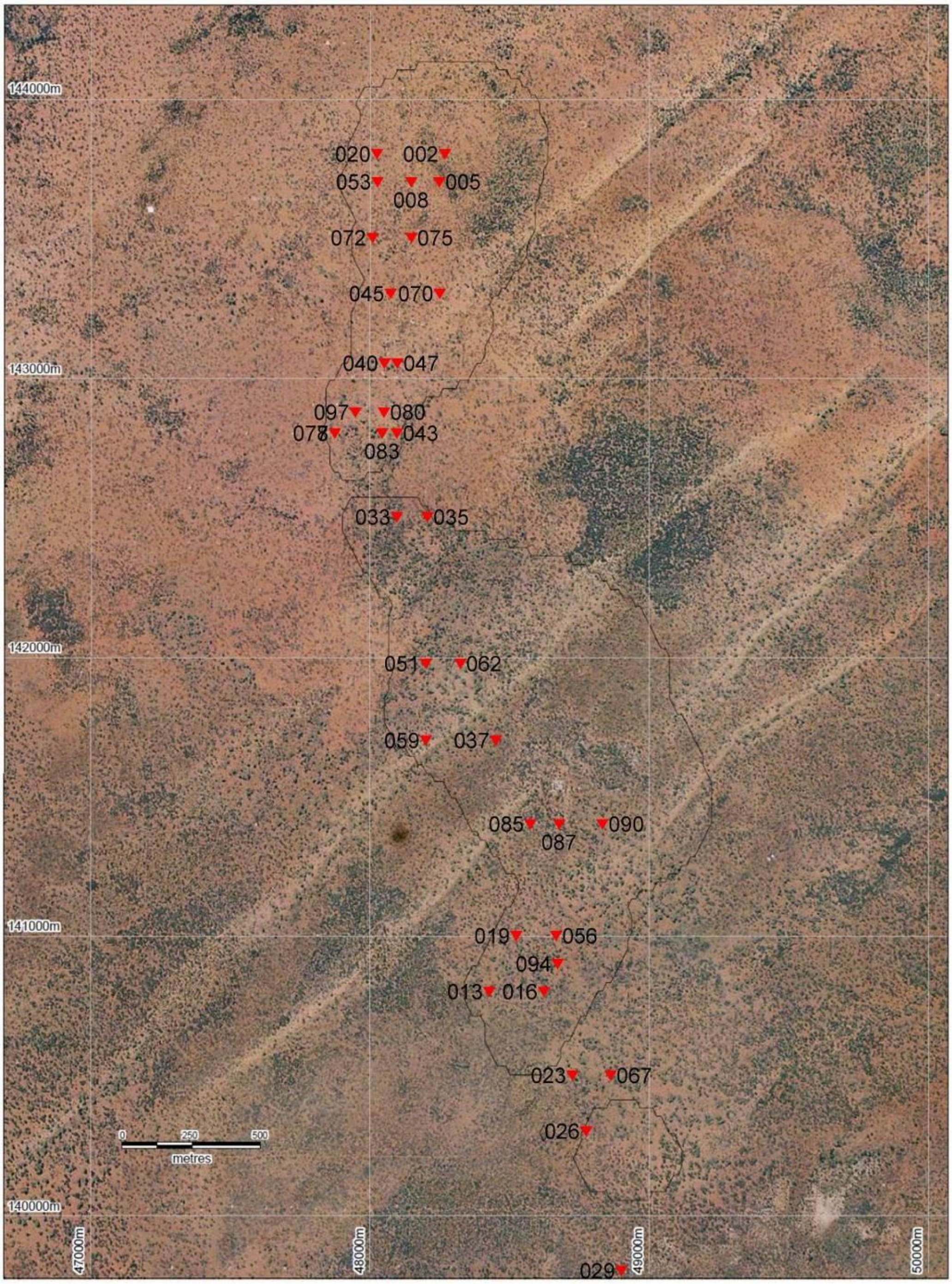

Figure 2: *Sample locations for USAP materials.*

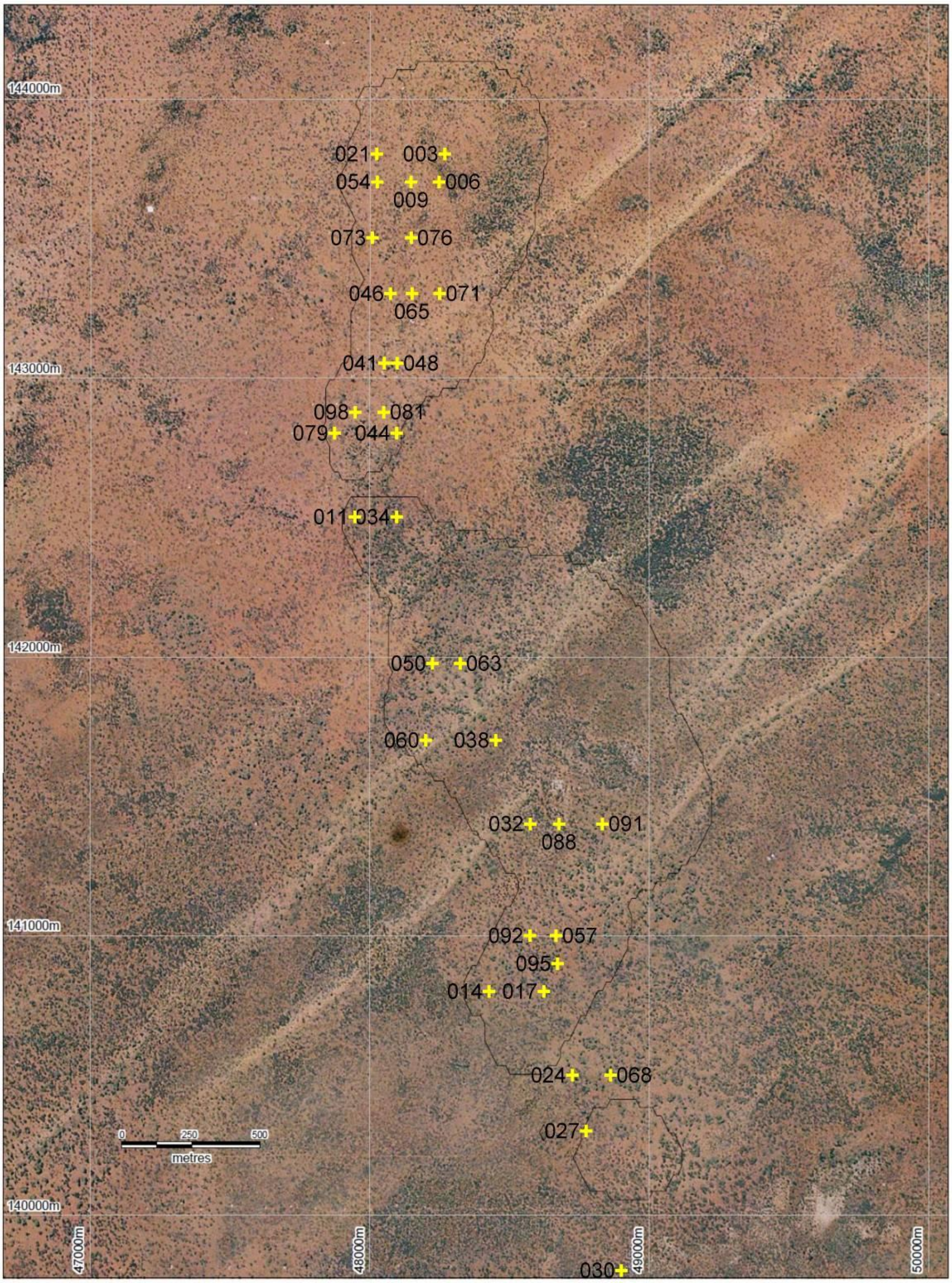

Figure 3: *Sample locations for LSAP materials.*

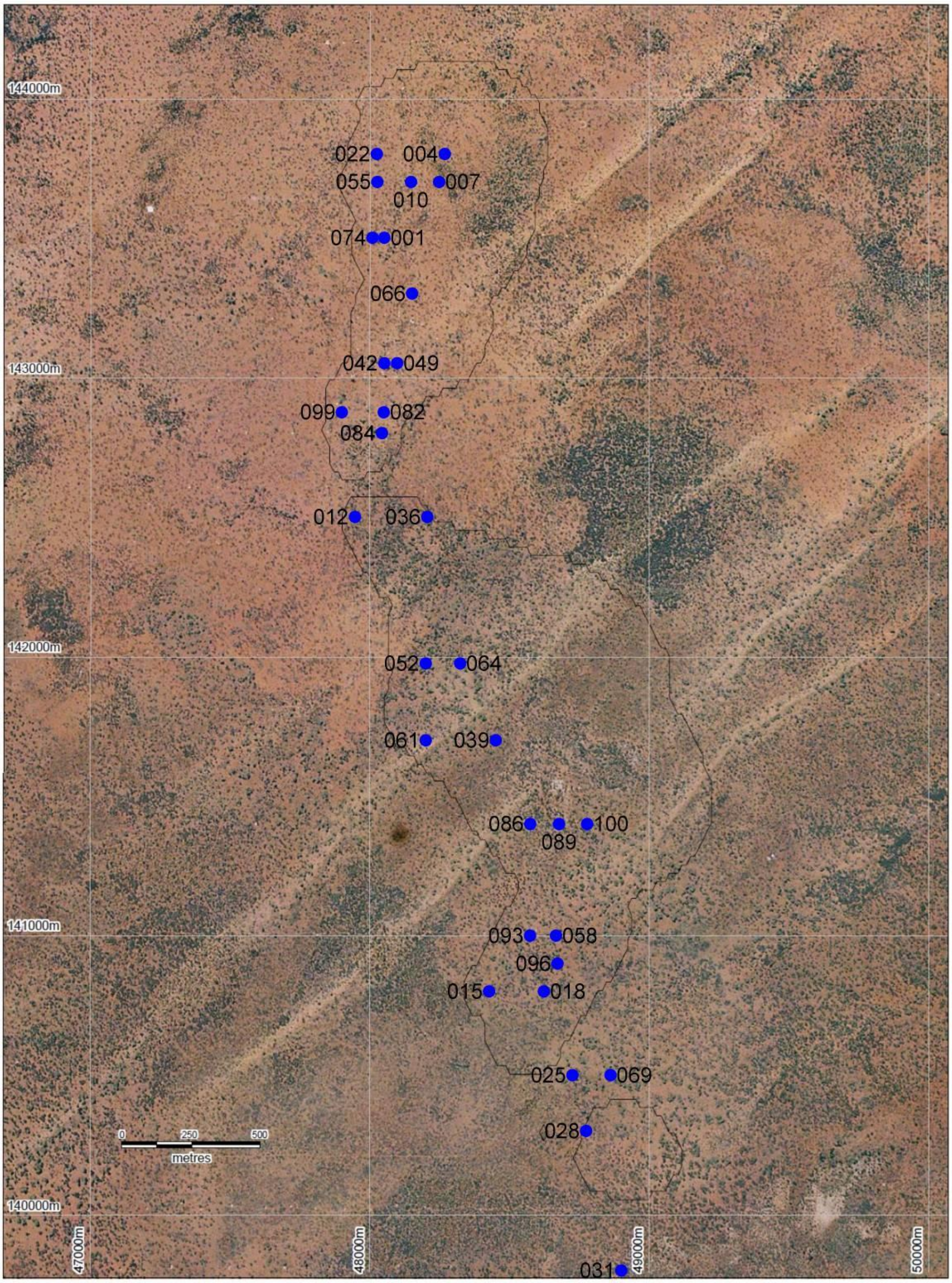

Figure 4: *Sample location of SAPRK materials.*

2.3. *Chemical analytes and physical assessments*

All samples were analysed for the following chemical properties:

- pH;
- Salinity ($EC_{1:5}$);
- Exchangeable cations (Al^{3+}, Ca^{2+}, Mg^{2+}, Na^{+} and K^{+});
- Cation Exchange Capacity (CEC)
- Sodium base saturation[1];
- Total P;
- Available P;
- Available K;
- Trace (extractable) elements (Cu, Zn, Mn, Fe);
- Available S; and
- Total metals (As, Cd, Cr, Cu, Pb, Ni, Zn, Hg).

Nitrogen concentrations were not measured. It was assumed that N values would be insignificant given the depth from which the weathered materials are being sourced. Concentrations of mineral nitrogen present in parent material are typically insignificant when compared to N requirements of vegetation.

2.3.1. pH

The acidity or alkalinity of a material is measured by the pH scale. Determination of guidelines for pH suitability relevant for a wide range of materials and sites is impossible, and the most rational approach is to consider naturally occurring soil pH values and the vegetation that is endemic on soil having these pH values. Waste materials that have similar pH values can be considered suitable for plant growth – at least with respect to pH.

For arid mineral (non-organic) soils, soil pH values commonly range from 6.5 – 9.0 (Peverill *et al.* 1999). This is supported by the findings of soil characterisation work previously completed for the Tropicana Gold Project (Outback Ecology, 2008). For soils ranging in depth from 0.0 – 5.0 m, pH (H_2O) ranges from 5.5 – 9.0. Therefore weathered materials with pH values ranging from 5.5 – 9.0 can be considerable suitable at this site.

The pH of a material is important as it strongly influences the chemical environment of the soil or waste material. It directly impacts on the rate of weathering and the availability of nutrients.

Alkaline materials often form where leaching is limited, as occurs in arid environments where evaporation often exceeds rainfall. For these materials,

[1] Sodium base saturation is numerically equivalent to Exchangeable Sodium Percentage, often abbreviated to ESP. The term Na base saturation is used in this report.

calcium, magnesium, potassium, and sodium occupy more of the soil cation exchange sites than hydrogen (pH is a measure of H^+ concentration), and as such pH values increase. Also, it is not uncommon for pH to increase with depth.

Nutrient availability changes with pH. For example, as pH falls below 6.0, availability of nitrogen, phosphorus, potassium, and sulphur tends to decrease. Also, as pH falls below approximately 5.5, Al^{3+} – usually strongly bound to exchange sites at pH values high than 5.5 – becomes increasingly available and can become toxic to vegetation. Little information relating to Al^{3+} toxicity in native vegetation is available. Therefore, where exchangeable Al^{3+} is present (i.e. where pH < 5.5), it is prudent to assume that it will potentially impact on vegetation.

2.3.2. Salinity

Soil salinity is often measured using the Electrical Conductivity of a solution containing 1 part soil to 5 parts of deionised water ($EC_{1:5}$). Salinity can be quite variable, and in surface soils, often reflects the degree to which a material has been leached. For waste materials where leaching is infrequent and saline groundwater is not present, the salinity of the parent material will have a significant bearing on the salinity of the weathered zone.

Most published salinity suitability ranking systems assume agricultural vegetation, and application of these ranking systems has little significance to plant species used in arid zone rehabilitation. The Western Australian Department of Agriculture and Food provides a summary of published salinity tolerance values for a range of common species used in revegetation of disturbed lands in Western Australia (Department of Agriculture and Food, 2004). These tolerance values are given as EC values measured **not** using the common 1:5 soil:water solution method, but the less common saturation extract method (EC_e) (Hazelton and Murphy,2007). Conversion between $EC_{1:5}$ and EC_e is dependent on particle size distribution. Hazelton and Murphy (2007) suggest that for sandy loam soils EC_e should be divided by approximately 15 to estimate $EC_{1:5}$, whereas EC_e for clay soils should be reduced by a factor of approximately 7 to estimate $EC_{1:5}$. Using these conversion factors, salt tolerant species (e.g. *Atriplex*, *Halosarcia*) are likely to exhibit some adverse impacts on vegetation growth at $EC_{1:5}$ values greater than approximately 2.0 dS/m. Plants are particularly sensitive to salt during germination and establishment. Many eucalyptus species have salt tolerance values ($EC_{1:5}$) for germination ranging from 0.5 – 2.0 dS/m.

Salinity trials performed near Kalgoorlie indicated that soil salinity ($EC_{1:5}$) in excess of 4 dS/m is likely to cause significant adverse impacts on germination and establishment of salt tolerant species (Jennings *et al.*, 1993). This same report showed drastic reduction in seedling establishment for $EC_{1:5}$ values greater than 0.5 dS/m. Interestingly, incorporation of rock (at rates ranging from 20-90%) provided the best conditions for plant establishment.

Landloch has observed poor vegetation performance – sparse vegetation that rarely grew taller than 10 cm – on waste landforms in the WA Goldfields where salinity of the growth media was approximately 7.0 dS/m ($EC_{1:5}$).

2.3.3. Exchangeable cations and CEC

The ability of a material to absorb and retain cations is measured by CEC. Measurement of exchangeable cations provides information on the types of cations being held on the soil exchange complex. The type and proportion of exchangeable cations has a major impact on the physical stability of the material. Of particular importance is the proportion of Na held on the exchange complex in relation to other cations (Ca and Mg). This is referred to as the Na base saturation.

CEC is calculated as the sum of the exchangeable cations – Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, and Al^{3+} where measured. Materials with CEC values of less than approximately 3 meq/100g are likely to be sandy or rocky, and have little ability to hold or retain nutrients. Materials with CEC values greater than approximately 3 meq/100g are likely to contain some clay and to have the ability to hold and retain nutrients. Further, CEC values greater than approximately 40 meq/100g indicate materials that have a high proportion of clays, and that these clays are likely to be reactive (typical of soils that shrink and swell).

The process of RC drilling effectively pulverises the materials as they are extracted, and determination of CEC for these materials is likely to overestimate actual CEC of the material if it were extracted using common mining techniques. Nonetheless, these CEC values give a suitable indication of the likely clay contents and potential reactivity of the waste materials.

2.3.4. Na base saturation

Calculation of Na base saturation uses the values of the exchangeable cations.

$$\text{Na base saturation} = 100 \times Na^{+} / \text{CEC}$$

where Na is exchangeable Na (meq/100g) and CEC is cation exchange capacity (meq/100g).

Typically, soils with Na base saturations greater than 6% are classed as sodic and dispersive. However, in practice, the potential for a soil to disperse is controlled by complex interactions between clay content, exchangeable cations and soil solution salinity. Importantly, dispersion is of particular concern for materials with appreciable clay contents. Sandy soils do not contain sufficient amounts of dispersive clay, and can be regarded as stable even though they may have a high Na base saturation. McKenzie *et al.* (2004, p.21) state that, *"In soils with low CECs* [low clay contents]*, a low or trace* *level of sodium can lead to an ESP* [Na base saturation] *greater than 6 but in these circumstances there is insufficient evidence of significant clay dispersion and poor physical properties"*. They consider the measurement of Na base saturation as suitable for indicating potential adverse physical properties when CEC is greater than 3 meq/100g and where exchangeable sodium exceeds 0.3 meq/100g.

Further to impacts of clay content on the interpretation of Na base saturation values, the tendency of the clay fraction in a material to disperse is controlled by soil salinity. As soil salinity decreases, soils become more unstable and dispersive. It is possible for a soil to be non-sodic by definition (i.e. have a Na base saturation greater than 6%), yet still exhibit dispersive tendencies. As soil salinity increases, soil aggregation is enhanced, and soils become increasingly stable. It follows that a sodic material that is saline can appear stable. Given this, interpretation of Na base saturation values is not a simple task, and should be considered carefully.

The interactions between Na base saturation and salinity have important implications for rehabilitation activities. Materials that appear stable can become increasingly unstable (dispersive) as soil salinity decreases through leaching by rainfall. Therefore, materials that are "sodic" by definition should be treated as at least potentially dispersive, even if they appear initially stable.

Materials with a tendency to disperse are not suitable for use as a growth medium as they are likely to:

- be hard setting;
- be potentially tunnel prone;
- have low infiltration and water holding capacity;
- lead to increased runoff and potential erosion; and
- limit germination and root growth.

2.3.5. Nutrients

Phosphorus (P) and potassium (K) are both essential elements for plant growth, and deficiencies often limit plant growth in both agricultural and native systems (McKenzie *et al*. 2004). Other nutrients (including S and trace elements) are also required, but in smaller quantities. The suitability of values of the different nutrients is complex, and determination of specific critical values for the Tropicana Gold Project site would require establishment of fertiliser trials, a significant (but undeniably valuable) task that would be completed over several years.

Given the complexity surrounding plant fertility, assessment of nutrient values for this characterisation uses published values, and Landloch's experience with fertiliser responses in vegetation.

2.3.6. Total metals

Metals are present in all soils, but may become concentrated in sub surface materials. High metal concentrations can lead to adverse impacts on the receiving ecosystem. Risks associated with human health are also of concern. Assessment of metal concentrations in mineralisation zones – by their definition – is likely to yield elevated metal levels in assessed materials. Therefore, assessment of metal concentrations should consider both:

1) Levels considered hazardous to human health, and
2) Background (natural) levels of total metals found in the area.

Materials with metal concentrations higher than considered acceptable from a human health perspective will require specific management, regardless of whether the levels are similar to naturally occurring levels. Therefore, values that exceed the Health Investigation Levels (HILs) provided by the Western Australian Department of Environment and Conservation are considered unacceptable (DoE, 2003).

From an environmental perspective, determining the suitability of a material's metal concentration must primarily consider how it compares with metal concentrations found in the environment to which the existing ecosystem is adapted. Generic Ecological Investigation Levels (EILs) can be found in contaminated site assessment guidelines (DoE, 2003). These EILs are based on toxic effects in vegetation and were developed for use in assessments for land in urban environments. The site is not located within an urban context, and the published EILS are of little relevance.

The guidelines state that, "S*oil EIL values…are not meant to be pass-fail criteria for contaminants in soils. However, contaminant values in excess of EIL figures should trigger further risk-based investigations to determine whether there is likely to be significant impact on the environment, including groundwater if contaminated soil is not treated and remains on site."* Further, the guidelines state that, *"In some circumstances higher EIL values may be acceptable for arsenic, cobalt, chromium, copper, nickel, lead and zinc in areas where soils naturally have high background concentrations of these substances."*

Site specific trigger levels for total metals in soils have been developed (360 Environmental, 2009). These levels were based on data for existing soil materials and were used as "ecological" suitability criteria for this report.

Twenty of the 100 weathered zone samples were analysed for total metals. The samples were selected to represent the relative proportion of each waste rock type across both the Tropicana and Havana mineralisation zones.

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2.3.7. Suitability criteria

For suitable vegetation growth on the Tropicana Gold Project, values of key material characteristics values considered desirable are[2]:

pH	5.5 – 9.0, with pH > 9.5 or < 5.0 requiring specific management	
$EC_{1:5}$	< 2.0 dS/m, with EC >4.0 dS/m requiring specific management	
CEC	3 – 40 meq/100g, with CEC >40 meq/100g indicating reactive clays[3]	
Na base saturation	< 6 %, with ESP >10% requiring specific management. Materials with CEC <3 meq/100g and Na < 0.3 meq/100g were not considered of concern.	
Al base saturation	Will potentially impact vegetation when present	
Total P	> 100 mg/kg	
Available P (Colwell)	≥ 6 mg/kg, with < 3 mg/kg requiring specific management	
Available K (Colwell)	> 60 mg/kg	
Available S	> 15 mg/kg with < 10 mg/kg requiring specific management	
Extractable Cu	>0.1 mg/kg	
Extractable Mn	>1 mg/kg	
Extractable Zn	>0.3 mg/kg	
Extractable Fe	No level set[4]	
	Ecological Levels[5]	Health Levels[6]
Total As	20 mg/kg	500 mg/kg
Total Cd	3 mg/kg	100 mg/kg
Total Cr	317 mg/kg	500 mg/kg
Total Cu	134 mg/kg	5,000 mg/kg
Total Pb	300 mg/kg	1,500 mg/kg
Total Ni	106 mg/kg	3,000 mg/kg
Total Zn	200 mg/kg	35,000 mg/kg
Total Hg	1 mg/kg	75 mg/kg

2.4. Physical assessments

Physical assessments of each sample included:

- Colour;
- Texture; and
- Modified Emerson dispersion test.

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[2] Units of mg/kg are equivalent to ppm

[3] Assumes that materials with CEC >40 meq/100g have clay contents greater than approximately 40-50%.

[4] Fe toxicity or insufficiency in soils is of little concern, and is not considered a risk at all in terms of land contamination. Fe levels are useful in assessing the degree to which other nutrients may be bound as iron oxides are responsible for cementation of soil particles.

[5] Based on site specific trigger levels (360 Environmental, 2009).

[6] Assumes land is used for "parks, recreational open space" purposes rather than "residential" purposes where extended contact with humans in much more likely.

Assessment of physical parameters important for plant growth – mainly texture and dispersion potential – is confounded by the disturbance caused by RC drilling. As a result, formal assessment of these properties was not performed. However, broad values of these properties can be inferred from the type of weathered material, associated chemical properties, and the occurrence of gritty and / or rocky fragments in the supplied sample.

2.4.1. Colour

Colour was assessed using the Munsell soil Colour Chart. The colour of the material, while being of limited value in determining significant variations in chemical properties may be useful for development of on-site material handling procedures.

2.4.2. Texture

Material texture has a controlling influence over many other materials properties. For example interpretation of Na base saturation depends on texture, with sandy materials being less prone to dispersion than clay-rich materials. Clay rich materials tend to have higher CEC, which is important in assessing nutrient availability.

Broad textures classes were assigned to the materials assessed. These classes were:

1) Powdery
2) Gritty/sandy
3) Rocky

Powdery materials are likely to contain higher clay contents than either of the other two classes. Materials that contain intact rocky fragments indicate that the material does contain a significant proportion of gravels or stones. Where those rocks are angular, rocks have likely been broken during RC drilling. Occurrence of rounded rock indicates that materials have been transported via water (alluvial sediments).

2.4.3. Emerson dispersion test

Assessment of dispersion potential using the Emerson dispersion test is not possible. Broadly, the Emerson dispersion test has three levels[7]:

Level 1) Testing of undisturbed aggregates. If dispersion occurs at this level, Emerson dispersion indices of 1 or 2 are assigned based on the degree of dispersion.

Level 2) Testing of soils that has been wet and disturbed. If dispersion occurs at this level, the material is given an Emerson index of 3.

Level 3) Testing of a 1:5 soil:water solution for dispersion or flocculation. If dispersion occurs at this level, the material is given an Emerson index of 5, and if flocculation occurs, an index of 6 is given.

A "modified" Emerson aggregate test was used to indicate dispersion potential. The RC drilling materials were subjected to the testing associated with Level 2 above. Where dispersion occurred, the materials were classified as potentially dispersive. Where dispersion did not occur, the materials were classed as potentially stable. Further, those materials that had an $EC_{1:5}$ greater than 2.0 dS/m were leached with deionised water to reduce salinity, and the Emerson test performed again on the leached sample. If a material was stable prior to leaching but became dispersive after leaching, the material was classified as potentially dispersive. If the material remained stable, it was classified as potentially stable.

Importantly, results of the Emerson dispersion test are deemed as less reliable (due to the disturbance caused by drilling) than dispersion potential as indicated by a material's Na base saturation, salinity, and texture. Where a material's chemical properties indicate that a material is potentially dispersive, but the Emerson test suggests the material is stable, it is assumed that that material is potentially unstable.

2.4.4. Refinement of physical characteristics

Once mining has commenced and relatively undisturbed material is available, refinement of the physical characteristics of the weathered zone materials is strongly recommended.

[7] Emerson tests can be complicated by the presence of gypsum in soils, with these soils being given an Emerson class of 4. Further classes are also given to soils that do not slake. However, this is uncommon and will not be able to be determined using the modified Emerson test.

3. MATERIAL CHARACTERISTICS

Complete results of chemical analyses are provided in Appendix B. Cells shaded blue highlight materials with properties that will require specific management, being significantly higher or lower than values considered suitable (Section 2.3.7). Cells shaded yellow highlight materials with properties that are slightly higher or lower than values considered "suitable". These materials may not require specific management, but will potentially impact on vegetation establishment and/or growth to some dgree.

Data presented in Section 3 represent the mean values of each parameter. The standard error for each mean is also given, and was calculated using a 95% confidence interval[8].

3.1. Comparison of Tropicana and Havana regolith classes

Comparison of the properties of the different regolith classes from Tropicana and Havana shows that little or no significant variation occurs in the measured values of most material properties, except for differences in:

1. Na base saturation and related changes in Ca and Mg cation concentrations, and
2. Material salinity.

However, these variations do not render the same waste from one mineralisation zone more or less suitable than the same waste from the other zone. While the Havana materials have lower Na base saturation than measured for materials found at Tropicana, the actual Na base saturation values for all samples regardless of the mineralisation zone will be an issue if not managed appropriately, as they are higher than 10%. Additionally, Havana saprolites tend to have lower salinity than Tropicana saprolites, but $EC_{1:5}$ values of samples from both zones never exceed 4.0 dS/m. Several Tropicana saprolites do exceed 2.0 dS/m and these higher salinity levels are likely to be associated with higher groundwater salinity in the Tropicana area Nonetheless, salinity levels are consistently below 4.0 dS/m.

Therefore, assessment of material properties will consider differences between rock types across the entire Tropicana Gold Project, and will combine data from both mineralisation zones.

[8] There is a 95% probability that the mean value reported is equal to the mean plus or minus the standard error. For example 10 ± 1 can be interpreted as meaning the there is a 95% probability that the actual mean value ranges from 9 to 11.

3.2. Saprolite materials

3.2.1. Occurrence

Saprolite materials dominate both the USAP and LSAP regolith classes and are not found with the SAPRK class. They typically occur between the gneiss and schist dominated saprock and below any transported and superficial surface deposits or lateritic residuum. Saprolites are present in both the Tropicana and Hanava mineralisation zones. Mean values (and the standard error) for measured characteristics for the saprolite materials are given in Table 2. Data for the USAP and LSAP classes have been provided separately.

3.2.2. Colour

The majority (~70%) of saprolites are either brown or yellow in colour. Some samples were white or red, with a few samples being grey or olive coloured.

3.2.3. Texture

The saprolite materials sampled from both the USAP and LSAP regolith classes were typically powdery (Figure 5). Therefore, it is inferred that these materials contain a significant proportion of clay and silt sized particles. A small proportion of samples were sandy/gritty or contained angular coarse fragments. More of the LSAP materials contain rocky fragments than the USAP materials, consistent with the LSAP material being slightly less weathered than the USAP.

When exposed on the surface of a constructed landform, saprolite tends to:

- be hard-setting,
- have low permeability,
- inhibit vegetation germination and establishment, and
- be highly erodible, via either or both gully erosion and tunnel erosion.

Saprolites are not suitable for use on the surface of a waste landform, and must be carefully managed to ensure that:

1. concentrated overland flows do not flow directly over them; and
2. water is not allowed to pond on them for extended periods of time.

Table 2: *Mean material properties for the saprolite material from the USAP and LSAP regolith classes*

Analyte	Units	USAP		LSAP	
		Avg	Std Err.	Avg	Std Err.
pH	-	6.4	0.3	7.4	0.2
EC	dS/m	2.0	0.2	1.2	0.2
CEC	meq/100g	15.4	2.4	19.8	2.5
Al base saturation	%	1.9-8.9 %, present in 38% of samples tested		3.9%, present in 4% of samples tested	
Ca base saturation	%	12.4	2.1	16.1	1.8
Mg base saturation	%	29.8	1.3	37.1	1.5
K base saturation	%	6.4	0.3	4.4	0.3
Na base saturation	%	49.3	2.9	42.2	2.7
Total P	mg/kg	366	52.1	320	47
Avail. P	mg/kg	1.5	0.2	3.6	0.6
Avail. K	mg/kg	798	104	1,263	111
S	mg/kg	208	27	125	19
Cu	mg/kg	0.3	0.0	0.3	0.1
Fe	mg/kg	6.3	1.2	5.9	0.6
Mn	mg/kg	0.5	0.4	2.6	1.0
Zn	mg/kg	0.6	0.1	0.7	0.1
Dominant texture	-	Powdery (75%), Gritty (17%)		Powdery (52%), Rocky (28%)	
Dominant colour	-	Browns and yellows		Browns and yellows	
Emerson	-	Potentially dispersive (66%)		Potentially dispersive (96%)	
Total Hg	mg/kg	<0.1	0	<0.1	0
Total As	mg/kg	5	1	7	5
Total Cd	mg/kg	<1	0	<1	0
Total Cr	mg/kg	73	20	98	47
Total Cu	mg/kg	14	6	85	40
Total Pb	mg/kg	6	3	19	2
Total Ni	mg/kg	10	3	50	18
Total Zn	mg/kg	7	2	156	53

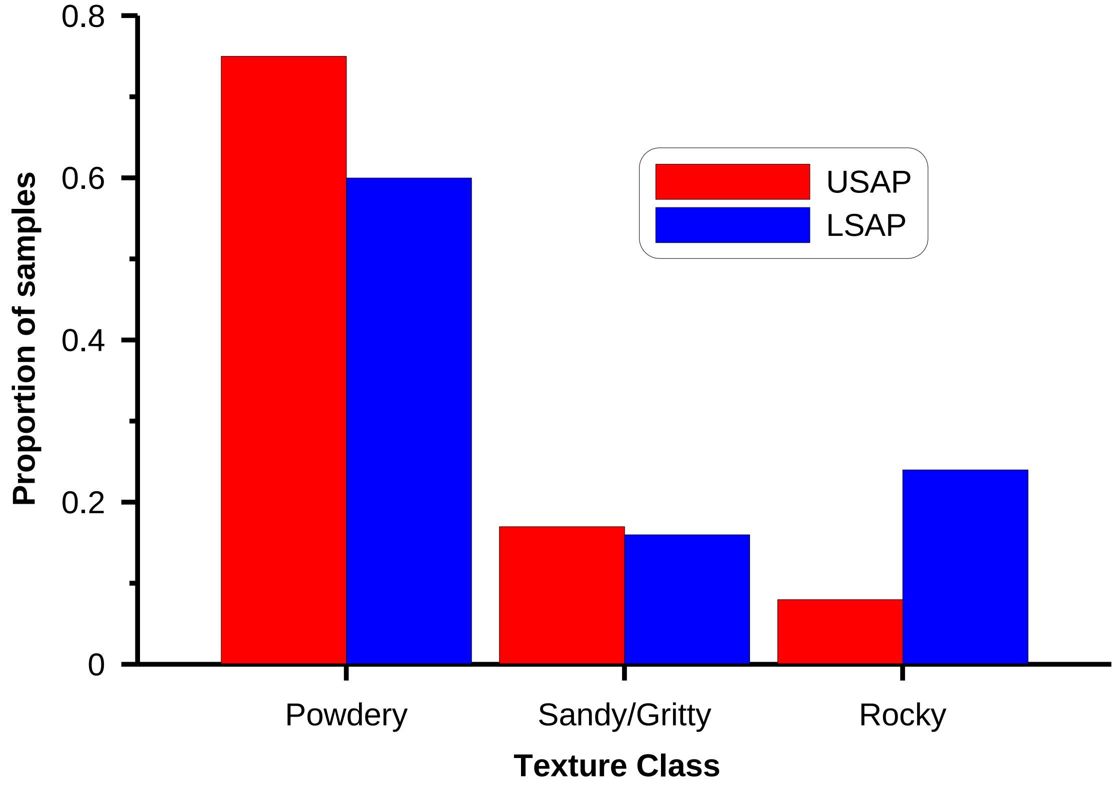

Figure 5: *Proportion of saprolite samples with different textures*

3.2.4. Dispersion potential

Results of the modified Emerson dispersion test are shown in Figure 6. Interestingly, more than 90% of the LSAP samples are potentially dispersive, whereas only 25% of the USAP material exhibited dispersive tendencies. Both the USAP and LSAP materials invariably have very high Na base saturation, but the USAP materials do tend to have higher $EC_{1:5}$. The mean $EC_{1:5}$ for the USAP material is 2.0 ± 0.2 dS/m and the mean $EC_{1:5}$ for the LSAP is 1.2 ± 0.2 dS/m.

For USAP material, the increased salinity may be acting to effectively mask the potential dispersion. As part of the modified Emerson dispersion test, materials with $EC_{1:5}$ greater than 2.0 dS/m were leached with deionised water to reduce salinity and the Emerson dispersion test repeated on the leached materials. Leaching was performed by placing approximately 10 mm of material into a 100 mm diameter Buchner funnel and leaching a maximum of 500 mL of deionised water through the material. During the leaching, many materials tunnelled and much of the water preferentially flowed through these tunnels rather than through the soil matrix. Several other samples dispersed so severely that little or no water passed through the sample. It is likely that the imperfect leaching caused little reduction in soil salinity and as a result, did not impact greatly on dispersion potential.

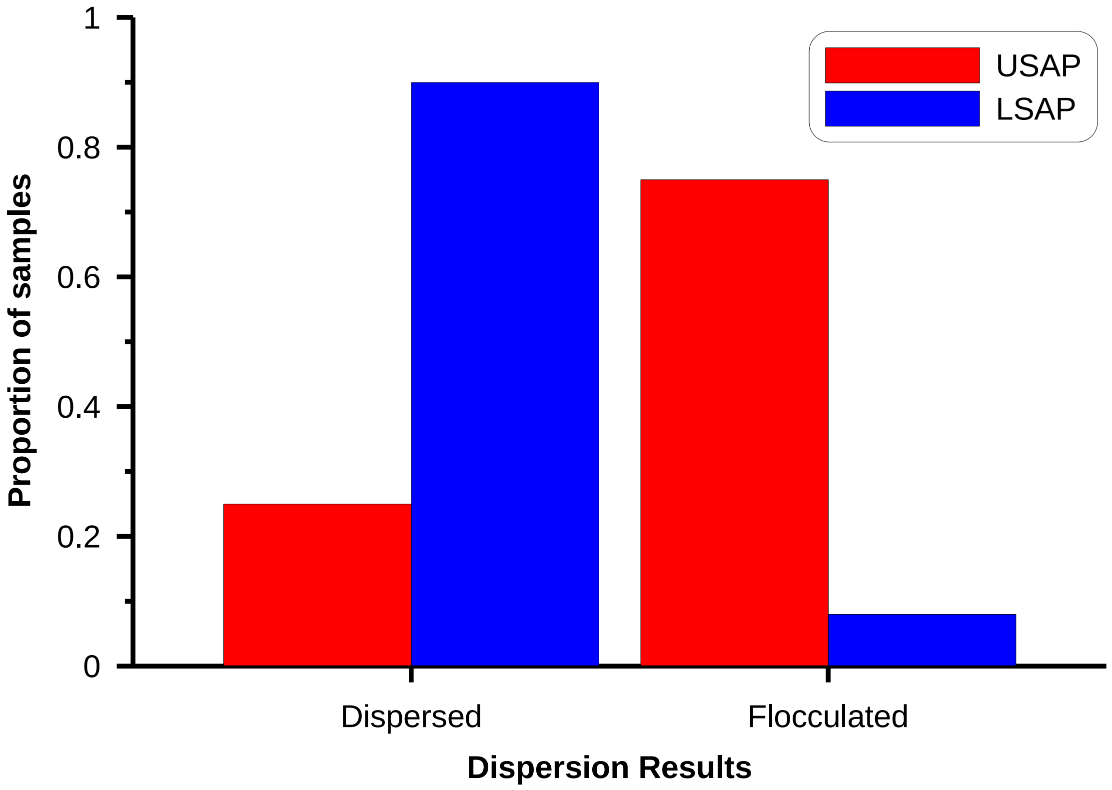

Figure 6: *Dispersion potential of saprolite samples.*

The observance of tunnelling through or indefinite ponding of water on samples leached with deionised water demonstrates the dispersive nature of these materials. If it is assumed that the saline saprolites become dispersive as salinity reduces, then 66% of the USAP samples and 96% of the LSAP samples are potentially dispersive. Given this, all saprolite materials should be assumed to be highly dispersive and are therefore unsuitable for placement near the surface of any constructed landform.

3.2.5. pH

The pH values of the USAP materials average 6.4, while the mean pH of the LSAP materials is 7.4. Importantly, 38% of the USAP materials samples had pH values less than 5.5 (which is why it is marked as likely to impact vegetation). For these materials, exchangeable Al was measured and ranged from 1.9 – 8.9 % base saturation. The materials with a low pH also tended to have elevated S. It is likely that these materials are acid generating, and risks associated with acid generation potential should be investigated further. Such an assessment is outside the scope of this report.

The mean pH value of the LSAP saprolites is within the range observed in natural soils that support vegetation and is not likely to adversely impact plant growth. One LSAP saprolite sample had a low pH and expression of exchangeable Al, and is likely to be acid generating.

3.2.6. Salinity

The salinity of the USAP materials is higher than the LSAP materials (Table 2). Salinity values for all saprolite materials never exceed 4.0 dS/m. Some impacts on plant growth, particularly during plant germination and establishment can be expected if the USAP material is used as a growth media.

3.2.7. Exchangeable cations and CEC

The mean CEC values of both the USAP and LSAP materials indicate that these materials contain significant proportions of clay, and that the clay is dominated by non-reactive clays. (Kaolinite clay is a non-reactive clay and is the dominant clay mineral in saprolite.)

These materials are more able to hold nutrients than sandier materials, but also tend to be relatively erodible.

3.2.8. Na base saturation

All materials have very high Na base saturations. When coupled with appreciable clay contents and relatively low soil salinity, these materials are highly likely to be unstable when placed in contact with water. Amendment of these materials to reduce Na base saturation would involve application of gypsum (a source of Ca that will act to reduce the dominance of Na on the soil exchange) at a rate of approximately 5-8 kg/t[9] of material.

3.2.9. Nutrients

Values of Total P tend to be adequate, but the amount of available P is typically low. Values for available K, available S, and trace elements are adequate, except for Mn in the USAP saprolites, where values tend to be low. Given that other factors limit the suitability of the saprolite materials for use a growth media, likely fertiliser requirements have not been estimated.

3.2.10. Total metals

Measured total metal concentrations for the USAP saprolite materials are all below the suitability criteria (both ecological and health) outlined in Section 2.3.7. Measured values for all LSAP materials are below the health suitability criteria. Mean total metal concentrations of LSAP materials were all below the ecological suitability criteria. However, some individual materials exceeded the ecological suitability criteria. One sample had a zinc concentration of 291

[9] Calculation of this gypsum amendment rate assumes a reduction of Na base saturation to 4% and a gypsum purity of 70%.

mg/kg, one sample had a copper concentration 194 mg/kg, and one sample had an arsenic concentration of 22 mg/kg. The variability in measured concentrations of these particular metals is high (as shown by large significant errors when compared to the mean). Given that total metal concentration values are – on average – lower than the ecological suitability criteria, the high values measured likely represent localised, discrete mineralisation areas.

3.3. Gneiss and schist materials

3.3.1. Occurrence

Gneiss and schist materials occur in all three regolith classes. However, the majority occurs in the SAPRK class, and only relatively small amount occur within USAP and LSAP. They typically occur below the saprolite clays. Gneiss and schist materials are present in both the Tropicana and Havana mineralisation zones. Mean values (and the mean standard error) for measured characteristics for the gneiss and schists are given in Table 3. Data for the USAP, LSAP, and SAPRK classes have been provided separately.

3.3.2. Colour

The majority (~70%) of material are either brown or yellow in colour. Materials tend to get lighter in colour with depth. LSAP materials are generally brown in colour, while SAPRK can include olive and grey coloured materials.

3.3.3. Texture

The majority of gneiss and schist materials contain either gritty materials or rocky coarse fragments. The LSAP gneiss materials do contain a significant proportion of powdery materials. The genesis of these fine materials is not obvious. The presence of gritty materials and materials containing coarse fragments indicate that these materials are typically less weathered than the overlying saprolites. These materials are also likely to contain reasonable proportions of relatively competent rocky fragments. The CEC values of the materials do indicate that these materials will contain some clay, though the measured CEC values may be overestimating the actual CEC as the disturbance caused by RC drilling is likely to break down particles that would otherwise remain intact had the materials been excavated using typical mining techniques.

Table 3a: *Mean material properties for the gneiss and schist materials from the USAP and LSAP regolith classes.*

Analyte	Units	USAP		LSAP	
		Avg	Std Err.	Avg	Std Err.
pH	-	6.4	0.7	8.1	0.4
EC	dS/m	1.4	0.3	0.4	0.1
CEC	meq/100g	23.2	13.8	12.2	2.2
Al base saturation	%	1.8-2.6 %, present in 40% of samples tested		Not present in any samples	
Ca base saturation	%	26.0	14.4	22.2	3.6
Mg base saturation	%	27.5	6.3	41.5	0.9
K base saturation	%	6.3	1.8	4.3	0.4
Na base saturation	%	39.3	7.8	32.1	3.2
Total P	mg/kg	303	60	210	52
Avail. P	mg/kg	1.2	0.2	1.1	0.1
Avail. K	mg/kg	730	50	1,376	316
S	mg/kg	162	32	42	8
Cu	mg/kg	0.2	0.0	0.2	0.1
Fe	mg/kg	5.6	1.9	5.1	1.1
Mn	mg/kg	0.2	0.2	1.9	1.1
Zn	mg/kg	0.8	0.3	0.8	0.3
Dominant texture	-	Gritty (40%), Rocky (40%)		Powdery (50%), Rocky (38%)	
Dominant colour	-	Browns, yellows		Light browns	
Emerson	-	Potentially dispersive (20%)		Potentially dispersive (75%)	
Total Hg	mg/kg	<0.1	0	<0.1	0
Total As	mg/kg	10	8	4	2
Total Cd	mg/kg	<1	0	1	0
Total Cr	mg/kg	35	11	80	46
Total Cu	mg/kg	16	10	61	37
Total Pb	mg/kg	7	4	16	4
Total Ni	mg/kg	16	7	114	80
Total Zn	mg/kg	20	11	109	3

***Table 3b:** Mean material properties for the gneiss and schist materials from the SAPRK regolith class.*

Analyte	Units	SAPRK Avg	SAPRK Std Err.
pH	-	8.4	0.2
EC	dS/m	0.5	0.1
CEC	meq/100g	11.1	1.2
Al base saturation	%	2.6 %, present in 3% of samples tested	
Ca base saturation	%	22.1	1.9
Mg base saturation	%	36.3	1.1
K base saturation	%	5.2	0.5
Na base saturation	%	36.3	2.1
Total P	mg/kg	192	20
Avail. P	mg/kg	2.7	0.5
Avail. K	mg/kg	1,649	147
S	mg/kg	46	10
Cu	mg/kg	0.3	0.1
Fe	mg/kg	6.9	0.7
Mn	mg/kg	2.2	0.8
Zn	mg/kg	1.4	0.7
Dominant texture	-	Rocky (38%), Gritty (31%), Powdery (31%)	
Dominant colour	-	Light brown, olives, greys	
Emerson	-	Potentially dispersive (94%)	
Total Hg	mg/kg	<0.1	0
Total As	mg/kg	5	2
Total Cd	mg/kg	1	0
Total Cr	mg/kg	75	9
Total Cu	mg/kg	31	9
Total Pb	mg/kg	12	1
Total Ni	mg/kg	46	4
Total Zn	mg/kg	76	12

3.3.4. Dispersion potential

Results of the modified Emerson dispersion test are shown in Table 3. Similarly to the saprolite clays, dispersion potential seems to increase with depth, with a smaller proportion of USAP materials exhibiting dispersive tendencies than the LSAP and SAPRK materials. Dispersion was recorded in 75% of the LSAP sample, and 94%of the SAPRK samples. Both the LSAP and SAPRK materials had significantly lower salinity (0.4 dS/m and 0.5 dS/m respectively) than the USAP materials (1.4 dS/m), and dispersion of the USAP samples may have been masked by the slightly elevated $EC_{1:5}$.

Given that the majority of the samples exhibit dispersive tendencies, and that they all have Na base saturation exceeding 10%, all gneiss and schist materials should be assumed to be dispersive and should be considered unsuitable for placement near the surface of any constructed landform.

3.3.5. pH

The pH values of the USAP materials average 6.4, while the mean pH of the LSAP and SAPRK materials is 8.1 and 8.4 respectively. Increases of pH with depth are common in arid areas, where leaching is limited or imperfect.

Two of the five USAP materials and one SAPRK sample (out of 32) had pH values less than 5.5. For these materials, exchangeable Al was measured, ranging from 1.8 – 2.6 % base saturation.

Of the 32 SAPRK samples, 9 had pH greater than 9.0. This pH is outside the range of pH observed in undisturbed soils, and has the potential to impact on plants growth.

3.3.6. Salinity

The salinity of all gneiss and schist materials never exceeds 4.0 dS/m and exceeds 2.0 dS/m in 2 samples (from a total of 45 samples). Salinity of the gneiss and schist materials is not likely to impact on plant growth if they are used as growth media.

3.3.7. Exchangeable cations and CEC

The mean CEC values of the USAP, LSAP, and SAPRK materials indicate that these materials contain some clay. CEC does tend to decrease with depth, likely due to decreasing clay content and increasing rockiness. CEC values indicate that the clays present are likely to be non-reactive and dominated by kaolinite. As such they will have similar nutrient holding ability to the overlying saprolites.

3.3.8. Na base saturation

All materials have very high Na base saturations and should be regarded as potentially unstable when water is allowed to pond on them, or when water is allowed to flow over them. Amendment of these materials to reduce Na base saturation would involve application of gypsum at a rate of approximately 10 kg/t[10] for the USAP materials, and 5 kg/t for the LSAP and SAPRK materials.

[10] Again, calculation of this gypsum amendment rate assumes a reduction of Na base saturation to 4% and a gypsum purity of 70%.

3.3.9. Nutrients

Values of Total P tend to be adequate, but the amount of available P is typically low. This is similar to the overlying saprolite materials. Values for available K, available S, and trace elements are adequate, except for Mn in the USAP saprolites, where values tend to be low. Given that other factors limit the suitability of the saprolite materials for use a growth media, likely fertiliser requirements have not been estimated.

3.3.10. Total metals

Mean total metal concentrations for the USAP and SAPRK material are below both the ecological and health and the suitability criteria. A nickel concentration of 193 mg/kg was measured in the LSAP sample (only one sample of this material type was tested). This value is below the health suitability criteria, but above the ecological suitability criteria.

3.4. Permian sediments

3.4.1. Occurrence

A total of 5 Permian sediment samples were analysed, as they are not commonly found within the weathered zone. Of the 5 samples taken, 4 were sampled from the Havana mineralisation zone. Samples were sourced exclusively from the USAP regolith class. They typically occur at shallow depths in the weathered zone.

Mean values (and standard error) for measured characteristics for the Permian sediments are given in Table 4.

3.4.2. Colour

The majority (~80%) of materials are either reddish brown or reddish yellow in colour.

3.4.3. Texture

Permian sediments contain either gritty materials or rocky coarse fragments. The presence of gritty materials and materials containing coarse fragments indicate that these samples are typically less weathered. This correlates well with their presence at shallow depths in the weathered zone. These materials are also likely to contain reasonable proportions of relatively competent rocky material. The CEC values do indicate that these materials will contain some fine particles, though CEC values measured are quite variable.

Table 4: *Mean material properties for the Permian sediments from the USAP regolith class.*

Analyte	Units	USAP	
		Avg	Std Err.
pH	-	5.1	0.9
EC	dS/m	1.2	0.2
CEC	meq/100g	12.3	5.5
Al base saturation	%	1.9-9.1 %, present in 80% of samples tested	
Ca base saturation	%	5.9	2.6
Mg base saturation	%	34.6	2.1
K base saturation	%	6.3	0.5
Na base saturation	%	48.4	3.5
Total P	mg/kg	340	186
Avail. P	mg/kg	1.0	0.0
Avail. K	mg/kg	254	204
S	mg/kg	136	27
Cu	mg/kg	0.3	0.1
Fe	mg/kg	7.8	3.6
Mn	mg/kg	0.2	0.2
Zn	mg/kg	0.6	0.1
Dominant texture	-	Gritty (40%), Rocky (40%)	
Dominant colour	-	Red browns, red yellows	
Emerson	-	Potentially dispersive (20%)	
Total Hg	mg/kg	<0.1	-
Total As	mg/kg	26	-
Total Cd	mg/kg	<1	-
Total Cr	mg/kg	51	-
Total Cu	mg/kg	34	-
Total Pb	mg/kg	14	-
Total Ni	mg/kg	12	-
Total Zn	mg/kg	17	-

3.4.4. Dispersion potential

Dispersion was recorded in only 1 of the 5 samples analysed. The gritty and rocky nature of these samples suggests that these materials are less dispersive than either the saprolites or gneiss and schist materials. Further testing once mining has commenced may be warranted to more conclusively determine the dispersion potential of this material. If it was shown to be stable (even with its high Na base saturation) and depending on the volume that is generated, this material may be able to be used as growth media. However, other chemical properties must also be considered (in particular pH)

3.4.5. pH

The pH values of the Permian materials average 5.1, and 80 % of the samples tested have measureable exchangeable Al base saturations. These low pH values will potentially adversely impact on vegetation growth. These materials are unlikely to be useful as growth media, based on this low pH. However, addition of lime may be beneficial to increase soil pH. Broadly, application of approximately 1.5 kg of lime for every tonne of material would be required to raise pH to approximately 6.5.

3.4.6. Salinity

The salinity of all Permian sediment materials never exceeds 2.0 dS/m. Salinity is not likely to impact on plant growth if they are used as a growth media.

3.4.7. Exchangeable cations and CEC

The mean CEC values of the Permian sediments indicate that they contain some clay, though CEC values are highly variable. It is likely that these materials are rocky in nature with a proportion of associated fine materials surrounding the rocks. As such, these materials may have little capacity to retain nutrients. Their rockiness may make them less susceptible to rill and gully erosion.

3.4.8. Na base saturation

All materials have very high Na base saturations. Prudence would suggest that these materials may be potentially unstable when water is allowed to pond on them. Their rockiness may provide some stability to erosion caused by overland flows. Amendment of these materials to reduce Na base saturation would require application of gypsum at a rate of approximately 5 kg/t[11] of material.

3.4.9. Nutrients

Values of Total P tend to be adequate, but the amount of available P is typically low. Values of available K are highly variable, though no sample measured has a value less than 238 mg/kg, well above the suitability criteria. Values for available S, and trace elements are adequate, except again for Mn, where values tend to be low. Given that other factors limit the suitability of the saprolite materials for use as growth media, likely fertiliser requirements have not been estimated.

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[11] Again, calculation of this gypsum amendment rate assumes a reduction of Na base saturation to 4% and a gypsum purity of 70%.

3.4.10. Total metals

One Permian sediment samples was assessed for total metal concentration (hence no calculation of standard error is possible). The material sampled had total metals concentrations below both the ecological and health suitability criteria except for slightly high arsenic. The value exceeds the ecological suitability criteria but does not exceed the health suitability criteria.

3.5. Tertiary materials

3.5.1. Occurrence

Only 1 tertiary weathered material was sampled. It is uncommon within the weathered zone. The sample was sourced from the Tropicana mineralisation zone and was located within the USAP regolith class. Tertiary materials tend to occur at shallow depths in the weathered zone.

Values for measured characteristics of the Tertiary material are given in Table 5.

3.5.2. Material properties

The Tertiary sample was reddish brown colour, and contained rocky coarse fragments. The presence of coarse fragments indicates that this material is likely to be less weathered than the saprolites or gneiss and schist materials. In fact, these materials are located at shallow depths in the weathered zone.

The CEC value of the material does indicate that clay sized particles are present along with the coarse fragments.

Dispersion was recorded for this material. Dispersion occurred rapidly (within 5 minutes of starting the test). The amount of dispersion is shown in Figure 7.

Given the rate and severity of observed dispersion, and the high Na base saturation of the material, it is likely that this material would be dispersive if it was extracted using common mining techniques rather than through RC drilling.

The pH and salinity values are of no concern from a vegetation growth point of view. As with all samples tested, Total P values are likely to be adequate, but the amount of available P is low. Available S, Ma, and Zn are low for this material. Fertiliser requirements have not been estimated as this material is unsuitable for use as a growth medium given its dispersion potential.

Total metals concentrations for the sample tested do not exceed either the ecological or health suitability criteria.

Table 5: *Material properties for the Tertiary material sourced from the USAP regolith class.*

Analyte	Units	Value
pH	-	8.1
EC	dS/m	0.2
CEC	meq/100g	21.9
Al base saturation	%	Not present
Ca base saturation	%	22.5
Mg base saturation	%	39.3
K base saturation	%	10.0
Na base saturation	%	28.2
Total P	mg/kg	854
Avail. P	mg/kg	1
Avail. K	mg/kg	1,361
S	mg/kg	5.3
Cu	mg/kg	0.2
Fe	mg/kg	4
Mn	mg/kg	<1
Zn	mg/kg	0.3
Texture	-	Rocky
Colour	-	Reddish brown
Emerson index	-	Potentially dispersive
Total Hg	mg/kg	<0.1
Total As	mg/kg	<1
Total Cd	mg/kg	<1
Total Cr	mg/kg	55
Total Cu	mg/kg	10
Total Pb	mg/kg	18
Total Ni	mg/kg	9
Total Zn	mg/kg	10

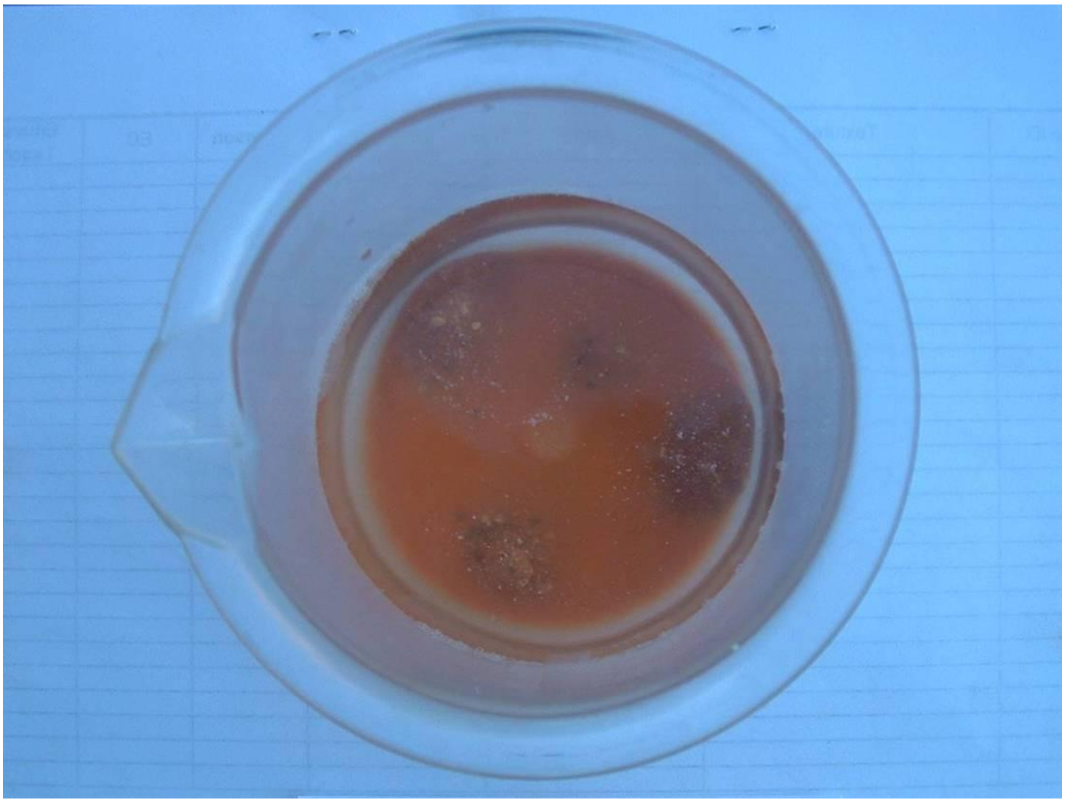

Figure 7: *Dispersion of the Tertiary material sample after 1 hour*

4. MANAGEMENT RECOMMENDATIONS

The weathered zone materials predominantly comprise either saprolites or gneiss and schist materials. Small proportions of Permian sediment and Tertiary materials were also sampled. Broadly, the weathered zone materials are characterised by:

1. Appreciable clay contents; saprolites are likely to have clays contents of 40-50%.
2. Very high Na base saturation.
3. Significant tendency to disperse (as illustrated by the modified Emerson dispersion test).
4. Generally acceptable salinity.
5. Low fertility.
6. Total metal concentrations below health based suitability criteria.
7. Mean total metal concentrations below ecological suitability criteria, with a few samples having values that exceed these criteria.

4.1. Potential for amendment

Amendment of the dispersion potential of the weathered zone materials will require application of gypsum to large volumes of those materials at rates ranging from 5-10 kg/t or 3.5-7.0 kg/m³ assuming a material bulk density of 1.4 t/m³. Given the remoteness of the site, supply of sufficient gypsum may be cost prohibitive. Gypsum in ready supply typically costs $80-$100 per tonne, but transport will be a major consideration. Assessment of these costs should be undertaken to confirm whether gypsum use is practicable.

4.2. Selective placement

If gypsum application is cost-prohibitive, then sodic weathered zone materials should be placed such that they are not near the surface of constructed waste dumps. Sufficient material must be placed over the weathered zone materials to:

1. Reduce the risk of saturated flows infiltrating through the weathered zone materials;
2. Ensure that water that may pond on them cannot preferentially flow to the outer batters of the waste landform, creating tunnels and possible causing landform failure; and
3. Ensure that materials with elevated metal concentrations when compared to background levels (these materials exist in localised areas) do not adversely impact vegetation.

The saprolitic materials are potentially useful for use as an encapsulation material. These issues are discussed below.

4.2.1. Tunnel erosion – risks and management

Tunnel erosion is the process whereby sub-surface materials are eroded by water, leaving the surface layers (initially) relatively intact. If tunnel erosion is left to continue, the roofs of the tunnels can collapse and gullies are formed immediately. There are several factors that make a hillslope tunnel-prone (Crouch, 1976). These factors include:

- Seasonal or variable rainfall patterns;
- Dispersive and impermeable sub-surface materials, often with a sharp interface between soil layers;
- Areas of rapid entry of water, associated with areas of ponding, and surface soil of high permeability, or soils subject to cracking via soil drying, plant roots and/or animal burrowing;
- Reduction in vegetation cover; and/or
- Existence of a hydraulic gradient in the dispersive soil layer, creating a tendency for water to flow.

Figure 8 shows the process of tunnel erosion.

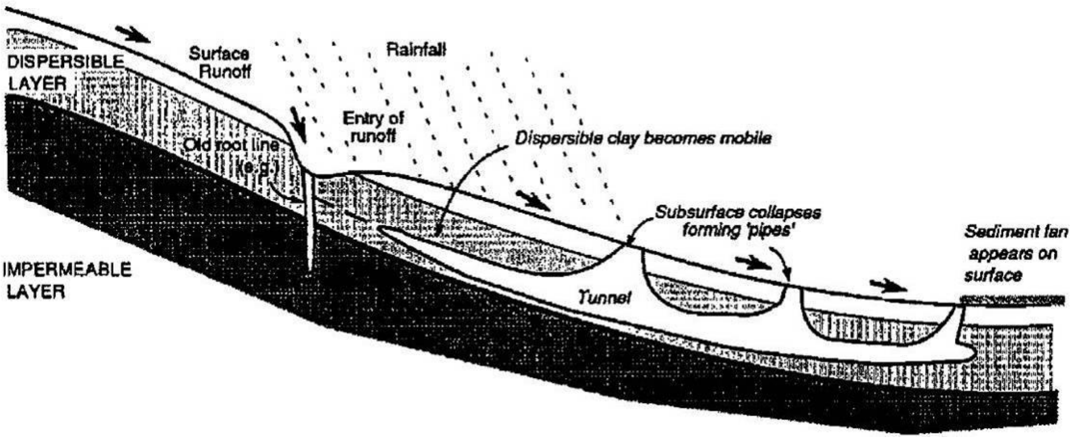

Figure 8: *Process of tunnel erosion*

The process consists of:

- Water flowing over the soil surface or below the surface. Water can enter the soil through soil cracks formed by plant roots or animal burrows. Cracks caused by shrinking and swelling of materials are not likely on this site.
- The dispersive soil becomes **saturated** and dispersed particles flow through the soil in the water **moving in the direction of the hydraulic gradient**.
- Obvious tunnel inlets develop as the surface soil slumps into the hole left by the removal of dispersed sub-surface materials. Tunnel outlets develop when the dispersed soil and water breaks the soil surface further down the slope (Figure 9).

Reducing the risk of tunnel erosion requires landform construction and rehabilitation practices that limit the tendency for dispersive materials to be saturated for extended periods. Importantly, practices must ensure that where hydraulic gradients occur, dispersive materials are not used. A key location where hydraulic gradients can occur is near the outer face of any constructed landform batter. It is important to ensure that saturated zones do not develop at depth, and do not have potential for the seepage outlets shown in figure 9 to occur. Placing dispersive materials below the wetting front of infiltrated water will eliminate the risk of saturation and lateral flow of water occurring.

Further, where hydraulic gradients do not exists i.e. inside the waste dump but away from the outer batters, tunnelling is not able to develop. In fact the low permeability of the dispersive materials makes these materials particularly useful for encapsulation of potentially acid forming materials.

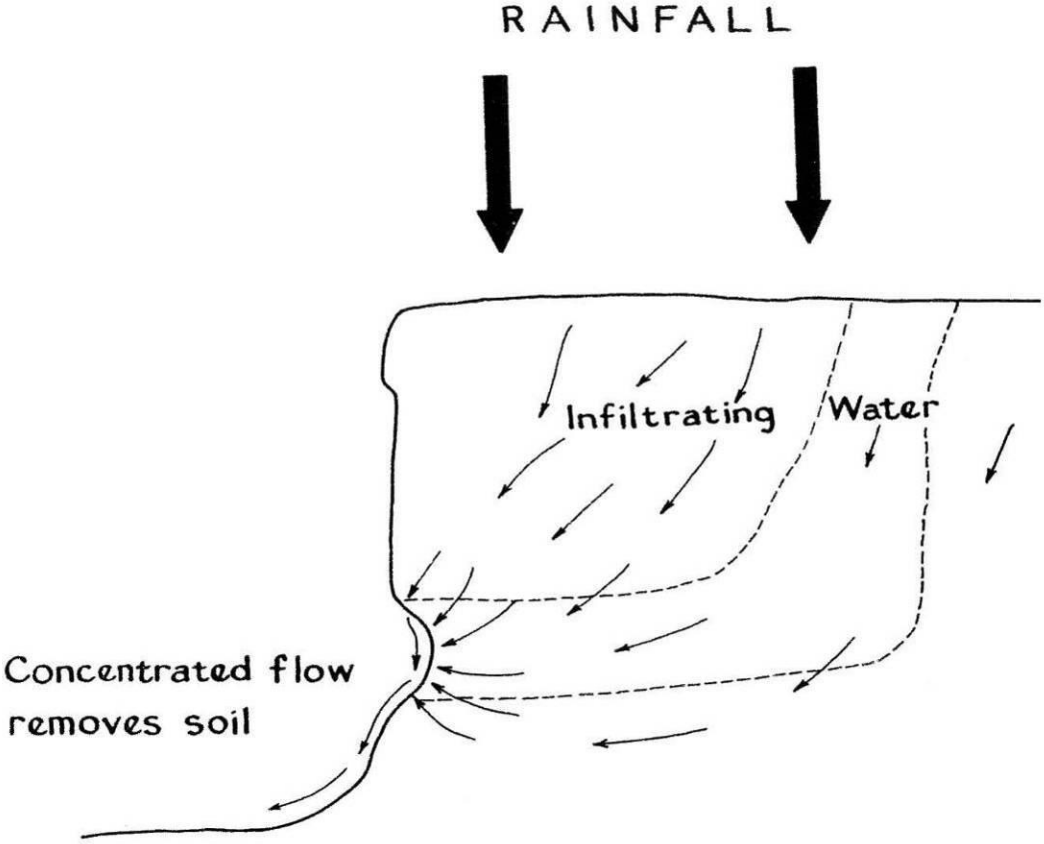

Figure 9: *Tunnel formation requires saturated soil, and a hydraulic gradient (tendency for water to flow). Diagram is adapted from Crouch (1976).*

4.2.2. Importance of vegetation

In arid environments, temporal variability of rainfall events is likely to favour deep rooted vegetation that is adapted to effectively extract the great majority of rainfall that may infiltrate. Further, the typically long periods between rainfall events that cause infiltration is likely to result in the existing vegetation extracting water from a large proportion of the root zone, as vegetation roots are likely to be present in most of the soil. Therefore, it is expected that deep drainage of water (movement below the effective root zone) will be reduced by the establishment of suitable vegetation. Reducing deep drainage will reduce the risk of tunnel erosion.

As well, increasing root growth through the surface soils will act to stabilise the surface against water erosion and the above-ground proportion of vegetation will be crucial in reducing the risk of excessive wind erosion.

5. CONCLUSION

The weathered zone materials are likely to be impermeable and dispersive. At depth in a waste dump, these properties are useful in limiting the movement of water and air. Therefore, these materials may be useful in encapsulating any potentially acid forming materials. Some of the weathered zone materials may be acid-forming themselves, and should be isolated and managed in a similar manner to other identified potentially acid forming materials.

However, successful rehabilitation of the surface of waste landforms constructed by the Tropicana Gold Project will require – among other things – careful management and placement of the weathered zone materials.

Placement of the weathered zone materials on, or close to, the surface of the waste landform is likely to result in rehabilitation failure. On the surface, these dispersive materials will cause excessive runoff, high rates of erosion, hard-set surfaces and failures of vegetation establishment. Placed below, but close to, the surface, these materials are likely to cause tunnel erosion and eventual gully formation.

Therefore, careful management of the available growth media will be crucial for rehabilitation success. The weathered zone materials must be covered with a sufficient depth of non-dispersive materials to reduce risks of tunnel erosion to extremely low levels. Consideration should be given to both the chemical suitability the water holding capacity of the growth media layer used. Providing a sufficient depth of growth medium will not only advantage vegetation growth, but will significantly reduce the environmental risks associated with managing the weathered zone materials.

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APPENDIX A – SUMMARY OF SOIL PHYSICAL AND CHEMICAL DATA

Table A-1: *Upper saprolite samples selected for analysis*

Sample ID	Deposit	Hole ID	Approx. Collar Coordinates (m) Easting	Northing	Down-hole Depth (m)	Major Rock Type
020	Tropicana	TPRC121	48025	143800	18	Saprolite
002		TPRC029	48268	143800	16	Permian sediments
053		TFRC111	48027	143700	13	Gneiss
005		TPRC027	48248	143700	15	Tertiary (ferricrete)
008		TPRC026	48147	143700	16	Saprolite
072		TPRC563	48009	143500	20	Saprolite
075		TFRC058	48148	143500	20	Saprolite
045		TFRC007	48074	143300	20	Saprolite
070		TPRC574	48250	143300	12	Saprolite
040		TPRC588	48052	143050	15	Saprolite
047		TPRC589	48098	143050	20	Saprolite
097		TFRC571	47948	142875	15	Saprolite
080		TFRC1110	48050	142875	25	Saprolite
077		TFRC1120	47874	142800	15	Saprolite
078		TFRC1120	47874	142800	40	Saprolite
083		TPRC008	48043	142800	20	Saprolite
043		TPRC603	48096	142800	20	Saprolite
033		TPRC616	48096	142500	10	Gneiss
035		TPRC617	48205	142500	15	Saprolite
051	Havana	TFRC3010	48200	141975	15	Saprolite
062		TPRC780	48323	141975	19	Saprolite
059		TFRC686	48200	141700	23	Saprolite
037		TPRC322	48450	141700	15	Permian sediments
085		TPRC137	48574	141400	10	Permian sediments
090		TFRC703	48832	141400	8	Saprolite
087		TPRC138	48677	141400	15	Permian sediments
019		TPRC158	48523	141000	14	Schist
056		TFRC716	48666	141000	10	Saprolite
094		TPRC497	48671	140900	15	Permian sediments
013		TPRC152	48426	140800	10	Saprolite
016		TPRC154	48623	140800	20	Saprolite
023		TPRC253	48725	140500	15	Saprolite
067		TPRC1003	48861	140500	13	Saprolite
026		TPRC255	48774	140300	14	Gneiss
029		TPRC300	48900	139800	22	Gneiss

Table A-2: *Lower saprolite samples selected for analysis*

Sample ID	Deposit	Hole ID	Approx. Collar Coordinates (m)		Down-hole Depth (m)	Major Rock Type
			Easting	Northing		
021	Tropicana	TPRC121	48025	143800	30	Saprolite
003		TPRC029	48268	143800	28	Saprolite
054		TFRC111	48027	143700	19	Saprolite
006		TPRC027	48248	143700	30	Saprolite
009		TPRC026	48147	143700	28	Saprolite
073		TPRC563	48009	143500	38	Saprolite
076		TFRC058	48148	143500	53	Saprolite
065		TPRC573	48151	143300	42	Saprolite
071		TPRC574	48250	143300	20	Gneiss
041		TPRC588	48052	143050	37	Saprolite
048		TPRC589	48098	143050	45	Saprolite
098		TFRC571	47948	142875	26	Saprolite
081		TFRC1110	48050	142875	55	Saprolite
079		TFRC1120	47874	142800	62	Saprolite
044		TPRC603	48096	142800	30	Saprolite
011		TPRC105	47947	142500	36	Schist
034		TPRC616	48096	142500	30	Saprolite
063	Havana	TPRC780	48323	141975	26	Saprolite
050		TFRC3011	48224	141975	33	Saprolite
060		TFRC686	48200	141700	32	Saprolite
038		TPRC322	48450	141700	32	Saprolite
032		TPRC137	48574	141400	35	Gneiss
091		TFRC703	48832	141400	30	Gneiss
088		TPRC138	48677	141400	33	Gneiss
092		TPRC665	48573	141000	14	Saprolite
057		TFRC716	48666	141000	21	Saprolite
095		TPRC497	48671	140900	35	Saprolite
014		TPRC152	48426	140800	35	Gneiss
017		TPRC154	48623	140800	32	Saprolite
024		TPRC253	48725	140500	35	Saprolite
068		TPRC1003	48861	140500	25	Saprolite
027		TPRC255	48774	140300	25	Gneiss
030		TPRC300	48900	139800	40	Gneiss

Table A-3: Saprock samples selected for analysis

Sample ID	Deposit	Hole ID	Approx. Collar Coordinates (m) Easting	Northing	Down-hole Depth (m)	Major Rock Type
022	Tropicana	TPRC121	48025	143800	40	Gneiss
004		TPRC029	48268	143800	36	Gneiss
055		TFRC111	48027	143700	30	Gneiss
007		TPRC027	48248	143700	45	Gneiss
010		TPRC026	48147	143700	58	Gneiss
074		TPRC563	48009	143500	50	Gneiss
001		TPRC019	48052	143500	65	Gneiss
046		TFRC007	48074	143300	40	Gneiss
066		TPRC573	48151	143300	64	Gneiss
042		TPRC588	48052	143050	44	Gneiss
049		TPRC589	48098	143050	55	Gneiss
099		TFRC570	47900	142875	75	Gneiss
082		TFRC1110	48050	142875	70	Gneiss
084		TPRC008	48043	142800	65	Gneiss
012		TPRC105	47947	142500	55	Schist
036		TPRC617	48205	142500	60	Gneiss
052	Havana	TFRC3010	48200	141975	28	Gneiss
064		TPRC780	48323	141975	36	Gneiss
061		TFRC686	48200	141700	44	Gneiss
039		TPRC322	48450	141700	43	Gneiss
086		TPRC137	48574	141400	55	Gneiss
100		TFRC702	48777	141400	45	Gneiss
089		TPRC138	48677	141400	55	Schist
093		TPRC665	48573	141000	36	Gneiss
058		TFRC716	48666	141000	40	Gneiss
096		TPRC497	48671	140900	50	Gneiss
015		TPRC152	48426	140800	60	Gneiss
018		TPRC154	48623	140800	47	Gneiss
025		TPRC253	48725	140500	46	Gneiss
069		TPRC1003	48861	140500	60	Gneiss
028		TPRC255	48774	140300	40	Gneiss
031		TPRC300	48900	139800	60	Gneiss

APPENDIX B – PHYSICAL AND CHEMICAL DATA

Table B-1: *Result of analyses for all saprolite materials from Havana: pH, EC, CEC, exchangeable cations*

Sample ID	Regolith Class	pH (-)	EC (dS/m)	Exchangeable cations					CEC (meq /100g)	Base saturation of exchangeable cations				
				Al (meq /100g)	Ca (meq /100g)	Mg (meq /100g)	K (meq /100g)	Na (meq /100g)		Al (%)	Ca (%)	Mg (%)	K (%)	Na (%)
024	LSAP	7.7	1.01		7.36	10.75	0.72	10.07	28.9		25.5	37.2	2.5	34.8
068	LSAP	6.7	1.29		6.5	18.04	2.29	11.54	38.4		16.9	47.0	6.0	30.1
023	USAP	8.6	1.05		4.6	5.0	0.9	4.3	14.8		31.3	33.4	6.0	29.3
067	USAP	5.8	3.85		6.3	17.1	2.4	15.6	41.4		15.3	41.3	5.8	37.7
017	LSAP	8.3	0.10		6.57	7.58	0.32	2.37	16.8		39.0	45.0	1.9	14.1
013	USAP	8.5	0.62		2.2	3.0	0.7	2.5	8.3		26.7	35.6	7.8	29.9
016	USAP	8.0	0.08		3.5	4.3	0.3	1.1	9.2		38.5	46.9	2.9	11.7
095	LSAP	8.6	0.20		2.5	4.03	0.27	2.02	8.8		28.3	45.7	3.1	22.9
092	LSAP	9.2	0.08		3.48	5.25	0.34	3.03	12.1		28.8	43.4	2.8	25.0
057	LSAP	7.2	1.08		6.97	9.62	1.14	5.64	23.4		29.8	41.2	4.9	24.1
056	USAP	7.0	0.82		1.3	3.6	0.8	3.6	9.3		14.0	39.1	8.7	38.2
090	USAP	4.7	1.45	0.34	0.6	2.4	0.8	4.6	8.8	3.9	7.3	27.5	8.7	52.7
060	LSAP	6.7	0.62		2.01	5.21	0.69	3.69	11.6		17.3	44.9	5.9	31.8
038	LSAP	6.9	0.80		5.99	15.03	0.98	11.01	33.0		18.1	45.5	3.0	33.4
059	USAP	5.7	1.05		0.5	2.2	0.5	3.5	6.7		8.1	33.1	6.7	52.0
063	LSAP	6.6	3.08		6.19	19.51	1.92	15.09	42.7		14.5	45.7	4.5	35.3
050	LSAP	7.4	0.86		3.23	7.38	0.78	5.01	16.4		19.7	45.0	4.8	30.5
051	USAP	5.2	1.74	0.98	0.7	3.2	0.6	5.6	11.0	8.9	6.1	28.8	5.3	51.0
062	USAP	5.4	2.78	1.44	3.5	6.9	0.9	8.2	20.9	6.9	16.5	33.0	4.3	39.3

Table B-2: *Result of analyses for saprolite materials from Havana: Nutrients, texture, colour code/description, and Emerson index.*

Sample ID	Regolith Class	Macronutrients (mg/kg)				Micronutrients (mg/kg)				Texture[12]	Munsell Colour Code	Colour Description	Emerson Index[13]
		Total P	Avail. P	Avail. K	S	Cu	Fe	Mn	Zn				
024	LSAP	282	3	1992	93.5	0.1	5	<1	0.2	P	2.5Y 6/4	Light yellowish brown	D
068	LSAP	893	1	1535	151.5	0.8	13	5	0.9	P	10YR 6/6	Brownish yellow	D
023	USAP	349	1	804	109.1	<0.1	2	<1	0.1	G	5YR 6/4	Light reddish brown	F
067	USAP	940	1	1239	513.7	0.5	9	<1	0.4	P	10YR 7/4	Very pale brown	D
017	LSAP	124	1	962	6.9	0.3	3	<1	0.3	P	2.5Y 6/6	Olive yellow	D
013	USAP	253	2	807	68.4	0.2	1	<1	0.5	P	2.5Y 7/4	Pale yellow	F
016	USAP	107	1	679	17.9	0.7	5	<1	0.6	R	7.5YR 4/4	Brown	D
095	LSAP	107	1	893	11.2	<0.1	3	<1	0.2	P	2.5Y 6/3	Light yellowish brown	D
092	LSAP	132	1	1752	4.8	0.4	6	2	0.4	G	2.5YR 5/4	Light olive brown	D
057	LSAP	444	1	815	217.1	0.8	9	<1	1.8	R	2.5YR 3/4	Dark reddish brown	D
056	USAP	314	1	497	92.6	0.3	12	<1	1.2	P	2.5YR 4/6	Red	D
090	USAP	296	1	619	104.7	0.5	4	<1	0.3	G	2.5YR 6/4	Light reddish brown	F
060	LSAP	270	3	697	60.9	0.2	6	9	1.4	P	5Y 4/2	Olive grey	D
038	LSAP	383	1	1499	96.1	0.3	10	23	0.4	P	10YR 5/8	Yellowish brown	D
059	USAP	175	2	275	120.7	0.2	14	<1	1.2	P	10YR 6/8	Brownish yellow	F
063	LSAP	748	3	1092	405.9	0.3	5	<1	3	P	7.5YR 5/6	Strong brown	D
050	LSAP	305	3	641	74.9	0.6	7	3	1.4	G	7.5YR 4/3	Brown	D
051	USAP	225	1	318	214.6	<0.1	8	<1	0.6	P	2.5Y 7/6	Yellow	F
062	USAP	349	2	764	475	0.3	13	<1	0.2	R	7.5YR 6/8	Reddish yellow	F

[12] P – Powdery; G – Gritty/sandy; R – Rocky
[13] D – Potentially dispersive; F – Potentially stable (flocculated)

Table B-3: *Result of analyses for all saprolite materials from Tropicana: pH, EC, CEC, exchangeable cations*

Sample ID	Regolith Class	pH (-)	EC (dS/m)	Exchangeable cations					CEC (meq /100g)	Base saturation of exchangeable cations				
				Al (meq /100g)	Ca (meq /100g)	Mg (meq /100g)	K (meq /100g)	Na (meq /100g)		Al (%)	Ca (%)	Mg (%)	K (%)	Na (%)
034	LSAP	7.4	1.02		3.28	8.64	0.66	9.12	21.7		15.1	39.8	3.0	42.0
035	USAP	3.4	2.75	0.41	1.3	4.5	1.0	8.2	15.4	2.7	8.1	29.3	6.3	53.5
079	LSAP	6.7	2.89		1.13	5.03	0.59	7.99	14.7		7.7	34.1	4.0	54.2
044	LSAP	4.5	2.34	0.81	1.31	6.9	1.03	10.77	20.8	3.9	6.3	33.1	4.9	51.7
077	USAP	5.2	2.05	0.68	0.2	2.2	0.7	5.7	9.5	7.2	2.0	23.4	7.0	60.4
078	USAP	6.4	2.22		0.5	2.6	0.6	5.9	9.7		5.2	27.2	6.6	61.0
083	USAP	8.4	2.60		2.1	2.4	0.6	6.5	11.7		18.0	20.7	5.5	55.8
043	USAP	4.1	1.88	0.53	0.3	2.6	0.5	6.0	10.0	5.3	3.2	26.1	5.1	60.3
098	LSAP	6.7	1.27		1.83	3.03	0.79	7.27	12.9		14.2	23.5	6.1	56.3
081	LSAP	7.5	2.53		2.4	6.59	0.57	17.53	27.1		8.9	24.3	2.1	64.7
097	USAP	4.5	3.31	0.89	0.4	3.8	0.9	9.2	15.2	5.9	2.9	24.9	5.7	60.7
080	USAP	4.9	3.22	0.5	1.8	7.6	1.7	14.2	25.7	1.9	7.0	29.5	6.4	55.2
041	LSAP	7.1	1.15		0.78	2.51	0.38	4.16	7.8		10.0	32.1	4.9	53.1
048	LSAP	6.4	2.30		1.15	4.73	0.37	8.8	15.1		7.6	31.4	2.5	58.5
040	USAP	6.1	2.64		0.3	2.9	0.8	7.6	11.7		2.9	25.1	6.7	65.3
047	USAP	4.4	2.99	1.34	0.7	4.6	1.1	10.5	18.2	7.4	4.1	25.0	5.9	57.7
065	LSAP	7.4	1.14		0.63	3.18	0.35	5.3	9.5		6.7	33.6	3.7	56.0
045	USAP	6.1	1.94		0.4	2.5	0.7	6.2	9.7		3.9	25.6	6.7	63.8
070	USAP	9.2	1.69		16.7	20.7	3.3	18.1	58.9		28.4	35.2	5.6	30.8
073	LSAP	7.6	1.81		0.64	3.95	0.68	7.17	12.4		5.1	31.8	5.5	57.6
076	LSAP	7.2	0.95		0.35	2.31	0.45	3.71	6.8		5.1	33.9	6.6	54.4
072	USAP	8.4	2.63		1.5	3.3	0.8	7.4	13.0		11.6	25.4	6.1	57.0

Sample ID	Regolith Class	pH (-)	EC (dS/m)	Exchangeable cations Al (meq /100g)	Ca (meq /100g)	Mg (meq /100g)	K (meq /100g)	Na (meq /100g)	CEC (meq /100g)	Base saturation of exchangeable cations Al (%)	Ca (%)	Mg (%)	K (%)	Na (%)
075	USAP	6.8	2.09		0.4	2.1	0.7	5.8	9.0		4.5	23.1	7.4	65.1
054	LSAP	9.0	0.39		0.97	1.21	0.28	1.76	4.2		23.0	28.7	6.6	41.7
006	LSAP	8.3	0.40		3.99	10.51	1.28	21.19	37.0		10.8	28.4	3.5	57.3
009	LSAP	7.8	1.00		2.89	7.83	0.77	8.61	20.1		14.4	39.0	3.8	42.8
008	USAP	7.7	0.43		1.9	2.9	0.9	3.3	8.9		20.9	31.9	10.3	36.9
021	LSAP	8.6	0.43		0.76	1.36	0.38	1.94	4.4		17.1	30.6	8.6	43.7
003	LSAP	7.0	2.12		6.63	20.51	2.48	18.54	48.2		13.8	42.6	5.1	38.5
020	USAP	8.1	2.06		1.5	3.2	0.7	7.7	13.2		11.4	24.5	5.6	58.5

Table B-4: *Result of analyses for saprolite materials from Tropicana: Nutrients, texture, colour code/description, and Emerson index.*

Sample ID	Regolith Class	Macronutrients (mg/kg) Total P	Avail. P	Avail. K	S	Micronutrients (mg/kg) Cu	Fe	Mn	Zn	Texture	Munsell Colour Code	Colour Description	Emerson Index
034	LSAP	258	1	2198	100.3	0.1	6	8	0.5	P	2.5Y 6/6	Olive yellow	D
035	USAP	379	1	765	452.9	0.2	26	1	0.4	P	7.5YR 5/6	Strong brown	F
079	LSAP	229	3	1516	209.4	0.1	3	2	0.4	P	5Y 7/6	Yellow	F
044	LSAP	403	7	940	236.9	0.3	14	3	1.1	P	2.5Y 7/2	Light grey	D
077	USAP	263	1	633	185.2	0.1	2	<1	0.1	P	10YR 8/1	White	F
078	USAP	251	3	441	159.7	0.1	1	<1	0.2	P	10YR 8/6	Yellow	F
083	USAP	249	1	518	205.3	0.2	1	<1	0.3	P	2.5Y 8/1	White	F
043	USAP	199	2	376	234.3	0.1	10	<1	0.7	P	2.5Y 7/4	Pale yellow	F

Sample ID	Regolith Class	Total P	Avail. P	Avail. K	S	Cu	Fe	Mn	Zn	Texture	Munsell Colour Code	Colour Description	Emerson Index
098	LSAP	308	1	676	228.3	<0.1	3	<1	0.4	P	10YR 8/4	Very pale brown	F
081	LSAP	222	9	1720	190.1	0.1	5	1	0.8	P	2.5YR 7/8	Light red	D
097	USAP	337	1	1222	307	0.1	4	<1	1	P	2.5Y 8/1	White	F
080	USAP	645	4	1606	292.2	0.5	6	3	0.7	P	7.5YR 6/4	Light brown	D
041	LSAP	148	5	817	107.4	0.2	6	1	0.4	P	5Y 5/2	Olive	D
048	LSAP	144	4	1284	194	0.1	3	2	1.2	P	2.5Y 6/3	Light yellowish brown	D
040	USAP	305	1	675	247.9	0.1	2	<1	0.4	P	10YR 8/1	White	F
047	USAP	417	3	838	297.8	0.4	10	9	0.7	P	10YR 6/6	Brownish yellow	D
065	LSAP	137	3	1117	95.4	0.1	4	2	0.4	R	2.5Y 6/3	Light yellowish brown	D
045	USAP	254	1	441	176.8	0.1	1	<1	0.7	P	2.5Y 8/1	White	F
070	USAP	1284	1	2711	96.5	0.3	6	<1	0.3	G	5YR 5/6	Yellowish red	F
073	LSAP	267	8	1051	132.9	0.2	6	<1	0.2	P	2.5Y 5/6	Light olive brown	D
076	LSAP	174	4	881	78.2	0.2	3	<1	0.3	R	2.5Y 7/6	Yellow	D
072	USAP	308	1	618	235.1	0.2	2	<1	0.4	P	10YR 8/1	White	F
075	USAP	258	1	505	153	0.2	<1	<1	0.2	P	10YR 8/1	White	F
054	LSAP	109	7	749	37.3	0.2	5	<1	0.8	R	2.5Y 5/4	Light olive brown	D
006	LSAP	499	4	2715	38.6	0.1	5	<1	0.5	R	2.5Y 5/4	Light olive brown	D
009	LSAP	300	1	1479	100.1	0.7	5	1	0.7	G	2.5Y 5/3	Light olive brown	D
008	USAP	358	1	800	49.8	0.6	3	<1	3.5	G	2.5YR 5/4	Reddish brown	D
021	LSAP	149	3	627	50.1	0.2	4	<1	0.2	R	2.5Y 6/6	Olive yellow	D
003	LSAP	967	12	1930	197.5	1.6	9	<1	0.7	G	10YR 5/6	Yellowish brown	D
020	USAP	289	1	1002	174.2	0.6	2	<1	0.5	P	5YR 5/6	Yellowish red	F

Table B-5: *Result of analyses for all gneiss and schist materials from Havana: pH, EC, CEC, exchangeable cations*

Sample ID	Regolith Class	pH (-)	EC (dS/m)	Exchangeable cations Al (meq /100g)	Ca (meq /100g)	Mg (meq /100g)	K (meq /100g)	Na (meq /100g)	CEC (meq /100g)	Base saturation of exchangeable cations Al (%)	Ca (%)	Mg (%)	K (%)	Na (%)
Gneiss materials														
030	LSAP	9.5	0.07		5.39	4.96	0.38	2.21	12.9		41.7	38.3	2.9	17.1
031	SAPRK	8.5	0.11		4.74	3.81	0.26	2.03	10.8		43.7	35.1	2.4	18.7
029	USAP	6.0	0.82		1.8	4.4	0.4	5.4	12.0		15.1	36.6	3.3	45.0
027	LSAP	7.2	0.46		2.21	3.87	0.38	3.13	9.6		23.0	40.4	4.0	32.6
028	SAPRK	7.6	0.19		2.27	3.3	0.33	1.72	7.6		29.8	43.3	4.3	22.6
026	USAP	4.9	0.47	0.15	0.8	2.2	0.7	2.0	5.8	2.6	13.0	37.8	12.0	34.7
025	SAPRK	8.9	0.23		1.92	2	0.23	1.7	5.9		32.8	34.2	3.9	29.1
069	SAPRK	9.3	0.16		5.54	7.2	0.72	5.83	19.3		28.7	37.3	3.7	30.2
014	LSAP	8.6	0.15		2.59	3.62	0.24	1.74	8.2		31.6	44.2	2.9	21.2
015	SAPRK	9.3	0.14		2.18	2.81	0.29	1.83	7.1		30.7	39.5	4.1	25.7
018	SAPRK	8.5	0.19		5.71	6.58	0.42	4.09	16.8		34.0	39.2	2.5	24.3
096	SAPRK	8.9	0.13		3.51	4.59	0.31	2.5	10.9		32.2	42.1	2.8	22.9
093	SAPRK	8.6	0.25		1.6	2.35	0.22	1.67	5.8		27.4	40.2	3.8	28.6
058	SAPRK	7.9	0.33		6	9.65	0.42	5.7	21.8		27.6	44.3	1.9	26.2
032	LSAP	7.8	0.52		1.89	4.19	0.56	3.09	9.7		19.4	43.1	5.8	31.8
091	LSAP	7.2	0.54		3.06	8.91	0.79	6.93	19.7		15.5	45.3	4.0	35.2
088	LSAP	6.4	0.64		0.59	2.58	0.22	2.67	6.1		9.7	42.6	3.6	44.1
086	SAPRK	9.3	0.09		1.5	0.82	0.37	0.4	3.1		48.5	26.5	12.0	12.9
100	SAPRK	5.0	0.74	0.2	0.25	3.22	0.42	3.51	7.6	2.6	3.3	42.4	5.5	46.2
061	SAPRK	8.4	0.34		2.63	4.67	0.4	3.65	11.4		23.2	41.1	3.5	32.2
039	SAPRK	9.0	0.09		7.69	15.19	1.03	9.16	33.1		23.3	45.9	3.1	27.7

Sample ID	Regolith Class	pH (-)	EC (dS/m)	Exchangeable cations					CEC (meq /100g)	Base saturation of exchangeable cations				
				Al (meq /100g)	Ca (meq /100g)	Mg (meq /100g)	K (meq /100g)	Na (meq /100g)		Al (%)	Ca (%)	Mg (%)	K (%)	Na (%)
052	SAPRK	7.8	0.45		1.12	2.19	0.36	1.9	5.6		20.1	39.3	6.5	34.1
064	SAPRK	9.1	0.19		4.63	8.09	0.83	4.1	17.7		26.2	45.8	4.7	23.2
							Schist materials							
019	USAP	7.4	1.56		0.6	3.3	0.8	5.1	9.8		6.2	34.2	7.8	51.9
089	SAPRK	9.2	0.09		3.86	5.05	0.41	3.27	12.6		30.7	40.1	3.3	26.0

Table B-6: *Result of analyses for gneiss and schist materials from Havana: Nutrients, texture, colour code/description, and Emerson index.*

Sample ID	Regolith Class	Macronutrients (mg/kg)			Micronutrients (mg/kg)					Texture	Munsell Colour Code	Colour Description	Emerson Index
		Total P	Avail. P	Avail. K	S	Cu	Fe	Mn	Zn				
							Gneiss materials						
030	LSAP	146	1	3438	5.2	<0.1	5	1	0.2	G	5Y 5/3	Olive	D
031	SAPRK	101	1	1799	9.4	<0.1	7	4	0.1	G	5Y 5/3	Olive	D
029	USAP	157	1	697	118.2	0.3	6	1	0.2	G	10YR 5/6	Yellowish brown	D
027	LSAP	149	1	824	66.1	<0.1	5	2	0.1	P	2.5Y 5/4	Light olive brown	D
028	SAPRK	130	1	1224	19.6	0.2	5	2	0.2	G	2.5Y 5/4	Light olive brown	D
026	USAP	269	1	733	80.6	0.2	6	<1	0.2	R	10YR 6/6	Brownish yellow	F
025	SAPRK	91	4	1164	23.2	<0.1	5	<1	0.2	G	2.5YR 6/6	Light red	D
069	SAPRK	281	1	1971	9.9	0.1	8	1	0.2	R	5Y 6/2	Light olive grey	D
014	LSAP	93	1	951	10.9	0.2	3	<1	1.2	R	2.5Y 6/4	Light yellowish brown	D
015	SAPRK	112	1	2265	11.4	<0.1	3	<1	0.6	R	5Y 5/2	Olive grey	D

Sample ID	Regolith Class	Macronutrients (mg/kg)			Micronutrients (mg/kg)					Texture	Munsell Colour Code	Colour Description	Emerson Index
		Total P	Avail. P	Avail. K	S	Cu	Fe	Mn	Zn				
018	SAPRK	162	1	1372	18.9	0.2	5	<1	0.7	R	5Y 5/3	Olive	D
096	SAPRK	121	1	1774	7.8	0.1	9	2	1	R	2.5Y 6/4	Light yellowish brown	D
093	SAPRK	86	4	1235	17.7	0.2	6	2	1.3	G	10YR 6/4	Light yellowish brown	D
058	SAPRK	164	4	1230	31.6	0.2	3	<1	1.3	R	2.5Y 5/3	Light olive brown	D
032	LSAP	220	1	701	60.5	<0.1	2	<1	0.3	P	5Y 5/2	Olive grey	F
091	LSAP	307	1	1188	50.3	0.4	7	9	1.1	R	2.5Y 5/3	Light olive brown	D
088	LSAP	86	2	826	62.2	0.1	3	1	0.5	P	10YR 6/4	Light yellowish brown	F
086	SAPRK	145	1	1149	12.8	1.1	12	7	0.6	G	5Y 5/1	Grey	F
100	SAPRK	165	1	682	75.7	0.2	6	1	0.7	P	5YR 6/6	Reddish yellow	D
061	SAPRK	157	5	1686	23.8	<0.1	4	2	0.1	P	2.5Y 6/3	Light yellowish brown	D
039	SAPRK	401	1	1583	41.9	0.1	9	2	0.3	P	5Y 6/3	Pale olive	D
052	SAPRK	141	1	308	48.4	0.1	6	<1	0.5	P	7.5YR 6/4	Light brown	D
064	SAPRK	322	1	981	14.5	0.7	20	22	0.3	R	2.5Y 5/2	Greyish brown	D
Schist materials													
019	USAP	297	1	583	142.2	0.2	1	<1	1.5	P	7.5YR 8/2	Pinkish white	F
089	SAPRK	161	2	4616	4.1	<0.1	5	2	0.3	P	5Y 5/2	Olive	D

Table B-7: Result of analyses for all gneiss and schist materials from Tropicana: pH, EC, CEC, exchangeable cations

Sample ID	Regolith Class	pH (-)	EC (dS/m)	Exchangeable cations: Al (meq /100g)	Ca (meq /100g)	Mg (meq /100g)	K (meq /100g)	Na (meq /100g)	CEC (meq /100g)	Base saturation of exchangeable cations: Al (%)	Ca (%)	Mg (%)	K (%)	Na (%)
							Gneiss materials							
036	SAPRK	9.3	0.14		2.34	4.38	0.32	3.56	10.6		22.1	41.3	3.0	33.6
033	USAP	5.2	1.94	0.19	1.3	2.6	0.7	5.5	10.3	1.8	12.7	25.0	6.7	53.7
084	SAPRK	8.6	0.70		1.57	4.52	0.62	4.78	11.5		13.7	39.3	5.4	41.6
099	SAPRK	5.9	0.91		1.2	1.33	0.43	1.76	4.7		25.4	28.2	9.1	37.3
082	SAPRK	8.1	0.81		0.8	2.45	0.39	4.44	8.1		9.9	30.3	4.8	55.0
042	SAPRK	7.8	0.55		0.9	2.54	0.54	2.95	6.9		13.0	36.7	7.8	42.6
049	SAPRK	8.0	0.63		1.13	2.76	0.29	4.49	8.7		13.0	31.8	3.3	51.8
071	LSAP	9.2	0.48		3.63	9.3	1.35	9.46	23.7		15.3	39.2	5.7	39.8
046	SAPRK	6.6	1.09		0.57	2.91	0.45	4.81	8.7		6.5	33.3	5.1	55.0
066	SAPRK	8.1	0.84		0.75	2.14	0.37	3.44	6.7		11.2	31.9	5.5	51.3
074	SAPRK	8.5	0.31		0.27	0.94	0.23	1.4	2.8		9.5	33.1	8.1	49.3
001	SAPRK	9.4	0.23		0.85	1.26	0.29	1.88	4.3		19.9	29.4	6.8	43.9
055	SAPRK	8.2	2.56		2.85	7.32	1.43	12.17	23.8		12.0	30.8	6.0	51.2
007	SAPRK	8.7	0.43		2.34	6.85	1.26	10.7	21.2		11.1	32.4	6.0	50.6
010	SAPRK	9.8	0.14		1.14	0.6	0.41	1.22	3.4		33.8	17.8	12.2	36.2
053	USAP	8.8	2.31		65.2	3.2	1.3	8.7	78.4		83.1	4.0	1.7	11.1
022	SAPRK	8.3	0.57		0.77	2.23	0.53	3.1	6.6		11.6	33.6	8.0	46.8
004	SAPRK	9.0	0.32		3.09	6.91	0.68	6.6	17.3		17.9	40.0	3.9	38.2
							Schist materials							
011	LSAP	8.7	0.55		1.55	2.87	0.39	2.55	7.4		21.1	39.0	5.3	34.6
012	SAPRK	8.1	0.62		1.69	4.26	0.48	5.79	12.2		13.8	34.9	3.9	47.4

Table B-8: *Result of analyses for gneiss and schist materials from Tropicana: Nutrients, texture, colour code/description, and Emerson index.*

Sample ID	Regolith Class	Macronutrients (mg/kg)				Micronutrients (mg/kg)				Texture	Munsell Colour Code	Colour Description	Emerson Index
		Total P	Avail. P	Avail. K	S	Cu	Fe	Mn	Zn				
Gneiss materials													
036	SAPRK	124	1	1671	11.2	0.2	10	1	0.8	G	5Y 5/4	Olive	D
033	USAP	270	2	741	259.3	0.2	12	<1	1.1	G	10YR 7/8	Yellow	F
084	SAPRK	240	1	1460	42.4	0.2	3	<1	0.4	G	2.5Y 6/3	Light yellowish brown	D
099	SAPRK	168	1	2952	205.4	1.6	9	4	23.5	G	2.5Y 5/1	Grey	F
082	SAPRK	152	1	2508	61	0.2	7	<1	0.3	P	2.5Y 6/4	Light yellowish brown	D
042	SAPRK	210	11	1102	56.1	1.2	5	5	1.4	R	5Y 4/1	Dark grey	D
049	SAPRK	113	5	1370	57.1	0.1	6	2	0.4	R	2.5Y 5/4	Light olive brown	D
071	LSAP	526	1	1583	36.4	0.4	12	2	0.3	R	2.5Y 6/4	Light yellowish brown	D
046	SAPRK	176	5	1137	106.6	0.4	3	<1	0.9	P	5Y 5/2	Olive	D
066	SAPRK	143	2	2178	67.1	0.1	5	<1	0.4	G	2.5Y 6/2	Light brownish grey	D
074	SAPRK	90	4	1318	22.7	<0.1	4	<1	0.3	R	2.5Y 6/3	Light yellowish brown	D
001	SAPRK	115	3	1898	20.4	0.3	3	<1	0.7	R	5Y 6/2	Light olive grey	D
055	SAPRK	559	4	1132	260.4	0.1	5	<1	0.5	P	2.5Y 5/3	Light olive brown	D
007	SAPRK	490	2	3485	45.8	0.2	7	2	0.5	P	5Y 5/2	Olive grey	D
010	SAPRK	160	1	1913	15.3	0.6	20	6	1	G	2.5Y 4/2	Dark greyish brown	D
053	USAP	524	1	897	209.8	0.2	3	<1	0.8	R	7.5YR 6/4	Light brown	F
022	SAPRK	206	10	1010	63.2	0.5	6	2	0.4	R	2.5Y 6/6	Olive yellow	D
004	SAPRK	267	2	1241	31.9	0.3	10	2	0.2	R	5Y 6/3	Pale olive	D
Schist materials													
011	LSAP	153	1	1498	42.6	0.4	4	<1	2.7	P	2.5Y 5/3	Light olive brown	D
012	SAPRK	185	4	1348	49.7	0.1	5	<1	5.1	P	5Y 5/3	Olive	D

Table B-9: *Result of analyses for all Permian sediments from Havana: pH, EC, CEC, exchangeable cations*

Sample ID	Regolith Class	pH (-)	EC (dS/m)	Exchangeable cations					CEC (meq /100g)	Base saturation of exchangeable cations				
				Al (meq /100g)	Ca (meq /100g)	Mg (meq /100g)	K (meq /100g)	Na (meq /100g)		Al (%)	Ca (%)	Mg (%)	K (%)	Na (%)
094	USAP	5.4	1.56	0.16	0.6	3.0	0.5	4.0	8.3	1.9	6.8	36.8	6.4	48.1
085	USAP	4.5	0.90	0.33	0.1	1.8	0.3	2.7	5.2	6.4	1.7	33.9	6.0	52.0
087	USAP	3.4	1.69	0.56	0.1	2.5	0.4	4.4	8.0	7.0	1.6	31.3	5.4	54.8
037	USAP	4.1	1.00	0.53	0.2	1.7	0.3	3.0	5.8	9.1	4.0	29.6	5.5	51.9

Table B-10: *Result of analyses for all Permian sediments from Havana: Nutrients, texture, colour code/description, and Emerson index.*

Sample ID	Regolith Class	Macronutrients (mg/kg)			Micronutrients (mg/kg)					Texture	Munsell Colour Code	Colour Description	Emerson Index
		Total P	Avail. P	Avail. K	S	Cu	Fe	Mn	Zn				
094	USAP	207	1	458	212.4	0.1	3	<1	0.4	R	2.5YR 5/4	Light olive brown	F
085	USAP	121	1	238	110.5	0.6	4	1	0.7	G	5YR 7/6	Reddish yellow	F
087	USAP	166	1	281	141	0.1	4	<1	0.4	P	2.5YR 5/6	Red	F
037	USAP	124	1	461	167.2	0.1	22	<1	0.5	G	5YR 5/6	Yellowish red	F

Table B-11: *Result of analyses for Permian sediment and Tertiary materials from Tropicana: pH, EC, CEC, exchangeable cations*

Sample ID	Regolith Class	pH (-)	EC (dS/m)	Exchangeable cations Al (meq /100g)	Ca (meq /100g)	Mg (meq /100g)	K (meq /100g)	Na (meq /100g)	CEC (meq /100g)	Base saturation of exchangeable cations Al (%)	Ca (%)	Mg (%)	K (%)	Na (%)
							Permian sediment							
002	USAP	8.3	0.65		5.3	14.2	2.8	12.0	34.4	0.0	15.5	41.4	8.1	35.0
							Tertiary material							
005	USAP	8.1	0.19		4.9	8.6	2.2	6.2	21.9	0.0	22.5	39.3	10.0	28.2

Table B-12: *Result of analyses for Permian sediment and Tertiary materials from Tropicana: Nutrients, texture, colour code/description, and Emerson index.*

Sample ID	Regolith Class	Macronutrients (mg/kg) Total P	Avail. P	Avail. K	Micronutrients (mg/kg) S	Cu	Fe	Mn	Zn	Texture	Munsell Colour Code	Colour Description	Emerson Index
							Permian sediment						
002	USAP	1081	1	1683	51.1	0.4	6	<1	0.8	P	2.5YR 4/4	Reddish brown	D
							Tertiary material						
005	USAP	854	1	1361	5.3	0.2	4	<1	0.3	R	5YR 4/4	Reddish brown	D

Table B-13: *Result of analyses for total metal concentration for all materials tested.*

Sample ID	Rock Type	Regolith Class	Total Hg (mg/kg	Total As (mg/kg	Total Cd (mg/kg	Total Cr (mg/kg	Total Cu (mg/kg	Total Pb (mg/kg	Total Ni (mg/kg	Total Zn (mg/kg
029	Gneiss	USAP	<0.1	<1	<1	40	12	6	30	41
019	Schist	USAP	<0.1	3	<1	15	2	2	5	3
091	Gneiss	LSAP	<0.1	5	<1	126	98	20	193	106
011	Schist	LSAP	<0.1	2	<1	34	24	12	34	112
015	Gneiss	SAPRK	<0.1	<1	1	74	18	7	44	46
086	Gneiss	SAPRK	<0.1	12	1	83	25	14	38	58
036	Gneiss	SAPRK	<0.1	2	<1	93	25	13	64	79
042	Gneiss	SAPRK	<0.1	9	<1	41	69	14	35	130
010	Gneiss	SAPRK	<0.1	<1	1	97	7	11	44	63
012	Schist	SAPRK	<0.1	5	<1	60	39	15	51	80
094	Perm. Sed.	USAP	<0.1	26	<1	51	34	14	12	17
067	Saprolite	USAP	<0.1	<1	<1	119	38	3	23	12
090	Saprolite	USAP	<0.1	7	<1	120	12	11	2	5
083	Saprolite	USAP	<0.1	<1	<1	34	5	6	11	8
040	Saprolite	USAP	<0.1	2	<1	20	1	5	5	4
050	Saprolite	LSAP	<0.1	22	1	238	194	19	81	191
079	Saprolite	LSAP	<0.1	2	<1	40	9	16	27	74
041	Saprolite	LSAP	<0.1	3	<1	46	42	25	11	67
009	Saprolite	LSAP	<0.1	5	<1	68	96	15	81	291
005	Tertiary	USAP	<0.1	<1	<1	55	10	18	9	10