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The geology of the coal-bearing rocks of the Karoo Sequence in the Tshikondeni Mine area, northern Transvaal.

by

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for the degree

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in the

Faculty of Science of the

University of Pretoria

Pretoria

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SAMEVATTING

Hierdie studie beskryf die algemene geologie van die Tshikondeni myngebied en poog om die paleoafsettings-omgewing van die verskillende eenhede te rekonstrueer. Die gehalte van die hoof steenkoollae is toe gekoppel aan die afsettingsmodel.

Die paleoafsettingsomgewing is bepaal deur die identifisering van sewe, vertikaal opgestapelde, genetiese eenhede van sedimentasie, wat bestaan uit twaalf veskillende litofasies. Die litofasies is herlei na sedimentêre prosesse, vanwaar 'n paleo-omgewings model afgelei is.

Afsetting, in die Tshikondeni gebied, het begin in glasiale, fluvioglasiale en lakustriene omgewings. Dit is gevolg deur deltaiese, fluviale en lakustriene sedimentasie met geassosieerde steenkoollae. Steenkoolverspreiding, petrografie en gehalte parameters blyk om nou gekoppel aan die kenmerke van die paleoomgewing te wees.

Struktureel is die gebied baie kompleks en baie verskuiwings kom voor. Al die verskuiwings het onstaan as gevolg van verlengings-tektoniek. Intrusiewe basaltiese gange en plate kom algemeen voor en bemoeilik ontginning van die ekonomiese steenkoollae nog verder.

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ABSTRACT

This study describes the general geology of the Tshikondeni Mine area, and suggests a reconstruction of the depositional palaeoenvironment of the different sedimentary units. The palaeoenvironmental model is further related to the quality of the main coal seams.

The sedimentary palaeoenvironment was established by identifying and describing seven vertically stacked genetic units of sedimentation, comprising twelve different lithofacies. These are related to sedimentary processes, from which a palaeoenvironmental model is derived.

The sedimentation at Tshikondeni commenced with glacial, glacio-fluvial and glaciolacustrine deposition. This was followed by deltaic, fluvial and lacustrine settings with associated coal seams. Coal distribution, petrography and quality parameters (ash, volatile matter) appear to be closely related to inferred palaeoenvironmental characteristics.

Structurally, the area is complex and numerous faults occur. The faulting is due to extensional tectonism. Intrusive basaltic dykes and sills are numerous and further complicate exploitation of the economic coal seams.

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1. Introduction.

1.1. Location of the study area.

The eastern Soutpansberg coalfield (Figure 1) is situated north-east of the Soutpansberg mountains and forms part of the Tshipise Basin of Karoo age. Tshikondeni Mine is situated in the north-eastern part of the Republic of South Africa, against the western boundary of the Kruger National Park (Figure 2).

1.2. Aim of his study.

(i) To describe the general geology of the Tshikondeni Mine area.

(ii) To determine and reconstruct the depositional palaeoenvironment of the different sedimentary units, including the economic coal seams.

1.3. Methods.

In an attempt to delineate properly the coal reserves in the area, ISCOR has drilled over 1200 boreholes, of which the author has logged more than 400. The borehole logs were then used to recognize lithofacies, determine their geometry and to establish vertical and lateral facies associations. The sedimentary sequence was then subdivided into eight genetic units of stratigraphy, each defined by distinctive marker horizons. Sedimentary palaeoenvironments are discussed within this framework. In addition, the petrography of the major coal seams was examined and used in depositional modelling.

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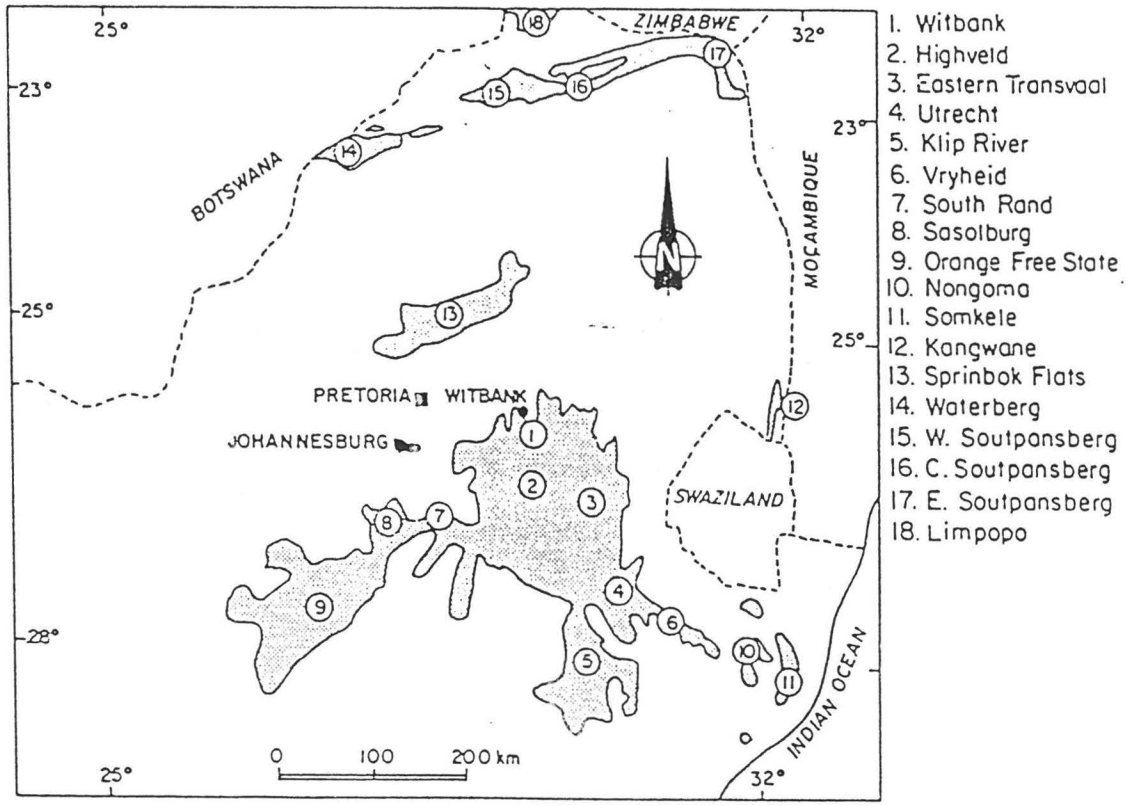


Figure 1. Coalfields within the northern platform facies of the Ecca Group (Redrawn from Snyman and Barclay, 1989).

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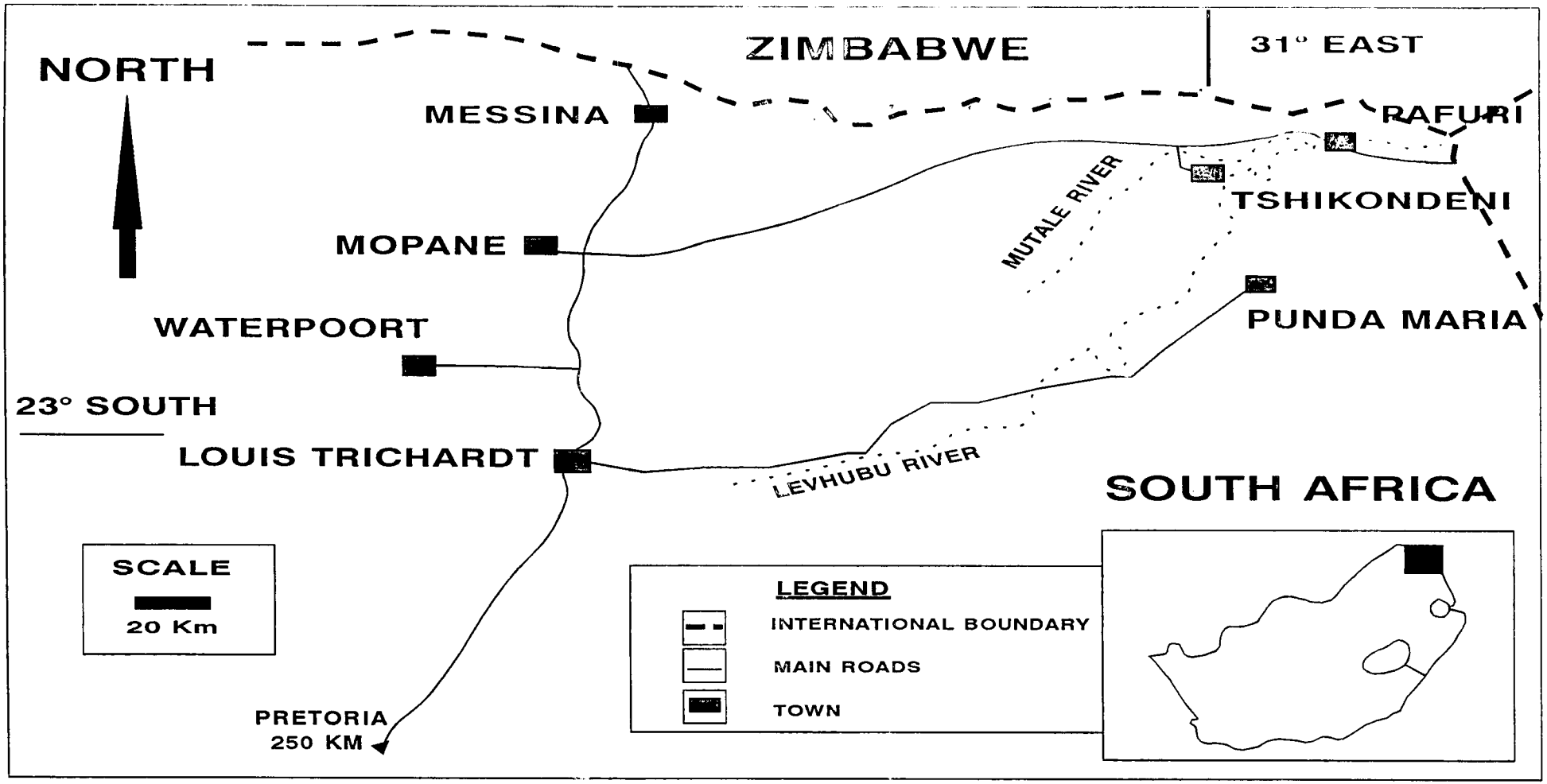


Figure 2. Location of the study area.

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The following definitions for sedimentary structures and grain size are used in this thesis.

1. Lamina - ≤ 0,5 cm thick.
2. Small scale ripple cross-lamination - ≤ 1,0 cm set thickness.
3. Large scale cross-bedding - ≥ 200 cm set thickness.
4. Massive - Beds that are homogeneous and lacking in internal structures over an interval of 80 cm.
5. Rippled and planar laminated - Ripple marks and horizontal laminae between 0,5 cm and 5cm high/thick.
6 Fine-grained - Grain size between 0,10 and 0,5 mm.
7. Medium-grained - Grain size between 0,5 and 1,5 mm.
8. Coarse-grained - Grain size between 1,5 and 4 mm.
9. Band - A coal layer of less than 30 cm thick.
10. Seam - A coal layer of more than 30 cm thick.
11. Stringer - A coal layer of less than 5 mm thick.

The analytical techniques used to determine the petrographic constituents of the coal are those recommended by the International Committee for Coal Petrography (published in the International Handbook of Coal Petrography in 1963, 1971 and in Stach et al., 1982). Maceral analyses were carried out, by ISCOR, under oil-immersion using 25x to 60x objectives and an automatic point counter. Reflectance measurements were taken on the surface of vitrinite particles and carried out in monochromatic green light (wavelength = 546 nm) by means of a photomultiplier.

Maceral group and mineral matter analysis of all the coal seams at an RD of 1,40 were undertaken to determine the changes in these parameters within the stratigraphy, and to relate these changes to sedimentary environments. Unfortunately, al the petrography that ISCOR has done was on the RD 1,40 fraction. The interpretation of the depositional

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conditions would have been more accurate if the raw coal properties (washed at an RD of 1,80) were available but the character of the coal seams can neverteheless be identified.

Ash analysis was done on the coal seams of samples 5 to 14, to determine the changes in these parameters within the stratigraphy and to relate these changes, if any, to depositional environments and/or floral species. Each of the coal seams was sampled and separated at an RD of 1,40 and analysed petrographically by ISCOR.

1.4. Previous work.

In the past most work done on the Karoo succession was concentrated on the Main Karoo Basin and very little literature is available on the study area. In Du Toit (1956) a map showing the Ecca Formation in the study region is published. Truswell (1977) mentioned that exposures of Karoo rocks are found in small areas in the extreme Northern Transvaal, but that these exposures are usually thin and typically contain neither the Dwyka nor the Beaufort and lowermost Stormberg strata. Van der Berg (1980) is the only author to have described any detailed geology from the Tshipise basin. According to Brandl (1981) the Karoo Sequence in the Tshipise basin is a conformable succession of formations and is partly sedimentary and partly volcanic.

1.5. General geology.

1.5.1 Structural geological framework.

The Karoo rocks in the Tshikondeni Mine area (TMA) unconformably overlie rocks of the ± 1750 Ma Soutpansberg

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Group, namely the Mabiligwe and Nzhelele Formations, which consist of quartzite, sandstones, mudrocks and basalt. The TMA is, furthermore, situated on the three-point coupling zone between the Limpopo mobile belt, the Sabi monocline and the Lebombo monocline (Figure 3) (Van der Berg, 1980)

The area under consideration was tectonically active during various geological periods. The Karoo rocks overlie the Archaean-Early Proterozoic Limpopo mobile belt (LMB), with its extensive east-northeast trending linear zones of high grade metamorphic tectonites. The north-eastern margin of the Kaapvaal craton was later down-faulted into a graben structure in which the pre-Karoo Soutpansberg Group was deposited (McCourt and Brandl, 1980). This faulting, which controlled graben formation, continued during deposition of the Karoo sediments and was reactivated in post-Karoo times, resulting in a very complex structural setting (Figure 4). Two main fracture systems have been identified, one trending east-northeast and the other north-northwest.

Karoo age sedimentary rocks in the TMA were deposited in a trough-like depression in rocks of the Soutpansberg Group. Intensive drilling in the area (±1400 boreholes) has shown that the Karoo rocks have been faulted into a series of horsts and grabens. All the prominent faults (throw greater than 60 m) strike northeast-southwest and tend to "meander" along strike (Figure 5). Transfer faults and antithetic normal faults are common. These smaller blocks (horsts and grabens) can be separated by faulting of up to 200 m throw (Figures 5 and 6).

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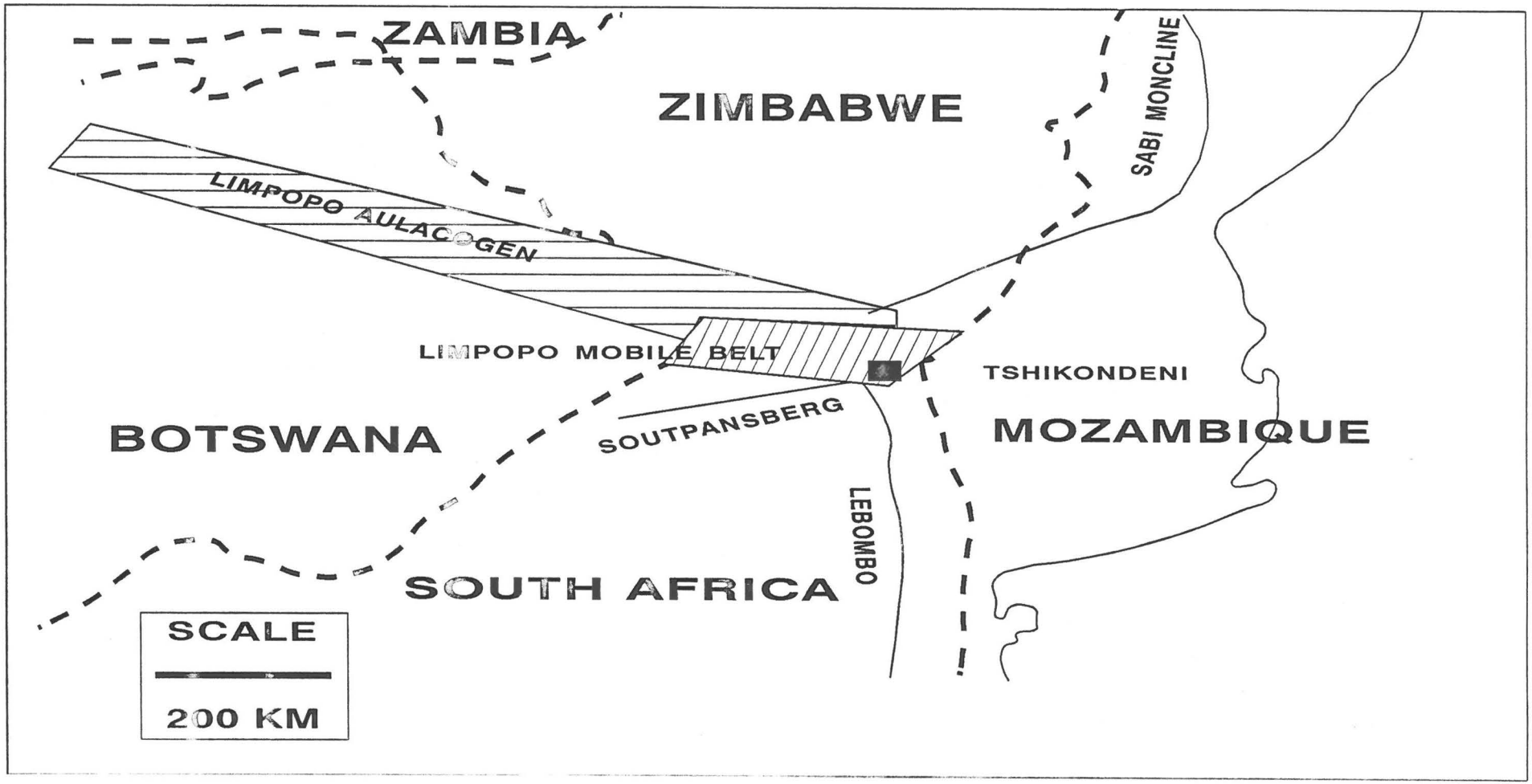
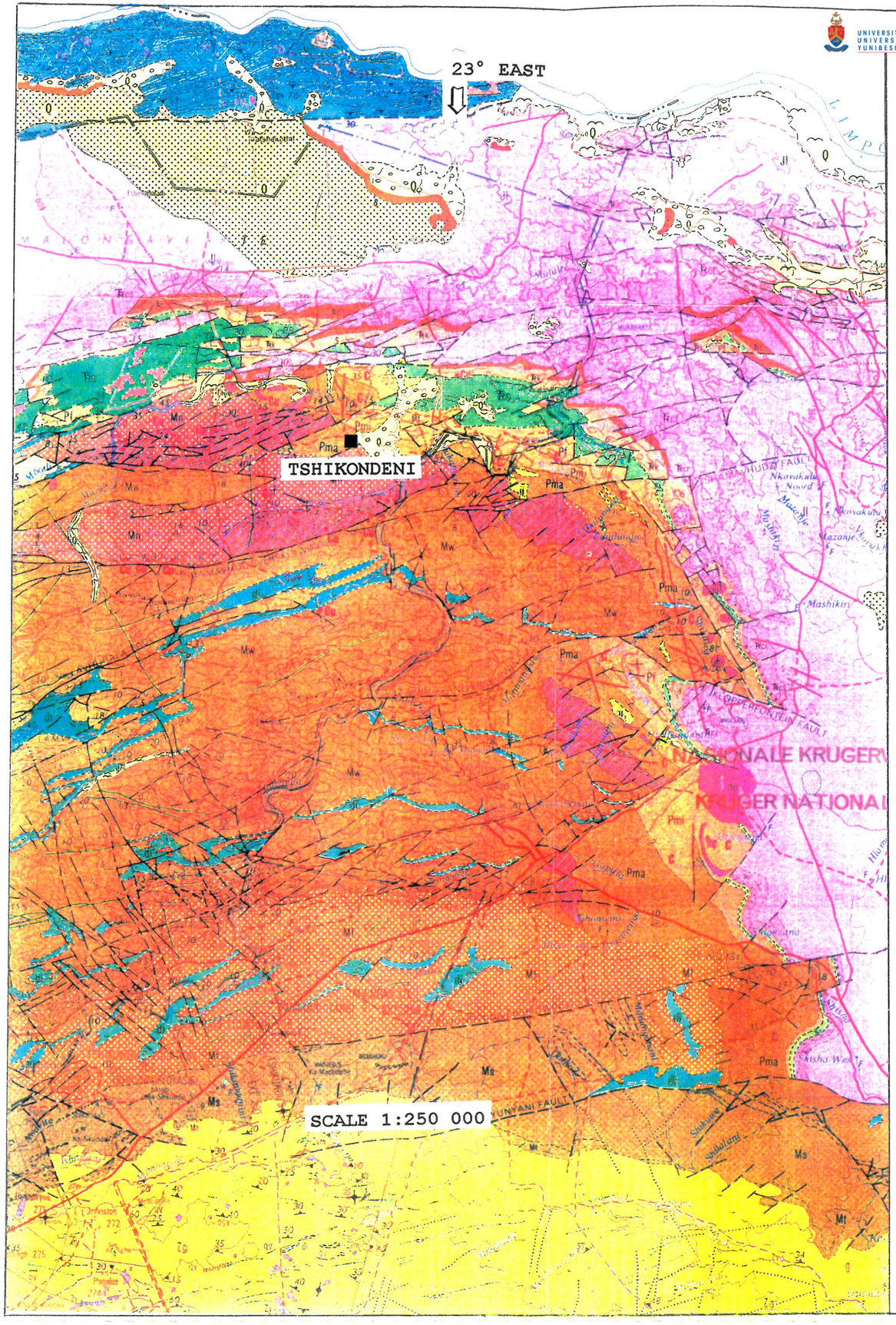


Figure 3. Three-point coupling of the Limpopo mobile belt, Sabi monocline and Lebombo monocline. From Van der Berg (1980).

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LITOSTRATIGRAFIESE EENHEID
LITHOSTRATIGRAPHIC UNIT

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LITHOSTRATIGRAPHIC UNIT

	FORMASIE FORMATION		
KWATERNÊR QUATERNARY			Q
KRYT CRETACEOUS	Malvernia		K
JURA JURASSIC			du, s, ij, ji
TRIAS TRIASSIC	OPEENVOLGING KAROO KAROO SEQUENCE	Jozini	Jj
		Letaba	Jl
		Clarens	Rcc, Rcr
		Bosbokpoort	Rb
		Klopperfontein	Rk
		Solitude	Rs
		Fripp	Pf
PERM PERMIAN		Mikambeni	Pmi
		Madzaringwe	Pma
		Tshidzi	Pt
MOKOLIUM MOKOLIAN	GROEP SOUTPANSBERG SOUTPANSBERG GROUP	Mabiligwe	Mm
		Nzhelele	Mn
		Wyllies Poort	Mw
		Fundudzi	Mf
		Sibasa (Ms) Stayt (Mst)	Ms, Mst
		Tshifhefhe	Mt
RANDIUM RANDIAN			
SWAZIUM SWAZIAN	KOMPLEKS BEITBRUG BEIT BRIDGE COMPLEX	Gumbu ‡	Zgu
		Malala Drift ‡	Zm
		Mount Dowe ‡	Zd
	GROEP GIYANI GIYANI GROUP		Zy
		Sandriviergneis Sand River Gneiss	Zs
	KOMPLEKS BEITBRUG BEIT BRIDGE COMPLEX	Bulaigneis Bulai Gneiss	Zbu
		Messina Suite Messina	Zme
		Jeromegraniet Jerome Granite	Zj
	GROEP GIYANI GIYANI GROUP		Zgy
			Zg

‡ Groep / Group
† Ongedifferensieer/Undifferentiated
Intrusiewe verhouding/Intrusive relation

Figure 4. Regional structural framework of the Tshikondeni Mine area (Adapted from Geological Survey 1:250 000 series).

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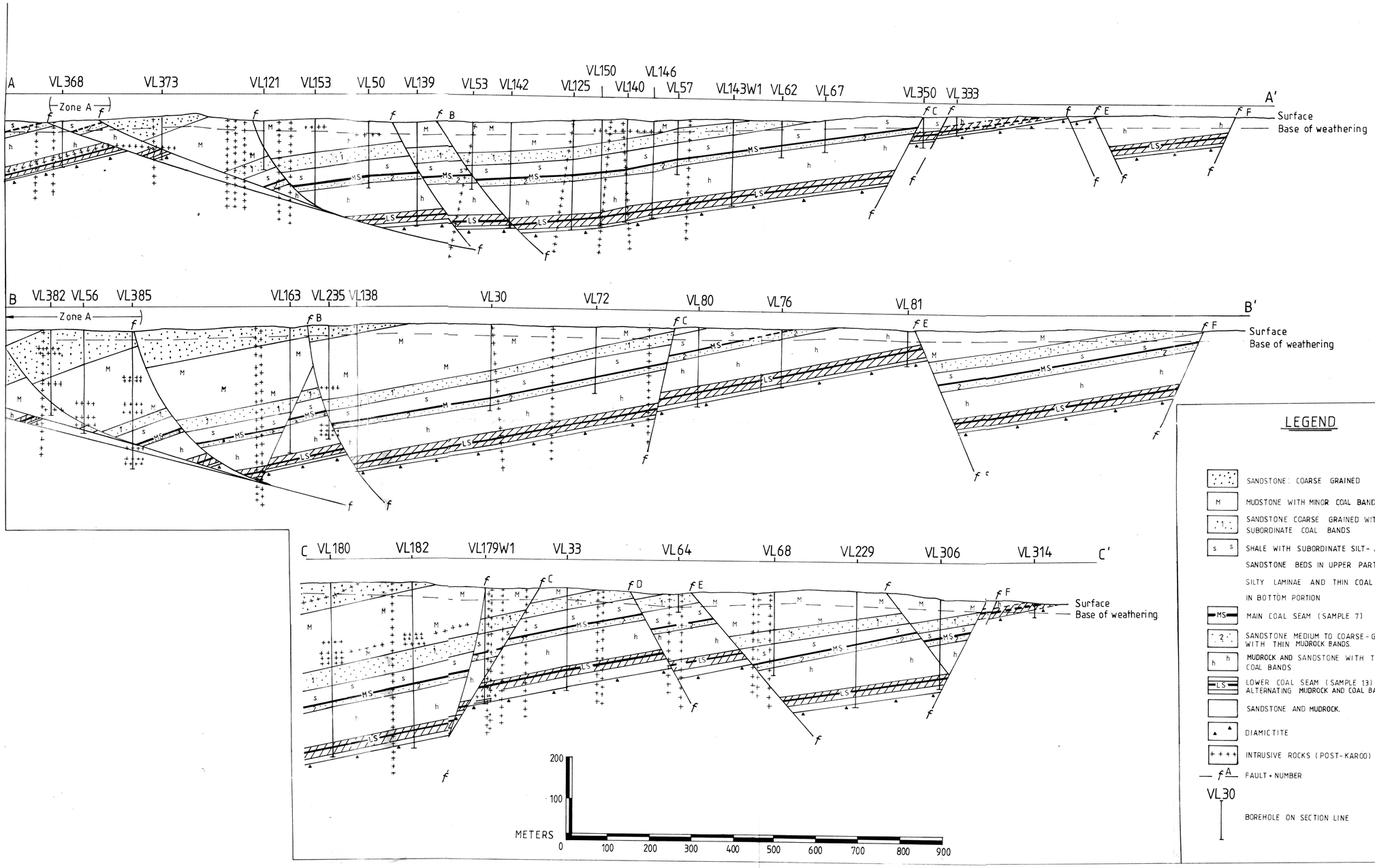
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Figure 5. Detailed structural map of the Tshikondeni Mine area.

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LEGEND

- SANDSTONE: COARSE GRAINED
- M — MUDSTONE WITH MINOR COAL BANDS
- SANDSTONE COARSE GRAINED WITH SUBORDINATE COAL BANDS
- s s — SHALE WITH SUBORDINATE SILT- AND SANDSTONE BEDS IN UPPER PART - SILTY LAMINAE AND THIN COAL BANDS IN BOTTOM PORTION
- MS — MAIN COAL SEAM (SAMPLE 7)
- 2 — SANDSTONE MEDIUM TO COARSE-GRAINED WITH THIN MUDROCK BANDS.
- h h — MUDROCK AND SANDSTONE WITH THIN COAL BANDS
- LS — LOWER COAL SEAM (SAMPLE 13) ALTERNATING MUDROCK AND COAL BANDS.
- SANDSTONE AND MUDROCK.
- DIAMICTITE
- INTRUSIVE ROCKS (POST-KAROO)
- f A — FAULT + NUMBER
- VL30 — BOREHOLE ON SECTION LINE

FRIPP FORMATION
MIKAMBENI FORMATION
MADZARINGWE FORMATION
TSHIDZI FORMATION

Figure 6. North-south profiles through the Tshikondeni Mine area (See figure 5 for profile positions).

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The faulting was caused by extensional tectonism, and the faults are all listric, normal faults. Later erosion left a long, northeast trending strip of detached Karoo rocks, up to 6 km wide, in the Tshikondeni area (Figure 5).

This extensional phase of tectonics occurred in a narrow time span - after deposition of the Karoo sediments and before the extrusion of the uppermost Karoo lavas. This is shown by the fact that all the sedimentary rocks have been extensively faulted in contrast to the relatively undisturbed "dolerite" dykes and sills that fed the lava extrusions. In figures 5 and 6 the position of the dykes was determined by surface mapping as well as magnetometer work carried out over a long period of time by ISCOR in the area. The dip of the dykes was inferred by drilling or magnetometer data.

According to Brandl (1981), minor faulting probably also took place before deposition of the Karoo rocks and it is probable that movement along the Bosbokpoort and Tshipise faults (Figure 4) occurred over a very long time.

1.5.2 Karoo Sequence in the Tshikondeni Mine area.

The Karoo formations in the area are largely covered by deposits of younger, unconsolidated boulder beds of the ± 100 Ma Malvernia Formation (Qb in figure 5) and recent alluvial sand (Qa in figure 5). Locally, the boulders are set in a sandy argillaceous matrix which is cemented by calcrete (Brandl, 1981). The stratigraphy of the Karoo rocks in the TMA is illustrated in Table 1 and Figures 7 and 9. Of the nine Karoo Formations in the region, only the lower four are encountered at the mine itself (Table 1, Figure 9).

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The uppermost Fripp Sandstone Formation (Pf in figure 5) overlies the coal-bearing strata in the Tshikondeni Mine area, and the thickness of this unit varies between 100 and 120 m. It occurs throughout the region and forms prominent ridges striking north-northeast. Cliffs of up to 30 m are common. The contact with the underlying mudrocks is erosive (Figure 8). The colour of the Fripp sandstones varies from white to greenish in places and they are fine-to coarse-grained, with several conglomerate bands.

THICKNESS	STRATIGRAPHIC UNIT	LITHOLOGY	Main Karoo basin correlate
± 120 m	Fripp Sandstone Formation	White, coarse-grained, cross-bedded and massive sandstone with thin pebble layers. Thin green siltstone and mudrock bands common. Burrows common.	Beaufort Formation
± 140 m	Mikambeni Formation	Grey to black laminated mudrock alternating with thin bright coal bands.	Upper Ecca. Volksrust Formation
± 220 m	Madzaringwe Formation	White to grey sandstone and siltstone layers alternating with mudrock layers and coal seams and bands. At the top is a massive sandstone of up to 45 m.	Lower Ecca. Vryheid and Pietermaritzburg Formations.
0-40 m	Tshidzi Formation	Diamictite, pink to grey with sandstone and varved mudrock in places.	Dwyka Formation

Table 1. The Karoo Sequence in the Tshikondeni Mine area. (Adapted from McCourt and Brandl (1980) and SACS (1980)).

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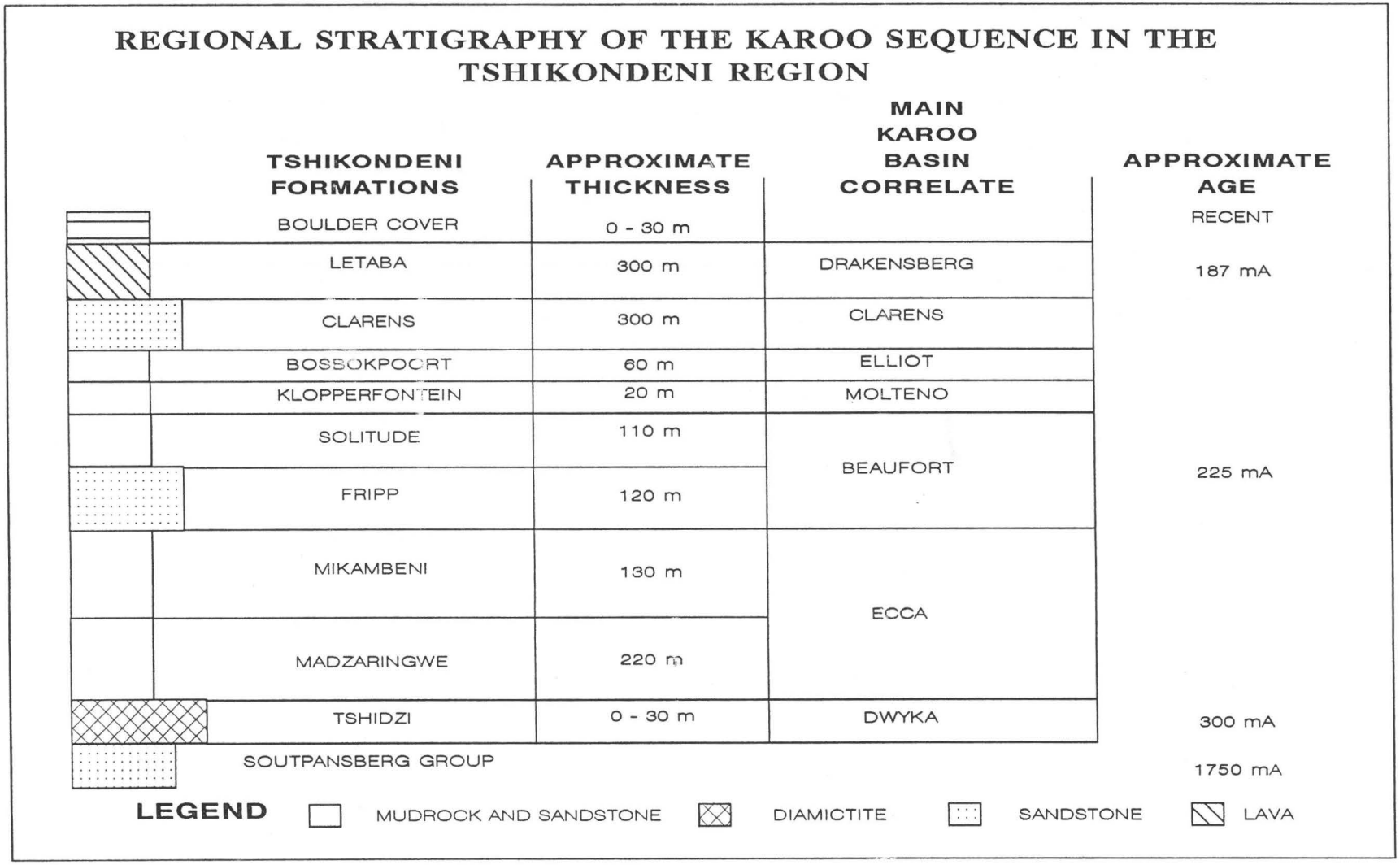


Figure 7. Lithostratigraphic column of the overall Tshikondeni Mine region.

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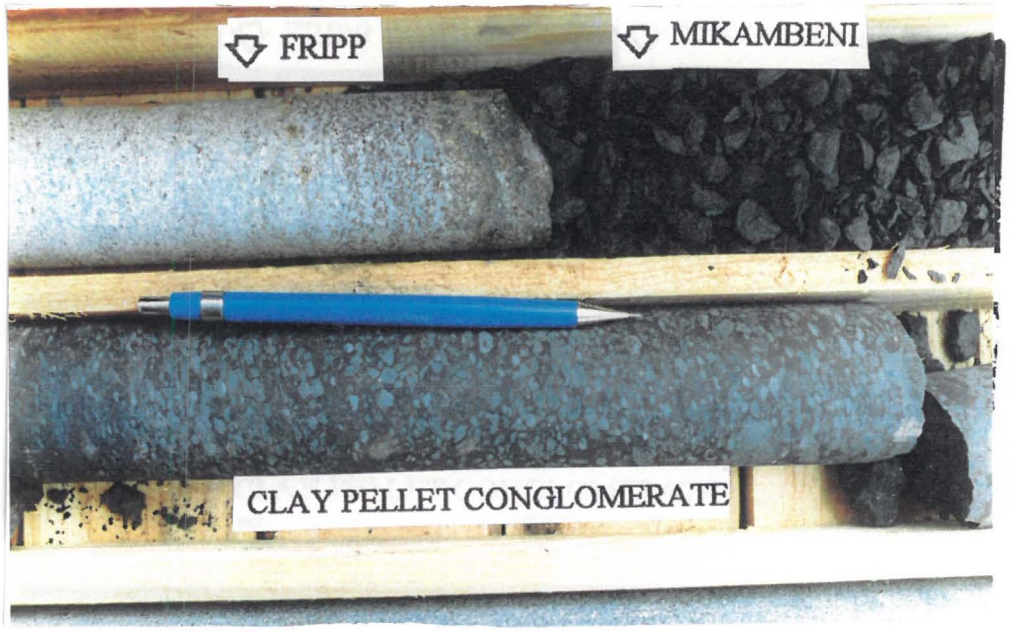


Figure 8. The base of the Fripp Formation (above pencil) and the top of the Mikambeni Formation (GUS7). The clay pellet conglomerate band (below pencil) is found in the upper half of the Mikambeni Formation.

1Angular to subangular pebbles, up to 4 cm in size, are found in some of the conglomerate bands. Worm burrows (Cylindrichnus) of up to 1,5 m in length are common. These are usually vertical and about 1 cm in diameter.

The underlying Mikambeni Formation (Pm in figure 5) consists of mudrock, clay-pellet conglomerate bands with a total thickness of up to 140 m. The thickness is fairly constant. Numerous thin coal seams, bands and stringers are found throughout. Towards the upper half of the formation these are fewer and further apart.

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The Madzaringwe Formation (Pma in figure 5) includes three distinct units, (Mc Court and Brandl, 1980), all of which can be recognized in the Tshikondeni Mine area:

(1) A basal carbonaceous zone, 10 to 40 m thick, consisting of carbonaceous mudrock, coaly mudrock, muddy coal, thin coal seams of up to 60 cm and a 3-4 m thick siltstone marker horizon.

(2) A main coal seam, 3-4 m thick, 100 to 130 m above the carbonaceous zone.

(3) A massive grey to white sandstone, 30 to 60 m thick, at the top of the formation, 30 to 40 m above the main coal seam.

This last unit exhibits numerous upward-fining, medium- to very coarse-grained, micaceous sandstones. It also includes thin bands of mudrock (± 1 m thick) and coal seams (40 cm thick).

The Tshidzi Formation (Pt in figure 5), forming the base of the Karoo succession in the area, consists of diamictite and subordinate thin beds of medium-grained sandstone, thin matrix-supported conglomerate layers and varved mudrock. The varved mudrocks occur sporadically and have only been intersected in a few boreholes. These facies alternate, but the diamictite usually occurs at the bottom of the succession with the sandstones and conglomerates forming a transition zone between the diamictite and the overlying mudrock and coal horizons.

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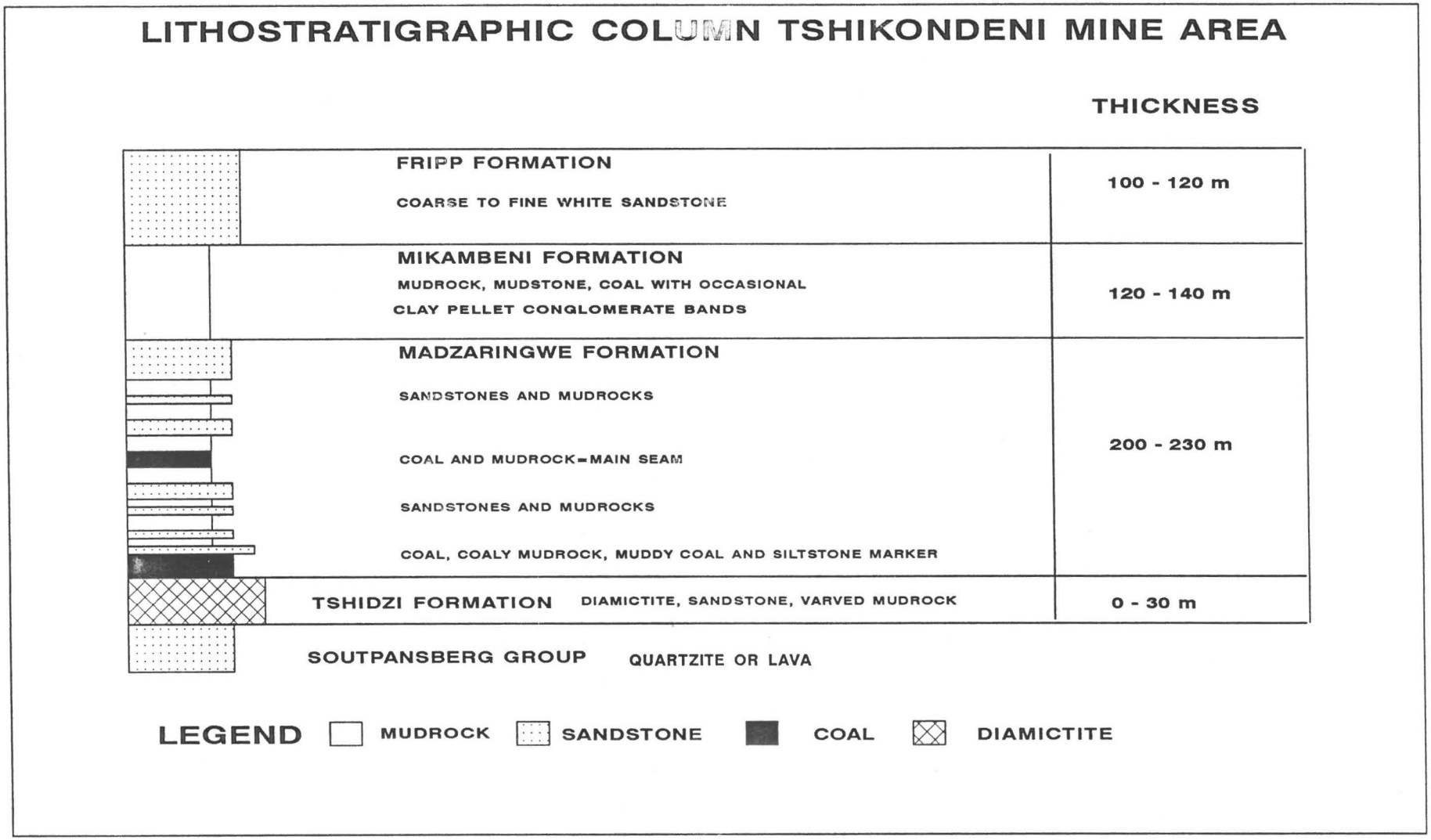


Figure 9. Detailed lithostratigraphy of the Tshikondeni Mine area.

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Over most of the study area, the floor rocks consist of pink, finely crystalline quartzite of the Soutpansberg Group (Nzhelele Formation), but locally, volcanic rocks (Mabiligwe Formation) also occur. The volcanic rocks are fine- to coarsely crystalline and green to brown in colour. Amygdales, of quartz, chlorite and chalcedony, are common in the lava. The floor quartzite is predominantly immature and argillaceous, exhibits thin bedding and ripple marks. Brandl (1981) gives an age for the volcanic rocks of 1750-1770 Ma.

According to Brandl, the sedimentary and volcanic rocks of the Soutpansberg Group were laid down in an elongated, fault-bounded depression, which developed by rifting along a major zone of weakness between the Central and Southern Marginal Zones of the Limpopo Mobile Belt. Cheney et al. (1990) state that the Soutpansberg sequences (± 1759 Ma) are older than the ± 1700 Ma, Waterberg Group.

1.5.3 Intrusive rocks.

"Dolerite" occurs as both dykes and sills (Figure 5). The sills are up to 30 m thick and dykes up to 15 m wide. Contact aureoles vary, but can reach up to 60 m on either side of the dykes. The rocks are fine to coarse crystalline and green to dark green and grey. Yellowish chill margins, flow banding and flow laminations are common. Some dykes have spinifex textures. Fitch and Miller (1984) dated the intrusive doleritic rocks in the northern Lebombo and Soutpansberg regions at 178 ± 5 my. The chemical composition of these rocks, sampled in the Tshikondeni mine, is shown in Table 2:

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The intrusive rocks display porphyritic textures (Figure 10) with olivine, clinopyroxene and elongated ilmenite being the most abundant minerals. The groundmass is very fine crystalline and consists of intergrown plagioclase and clinopyroxene. The olivine grains vary in size between 0,5 mm and 25 mm, are euhedral to sub-euhedral in shape and are commonly altered to serpentine (Figure 11).

Element	Average (Hamilton, 1990) n=100
SiO2	50.50
Al2O3	9.80
Fe2O3	12.84
TiO2	3.75
P2O5	0.64
CaO	8.59
MgO	10.48
Na2O	1.43
K2O	1.76
MnO	0.21

Table 2. Average chemical composition of dolerite samples as determined by XRF analysis (Normalized on a loss-free basis with total iron reported as Fe2O3).

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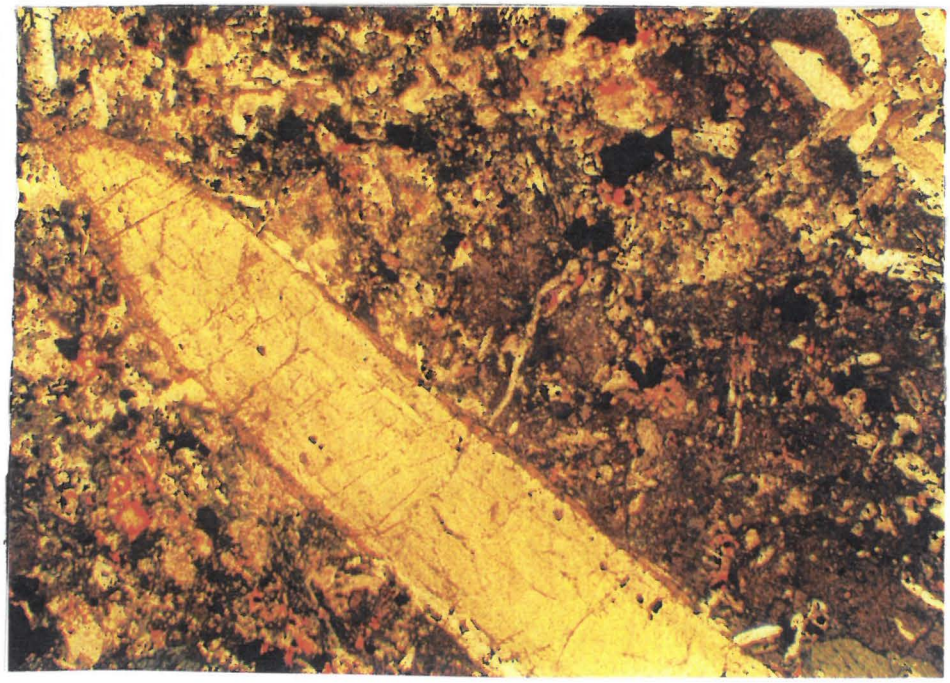


Figure 10. Large phenocrysts are common in the intrusive rocks. Magnification 10X. Crossed nicols.

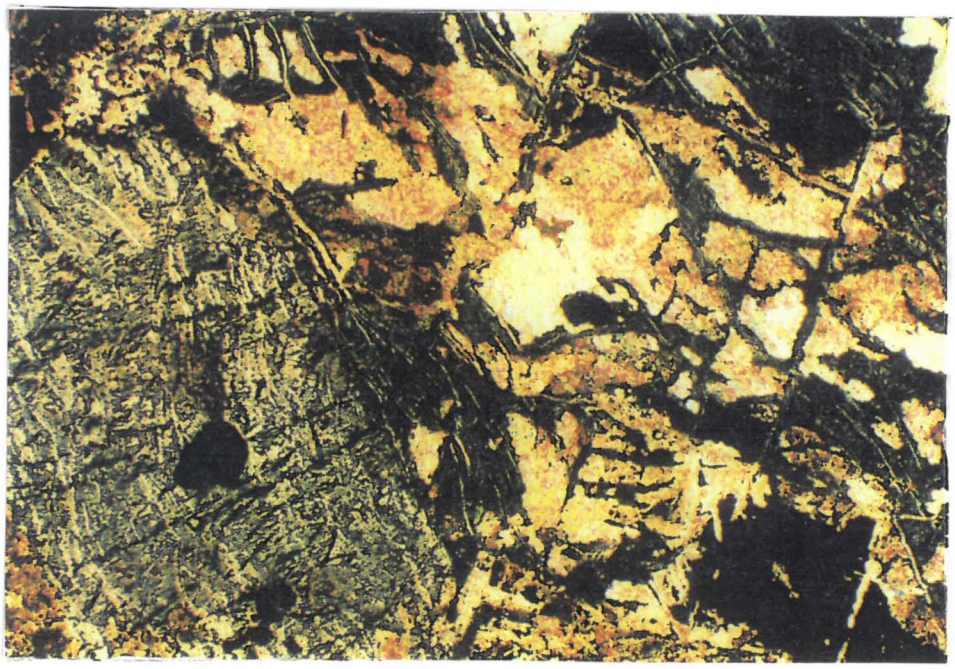


Figure 11. Alteration of olivine to serpentine in the intrusive rocks. Magnification 10X. Crossed nicols.

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At the contacts with the country rocks (Figure 12), the "dolerite" has usually undergone alteration, and this zone varies from 0-1 m in width. The alteration involves replacement of the groundmass by calcite, dolomite and chlorite (Hamilton, 1990). Fragments of coal and wall rock are also found in these alteration zones, indicating that assimilation of country rock occurred. Brecciation and fracturing at the contacts are common, as are slickensides.

Hamilton (1990) came to the following conclusions after investigating the intrusive rocks at Tshikondeni:

(1) They are basaltic (Table 2) and are associated with the Letaba Basalt Formation.

(2) All are related in space and time by fractional crystallization.

(3) Borehole-to-borehole correlation is of limited value to which this writer concurs.

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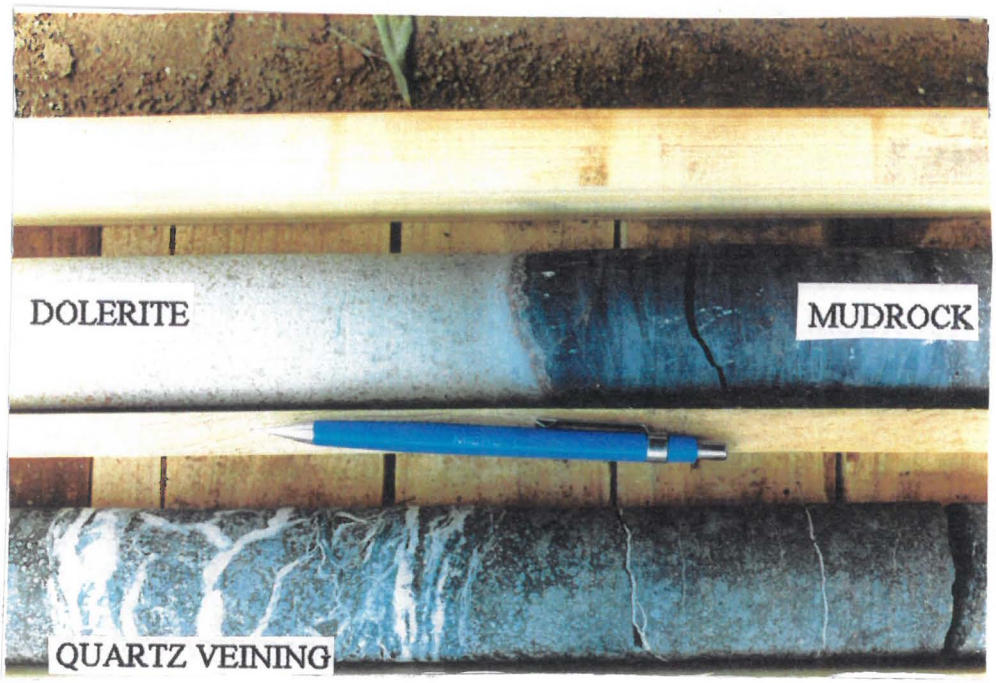


Figure 12. Contact between altered "dolerite" and host rock (here mudrock (above pencil)). The dolerite below the pencil has a typical green colour and shows some quartz-veining.

2. Lithofacies.

Twelve lithofacies are identified in the study area (Table 3).

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Diamictite facies	(D) Massive diamictite
Sandstone facies	(S) Large scale cross-bedded sandstone (Sr) Ripple cross-laminated and planar laminated sandstone/siltstone (Sg) Graded sandstone (Sm) Massive sandstone
Mudrock facies	(Mv) Varved mudrock (Mu) Undifferentiated mudrock (Mp) Mudrock with quartz grains and quartz pebble bands (Ml) Mudrock with silty laminae and convolute laminations (Mm) Massive black mudrock (Mc) Clay pellet conglomerate
Coal facies	(C) Coal

Table 3. Facies identified in the Tshikondeni Mine area.

Table 4 gives a summary of the facies types and their primary distinguishing characteristics. Volumetrically, the following facies make up the bulk of the Tshidzi, Madzaringwe and Mikambeni Formations (facies in order of importance):

Tshidzi - D, Sg, Sm, Mv and Mm.
Madzaringwe - Sr, Sg, Ml, Mp, S, Sm, Mm and C.
Mikambeni - Mu, C and Mc

The proportions of lithotypes within the Karoo formations in the TMA are shown in Figure 13.

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Facies (Code)	Distinguishing Characteristics
Diamictite facies (D)	Maximum thickness of 8 m. Boulders of up to 2 m in diameter. Extrabasinal clasts of lava and quartzite. Poorly sorted. Clast- to matrix-supported. Erosive basal contact. Found throughout the TMA.
Large scale cross-bedded sandstone (S)	Maximum thickness of 3 m. Large scale trough and planar cross-bedding. Grain-supported. Medium- to coarse-grained. Poorly to well sorted.
Ripple cross-laminated sandstone/siltstone (Sr)	Maximum thickness of 10 m. Fine- grained. Ripple and planar lamination. Upward-fining or -coarsening. Bioturbated (Cylindrichnus) in places. Soft sediment deformation structures.
Graded sandstone (Sg)	Maximum thickness of 3 m. Medium- to coarse-grained. Good sorting. Angular to subangular grains. Soft sediment deformation structures and bioturbation (Cylindrichnus) in places.
Massive sandstone (Sm)	Maximum thickness of 2 m. Medium- to coarse- grained. Well sorted. Bioturbated (Cylindrichnus) in places. Difficult correlation over TMA.
Varved mudrock (Mv)	Maximum thickness of 1 m. White to grey. Finely laminated. Dropstones of up to 150 mm. Poor lateral correlation.
Undifferentiated mud-rock (Mu)	Maximum thickness of 160 m. Grey to black. Thin siderite bands (< 30 cm) common. Imprints of Glossopteris throughout. Good correlation over TMA.
Mudrock with quartz grains and quartz pebble bands throughout (Mp)	Maximum thickness of 15 m. Grey to black. Quartz grains and pebble bands common. Good correlation over TMA.
Mudrock with silty la-minae and convolute laminations (Ml)	Maximum thickness of 8 m. Dark grey. Erosional truncation of silty laminae in places.
Massive black mudrock (Mm)	Maximum thickness of 15 m. Black. Carbonaceous. Associated with coal.
Clay pellet conglome-rate (Mc)	Maximum thickness of 1 m. Occurs in the upper part of the Mikambeni Formation. Angular to spherical mudrock clasts of up to 5cm. Locally imbricated. Occurs throughout the TMA but is not easily correlated.
Coal (C)	Maximum thickness of 1 m. Alternates with mudrock. Medium volatile bituminous coal. Two main seams - samples 7 and 13C.

Table 4. Facies types and their distinguishing characteristics.

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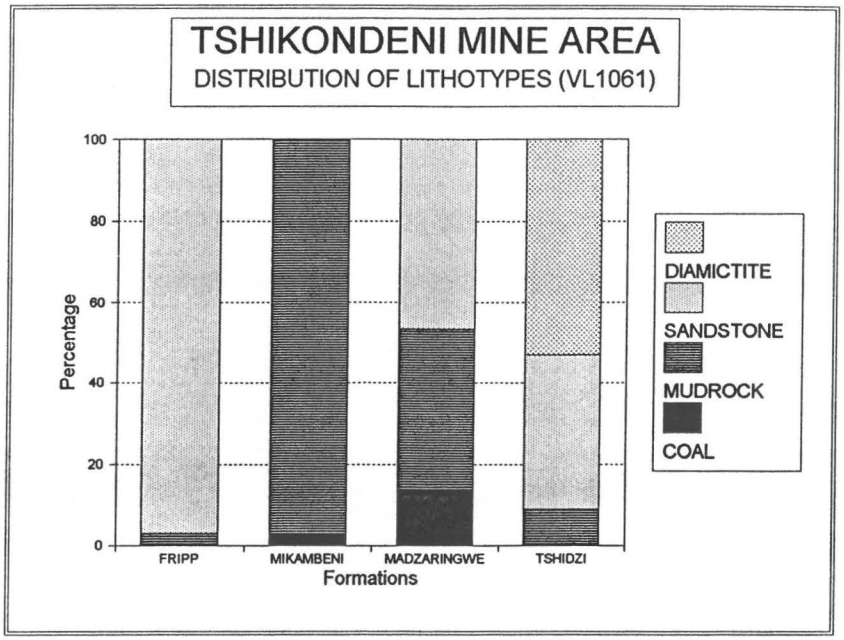


Figure 13. The proportion of lithotypes in the Tshikondeni Mine area stratigraphy.

2.1 Diamictite facies

Massive diamictite (D)

Over most of the study area, diamictite is found on top of the Soutpansberg palaeofloor. The top contact varies from sharp to gradational but the bottom contact with the Soutpansberg rocks is always sharp and unconformable (Figure 14).

The diamictite facies is massive, clast- to matrix-supported, poorly sorted, polymict and consists of fragments of varying size and shape (Figure 15). The fragments are unsorted and

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show no specific orientation. The diamictite occurs as individual layers between 0,25 and 8 m thick. The colour varies from pink and grey to bluish-green. Clasts are rounded to subrounded, can attain a size of up to 2,1 m (Figure 16), and consist mostly of Soutpansberg quartzite and lava set in a sandy or muddy matrix. The diamictite has an upwards-fining tendency in places. The clasts vary in size (Figures 15, 16 and 16a).

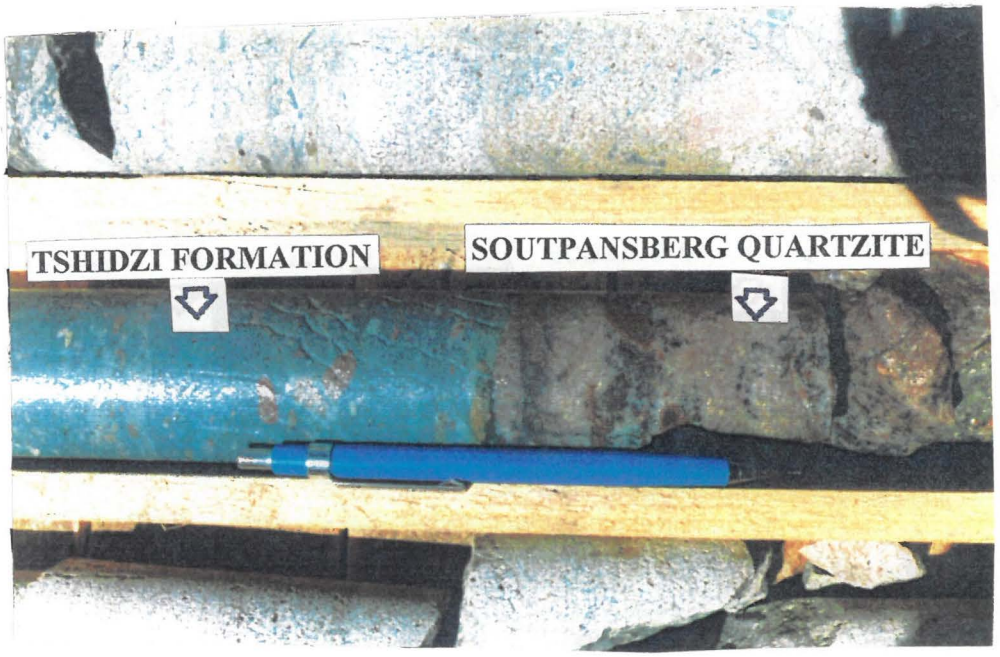


Figure 14. The contact (above pencil) between the Soutpansberg quartzite and the Tshidzi Formation (in VL1061).

The green variety is matrix-supported (Figure 14). The clasts are polymict but more angular than the pink variety. According to Van der Berg (1980), clasts of up to 2 m have been found west of Tshipise. McCourt and Brandl (1980) identified clasts up to 600 mm at the type locality of the Tshidzi Formation.

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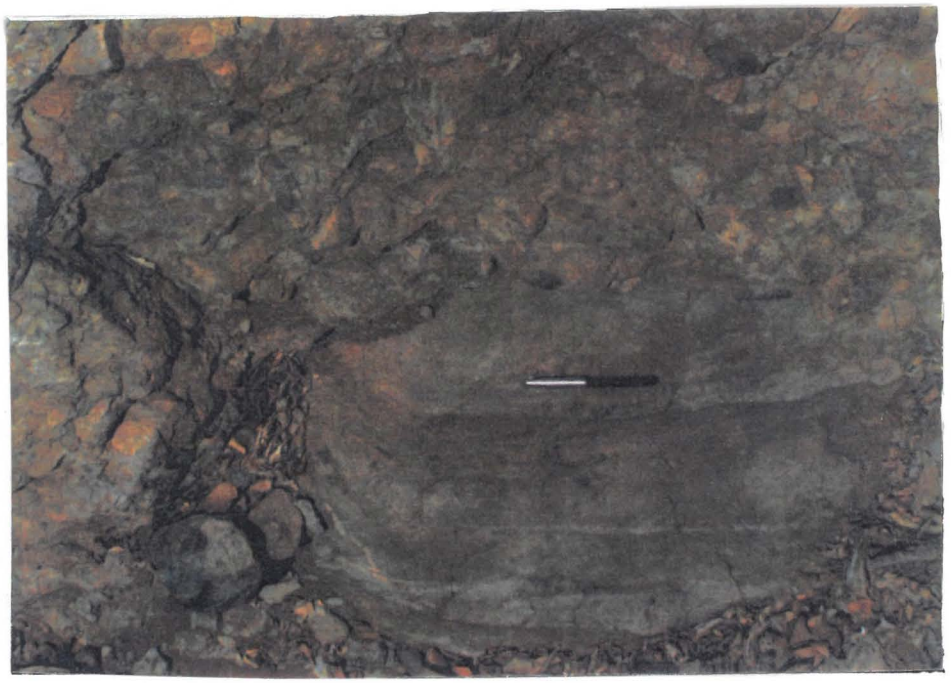


Figure 15. Diamictite outcrop in an area near the Tshikondeni mine.



Figure 16. Large boulders of Soutpansberg quartzite, found in the diamictite.

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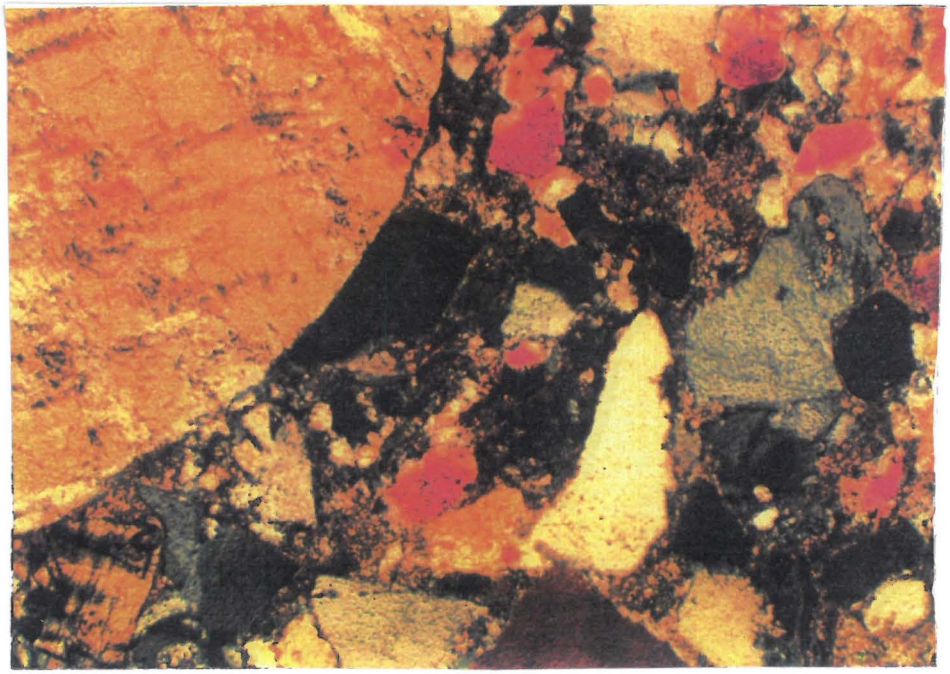


Figure 16a. Photomicrograph of rounded quartzite pebble (dropstone), top left of picture. Magnification 10X. Crossed Nicols.

The diamictites are locally interbedded with medium- to coarse-grained, massive (Sm) sandstones or varved mudrocks (Mv). The sandstone layers are up to 50 cm thick and exhibit dewatering structures.

2.2 Sandstone facies.

2.2.1 Large scale cross-bedded sandstone (S).

This lithofacies consists of units of varying thickness (0,5 - 3 m) scattered throughout the TMA succession. The sandstones are light grey to white in colour, medium- to coarse-grained, and exhibit low angle planar (± 10mm set thickness and foreset dip angle < 2°) and trough cross-bedding (± 2m trough depths).

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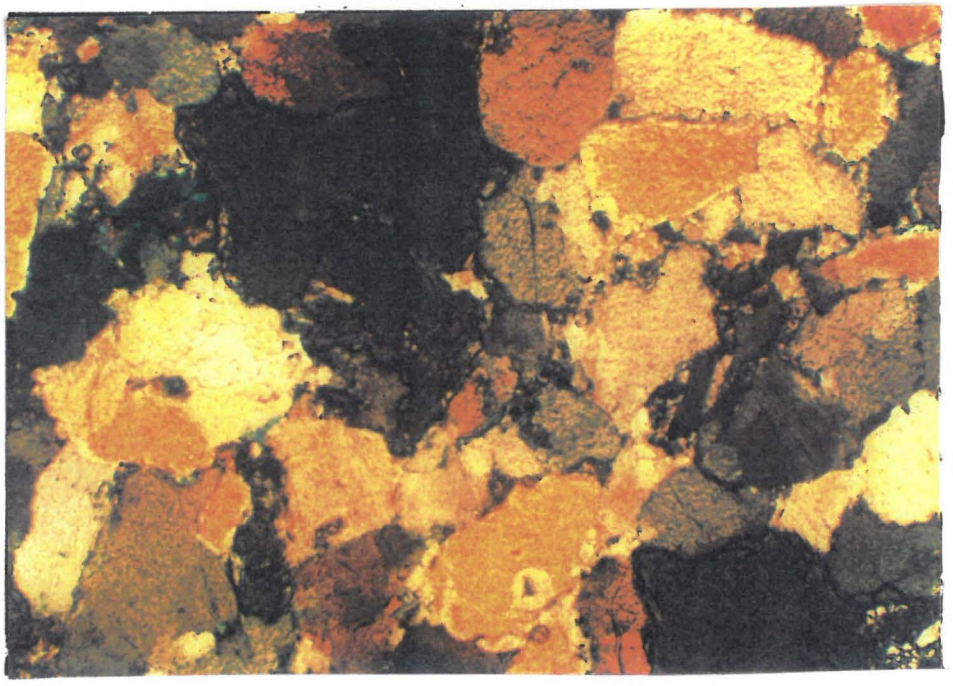


Figure 17. Coarse-grained sandstone, Facies S. Magnification 10X. Crossed Nicols.

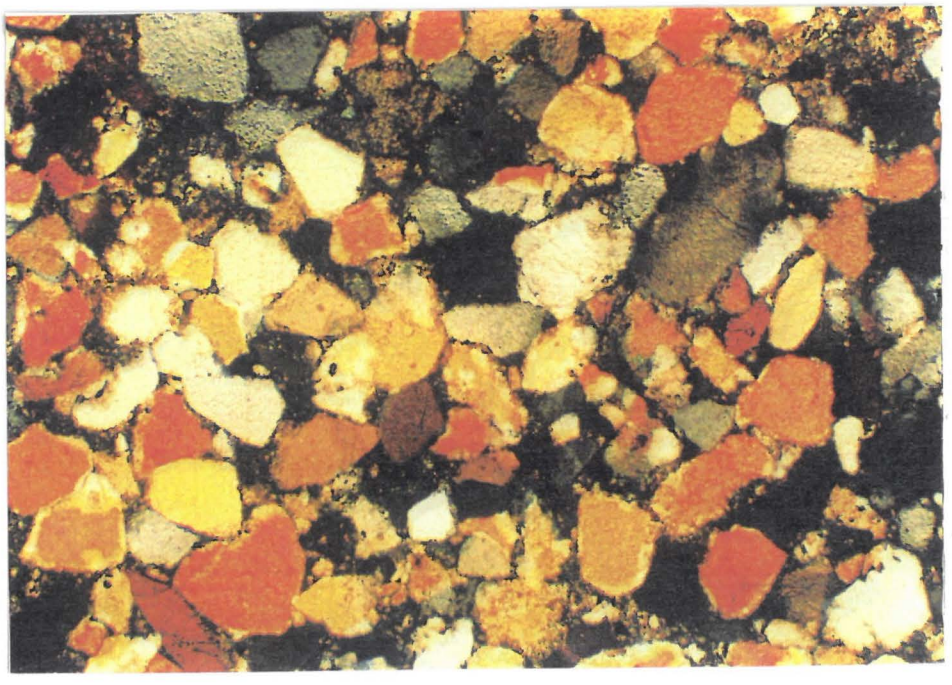


Figure 18. Medium-grained sandstone, Facies S. Magnification 10X. Crossed Nicols.

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These sandstones contains mica and is slightly feldspathic; the feldspars are usually partly weathered to kaolinite, which enhances the white colour of this facies. The facies is mainly grain-supported and well to poorly sorted (Figure 17). The grains consist primarily of quartz. The finer-grained variety shows better rounding of the grains (Figure 18). Occasional bioturbation (Cylindrichnus worm burrows) is found in the facies. The lateral correlation of this facies is problematic, but it occurs throughout the study area.

2.2.2 Ripple cross-laminated and planar laminated sandstone/siltstone (Sr).

These rocks are white to light grey, fine-grained and consist of quartz grains and densely packed biotite flakes (Figure 19). Climbing ripple structures are the most common, with individual ripples not higher than 2 cm. Subordinate planar laminae are mostly approximately 0,5 cm thick. The contacts of this facies are usually gradational and the thickness varies between 0,5 and 7,0 m. This facies is generally upward-fining or upward-coarsening (Figure 20). When the facies becomes coarser, the climbing ripples tend to disappear and the facies then grades into a graded sandstone (Facies Sg).

This facies generally occurs at the top and base, respectively, of upward-fining or upward-coarsening sandstone units, which are more than 10 m thick and which occur throughout the Madzaringwe Formation. When Facies Sr occurs at the bottom of such an upward-coarsening sandstone unit, it usually grades from mudrock to siltstone to fine-grained sandstone over a distance of about 2 m.

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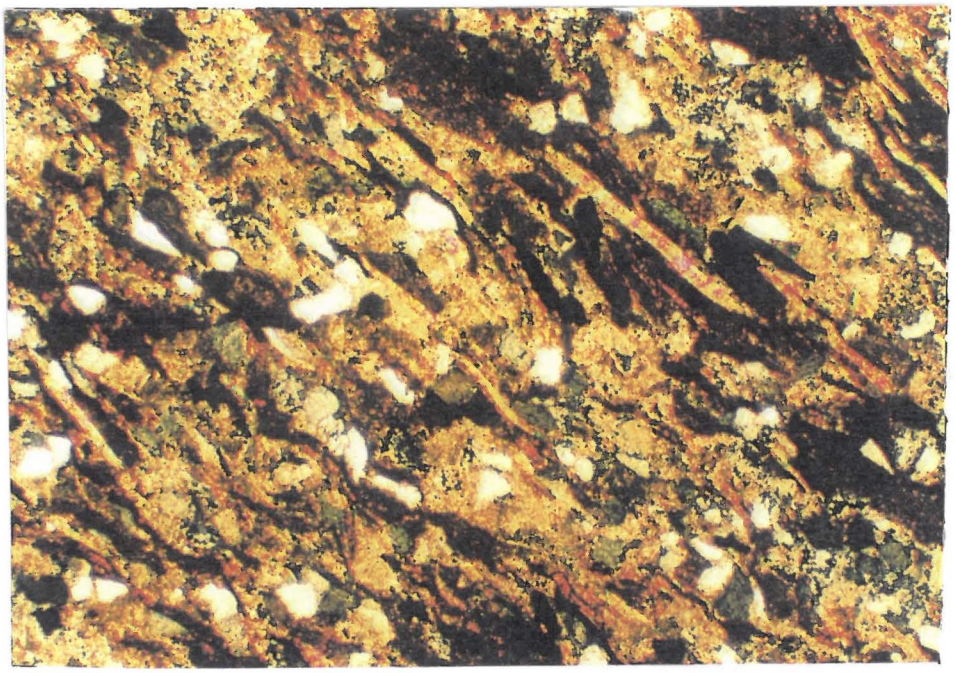


Figure 19. Fine-grained sandstone (Facies Sr) in VL1061. Note alignment of biotite. Magnification 10X. Crossed Nicols.

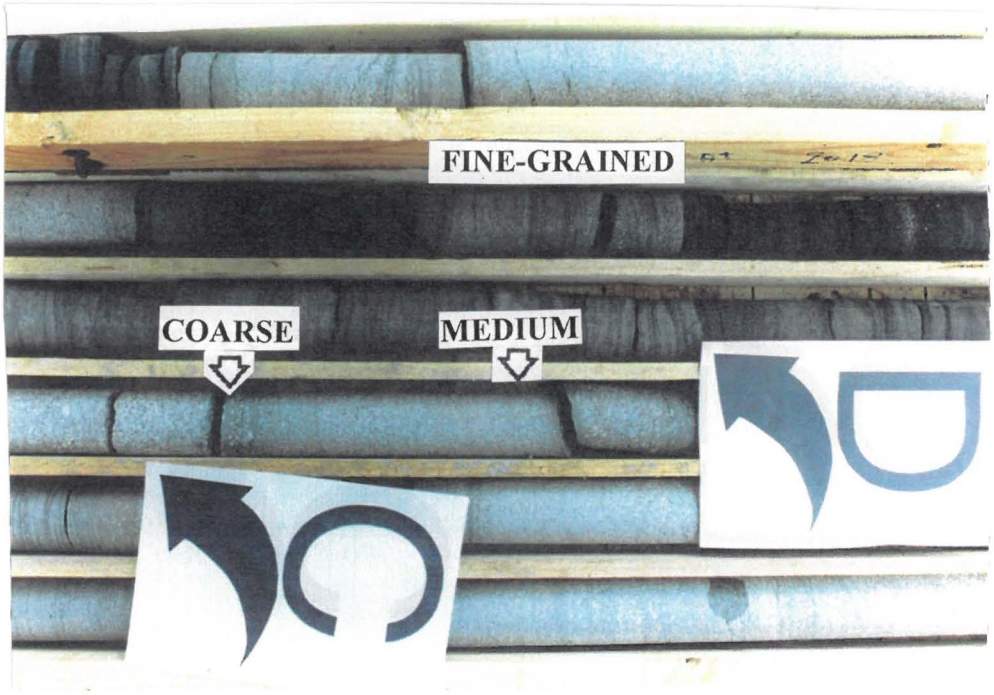


Figure 20. The two main types of sandstone in the TMA. Medium- to coarse-grained sandstone, Facies Sg (marker C), grading from coarse- (left) to fine-grained (right). Note climbing-ripple structures and planar laminations (marker D).

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In rare instances, thin beds (< 30cm) of this facies may be bioturbated, especially if they occur at the top of a thick (>8 m) sandstone unit. The bioturbation usually comprises Cylindrichnus burrows (Figure 21). Facies Sr is the most common lithofacies found in the Madzaringwe Formation, where it alternates with the other two sandstone facies.

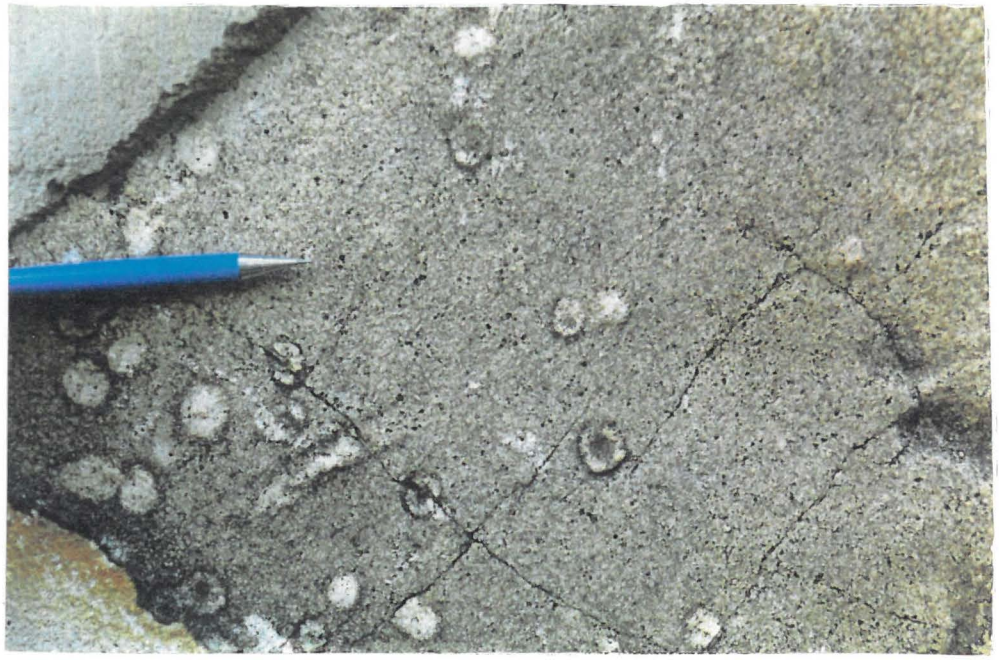


Figure 21. Cylindrichnus worm burrows, Facies Sr.

2.2.3 Graded sandstone (Sg).

This lithofacies is most common in the sandstone units capping the Madzaringwe Formation and it occurs throughout the study area. Individual units attain a thickness of 3 m. They are white to light grey in colour and consist of quartz (± 65%) and minor feldspar, clay minerals and sedimentary rock fragments set in a quartz cement. These sandstones are medium- to coarse-grained and locally gritty. The grain sorting is better for the finer sandstones of the facies and grain shapes

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are subrounded to angular. This facies does not exhibit any ripple marks or planar laminations and is either upward-fining or upward-coarsening. Locally, Cylindrichnus burrows are found.

In the Tshidzi Formation, poorly developed upward-fining Facies Sg sandstones are sometimes developed, interbedded with the diamictite facies. They exhibit soft sediment deformation and dewatering structures locally, and do not have a large lateral extent, but occur in local irregularities in the palaeofloor.

2.2.4 Massive sandstone (Sm).

The massive sandstone facies is not very common and usually occurs at random in the stratigraphy of the Tshidzi and Madzaringwe Formations. This facies attains a maximum thickness of 2 m. These sandstones are usually coarse-grained to gritty, and the colour varies from grey to cream, and even to black, due to the presence of carbonaceous material. They are well sorted but the grain shapes are angular to subangular. Grains consist almost exclusively of quartz with minor amounts of feldspar, set in quartz cement. Cylindrichnus burrows occur locally in this facies.

Massive sandstone (Facies Sm) units are interbedded with the diamictites of the Tshidzi Formation, where they attain a maximum thickness of 2 m. These specific sandstones are cream coloured and interbedded with other sandstone facies. They are medium-grained and it is possible to correlate them from borehole to borehole, where they occur. The lateral extent usually depends on the relief of the palaeofloor and can reach an area of 500 m².

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2.3 Mudrock Facies.

"The terminology of the fine-grained sedimentary rocks has been confused by the absence of generally accepted terms for distinguishing clearly between texture and mineral composition" (Blatt et al., 1980 pg 381). Most of the classification systems for mudrocks are based on laboratory techniques such as disaggregation, sieving and settling velocities. The classification of the mudrocks in this thesis is based on proposals by Blatt et al. (1980), where the criteria of sight and touch are used (Table 5).

Ideal size definition	Field criteria	Non fissile mudrock
> 2/3 silt	Abundant silt visible with hand lens	Siltstone
> 1/3 < 2/3 silt	Feels gritty when chewed	Mudstone
< 1/3 silt	Feels smooth when chewed	Claystone

Table 5. Classification of mudrocks. From Blatt et al. (1980).

2.3.1 Varved mudrock (Mv).

In the study area, only a few instances of varved mudrock have been intersected by drilling. These vary in thickness, but the individual layers are less than 1 m thick. The varved mudrocks are white to light grey and finely laminated. On exposure, the laminae turn red due to iron oxide staining (Figure 22). The individual laminae vary between < 1 mm and ± 10 mm thickness. They contain dropstones of up to 150 mm, which deformed the underlying mudrock layers (Figure 22). The dropstones consist of well rounded, white and pink quartzite clasts from the Soutpansberg Group. Soft sediment deformation structures are

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common. The top and bottom contacts of the varved mudrocks with other facies are sharp and irregular. Thin (< 1 m) diamictite and sandstone layers alternate locally with the varved facies.

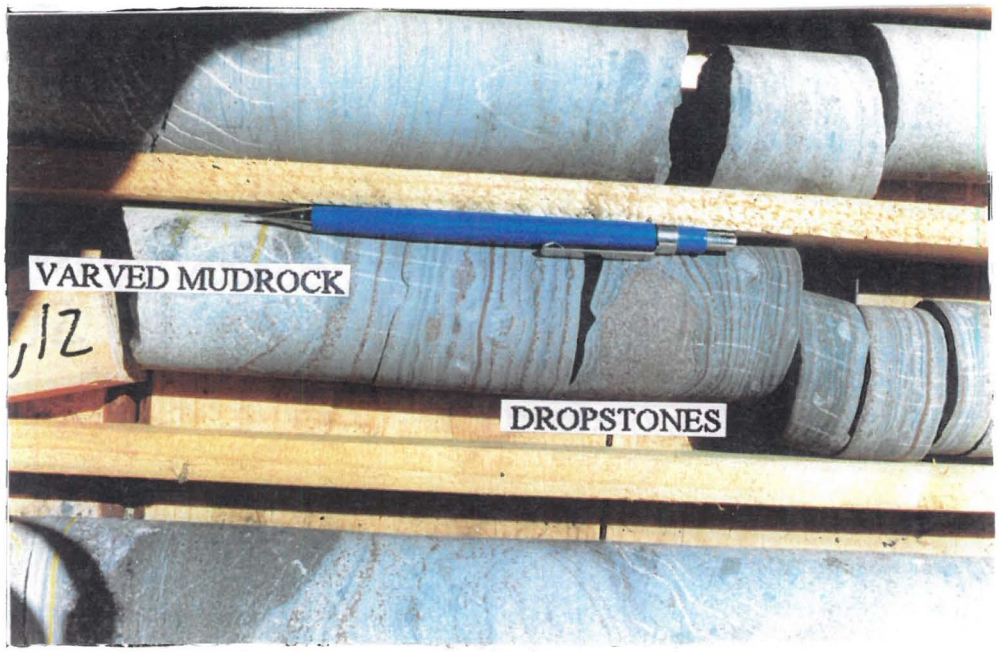


Figure 22. Varved mudrock (Facies Mv) in borehole VL1061. Bottom is towards the right. Note dropstones below pen and red colouration of certain iron-rich laminae.

No lateral correlation across the TMA is possible due to the scarcity of intersections, but it does appear as if the varved mudrocks are confined to local areas not larger than 200 m².

2.3.2 Undifferentiated mudrock (Mu).

The term undifferentiated mudrock is used to describe the argillaceous facies types which characterise the Mikambeni Formation, and which consist exclusively of mudrock and of

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coal seams, bands and coal stringers. The silt and clay content of these mudrocks varies throughout and to make a distinction between the different types of mudrocks is difficult.

These mudrocks are grey, light grey to black (carbonaceous material) with coal in places. Thin siderite bands of up to 30 cm are found throughout, and these turn dark brown to red on exposure. The total thickness of the Mikambeni Formation varies between 120 m and 140 m and leaf imprints (Glossopteris) and fragments of preserved plant material are common.

2.3.3 Clay pellet conglomerate bands (Mc).

Numerous clay pellet conglomerate bands are scattered throughout the upper third of the Mikambeni Formation and vary in thickness, but none is more than 1 m thick. These bands consist of angular to rounded, discoidal to spherical and also deformed mudrock clasts, showing imbrication and, rarely, grading. Pellets vary in size with an average of ± 5 cm and may occur as framework constituents or single clasts. In some cases the clay pellet conglomerate has an almost massive appearance. Siderite enrichment is nearly always associated with the clay pellet conglomerate bands.

2.3.4 Mudrock with quartz grains and quartz pebble bands (Mp).

The mudrocks of the lower half of the Madzaringwe Formation are dark grey to black and have quartz grains and thin (0,10 m) quartz pebble bands scattered throughout (Figures 24 and 25).

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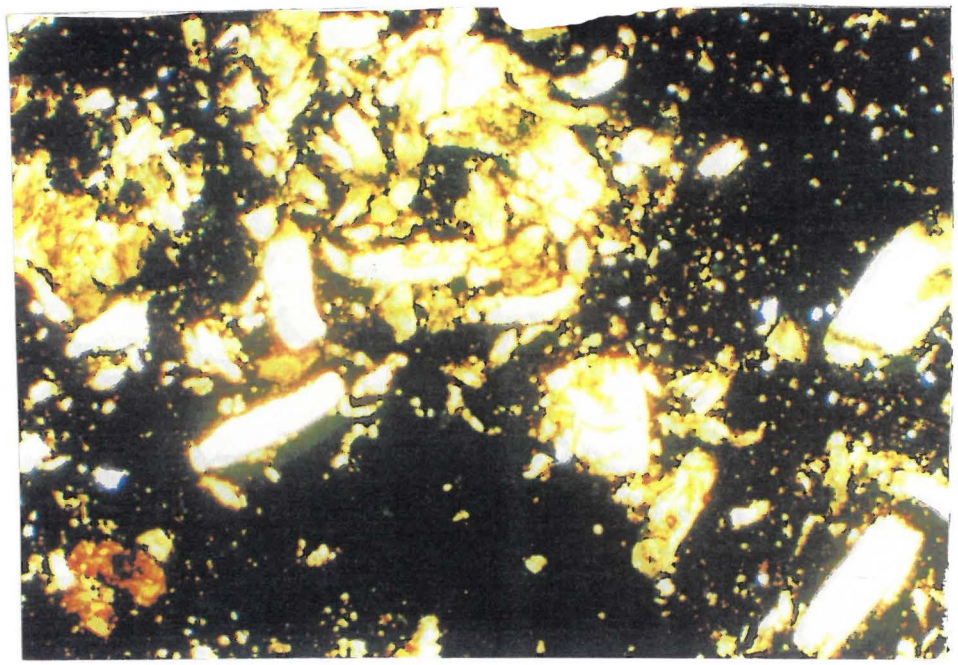


Figure 24. Mudrock with quartz grains and quartz pebble bands (Facies Mp). Magnification 10X. Crossed Nicols.

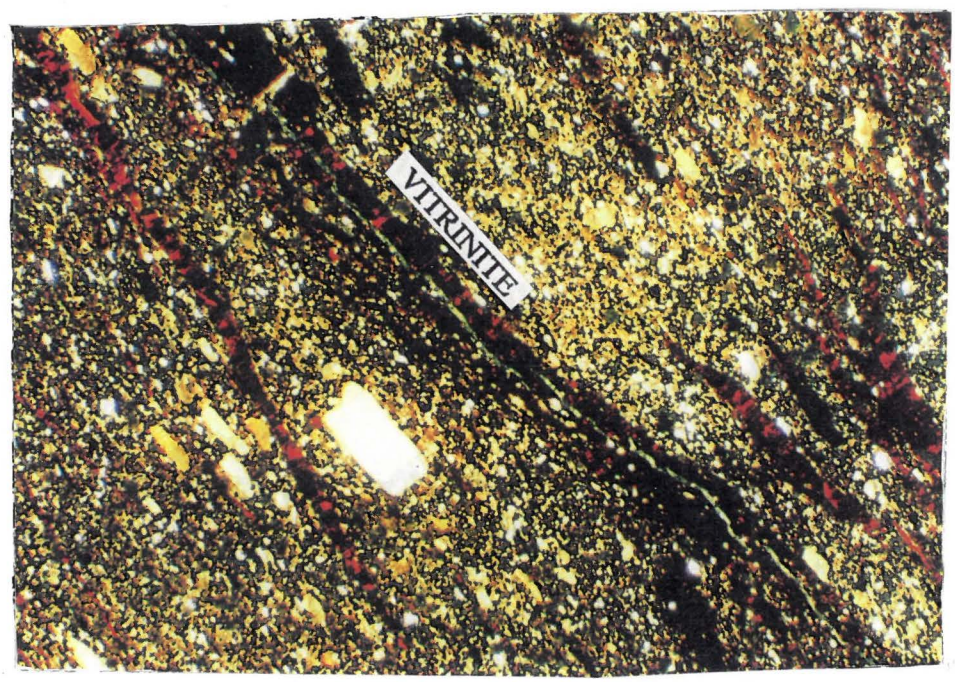


Figure 25. Mudrock with quartz grains and quartz pebble bands (Facies Mp). Magnification 10X. Crossed Nicols.

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These grains are angular, ± 1 mm to 7 mm in diameter, and consist exclusively of quartz.

The grains appear to have been dropped into the mudrocks, as there is a tendency for them to deform the underlying mudrock laminae and also to have mudrock laminae draped over them. Individual units of this mudrock facies are up to 15 m thick. Higher up in the Madzaringwe stratigraphy, this facies is replaced by mudrocks with silty laminae and convolute lamination (Facies Ml). The red lines in figure 25 are vitrinite laminae. Notice also how grains are aligned perpendicular to the direction of compaction.

2.3.5 Mudrock with silty laminae and convolute lamination (Ml).

In the upper third of the Madzaringwe Formation, the mudrocks are dark grey with silty laminae and convolute lamination (Figure 26). This facies becomes carbonaceous to coaly in places due to the presence of plant material. The thickest individual occurrence of this lithofacies is just above coal sample 6 (Table 6) and is up to 8 m thick. The silty laminae are defined by very small, rounded quartz grains and are lenticular in places.

The individual laminae are about 5 mm thick (Figure 27). Erosional truncation of the silty laminae is common. This lithofacies can be correlated over the whole TMA.

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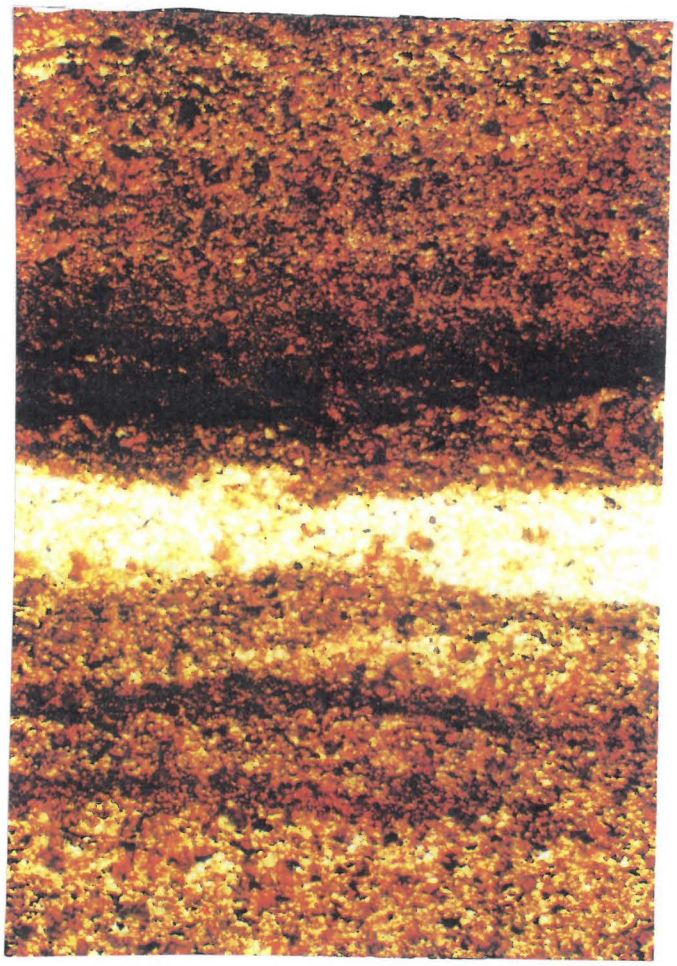


Figure 26. Mudrock with silty laminae - facies Ml. Magnification 10X. Crossed Nicols.

2.3.6 Massive black mudrock (Mm).

In the lower parts of the Madzaringwe Formation, a mudrock facies occurs which is massive, black and highly carbonaceous, and nearly always associated with coal seams. The thickness of the facies in this area varies between 10 and 50 cm. A much thicker unit of massive black mudrock is also found slightly higher in the Madzaringwe Formation and is up to 15 m thick. Massive black mudrocks are also found at or near the contacts with all the coal seams throughout the TMA succession.

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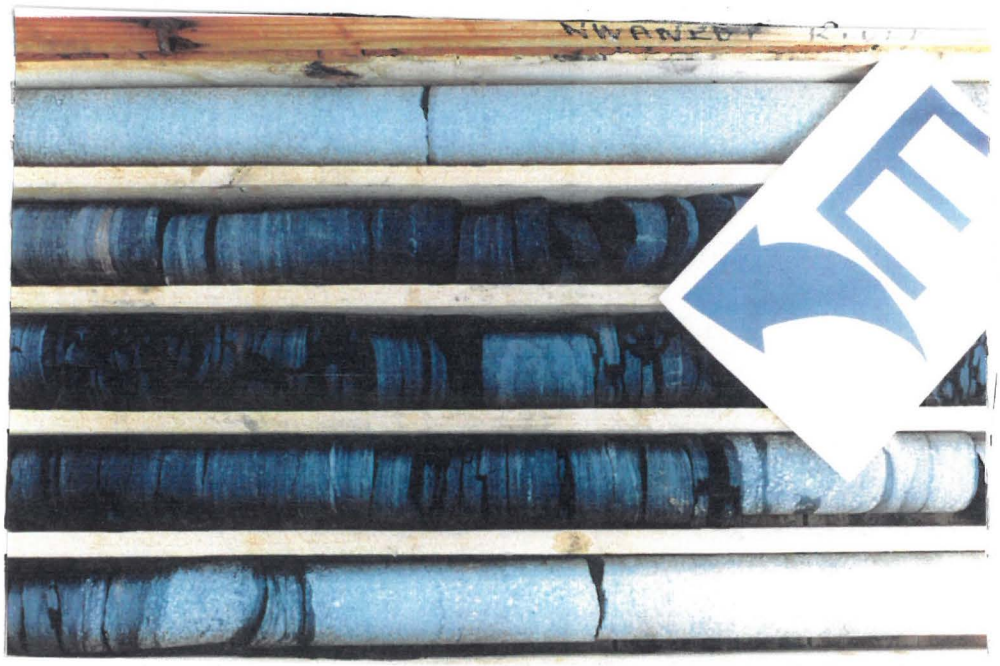


Figure 27. Typical facies M1 mudrock. Note common silty laminae and convolute laminations.

2.4 Coal facies (C).

Coal, of varying quality and thickness, is found throughout the Mikambeni and Madzaringwe Formations. The thickness of individual seams varies from 1 cm to over 1 m. Thin carbonaceous layers occur in the Tshidzi Formation, but these are rare. Nearly all the thicker seams (>30 cm) scattered throughout the Madzaringwe Formation, act as marker horizons and are laterally continuous over the whole area, making correlation of the different sedimentary units easier. Table 6 gives a summary of the classification of the coal seams in the TMA. This classification, used by ISCOR, is based on thickness and distinguishable geological features such as mudrock partings. Figure 28 illustrates the position of the coal seams in the TMA.

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Sample number	Description	Position and thickness
1	Four to five thin coal bands (up to 10 cm), separated by carbonaceous mudrock and grey mudrock. Near top of Mikambeni Formation.	± 10 m below Fripp ± 60 m thick
2	Four to six coal bands (up to 15 cm), separated by grey and carbonaceous mudrock.	± 5 m below sample 1. ± 5 m thick
3	Three to five coal bands (up to 32 cm), separated by grey and carbonaceous mudrock.	± 16 m below sample 2. ± 7 m thick.
4	Three to six coal bands (up to 60 cm), separated by grey and carbonaceous mudrock. Marks the bottom of Mikambeni Formation.	± 5 m below sample 3. ± 5 m thick.
5	Three to seven coal bands (up to 30 cm), separated by sandstone, siltstone and mudrock. Found in the upper 55 m of the Madzaringwe Formation.	± 20 m below sample 4. ± 50 m thick.
6	Nine to fifteen coal bands (up to 40 cm), separated by mudrock. Found in the roof of the main mining zone (Main seam).	± 14 m below sample 5. ± 2,5 m thick.
7	Divided into 7A, 7B and 7C. Seven to nine coal bands (up to 3,5 m) separated by carbonaceous mudrock. Several mudrock marker horizons. Pyrite common in some areas. In areas no sample 7C is developed. **Main Seam.**	Directly below sample 6. ± 3,5 m thick.
8	Two to three coal bands (up to 30 cm), separated by mudrock and fine-grained sandstone.	± 20 m below sample 7. ± 2 m thick.
9	Three to five coal bands (up to 25 cm), separated by mudrock, sandstone and siltstone.	± 18 m below sample 8. ± 2 m thick.
10	Two to three coal bands (up to 50 cm), separated by siltstone and coarse sandstone.	± 9 m below sample 9. ± 2,5 m thick.
11	One thin coal band (up to 20 cm). Mostly absent.	± 40 m below sample 10. ± 0,2 m thick.
12	Zone of carbonaceous mudrock, coaly mudrock, shaly coal and coal. Siderite lenses common.	± 5 m below sample 11. ± 5,0 m thick.
13	Divided into 13A, 13B and 13C. Zones of carbonaceous mudrock, coaly mudrock, shaly coal and coal. Bottom 2,5 m is **Lower Seam**. The floor is always a ± 4 m siltstone marker. Siderite lenses and nodules common.	Directly below sample 12. ± 12,0 m thick.
14	Divided into 14A, 14B and 14C. Zone of mudrocks and low grade coal. Siderite lenses and nodules common.	Directly below sample 13. ± 12 m thick.
15	Zone of carbonaceous mudrock, coaly mudrock and shaly coal (up to 4 m). Near bottom of Madzaringwe Formation. Siderite lenses and nodules common.	2 m to 5 m below sample 14. ± 4 m thick.

Table 6. Classification of the coal seams in the Tshikondeni Mine area.

The coal zone at the bottom of the Madzaringwe Formation (Lower Seam of TMA) consists of bright coal layers, alternating with dull coal with a high clastic mineral content and mudrock with a high carbon content.

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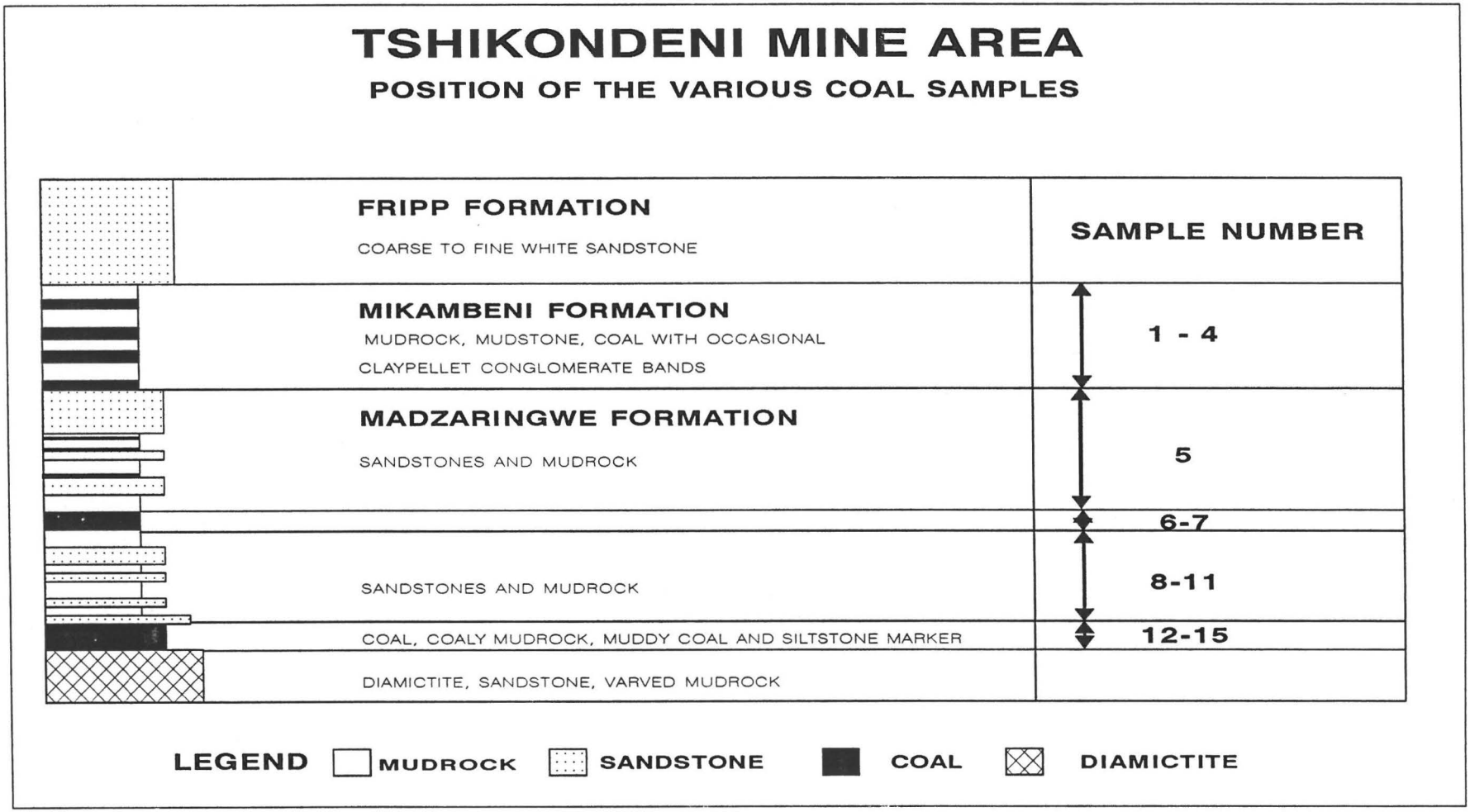


Figure 28. Stratigraphic position of the coal seams in the Tshikondeni Mine area.

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Coal zone thickness varies between 1,59 m and 3,5 m with an average of 2,30 m, whereas the mudrock content varies between 3,5% and 39,8% (Ave = 16,5%). Siderite lenses and nodules are common throughout the Lower Seam (Figure 29).

Rapid lateral facies changes make the correlation between the different lithological units of the Lower Seam difficult.

Fossils are extremely rare in the mudrock and coal layers developed near the bottom of the Madzaringwe Formation.

Sample 7 (Main Seam) was deposited ± 120 m above the Karoo floor and a small variation in lithology is noted. Near the base of sample 7 there are usually two mudrock layers with, locally, a third or fourth developed. Sample 7 (Table 6) consists mainly of bright coal layers and thin carbonaceous mudrock bands.



Figure 29. Siderite nodules within the coal zone at the base of the Madzaringwe Formation.

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The proportion of mudrock in sample 7 is on average 3,3% and the mining height varies between 1,98 m and 3,44 m, with an average of 2,62 m. Siderite is less common in sample 7 than in the Lower seam. Pyrite nodules are, however, common in the lower part of the main seam in certain areas.

Fossils are also found in the Main Seam and the highly carbonaceous mudrock surrounding it. Large tree trunk impressions are found in the roof of sample 7.

2.4.1 Petrography of the coal seams.

Figures 29A to 29D illustrate the petrographic results of all the main coal seams found in the Tshikondeni Mine area at an RD of 1,40. Table 6A gives a summary of the petrographic data. Depth of the coal seams is given relative to sample 1 and Vit = % Vitrinite, RSF = % Reactive Semifusinite, Inert = %Inertinite, Miner = % Minerals, Reac = % Reactives.

The petrographic analysis of the coal seams reveals that they are vitrinite-rich. The vitrinite content ranges from 68% to 94% (Figure 29A).

The lower coal seams (Samples 12 to 14) have a lower vitrinite content than the rest of the seams. The reactive semifusinite (RSF) content varies between 0,05% and 12% (Figure 29B). The inertinite content varies between 1% and 15% (Figure 29B) while the mineral matter content is less than 6,5% (Figure 29C). From figure 29A it is obvious that the high vitrinite content corresponds to low RSF and inertinite contents. The distribution of minerals throughout the succession (Figure 29C) does not appear to be directly linked to the distribution of any of the macerals.

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The uppermost (Samples 1-3) and the lowermost (Samples 12-14) coal seams have the lowest mineral matter content.

Sample	Rela-tive depth (m)	VIT	RSF	INERT	MINER	REAC	%RoV
1	0	90.67	1.17	3.90	4.27	91.83	1.19
2	5	94.43	0.39	1.35	3.84	94.75	1.15
3	25	91.23	1.09	3.69	3.99	92.09	1.21
4	32	90.52	0.96	2.59	5.90	91.23	1.21
5	42	89.87	1.30	3.40	5.43	90.99	1.25
6	106	85.73	2.23	5.56	6.43	86.72	1.32
7-Main seam	109	83.87	3.22	6.84	6.07	85.32	1.32
8	129	85.68	2.40	6.12	5.76	87.01	1.29
9	150	84.20	3.30	7.09	5.40	85.08	1.32
10	161	85.35	2.56	6.38	5.74	86.40	1.32
11	203	93.10	0.80	1.20	4.90	93.30	1.35
12	208	69.79	12.09	13.51	4.69	71.18	1.40
13-Lower seam	213	69.46	11.52	15.07	4.40	70.27	1.39
14	225	75.19	7.99	12.25	4.57	75.56	1.40

Table 6A. Petrography of the main coal seams in the Tshikondeni Mine area.

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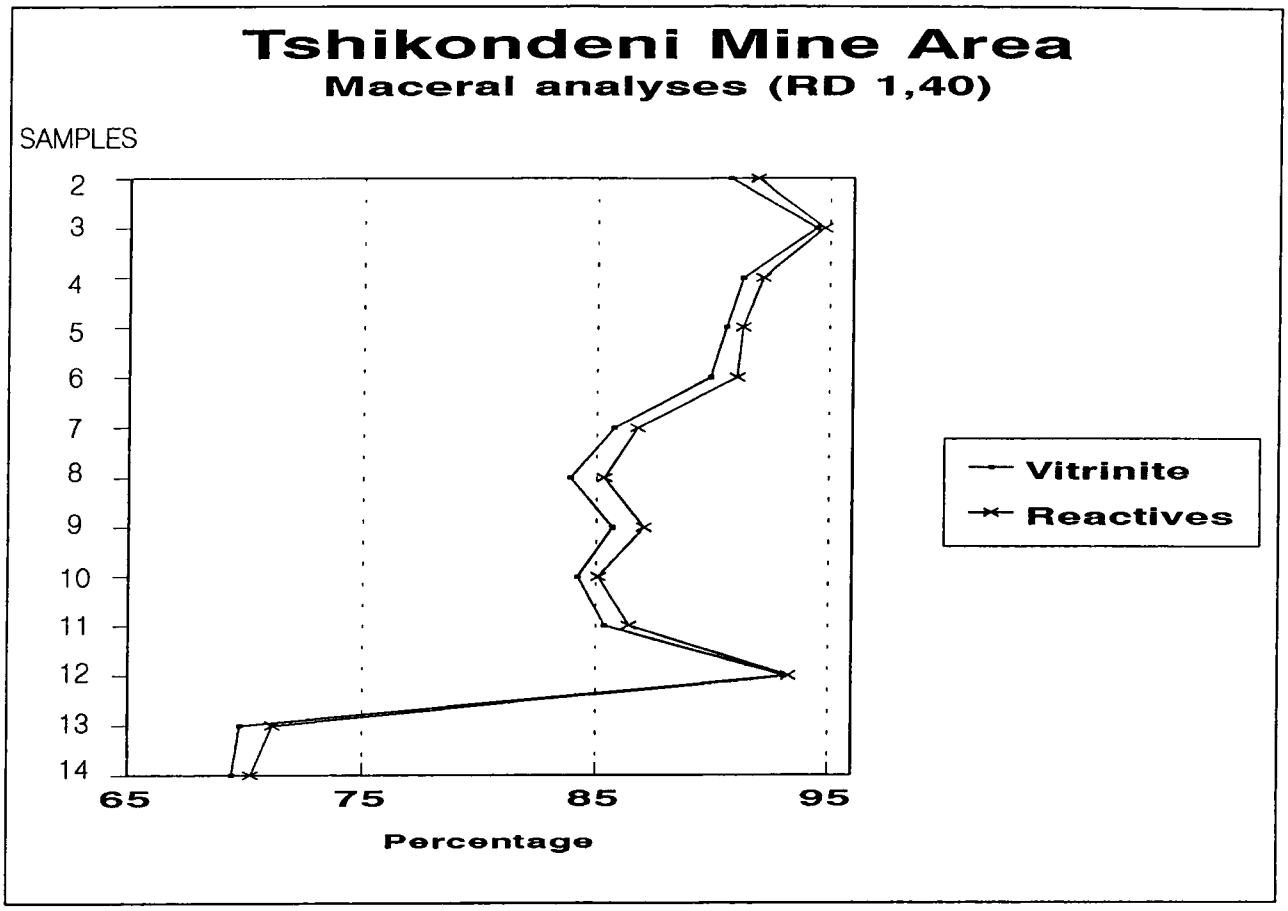


Figure 29A. Variation in vitrinite content and reactives in the float fraction at RD 1,40 with increasing depth (Samples 2 to 14).

The distribution of the reactives (Figure 29A) is a reflection of the total distribution of the vitrinite and RSF. An interesting aspect of the petrographic analysis is the %RoV (Figure 29D). There is a general increase in rank from sample 1 to sample 14, from 1,15% to 1,40%.

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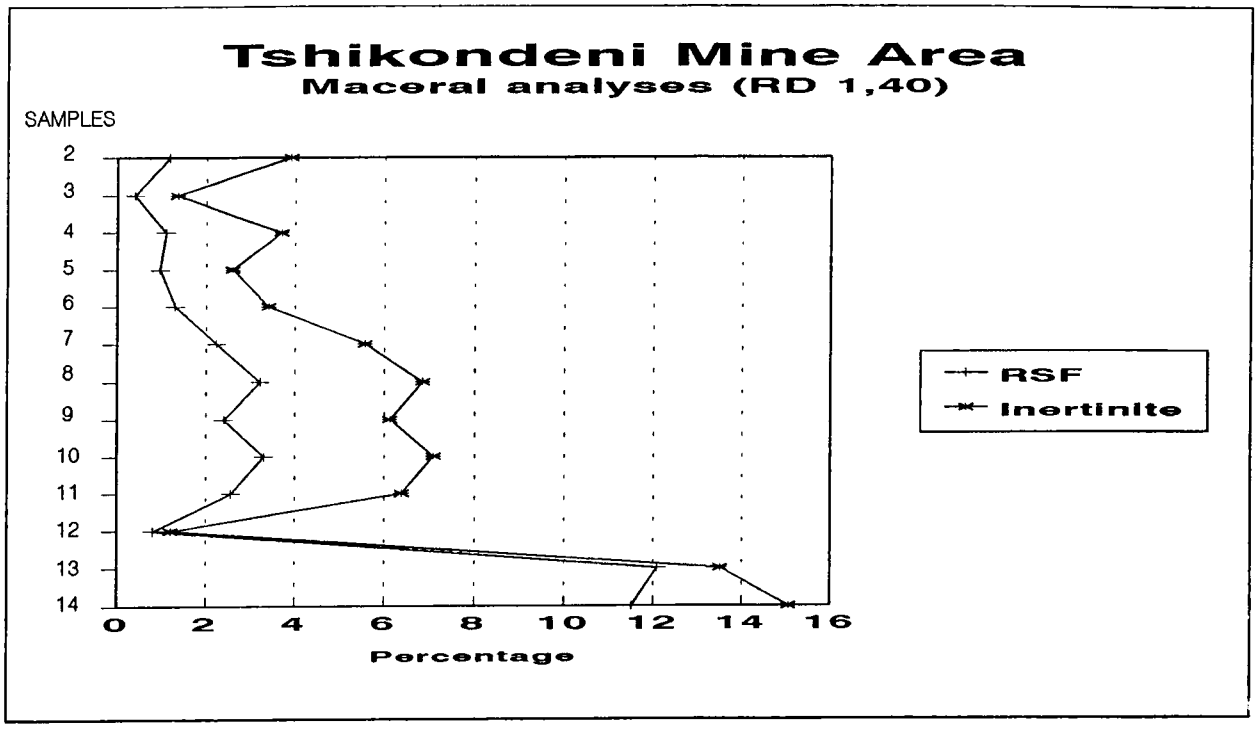


Figure 29B. Variation in reactive semifusinite and inertinite content in the float fraction at RD 1,40 with increasing depth (Samples 2 to 14).

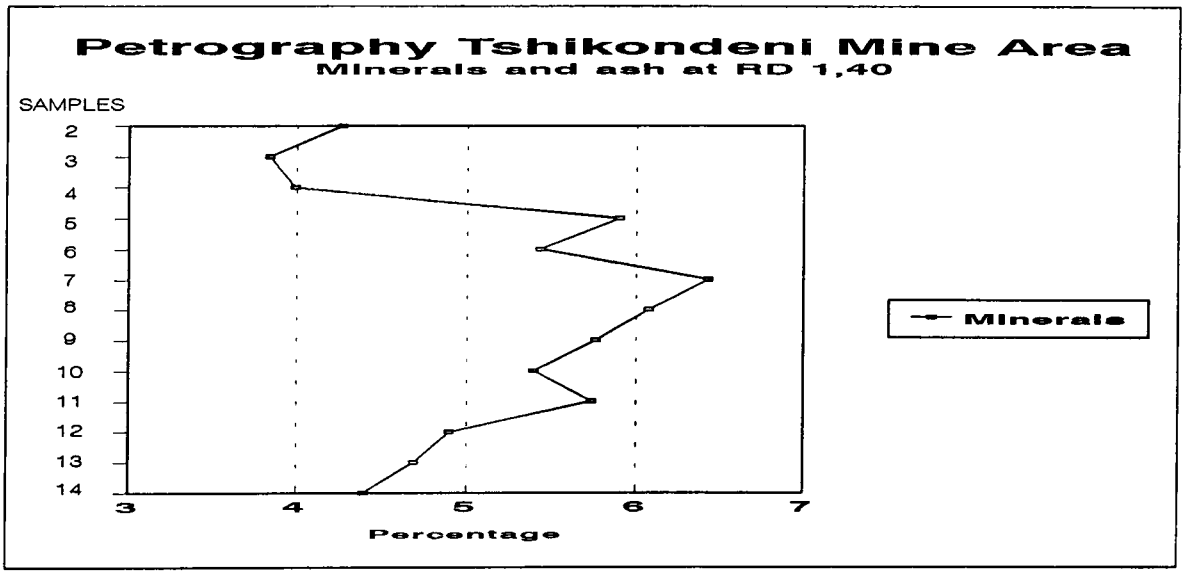


Figure 29C. Variation in mineral matter content in the float fraction at RD 1,40 with increasing depth.

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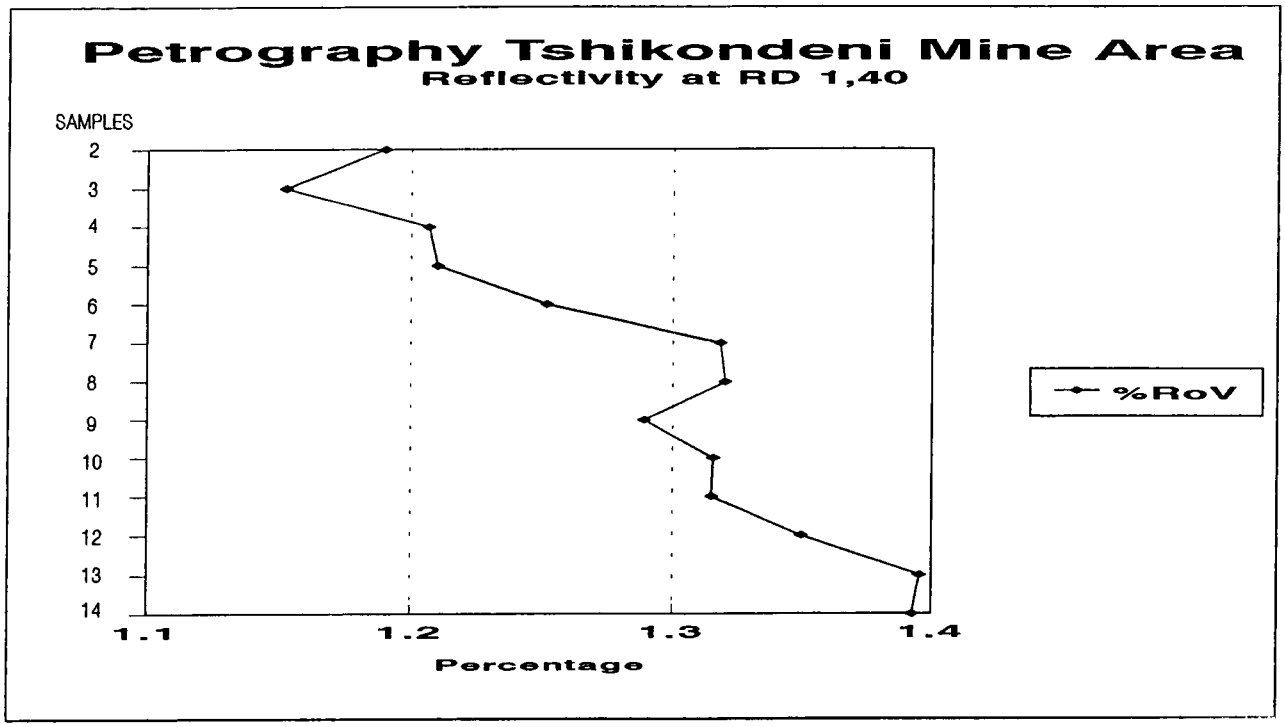


Figure 29D. Variation in %RoV in the float fraction at RD 1,40.

3. Genetic units of sedimentation.

The complex three-dimensional association of the different facies necessitated the use of some kind of facies association concept, as a tool to properly describe the detailed sedimentology of the TMA. The facies types and their distinguishing characteristics are summed up in table 8.

A Markov analysis of the vertical facies transitions (Table 7 and Figure 30), based on lithology change, provides some information on the three-dimensional relationships, but obviously excludes lateral transitions. For this reason genetic units of sedimentation (GUS) will be used in this thesis.

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Le Blanc Smith (1980) showed that genetic stratigraphy can be a valuable correlation tool in an area such as the Witbank coalfield. Siepker (1986) also used genetic stratigraphy in describing the geology of the Waterberg coalfield.

A genetic increment is defined by Busch (1971) as "an interval of strata representing one cycle of sedimentation in which each lithological component (or lithofacies in this thesis) is related genetically to all others."

	D	S	Sr	Sg	Sm	Mv	Mu	Mp	Ml	Mm	Mc	C	Total
D	-	20			20	80							120
S	10	-	50							20			80
Sr		10	-	35	14			22	14			5	100
Sg		16	42	-				10	12	10		10	100
Sm	6		25	50	-			12					93
Mv	75		25			-							100
Mu	81		92	50	0	0	-	22			3		248
Mp			46	15	8			-	8			23	100
Ml			40	20					-			40	100
Mm			10	3	2					-		85	100
Mc							3				-		3
C			7	38	3		50		4	86	0	-	188
Total	172	46	337	211	47	80	53	66	38	116	3	163	1332

Table 7. Markov analysis of the lithology changes in the Tshikondeni Mine area.

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Hagelskamp et al. (1988), describing part of the Highveld coalfield, used as basis for their model of depositional environments, a series of "events". These "events" delineate single sedimentary processes or several contemporaneous processes, which comprised the environment in which the respective lithofacies associations were laid down.

These "events" fit Busch's (1971) proposal of the term genetic increment of strata and clearly illustrate that the method can be used successfully to describe the sedimentological development of coalfields.

Within coalfields, detailed stratigraphy was previously based primarily on coal seams as stratigraphic markers, although some other prominent sedimentary stratigraphic marker horizons were also used (Winter et al., 1987). In this thesis, coal seams, unconformities and horizons marking major lithological changes are used as marker horizons.

The stratigraphic succession in the study area is subdivided into eight genetically-related increments of sedimentation or depositional sequences, here termed genetic units of sedimentation, namely GUS1 to GUS7. This was done to simplify the interpretation of the facies present in the large number of boreholes drilled in the area.

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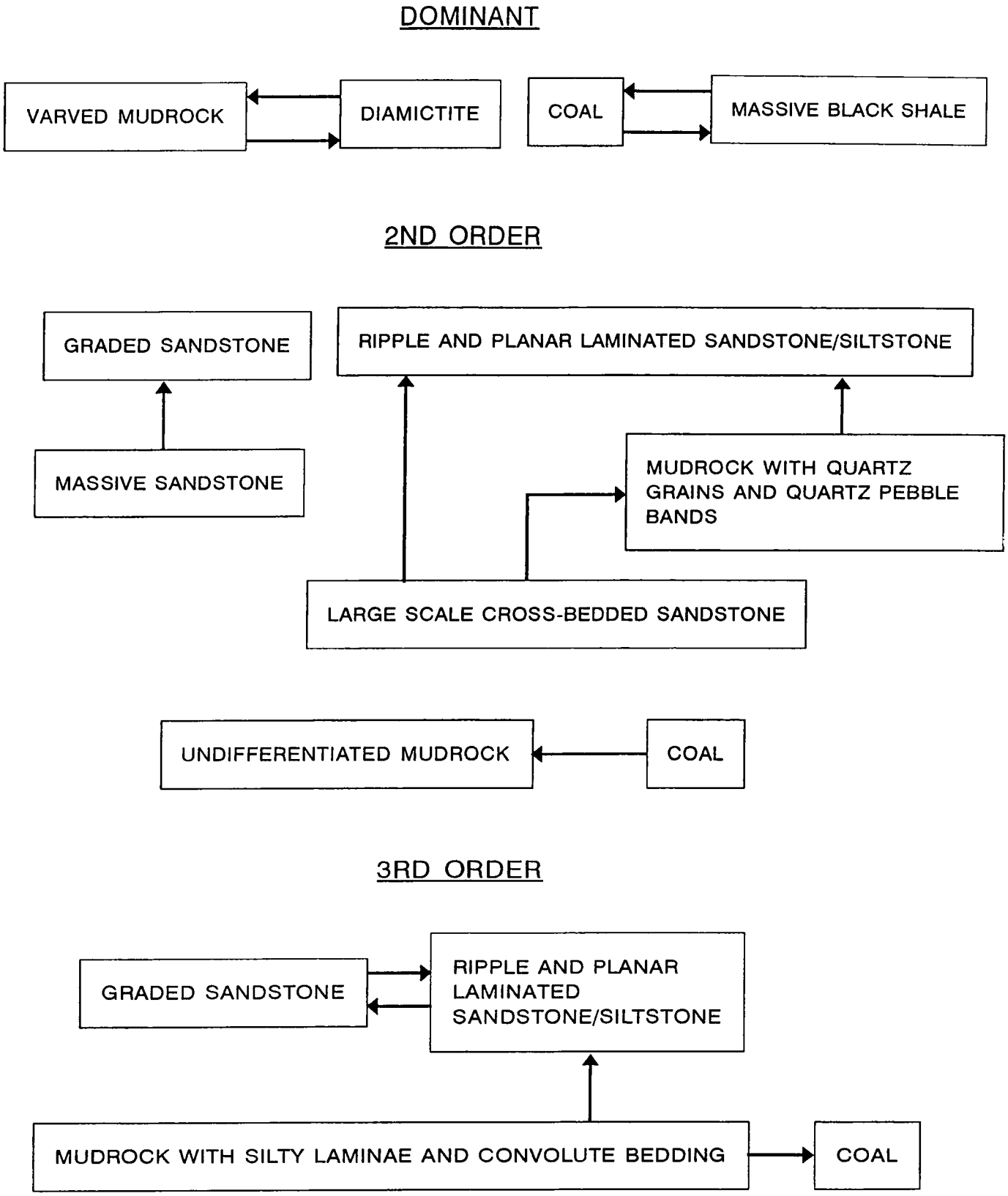


Figure 30. Major vertical facies associations in the Tshikondeni Mine area. Data from table 7.

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Facies (Code)	Distinguishing Characteristics
Diamictite facies (D)	Maximum thickness of 8 m. Boulders of up to 2 m in diameter. Extrabasinal clasts of lava and quartzite. Poorly sorted. Clast- to matrix-supported. Erosive basal contact. Found throughout the TMA.
Large scale cross-bedded sandstone (S)	Maximum thickness of 3 m. Large scale trough and planar cross-bedding. Grain-supported. Medium- to coarse-grained. Poorly to well sorted.
Ripple cross-laminated sandstone/siltstone (Sr)	Maximum thickness of 10 m. Fine- grained. Ripple and planar lamination. Upward-fining or -coarsening. Bioturbated (Cylindrichnus) in places. Soft sediment deformation structures.
Graded sandstone (Sg)	Maximum thickness of 3 m. Medium- to coarse-grained. Good sorting. Angular to subangular grains. Soft sediment deformation structures and bioturbation (Cylindrichnus) in places.
Massive sandstone (Sm)	Maximum thickness of 2 m. Medium- to coarse-grained. Well sorted. Bioturbated (Cylindrichnus) in places. Difficult correlation over TMA.
Varved mudrock (Mv)	Maximum thickness of 1 m. White to grey. Finely laminated. Dropstones of up to 150 mm. Poor lateral correlation.
Undifferentiated mudrock (Mu)	Maximum thickness of 160 m. Grey to black. Thin siderite bands (< 30 cm) common. Imprints of Glossopteris throughout. Good correlation over TMA.
Mudrock with quartz grains and quartz pebble bands throughout (Mp)	Maximum thickness of 15 m. Grey to black. Quartz grains and pebble bands common. Good correlation over TMA.
Mudrock with silty laminae and convolute laminations (Ml)	Maximum thickness of 8 m. Dark grey. Erosional truncation of silty laminae in places.
Massive black mudrock (Mm)	Maximum thickness of 15 m. Black. Carbonaceous. Associated with coal.
Clay pellet conglomerate (Mc)	Maximum thickness of 1 m. Occurs in the upper part of the Mikambeni Formation. Angular to spherical mudrock clasts of up to 5cm. Locally imbricated. Occurs throughout the TMA but is not easily correlated.
Coal (C)	Maximum thickness of 1 m. Alternates with mudrock. Medium volatile bituminous coal. Two main seams - samples 7 and 13C.

Table 8. Facies and their distinguishing characteristics.

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Table 9 illustrates how the informal genetic stratigraphy proposed for this study relates to the formal lithostratigraphy of SACS (1980). GUS1 is the oldest genetic sequence and GUS7 the youngest.

Figure 31 illustrates the thickness and overall lithology of the different genetic units of sedimentation in the TMA.

Lithostratigraphy	**Genetic Stratigraphy**
Mikambeni Formation	GUS7
Madzaringwe Formation	GUS6 GUS5 GUS4 GUS3U GUS3L GUS2
Tshidzi Formation	GUS1

Table 9. Comparison of informal genetic stratigraphy to the lithostratigraphy of SACS (1980).

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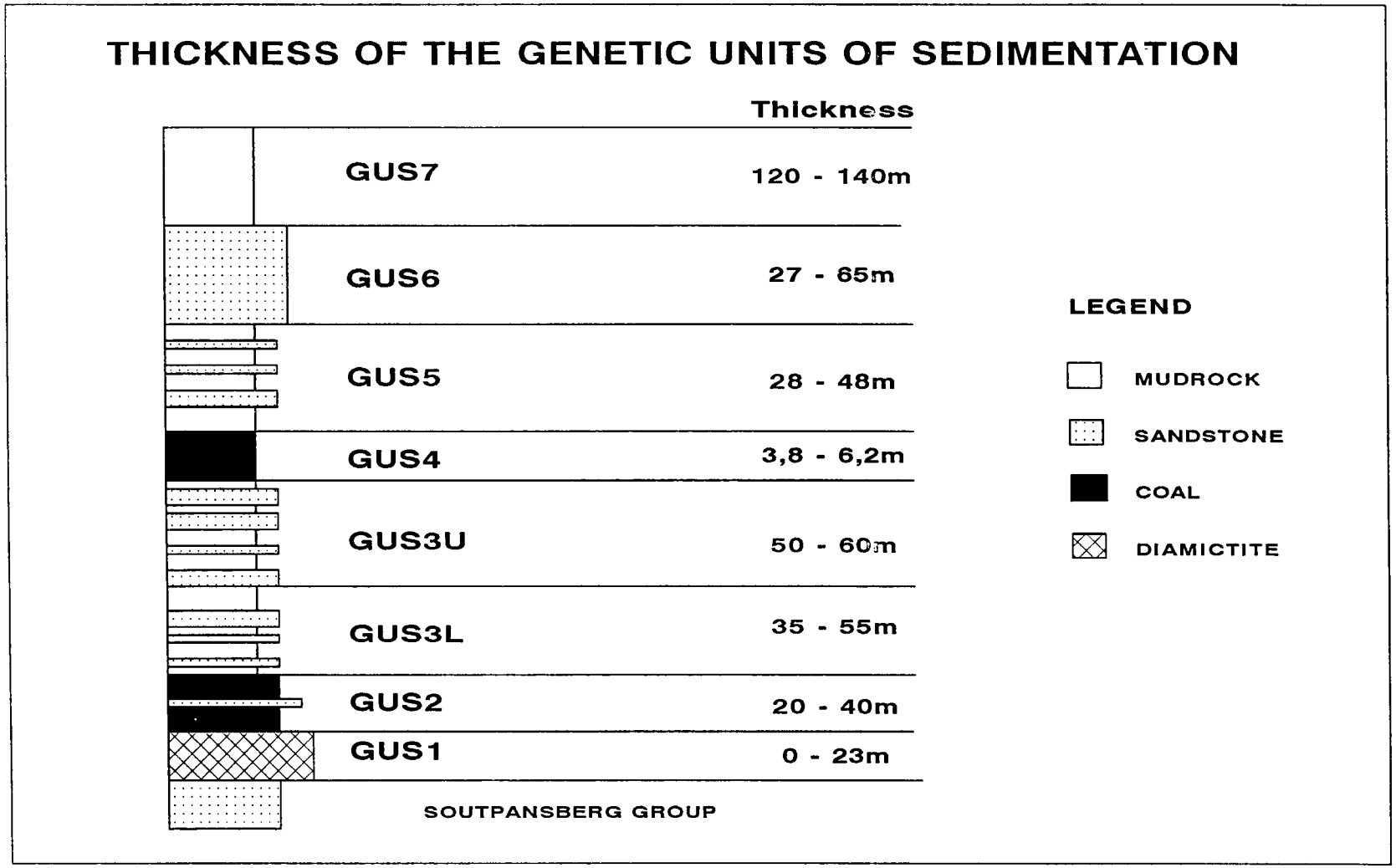


Figure 31. Thickness of the various genetic units of sedimentation in the Tshikondeni Mine area.

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3.1 Marker horizons.

Nine marker horizons were chosen to subdivide the Karoo succession in the TMA into genetic units of sedimentation. These are shown in Figure 32. These marker horizons are easily recognizable and are easily correlatable from borehole to borehole. They are:

MARKER 1 : The unconformity between the Karoo succession and the Karoo floor rocks (Figure 14).

MARKER 2: The upper contact of the diamictite or associated sandstone units with the lower coal horizon. Where the diamictite is not present, this marker coincides with marker horizon 1.

MARKER 3: The upper contact of the lower coal zone and the first mudrock or sandstone above this lower coal zone.

MARKER 4: The sharp bottom contact of the sandstone unit containing the first good accumulation of coal above the lower coal seams. This correlates with the sandstone unit directly below sample 10 (Table 6).

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MARKER 5: The bottom contact of the thick coal development containing samples 6 and 7 (Main coal seam) (Table 6) above sample 10.

MARKER 6: The top contact of the thick coal development containing samples 6 and 7.

MARKER 7: The top contact of the first thick (> 1,0 m) mudrock layer below the sandstones capping the Madzaringwe Formation.

MARKER 8: The top contact of the sandstones or siltstones capping the Madzaringwe Formation. (This is also the first siltstone or sandstone below sample 4 - the last coal seams of the Mikambeni Formation.

MARKER 9: The contact between the Fripp Formation sandstones and the Mikambeni Formation mudrocks.

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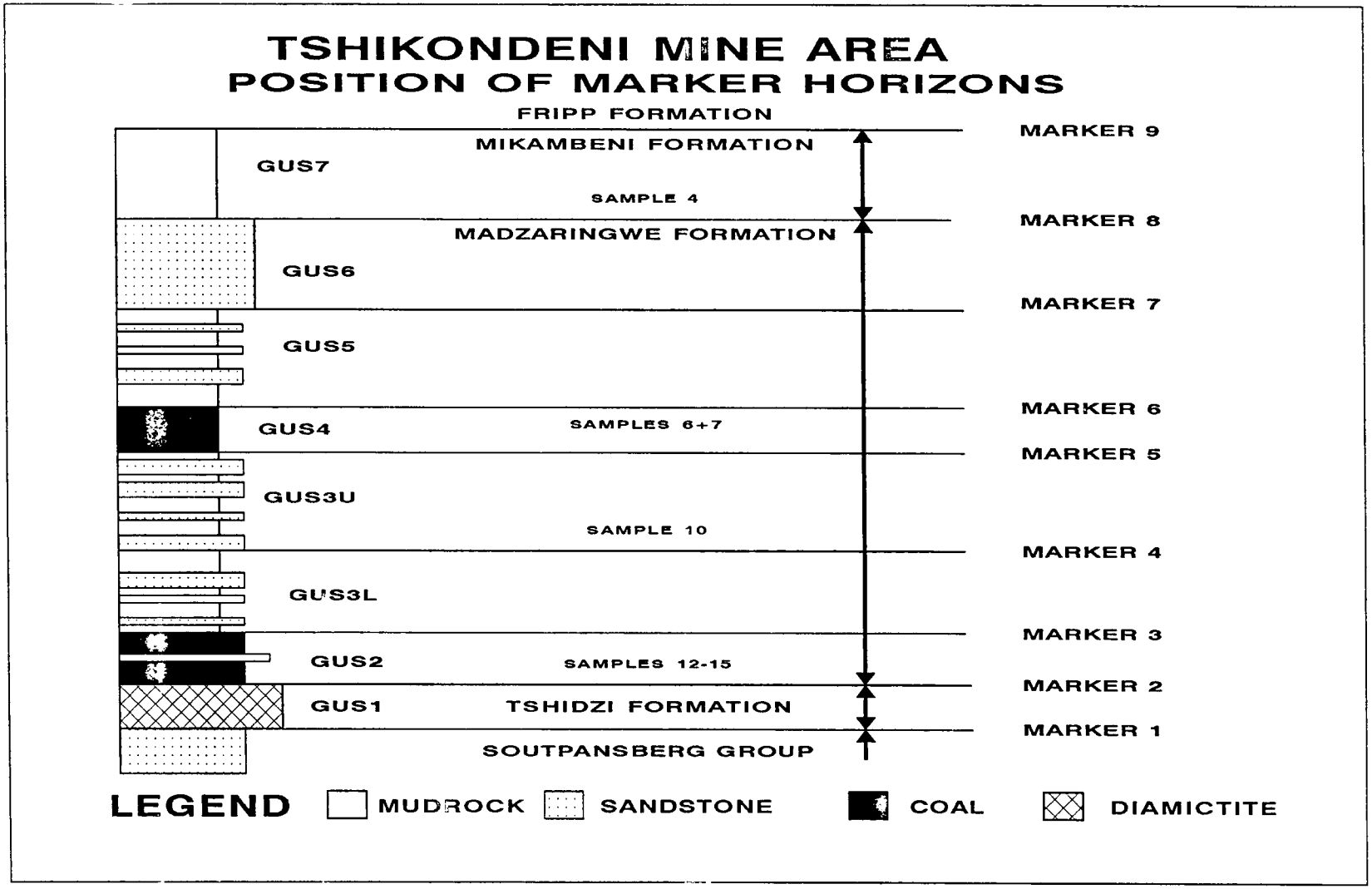


Figure 32. Position of marker horizons in the Tshikondeni Mine area.

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3.2 Genetic unit of sedimentation 1 (GUS1).

GUS1 is situated between marker horizons 1 and 2 and comprises the following facies (Table 10 and Figure 33) which make up the Tshidzi Formation in the study area (Figures 34 and 35.):

Diamictite facies	± 53% - 100% of thickness. Massive diamictite (D)
Sandstone facies	± 0% - 38% of thickness. Graded sandstone (Sg) Massive sandstone(Sm)
Mudrock facies	± 0% - 9% of thickness. Massive black mudrock (Mm) Varved mudrock (Mv)
Coal facies	± 0% - 0,05% of thickness. Coal (C)

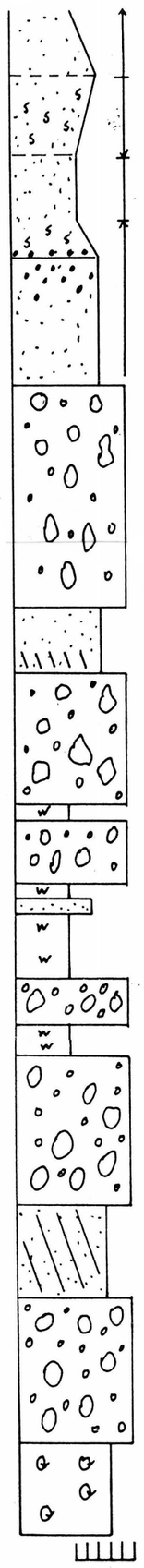
Table 10. Distribution of facies in GUS1.

A lithological profile of GUS1, as found in the reference borehole VL1061, is shown in figure 33.

GUS1 is the unit in the study area showing the greatest variation in thickness - between 0 m and 23 m with an average of ± 8 m (Figures 39 and 41). Massive diamictite is the most prominent facies in this unit (Figure 33). Usually GUS1 consists of diamictite and lesser amounts of massive or graded sandstone (Figures 34, 35 and 37), but varved mudrock, containing dropstones (Figure 38), is intersected occasionally.

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GUS1



DEPTH (m)	THICKNESS (m)	
442.29		
		SANDSTONE GREY FINE- TO MEDIUM-GRAINED
	1.40	
443.69		
		SANDSTONE GREY FINE- TO MEDIUM-GRAINED
		PYRITE, CONCRETION(S) RIPPLE CROSS-BEDDED SOFT SEDIMENT
	1.38	DEFORMATION
445.07		
		SILTSTONE DARK GREY PYRITE, CONCRETION(S) CARBONACEOUS
	1.03	
446.10		
		SANDSTONE WHITE LAMINATED SLUMPING
446.67	0.57	
		SANDSTONE WHITE FINE-GRAINED
	1.15	
447.88		
448.15	0.27	SANDSTONE WHITE MEDIUM-GRAINED MASSIVE
		SANDSTONE GREY FINE-GRAINED MASSIVE
	0.89	
449.04		
		DIAMICTITE PINK
	3.89	
452.93		
		SANDSTONE WHITE MASSIVE CROSS-BEDDED SHARP
	1.26	
454.19		
		DIAMICTITE PINK MICACEOUS
	1.58	
455.77		
456.09	0.32	DIAMICTITE WHITE
		QUARTZITE PINK
456.77	0.37	VARVED SHALE PINK
456.93	0.16	DIAMICTITE BROWN
		DIAMICTITE GREY
	0.72	
457.65		
457.91	0.26	VARVED SHALE GREY
458.07	0.16	SANDSTONE LIGHT GREY RIPPLE CROSS-BEDDED
		VARVED SHALE BROWN SHARP
	1.05	
459.12		
		DIAMICTITE
	0.86	
459.98		
		VARVED SHALE BROWN
460.49	0.51	DIAMICTITE WHITE
	2.92	
463.41		
		SANDSTONE WHITE MEDIUM-GRAINED CROSS-BEDDED DIP 30-40
	1.78	
465.19		
465.67	0.48	DIAMICTITE WHITE
		DIAMICTITE GREEN SHARP
	1.86	
467.53		
		QUARTZITE PINK MEDIUM-GRAINED END OF BOREHOLE
	1.69	
469.22		

LEGEND

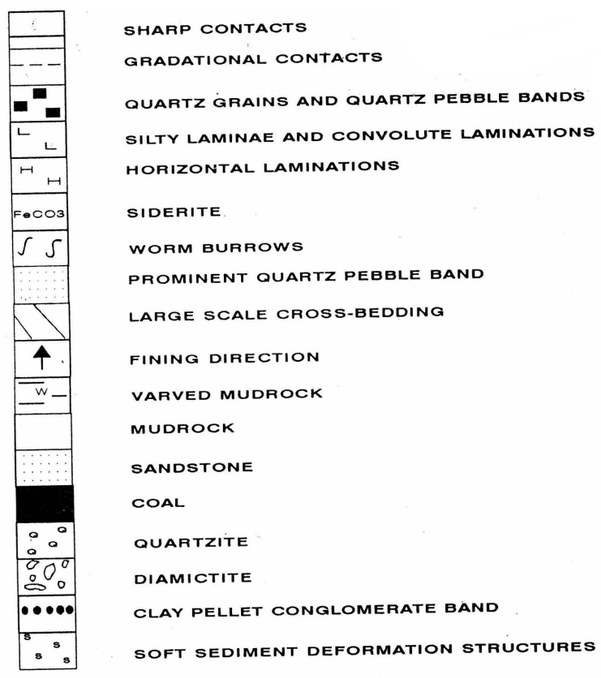


Figure 33. Lithological profile of GUS1.

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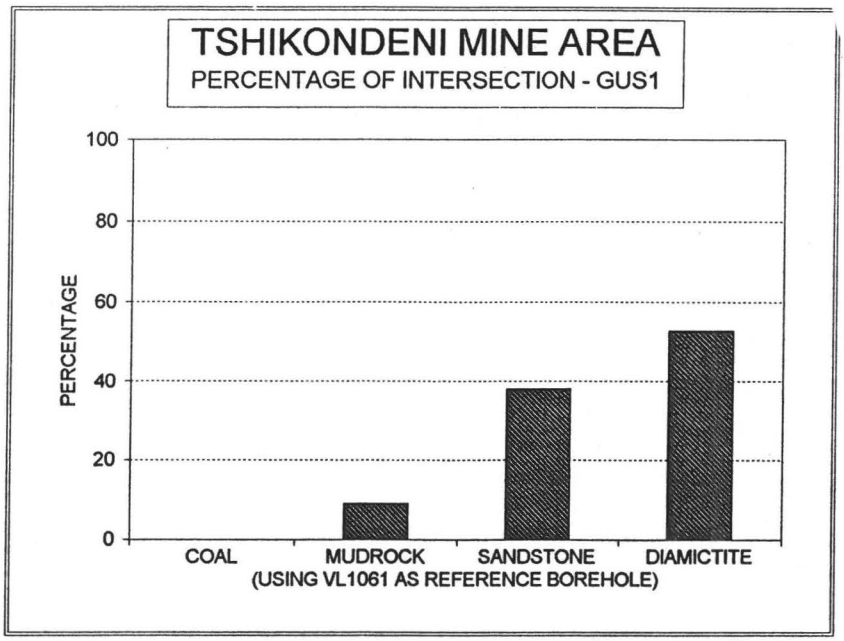


Figure 34. Percentage of the different rock types in GUS1.(Calculated by dividing the total thickness of the different rock types by the total thickness of the intersection, multiplied by 100).

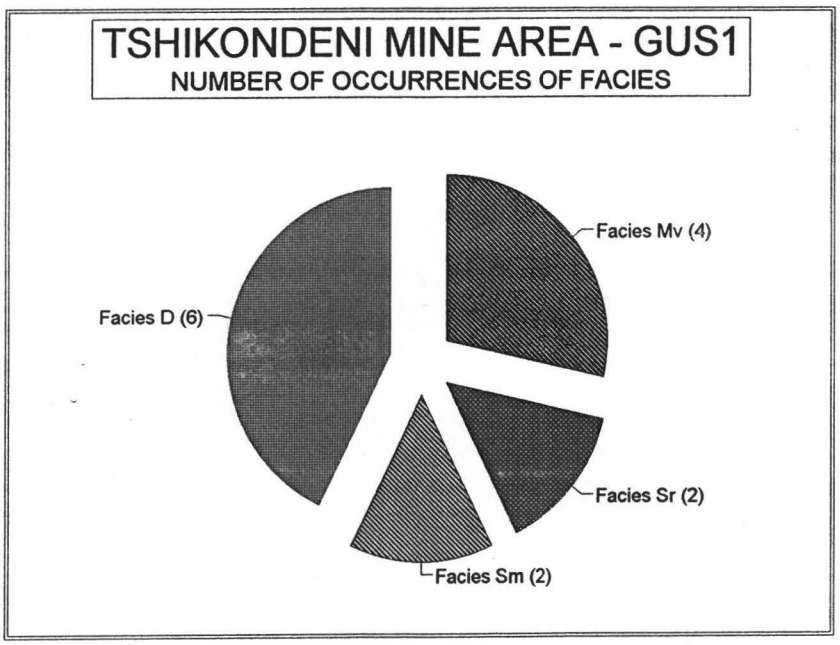


Figure 35. Pie diagram of the distribution of facies in GUS1 using VL1061 as reference. (Numbers in brackets are the number of occurrences in the intersection of the specific facies type).

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Very thin coal bands (<5 cm) occur sporadically in the graded sandstones. These are, however, very rare. The thickest accumulation of GUS1 is found in the south-western part of the study area (Figure 39).

Fine- to coarse-grained sandstones of between 0,5 m and 2,0 m thickness, typically cap GUS1 towards the west of the study area (Figures 36 and 37).



Figure 36. Contact between GUS1 and GUS2 in the Levhuvhu river. The person is standing on the sandstones usually capping GUS1.

A three-dimensional plot of the possible floor to GUS1 is shown in figure 40. This figure has been constructed assuming that GUS2, consisting of coal and mudrocks, was deposited on an even floor. This floor was taken as a reference surface, from which the thickness of GUS1 was subtracted. Thick development of GUS1 is thus indicative of palaeolow's and thin

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development of GUS1, of palaeohigh's in the floor rocks prior to deposition of GUS1. The values were then inverted and plotted in three dimensions, to give figure 40.

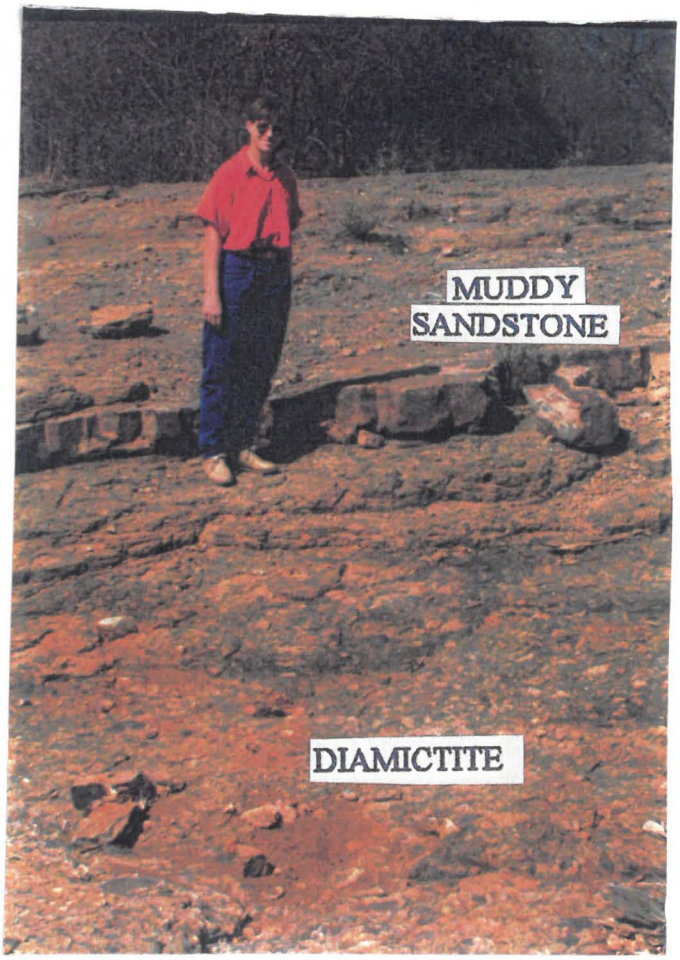


Figure 37. GUS1 in an area near the mine. Person is standing on diamictite and the layer behind her is a muddy sandstone capping GUS1.

GUS1 is found throughout the TMA but is often missing locally, due to the effects of faulting. A fairly irregular floor is inferred from Figure 40.

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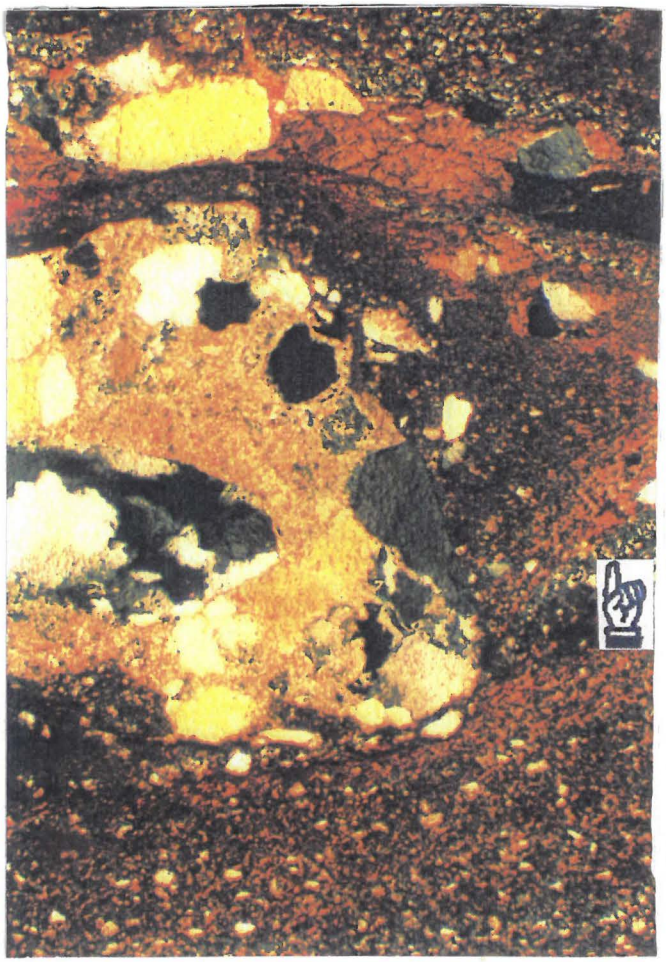


Figure 38. Dropstone in varved mudrock of GUS1. Note draped mudrock layers. Magnification 10X. Crossed Nicols.

The fence diagram for GUS1 (figure 41) illustrates the variable thickness of this unit in an east-west direction.

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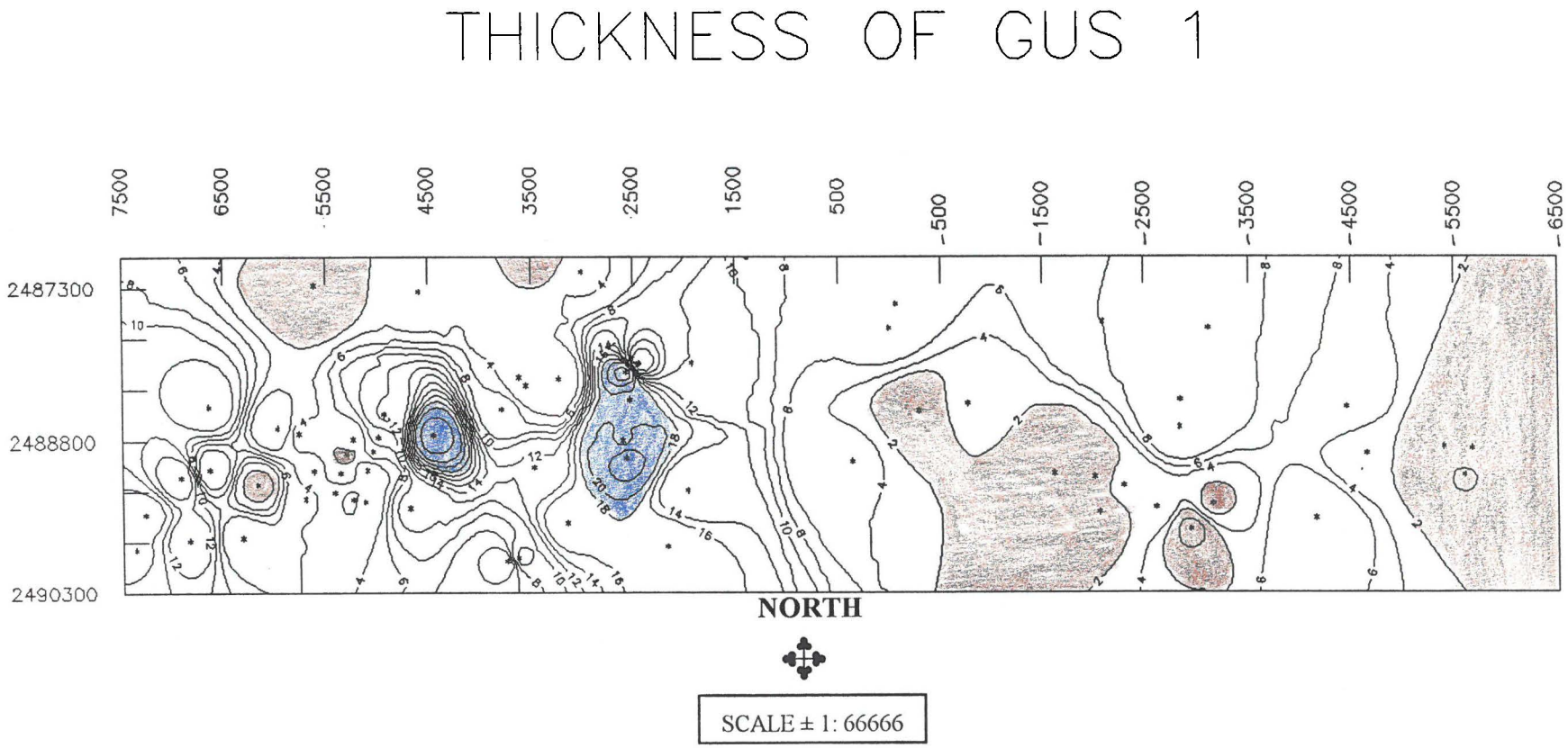


Figure 39. Thickness contours (in metres) of GUS1 in the TMA. (Thick areas in blue and thin areas in brown). Refer to figure 5 for position of grid.

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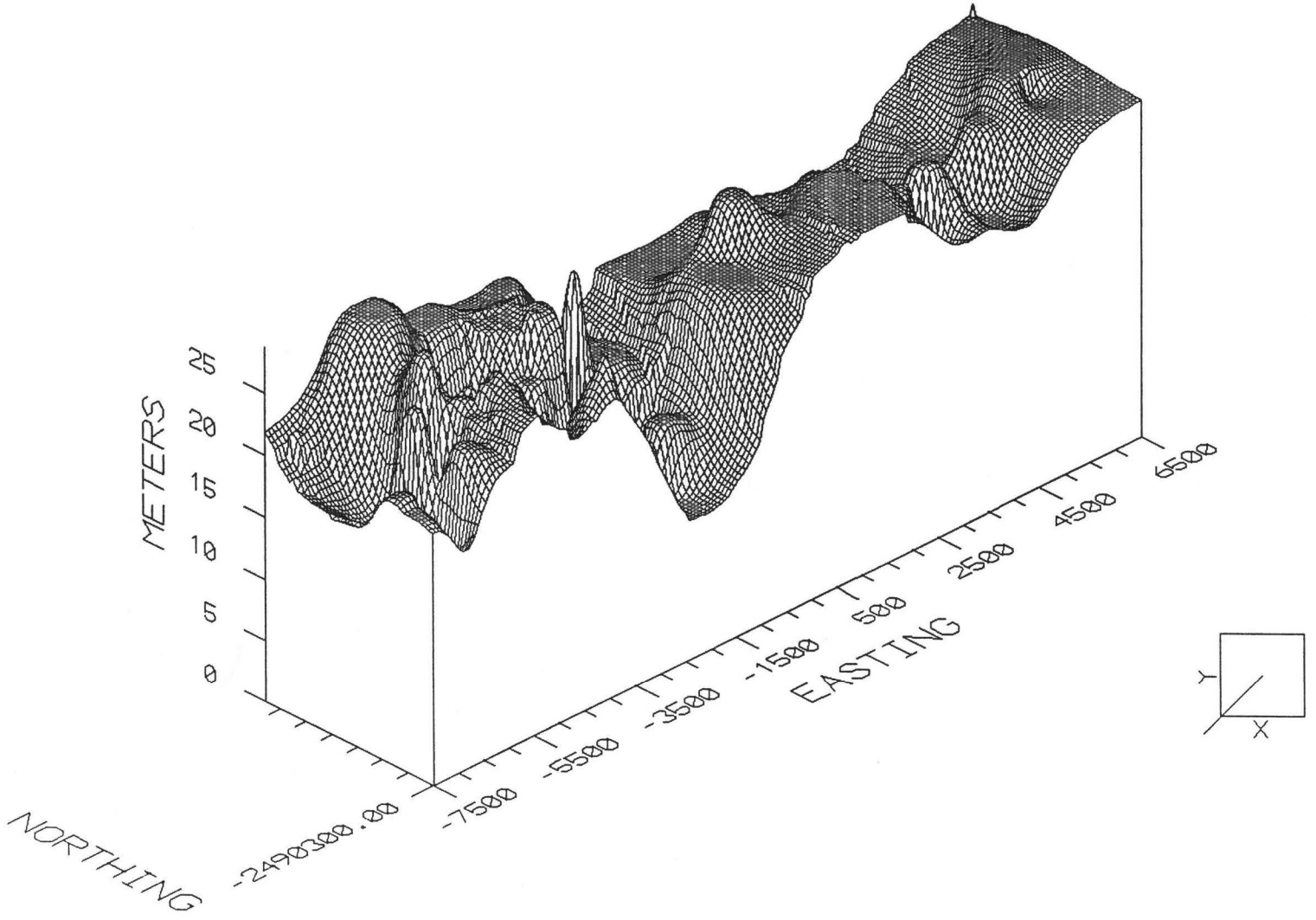


Figure 40. Three dimensional contour plan of an inferred floor to GUS1. See text for details of construction.

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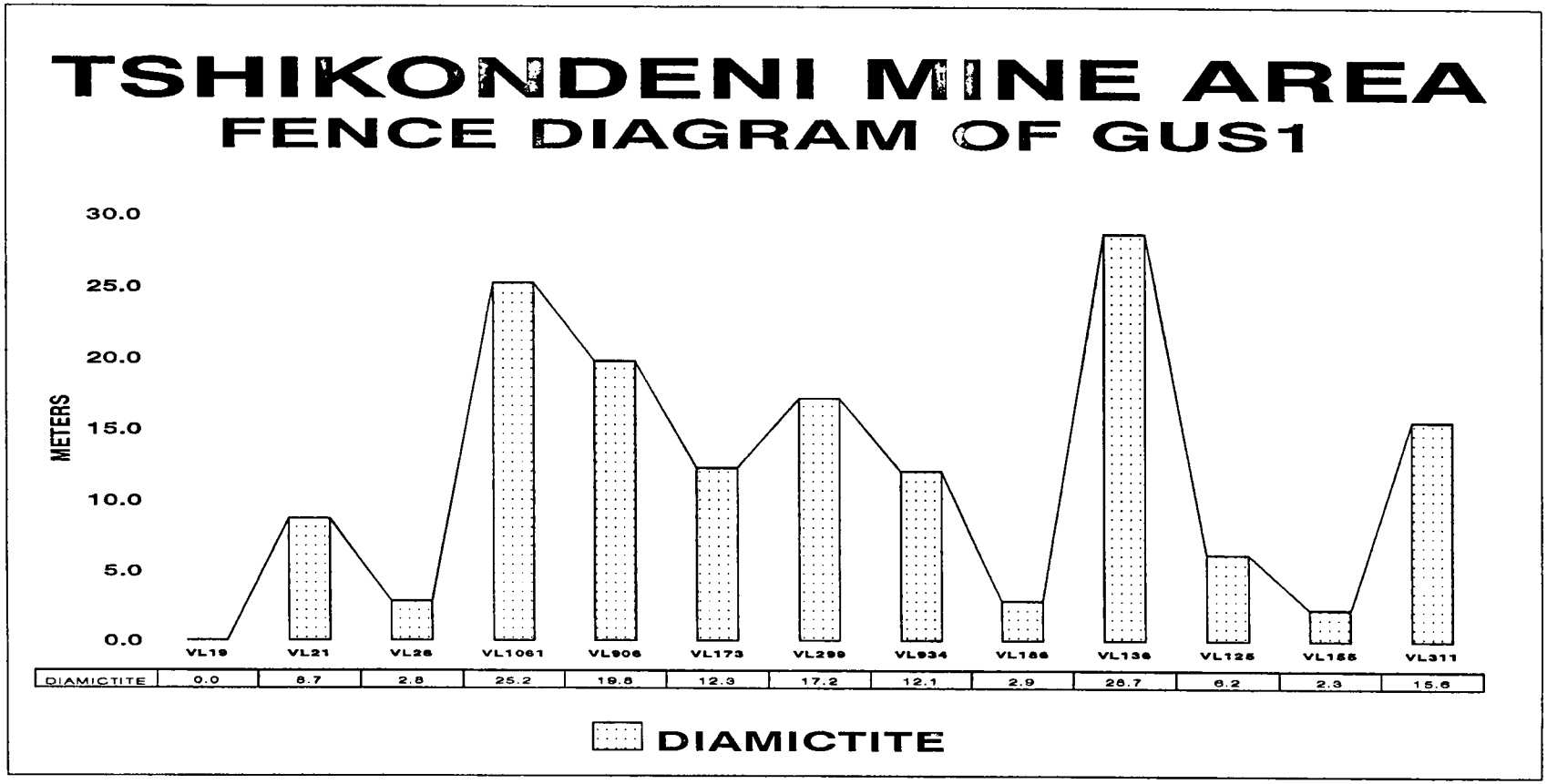


Figure 41. Fence diagram of GUS1 in the Tshikondeni Mine area. See figure 42 for location of boreholes.

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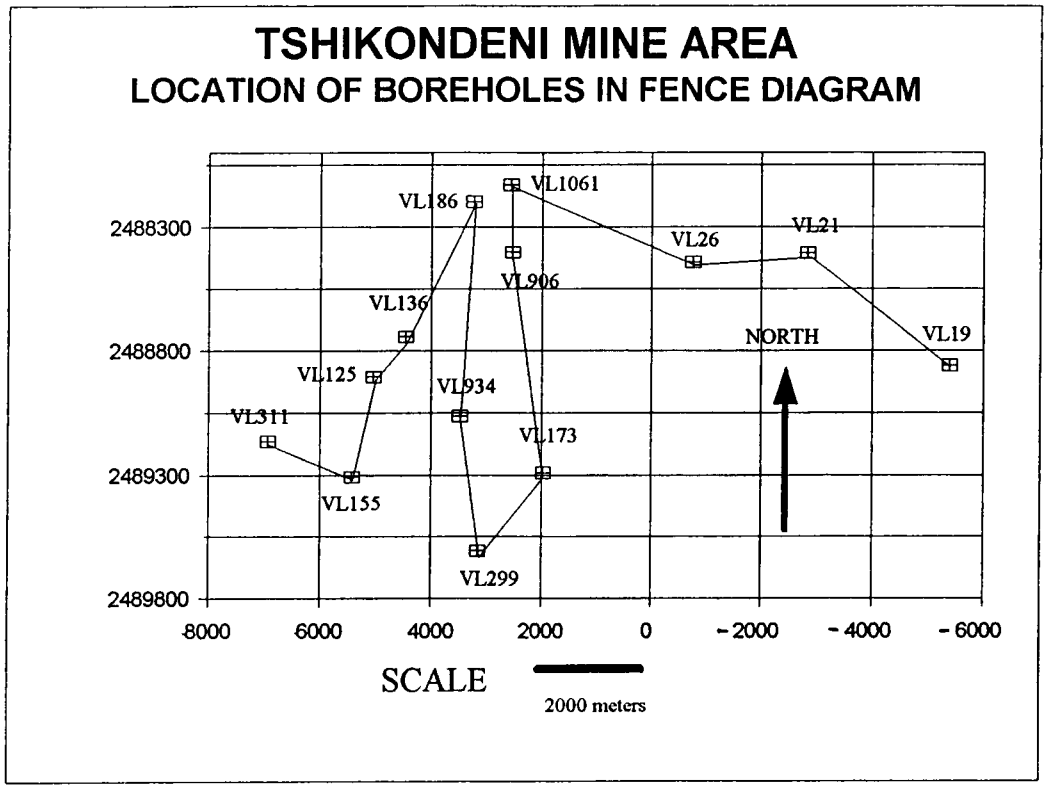


Figure 42. Location of boreholes illustrated on the fence diagram of GUS1.

3.3 Genetic unit of sedimentation 2 (GUS2).

This unit is developed between marker horizons 2 and 3 (Figure 32) and varies in thickness between 20 and 40 m (Figure 49). The following facies make up the bulk of GUS2 (Table 11 and Figures 43 and 44):

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Sandstone facies	± 1% of thickness. Ripple and planar laminated sand-stone/siltstone (Sr)
Mudrock facies	± 56% of thickness. Massive black mudrock (Mm)
Coal facies	± 43% of thickness. Coal (C)

Table 11. Distribution of facies in GUS2.

GUS2 consists almost exclusively of mudrock and carbonaceous material of varying quality (subdivisions SH1 and SH2 of GUS2), with a siltstone marker horizon (subdivision SS1 of GUS2) of 1,00 m to 4,00 m thickness (Figures 44, 45 and 46). This siltstone marker is developed over the whole area and usually has a thin coal seam (<15 cm) about 30 cm from the top. The rest of GUS2 is made up of coal, shaly coal, coaly mudrock and carbonaceous mudrock layers of varying thickness (SH1 and SH2) (Figures 44 and 46).

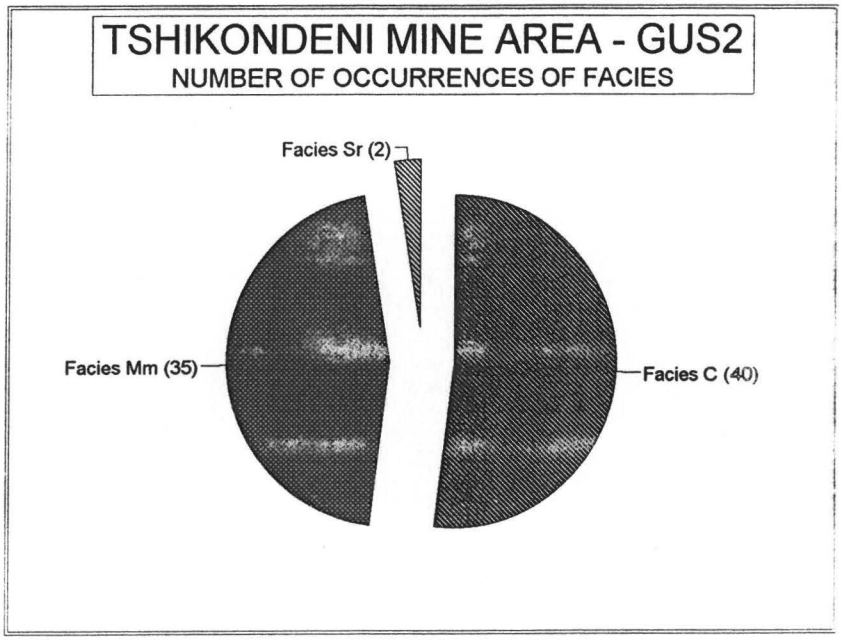
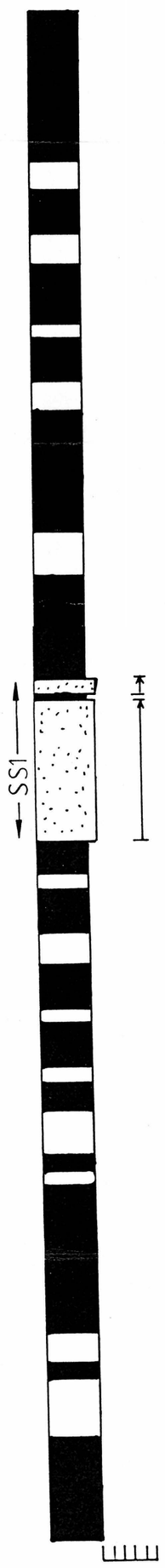


Figure 43. Pie diagram of the distribution of facies in GUS2.

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GUS2



DEPTH (m)	THICKNESS (m)	
408.72		
409.08	0.31	COAL, BRIGHT 30:70
409.47	0.37	COAL, SHALY
		COAL, BRIGHT 20:80
	1.10	
410.79		
411.11	0.20	COAL, SHALY
		SHALE, COALY
411.81	0.70	
411.98	0.17	COAL, BRIGHT 30:70 SHARP
412.19	0.21	SHALE DARK GREY
412.41	0.18	SHALE GREY
412.63	0.22	SHALE, COALY
412.87	0.17	COAL, SHALY
413.19	0.19	SHALE, COALY
		SHALE DARK GREY
413.64	0.45	
		COAL, SHALY
414.28	0.45	
414.55	0.21	SHALE, COALY
415.07	0.38	SHALE, COALY
415.24	0.17	SHALE DARK GREY
415.46	0.22	SHALE, COALY
		SHALE, COALY
416.00	0.49	
		SHALE DARK GREY
416.53	0.53	
417.30	0.40	COAL, SHALY
417.58	0.17	COAL, BRIGHT 60:40
418.43	0.32	SHALE, COALY JOINTED
418.68	0.25	COAL, BRIGHT 30:70
419.18	0.40	COAL, BRIGHT 30:70
419.62	0.31	COAL, BRIGHT 40:60
420.11	0.41	COAL, BRIGHT 30:70
420.39	0.15	COAL, BRIGHT 40:60
420.54	0.15	SHALE GREY
		SHALE GREY
421.10	0.51	
421.65	0.26	COAL, BRIGHT 50:50
421.89	0.24	SHALE, COALY
		COAL, BRIGHT 60:40
422.57	0.59	
422.74	0.17	SHALE, COALY
422.99	0.25	COAL, BRIGHT 30:70
423.59	0.30	COAL, BRIGHT 50:50
423.92	0.33	SILTSTONE GREY UPWARD-FINING
		SILTSTONE GREY BECOMING QUITE SANDY, UPWARD COARSE-NING.
	2.76	
426.77		
427.07	0.19	COAL, BRIGHT 20:80
427.56	0.15	COAL, BRIGHT 20:80
427.91	0.20	SHALE BLACK
428.19	0.19	SHALE, COALY
428.48	0.29	SHALE, COALY
428.79	0.17	COAL, BRIGHT 40:60
429.37	0.29	SHALE BLACK
429.82	0.22	SHALE BLACK
430.25	0.32	SHALE, COALY
430.45	0.20	COAL, BRIGHT 30:70
431.07	0.27	COAL, SHALY
431.45	0.38	SHALE BLACK
431.72	0.16	COAL, SHALY
431.88	0.16	COAL, BRIGHT 20:80
432.18	0.16	COAL, BRIGHT 30:70
432.33	0.15	SHALE BLACK
432.95	0.16	COAL, BRIGHT 60:40
433.21	0.17	SHALE, COALY
433.69	0.19	SHALE BLACK
433.93	0.19	SHALE BLACK CARBONACEOUS
434.41	0.27	SHALE BLACK
434.73	0.15	COAL, BRIGHT 20:80
435.14	0.41	SHALE BLACK
435.29	0.15	SHALE, COALY
435.56	0.24	SHALE, COALY
		COAL, SHALY JOINTED, SLICKENSIDED
	0.81	
436.50		
436.75	0.25	SHALE, COALY
436.95	0.20	COAL, SHALY CORE JOINTED
437.37	0.31	SHALE, COALY JOINTED
437.63	0.26	COAL, SHALY
437.94	0.18	SHALE, COALY
		SHALE BLACK
438.58	0.64	
438.79	0.21	SHALE, COALY
		SHALE BLACK SLICKENSIDED JOINTS
	1.16	
439.95		
440.45	0.30	COAL, SHALY
		COAL, BRIGHT 30:70
	0.71	
441.16		
441.40	0.24	COAL, SHALY
		COAL, BRIGHT 40:60
441.98	0.58	

LEGEND

- SHARP CONTACTS
- GRADATIONAL CONTACTS
- QUARTZ GRAINS AND QUARTZ PEBBLE BANDS
- SILTY LAMINAE AND CONVOLUTE LAMINATIONS
- HORIZONTAL LAMINATIONS
- RIPPLE CROSS-LAMINATION
- Fe•CO3 SIDERITE
- WORM BURROWS
- PROMINENT QUARTZ PEBBLE BAND
- LARGE SCALE CROSS-BEDDING
- FINING DIRECTION
- W VARVED MUDROCK
- MUDROCK
- SANDSTONE
- COAL
- CLAY PELLET CONGLOMERATE BAND
- QUARTZITE
- SOFT SEDIMENT DEFORMATION STRUCTURES
- SS1 GENETIC UNIT OF SEDIMENTATION SUBDIVISION
- DOLERITE

Figure 44. Lithological profile of GUS2 (borehole VL1061).

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The thickest accumulation of GUS2 is found in the centre of the study area and in a small area towards the east (Figures 46 and 49). GUS2 thins towards the south-east, west and north-west. The thinnest occurrence of GUS2 corresponds well with the thin parts of GUS1 (Figure 39 and 49), suggesting that palaeohigh's in the floor may have influenced deposition of GUS1 and GUS2 (Figures 40 and 48).

The floor of GUS2 is more irregular than that of GUS1, compare figures 40 and 48.

GUS2 is always overlain by a mudrock with quartz grains and quartz pebble bands (Mm) (the floor of GUS3).

From the fence diagram of GUS2 (Figure 46) it is apparent that the lower part of GUS2 (SH1) varies in thickness.

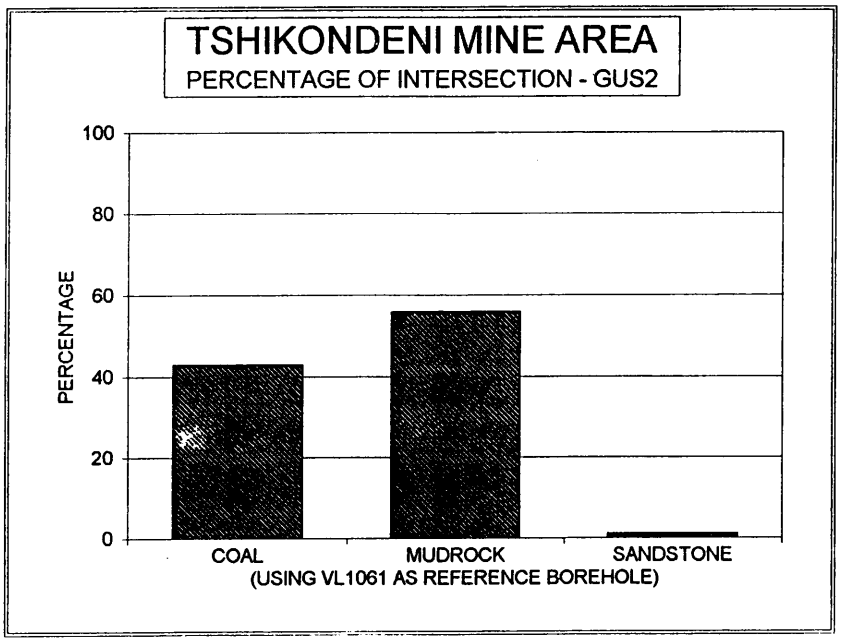


Figure 45. Percentage of the different rock types in GUS2.

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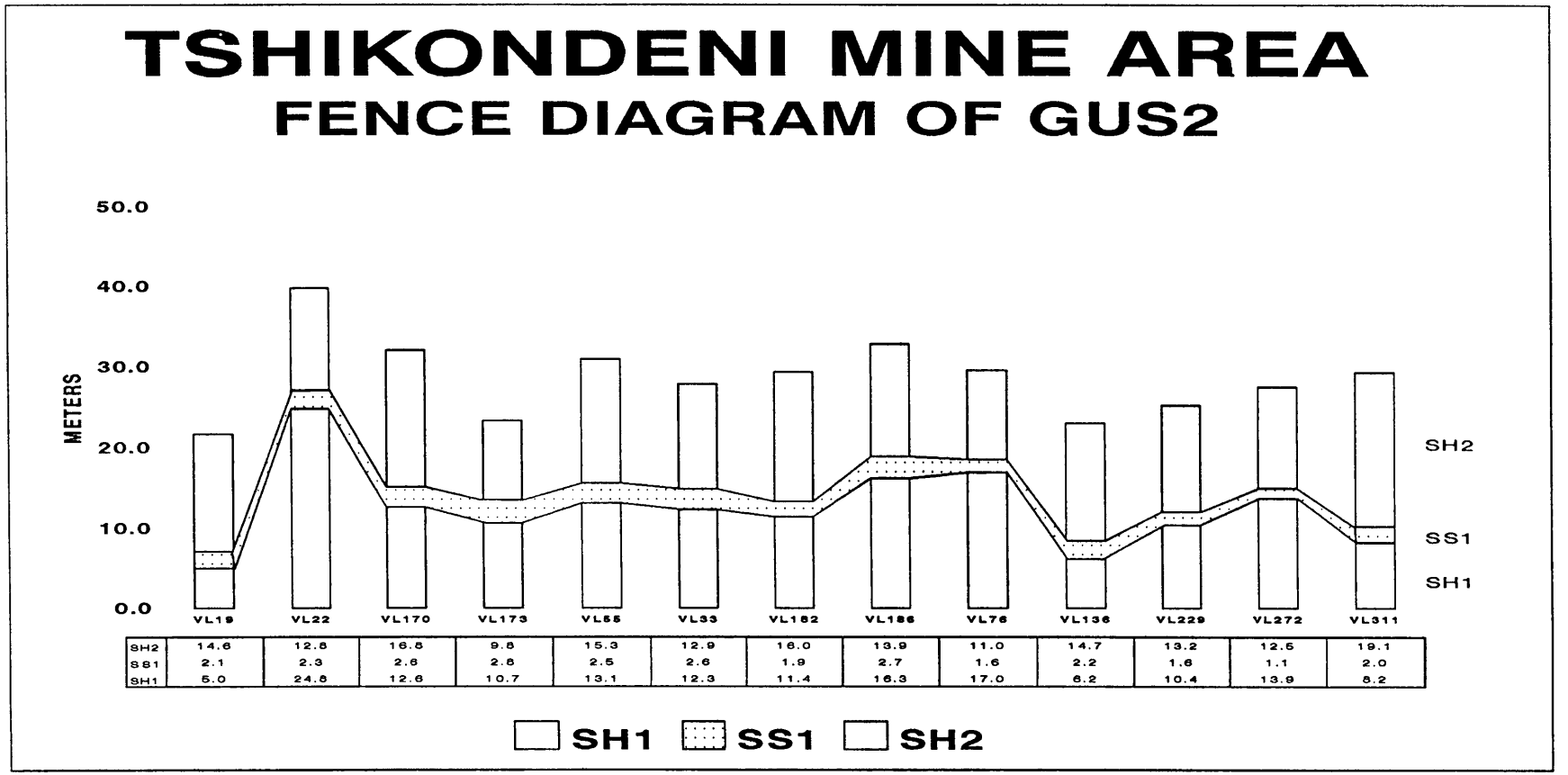


Figure 46. Fence diagram of GUS2 in the Tshikondeni Mine area. See figure 47 for the location of boreholes.

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Borehole VL19 in the east has poorly developed SH1 but in all the boreholes SH2 is fairly constant (Figure 46). There is a slight thinning of SS1 towards the west.

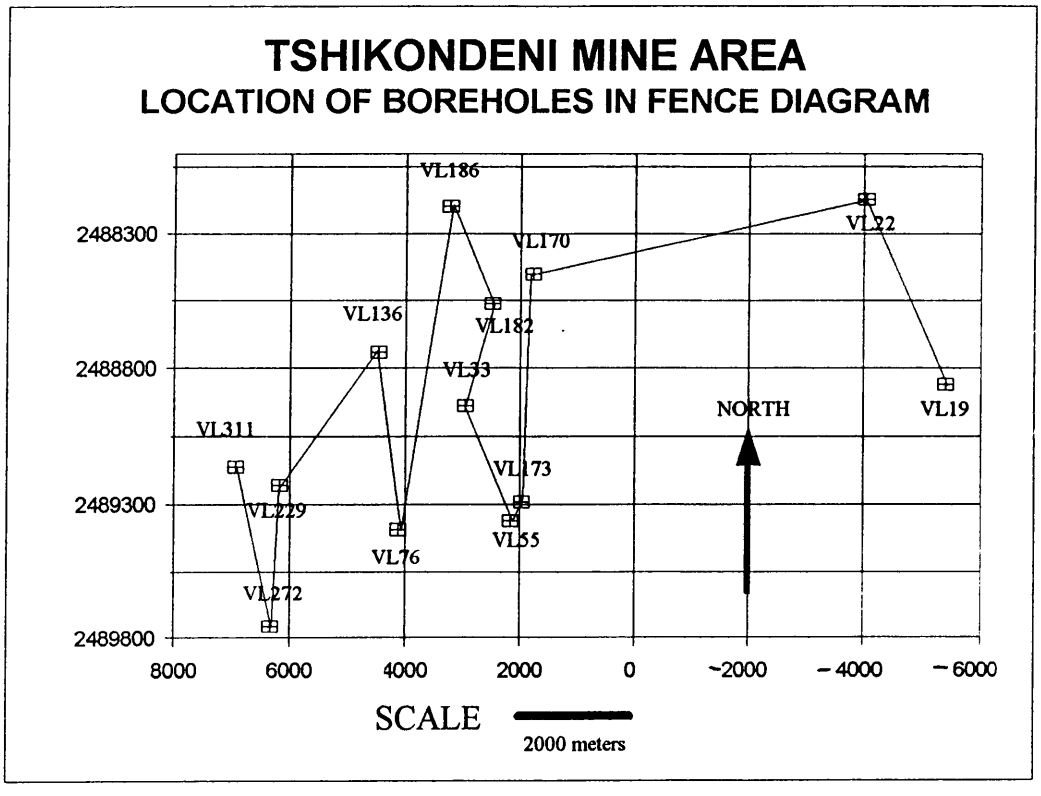


Figure 47. Location of boreholes illustrated on the fence diagram of GUS2.

SS1 is locally upward-coarsening in the upper part and upward-fining in the lower part. A contour plan of a possible floor to GUS2 was drawn (Figure 48), on the same basis as for GUS1, but using the base of GUS3 as reference surface. This illustrates that the floor for GUS2 may have still been very uneven, even more so than for GUS1.

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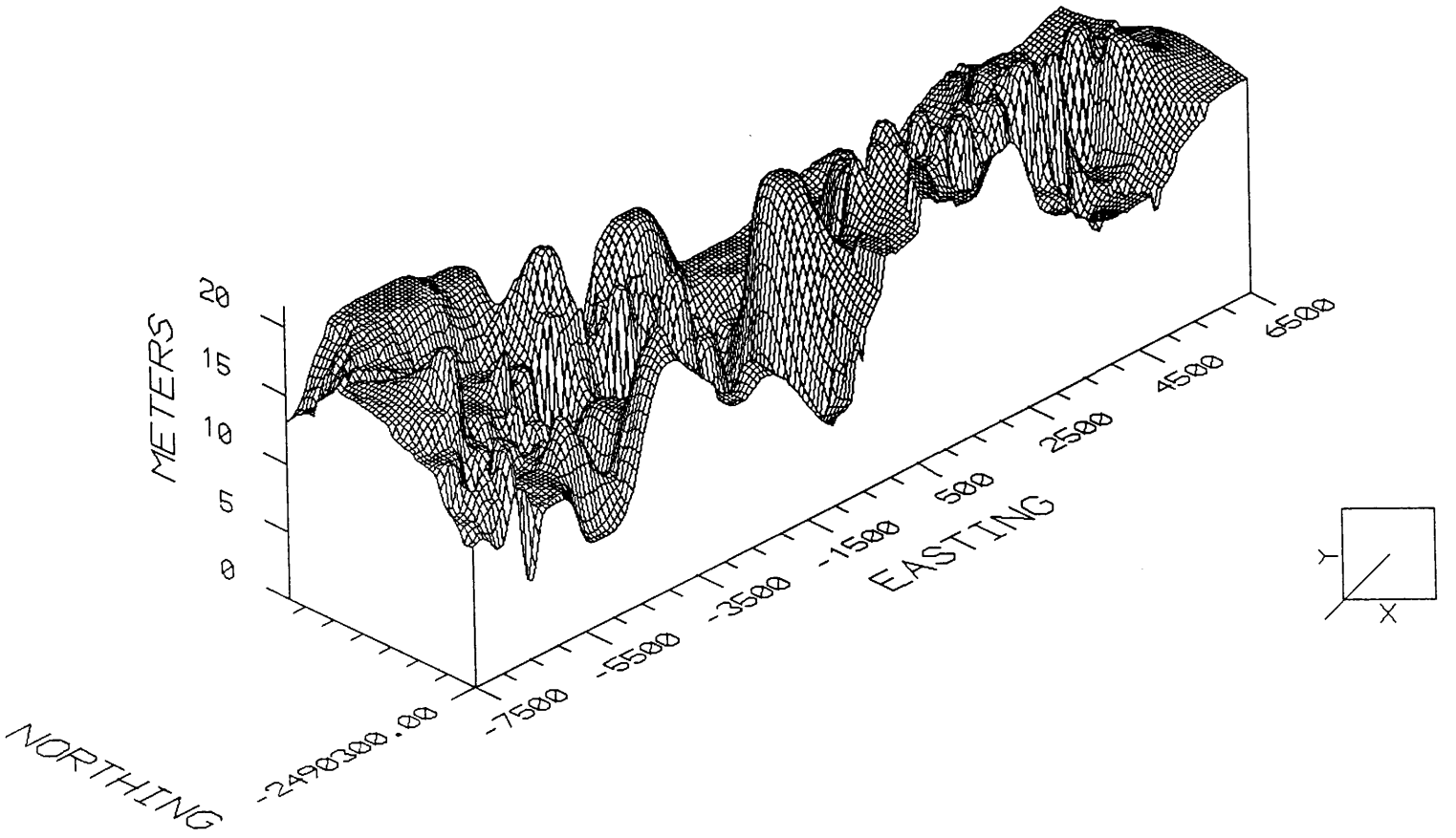


Figure 48. Contour plan of an inferred floor to GUS2.

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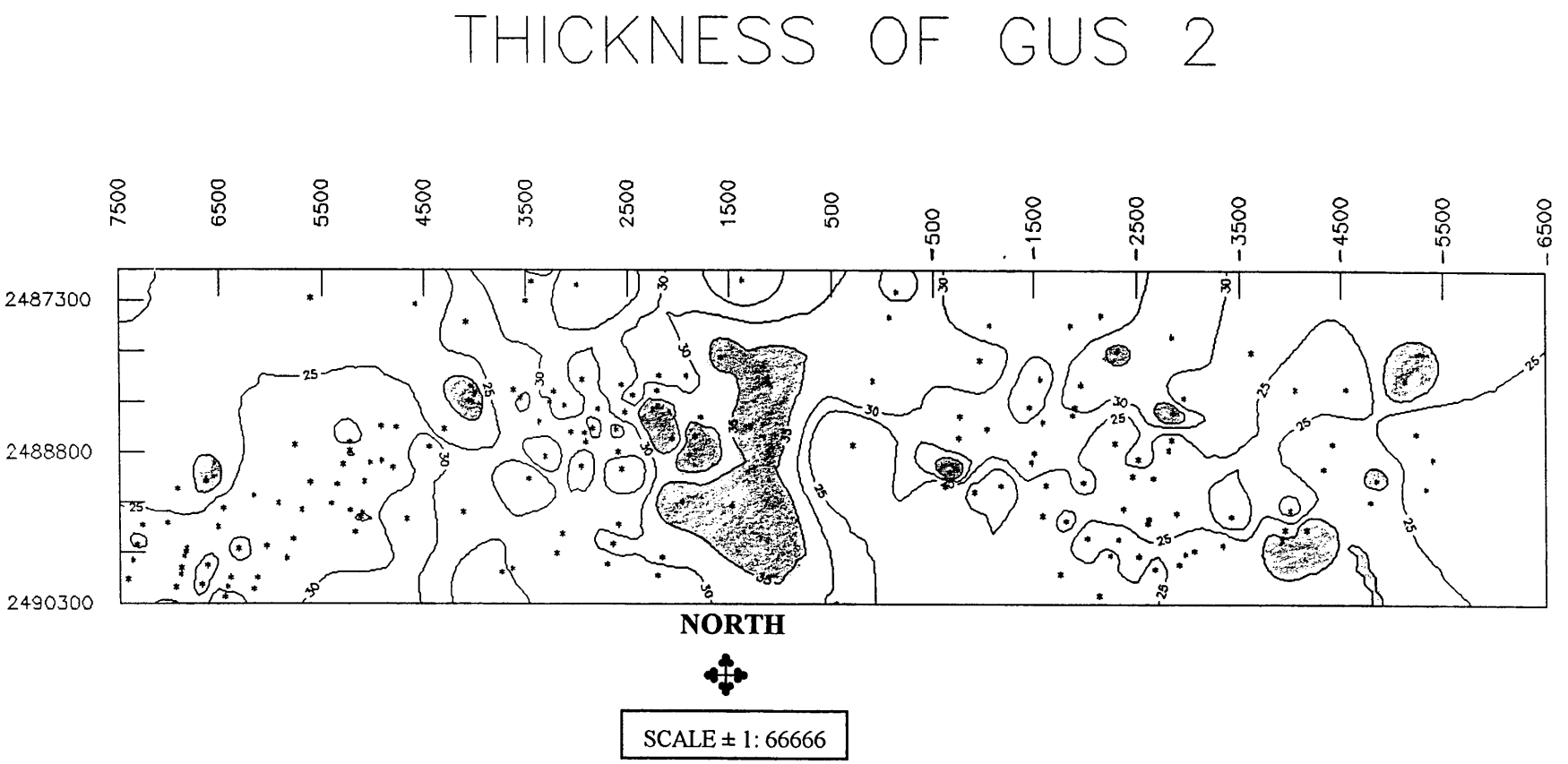


Figure 49. Thickness contours (in metres) of GUS2. (Thick areas in blue and thin areas in brown).

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3.4 Genetic unit of sedimentation 3 - (GUS3).

Genetic unit of sedimentation 3 is subdivided into two parts: Genetic unit of sedimentation - 3L, the lower part of GUS3 and Genetic unit of sedimentation - 3U, the upper part of GUS3. The reason for this is that, in the lower part of GUS3, no coal is present (except in a few boreholes), while coal is present in the upper part of GUS3. It is possible that erosion frequently removed sample 11 from GUS3L, as it is only present locally. There is a general upward-coarsening arrangement of sedimentary units from the bottom of GUS3 to the top.

3.4.1 Genetic unit of sedimentation 3 - Lower part (GUS3L).

This unit, bounded by markers 3 and 4 (Figure 32), attains a maximum thickness of 55 m in the centre of the study area (Figure 52) and consists of sandstone, coal and mudrock (Figure 51). The minimum thickness of about 35 m occurs in the west. The following facies are the most prominent in GUS3L (Table 12 and Figures 50 and 53):

Sandstone facies	± 28% of thickness. Ripple and planar laminated sand-stone/siltstone (Sr) Graded sandstone (Sg)
Mudrock facies	± 71% of thickness. Mudrock with quartz grains and quartz pebble bands (Mp) Massive black mudrock (Mm)
Coal facies	± 1% of thickness. Coal (C)

Table 12. Distribution of facies in GUS3L.

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Only one thin occurrence of coal (Sample 11, Table 6) is intersected sporadically. GUS3L consists essentially of three sandstones units (SS1-SS3) and four mudrock units (SH1-SH4) which alternate with each other (Figure 53) with generally gradational contacts between them.

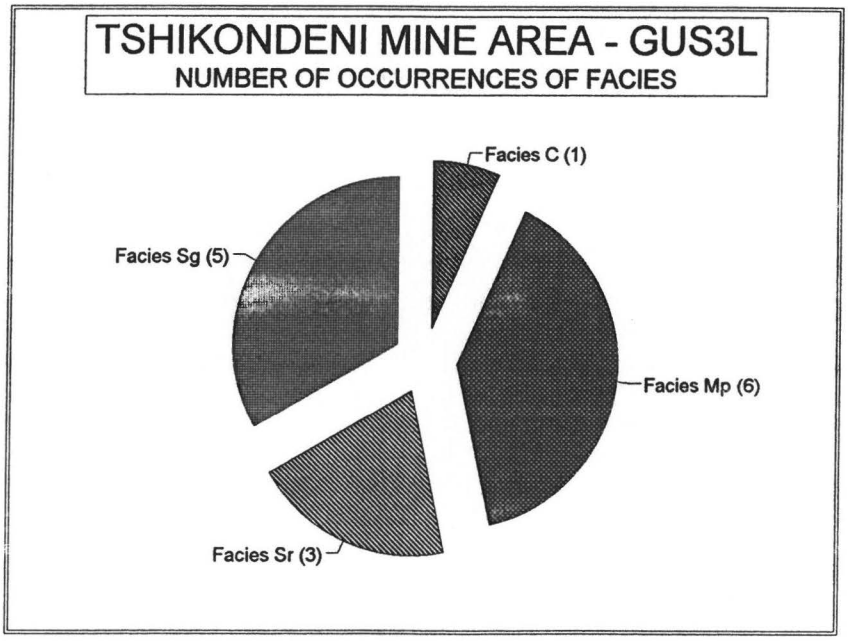


Figure 50. Pie diagram of the distribution of facies in GUS3L.

The lowermost mudrock unit (SH1) (Figure 53) is situated on top of the coals of GUS2, and has a gradational to sharp top contact with the succeeding sandstone unit (SS1). The bottom contact with GUS2 is always sharp. SH1 is between 0,5 m and 2,0 m thick (Figure 54)and consists exclusively of mudrock with quartz grains and quartz pebble bands (facies Mp). SS1 contains an upward-fining and an upward-coarsening sandstone sequence (facies Sg) and varies between 4,0 and 8,0 m thickness with an average of 5 m (Figure 54).

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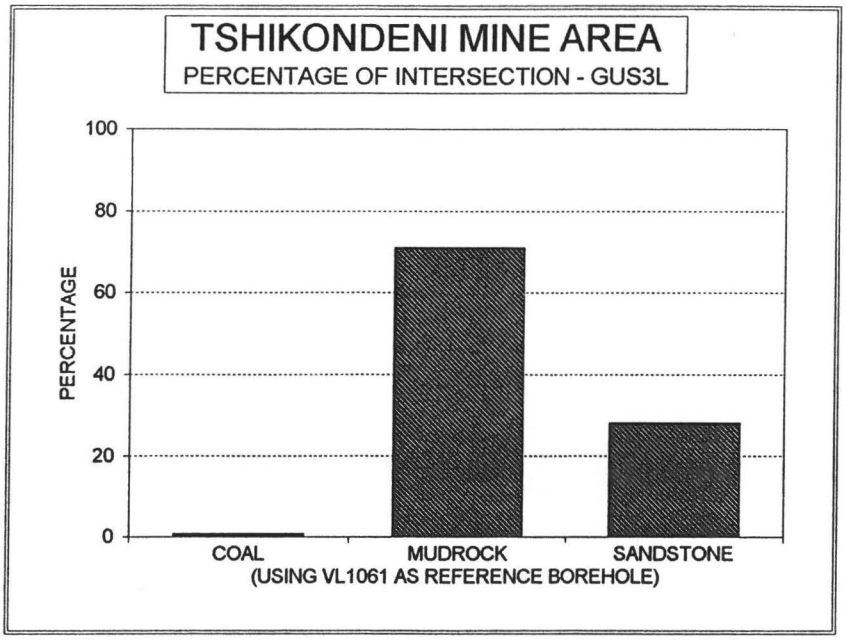


Figure 51. Percentage of the different rock types in GUS3L.

The upward-coarsening upper portion of SS1 varies between 0,7 m and 1,0 m in thickness. Horizontal laminations and ripple cross-bedding (facies Sr) occur in the finer sandstones and a silty mudrock band (facies Ml) separating the two sandstone sequences in SS1 becomes a siltstone in places.

SH2 consists of two types of mudrock, the upper half being facies Mp and the lower, facies Mm. The average thickness is ± 8,0 m. The lower mudrock is part of an upward-fining sequence of SS1 sandstone and SH2 mudrocks and the upper mudrocks, part of an upward-coarsening succession of SS2 sandstones and SH2 mudrocks. Quartz grains are very prominent in the upper part of this unit.

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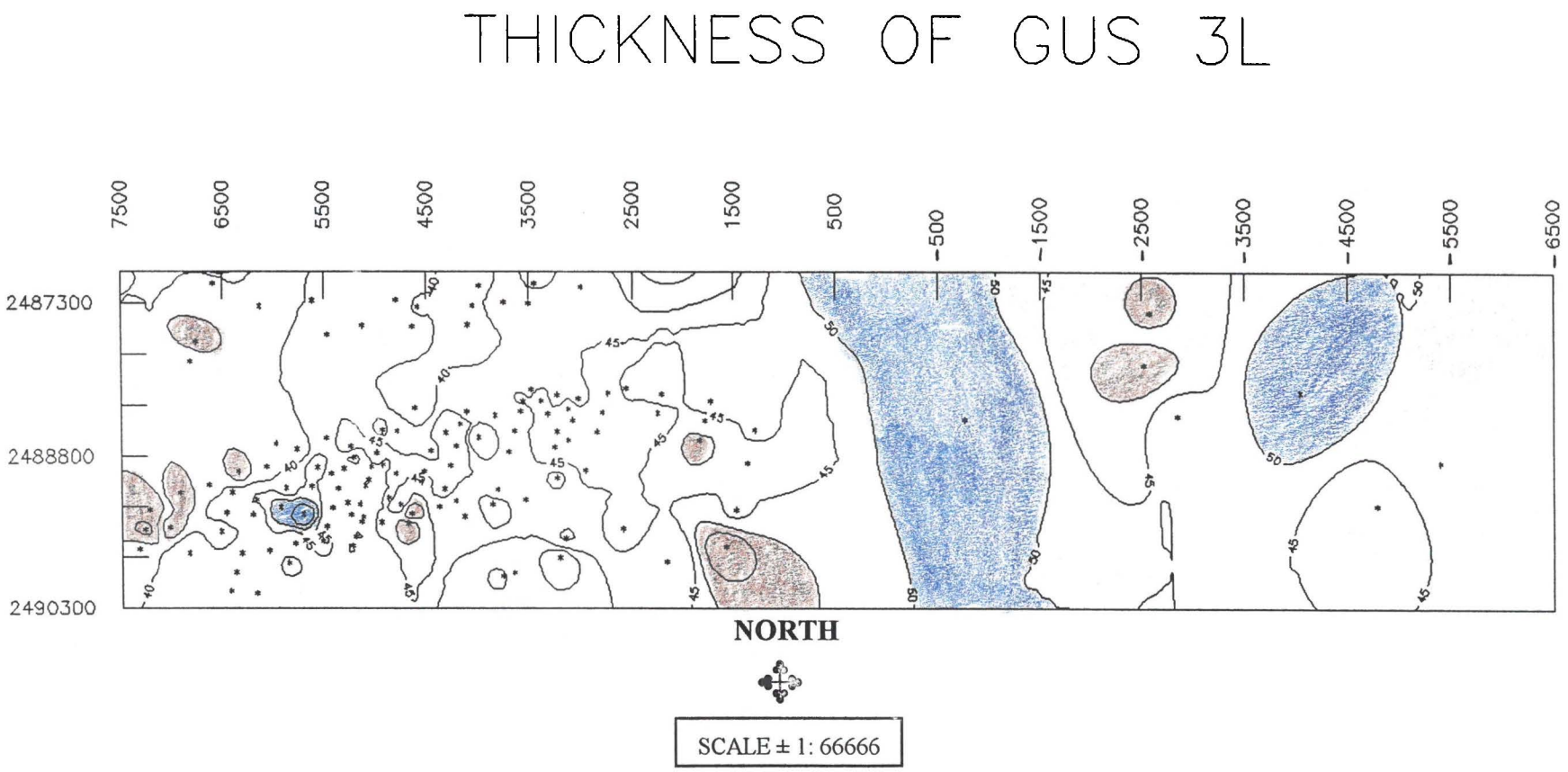


Figure 52. Thickness contours (in metres) of GUS3L. (Thick parts in blue and thin parts in brown).

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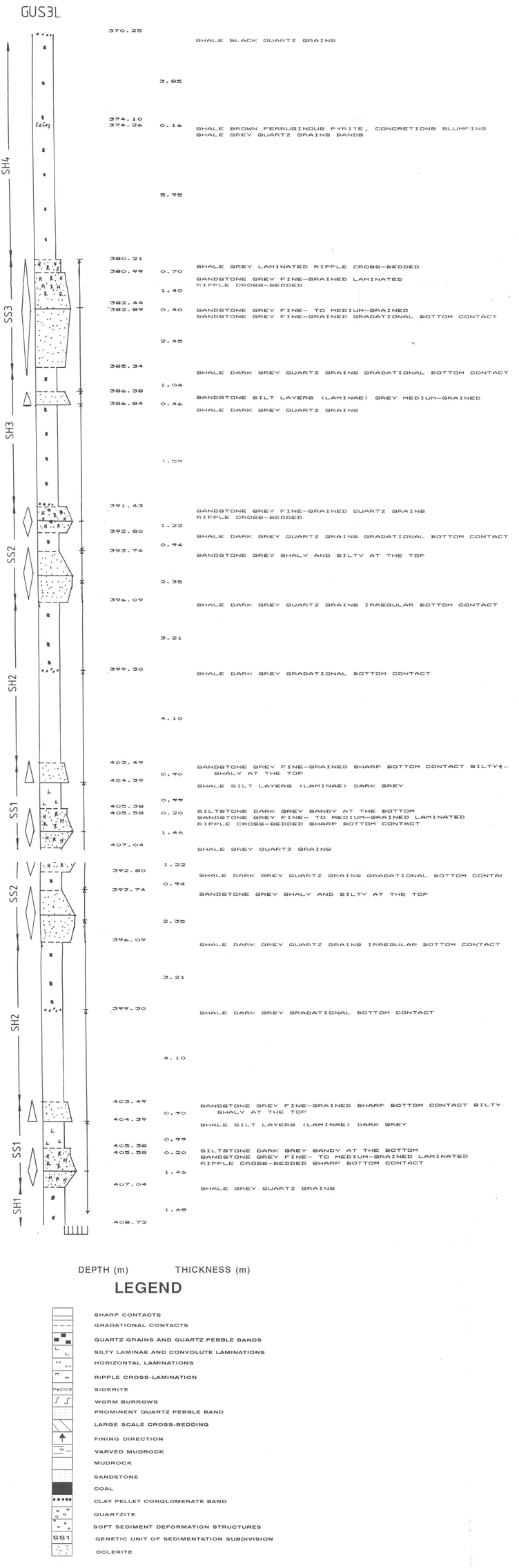
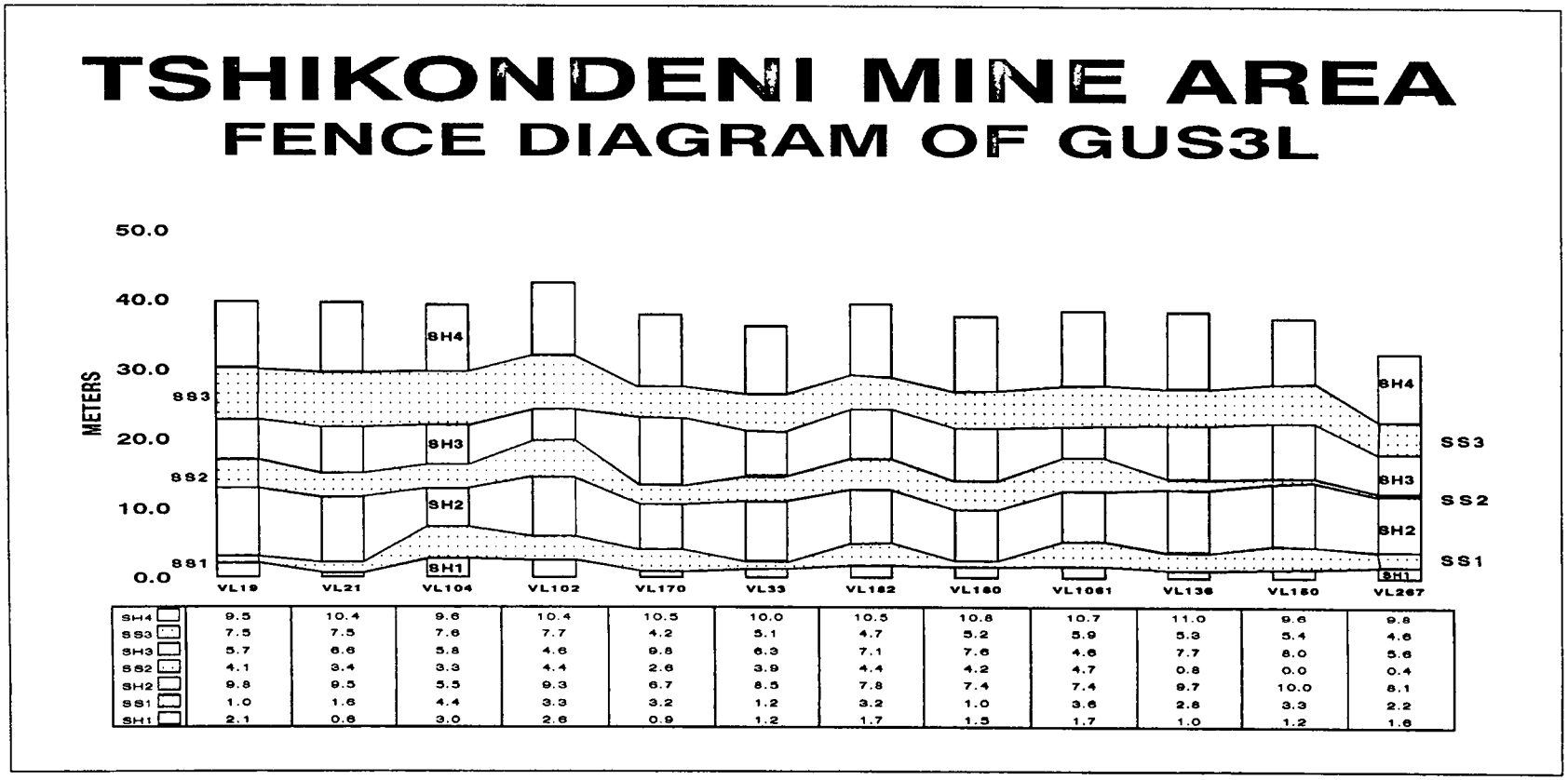


Figure 53. Lithological profile of GUS3L.

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	VL19	VL21	VL104	VL102	VL170	VL33	VL182	VL180	VL1061	VL136	VL150	VL267
SH4	9.5	10.4	9.6	10.4	10.5	10.0	10.5	10.8	10.7	11.0	9.6	9.8
SS3	7.5	7.5	7.6	7.7	4.2	5.1	4.7	5.2	5.9	5.3	5.4	4.6
SH3	5.7	6.6	5.8	4.6	9.8	6.3	7.1	7.6	4.6	7.7	8.0	5.6
SS2	4.1	3.4	3.3	4.4	2.6	3.9	4.4	4.2	4.7	0.8	0.0	0.4
SH2	9.8	9.5	5.5	9.3	6.7	8.5	7.8	7.4	7.4	9.7	10.0	8.1
SS1	1.0	1.6	4.4	3.3	3.2	1.2	3.2	1.0	3.6	2.8	3.3	2.2
SH1	2.1	0.6	3.0	2.6	0.9	1.2	1.7	1.5	1.7	1.0	1.2	1.6

Figure 54. Fence diagram of GUS3L in the Tshikondeni Mine area. Refer to figure 55 for location of boreholes.

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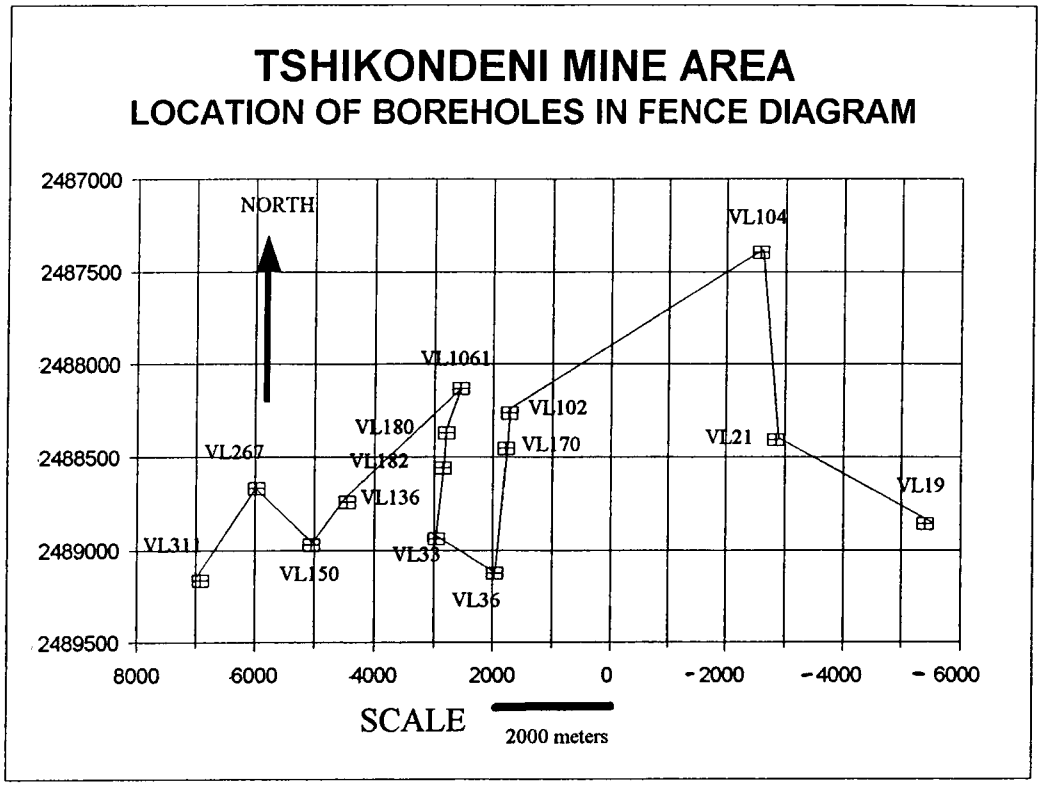


Figure 55. Location of boreholes illustrated on the fence diagram of GUS3L.

The thickness of the SS2 sandstones (Figure 54) averages 4,0 m, but they pinch out towards the west. Grain sizes vary between fine and coarse and the upper sandstones have abundant ripple cross-laminations (facies Sr). Locally, there is a thin quartz pebble lag on top of SS2. The colour of this lag is white to light grey.

SH3 (Figure 53) is upward-fining locally and consists of grey to dark grey facies Mp mudrock. Quartz pebble bands up to 50 cm thick occur and the total thickness varies between 4 m and 10 m. The thickness does, however, vary somewhat (Figure 54).

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The top of SH3 again becomes silty and forms the base for an upward-coarsening sequence passing into SS3, above it.

SS3 consists mostly of white facies Sg sandstones of varying grain size and of relatively constant thickness (average = 5 m), being either upward-coarsening or upward-fining. The contacts of SS3 are sharp to gradational. The top half of SS3, which is finer-grained, exhibits ripple cross-lamination and horizontal laminations, typical of facies Sr sandstones.

SH4, the upper unit of GUS3L, consists of mudrock with quartz grains and quartz pebble bands (facies Mp), with some siderite enrichment in places. This mudrock is grey to dark grey but the quartz pebble bands and grains are white (Figure 56).

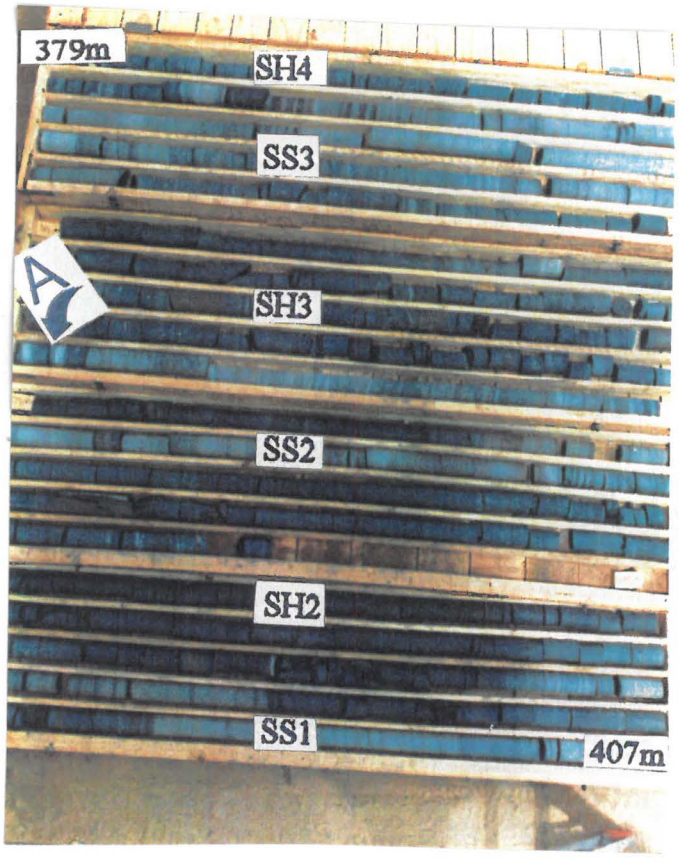


Figure 56. GUS3L between 379 m and 407 m. Marker A points to a quartz pebble band.

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3.4.2 Genetic unit of sedimentation 3 - Upper part (GUS3U).

GUS3U occurs between markers 4 and 5 (Figure 32) and shows little variation in thickness (between 50 and 60 m) (Figures 61 and 62). GUS3U consists of the following facies (Table 13 and Figures 57 and 59):

Sandstone facies	± 59% of thickness. Large scale cross-bedded sandstone (S) Ripple and planar laminated sandstone/ siltstone (Sr) Graded sandstone (Sg) Massive sandstone (Sm)
Mudrock facies	± 38% of thickness. Mudrock with quartz grains and quartz pebble bands (Mp) Massive black mudrock (Mm)
Coal facies	± 3% of thickness. Coal (C)

Table 13. Distribution of facies in GUS3U.

GUS3U consists of four sandstone units (SS1-SS4) and four mudrock units (SH1-SH4) (Figures 58 and 60) which alternate with each other. Coal sample 10 (Table 6) occurs in SS1 as two coal bands, each between 30 cm and 80 cm thick. Between these two coal bands is an upward-fining, fine- to coarse-grained sandstone with horizontal laminae and ripple cross-lamination (facies Sr).

SS1 consists predominantly of three to four, fine- to coarse-grained, white, upward-fining sandstone beds (facies Sg).

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Above sample 10, a single upward-coarsening sandstone bed of about 40 cm thickness is found. The sandstones underlying the coal seams are carbonaceous.
The thickness of SS1 varies between 7 m and 23 m but there is a general thickening trend towards the west.

These sandstones (facies Sg) are slightly coarser than those of GUS3L. The sandstone capping SS1 is mostly massive (facies Sm), with lenses of large scale cross-bedded coarser sandstone (facies Sp), and horizontal laminae and ripple cross-lamination in the localised occurrences of finer sandstones (facies Sr) at the top, and is usually 3 m thick. The lower coal seams of sample 9 (Table 6) occur at the top of SS1.

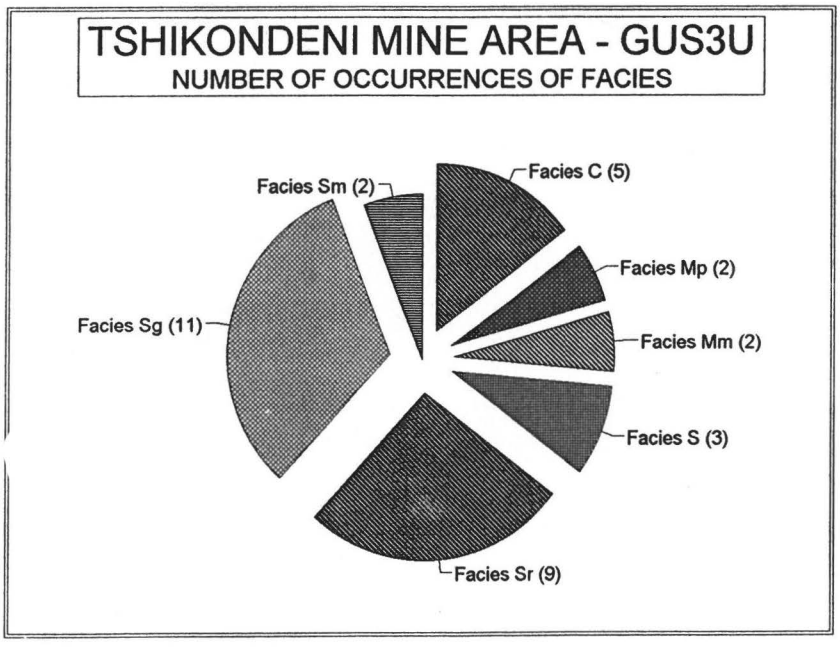


Figure 57. Pie diagram of the distribution of facies in GUS3U.

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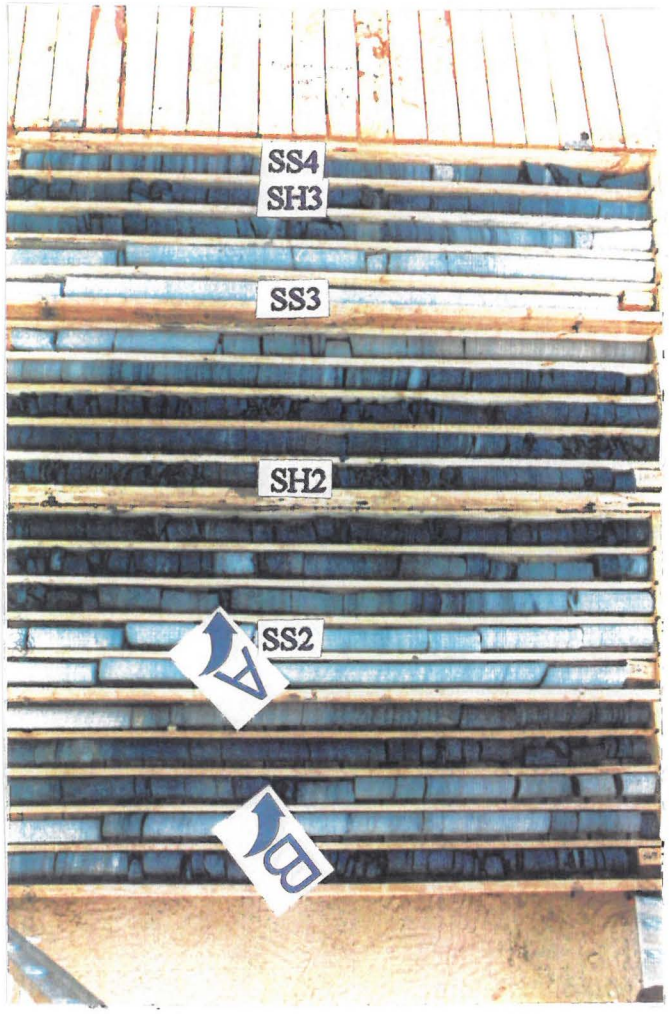


Figure 58. GUS3U (± 320 m to 349 m). The following units of GUS3U are illustrated: SS4, SH3, SS3, SH2 and SS2.

SH1 comprises grey to dark grey, facies Mp mudrock. The thickness of this unit does not vary very much (between 6 m and 11 m - mostly 6 m), but it appears as if there was a tendency to fill irregularities in the floor, as SH1 is thicker over the thin parts of SS1 (Figure 62). SH1 is thinner towards the east and west.

SS2 consists of two sandstone beds separated by a thin (2 m) facies Mm mudrock (Figure 60). The upper coal band of sample 9 occurs above the lower sandstone of SS2 and sample 8 (table 6)

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occurs near the top of the upper sandstone of SS2. The thickness of SS2 decreases towards the west and the average is 11 m. The colour of these sandstones (mostly facies Sg) varies from white to black near the coal layers and the contacts between some of the different sandstone beds are sharp.

The lower sandstone in SS2 (facies Sg) has a gradational lower contact, becomes medium- to coarse-grained about 50 cm from the base and then becomes finer towards the top (Figure 60). The finer parts of the sandstone have horizontal laminations and ripple cross-lamination (facies Sr).

The upper sandstone (facies Sg) in SS2 has gradational contacts, and is also upward-coarsening in the bottom half and upward-fining in the top half. Large scale cross-bedding is found in the coarse sandstones (facies S) and ripple cross-lamination and horizontal laminae in the finer arenites (facies Sr). At both the upper and lower contact of SS2, are thin quartz pebble bands.

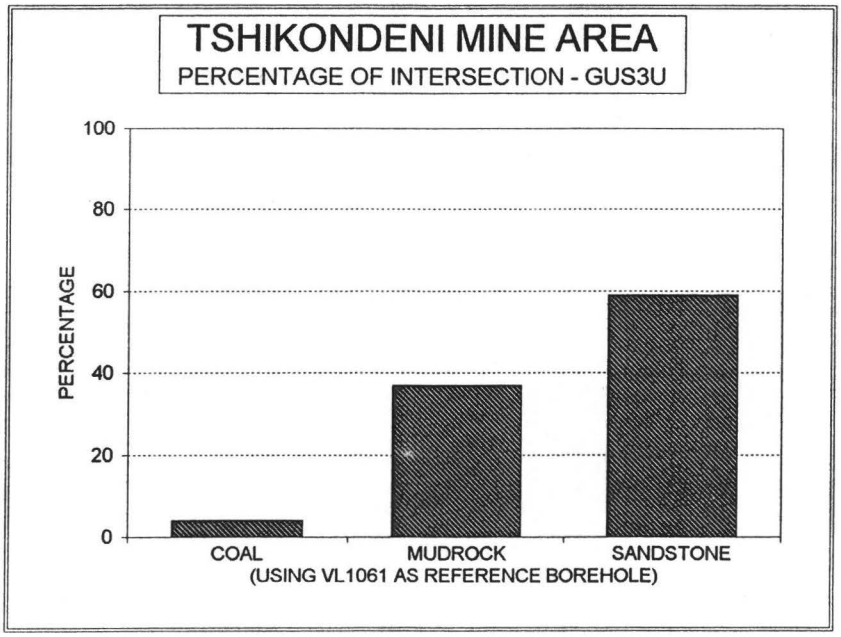


Figure 59. Percentage of the different rock types in GUS3U.

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SH2, above SS2, has a constant thickness over the whole TMA, with virtually no variation (Figures 61 and 62). The mudrock is also very silty in places (facies Ml) and grades into a fine-grained sandstone (facies Sr) at the top.

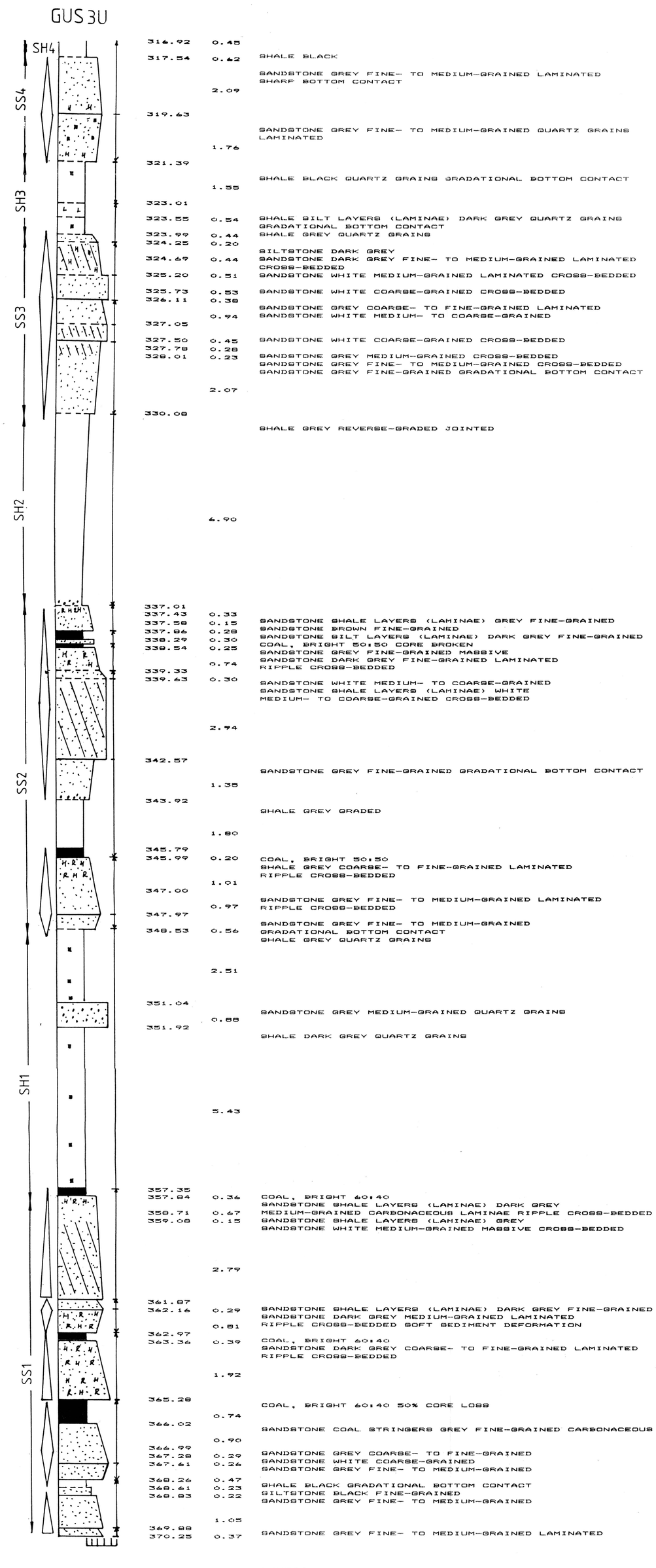
SS3 consist of a single, medium-grained sandstone unit having sharp and gradational internal bedding contacts (facies Sg). Horizontal laminations and ripple cross-lamination are found in the finer parts (facies Sr). The thickness of SS3 is reasonably consistent throughout the area and varies between 4,0 m and 10,7 m (average = 6,0 m).

SH3 is a prominent mudrock layer (facies Ml) separating SS3 and SS4 (Figure 60) and has a constant thickness over the whole TMA, varying between 3,0 and 4,5 m (average 3,5 m). There is a general upward-coarsening tendency.

SS4 has a fairly constant thickness, although borehole VL104 has an abnormal development of SS4 (Figure 62). This thick development of this (facies Sg) sandstone did, however, not occur at the expense of the underlying mudrock and sandstone units (i.e. cutting into the floor). The average thickness of SS4 is 4,5 m and it is medium- to coarse-grained.

SH4, capping SS4, is important in that it is directly below the main coal seam being mined at present. This (facies Mm) mudrock breaks up and gives way underneath vehicles during the mining process and contaminates the product fed to the beneficiation plant. The thickness of this mudrock unit is thus always well recorded and varies between 0,0 m and 4,0 m. It is, however, usually no more than 50 cm thick. This mudrock is very silty in places (facies Ml).

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LEGEND

Figure 60. Lithological profile of GUS3U.

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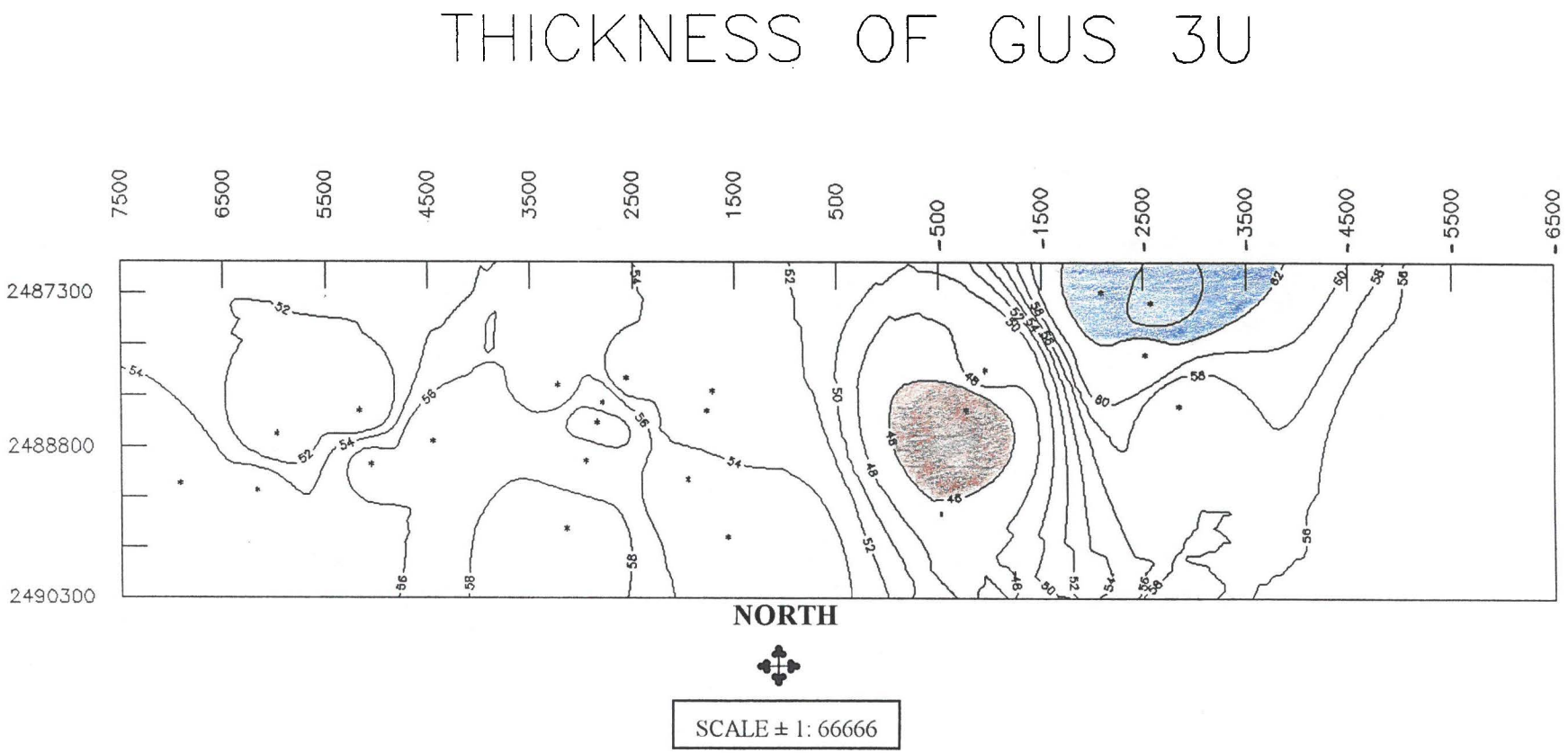


Figure 61. Thickness contours (in metres) of GUS3U.(Thick parts in blue and thin parts in brown)

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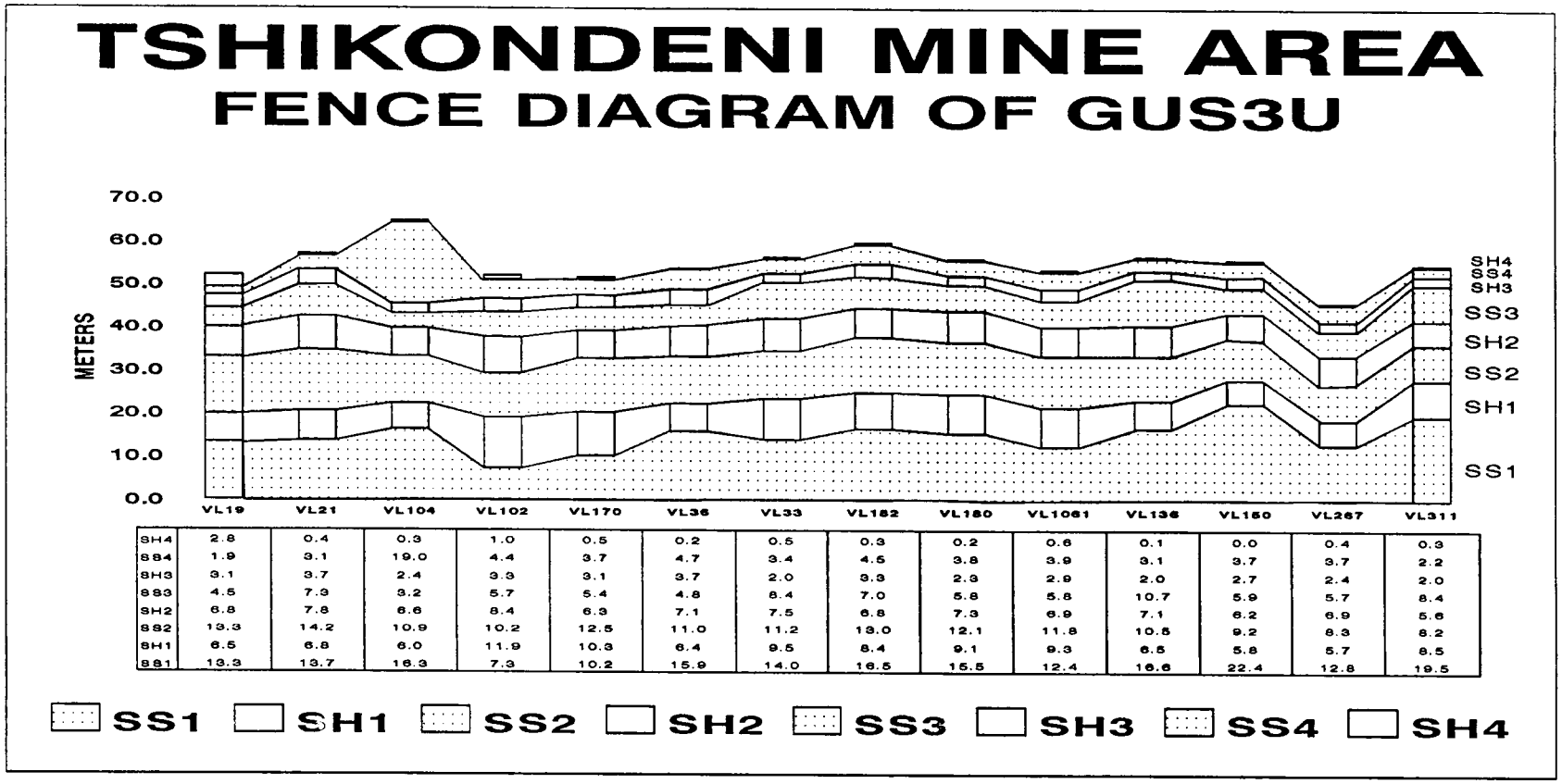


Figure 62. Fence diagram of GUS3U in the Tshikondeni Mine area. Refer to figure 63 for location of boreholes.

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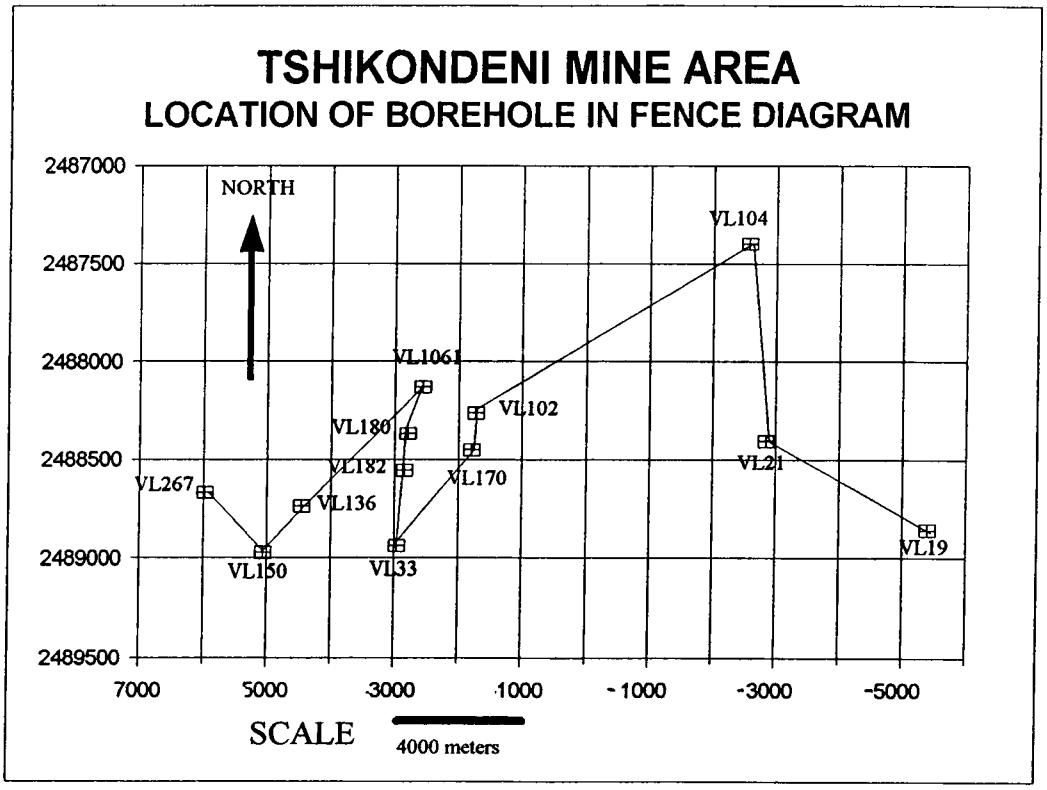


Figure 63. Location of boreholes illustrated on the fence diagram of GUS3U.

3.5 Genetic unit of sedimentation 4 (GUS4).

GUS4 is found between markers 5 and 6 (Figure 32) and contains sample 7 - the Main seam (Table 6), which is being mined at present. GUS4 consists exclusively of coal, of varying quality, and of black, carbonaceous, mudrock (Table 14 and Figures 64,65 and 66).

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Mudrock facies	± 32% of thickness. Massive black mudrock (Mm)
Coal facies	± 68% of thickness. Coal (C)

Table 14. Distribution of facies in GUS4.

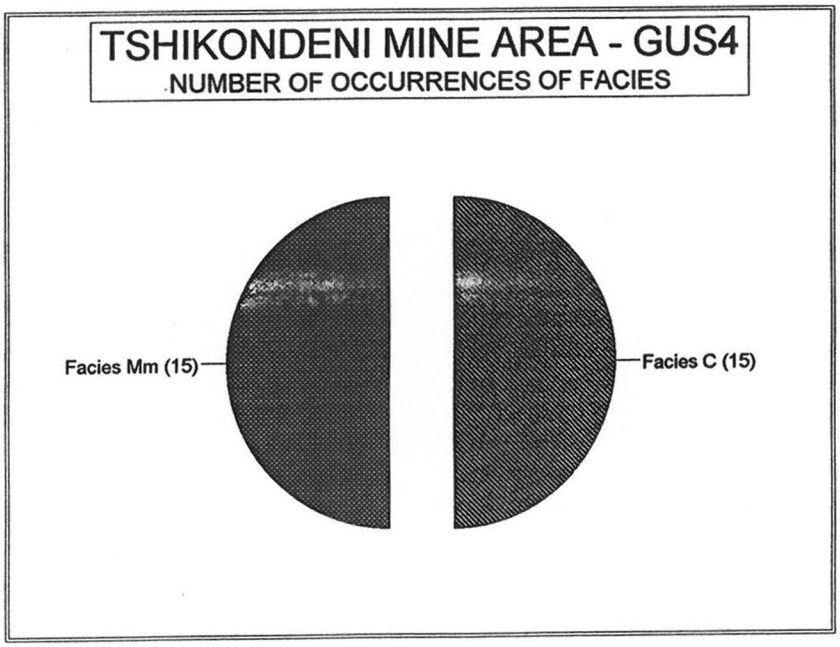


Figure 64. Pie diagram of the distribution of facies in GUS4.

GUS4 varies in thickness between 3,8 and 6,2 m over the whole TMA (± 56 km²) (Figures 67,69 and 70); it is thin in the east and west (northern areas disregarded due to a lack of information) and best developed in the central areas of the TMA (Figure 67).

A contour map showing the likely floor to GUS4, is shown in figure 68. This illustrates a very regular floor and was constructed using the same method as previously described. At

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rare localities in the mine, lenticular sandstones, called "channels", are found in the footwall of GUS4. These vary in thickness up to 1,00 m and are 5,00 m to 30,00 m in width. These are possibly channel-fills or irregularities in the floor caused by compactional draping. Large tree trunk impressions are found in the roof of sample 7.

From figure 70, it can be seen that the lower part of GUS4, sample 7C, pinches out towards the east of the TMA. Sample 6 occurs throughout the whole area and the thickness is not constant. It is, however, better developed in the central areas of the TMA.

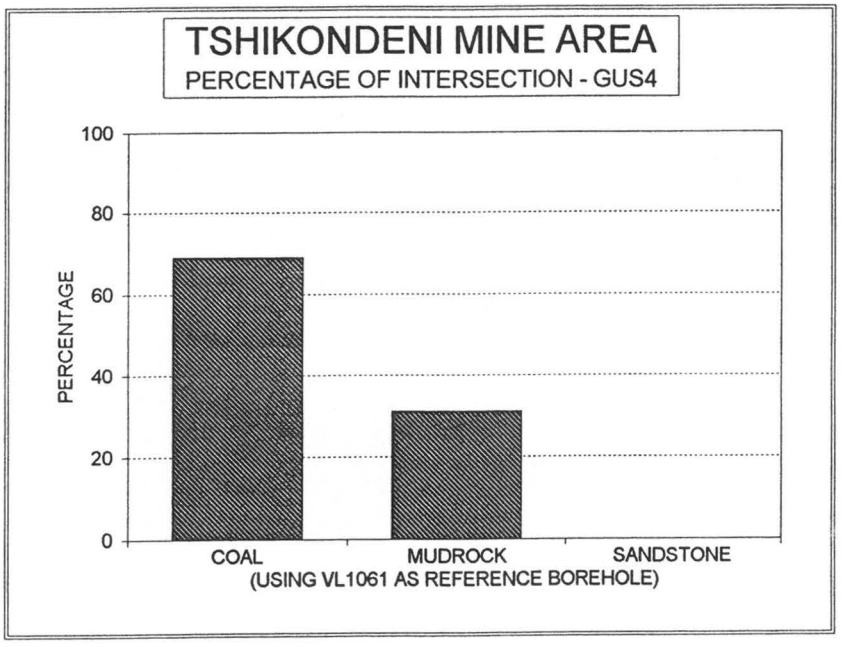


Figure 65. Percentage of the different rock types in GUS4.

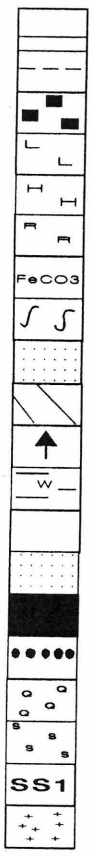
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GUS4



DEPTH (m)	THICKNESS (m)	
311.00		
311.06	0.06	SHALE SILT LAYERS (LAMINAE) GREY
311.13	0.07	COAL, BRIGHT 20:80
		COAL, BRIGHT 20:80
311.33	0.18	
		COAL, BRIGHT 30:70
311.51	0.14	
311.62	0.09	COAL, BRIGHT 20:80
		SHALE BLACK CARBONACEOUS
	0.46	
312.08		
312.19	0.11	COAL, BRIGHT 50:50
		SHALE BLACK
	0.22	
312.41		
312.51	0.10	COAL, BRIGHT 20:80
312.57	0.06	SHALE BLACK
312.65	0.05	SHALE, COALY
312.71	0.06	COAL, BRIGHT 20:80
		COAL, BRIGHT 50:50
312.90	0.15	
312.98	0.08	SHALE BLACK CARBONACEOUS
313.09	0.08	SHALE CARBONACEOUS
313.19	0.08	SHALE BLACK
313.30	0.11	COAL, BRIGHT 30:70
313.42	0.12	SHALE CARBONACEOUS
313.53	0.07	SHALE CARBONACEOUS
313.65	0.12	COAL, BRIGHT 20:80
		COAL, BRIGHT 50:50
	0.28	
313.97		
314.08	0.09	COAL, BRIGHT 50:50
314.16	0.08	SHALE CARBONACEOUS
314.28	0.08	SHALE CARBONACEOUS
		COAL, BRIGHT 60:40
314.43	0.15	
314.48	0.05	SHALE, COALY
		COAL, BRIGHT 60:40
	0.90	
315.38		
315.43	0.05	SHALE CARBONACEOUS
		COAL, BRIGHT 60:40
	0.30	
315.73		
		COAL, BRIGHT 60:40 PYRITE, CONCRETION(S)
315.94	0.21	
		COAL, BRIGHT 60:40
	0.30	
316.24		
316.29	0.05	SHALE CARBONACEOUS
316.38	0.09	COAL, BRIGHT 50:50
316.47	0.09	SHALE CARBONACEOUS
		COAL, BRIGHT 60:40
	0.45	
316.92		
317.00	0.08	SHALE BLACK

LEGEND



- SHARP CONTACTS
- GRADATIONAL CONTACTS
- QUARTZ GRAINS AND QUARTZ PEBBLE BANDS
- SILTY LAMINAE AND CONVOLUTE LAMINATIONS
- HORIZONTAL LAMINATIONS
- RIPPLE CROSS-LAMINATION
- SIDERITE
- WORM BURROWS
- PROMINENT QUARTZ PEBBLE BAND
- LARGE SCALE CROSS-BEDDING
- FINING DIRECTION
- VARVED MUDROCK
- MUDROCK
- SANDSTONE
- COAL
- CLAY PELLET CONGLOMERATE BAND
- QUARTZITE
- SOFT SEDIMENT DEFORMATION STRUCTURES
- GENETIC UNIT OF SEDIMENTATION SUBDIVISION
- DOLERITE

Figure 66. Lithological profile of GUS4 in the Tshikondeni Mine area.

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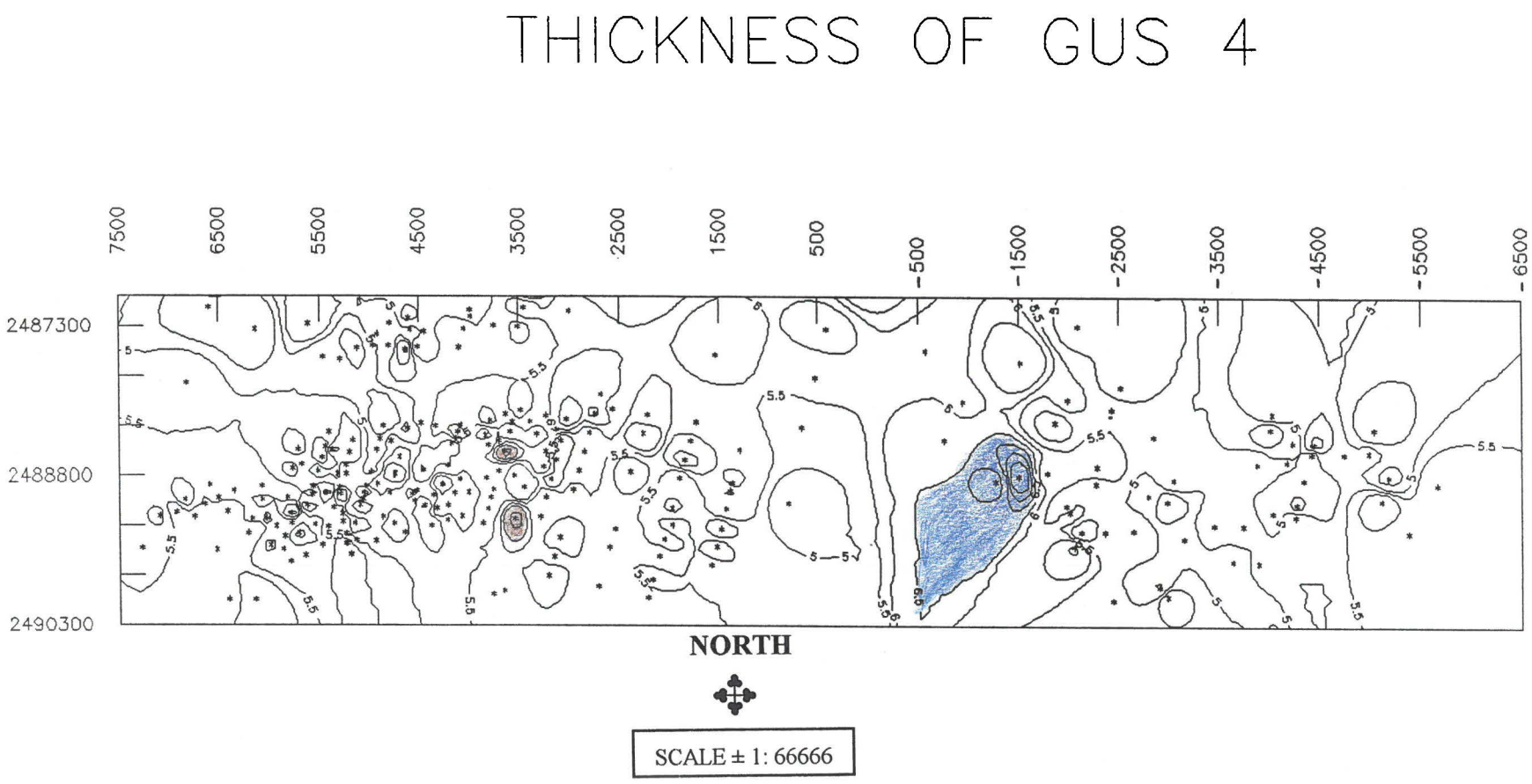


Figure 67. Thickness contours (in metres) of GUS4. (Thick areas in blue, and thin areas in brown).

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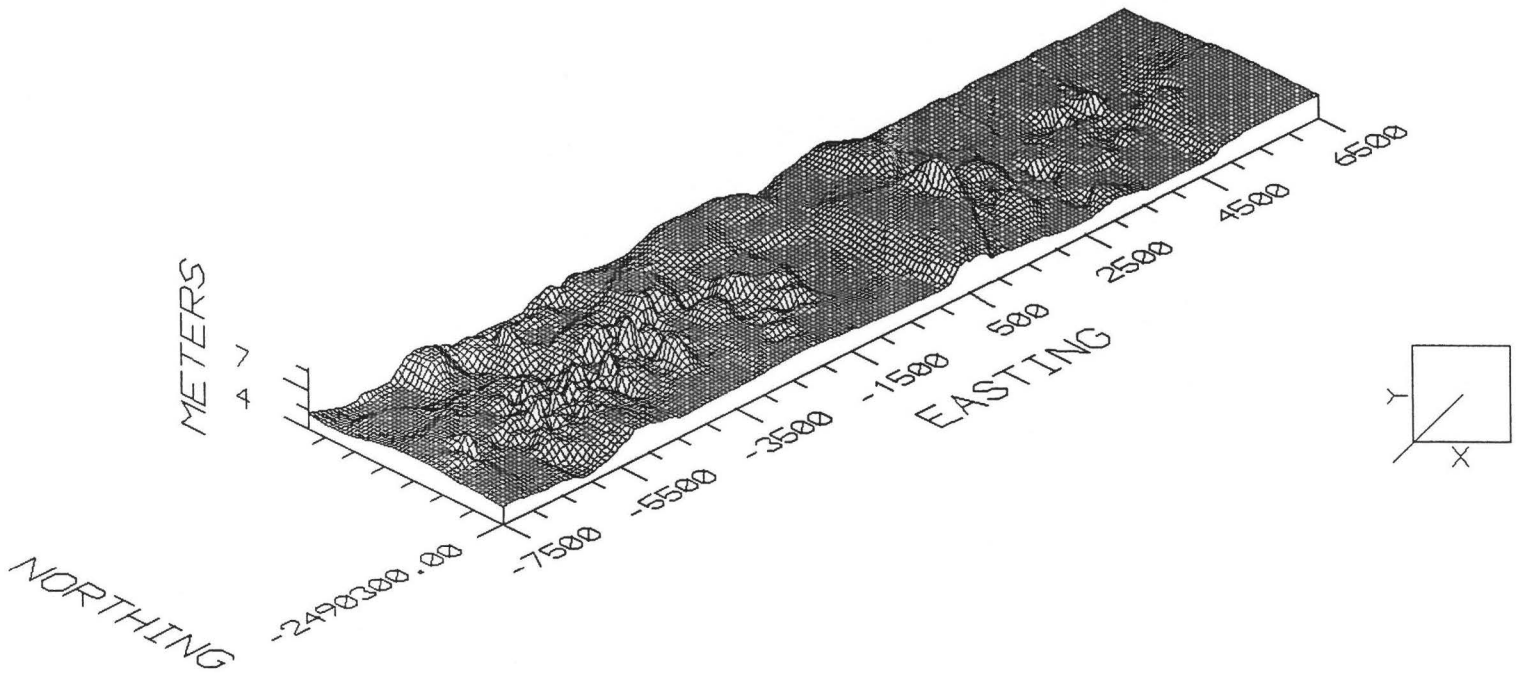


Figure 68. Contour map of an inferred floor to GUS4.

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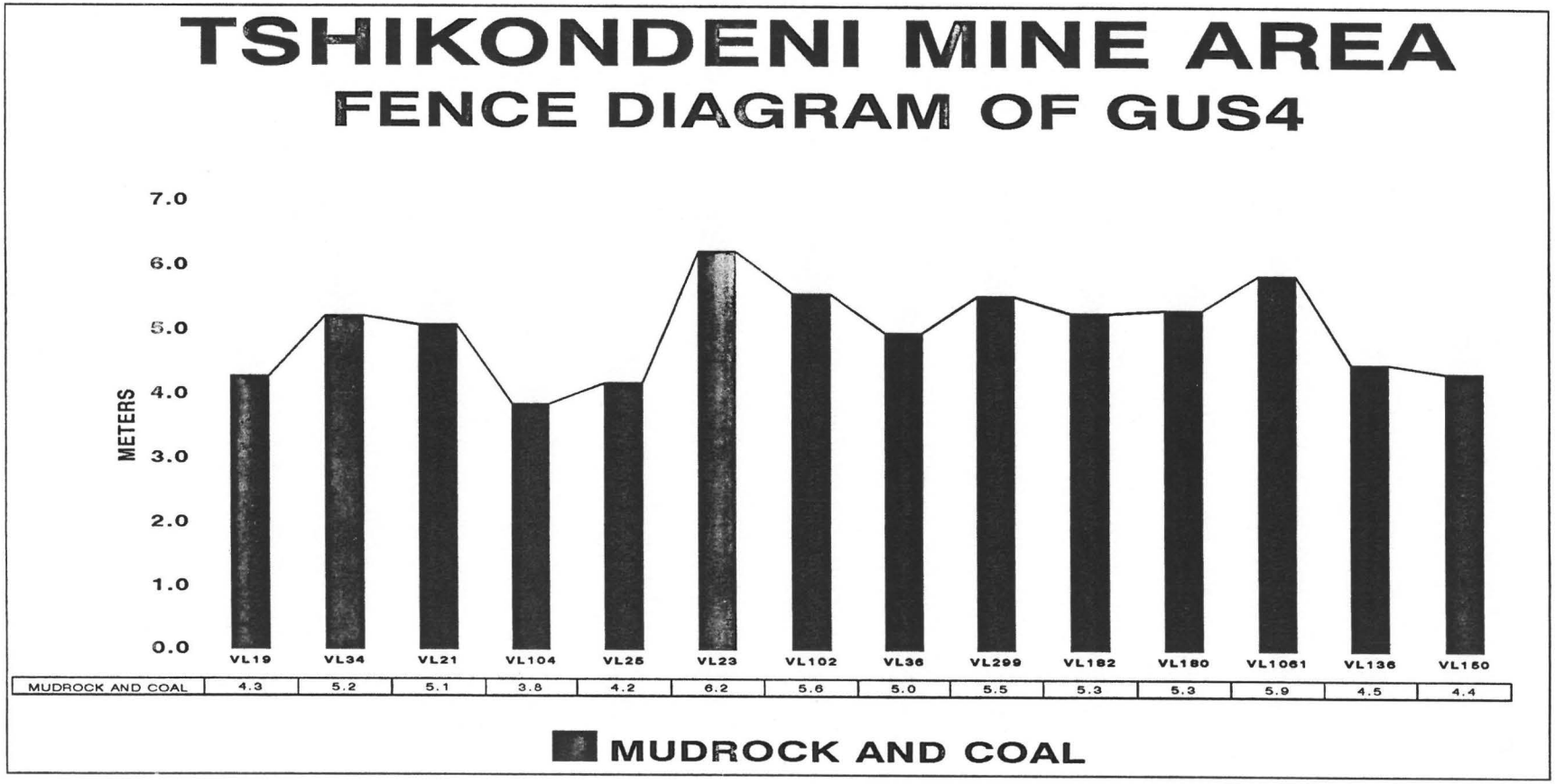


Figure 69. Fence diagram of GUS4 in the Tshikondeni Mine area. Refer to figure 71 for location of boreholes.

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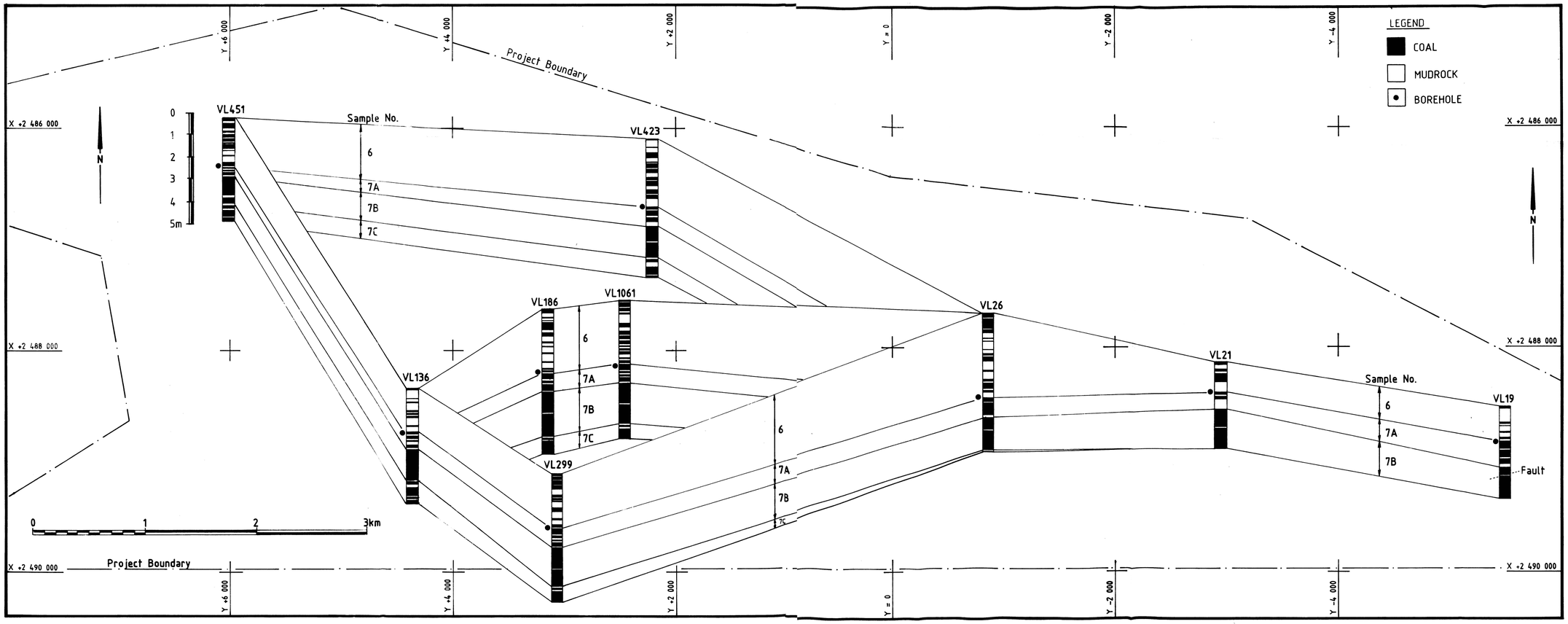


Figure 70. Detailed fence diagram of GUS4 in the Tshikondeni Mine area.

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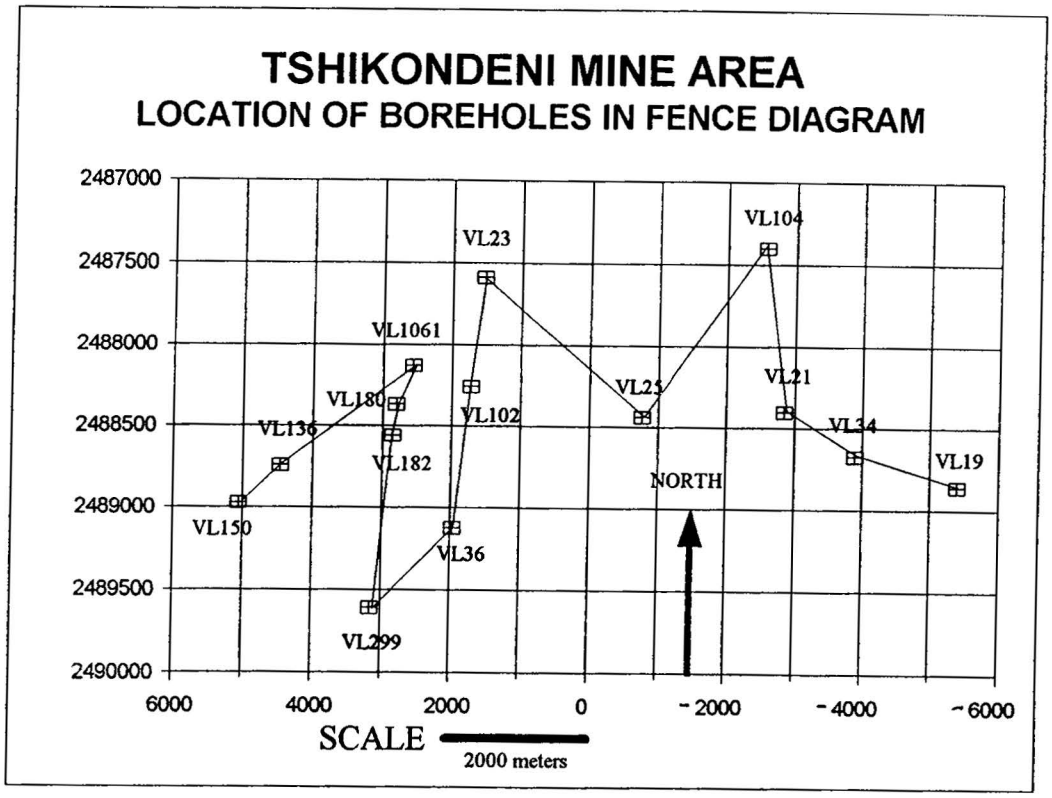


Figure 71. Location of boreholes illustrated on the fence diagram of GUS4 (Figure 69).

3.6 Genetic unit of sedimentation 5 (GUS5).

GUS5 is located above samples 6 and 7 between markers 6 and 7 (Table 6 and Figure 32). It does not vary much in thickness - between 28 and 48 m (Figure 74). It appears as if the first unit of GUS5, SH1 (Figure 73), initially filled the irregularities in the floor, as it is better developed over the thinner parts of GUS4. GUS5 consists of the following facies, (Table 15 and Figures 72 and 75):

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Sandstone facies	±41% of thickness Ripple and planar laminated sandstone/ siltstone (Sr) Graded sandstone (Sg) Massive sandstone (Sm)
Mudrock facies	± 58% of thickness Mudrock with silty laminae and convolute laminations (Ml) Massive black mudrock (Mm)
Coal facies	± 1% of thickness Coal (C)

Table 15. Distribution of facies in GUS5.

GUS5 consists of four mudrock units (SH1 - SH4) alternating with three sandstone units (SS1 - SS3) (Figures 73 and 78). SH1 consists of facies Ml mudrock and is between 6,5 and 14 m thick. The thickness varies and no definite trends could be detected. Locally, thin quartz pebble bands are found near the top of SH1.

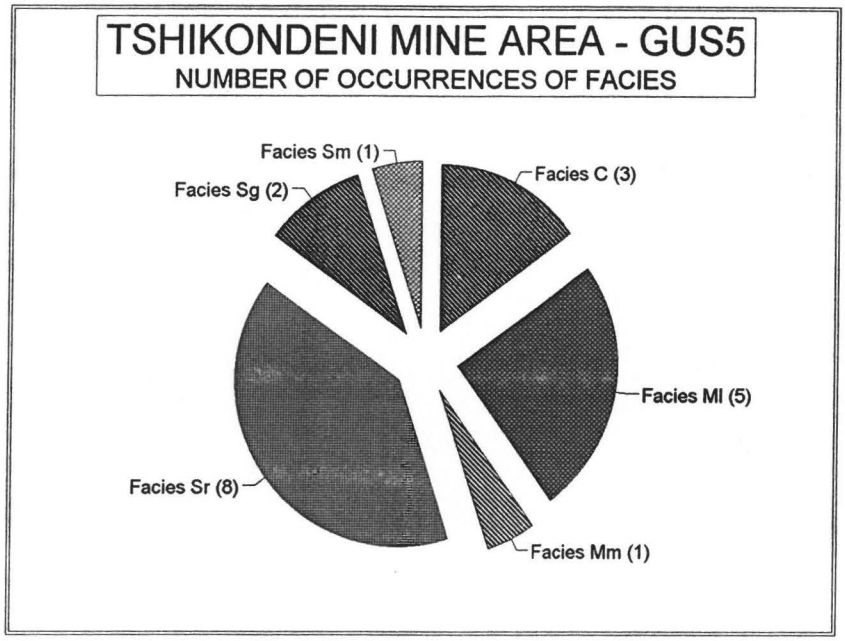


Figure 72. Pie diagram of the distribution of facies in GUS5.

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SS1 is a thin unit, between 2,5 m and 9 m, which is thinner over the central areas of the TMA. It consists of upward-coarsening and upward-fining sandstones (Figure 73) (facies Sg and Sr). Both the top and bottom contacts of SS1 tend to be sharp, but the internal contacts are gradational. The grain size varies between fine- and medium-grained and horizontal laminations and ripple cross-lamination are common (facies Sr) in the finer parts.

SH2, above SS1 is a typical facies Ml mudrock and only in borehole VL150 does it attain a thickness of 7,5 m, whereas the average is ± 4,0 m. It forms an upwards- coarsening succession with sandstone sequence SS2, and grades into this sandstone. The thickness stays fairly constant over the TMA.

SS2 (facies Sg and Sr) is one of the few units in the study area that pinches out completely in the western part of the TMA, only to reappear in the extreme western part of the region (Figure 76). The maximum thickness is 5,5 m and it consists of up to seven sandstone beds. Horizontal laminations are found in the finer sandstones (facies Sr). The lowermost coal band of sample 5 (Table 6) usually occurs near the top of SS2. The top and bottom contacts of SS2 are gradational (facies Sg) but the internal contacts are sharp.

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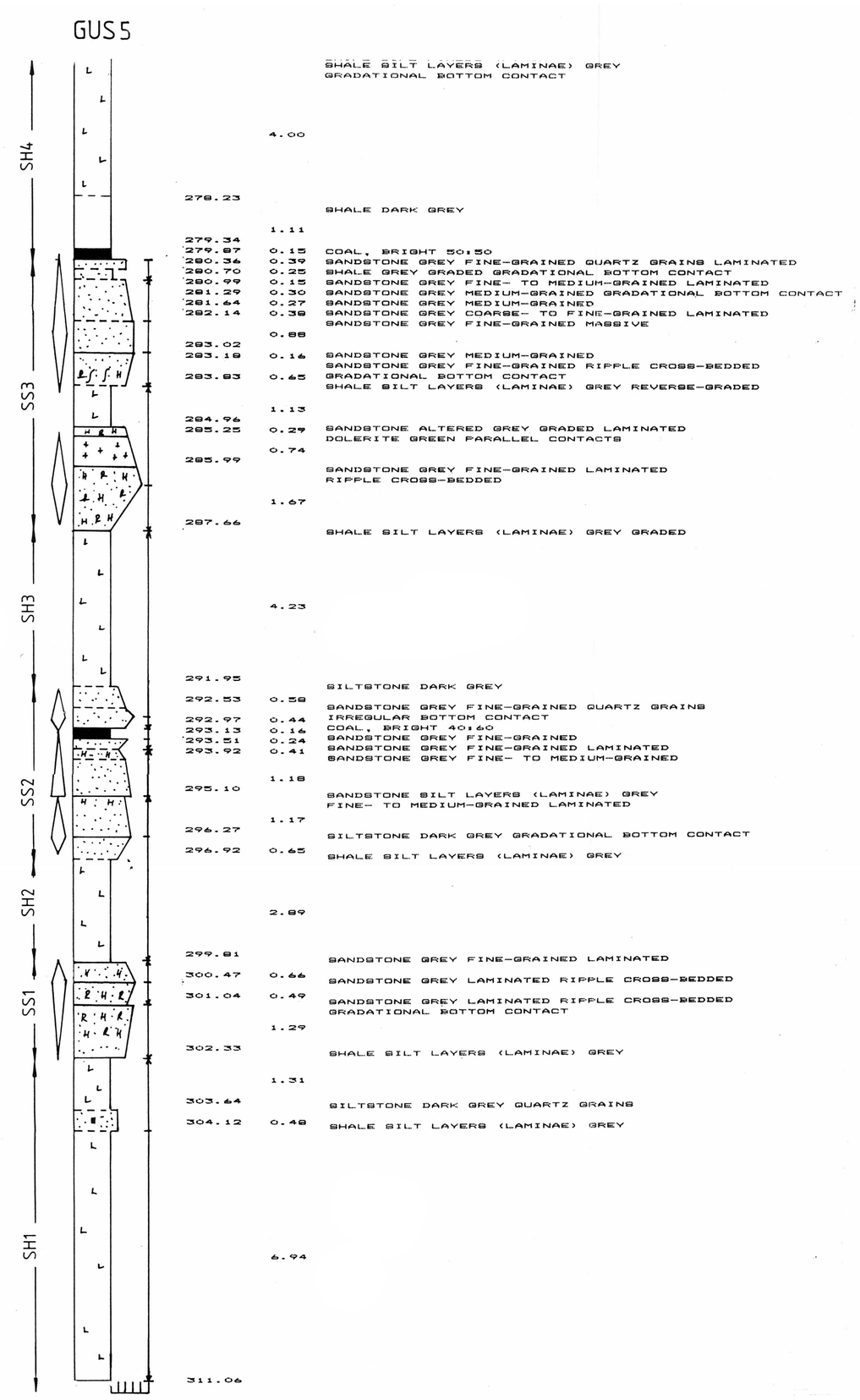


Figure 73. Lithological profile of GUS5.

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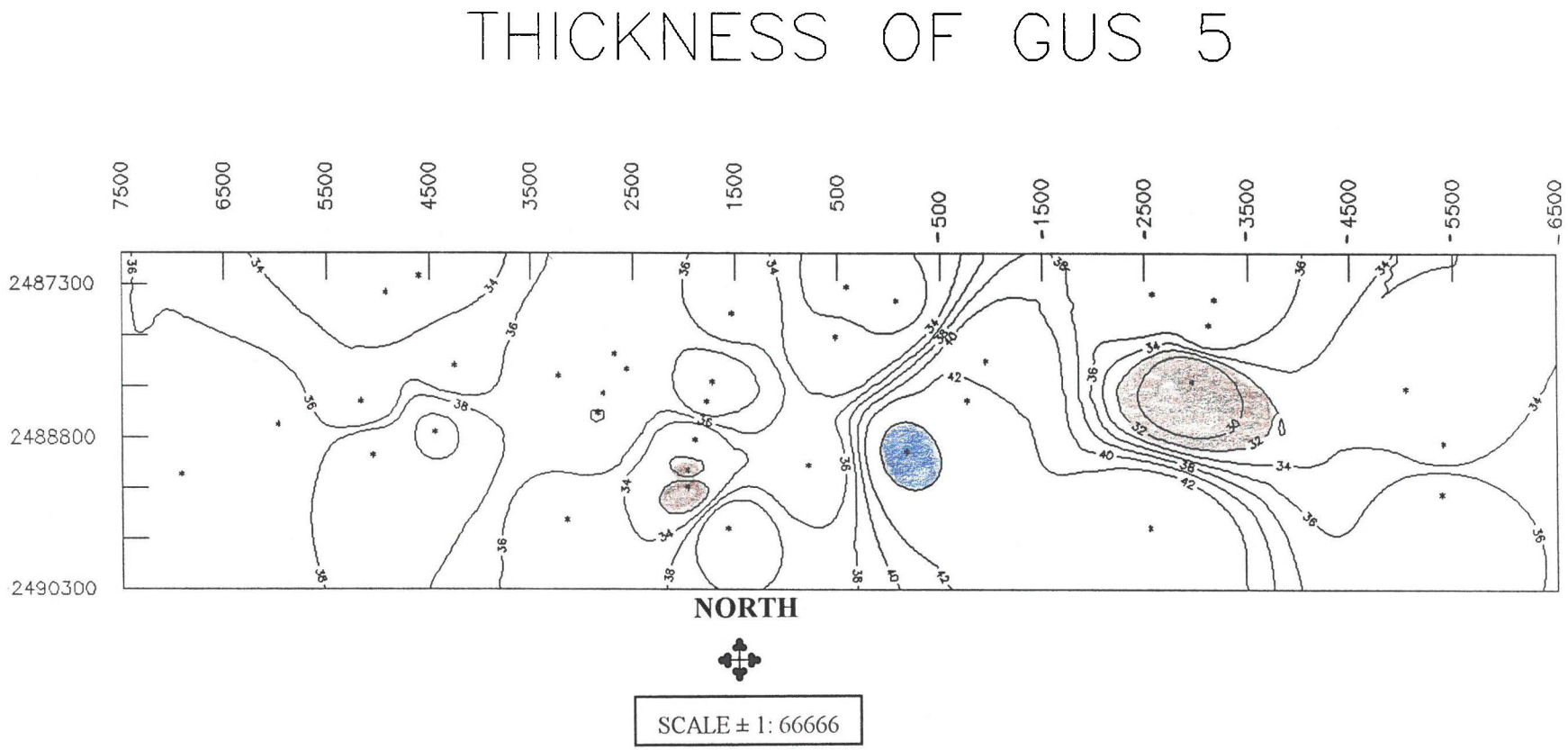


Figure 74. Thickness contours (in metres) of GUS5. (Thick areas in blue and thin areas in brown).

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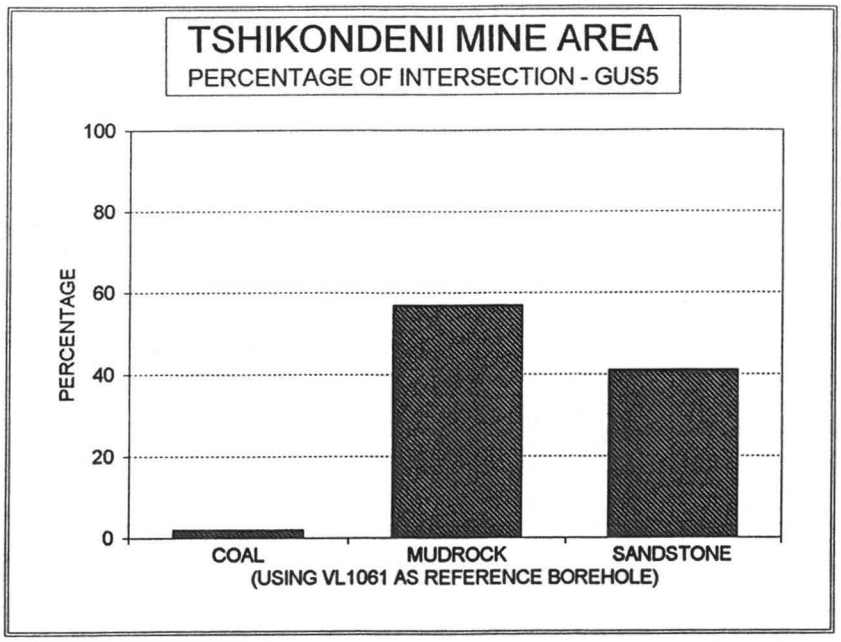


Figure 75. Percentage of the different rock types in GUS5.

SH3 consists of mudrock with silty laminae and convolute laminations (facies Ml) and is upward-fining. The thickness varies between 1,5 m and 6,5 m (average = 3,5 m). SH3 is thin in the east and better developed in the central and western areas (Figure 76).

Above SH3 is SS3, two sandstone units with upward-coarsening basal sequences and gradational lower contacts (facies Sr and Sg). The upper parts of these two sandstone units (facies Sr) have sharp basal contacts with the lower upward-coarsening sequences, and are upward-fining. The thickness of SS3 varies between 5,0 m and 13,0 m (average of 8,0 m). In areas where SS3 is thick (Figure 76), this is not at the expense of the underlying mudrock.

In borehole VL33, it can be seen that the thin development of SS3 occurs on top of a thin development of SH3.

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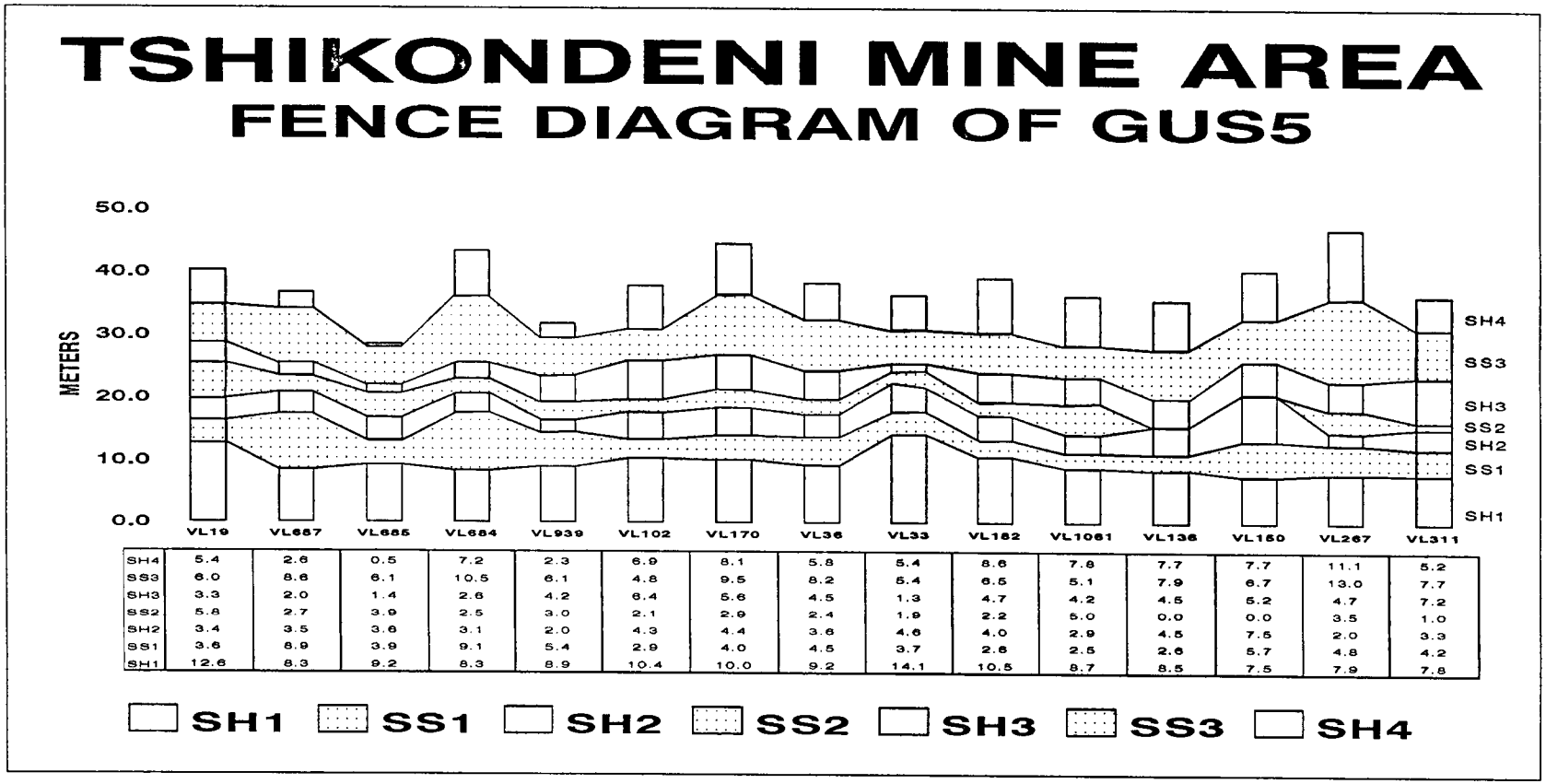


Figure 76. Fence diagram of GUS5 in the Tshikondeni Mine area. Refer to figure 77 for location of boreholes.

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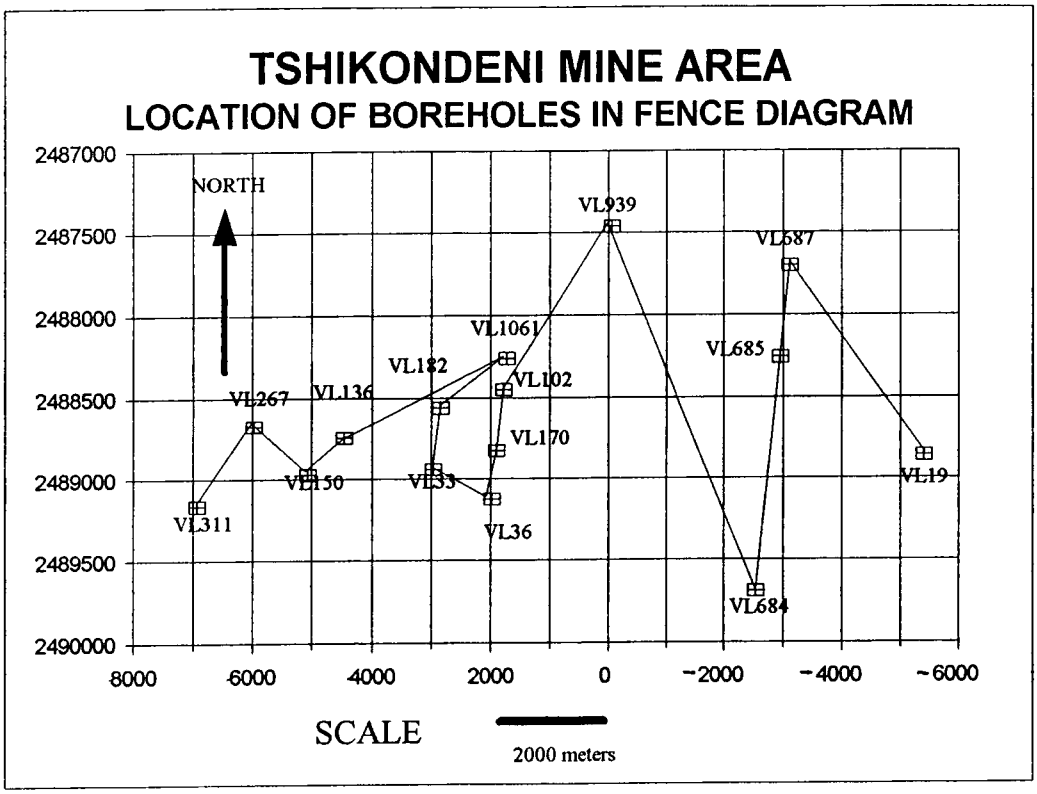


Figure 77. Location of boreholes illustrated on the fence diagram of GUS5.

The thick development of SS3 in VL170 is on top of an average development of SH3 (Figure 76). A thin mudrock with silty laminae and convolute laminations (facies Ml) between the two sandstone units of SS3 (Figure 73) varies in thickness (±1,5 metres) and is locally silty. Worm burrows are found in the lower part of the top sandstone. One of the coal seams of sample 5 occurs above SS3.

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SH4 (facies M1) is the uppermost unit of GUS5. It shows quite a variation in thickness, but towards the west it is better developed (Figure 76). It is all but absent in boreholes VL683 and VL939. The thickness varies between 0,5 and 11 m.

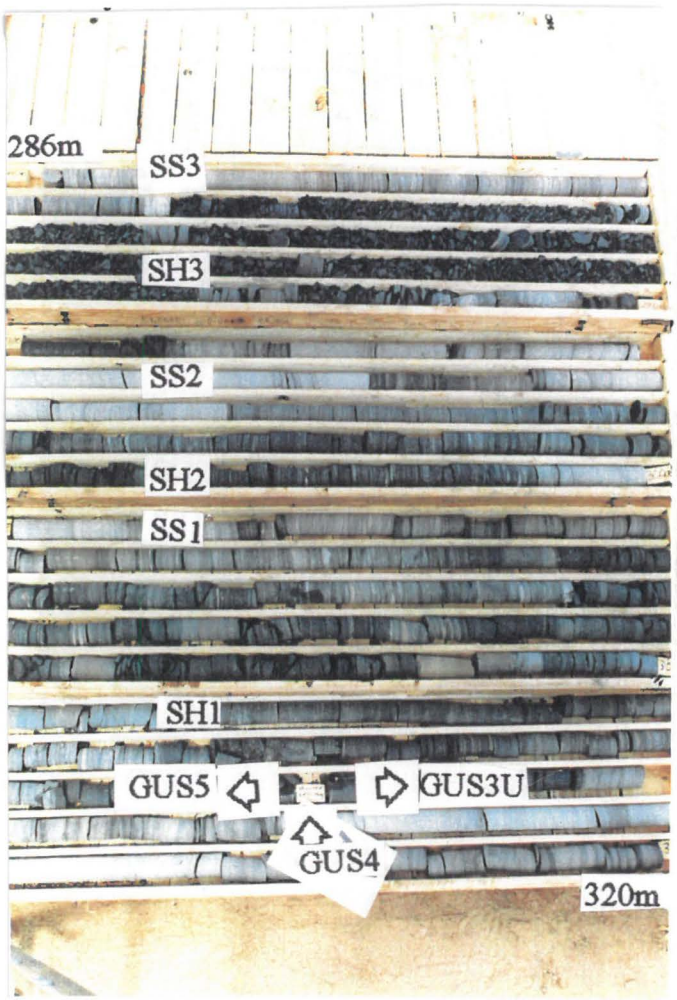


Figure 78. The lower part of GUS5, GUS4 (removed) and the top of GUS3U.

3.7 Genetic unit of sedimentation 6 (GUS6).

GUS6, capping the Madzaringwe Formation, consists of up to 6 upward-fining sandstone cycles, interspersed with a few

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upward-coarsening sandstone cycles (Figures 80 and 82) (facies S, Sr, Sg and Sm). GUS6 is found between markers 7 and 8 (Figure 32) and varies in thickness between 27 m and 65 m (Figure 83). The following facies make up the bulk of GUS6 (Table 16 and Figures 79 and 81):

Sandstone facies	± 94% of thickness Large scale cross-bedded sandstone (S) Ripple and planar laminated sandstone/siltstone (Sr) Graded sandstone (Sg) Massive sandstone (Sm)
Mudrock facies	± 5% of thickness Mudrock with silty laminae and convolute laminations (Ml) Massive black mudrock (Mm)
Coal facies	± 1% of thickness Coal (C)

Table 16. Distribution of facies in GUS6.

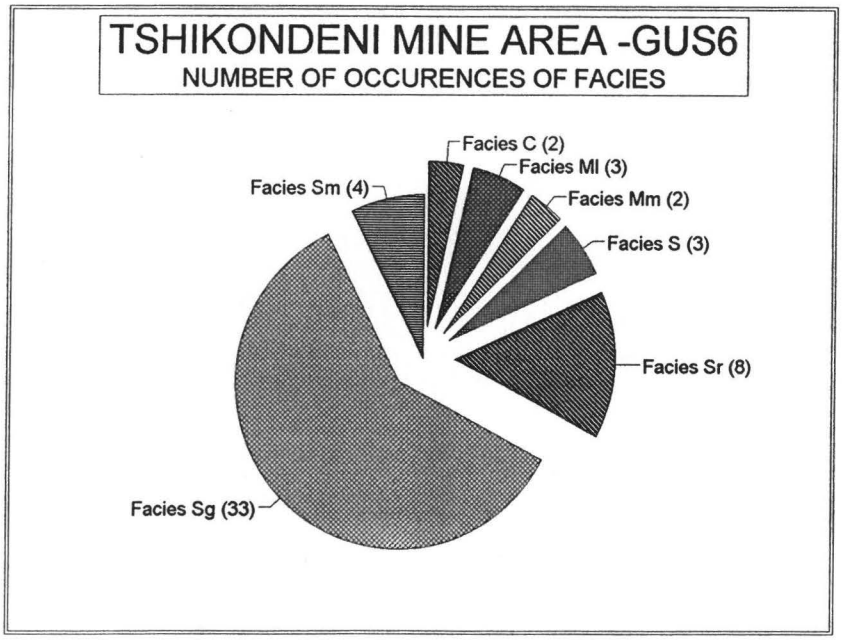
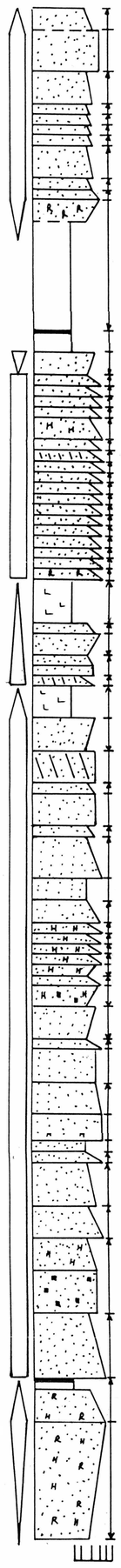


Figure 79. Pie diagram of the distribution of facies in GUS6.

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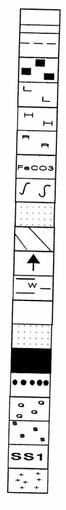
GUS6



232.34	0.68	SANDSTONE GREY FINE-GRAINED GRADATIONAL BOTTOM CONTACT
	1.06	SANDSTONE WHITE COARSE-GRAINED SHALY CLASTS THROUGHOUT.
233.40	0.90	SANDSTONE GREY FINE- TO MEDIUM-GRAINED SHALE LAMINAE AND
234.30		SHALE CLASTS THROUGHOUT.
234.71	0.41	
234.90	0.19	SANDSTONE GREY COARSE-GRAINED
235.30	0.27	SANDSTONE DARK GREY FINE-GRAINED
235.80	0.40	SANDSTONE GREY FINE-GRAINED
		SANDSTONE GREY FINE- TO MEDIUM-GRAINED
236.27	0.47	SANDSTONE GREY FINE- TO MEDIUM-GRAINED
236.59	0.32	NO.
236.89	0.30	SANDSTONE GREY FINE- TO MEDIUM-GRAINED
237.15	0.26	SANDSTONE DARK GREY COARSE- TO FINE-GRAINED
		SANDSTONE GREY COARSE- TO FINE-GRAINED
237.65	0.50	SANDSTONE DARK GREY FINE-GRAINED LAMINATED
		RIPPLE CROSS-BEDDED GRADATIONAL BOTTOM CONTACT
		SHALE GREY SILTY
	2.77	
240.42		
		SHALE DARK GREY
241.37	0.66	
		SANDSTONE GREY MEDIUM-GRAINED
242.12	0.56	
242.40	0.28	SANDSTONE GREY COARSE- TO FINE-GRAINED
242.70	0.22	SANDSTONE GREY COARSE- TO FINE-GRAINED
243.06	0.36	SANDSTONE GREY COARSE- TO FINE-GRAINED
243.36	0.30	SANDSTONE GREY COARSE- TO FINE-GRAINED
		SANDSTONE GREY COARSE- TO FINE-GRAINED FINE PART HAS HOR
243.95	0.59	IZONTAL LAMINAE AND RIPPLE CROSSBEDDING.
244.25	0.21	SANDSTONE GREY COARSE- TO FINE-GRAINED
244.54	0.29	SANDSTONE GREY COARSE- TO FINE-GRAINED
244.92	0.25	SANDSTONE GREY COARSE- TO FINE-GRAINED
245.25	0.33	SANDSTONE GREY COARSE- TO FINE-GRAINED
245.47	0.22	SANDSTONE GREY COARSE- TO FINE-GRAINED
245.74	0.27	SANDSTONE GREY COARSE- TO FINE-GRAINED
245.94	0.20	SANDSTONE DARK GREY COARSE- TO FINE-GRAINED
246.35	0.41	SANDSTONE GREY COARSE- TO FINE-GRAINED
246.79	0.31	SANDSTONE GREY COARSE- TO FINE-GRAINED
246.94	0.15	SANDSTONE GREY COARSE- TO FINE-GRAINED
247.13	0.19	SANDSTONE GREY MEDIUM- TO COARSE-GRAINED
247.39	0.26	SANDSTONE GREY COARSE- TO FINE-GRAINED
247.63	0.31	SANDSTONE GREY FINE- TO MEDIUM-GRAINED CROSS-BEDDED
		SHALE GREY CARBONACEOUS
	1.03	
248.86		
249.02	0.16	SANDSTONE GREY FINE- TO MEDIUM-GRAINED
		SANDSTONE GREY COARSE- TO FINE-GRAINED
249.56	0.54	
249.96	0.40	SANDSTONE SHALE LAYERS (LAMINAE) GREY FINE-GRAINED
250.13	0.17	SANDSTONE DARK GREY
250.59	0.46	SANDSTONE SILT LAYERS (LAMINAE) GREY
		SHALE SILT LAYERS (LAMINAE) GREY
	0.93	
251.52		
		SANDSTONE SILT LAYERS (LAMINAE) DARK GREY
	0.96	
252.52		
		SANDSTONE SILT LAYERS (LAMINAE) GREY MEDIUM-GRAINED
	0.97	CROSS-BEDDED
253.49		
253.77	0.28	SANDSTONE SILT LAYERS (LAMINAE) GREY
		SANDSTONE GREY MEDIUM-GRAINED
	0.76	
254.53		
254.74	0.21	SANDSTONE GREY FINE- TO MEDIUM-GRAINED
		SANDSTONE GREY COARSE- TO FINE-GRAINED
	1.11	
255.85		
		SANDSTONE GREY FINE-GRAINED LAMINATED
256.33	0.43	
		SANDSTONE GREY COARSE- TO FINE-GRAINED
256.83	0.50	
257.25	0.42	SANDSTONE GREY COARSE- TO FINE-GRAINED
257.53	0.28	SANDSTONE GREY COARSE- TO FINE-GRAINED LAMINATED
257.69	0.16	SANDSTONE GREY COARSE- TO FINE-GRAINED
257.86	0.17	SANDSTONE GREY COARSE- TO FINE-GRAINED
258.17	0.31	SANDSTONE GREY FINE- TO MEDIUM-GRAINED LAMINATED
258.50	0.33	SANDSTONE GREY COARSE- TO FINE-GRAINED
		SANDSTONE GREY FINE- TO MEDIUM-GRAINED QUARTZ GRAINS
259.04	0.54	LAMINATED
		SANDSTONE GREY FINE- TO MEDIUM-GRAINED
	0.89	
259.93		
260.18	0.25	SANDSTONE GREY COARSE- TO FINE-GRAINED
		SANDSTONE GREY MEDIUM-GRAINED
	0.90	
261.08		
		SANDSTONE GREY COARSE-GRAINED
	0.80	
261.88		
		SANDSTONE GREY COARSE-GRAINED
263.13		
263.59	0.39	SANDSTONE GREY FINE-GRAINED
263.86	0.27	SANDSTONE GREY COARSE- TO FINE-GRAINED
		SANDSTONE GREY FINE- TO MEDIUM-GRAINED
	1.18	
265.04		
		SANDSTONE GREY COARSE- TO FINE-GRAINED
	0.81	
265.85		
		SANDSTONE GREY COARSE- TO FINE-GRAINED LAMINATED
	0.93	
266.78		
		SANDSTONE SHALE LAYERS (LAMINAE) GREY MEDIUM-GRAINED
		QUARTZ GRAINS COAL LAMINAE
	0.99	
267.77		
		SANDSTONE GREY COARSE- TO FINE-GRAINED
	1.82	
269.59		
269.89	0.20	SHALE COAL STRINGERS 2% BLACK CARBONACEOUS
		SANDSTONE GREY FINE-GRAINED QUARTZ GRAINS LAMINATED
		RIPPLE CROSS-BEDDED SOFT SEDIMENT DEFORMATION
	4.16	
274.23		

DEPTH (m) THICKNESS (m)

LEGEND



- SHARP CONTACTS
- GRADATIONAL CONTACTS
- QUARTZ GRAINS AND QUARTZ PEBBLE BANDS
- SILTY LAMINAE AND CONVOLUTE LAMINATIONS
- HORIZONTAL LAMINATIONS
- RIPPLE CROSS-LAMINATION
- SIDERITE
- WORM BURROWS
- PROMINENT QUARTZ PEBBLE BAND
- LARGE SCALE CROSS-BEDDING
- FINING DIRECTION
- VARVED MUDROCK
- MUDROCK
- SANDSTONE
- COAL
- CLAY PELLET CONGLOMERATE BAND
- QUARTZITE
- SOFT SEDIMENT DEFORMATION STRUCTURES
- GENETIC UNIT OF SEDIMENTATION SUBDIVISION
- DOLERITE

Figure 80. Lithological profile of GUS6.

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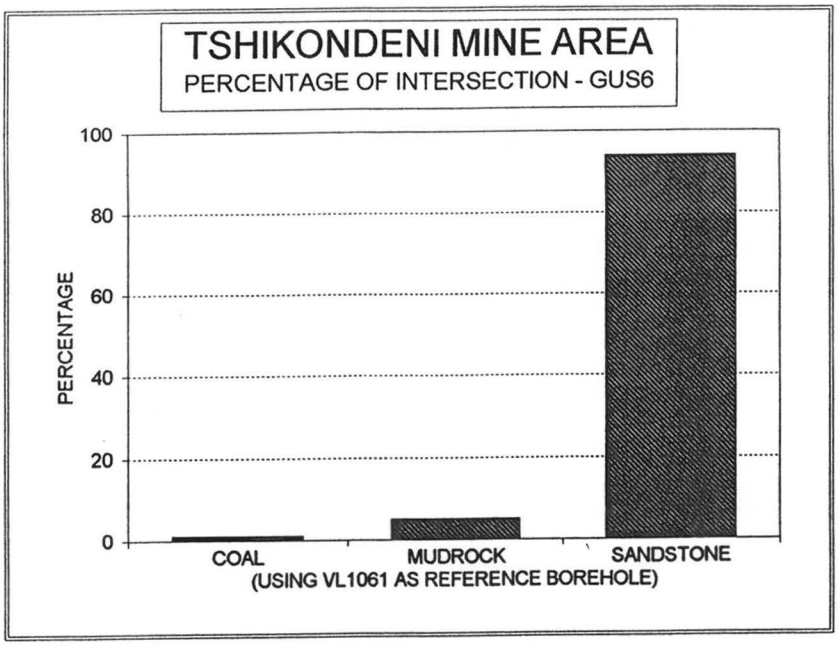


Figure 81. Percentage of the different rock types in GUS6.

The upper and lower 5,0 m -10,0 m of GUS6 normally consists of upward-coarsening and upward-fining facies Sg and Sr sandstones (Figures 80 and 85b). The sandstones of these upper and lower portions of GUS6 normally vary from silty to coarse-grained. The silty sandstones locally grade laterally into a silty mudrock (facies Ml).

The rest of GUS6 consists of fine- to coarse-grained sandstones (facies Sg), comprising either upward-coarsening or upward-fining cycles (upward-fining cycles predominate). Locally the coarse-grained sandstones have some small pebbles scattered through them. The sandstone is white to light grey in colour. Horizontal laminations occur in the finer sandstones. In the finer parts of GUS6 there is usually also some planar- and ripple cross-lamination - facies Sr. Subordinate massive (facies Sm) sandstones are medium- to coarse-grained, with, in addition, some medium-grained sandstones exhibiting large scale cross-bedding (facies S).

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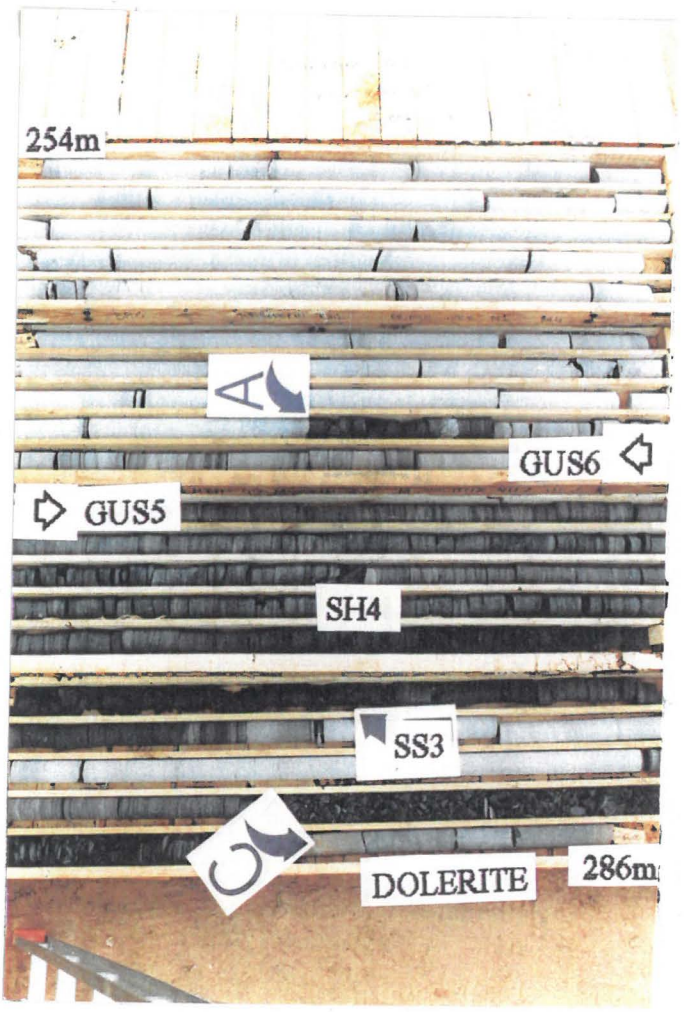


Figure 82. The lower half of GUS6 and the top of GUS5 (254 m - 286 m).

The amount of mudrock in the medial portion of GUS6 varies from 0% to about 3%; these mudrocks normally belong to facies Ml. Some coal seams are also found scattered throughout GUS6 but they are thin, less than 0,30 m, and form part of sample 5. The thickness of GUS6 (Figure 83) varies between 40,0 m and 50,0 m. The fence diagram of GUS6 illustrates the variable thickness (Figure 84). Figure 86 illustrates the following, white massive sandstone (facies Sm), marker C, ripple cross laminated and planar laminated sandstone/siltstone, (facies Sr), marker D as well as upward-fining sandstone (facies Sg) at marker E, and a sharp bottom contact, marker F.

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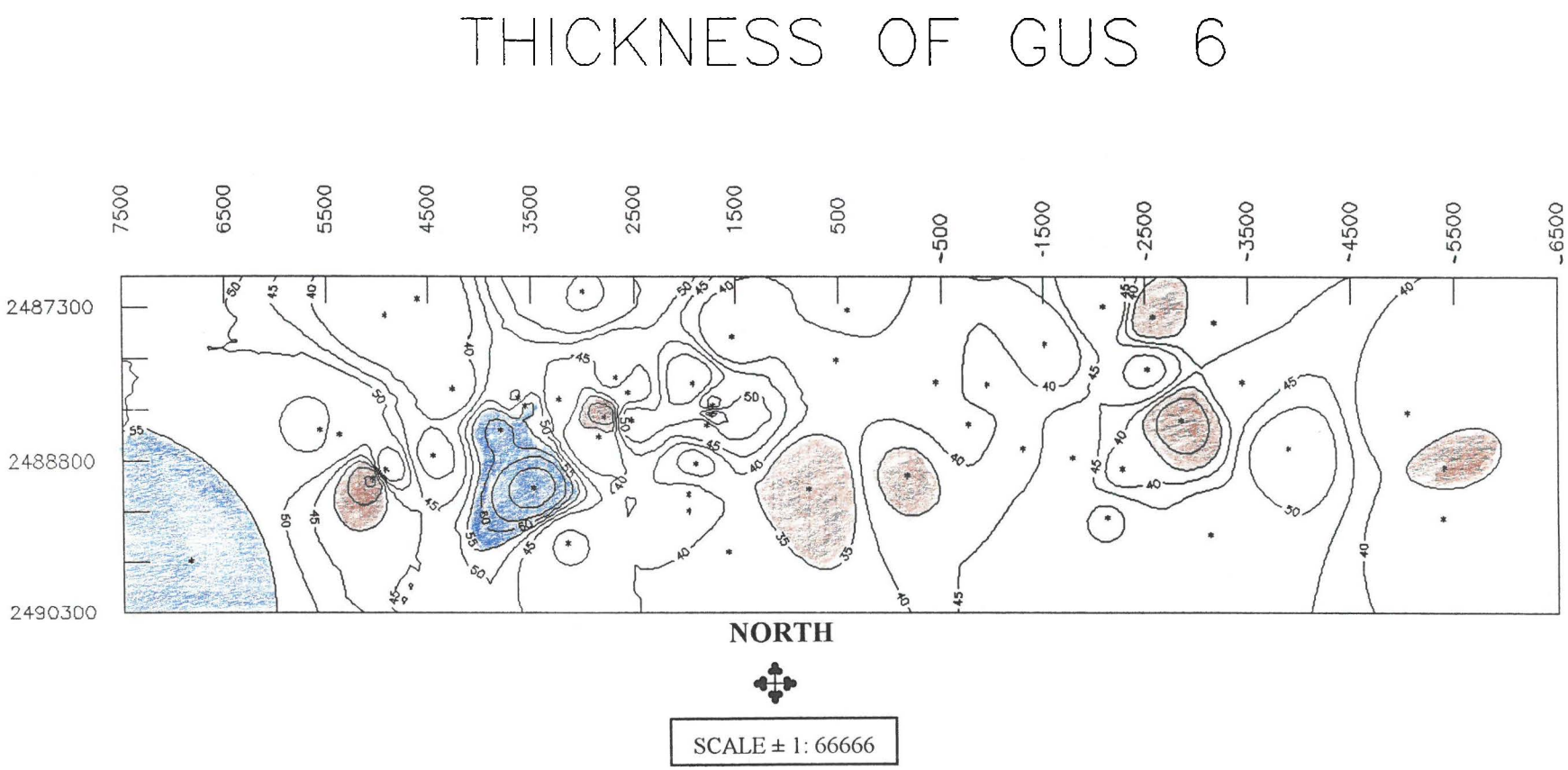


Figure 83. Thickness contours (in metres) of GUS6. (Thick areas in blue and thin areas in brown).

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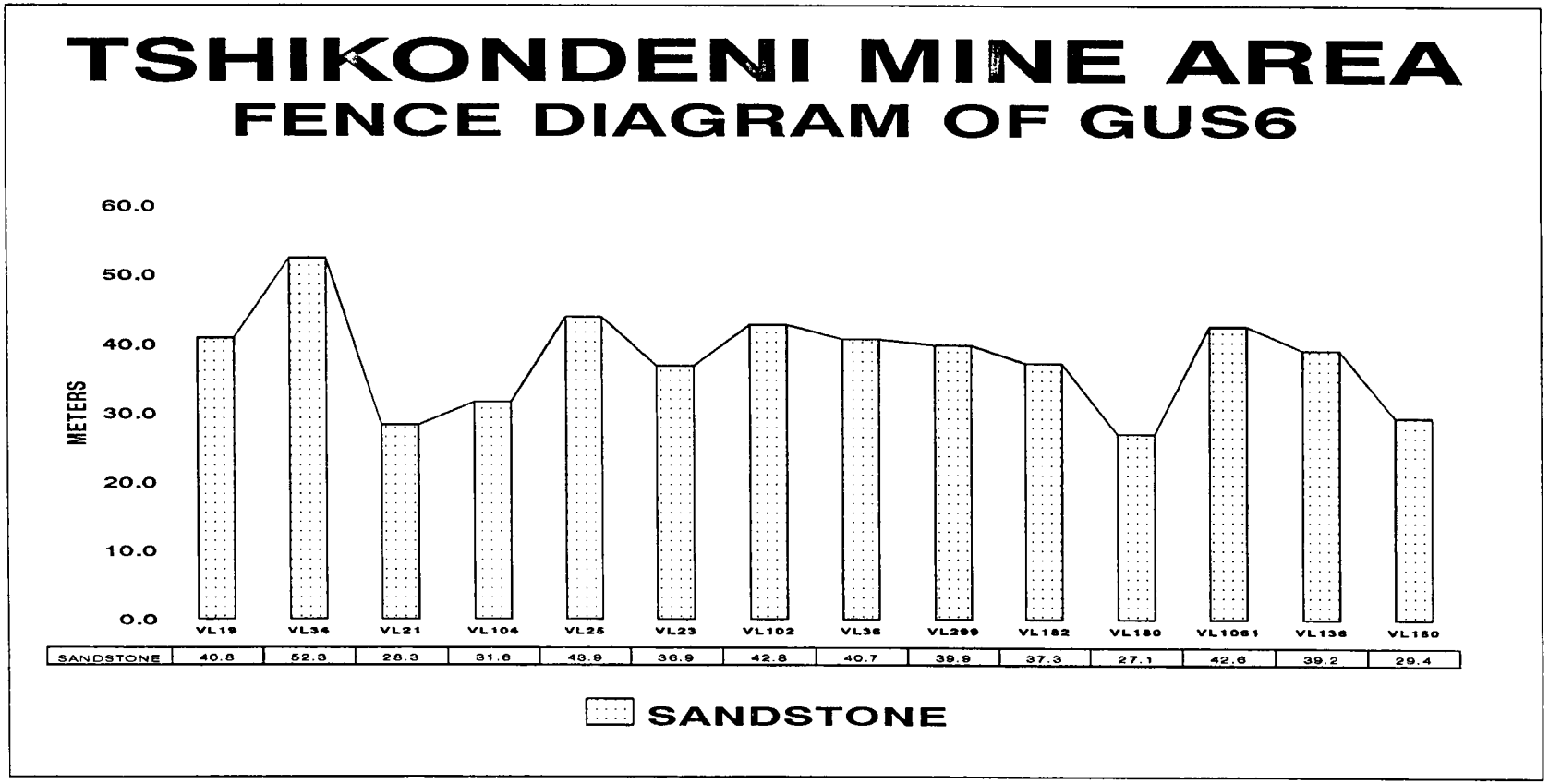


Figure 84. Fence diagram of GUS6 in the Tshikondeni Mine area. Refer to figure 85 for the location of boreholes.

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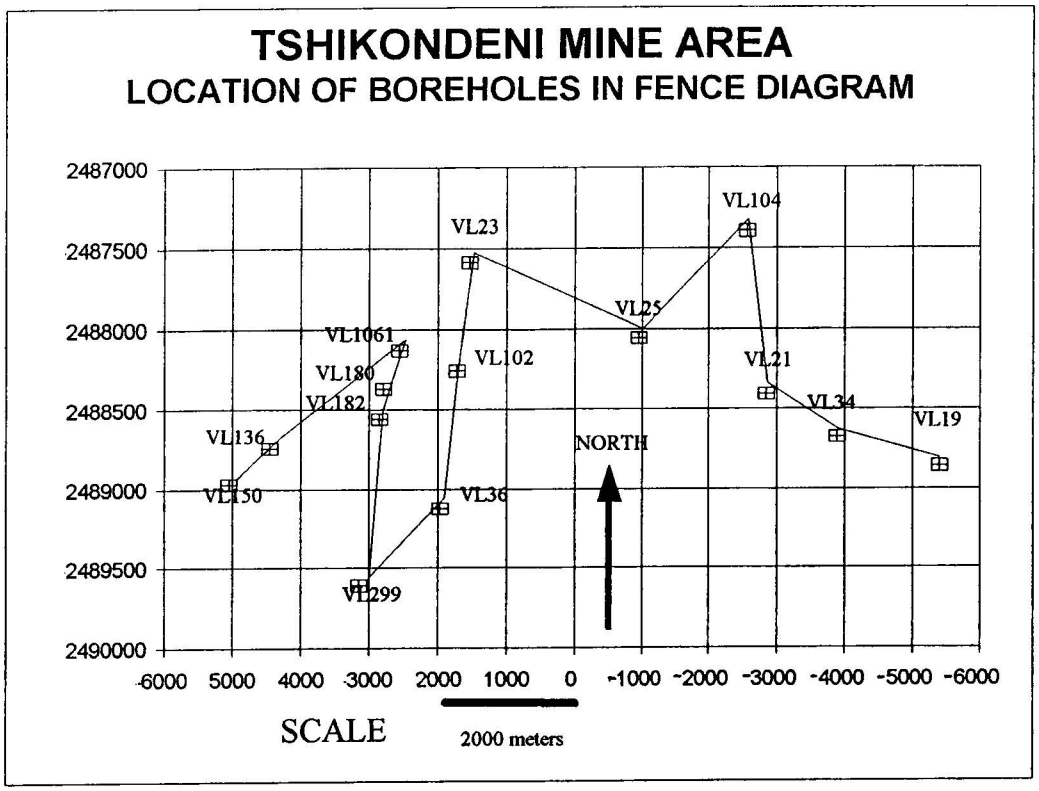


Figure 85. Location of boreholes illustrated on the fence diagram of GUS6

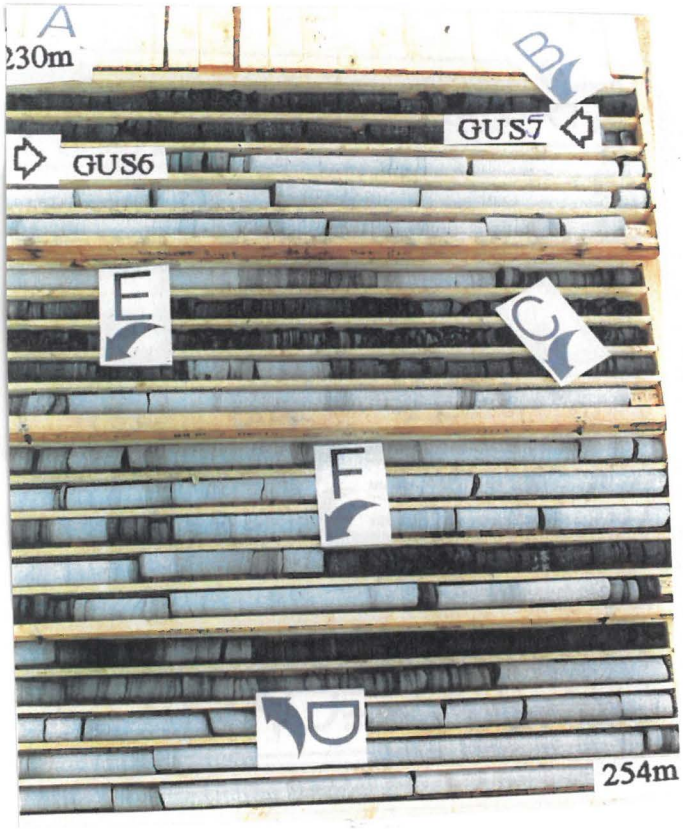


Figure 85b. GUS7 (Marker B) and the top part of GUS6 (230m-254m).

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3.8 Genetic unit of sedimentation 7 (GUS7).

GUS7 consists of undifferentiated mudrock, thin coal bands and stringers (Figure 88) and clay pellet conglomerate bands. It is situated between marker horizons 8 and 9 (Figure 32). The thickness of GUS7 varies between 120,0 m and 140,0 m (Figures 89 and 90). The following facies make up the bulk of GUS7 (Table 17 and Figures 86 and 87):

Mudrock facies	± 98% of thickness Undifferentiated mudrock (Mu) Clay pellet conglomerate (Mc)
Coal facies	± 2% of thickness Coal (C)

Table 17. Distribution of facies in GUS7.

The thickness of GUS7 does not vary much over the study area (Figures 89 and 90).

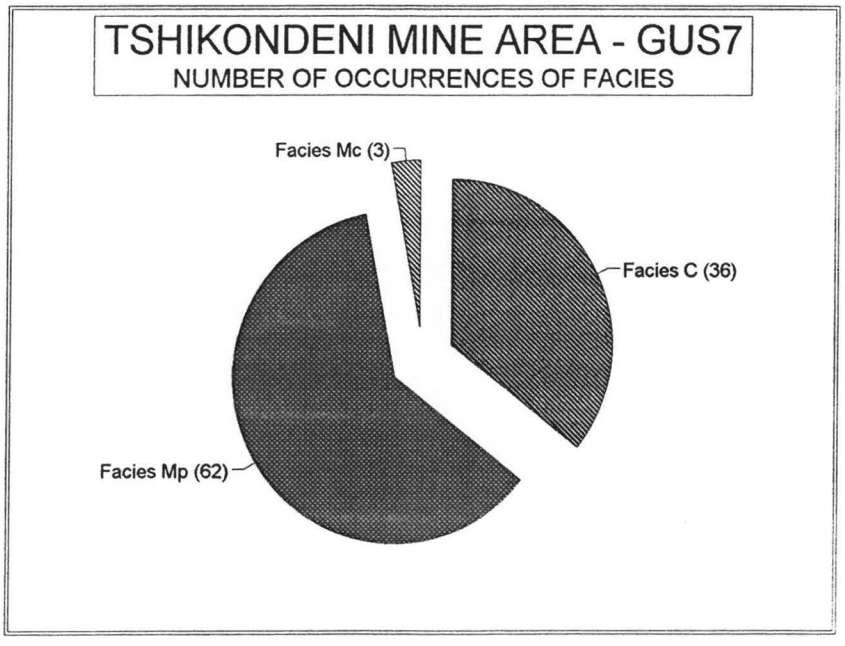


Figure 86. Pie diagram of the distribution of facies in GUS7.

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The lower part of GUS7 consists of carbonaceous mudrock (facies Mu) with thin coal bands and stringers, whereas the upper half is more restricted to mudrocks which are grey to light grey in colour (Figure 88) with thin coal bands and stringers. In most of the top half of GUS7, the bedding is distorted. Thin zones (< 30 cm) of siderite enrichment are common throughout GUS7.

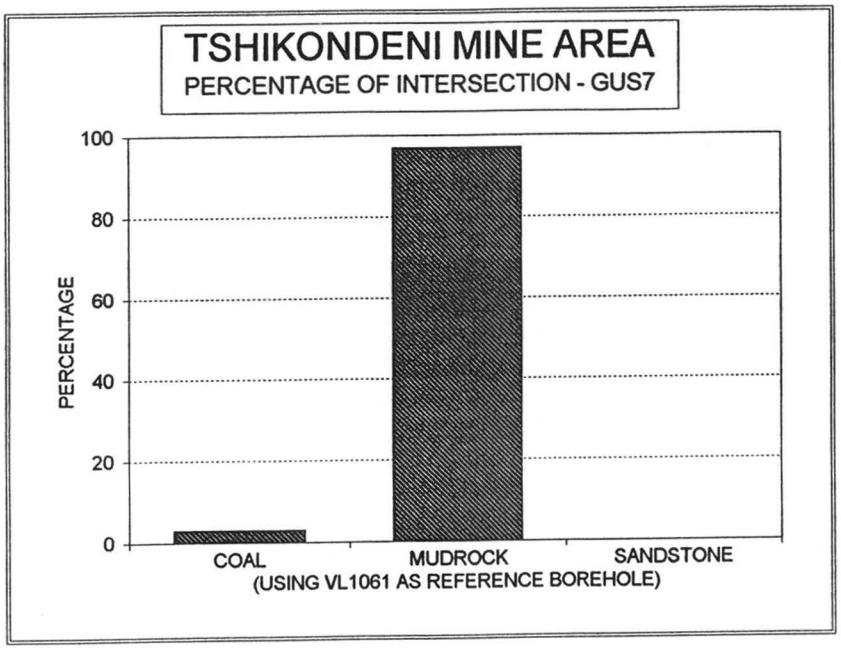


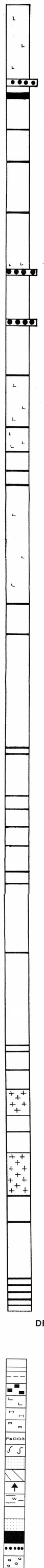
Figure 87. Percentage of the different rock types in GUS7.

Numerous clay pellet conglomerate (facies Mc) and siderite-enriched bands are found throughout GUS7. No signs of trace fossils were seen, but abundant plant remains are found throughout GUS7. The plant remains consist mostly of fragments of Glossopteris leaves.

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GUS 7



84.34		SHALE GREY SILTY START OF MIKAMBENI FORMATION.
	9.26	
92.60		
93.13	0.53	CLAY PELLET CONGLOMERATE GREY CLAYPILL CONGLOMERATE.
94.16	0.64	SHALE DARK GREY
94.60	0.44	COAL, BRIGHT 30:70
		SHALE GREY JOINTED, BROKEN IN PLACES.
	3.47	
98.07		
		SHALE DARK GREY CARBONACEOUS
	3.18	
101.30		
		SHALE GREY CARBONACEOUS SILTY AT BOTTOM 30x.
	6.33	
101.30		
		SHALE GREY CARBONACEOUS SILTY AT BOTTOM 30x.
	6.33	
107.77		
109.08	0.84	CLAY PELLET CONGLOMERATE GREY CLAYPILL CONGLOMERATE.
		SHALE DARK GREY SILTY
	5.12	
114.20		
114.62	0.42	CLAY PELLET CONGLOMERATE GREY CLAYPILL CONGLOMERATE.
		SHALE GREY CARBONACEOUS TOWARDS BOTTOM
	5.43	
120.05		
		SHALE DARK GREY SILTY BAKED TOWARDS THE BOTTOM.
	4.13	
124.25		
124.76	0.51	DOLERITE GREEN BRECCIATION OF COAL AT THE CONTACTS.
125.44	0.68	SHALE BAKED
		SHALE GREY SILTY CARBONACEOUS
	2.97	
128.47		
		SHALE GREY CARBONACEOUS
	1.78	
130.44		
		SHALE GREY CARBONACEOUS
131.68	1.23	
		SHALE GREY SILTY SANDY IN PLACES. SOME FLATTENED SHALE LASTS.
	13.67	
145.60		
		SHALE GREY
	3.60	
149.38		
		SHALE DARK GREY CARBONACEOUS JOINTED
	11.02	
160.65		
161.78	1.13	SHALE SILT LAYERS (LAMINAE) GREY CARBONACEOUS SLICKENSIDED JOINTS AT THE BOTTOM.
162.23	0.42	SHALE GREY CARBONACEOUS
163.81	0.81	SHALE GREY SLUMPING
		SHALE GREY SLUMPING
	3.88	
167.86		
		SHALE GREY CARBONACEOUS
169.71	1.67	
		SHALE GREY SLUMPING 5CM. CLAYPILL CONGLOMERATE BAND AT
	2.12	THE BOTTOM.
171.96		
		SHALE GREY SLUMPING
	2.18	
174.25		
175.49	0.86	SHALE DARK GREY
		SHALE GREY CARBONACEOUS
	3.03	
178.64		
		SHALE GREY SILTY
179.78	1.06	
		SHALE GREY SILTY
	7.86	
188.10		
		SHALE GREY CARBONACEOUS JOINTED.
	10.05	
198.31		
199.04	0.45	SHALE COAL STRINGERS BLACK CARBONACEOUS
		SHALE BLACK CARBONACEOUS
	2.45	
201.77		
		SHALE COAL STRINGERS BLACK CARBONACEOUS
	1.95	
203.86		
		DOLERITE GREEN CALCITE VEIN(S) MOTTLED, CONTACTS PARALLEL TO BEDDING. SILL
	3.03	
207.17		
		SHALE BLACK CARBONACEOUS PYRITE, SPECKS
	2.03	
209.20		
		SHALE BAKED GREY
	1.98	
211.29		
		DOLERITE GREEN CALCITE VEIN(S) CHILLED ON EITHER SIDE, CONTACTS PARALLEL TO BEDDING, SILL.
	4.74	
216.03		
		SHALE BAKED GREY CARBONACEOUS
	2.63	
219.12		
		SHALE GREY CARBONACEOUS SLUMPING
	6.20	
225.67		
226.36	0.63	SHALE GREY
226.78	0.39	SHALE GREY SILTY
227.76	0.86	SHALE COAL STRINGERS DARK GREY CARBONACEOUS SILTY
229.56	0.50	SHALE SILT LAYERS (LAMINAE) DARK GREY
231.04	0.65	SHALE BLACK CARBONACEOUS

DEPTH (m) THICKNESS (m)

LEGEND

SHARP CONTACTS
GRADATIONAL CONTACTS
QUARTZ GRAINS AND QUARTZ PEBBLE BANDS
SILTY LAMINAE AND CONVOLUTE LAMINATIONS
HORIZONTAL LAMINATIONS
RIPPLE CROSS-LAMINATION
SIDERITE
WORM BURROWS
PROMINENT QUARTZ PEBBLE BAND
LARGE SCALE CROSS-BEDDING
FINING DIRECTION
VARVED MUDROCK
MUDROCK
SANDSTONE
COAL
CLAY PELLET CONGLOMERATE BAND
QUARTZITE
SOFT SEDIMENT DEFORMATION STRUCTURES
GENETIC UNIT OF SEDIMENTATION SUBDIVISION
DOLERITE

Figure 88. Lithological profile of GUS7.

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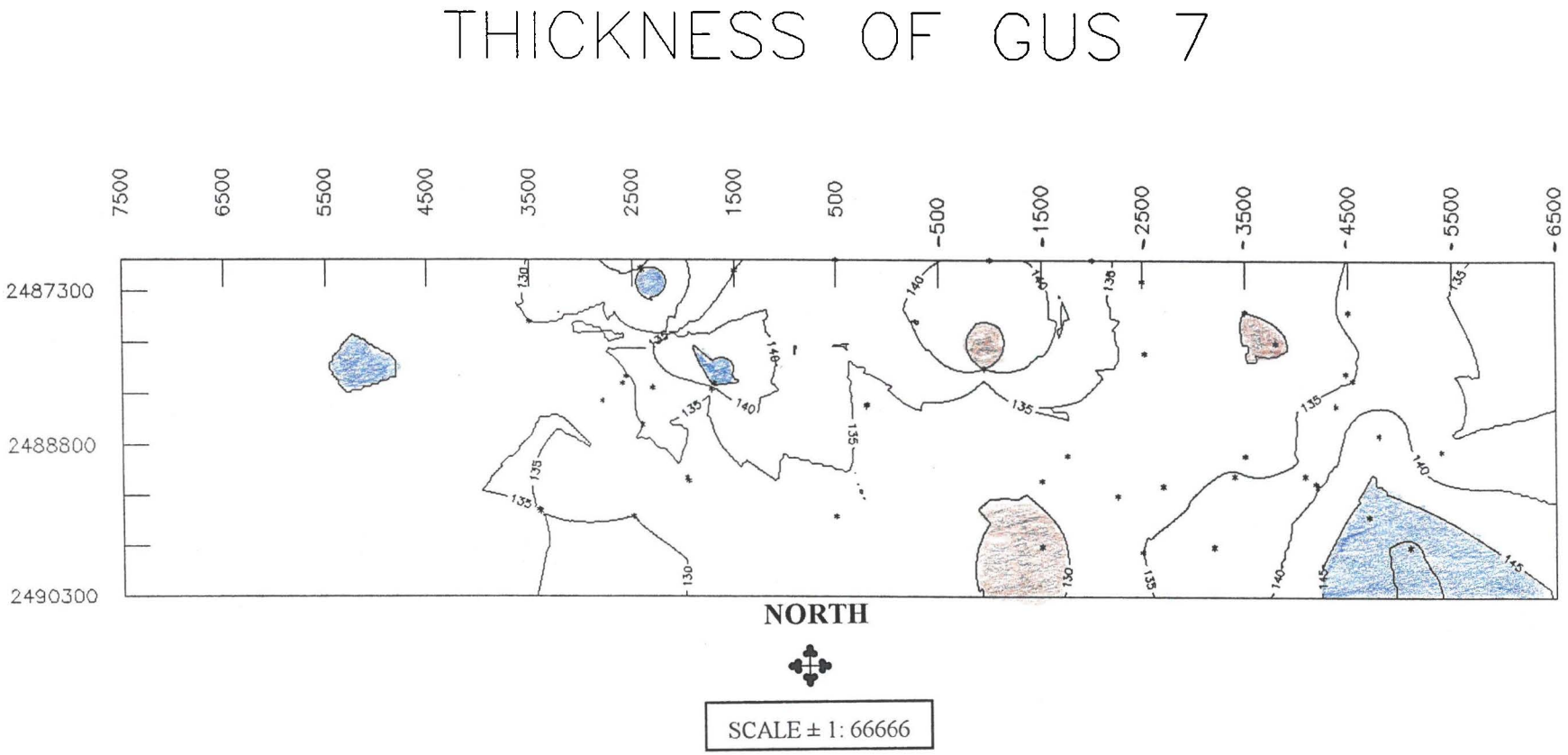


Figure 89. Thickness contours (in metres) of GUS7. (Thick areas in blue and thin areas in brown).

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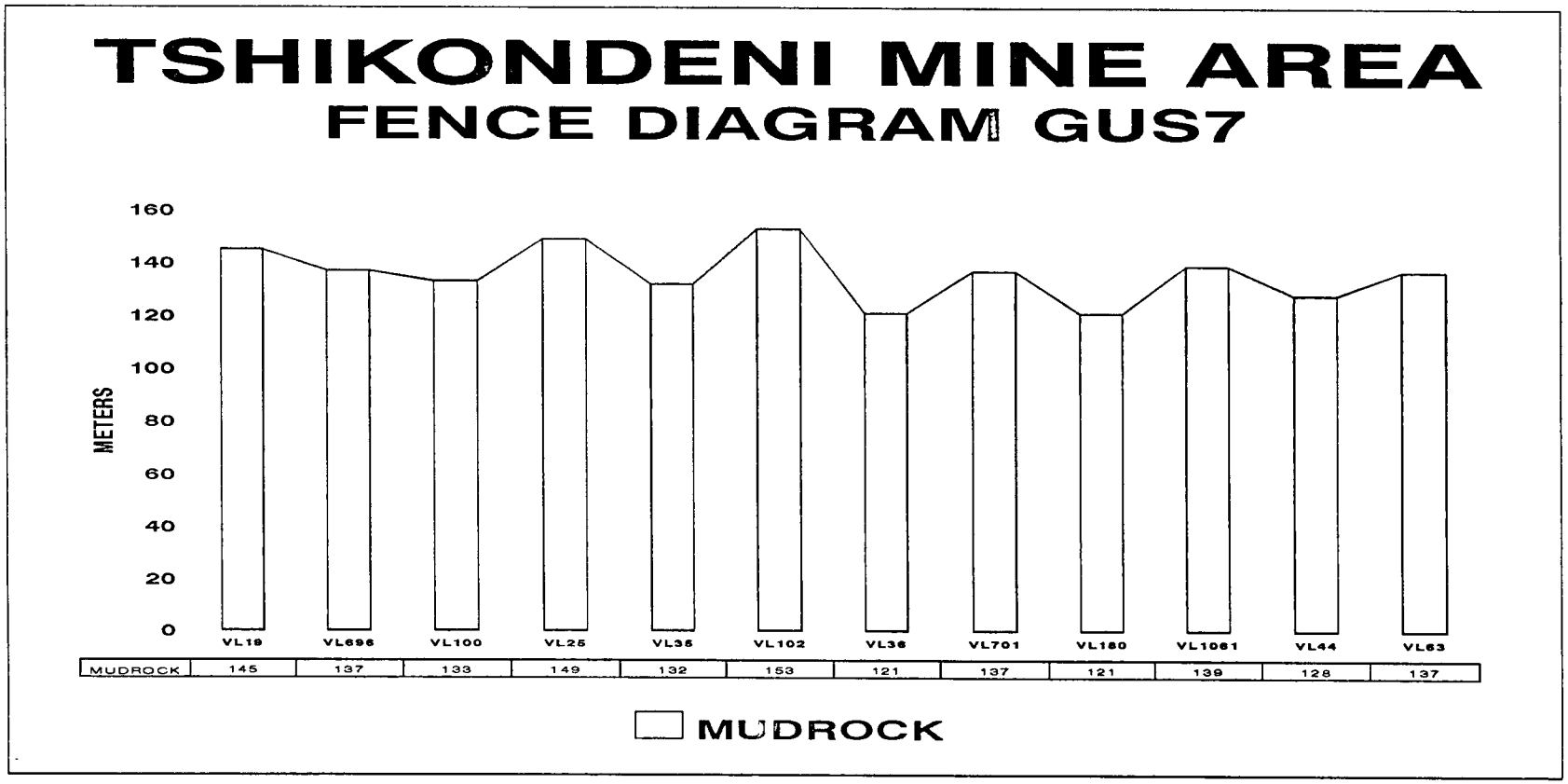


Figure 90. Fence diagram of GUS7 in the Tshikondeni Mine area. Refer to figure 91 for the location of boreholes.

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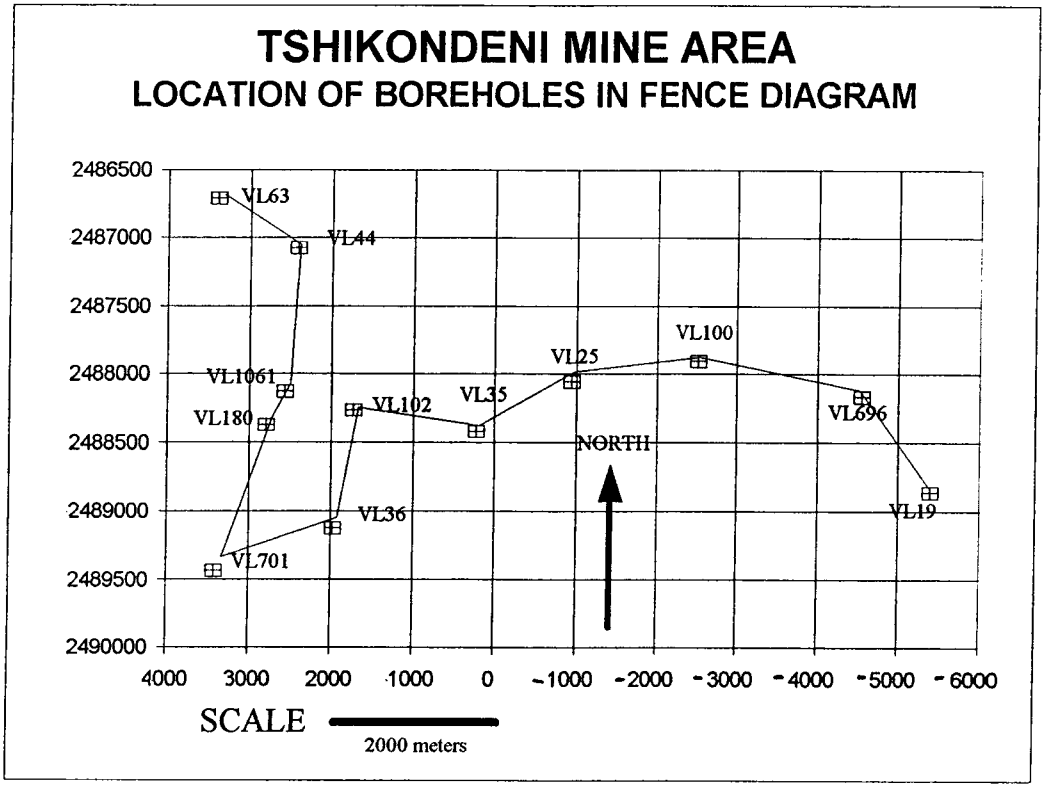


Figure 91. Location of boreholes illustrated on the fence diagram of GUS7.

4. Discussion of depositional palaeoenvironments.

4.1 Diamictite facies.

4.1.1 Massive diamictite (D).

The diamictite, as intersected in most boreholes at Tshikondeni, is usually a pink to grey, clast- to matrix-supported, polymict rock. Sometimes remnants of a green, matrix-supported, polymict rock are found.

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The pink type, described as diamictite in the logs, is in fact a glacio-fluvial conglomerate, as is suggested by the following facts:

- The rock is generally clast-supported.
- The polymict fragments are rounded to subrounded, thus providing evidence of reworking.
- The fragments are unsorted and show no specific orientation (in the TMA), a possible sign that they were not transported very far, similar to Miall's (1985) type Dmm, massive diamictite.

The green type of diamictite is most probably a glacial tillite, due to the following:

- The rock is matrix-supported.
- The clasts are polymict but more angular than the pink variety.

The poor sorting and massive nature of the green diamictites point to either debris-flow deposition of reworked glacial till, or to subglacial till sedimentation (Reading, 1978; Miall, 1980). These matrix- supported diamictites at Tshikondeni are analogous to debris-flow reworked glacial till deposits from the Witbank coalfield described by Le Blanc Smith (1980), and to glacial tills from the Rietspruit coal mine at Witbank (Cairncross and Cadle, 1988).

The clast-supported (pink-coloured) diamictites in the prese.. study area probably reflect fluvioglacial reworking of glacial till, with water transport providing some rounding of the clasts. The interbedded conglomerates and sandstones found in the diamictites (Figure 53) also point to such deposition. Associated minor varved mudrocks point to localized glaciolacustrine sedimentation (Reading, 1978; Visser, 1990)

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4.2. Sandstone facies.

4.2.1 Large scale cross-bedded sandstones (S).

Large scale planar cross-bedded sandstones (S) are usually ascribed to the migration of linguoid transverse bars, sandwaves and side-attached bars (lower flow regime) within a large river channel (Miall, 1978; Reineck and Singh, 1980; Taverner-Smith et al., 1988; Cairncross and Cadle, 1988). A further possible mode of origin of such cross-bedded sandstones is shallow marine shelf deposits (Reading, 1978). Large-scale planar cross-bedding is also the most abundant structure formed by the migration of aeolian dunes (Hunter, 1977).

The most probable origin for the S sandstones at Tshikondeni is due to the migration of megaripples within a large river channel. Shallow marine shelf deposits would probably have contained some remains of marine fossils, and the high foreset dip angles associated with aeolian dunes (up to 33°; Reading, 1978) are not found in the TMA sandstones of facies S.

4.2.2 Ripple cross-laminated and planar laminated sandstone/siltstone (Sr).

The development of climbing ripple cross-lamination from migrating ripples requires that abundant sediment be continually fed to a current or wave, so that the ripples are built upwards in overlapping series rather than moving in a downcurrent direction (McKee, 1965; Boggs, 1987). In the upper flow regime, higher energy currents form planar laminae of sand, because with increasing velocity fine sand migrates due to traction and saltation (McKee, 1965; Coleman and Gagliano,

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1965; Miall 1978). Preservation of lower flow regime plane beds is very unlikely (Boggs, 1987).

Horizontal laminae may occur in high-gradient braided perennial or ephemeral streams or in low gradient meandering, perennial streams (Harms, 1965). Planar laminated sandstones are also deposited in high constructive deltaic systems (Cairncross and Cadle, 1988). Within an active delta, most of the parallel lamination seemingly results from either a segregation of particles by differential settling initiated by changes in current velocity, or from changes in water chemistry (Coleman and Gagliano, 1965; Boggs, 1987).

Climbing ripple cross-laminated sandstone is deposited by gentle traction currents in a variety of shallow water, low energy environments, namely fluvial, lagoonal, estuarine and marine (Coleman and Gagliano, 1965; Miall, 1978; Leeder, 1982; Tavener-Smith et al., 1988).

Cylindrichnus burrows are found in high energy, shallow water environments (Boggs, 1987) and are associated with sandstones at the top of coarsening-upward deltaic sequences (Turner et al., 1981). The position of Cylindrichnus burrows at the top of coarsening-upward sequences in the TMA facies, supports the interpretation that the organism inhabited distributary mouth bars during temporary abandonment (Taverner Smith et al., 1988).

This facies may thus reflect deposition in a variety of environments, such as meandering or braided streams or in deltas, possibly combined with lower energy systems such as lagoons and estuaries (Boggs, 1987). The variation in current energy is evident in the structures found in these facies Sr sandstones, namely planar lamination and small climbing ripple structures (Taverner-Smith et al., 1988).

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4.2.3 Graded sandstone (Sg).

Deltaic mouth bar progradation produces large scale sandstone sequences due to the increasing energy levels (Reading, 1978; Miall, 1978; Boggs, 1987). Progradation of subaerial delta-plain sediments over subaqueous delta-plain sediments may produce smaller scale upwards-coarsening sequences (Boggs, 1987).

The general upward fining of channel-fill sequences results from either lateral migration of the channel, or, more commonly, from channel abandonment with the fine member representing infilling by diminishing flow (Reading, 1978). Upward-fining fluvial sandstones are produced by diminishing energy levels and upward-coarsening fluvial sandstones by increasing energy levels. Vertical grading is also a characteristic of turbidite deposits (Reading, 1978). Upward-fining and upward-coarsening sequences may also occur within alluvial fan deposits (Reineck and Singh, 1980; Leeder, 1982); however, no conglomerates as one would expect in fan sediments, are known in the study area.

The fact that most of the sandstone sequences in the lower two-thirds of the Madzaringwe Formation have gradational lower contacts and become progressively coarser in the first two or three metres is an indication of increasing energy levels. Often, these upward-coarsening cycles are capped by a sandstone unit having a sharp basal contact and which is upward-fining.

These combinations possibly reflect deltaic sedimentation in the lower portions, passing up into distributary channels or meandering river channels on a landward-situated fluvial feeder system.

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4.2.4 Massive sandstone (Sm).

Secondary massive sandstones are thought to lose their internal structures because of liquefaction, induced by slope instability or sudden shock acting on saturated soft sediment (Boggs, 1987; Tavener-Smith et al., 1988). Alternatively, some massive bedding may be a secondary feature produced by extensive bioturbation (Boggs, 1987).

Rapid deposition from sandy, high density turbidity currents produces primary massive sandstones (Reading, 1978; Boggs, 1987; Higgs, 1990). The lack of scour marks and tool marks in this facies in the TMA indicates that turbidity currents are an unlikely genetic mechanism for these massive sandstones.

The sheet-like geometry of the facies Sm sandstones is an indication that they may have been subject to liquefaction, perhaps related to the complex faults systems defining the Soutpansberg and Karoo basins. Bioturbation is unlikely to have been quite so pervasive.

4.3 Mudrock facies.

The following can be said of mudrocks in general: "Mudrocks form under any environmental conditions in which fine sediment is abundant and water energy is sufficiently low to allow suspension settling of fine silt and clay" (Boggs, 1987 pg 215).

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4.3.1 Varved Mudrock (Mv).

Rhythmites of silt and clay may form in two ways (Reading, 1978):

- Fine sediment (silt and clay) is transported as a density underflow, (of sediment-laden streams) into lakes, forming discrete-event turbiditic rhythmites;
- Strong seasonal variation in run-off leads to deposition of coarser sediment during the summer and finer sediment during winter, thus forming glacial lake varves (Leeder, 1982; Miall, 1985).

The latter is considered more likely for the TMA, due to the presence of associated dropstones. Dropstone argillite is formed by suspension settling of mud from meltwater plumes and the "rainout" of coarser, ice-rafted, debris from floating icebergs (Visser, 1990), within a basin setting.

When varved mudrocks overlie diamictite, as in the TMA, it suggests proglacial lacustrine deposits. Such lakes are in direct contact with the glaciers (Eyles and Miall, 1984) and receive sediment directly from the glacier. Large lakes could also result in the formation of dropstones in suspension-deposited muds. This facies is thus thought to represent glaciolacustrine sedimentation.

4.3.2 Undifferentiated mudrock (Mu).

In the TMA study area, the term undifferentiated mudrock was applied to sedimentary rocks found in the Mikambeni Formation, which consisted of mudrocks having a variable amount of clay and silty material.

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Deposition from suspension under low energy conditions is inferred. The origin of this facies could be associated with overbank waning flood deposits, swamp deposits, or basinal sediments. The association with siderite, Glossopteris plant remains and coal seamlets points to a reducing overbank swamp environment rather than central basinal conditions.

4.3.3. Clay pellet conglomerate (Mc).

Clay clasts are locally derived either by reworking desiccated, mud crack-generated fragments or by the hydraulic erosion of cohesive mud laminae or beds (Potter et al., 1977).

According to HJ van der Berg (pers. comm.,1994), the clay pellet conglomerate bands could, locally, have been formed from mud beds exposed to the elements above the water level, which dried out, and were then reworked by later flooding. It is also possible that some of the muds were reworked by Cylindrichnus and become structureless, and were then later eroded by hydraulic action.

The upward-fining nature of many of these clay pellet conglomerates is typical of fluvial environments (Reading, 1978; Miall, 1978; Reineck and Singh, 1980; Leeder, 1982)

4.3.4 Mudrock with quartz grains and quartz pebble bands (Mp).

Mudrock with quartz grains and quartz pebble bands occurs in the glaciomarine environment, where glacial debris can be rafted by an ice shelf or by icebergs (Reading, 1978), resulting in deposition of coarser pebbles and grains and of

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fine suspension particles onto a muddy floor. Van Vuuren and Cole (1979) state that mudrocks with scattered quartz grains are common in the pro-delta environment where there are periodic sand influxes due to storms. McCourt and Brandl (1980) interpreted these quartz pebble bands as crevasse splay deposits in a fluvial environment.

The mudrock with quartz grains and quartz pebble bands in the study area probably represents a glaciomarine (or possibly glaciolacustrine) environment, due to the fact that the quartz pebbles appear to be positioned with their sharp edges pointed downwards, an indication that they were probably rained out of floating icebergs under quiescent conditions. The sediments were, to a large degree, still unconsolidated which allowed for the penetration of the underlying mud layers. Some of the thicker quartz pebble bands could, however, be the result of crevasse splay sedimentation within fluvial systems.

4.3.5 Mudrock with silty laminae and convolute lamination (M1).

Lenticular silty laminations probably represent impoverished current ripples that formed on a clay bottom, and which were later blanketed by suspended clay. Convolute laminations may result from:

- an over-riding force (silt-laden currents),
- differential overloading and
- slow mass movement of saturated sediments on an inclined slope (Coleman and Gagliano, 1965).

Convolute laminations are common structures in muddy, fine-grained sands and silts, within intertidal-flats, river floodplain sediments, and point-bar deposits that have been

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rapidly deposited (Leeder, 1982; Boggs, 1987). Distorted laminations are very common in deltaic and fluvial deposits (Coleman and Gagliano, 1965).

From the fence diagram of GUS5 (Figure 89), the genetic unit in which this facies is most common, it is evident that the facies has a sheet-like geometry. This would tend to support a floodplain setting, subject to overriding current activity during a flood, or to differential overloading upon burial by succeeding fluvial deposits.

4.3.6 Massive black mudrock (Mm).

These mudrocks probably represent fair weather suspension deposits, and the black colour points to an anoxic environment (Jackson et al., 1990). The description of this lithofacies closely resembles that of Miall's (1978) C and Fsc - lithofacies, which are interpreted as swamp and backswamp deposits. Cairncross and Cadle (1988) interpreted the same type of lithofacies in the Witbank area as deposition from suspension under quiescent conditions in a high constructive deltaic environment.

4.4 Coal facies.

Coal is formed by autochthonous accumulation of peat in a peat swamp under acid, reducing conditions (Falcon and Snyman, 1986). Potential coal-bearing sites are restricted to those environments of high plant productivity, low sediment influx, limited plant tissue oxidation and bioregeneration, and high preservation potential (Leeder, 1982). Peat accumulation is a slow process, varying between 0,8 mm and 50 mm per year (Smuts, 1992).

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According to Galloway and Hobday (1983), the following palaeoenvironments are favourable sites for coal formation:

(a) back-barrier swamps,
(b) deltas,
(c) river systems and
(d) alluvial fans.

Coal in back-barrier swamps is laterally discontinuous and has a high sulphur content (Galloway and Hobday, 1983). Coals forming in the delta environment would usually be overlain by a thick, upward-coarsening sandy sedimentary unit and would tend to be lobate (Hamilton, 1985). Alluvial fans are lobate in plan view and wedge-shaped or lenticular in cross-section (Boggs, 1987). Abrupt facies changes are also typical of preserved fan deposits (Boggs, 1987). The widespread nature and essentially planar geometry of the TMA coals cannot easily be reconciled with the above three interpretations. A fluvial setting is thus inferred.

At any particular time in a meandering stream system, sedimentation may take place in the channel, on point-bars and in overbank environments (Boggs, 1987). Parallel laminations may be interbedded with cross-bedded units at various levels and the classical upward-fining sequence, as proposed by Allen (1970) for meandering stream deposits, seems to describe the facies associated with coal in the TMA area.

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4.4.1 Interpretation of the coal petrography.

The influence of the sedimentology on the petrography.

(a) Lower coal seams (Samples 12 - 14).

The diamictite, sandstone and varved mudrocks below the lower coal seams suggest that the peat accumulated in a paraglacial environment. The high RSF and inertinite content suggest that oxidizing conditions were more prevalent during peat accumulation, as an increase in oxygen permits a higher degree of fusinitization when compared to that found in vitrinite (Falcon and Snyman, 1986)

The slight increase in RSF, inertinite content and the slight decrease in vitrinite content are probably accounted for by the slower subsidence of the peat swamp with time and a slight lowering of the water table (Holland et al., 1989). The mineral matter content varies somewhat which indicates that the clastic influx into the swamp, during peat accumulation, was not constant.

(b) Middle coal seams (Samples 4 - 11).

Excluding Sample 11, the vitrinite content of the coal seams stays constant, but there is a marked jump in vitrinite content from the lower coal seams to the middle coal seams (± 15%). The vitrinite content of these coal seams suggests that the rate of subsidence of the peat swamps kept pace with the rate of accumulation. The inertinite content decreased, suggesting a higher rate of subsidence for the peat swamps (Holland et al., 1989). The decrease in RSF also suggests that oxidation of the swamp was less - probably due to higher water levels. The trend in mineral matter suggests that clastic influx reached a peak during deposition of Sample 6. The

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abrupt increase in vitrinite content of sample 12 points to a rapid rise in the water table.

(c) Upper coal seams (Samples 1 - 3).

There is a general increase in the vitrinite content towards sample 1. This is an indication that conditions at these times were near optimal for peat accumulation. Swamps were far removed from clastic influx, as is shown by the decrease in mineral matter content (Figure 29C). The decrease in RSF content suggests that conditions were less oxidizing for samples 1 to 3. The rapid increase in vitrinite content for sample 2 shows that the level of the water table rose rapidly.

4.4.2. The causes of coalification.

The coals in the TMA have a high rank (% RoV > 1,10) and were influenced by dolerites and, possibly, also by the high geo-thermal gradient. Assuming an age for the coal of about 250 Ma, this implies a maximum temperature of coalification of about 130°C for the lower coals (% RoV of ± 1,40, Table 6A) and 120°C for the coals just below the Fripp Formation (Samples 1 to 3), according to the nomogram of Bostick et al. (1979) (Figure 97).

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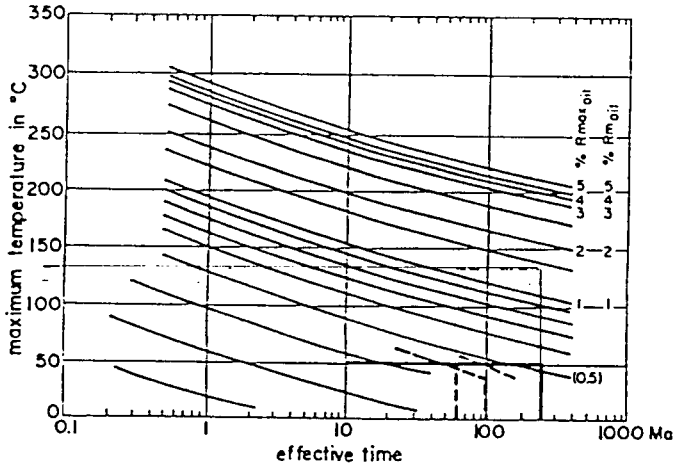


Figure 97. The relationship between maximum temperature of metamorphism, effective heating time and vitrinite reflectance (After Bostick et al., 1979).

A second temperature of coalification diagram (Figure 98), was devised by Teichmuller et al. (1968), who also considered the percentage volatile matter of the coal as an important factor. According to this nomogram (Figure 98), a coal with 23% volatile matter (lower coals of the TMA) and an age of about 250 Ma, would have a coalification temperature of about 87°C. A coal with 26% volatile matter (Samples 2 to 4 of the TMA) would have a coalification temperature of about 80°C.

Using the TMA data (Table 6A), it is also possible to calculate the historical geothermal gradient at the time of formation of the coal seams. The distance between sample 4 and the lower coal seam is about 200 metres and the inferred temperature difference is 7°C. The geothermal gradient would then be 35°C/1000 m. The modern geothermal gradient is about 43°C/1000 m (M.O.W. Jones, pers. comm., 1993).

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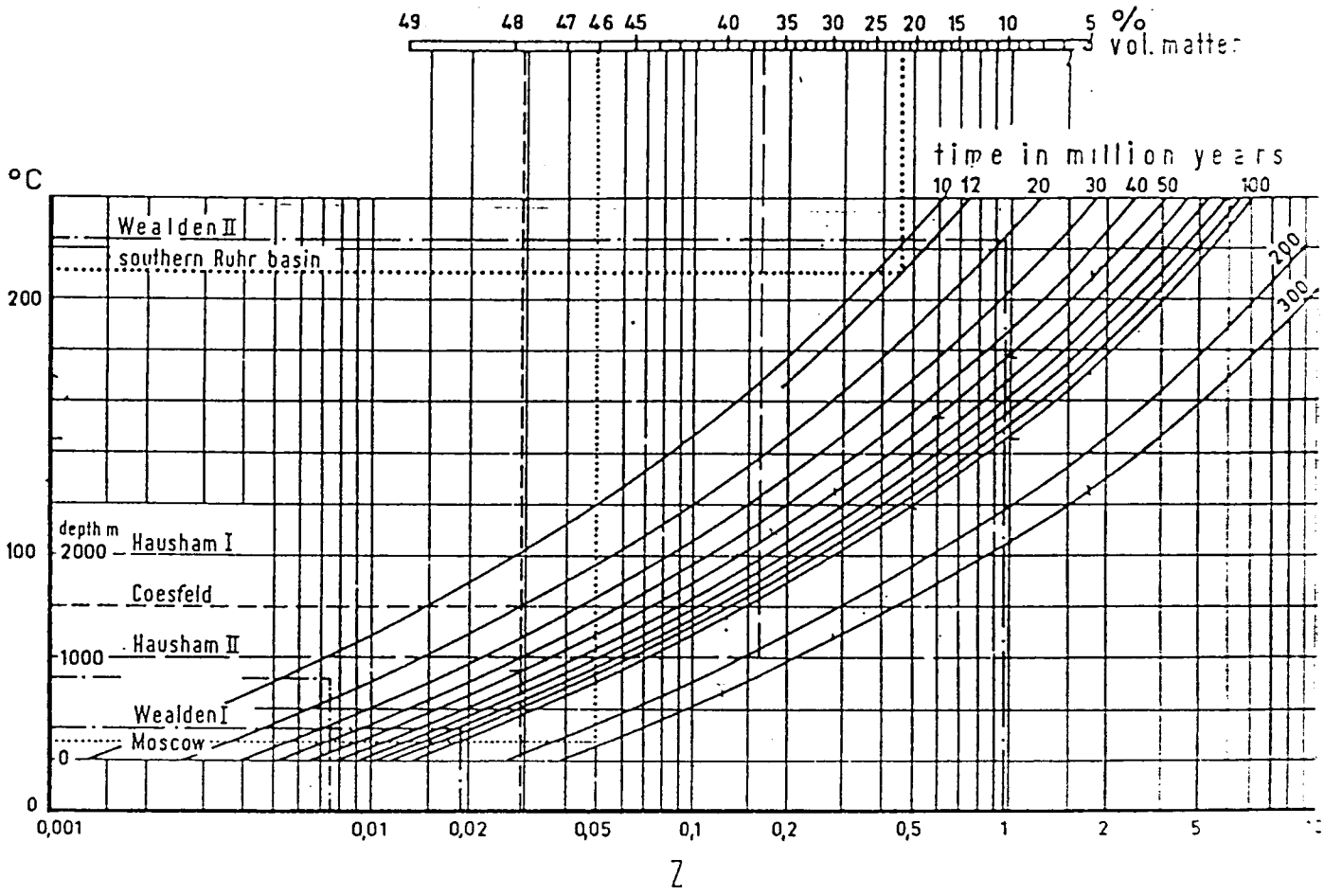


Figure 98. Nomogram of Teichmuller et al. (1968). Z = ∛RoV.

4.4.3. Ash analysis.

SiO2.

The SiO2 content for samples 5-9 is constant and there is a decrease in SiO2 content for the Lower coal seams (samples 12-14) (Figure 99). This is most probably related to a change in fabric of the coal for the higher samples (Figure 99), or to the type of plant that existed at this time, as different floral species have different affinities for certain inorganic elements.

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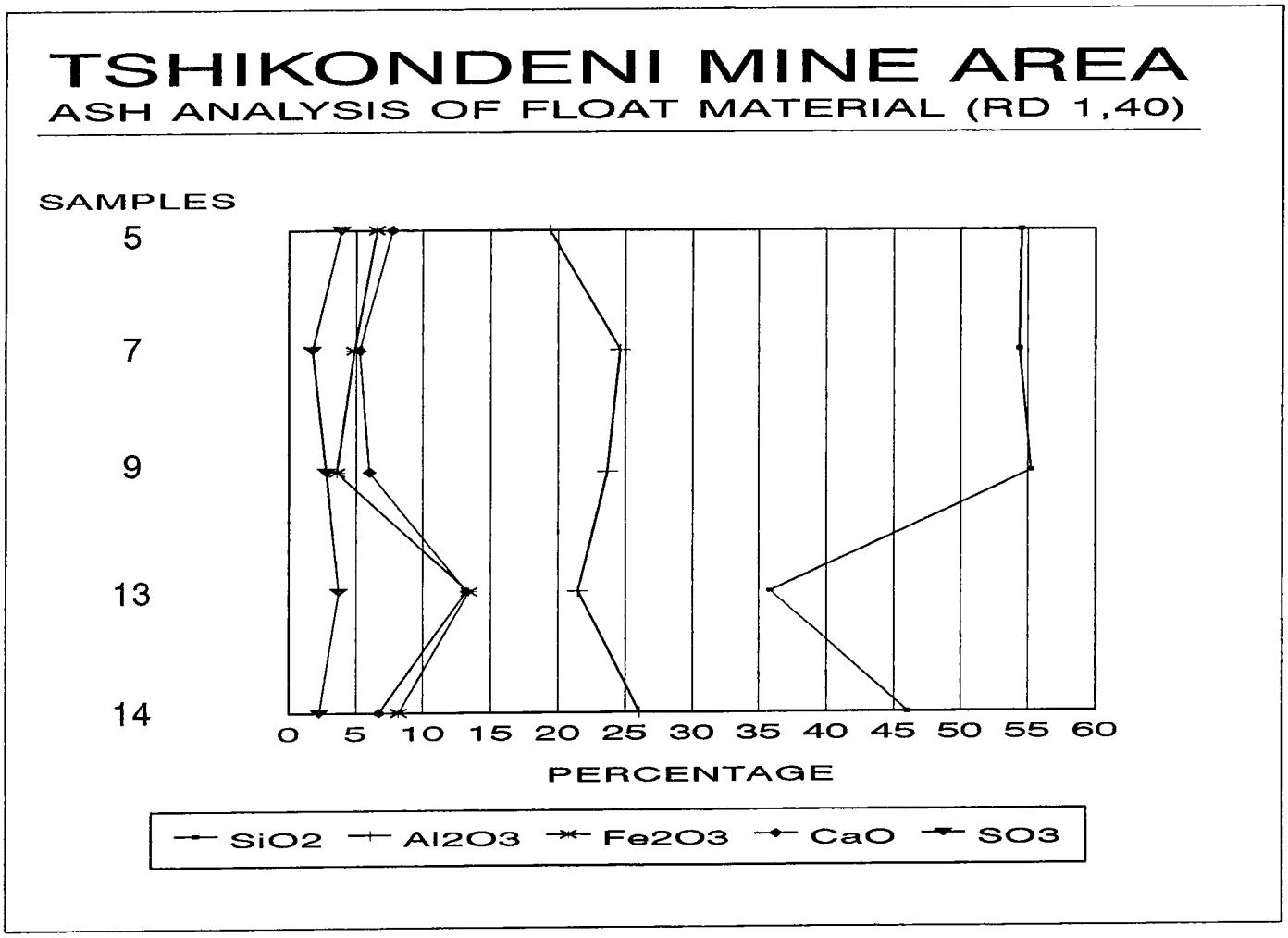


Figure 99. Ash analysis of float material (RD = 1,40) for SiO2, Al2O3, Fe2O3, CaO and SO3.

Al2O3, Fe2O3, CaO and SO3.

All these elements are evenly distributed throughout the succession (Figure 99) except for iron and calcium in sample 13. The reason for this is probably linked to the depositional environment at this time.

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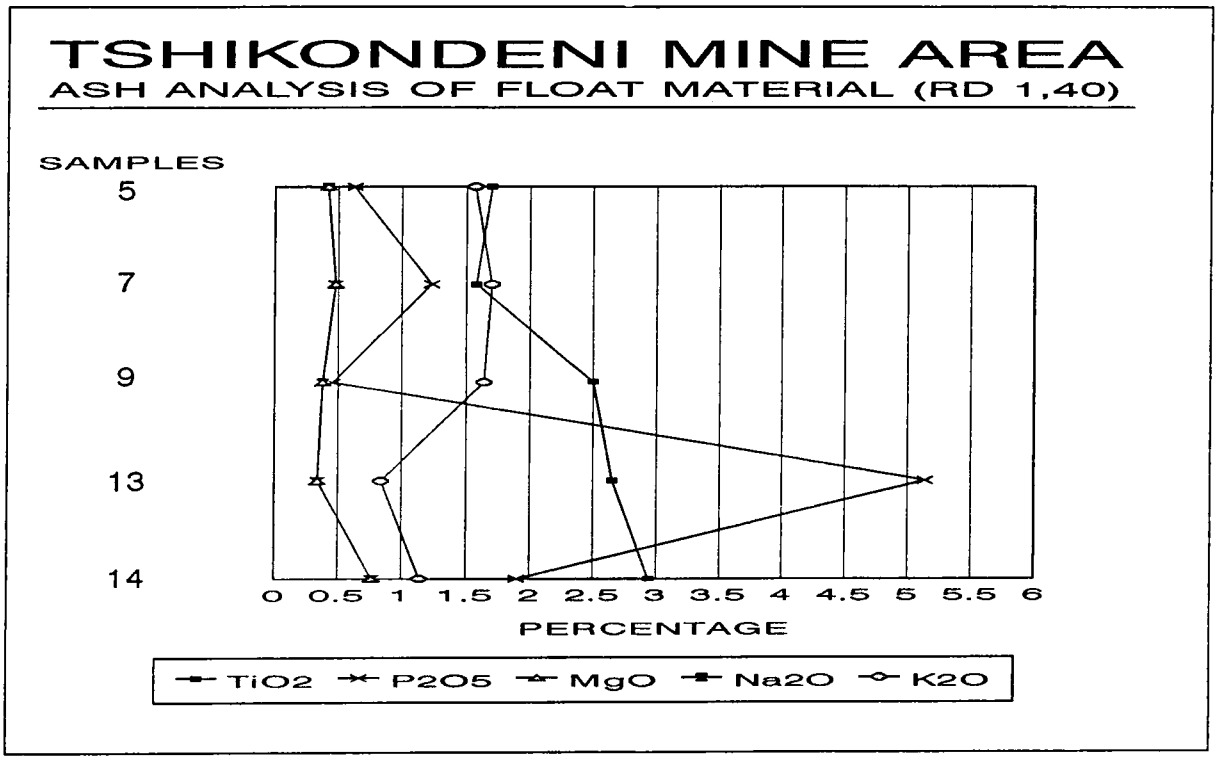


Figure 100. Ash analysis of float material (RD = 1,40) for TiO2, P2O5, MgO, Na2O and K2O.

P2O5.

The P2O5 content of the ash shows a marked increase in sample 13 (9 times) (Figure 100). The reason for this is possibly related to the type of plant species abundant at this time, or to the provenance area of the mineral matter (Renton and Cecil, 1979).

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TiO2, MgO, Na2O and K2O.

The distribution of these elements is virtually constant throughout the succession. There is a slight decrease in TiO2, in the upper samples but the reason for this is as yet unclear.

5. Interpretation of the genetic units of sedimentation.

5.1 Genetic unit of sedimentation 1 (GUS1).

After deposition of glacial tillite, of which there are sporadic occurrences in the TMA, these GUS1 deposits were most likely reworked by high energy streams which had the capacity to move large pebbles and boulders of up to 2,0 m. Nearly all the till appear to have been reworked. The rivers were probably caused by the melting of the glaciers as they retreated. Unfortunately, no concrete evidence was found of the direction in which the glaciers moved. A floor contour map of GUS1 (Figure 89) suggests a highly irregular floor.

Visser and Loock (1988) described a similar glaciogene lithofacies at Barkley West. They attribute the lack of matrix to the action of meltwater. Deposition of diamictite was caused by rapid melting of basal ice and the accumulation of debris at the floor of the glacier. They also state that it is difficult to move large boulders and suggest that melting of the ice roof of cavities would have flushed out most of the finer material.

Sandstones were locally deposited on top of the TMA diamictite indicating that the energy of the fluvioglacial rivers

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decreased as the ice retreated further. Soft sediment deformation and slumping are common in the sandstones, confirming that they were deposited in a saturated state and subjected to slope instabilities. Sporadic pebble lags, consisting of fragments of quartzite and lava, occur in these sandstones, probably indicating occasional high energy floods. Massive, structureless sandstones most likely lost their internal structures because of liquefaction, induced by slope instability or sudden shock acting on saturated soft sediment (Tavener-Smith et al., 1988). Plant remains in the sandstones show that trees were starting to grow on the proglacial flats in front of the retreating icecap. Conditions were, however, not favourable at this stage for the formation of thick coal seams. The small pockets of coal found can be regarded as precursors of GUS2.

Associated mudrock is not common and this is probably due to its poor preservation potential in a glaciofluvial environment. The limited varved mudrock deposits were probably formed by suspension settling of mud from meltwater plumes and the rain-out of ice-rafted debris from floating icebergs in a lacustrine setting, similar to that discussed by Visser (1990) for the main Karoo basin.

The conditions during deposition of GUS1 could thus generally be described as predominantly glaciofluvial. The probable transport direction of the diamictite, as deduced from studies towards the Tshipise area, was from the north-east (Vd Berg, 1980).

5.2 Genetic unit of sedimentation 2 (GUS2).

GUS2 most probably originated from peat accumulation under a cold climate, following and accompanying glacial retreat.

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These swamps could have formed close to active clastic environments in cool, temperate areas. The cool climate resulted in sparse and dwarf-like plants. The cold climate inhibited fermentation of the organic material.

The Karoo floor, because of tectonism and glacial activity, was not even. The coarse GUS1 fluvioglacial sediments filled the largest of the depressions in the floor and a gentle, undulating floor probably served as base for the first coal deposits (GUS2). This palaeotopography probably had a direct influence on water depth and floral growth.

Differential compaction and a thick accumulation of organic material occurred. As a result of a change in water level the higher areas could have been exposed, and oxidation of the organic material took place, this being broken down to form inorganic-rich lenses. This could explain the variation in coal thickness and lithology.

The association of siltstones, carbonaceous mudrocks and coal in GUS2 indicates a low energy, swampy, environment which, in deltaic systems, occurs in interdistributary embayments which are protected from basinal influences by levees, and which, in fluvial systems, occurs on floodplains, abandoned channels and in oxbow lakes (Reading, 1982).

5.3 Genetic unit of sedimentation 3 (GUS3L, GUS3U) and genetic unit of sedimentation 5.

All three of these genetic units of sedimentation, GUS3L, GUS3U and GUS5, have the same sedimentological character and are thus considered together.

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GUS3L.

Marker 3 (Figure 32) is important as it represents the start of the first major sediment progradation into the basin. All three sandstone units of GUS3L have upward- coarsening, typically deltaic, characteristics in the lower parts, and all are capped by fluvial type upward-fining sequences of varying thickness. These inferred deltaic and fluvial sandstone units are separated by silty mudrocks, with gradational contacts. Quartz grains and pebbles are scattered throughout the mudrocks and may represent dropstones from remnant GUS1 floating icebergs. SH1 represents the first mudrock trans-gression, SH2 the second, SH3 the third and SH4 the final basin transgression of GUS3L. These are inferred to be prodelta mudrocks (Van Vuuren and Cole, 1979), being dark grey, interlaminated with siltstone and containing scattered, coarse, quartz grains.

As a result of delta progradation, the basinal mudrocks graded up into sandstones assigned to the delta-front environment. These are represented by the start of each upward-coarsening cycle found in GUS3L (ie SS1, SS2 and SS3)

The upper part of each sandstone cycle represents sediments from the delta-plain and distributary channel environments. These are laminated, finer sandstones. Locally, pebbly sandstones are found on top of SS2. The upward-coarsening cycle at the top of SS2 may represent a crevasse splay deposit (Van Vuuren and Cole, 1979). Similar upward-coarsening cycles have been described by Cairncross and Winter (1984).
The absence of preserved tidal structures shows that the deltas were not significantly influenced by tidal processes. This was also noted by Cairncross and Winter (1984) at the Rietspruit coal mine. The rate of sediment influx may also

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have exceeded the rate at which any tides and waves could rework the sandstones.

The fence diagram of GUS3L (Figure 54) suggests that these deltas graded into each other laterally and now have the appearance of a sheet-like deposit. Thickening, probably over the central parts of the deltas, and thinning over the edges of the inferred deltas, can be interpreted from this fence diagram.

Taverner-Smith et al. (1988) reported an idealized coal-bearing cycle in the Vryheid Formation of Northern Natal and also envisaged the upward-coarsening, lower part of the cycle as a prograding delta-front. The upward-fining, upper part of the cycle was thought to represent an upper delta-plain or fluvial environment (Taverner-Smith et al., 1988).

The sandstone units in the TMA become progressively coarser and thicker towards the top of GUS3L, and this is an indication that delta progradation became stronger towards the top of GUS3L. The progradation could have been a response to uplift of source areas, or may reflect increased melting of retreating ice sheets.

The precise morphology and extent of individual delta lobes are difficult to determine in the study area, due to the complex pattern of overlapping and interfingering of larger and smaller progradational sequences. The geometry is, however, sheet-like, suggesting lobate rather than elongate delta complexes.

In conclusion, GUS3L probably represents an assembly of prograding deltas, having a sheet-like appearance, and basinal to prodeltaic mudrocks. Glaciers, in some areas, were possibly melting during warmer periods and feeding sandstones into the

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basin, whereas during colder periods, icebergs may locally have been released into the basin, feeding coarser material to the muddy sediments below. Locally, small peat marshes formed on top of the deltas (ie sample 11 on top of SS1), but mostly the marshes did not survive the next deltaic progradation.

GUS3U.

GUS3U is similar to GUS3L, with the exception that inferred upper delta-plain coals had time to form. Reworking by fluvial sediments probably removed evidence of a prograding delta-front in SS1, and only upper delta-plain sediments were preserved.

From the fence diagram of GUS3U (Figure 62) a number of characteristics of SS1 can be inferred. There is a general thickening from east to west, and from north to south. Lobate thinning and thickening trends, as seen in GUS3L, are not evident in SS1, and it is possible that original inferred delta sandstones in SS1 were reworked by fluvial processes. Alternatively, SS1 may represent more proximal fluvial sediments within an overall deltaic setting. Fining-upward sequences have been widely interpreted as being fluvial in origin in the main Karoo basin. Meandering river systems have been inferred by several authors, for example, Roberts (1988). Probable crevasse splay successions are found in SS1, supporting this assertion.

SS2 and SS4 show lobate thickening and thinning, as, to a lesser extent, does SS3. SS2 consists of two inferred deltaic sandstone sequences, separated by a thin (3,3 m) transgressive mudrock sequence. The peat swamps, inferred for GUS3U, probably developed on broad, upper delta-plain fluvial environments (Roberts, 1988).

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GUS5.

GUS5 is similar to GUS3L and GUS3U. It consists of four inferred deltaic sandstone sequences, separated by transgressive mudrock sequences. Quartz grains and pebbles are virtually absent in the mudrocks in this unit and silty laminae become more prominent, an indication that glaciers were probably far removed, or absent, and did not directly contribute detritus, although they may still have controlled the water level in the basin as a whole. Crevasse splay deposits are found locally, and coals were preserved in inferred upper delta-plain settings to a lesser extent.

5.4 Genetic unit of sedimentation 4.

The coals and mudrocks of GUS4 were probably formed on an abandoned delta-plain environment. The tempo of subsidence and compaction was sufficiently slow to allow the formation of large peat swamps to take place. The thin mudrock bands found throughout are possibly an indication of flooding in this distal part of the basin (Casshyap and Tewan, 1984).

It is interesting that no definite sandstone channels have been identified in the TMA study area. Soft sediment deformation and compaction of the sandstone below GUS4 locally created an uneven floor to the coal swamps. The middle marker of sample 7B is found throughout the TMA and may be interpreted as a tonstein. The variable thickness, however, probably excludes this possibility unless the TMA is inferred to have been close to the source, where prevailing winds could have played a role in causing variable thickness.

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If the following are assumed:

(a) an annual growth rate of ± 1 mm per year (Stach et al., 1975),
(b) 69% of GUS4 is coals (Figure 65),
(c) the average thickness of GUS4 is 5 m (Figure 69),
(d) a compaction ratio of 7:1 (Stach et al., 1975),

then the coals of GUS4 could represent about 24 000 years of plant growth.

In conclusion, GUS4 was most likely deposited during a stable period in the tectonic history of the basin. The irregularities of the basin floor were mostly already evened out by preceding sediments and the effects of differential compaction. GUS4 was most likely deposited in an abandoned delta-plain environment. The variation in the characteristics of the swamp was small. Deposition was uniform and change in the water table affected the entire deposit. The climate was moderate and vegetation was lush. Tall trees were abundant, as evidenced by large tree trunk impressions in the roof of the mine.

5.5 Genetic unit of sedimentation 6.

GUS6 consists largely of upward-fining cycles interpreted as being fluvial sandstones, with minor inferred crevasse-splay deposits and overbank mudrocks. Mudrocks, which probably completed most of the upward-fining cycles, were most likely reworked by erosion. Subordinate massive sandstones are interpreted as bar or sand wave deposits which were probably laid down rapidly (Higgs, 1990). The few upward-coarsening sandstone sequences are probably due to increasing energy levels during flooding.

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The individual sandstone units are very thin, an indication of reworking of the individual cycles. GUS6 is interpreted as reflecting a fluvial environment, development on a filled basin represented by GUS1 to GUS5.

5.6 Genetic unit of sedimentation 7.

GUS7 consists exclusively of mudrocks and thin coal seams. The mudrocks have Glossopteris leaf fragments scattered throughout, and according to Taverner Smith et al. (1988) Glossopteris had a preference for more aerated soil in better drained, slightly raised palaoenvironments. The fact that most of the fossil leaves found are broken, suggests that they were transported from adjacent, more elevated areas.

Soft sediment deformation and clay pellet conglomerate bands are common, pointing to liquefaction induced by slope instability of saturated soft sediment, or by downslope gravity displacement (Taverner Smith et al., 1988), as well as erosion.

No scattered quartz grains or pebbles are present in GUS7. The depositional environment was most likely quiet and the hinterland low, since no coarse material was transported into the basin. GUS7 also probably represents a transgressive event that occurred under shallow water conditions, much the same as the Volksrust Formation in the Mhlatuze River area in Zululand (Taverner Smith et al., 1988).

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6. Model of depositional palaeoenvironment.

The pre-Karoo topography in the main Karoo basin is the result of erosion by glaciers during the Permo-Carboniferous glaciation of Gondwana (Du Toit, 1956; Tankard et al., 1982; Hagelskamp, 1987). A similar process is inferred for the Karoo basin in the TMA study area.

The basal Karoo rocks in the TMA were deposited on an irregular floor. These deposits consisted of unconsolidated diamictite, conglomerates, sandstones and varved mudrocks, which filled many of the irregularities in the floor. Glacial retreat produced meltwater discharge that reworked the unconsolidated till, laying down coarse, gravelly detritus and sandstones. Varved glacial lacustrine deposits formed in localized palaeotopograhic lows.

As the ice sheets retreated, juvenile swamp flora began to develop on the underlying clastic sediments. These swamps were stagnant and not very well developed. Clastic sediments (mudrocks) are interlayered with the coal seams and lateral correlation of the individual seams is difficult, but it does appear as if certain periods of time could have been favourable for the development of different quality coal seams (Sample 13). A predominance of mixed coal lithotypes indicates inferior peat preservation conditions due to contact with oxygen-rich waters (Stach et al., 1982). Siderite was associated with these first coal deposits, due to the generally reducing conditions of formation (Hagelskamp, 1987). Differential compaction and small scale, normal faulting along active fault planes, also assisted in creating an uneven floor locally.

A laterally continuous quartz pebble band on top of the lower coal zone delineates the start of the first major rise in the

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regional water level of the basin. The pre-existing coal swamps were drowned and were succeeded by extensive lacustrine conditions.

The next phase was characterized by a gently undulating palaeotopography and by numerous upward-coarsening deltaic sequences, terminating in upward-fining fluvial sequences capped by coal seams. Reworking, by fluvial processes, resulted in several, extensive, sheet-like sandstone deposits. These fluvial processes were dominated by low energy meandering river systems and a gentle palaeoslope. Extensive floodplains resulted and at certain times produced favourable conditions for widespread, uniform peat growth and preservation i.e. samples 10, 9, 8, 7, and 6 in GUS3L, GUS3U, and GUS4. The fact that he coal and shale bands alternate at regular intervals, suggests a fluxuating water table with corresponding reducing and mildly oxidation and periodic sedimentation conditions. The rank of the coal is apparently mostly influenced by dolerites. All of these swamps were drowned by succeeding extensive lacustrine, or, alternately, fluvial conditions.

The assemblage of mudstone and coal points to a backswamp environment for GUS4, the main coal zone in the TMA. This backswamp palaeoenvironment apparently had no channel influences and therefore no influx of clastic material that could have formed lenses and channels. The palaeoslope during this time was so small that a small rise in water level influenced the entire deposit. As time progressed the palaeoslope became slightly greater as the mudstones of sample 6 (towards the top of GUS4) are laterally discontinuous. GUS4 is overlapped by a thick mudrock layer, indicating a gradual rise in the regional water level.

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GUS 4 was succeeded by further deltaic deposits (GUS5) and then fluvial processes became dominant (GUS6), which resulted in numerous upward-fining, cross-bedded sandstone cycles. Peat preservation potential was low, as the laterally discontinuous coal seams of sample 5 illustrate. Towards the end of this fluvial period, conditions again became favourable for the formation of upward-coarsening deltaic cycles, which were followed by deposition of related upward-fining fluvial cycles. Sedimentation of GUS6 was concluded with the deposition of the peat swamps of sample 4.

The whole study area was then drowned and lacustrine conditions prevailed (GUS7- Mikambeni Formation). At certain times, in local areas, peat swamps were formed (samples 3, 2 and 1). Conditions were waterlogged and soft sediment deformation and mass flow sedimentation were common. Leaf fragments were continuously washed into the basin.

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