CHAPTER 4 DESCRIPTION OF SOILS

4.1 INTRODUCTION

The aim of this chapter is to present the physical, mineralogical and geotechnical properties of the soils in the study area, as determined during field work and subsequent laboratory investigations. Chemical properties of the soils are discussed in Chapters 5 and 6. The soil sequence along the investigated transect is described and the variations in grading, geotechnical and mineralogical properties within and between the different soil units are shown.

4.2 METHODOLOGY

4.2.1 Field work

Fieldwork was carried out intermittently between January 1998 and June 1998. Twenty-eight test pits along a transect were excavated by means of a truck-mounted backactor (the positions of the test pits are shown in Figure 3.1). The test pits were excavated to a maximum depth of 2,40 m to determine depth to bedrock, pedological conditions and the possible presence of perched ground water bodies. All test pits were logged according to the MCCSSO (moisture, colour, consistency, structure, soil type and origin) method proposed by Jennings, Brink & Williams (1973). Eighty-eight disturbed samples were taken from individual horizons from the test pits for geotechnical, mineralogical and geochemical testing. Seven shallow holes were excavated to a depth not exceeding 0,60 m to take soil samples from the upper soil profile.

4.2.2 Laboratory work

Eighty-eight samples were tested for their geotechnical properties. Thirty samples are from the tailings and the remaining fifty-eight are from the underlying soils. A schedule of the routine soils testing and the methods used appears in Table 4.1.

Table 4.1 Schedule of the routine soils testing and test methods.

Soil property	**Standard / Method / Equipment**
Grain size distribution	ASTM, D 422 & D4318-95 (1996)
Atterberg limits	TMH 1 (1990)
Soil classification	Unified Soil Classification System (ASTM, D2487 - 1969, (1970))
Degree of expansiveness	Van der Merwe (1964)
Mineralogical analyses	Quantitative XRD analyses with Philips XRD unit and Ziemans difrac 80 software

A summary of the grain size distribution analyses, Atterberg test results, soil classification and degree of expansiveness is presented in Table A.1 in Appendix A.

4.3 SOILS

Twenty-eight test pits were excavated along a transect as shown in Figure 3.1. The soils along the transect comprise sandy colluvial material between Test Pits 28 to 16, and clayey alluvial material between Test Pits 15 to 1. The alluvial soils were deposited by the Kromdraai Spruit, a seasonal stream which forms the south-eastern boundary of the study area.

4.3.1 Colluvial soil descriptions and geotechnical properties

The colluvial portion of the transect starts ±75 m north west of the remnants of tailings dam number 4 and extends for ± 480 m towards the south east (Figures 3.1 and 4.1) . Forty-two representative samples (sample numbers MT 16/1 to MT 28/3) were taken, of which twenty-seven are soil samples and the remaining fifteen are tailings.

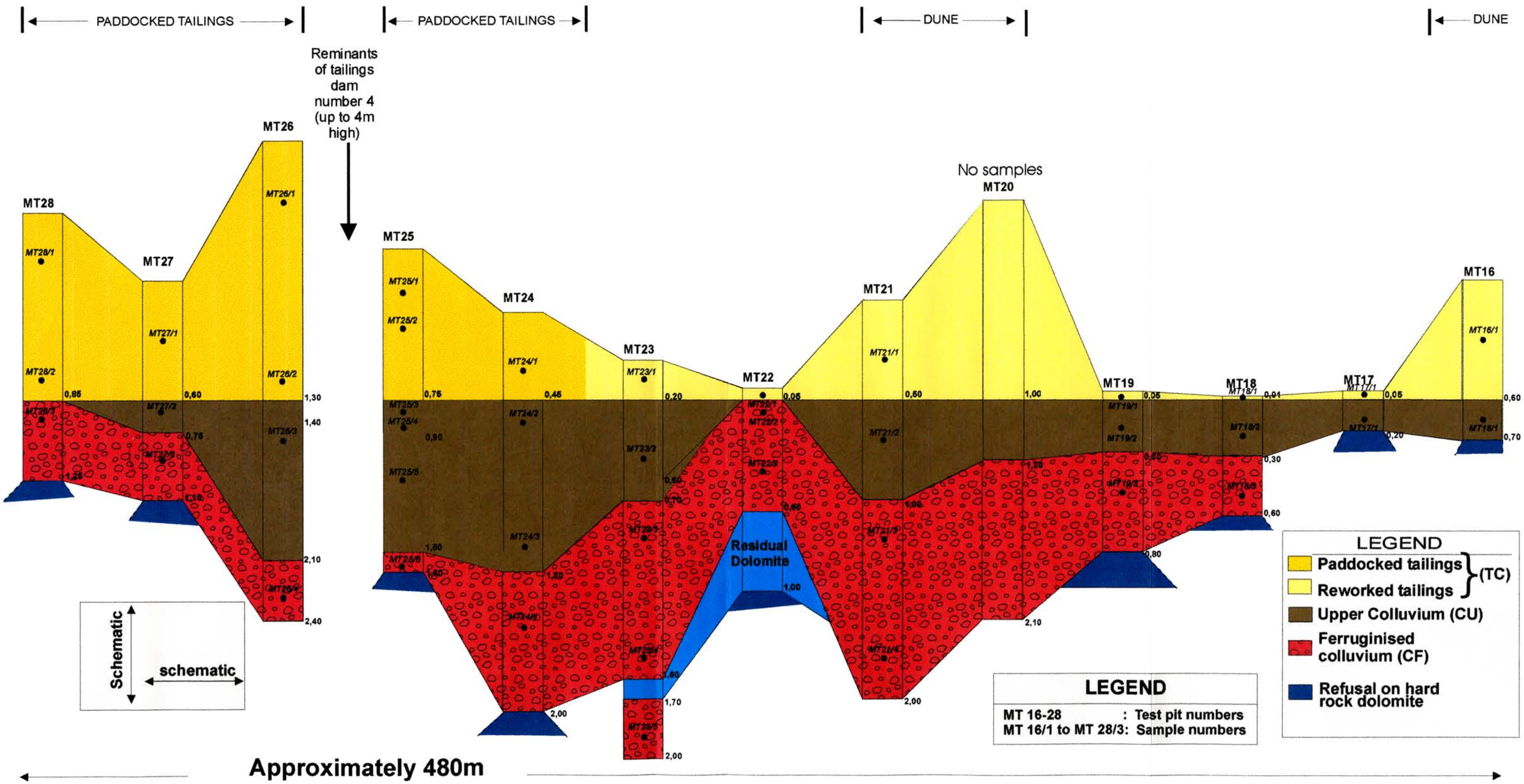


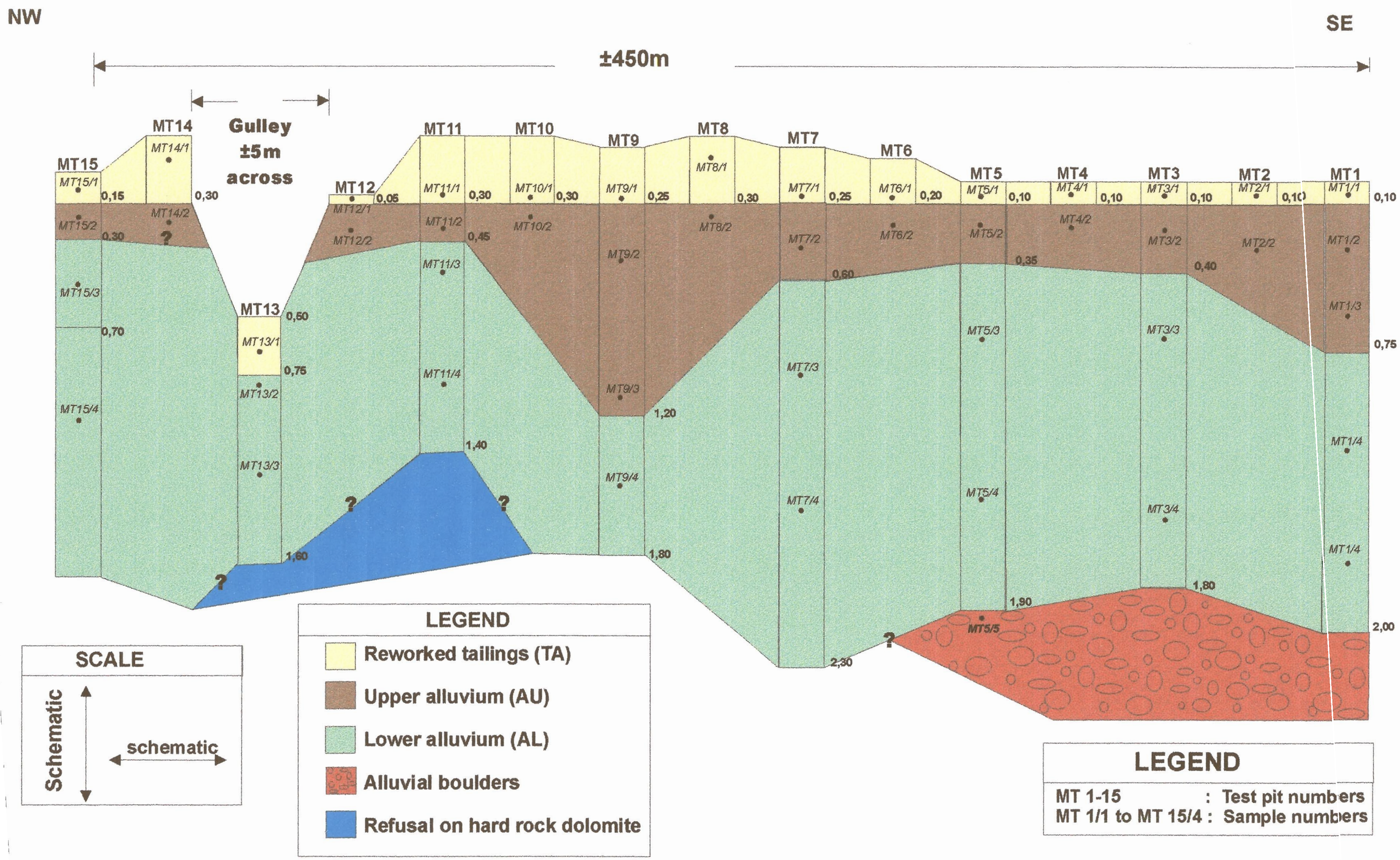
Figure 4.1 Schematic cross section of the colluvial soils and sampling positions

Two distinct soil units occur in the transect underneath the tailings (Figure 4.1). Between Test Pit 28 and 24 the tailings occur as *in situ* paddocked material. Towards Test Pit 16, the tailings occur as eaolian and sheetwash redistributed material. The two tailings units are discussed together as unit TC. Unit CU is a sandy colluvial topsoil unit which is normally underlain by a nodular ferruginised colluvial unit (CF). Unit CF is sometimes underlain by residual dolomite or hard rock dolomite of the Monte Christo Formation. Soil descriptions (after Jennings *et. al.*1979) and Unified Soil Classes of each unit are shown in Table 4.2

The sheetwash / aeolian reworked tailings is mainly composed of sand-sized particles, having on average 67 per cent sand, while the paddocked tailings is mainly composed of silt-sized particles, with silt constituting on average 58 per cent of the samples. Units CU and CF are mainly composed of sandy material with only the nodular ferrugenized unit (CF) having a considerable gravel component (19 per cent on average) consisting of iron / manganese concretions (nodules). All the soil units have a low expansiveness index, indicating that the soils are not prone to swelling.

4.3.2 Alluvial soils description and geotechnical properties

The alluvial soils overlain by reworked gold mine tailings were investigated by means of eight deep test pits and seven shallow test pits (Figure 4.2). The deeper test pits (Test Pits 1, 3, 5, 7, 9, 11, 13 and 15) serve to identify the underlying soils and accommodate sampling, while the remaining shallow test pits were excavated to a depth not exceeding 0,60 m for sampling the upper soil units. This portion starts ±230 m south east of the remnants of tailings dam number 4, progressing ± 480 m south east and terminating on the bank of the Kromdraai Spruit (Figure 3.1). Three characteristic soil units were identified (Figure 4.2) from which thirty-one soil samples and fifteen tailings samples (sample numbers MT1/1 to MT15/4) were taken. Unit TA represents the reworked tailings while AU is an alluvial topsoil unit. Unit AL represents alluvial subsoil which occurs underneath unit AU. Profile descriptions and Unified Soil Classes of each unit are shown in Table 4.3.



igure 4.2 Schematic cross section of the alluvial soils and sampling positions

Table 4.2 Colluvial soil unit description and percentage of Unified Soil Classification classes for each soil unit

Soil unit	Soil Description	Number of samples	(percentage) U.S.C.S. class
Colluvial soils			
TC	Slightly moist, pale yellow brown to light grey, very soft, intact silt; Paddocked or sheetwash and aeolian deposited tailings.	15	(60 %) SM (40 %) ML
CU	Slightly moist, red brown to dark red brown, loose to occasionally medium dense, voided, silty to clayey sand; Colluvium. Unit CU is absent from test pits 22 and 28 indicating these to be disturbed soils.	12	(75 %) SC - SM (17 %) SM (8 %) SC
CF	Abundant coarse-, medium- and fine-grained, sub-rounded to rounded iron / manganese nodules in slightly moist to moist, pale yellow brown or red brown, clayey sand; Nodular ferruginised colluvium. The overall consistency is loose.	14	(50 %) SC - SM (36 %) SM (14 %) SC

SC = Clayey sand, SM = Silty sand, SC - SM = Silty clayey sand, ML = Silt

Table 4.3 Alluvial soil unit description and percentage of Unified Soil Classification classes for each soil unit

Soil unit	**Soil Description**	**Number of samples**	**(percentage) U.S.C.S. class**
Alluvial soils			
TA	This unit is composed of sheetwash and aeolian deposited tailings, consisting of slightly moist, pale yellow brown to light grey, very soft, intact silt.	15	(73 %) ML (13.5 %) CL (13.5 %) SM
AU	Moist, dark grey or dark brown mottled yellow brown, soft to stiff, slightly to distinctly shattered, clay or sandy clay; Alluvium. Monoclinic gypsum crystals (up to 2 cm in length) occur in test pits 9 and 11.	16	(75 %) CL (25 %) CH
AL	Moist, dark grey to dark olive grey, mottled light yellow brown and white, soft to firm with depth, intact or slightly shattered to shattered with depth (slickensided in test pit 11), clay or sandy clay with occasional medium- and fine-grained calcrete and scattered ferricrete nodules with depth. Small sand lenses were observed in test pit 5. Gypsum crystals occur in test pits 9, 13 and 15.	16	(50 %) CL (44 %) CH (6 %) SC

CL = low plastic clay, CH = highly plastic clay, SC = Clayey sand, SM = Silty sand, ML = Silt

The tailings unit (TA) is mainly composed of silt-sized particles, having on average 17,35 per cent clay, 53,89 per cent silt and 28,67 per cent sand. The alluvial topsoil unit AU is composed of approximately equal parts of clay, silt and sand, having on average 36,02 per cent clay, 29,67 per cent silt and 33,49 per cent sand. The alluvial subsoil (unit AU) has however a higher clay content, being on average 43,87 per cent. All the soil units usually have medium to high expansiveness indices, showing the material to be prone to swelling and shrinkage as soil moisture content varies.

4.4 TAXONOMIC CLASSIFICATION AND GENERAL DESCRIPTION OF THE SOILS

According to the South African soil classification system (Soil Classification Working Group, 1991) the colluvial soils are classified in either the Bainsvlei form (profiles MT21, 23, 24 and 25) or the Westleigh form (profiles MT18, 19 and 27)). The diagnostic horizon sequence for the Bainsvlei form is Orthic A / Red apedal B / Soft plinthic B. The Orthic A horizon is just an ordinary topsoil with no special features. The Red apedal B horizon is a structureless to weakly structured well aerated horizon. The Soft plinthic B horizon is a horizon with abundant high chroma (bright red and / or yellow) mottles and / or iron or iron / manganese concretions (nodules) in a soil matrix having at least some grey colours. The Soft plinthic B horizon indicates a layer in which a fluctuating water table, and consequently alternating reducing and oxidizing conditions, is found. In the South African Highveld it has been observed that very intensive lateral movement of water occurs in this layer and that large quantities of dissolved ions are also transported laterally in the process (MC Laker, personal communication). The latter is especially the case for elements which become more soluble in the reduced state. According to the USDA's Soil Taxonomy (Soil Survey Staff, 1975), one of the two international reference soil classification systems, the Bainsvlei and Westleigh soils are both classified as Plintustalfs.

The soils on the alluvial terrace of the Kromdraai Spruit are classified as Rensburg soils according to the South African soil classification system (Soil Classification Working Group, 1991). The diagnostic horizon sequence for the Rensburg form is Vertic A horizon / G horizon.

A Vertic A horizon is a topsoil which has a high content of swelling clays. A G horizon is a sticky clay horizon with dull colours reflecting permanent waterlogging, i.e. a permanent condition of poor aeration (reducing conditions). In the USDA's Soil Taxonomy it is classified as a Vertic Haplaquept.

4.5 MINERALOGICAL COMPOSITION

The mineralogical compositions of the some tailings as well as alluvial and colluvial samples are contained in Table B.1 in Appendix B. Sixty one samples were analysed for their mineralogical composition. These samples include all the alluvial soils and a portion of the colluvial and tailings samples. The averaged mineralogical compositions of the tailings, alluvial and colluvial soils are shown in Table 4.4.

Table 4.4 Average mineralogical compositions of the some tailings, colluvial and alluvial soil samples.

Soil unit	n	Ca	D	Sid	H/G	J	G	T	M	P	Q	Mi	C	S	I/S
TC, TA	20	0,1	0,1	0	0	3,6	0,1	0	0	0,1	84,9	4,3	0,8	1,2	4,7
CU	5	0	0	0	1,2	0	0	1,2	1,2	0	89,4	0,6	0	0	6,8
CF	4	0	0	0	5,3	0	0	14	0	0	70,3	0	0	0	13,7
AU	16	0	0,2	0	0	0	3,4	0	0,9	0,4	78,8	0,3	0	13,4	2,6
AL	16	0,9	0	0,2	0	0	0,1	0	0	0,1	80,8	0,1	0	16,4	1,4

n = number of samples, Ca = calcite, D = dolomite, S = siderite, H/G = haematite / goethite, J = jarosite, G = gypsum, T = todorokite, M = microcline, P = plagioclase, Q = quartz, Mi = mica, C = chlorite, S = smectite, I/S = Illite / smectite interstratification

The tailings material, units TC and TA, is mainly composed of quartz, mica, jarosite and illite / smectite interstratification with calcite, dolomite, gypsum, plagioclase, chlorite and smectite present in trace quantities. The presence of jarosite (3[$KFe^{3+}(OH)_6(SO_4)_2$] indicates that the tailings produce sulphate, as would be expected during acid mine drainage.

The colluvial topsoil, unit CU (representing Orthic A and Red Apedal B horizons), consists mostly of quartz with lesser amounts of haematite / goethite, todorokite, microcline, mica and clay minerals reported as illite / smectite interstratification. The underlying nodular concretionary layer, unit CF (represents Soft plinthic B horizons), shows higher haematite / goethite, todorokite and clay mineral content in the form of illite / smectite interstratifications, as could be expected from a Soft plinthic horizon. Haematite and goethite are Fe-oxide minerals (Fe_2O_3 and α-FeOOH respectively) while todorokite is a Mn-oxide mineral ($NaMn_6O_{12}\cdot 3H_2O$). The Mn-oxide mineral content in the concretions / nodular ferricrete exceeds the Fe-oxide mineral content. The latter is not unexpected in view of the Mn rich dolomite underlying the study area.

The alluvial topsoil, unit AU (representing the Vertic A horizon), is mostly composed of quartz and smectite with lesser quantities of gypsum. Dolomite, microcline, plagioclase and mica occur in trace concentrations. The presence of gypsum,($4[CaSO_4\cdot 2H_2O]$), in excess of 20 per cent in the alluvial topsoil samples MT11/2 and MT13/2, indicates that sufficient sulphate is produced in the tailings to enable the crystallization of gypsum in the topsoil. The underlying alluvial subsoils (unit AL) has less gypsum but increased concentrations of quartz and smectite as well as increased trace quantities of calcite. The presence of calcite ($CaCO_3$) indicates an increase in Ca^{2+} with depth in the alluvial soils. Siderite ($Fe^{2+}CO_3$) occurs in MT3/4, showing that reducing conditions occur with depth in Test Pit MT3. Unit AL represents G-horizons (i.e gleyed soil material). A G-horizon indicates practically permanent wetness and consequently poor aeration. The typical G-colours indicate that iron is in the ferrous (reduced) condition, which facilitates the formation of siderite. It is also logical to have less gypsum, which is relatively soluble, under such wet conditions.

4.6 SUMMARY

SOIL PROPERTIES

- The colluvial soils classify as Westleigh and Bainsvlei soil forms while the alluvium classifies as a Rensburg soil form according to the South African taxonomic soil classification system. According to the USDA's Soil Taxonomy the Bainsvlei and Westleigh soils are both classified as Plintustalfs while the Rensburg soil is classified as a Vertic Haplaquept.

GEOTECHNICAL PROPERTIES

- The tailings deposited on the colluvial soils show a higher sand fraction (50 - 74 per cent) when compared to the paddocked tailings (13 - 60 per cent) and the tailings deposited on the alluvial soils (4 - 60 per cent). This may indicate that the tailings deposited nearest to the remnants of tailings dam 4 has a greater aeolian component than the tailings deposited on the floodplain of the Kromdraai Spruit. The tailings on the floodplain shows a decrease in sand content towards the Kromdraai Spruit which is consistent with the aeolian and sheetwash depositioning processes where finer material are deposited farthest away from the source (Reading, 1996).

- The colluvial soils are sandy, having an average clay content of 10 per cent and an average sand component of 59 per cent. The alluvial soils are however clayey with an average clay content of 37 per cent and an average sand content of 33 per cent.

- The soil profiles at Test Pits MT22 and MT28 are disturbed as the colluvial topsoil unit (CT) is not present. The colluvial topsoil is characterized by a lateral increase in clay content towards the alluvial soils (Test Pit MT15). There is also a decrease in sand content and an increase in gravel content with depth as the nodular ferruginised unit (CF) is encountered. Unit CF usually exhibits a slightly increased clay content when compared with the overlying soils.

- The alluvial soils usually show an increase in clay content with depth with a corresponding decrease in sand-sized particles. Unit AU (alluvial topsoil) shows a lateral increase in clay content towards the Kromdraai Spruit.

MINERALOGICAL COMPOSITION

- The tailings is mainly composed of quartz, mica, jarosite and illite / smectite interstratification while calcite, dolomite, gypsum, plagioclase, chlorite and smectite are present in trace quantities.

- Unit CU consists mostly of quartz with lesser amounts of haematite / goethite, todorokite, microcline, mica and undifferentiated clay minerals. Unit CF has a higher haematite / goethite, todorokite and clay mineral content than unit CU. The Mn - oxide content (todorokite) exceeds the Fe-oxide mineral content in unit CF.

- Unit AU is mostly composed of quartz and smectite, while it contains lesser quantities of gypsum and dolomite, microcline, plagioclase and trace concentration of mica. The underlying unit AL has less gypsum, but increased concentrations of quartz and smectite as well as increased trace quantities of calcite .