The practical application of Vectar Processed densities in proving the lateral continuity of coal Zones and Samples in the Ellisras Basin, South Africa in support of effective Mineral Resource adjudication

by

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DECLARATION

I declare that this thesis, which I hereby submit for the degree Philosophiae Doctor at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

JH Sullivan

24 May 2014

ABSTRACT

The practical application of Vectar Processed densities in proving the lateral continuity of coal Zones and Samples in the Ellisras Basin, South Africa thus supporting a Competent Person to adjudicate Mineral Resources more effectively

by

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Keywords: Ellisras Basin, Groenfontein, geophysical logging, cumulative distribution diagrams, lateral correlation, SANS data point, classification of Resources.

The Ellisras Basin, with huge coal resources, is fault-bounded along its southern and northern margins and is a graben-type deposit. The study area is situated in the south-western part of the Limpopo Province of the Republic of South Africa and is geologically located in the Ellisras Basin. In this area the basin is influenced by three major fault zones, the Eenzaamheid Fault delineating its southern limit, the Zoetfontein Fault near its northern limit and the Daarby Fault, with a down-throw of approximately 350 m towards the north-east. Sedimentological facies changes also influence the continuity of the coal zones, with deterioration in coal development.

The exploration project was a collaboration between two of the large role players in the South African coal mining industry Sasol and Exxaro, for the purpose of identifying whether the coal

in the Ellisras Basin could be used for gasification purposes in the Sasol process, and that enough resources exist on the farms on which the two companies have the exploration rights.. The prospecting method used at the Project area, situated 50 kilometer west of the town of Lephalale in the Limpopo Province of South Africa, comprises the drilling of cored exploration boreholes on a random spacing of ± 1 000 m x 1 000 m, together with infill percussion drilling.

The use of slimline geophysical methods to log lithologies is a technique which has been used extensively in the mining industry over a number of years. At the Project area the correlation between the measured densities derived from the traditional method of air and water measurement and those derived from Vectar processed derived densities from geophysical logging is better than 95%. As a method of “fingerprinting” the various coal zones and samples it was decided to calculate the distribution of relative densities in the chosen geological intersection. The data was then used to portray geophysically derived relative density cumulative distribution line diagrams (GDCDD) of the various lithotypes on either a sample-by-sample or zone-by-zone basis.

Using the classification method proposed, the various coal seams and zones can be correlated to a high degree and discrepancies easily identified. The lateral correlation between lithologies can be accurately described and substantiated, and this would convince a Competent Person that the method proposed is invaluable in classifying coal resources in the coal basins.

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ABBREVIATIONS

ACT	Advanced Coal Technologies – A company doing coal analysis in Pretoria
CIM	Canadian Institute of Mining, Metallurgy
CMMI	Council of Mining and Metallurgical Institutions
CRIRSCO	Committee for Mineral Reserves International Reporting Standards
ECE	Economic Commission for Europe
GDCDD	Geophysically Derived (Relative density) Cumulative Distribution Line Diagram
IMMM	Institute of Materials, Minerals, and Mining
JORC	Joint Ore Reserves Committee
JSE	Johannesburg Stock Exchange
MSD	Multiple seam deposit type coal
SAIMM	South African Institute of Mining and Metallurgy
SAMREC	South African Mineral Resources Committee
SAMREC Code	The South African Code for Reporting of Mineral Resources and Mineral Reserves
SAMVAL	The South African Mineral Asset Valuation Committee
SANS	South African National Standard
SME	Society for Mining, Metallurgy, and Exploration
TISD	Thick interbedded seam deposit type
UN-ECE	United Nations Economic Commission for Europe
UNFC	United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources

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DEFINITIONS

ADEN (in las file)	A las file is data readings as received from the geophysical probe usually in text format. ADEN is also known as Vectar processed density readings.
CADE (in las file)	Calliper width from density tool.
Calliper	A device for measuring the diameter of the internal wall of a borehole or tubing using an arm.
CODE (in las file)	Compensated density.
Competent Person	A person who has a minimum of five years' experience relevant to the style of Mineralisation and type of deposit or class of deposit under consideration and to the activity he or she is undertaking and is registered with one or more recognized professional organisations.
Compensated density	A density log that has been corrected for the effect of mud and mudcake by using two or more detectors at different spacing's from the source. The shorter the spacing, the shallower the depth of investigation and the larger the effect of the mudcake. Thus, a short-spaced detector, which is very sensitive to the mudcake, can be used to correct a long-spaced detector, which is only slightly sensitive to it. In a typical two-detector compensation scheme, the density measured by the detector furthest spaced from the receiving part of the probe and this value is corrected by a factor, which is a deduced function from the difference between near- and long-spaced densities. The correction is found to depend on the difference between formation and mudcake density multiplied by mudcake thickness. Although there are three unknowns, simple functions are reliable for moderate corrections. Experimental results are often presented in the form of a spine and ribs plot. There are other schemes using, for example, more detectors.

Degree of Compensation	Propagation logs rely on measuring the difference in properties of a wave at two receivers. The borehole influences this difference if the tool is tilted or if there is a cavity opposite one of the receivers. The effect can be compensated for by using two transmitters that radiate sequentially in opposite directions. In ideal conditions, the effect of a tilt or a cavity is exactly opposite for the two transmitters, so that an average gives the correct result. Borehole compensation is different from borehole correction.
DENB (in las file)	Short-spaced density readings. Also referred to as near-spaced density readings.
DENL (in las file)	Long-spaced density readings.
DEPT (in las file)	Depth in metre.
DEPO (in las file)	Density porosity readings.
Factoring	Some mathematical correction applied to make anomalous data acceptable.
Gamma ray (in las file)	The principle of an activation log, which is a log of elemental concentrations derived from the characteristic energy levels of gamma rays emitted by a nucleus that has been activated by neutron bombardment.
GRDE (in las file)	Gamma ray readings from density tool.
HQ/TNW	Specific diameter or size of diamond core drilling.

Size	Hole (outside) diameter, mm	Core (inside) diameter, mm
NQ	75.7	47.6
HQ	96	63.5

Las file	A las file is data readings as received from the geophysical probe, usually in text format.
Study area	Geographical area on which the work for this thesis was done. The area consists of nine farms in the Steenbokpan district.
Proximate data	The proximate analysis of coal was developed as a simple means of determining the distribution of products obtained when the coal sample is heated under specified conditions. Proximate analysis separates the products into four groups: (1) moisture, (2) volatile matter, consisting of gases and vapours driven off during pyrolysis, (3) fixed carbon, the non-volatile fraction of coal, and (4) ash, the inorganic residue remaining after combustion. Proximate analysis is the most often used analysis for characterizing coals in connection with their utilisation.
Samples	The coal formations display such a well-developed repetition of coal-mudstone assemblages that it can be divided into seven sedimentation cycles or coal zones. Smaller sub-cycles or samples are contained within these coal zones.
Vectar (Vertical Enhancement by Combination and Transformation of Associated Responses)	Method by which a digital filter is used to smear the short-spaced log to match the resolution of the long-spaced density (and also compensated) log.
Zones	The coal formations display such a well-developed repetition of coal-mudstone assemblages that it can be divided into seven sedimentation cycles or coal zones.

1 INTRODUCTION

The SAMREC Code (the Code), launched in March 2000, governs all forms of public disclosure relating to exploration results, Mineral Resources and Mineral Reserves by Mineral companies in South Africa. The SAMREC Code (2007) defines a 'Mineral resource' is a concentration or occurrence of material of economic interest in or on the earth's crust in such form, quality and quantity that there are reasonable and realistic prospect for eventual economic extraction. The location, quantity, grade, continuity and other geological characteristics of a Mineral resource are known, or estimated from specific geological evidence, sampling and knowledge interpreted from an appropriately constrained and portrayed geological model. Mineral Resources are subdivided, and must be so reported, in order of increasing confidence in respect of geoscientific evidence, into Inferred, Indicated or Measured categories. Portions of a deposit that do not have reasonable and realistic prospects for eventual economic extraction should not be classified as a Mineral resource.

The Code also provides for a two-way relationship between Mineral Resources and Mineral Reserves. This accounts for uncertainties associated with any of the modifying factors considered when converting Mineral Resources to Mineral Reserves which may result in there being a lower level of confidence in the Mineral Reserves than in the corresponding Mineral Resources. Allocation into the appropriate reserve or resource category must be made by a Competent Person. General concepts for reporting coal Resources and coal Reserves were established with the publication of the SAMREC Code, prepared by the South African Mineral Committee under the auspices of the SAIMM. The Code provides the framework and standards for public reporting for the Johannesburg Stock Exchange (JSE).

This section of the listing rules (Section 12) of the JSE, sets out the criteria for the listing of, and the additional disclosure requirements for, Mineral Companies, and in certain circumstances, substantial Mineral assets of non-Mineral Companies.

The Code has been adopted by the relevant National Reporting Organisations (NROs) including SAIMM and SAMREC member organisations and is incorporated in the JSE listing requirements.

In South Africa, the Code sets out a required minimum standard for the public reporting of exploration results, Mineral Resources and Mineral Reserves. References in the Code to public report or public reporting pertain to those reports detailing exploration results, Mineral Resources and Mineral Reserves and prepared as information for investors or potential investors and their advisers. The Code takes into account issues of a global nature while addressing certain circumstances unique to South Africa. The following principles govern the application of the Code:

- **Materiality:** A public report contains all the relevant information that investors and their professional advisors would reasonably require, and expect to find, for the purpose of making a reasoned and balanced judgement regarding the exploration results, Mineral Resources and Mineral Reserves being reported on.

- **Transparency:** The reader of a public report must be provided with sufficient information, the presentation of which is clear and unambiguous, to understand the report and not be misled.

- **Competency:** The public report is based on work that is the responsibility of suitably qualified and experienced persons who are subject to an enforceable professional code of ethics. Public reports dealing with Exploration Results, Mineral Resources and Mineral Reserves must use only the terms Proved or Probable Mineral Reserves, Measured Mineral Resource, Indicated and Inferred Mineral Resources and Exploration Results. Thus only Resources/Reserves whose presence was proven beyond a certain level of certainty are reported. Figure 1 indicates the relationships between the various categories of reporting of Resources and Reserves as used in the SAMREC Code (2009)

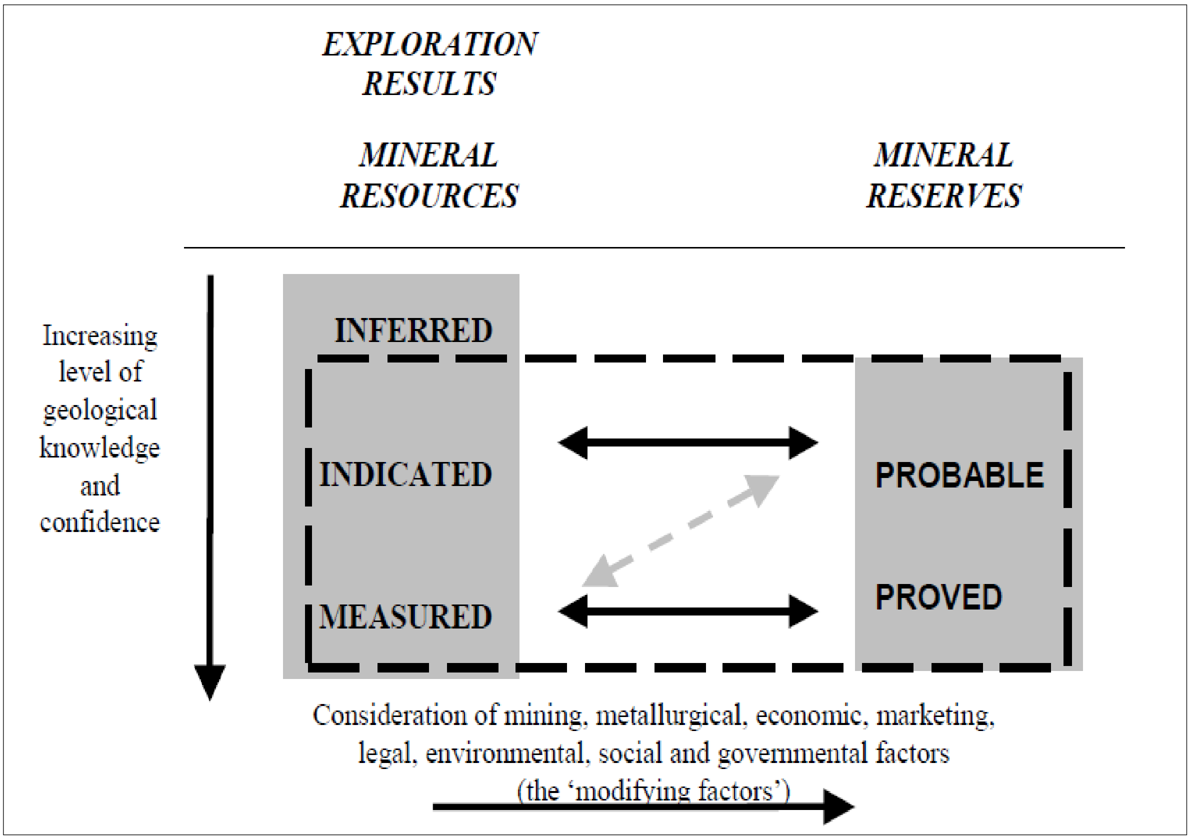

Figure 1 The relationships between the various categories of reporting of Resources and Reserves according to the SAMREC Code

The SAMREC Guidelines stipulate that:

- Evaluation techniques and key assumptions *must* be disclosed as per Clause 27, SAMREC code (2009);
- metallurgical recovery factors *must* be included in public reports, SAMREC code (2007); and
- that if any of the data is materially adjusted or modified for the purpose of making the estimate, SAMREC code, (2000), this fact *must* be clearly disclosed in the public report".

During the compilation of the SAMREC Code, it was soon apparent, SANS standard, (2004) that additional guidelines and parameters were required to standardise the reporting of coal Resources and coal Reserves for both Securities Exchange requirements and for the South African National Coal resource and Coal reserve Inventory (the National Coal Inventory). The standard was prepared in conjunction with the Code by the SAMREC Coal Commodity Specific Sub-committee. The mechanistic application of the SANS standard by Competent Persons has led to instances where Resources were downgraded, based on the standard recommended in the SANS standard and not on real, practical issues. There are dispute mechanisms available, but these are not preferred as an amicable solution should be arrived at before going into dispute. The SANS standard makes specific mention of two basic coal deposit types, which are representative of South African coal deposits, i.e.; multiple seam and thick interbedded seam deposit types (Figure 2),.

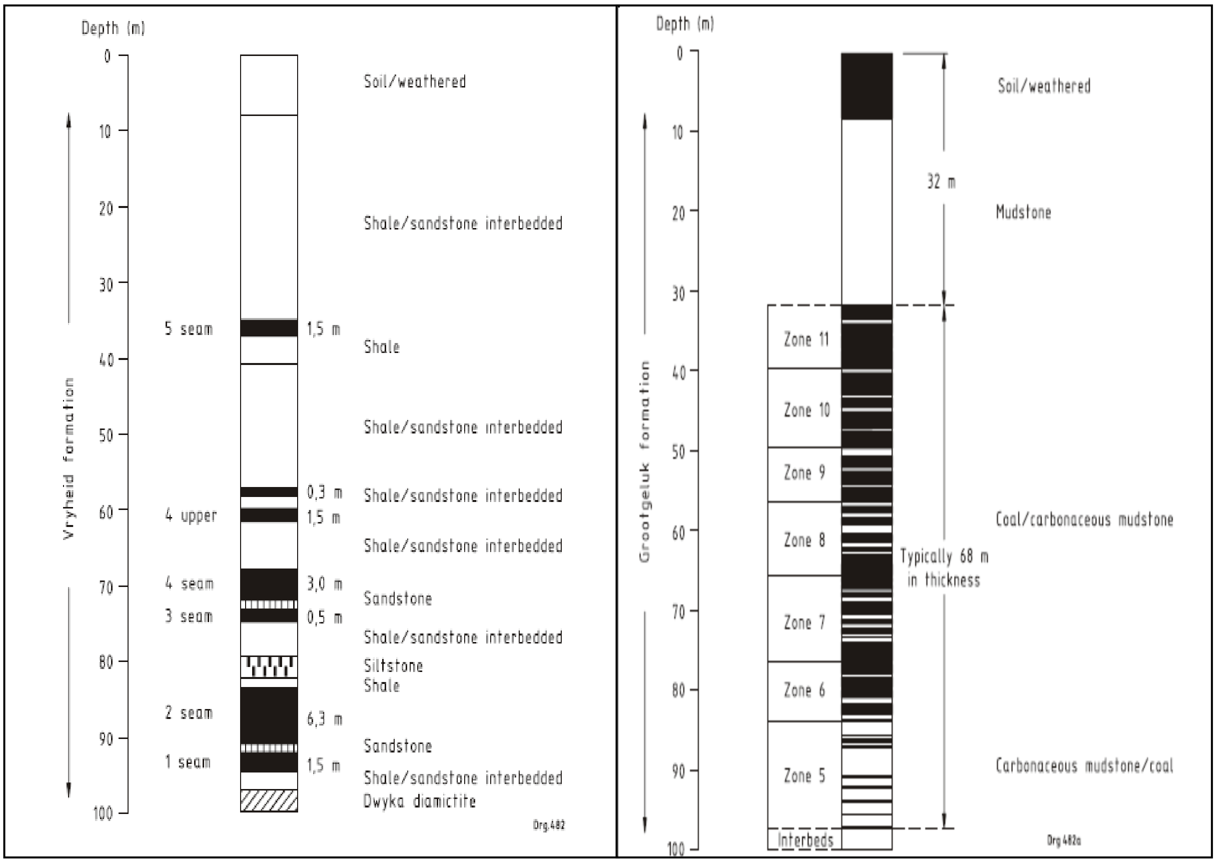

Figure 2 Multiple seam deposit type Coal resource (<50%ash) and thick interbedded seam deposit type on right, SANS (2004)

- Multiple seam deposit type coal (MSD) is characterised by a discrete number of coal seams (see Figure 2), typically between 0,5 m and 7,0 m in thickness, separated by inter-burden units whose thickness generally significantly exceeds the thickness of the individual coal seams (typically Witbank and Highveld coal types). The typical associated drilling densities, required in this deposit type, which is subject to the opinion of the Competent Person, is depicted in Figure 3.

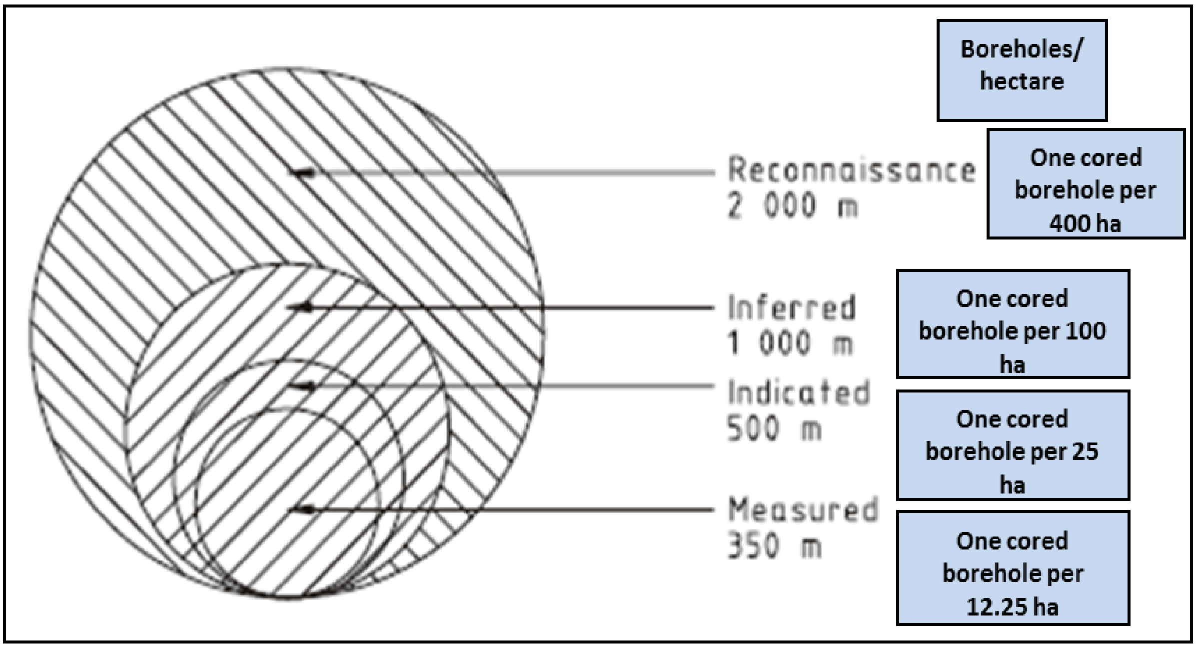

Figure 3 Drilling densities required for a multiple seam deposit

- Thick interbedded seam deposit type (TISD), characterized by a succession of multiple, thin interbedded coal and non-coal layers with a total thickness of typically between 40 m and 70 m (Figure 2) (typically encountered in the Ellisras Basin). The typical associated drilling density, subject to the expert opinion of the Competent Person is depicted in Figure 3 and Figure 4.

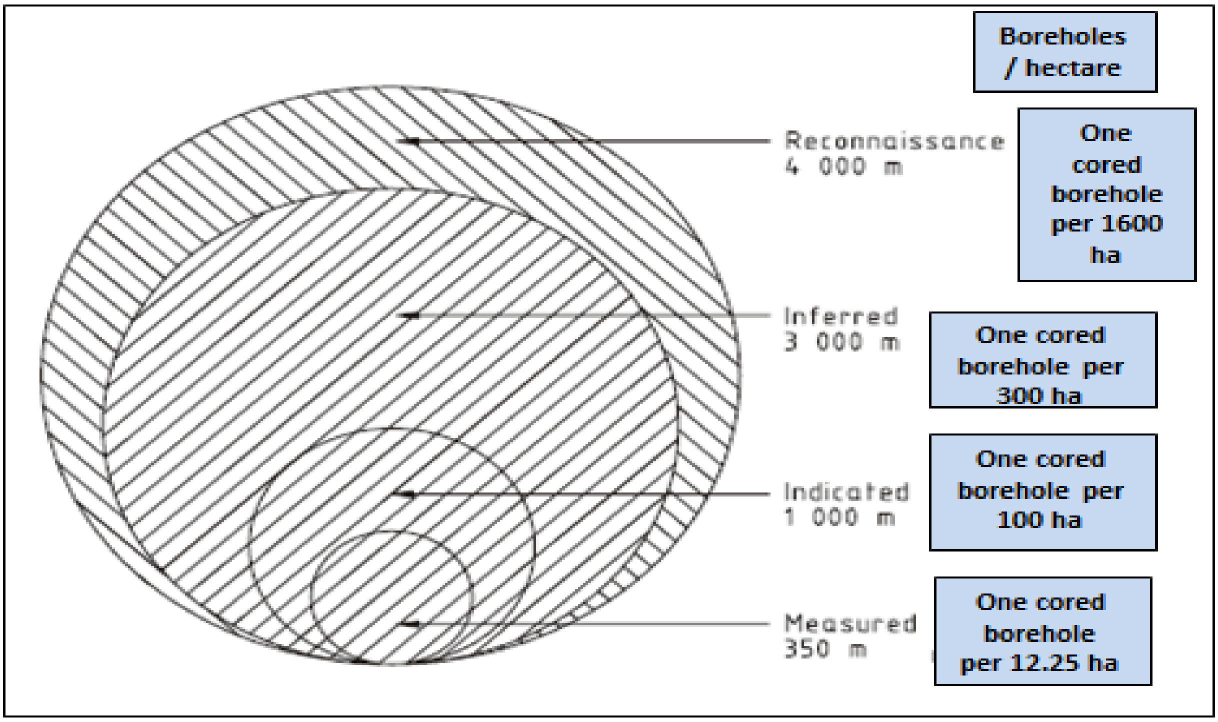

Figure 4 Drilling densities required for a thick interbedded seam deposit

One can note from Figure 4 that the Ellisras Basin deposits have twice the recommended distance between the boreholes for the Inferred Mineral Resource and Indicated Mineral Resource categories because the inherent thickness and lateral continuity of the coal seams in the area makes correlation possible. The exception is the 350 m distance between data points recommended for both deposit types in the measured Mineral resource categories. The reason this was done at the time the standard was written, was because insufficient enough data was available at the time on the Ellisras Basin which could shed light on the recommended drilling densities for measured Mineral resource purposes, Dingemans, D, (2012, personal comment).

During the course of the author's work, a due diligence study was carried out by external auditors on the status of resources necessary as feedstock for the planned Medupi power station. The auditors of that study made the following important conclusion regarding the status of the resources namely, that the resources, that were expected to be at a measured state, were classified as indicated based solely on the fact that the drilling density did not meet the 350 m or 8 boreholes per 100 hectare specified in the SANS standard. The distances mentioned in the SANS standard were not utilised as indicative but as prescriptive. Opinions gathered from other consulting companies confirmed that while indications in the SANS standard could be interpreted as prescriptive, they may be used as additional information by the Competent Person:

- The mechanistic application of the SANS standard by Competent Persons has led to disputes in the classification of resources at some mines;
- the cost of analysis of one borehole in the Ellisras Basin, based on determining the metallurgical and heating properties of the coal, is in the region of R1,5 million per borehole. This excludes costs for testing the coal for gasification suitability; and
- the graphical depiction, of the position of these eight boreholes, is not given in the SANS standard and is open to interpretation. There is general consensus that these eight boreholes must be evenly distributed. Some indication is given in Figure 5.

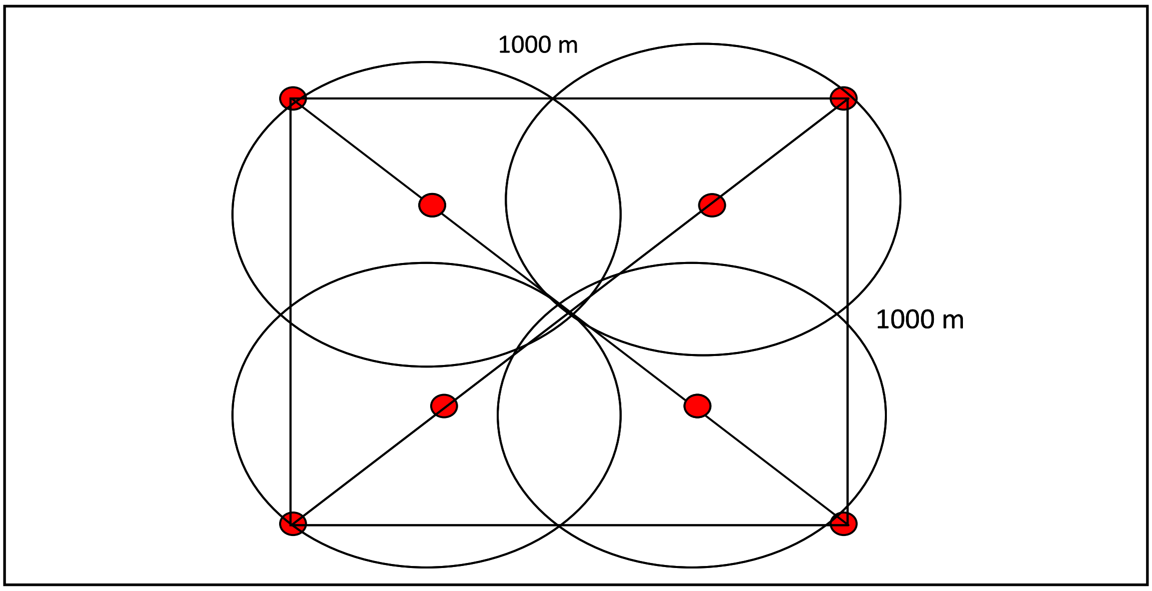

Figure 5 Distribution of boreholes to get to eight boreholes per 100 hectare

Borehole logging or well logging, commencing in 1928, makes use of an instrument to describe a specific physical feature of the intersected lithological units present in a drilled borehole. Logging may be done during or after the drilling process is completed. The logging procedure consists of lowering a logging tool, attached to a cable, and a measuring system into the borehole, and measuring one or several parameters while the probe is hoisted up the borehole at a pre-determined speed. The logging tool is designed to measure radioactivity, electrical or a variety of other properties of the surrounding rocks or fluid present in the borehole. In this thesis, the main emphasis is on the collection of density measurements. The data is captured in real time through the wire line cable and supplied to the client in paper or electronic format. In the 1960’s, it was discovered that coal can be delineated accurately by high resolution density, neutron and gamma ray logs.

“Slimline logging in coal has been in use since 1960 and the use thereof has spread over the whole world. It is the industry standard”, Firth (1999). The method for correlating well logs was patented in America on the 13 December 2007 - US 7,295,926 B2. The inventor was Benjamin Peter Jeffryes, of Riston (UK) and the assignee, Schlumberger Technology Corporation, Ridgefield, CT (US), US Patent (2007).

All boreholes in this study were geophysically logged and the various coal seams correlated over the entire Study area. When the need arose to have the relative density information of the various coal seams independently verified, an innovative method was devised to determine the relative densities of the various coal samples. The geophysically derived relative density values were compared to the analytically determined relative densities and a correlation of more than 95% was proved. This method was so successful that it was used as basis for checking for weighing errors made by the technical assistants during the course of their work.

It was also found that a specifically derived relative density value, the Vectar processed density, was the best when compared with the analytically determined relative densities. Using the geophysical data to “fingerprint” each sample became standard practice at this time, eventually resulting in a method whereby the Vectar processed density graphs of the various coal samples could be correlated and compared over the entire Study area.

The aim of this thesis includes proving that other drilling data (a combination of percussion drilling and geophysical logging), distinct from cored drilling data alone, can provide data points for proving the lateral continuity of the ore body, both in terms of structure and quality, and may be used by a Competent Person to estimate the tonnage, grade and yield with a higher level of confidence.

2 THE AIM OF THIS THESIS

The aim of this thesis includes proving that, other drilling data (a combination of percussion drilling and geophysical logging), distinct from cored drilling data alone, can provide data points for proving the lateral continuity of the ore body, both in terms of structure and quality, that may be used by a Competent Person to estimate the tonnage, grade and yield of the coal deposit with a higher level of confidence.

The SANS working group formulated the SANS10320 standard that deals specifically with coal resource classification. The SANS 10320 standard states that, for the purpose of classifying thick, inter-bedded seam deposit Resources, such as those found in the Ellisras Basin, in the Mineral resource category, there has to be quality data points at a recommended spacing of 350 m apart, which is similar in practice to the other coal basins in South Africa.

All the distance requirements, for classifying the resources in the Inferred or Indicated Mineral Resource category, were double for the Ellisras Basin than those of other areas in South Africa. The latter would usually be classified as multiple seam deposits (such as found in the Witbank area).

When officially reporting resources, it was found that some Competent Persons viewed the recommended spacing requirement of 350 m, not as a guideline, but as a ”law”. The primary aim of this thesis is determining whether the devised method of reworking the geophysical data (GDCDD–method) could give a Competent Person enough confidence in the validity of specific data, to influence their opinion; resulting in the possible reclassification of the resources to a higher category. For instance, from Inferred to the Indicated category or from Indicated to the Measured Mineral Resource category.

During the course of the project the most applicable geophysical density measurement was identified which correlated the best with the relative densities as measured with the Archimedes' method. These density measurements as extremely important as they are used in the modelling process to determine the in-situ tonnes.

The method devised was used to prove that data from percussion drilling could also serve as a dependable point of observation to classify resources.

- The first step in this process was determining how accurately the geophysical data predicted the relative density of the coal seams on the Study area;
- a method (GDCDD-method) was then devised using the geophysical log to ‘fingerprint’ the various coal seams and specific parts (samples) of the coal seams;
- the devised method was used to illustrate the correlation between the samples over a widely spread geographic area and was used to demonstrate that the ‘fingerprint’ for the percussion boreholes is identical to the cored boreholes;
- the devised method was used to illustrate the correlation between the zones over a wide area and to demonstrate that the ‘fingerprint’ for the percussion boreholes is identical to the cored boreholes; and
- the suitability of the proposed method on the classification of the coal resources, was discussed in table format.

3 LITERATURE STUDY

The literature study was done upon four aspects of the study:

- The requirements of the SAMREC code;
- applicability and accuracy of geophysical density logging of coal;
- distance based drilling patterns; and
- the responsibilities of the Competent Person.

3.1 SAMREC Code

Structural changes in the mining sector during the past decade, mainly as a consequence of globalisation, have had a profound impact on the financing of new mining and exploration projects, Frick (2002). The present structure relies heavily on obtaining financing on capital markets in the developed world. Most of the capital used for direct foreign investment in the mining sector in Africa is raised on a small number of stock exchanges in Europe, North America, Australia and South Africa. Over time, all these institutions developed codes of corporate governance requiring transparent financial public disclosure.

By the early 1990's, two international groups, the Council of Mining and Metallurgical Institutions (CMMI) and United Nations Economic Commission for Europe (UN-ECE),were working independently towards the development of international definitions for Mineral resource and Mineral Reserve classification. A sub-committee of the CMMI, Committee for Mineral Reserves International Reporting Standards (CRIRSCO) was made up of representatives from Australia, the Canadian Institute of Mining, Metallurgy (CIM), the South African Institute of Mining and Metallurgy (SAIMM), the Institute of Materials, Minerals, and Mining (IMMM), and the Society for Mining, Metallurgy, and Exploration (SME). These groups met for the first time in 1994 during the 15th CMMI Congress in Sun City, South Africa.

This CRIRSCO sub-committee also stated that since 1992, however, the UN-ECE had been developing its own set of definitions (the UNFC). The UNFC enabled the comparison of different national Mineral resource and Mineral Reserve classification systems, particularly for those countries in transition to market economies. These two groups soon realised that their efforts would be more fruitful if the results were merged. In 1998 and 1999, the UN-ECE and CRIRSCO met in Geneva where the UN-ECE agreed to adopt, with minor modifications, the CRIRSCO definitions into the UNFC for Mineral Resources and Mineral Reserves that were common to both systems. The UN-ECE suggested that CRIRSCO definitions be reduced into shorter sentences to facilitate translation and to give the definitions true international status. .

The UN-ECE has published and approved the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources (UNFC-2009) in 2009 in cooperation with CRIRSCO and the Society for Petroleum Engineers (SPE), the World Petroleum Council (WPC), the American Association of Petroleum Geologists (AAPG) and the Society of Petroleum Evaluation Engineers (SPEE) United Nations, (2010). This code represents an umbrella classification of a universal character which reconciles, unifies and expands, at a high-level, the classification definitions of the CRIRSCO template for Minerals and coal and the Petroleum Resource Management System (PRMS) for oil and gas. The UNFC-2009 framework remains outside the immediate scope of this study, which is linked to the South African coal industry and therefore to the national South African code".

The coordination of Mineral resource and Mineral Reserve definitions by UN-ECE and CRIRSCO gave consistency in the accompanying Guidelines to the definitions. The effect of this was that the reporting codes of individual countries were then revised along similar lines. The similarity of the reporting codes of CRIRSCO member countries has reached a point where there is now development of:

- An international definition for the Competent Person;
- a list of principles which would provide minimum requirements for professional institutions overseeing the Competent Person(s); and
- International Reporting Code and Guidelines.

To this end, the following draft documents have been prepared by CRIRSCO for submission to its member countries for review:

- International Guidelines for Reporting Mineral Resources and Mineral Reserves;
- International Definition of the Competent Person; and
- International Rules of Conduct for the Competent Person.

The SAMREC Code, launched in March 2000, governs all forms of public disclosure relating to exploration results, Mineral Resources and Mineral Reserves by mineral companies in South Africa. According to Mullins (2008), "the JSE has also seen huge growth in market capitalisation and one-third of the JSE is still resource dominated, which is comparable to other stock exchanges, such as those in Australia and Canada. The SAMREC and SAMVAL Codes must be viewed in the context of the industry which they were designed to support. Confidence in our resources, reserves and the valuation of these, underpin this trillion dollar industry."

Mineral resource confidence classification should take into account practical considerations such as drilling, sampling and assay integrity, borehole spacing, geological control and continuity, grade continuity, estimation method and block size, potential mining method and reporting period, Snowden (2001).

Lundell (2006), states that during the late 1990's, unfortunate developments within the mining industry made clear the need to develop uniform Canadian standards to govern how issuers disclose scientific and technical information about mineral projects to the public. The response was National Instrument 43-101, a rule issued by the Canadian Securities Administrators which aimed to restore public confidence in mining related stocks by enhancing the accuracy and integrity of public disclosure in the mining sector. The Instrument governs the public disclosure of scientific and technical information by publicly traded mining companies, covers oral statements as well as written documents and websites, and requires that all disclosure be based on advice by Qualified Person who, in some cases, must be independent of the mining company and the property. A Qualified Person as defined in the Instrument is an individual who:

- Is an engineer or geoscientist with at least five years of experience in mineral exploration, mine development or operation or mineral project assessment, or any combination of these;
- has experience relevant to the subject matter of the mineral project and the technical report; and
- has been a member in good standing of a recognised professional association.

Vaughan and Felderhof (2002), mentioned that the choice of the appropriate category of mineral reserve is determined primarily by the relevant level of confidence of the mineral resource.

Figure 1 (on p. 21) shows the direct relationship between Indicated Mineral Resources and Probable Mineral Reserves and between Measured Mineral Resources and Proved Mineral Reserves used in the SAMREC code. The code also provides for a two-way relationship between Measured Mineral Resources and Probable Mineral Reserves. This accounts for any of the uncertainties associated with any of the modifying factors considered when converting Mineral Resources to Mineral Reserves which may result in there being a lower level of confidence in the Mineral Reserves than in the corresponding Mineral Resources. An Indicated Mineral Resource could never be converted to a Proved Mineral Reserve. Allocation into the appropriate category must be made by a Competent Person.

Gluskoter (2000), mentions that the National Coal resource Assessment of the United States of America uses the following categories when classifying coal resources:

- Measured Mineral Resource: coal within a radius of 400 m of a control point where the thickness of the coal has been measured;
- Indicated Resources: coal within a radius of 400 m to 1 200 m of a control point;
- Inferred Resources: within a radius of 1 200 m to 5 km of a control point; and
- Hypothetical Resources: coal beyond a radius of 5 km from a control point.

The JORC code (2004) mentions the following:

- An Inferred Mineral Resource is that part of a mineral resource for which tonnage, grade and mineral content can be estimated with a low level of confidence;
- Indicated Mineral Resource is that part of a mineral resource for which tonnage, densities, shape, physical characteristics, grade and mineral content can be estimated with a reasonable level of confidence; and
- Measured Mineral Resource is that part of a mineral resource for which tonnage, densities, shape, physical characteristics, grade and mineral content can be estimated with a high level of confidence.

What is important to note is that the JORC Code does not make any mention of actual distances from control points.

3.2 Applicability and accuracy of geophysical density logging of coal

Geophysical logging has long been an invaluable aid to correlating lithologies world-wide and provide economical information Wood et al (1983). Ryder (2002) states that the use of geophysical logging as a tool in sequence stratigraphy is “seriously under-developed”. The use of gamma rays (to determine specific lithological boundaries), spontaneous potential logs (which measures changes in electrical potential between an electrode on the sonde and one at the surface) and resistivity logs (which measures the resistivity of fluids in the surrounding rock to an applied electrical current) is commonplace Ryder (2002). The use of density measurements as a means of correlating stratigraphy is not mentioned anywhere in press. An internet search and direct approaches to various organizations and individuals has confirmed this state of affairs.

According to Binzhong and Esterle (2008), coal responds well to most geophysical logging methods because its properties contrast well with those of other lithological units commonly intersected in coal-bearing sequences. Coal has in general a low density, a lower seismic velocity, lower magnetic susceptibility, a higher electrical resistivity, and lower radioactivity compared to surrounding rocks. Density logs are routinely and easily acquired during the exploration process, but they are influenced inter alia by the decay of the source, mud caking, borehole cavities, and the presence of water, logging speed, and good pre-shift calibration.

The density tool logging technique is based on subjecting the surrounding formation to a bombardment of medium energy (0,2-2,0MeV) collimated gamma rays and measurement of their attenuation between the energy source and the energy detector, Ryder (2002). The attenuation (or Compton scattering) is a function of the number of electrons that the formation contains – its electron density (electrons/cm3) – which is in turn very closely related to its common density; the gamma log does not record the electron density, it measures the attenuation, resulting from the electron density, Ryder (2002).

Binzhong and Esterle (2008) also described how density logs were derived from the interaction of gamma rays from a gamma ray source (usually Caesium (Cs) 137) through Compton scattering within the formation rock surrounding the borehole. A density log is a record of the electron density (which is the number of electrons per cm^3) of rocks adjacent to a drill hole. The log measures the induced gamma rays emitted by the rocks after bombarding them with a gamma ray source encased in a probe and lowered into the drill hole. The more dense the rocks, the more gamma rays they absorb. Ryder (2002) discussed how accurate densities could be measured with geophysics (Figure 6).

Compound	Formula	Actual density ρ_b, g/cm³	Tool density based on electron density (ρe), g/cm³	*Density given on log g/cm³
Quartz	SiO_2	2.654	2.650	2.648
Calcite	$CaCO_3$	2.710	2.708	2.710
Dolomite	$CaCO_3MgCO_3$	2.850	2.863	2.850
Halite	NaCl	2.165	2.074	2.032
Gypsum	$CaSO_4 2H_2O$	2.320	2.372	2.351
Anhydrite	$CaSO_4$	2.960	2.957	2.977
Sylvite	KCl	1.984	1.916	1.863
Coal bituminous		1.200	1.272	1.173
		1.500	1.590	1.514
Coal anthracite		1.400	1.442	1.355
		1.800	1.852	1.796

Figure 6 Statistics for coal density measurement by various means illustrating that accurate densities can be measured with geophysics. *Density = induced density, Ryder (2002).

One can deduce from the above data that the geophysical data corresponds well to the actual relative density values. The geophysical density data, on which this thesis is based, was obtained by use of a dual density sonde supplied by an internationally known company, Weatherford. This tool has a diameter of 76 mm (3 inches) and collects the following information:

- short and long-spaced density;
- compensated density;
- degree of compensation;
- calliper and borehole volume; and
- gamma ray - naturally occurring gamma radiation which originates from the radioactive isotope of potassium (K_40), and from isotopes in the decay chains of uranium 238 and thorium 232. Among clastic rocks, these tend to have low abundance in sandstones and coals, but generally a high abundance of in clay Minerals.

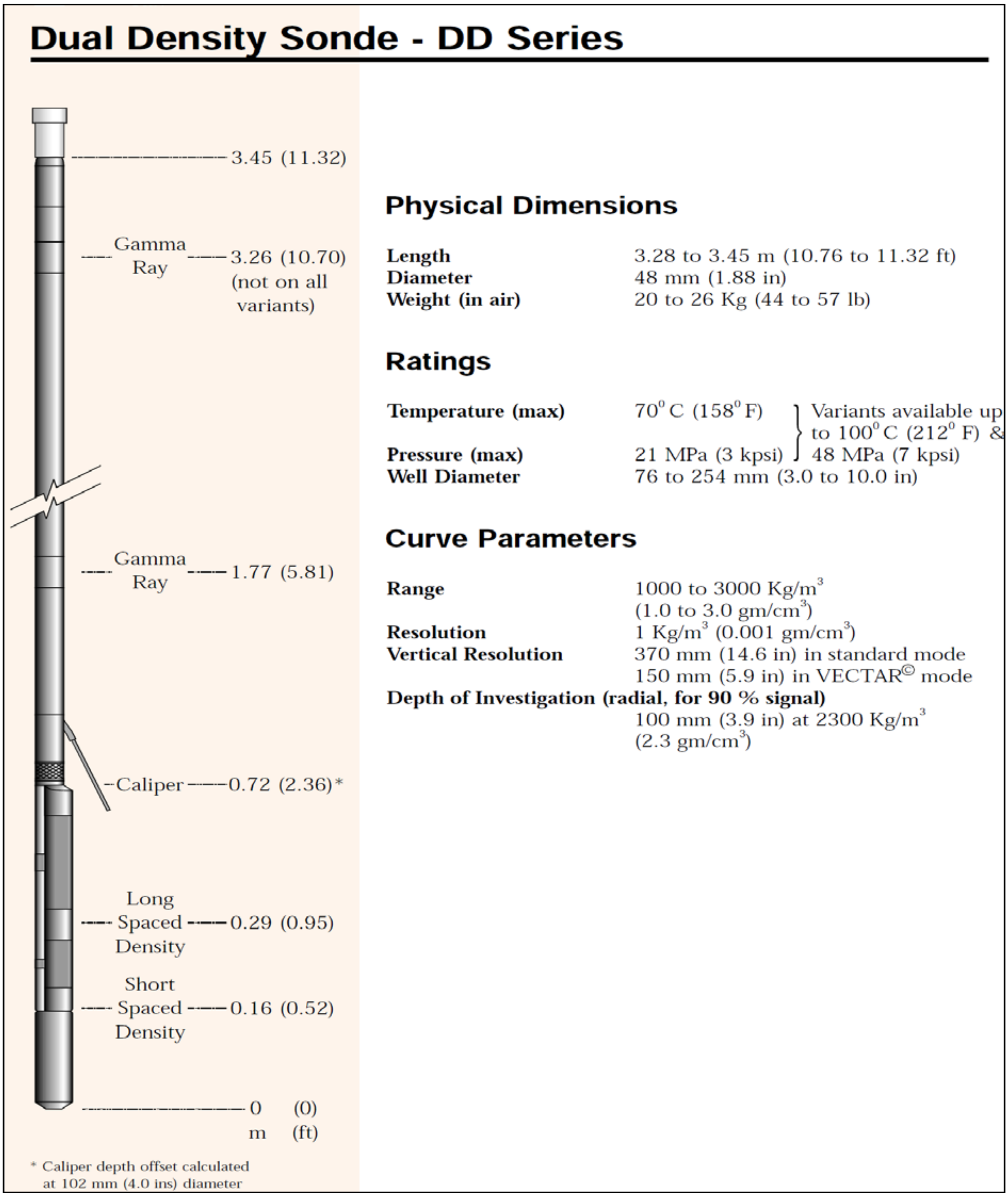

Figure 7 Dual density sonde (from Weatherford promotional material) showing various operating parameters and physical measurements

This sonde is a dual detector density tool in which the near and far measurements of density are characterised and calibrated independently, and then combined in model-based algorithms which correct for borehole size, fluid density variations and mudcake effects. This results in a compensated density field log which can be further corrected using Vectar processing of the compensated density log. This produces a log with the spatial resolution of a short-spaced log.

In the coal mining industry, these tools are used for:

- Coal identification;
- coal quality;
- porosity/Lithology;
- enhanced resolution logging; and
- gas detection.

3.2.1 Vectar Processing

Firth (1999), mentions that high resolution devices suffer one major drawback: borehole effects become more pronounced as vertical resolution increases. The result is that rough boreholes will adversely affect results, and thus detectors with longer spacing's (and hence lower vertical resolution, but reduced borehole effects are normally preferred.

There is a way, however, to partially circumvent this dilemma. From any tool that has at least two measurements, it is possible to extract the high resolution log and impose it on the poorer resolution (generally compensated) log. This is Vectar (ADEN) processing. It's most notable application is in density logging where it produces the high resolution compensated curve. The key to Vectar processing is in the digital filter used to smear the short -spacing log to match the resolution of the long (and the compensated) log. Subtracting the unfiltered short spaced log from the smeared original, leaves bed boundary information while eliminating stick-offs due to borehole effects. Adding the boundary information to the compensated curve (weighted by a function of the degree of compensation) gives an unconditional improvement to the resolution of the compensated log. To get the best results from density logs, the good vertical resolution of the short-spaced log has to be combined with the good quantitative measurement of the compensated log. This is done by the mechanism known as Vectar processing.

According to Samworth (2010), Vectar processing can be considered in two ways:

- Imposition of the short-spacing log resolution upon the compensated, or long spaced log; or
- continuous dynamic calibration of the short-spacing log by the compensated or long spaced log.

Vectar processing, which uses compensated density as a base, produces a log that is preferable to using either the short spaced or long spaced log.

An example of the effect of this is shown in Figure 8

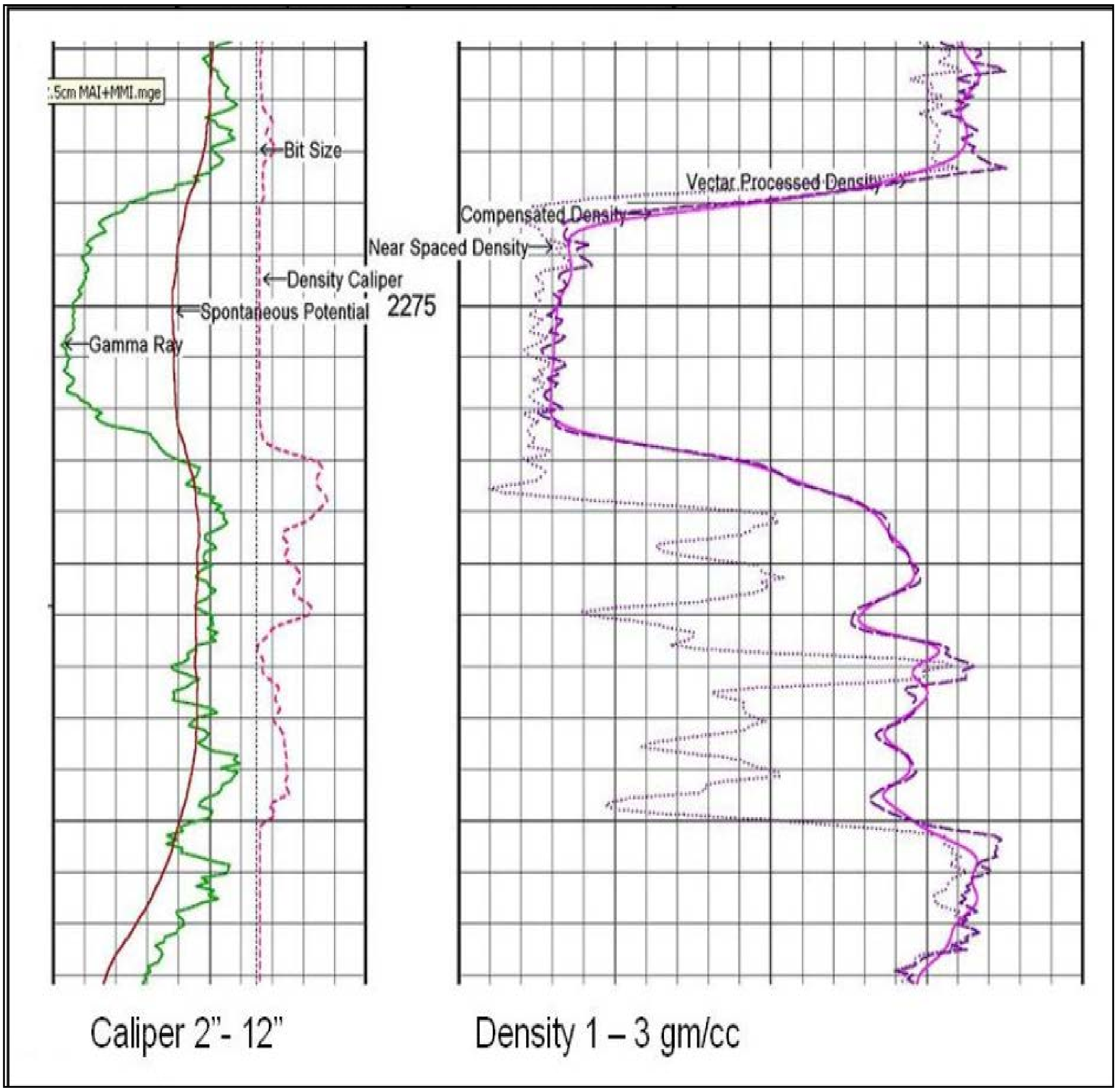

Figure 8 Example of a geophysical density log. The graph on left is natural gamma and calliper log and the one on the right is the various density logs

In Figure 8 the following can be observed when comparing the Vectar log with the near-spaced density log and compensated density log:

- The Vectar log overlays the compensated log in value; and
- the effects of the cavities on the near-spaced log are suppressed.

3.3 Distance only based drilling patterns

The distance between the data points can be related to the sample, drill-hole distance spacing and/or to the variography range calculated by means of geostatistics (Figure 9). One of the disadvantages of this method is that the resources are classified in a range of concentric or rectangular circles for which the area needs to be calculated. Generating these shapes depends on the particular modelling or drafting package. Minex calculates rectangles (as in Figure 10) and ArcGIS, circles as in Figure 11.

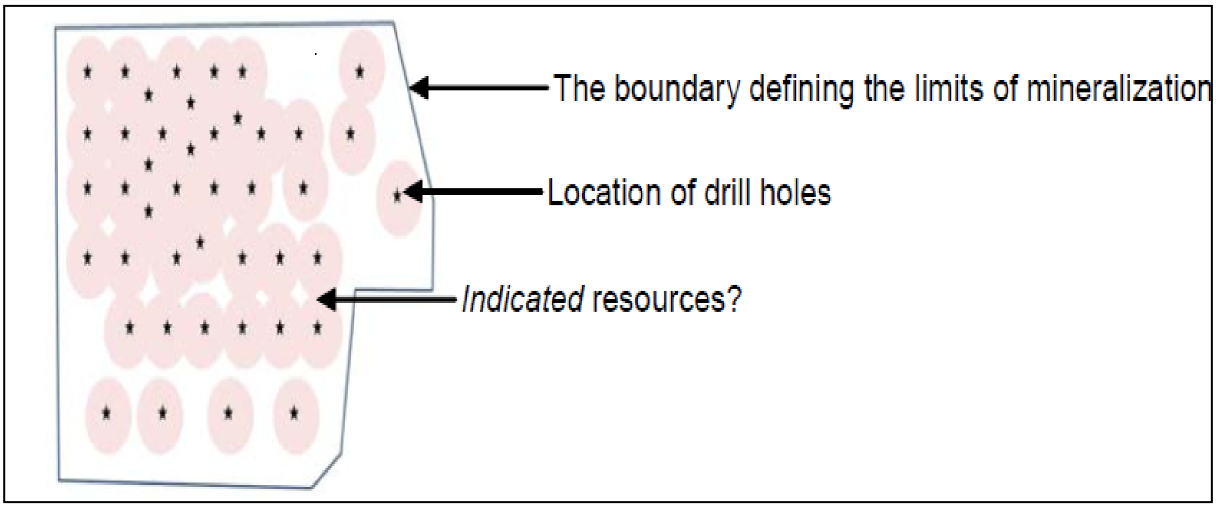

Figure 9 Map illustrating a resource classification scheme using only distance criteria. The solid stars represent the location of drill holes. The filled circles represent the area covered by the search parameters surrounding a hole. The filled circles may represent the portion of a deposit, potentially classified as Indicated Resources, Pincock Perspectives (2009)

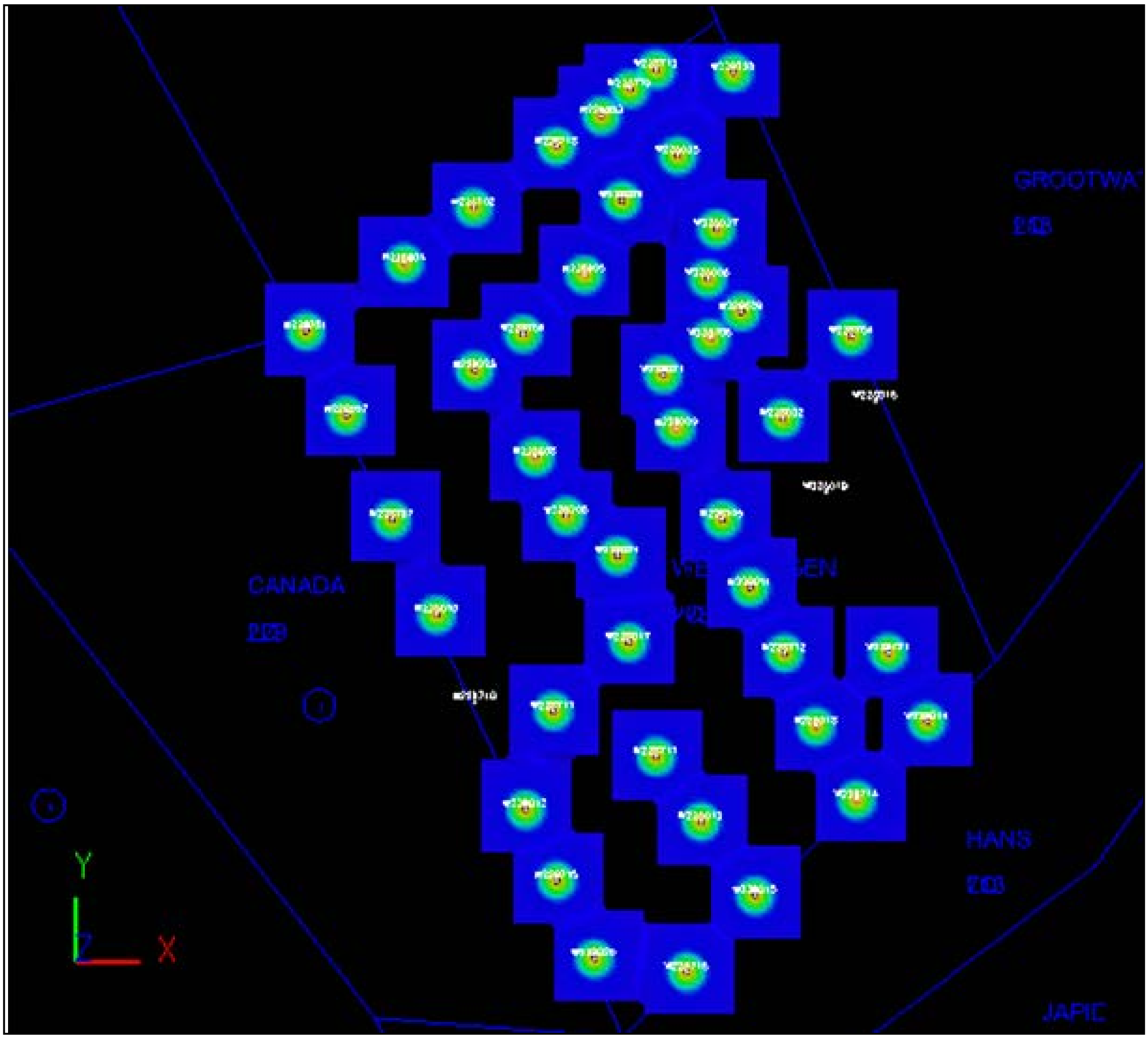

Figure 10 Rectangles drawn around data points (boreholes) as modelled in the geological modelling package - Minex

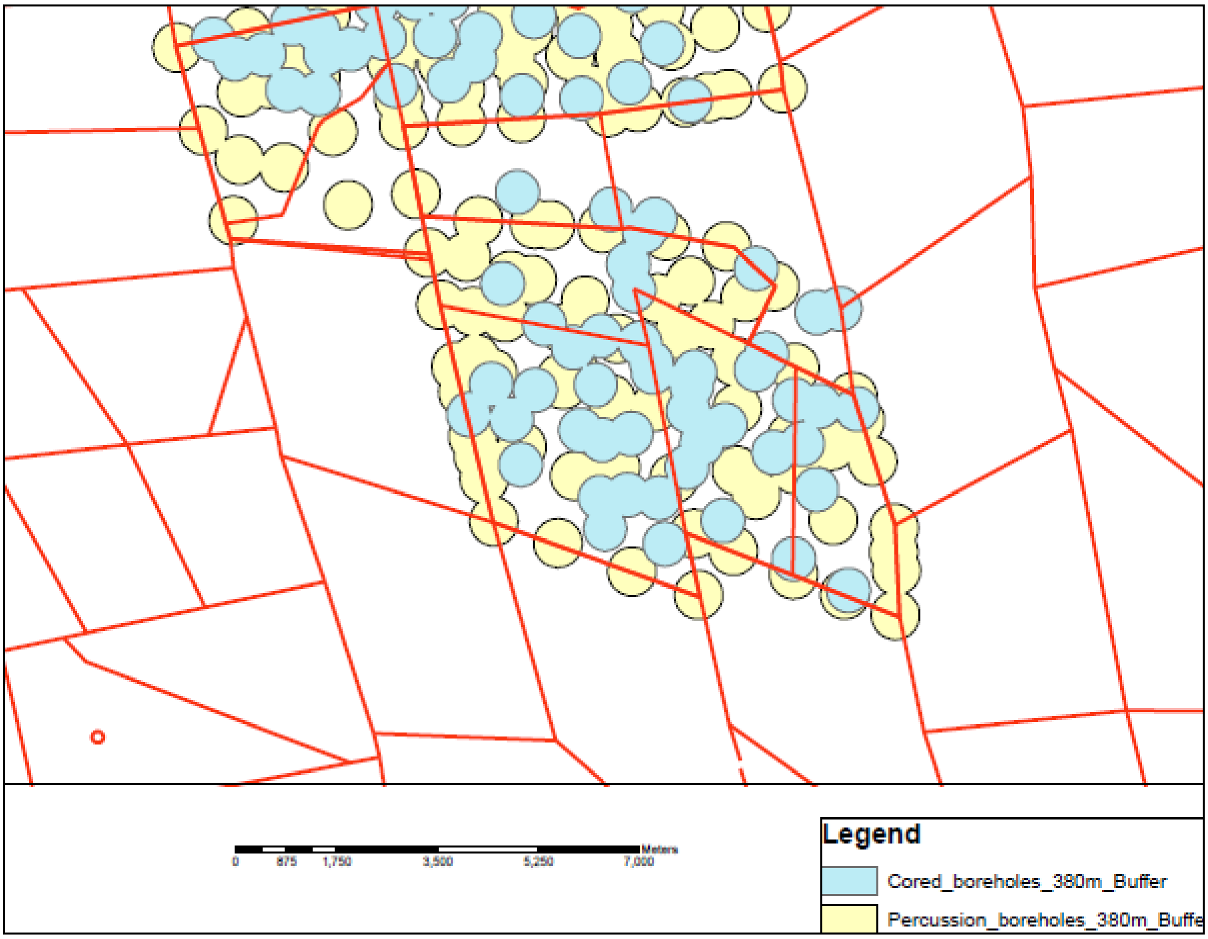

Figure 11 Circles drawn around data points (boreholes) at the study area, with ArcGIS, an ESRI product

3.3.1 Resource classification based on drillhole density

The basis for classifying the resources is based on how many boreholes occur in a specific area, and the presumption is that the denser the pattern, the more reliable the information, (as in Figure 12).

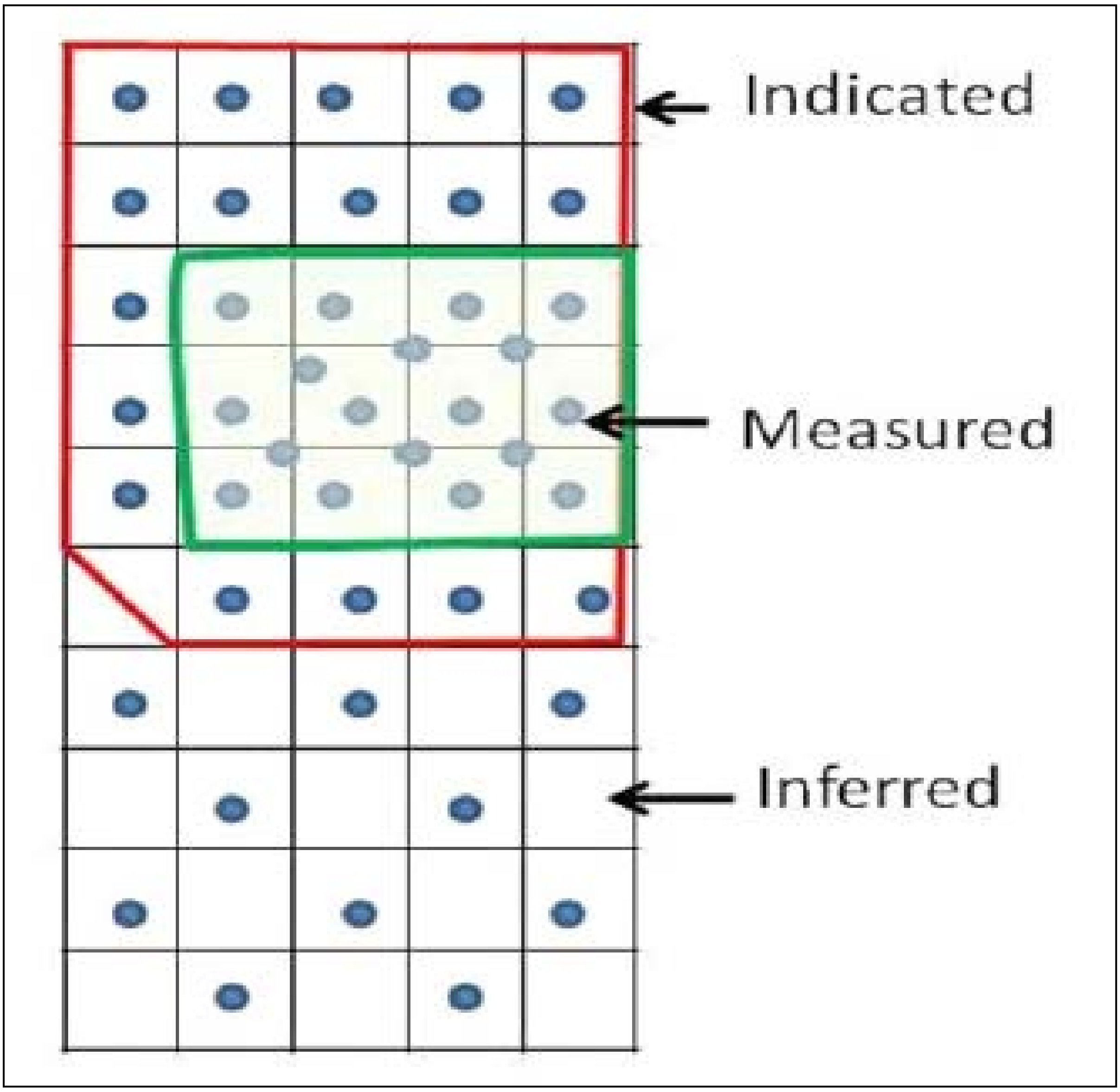

Figure 12 Resource classification based on drilling density, Pincock Perspectives (2009)

Figure 12 illustrates the common method for classifying resources in the Ellisras Basin.

3.4 Rules of conduct for a Competent Person

When preparing reports, Competent Persons need to be confident they can face their peers and demonstrate competence in the commodity, type of deposit, and situation under consideration. Where doubt exists, they should seek advice from appropriately experienced colleagues or decline to act as a Competent Person in a particular situation. There are no specific rules for the resolution of disputes between a company and a consultant, between a company and another company, or between a company, individual or stock exchange. The parties can go to court, or seek advice from consultants /experts, or the matter may go to arbitration with some professional body (like the South African Council for Natural Scientific Professions (SACNASP)), or referred to a panel of experts - as in the case of public reports published by the JSE. Any person (or company) being under suspicion of misconduct, negligence or involved in a dispute should have, and has, the right to defend themselves with the means considered most appropriate, Camisani (2010, personal comment). According to Felderhof and Vaughn (2002), resources and reserves public reporting regulations are becoming more stringent in many mining countries, requiring the particular expertise and experience of professional resources and reserves auditors.

The Code recognises that estimation of Mineral Resources and Mineral Reserves:

- Is a team effort compiled under the direction of a Competent Person;
- each Competent Person should accept responsibility for his or her own contribution where, there is a clear division of responsibilities within a team;
- the Competent Person is responsible for the report as a whole report; and
- the Competent Person should ensure that the work of the other contributors is acceptable.

François-Bongarçon (1998) stated that “The most striking fact for a consultant doing regular detailed due-diligence studies are how differently people, companies and financing institutions react to having their work, or the object of their interest, audited”. He also stated that there is a trend towards the rule of thumb that reserves be known on an annual basis within ± 15 relative percent at 90 percent confidence. This would mean that, on average, for one year in 20, the tonnage, grade or contained metal will be less than 85 percent of the estimate, which could be considered a reasonable business risk.

The orebody is the only real asset in a mining project and the only one that will generate revenue. If it should be misrepresented, it would be a major concern to bankers, Benning (2000). To gain comfort, potential lenders will want to see that extensive exploration programmes have been undertaken and that the results vetted by appropriate independent parties, and finally, that they have been audited by credible consulting engineers.

There are several ways in which risk, in respect of confidence, can be quantified and methods such as geostatistics have been exhaustively described by many authors in a great many articles. One of the newer techniques is conditional simulation, a method which allows one to evaluate practically any variable that can impact on a reserve. Some forms of risk are impossible to quantify, such as geological interpretation and the competence of the team doing the field work.

3.5 Comment on the literature study

An internet search, as well as email contact with universities and geophysical organisations, revealed no information on the subject of using and applying relative density measurements for ‘fingerprinting’ coal seams. The use of geophysics for density measurement is proven technology and very accurate. The classification of coal resources and the data on which this is based on, is subject to the scrutiny of a Competent Person and his/her professional opinion as regards to the quality of data on which the assumptions are based.

4 THE STUDY AREA

The Study area is situated in the southwestern part of the Limpopo Province of the Republic of South Africa (Figure 13) and is geologically located in the Ellisras Basin (cf Waterberg Coalfield). The exploration project was based on collaboration between two large role players in the South African coal mining industry, namely, Sasol and Exxaro. They collaborated for the purpose of identifying whether the coals in the Ellisras Basin was suitable for gasification purposes in the Sasol process, and that sufficient reserves existed on the farms on which the two companies have coal exploration rights. The Study area is situated within the boundaries of the Lephalale Magisterial District, in close proximity to the village of Steenbokpan. The Permo-Carboniferous Ellisras Basin, forming part of the Karoo Supergroup, and effectively thus, the Ellisras Basin, extends approximately 90 km east-west and approximately 40 km north-south near the northwestern border of the South Africa, and also extends into Botswana, where it passes into the much larger Kalahari (Karoo) Basin.

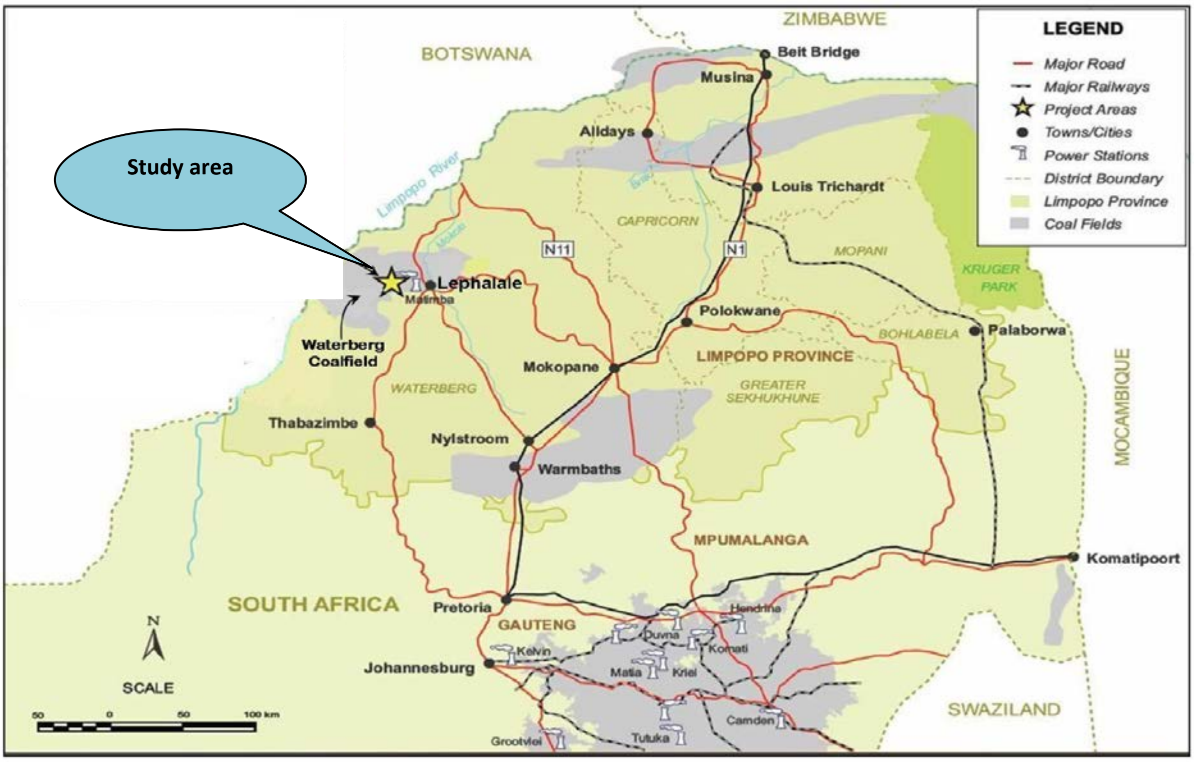

Figure 13 Location of the Study area after Sambo (2008)

The Study area (Figure 14) consists of nine farms and extends roughly 20 km from north to south and 10 km east to west (20 000 hectares).

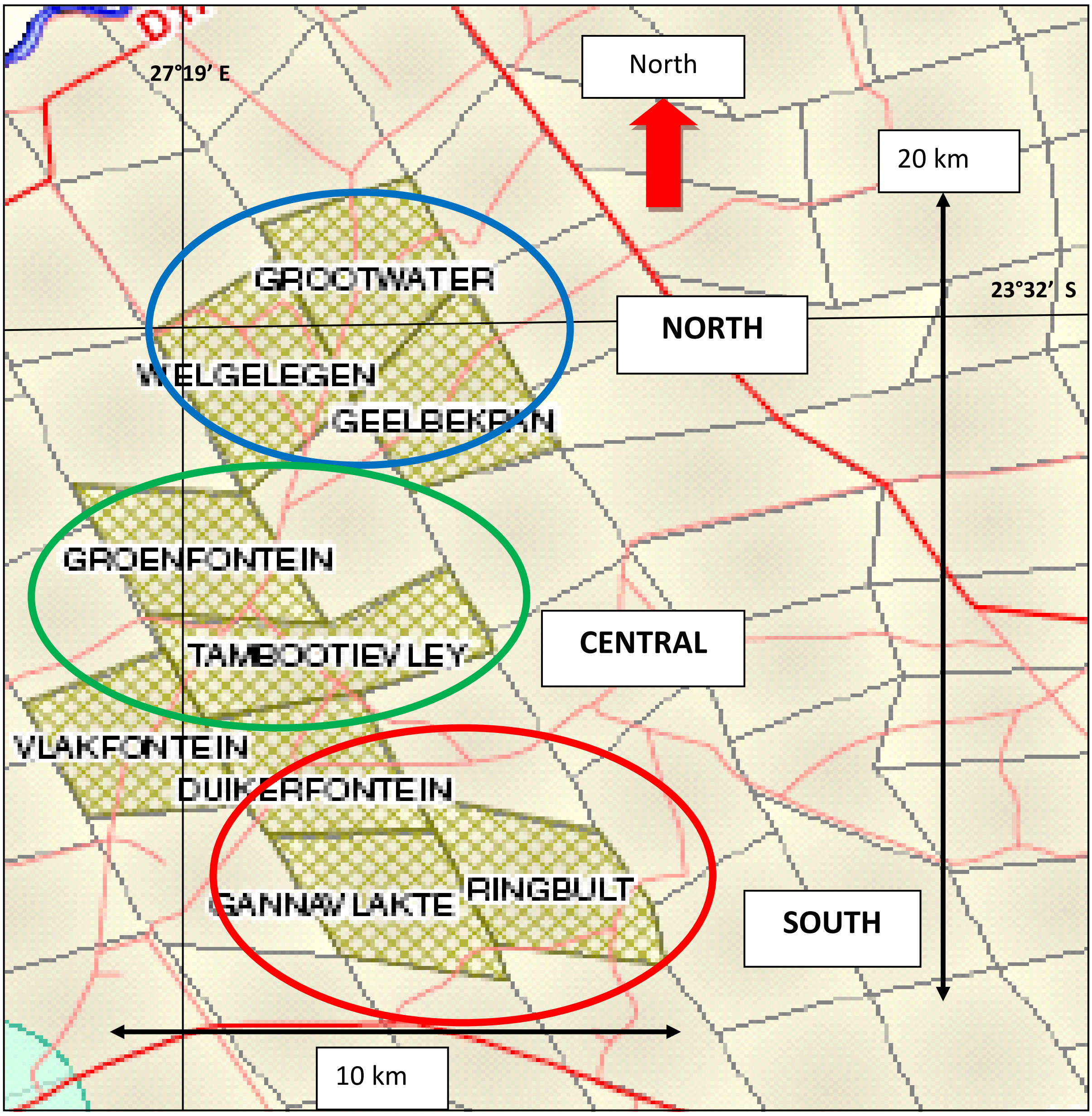

Figure 14 Location of the nine farms and geographic areas in the Study area

4.1 Regional structural setting

The Ellisras Basin forms a small part of the Kalahari Basin, which is a widespread basin occurring in South Africa, Botswana and Namibia (Figure 15).

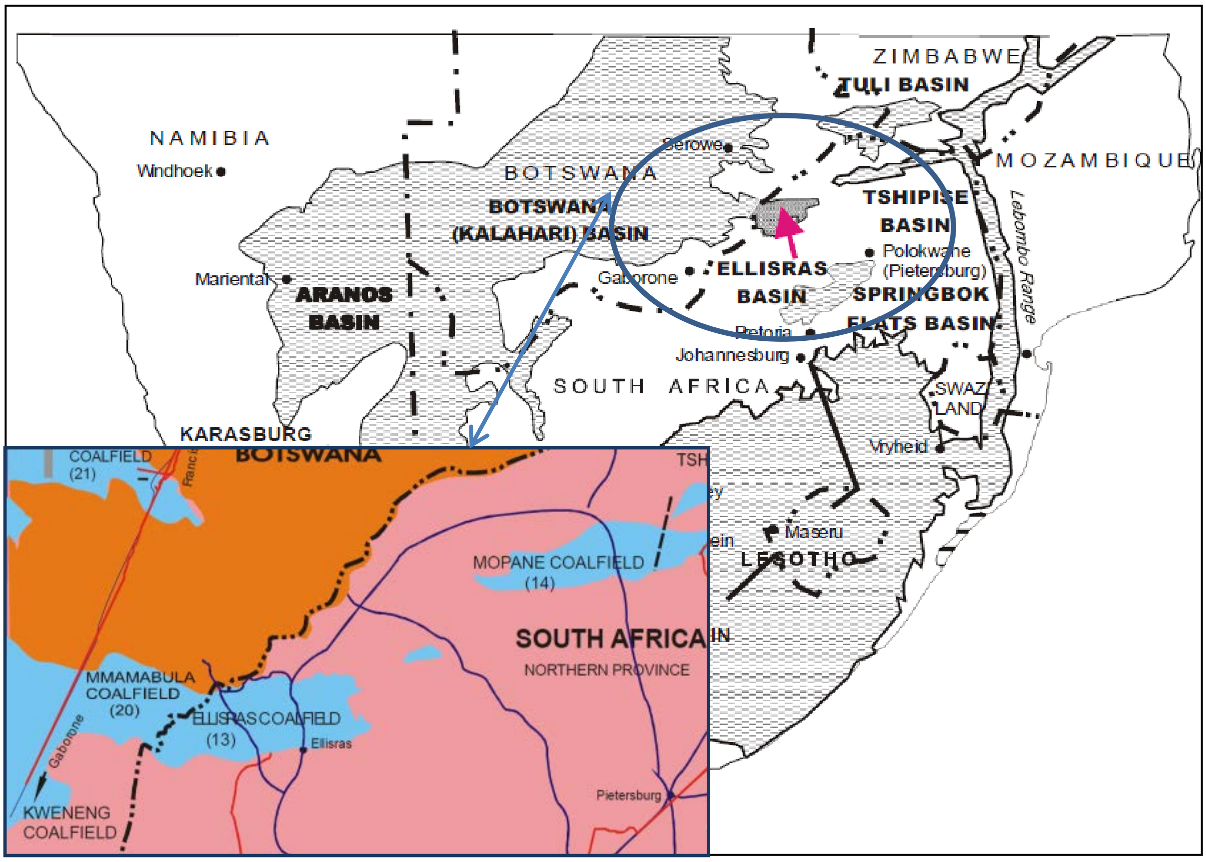

Figure 15 The Ellisras Basin and other Karoo basins in southern Africa, Mtimkulu (2009)

The structural history of this area has been well documented by Mtimkulu (2009) and the following is an abridged version of that work. The Ellisras Basin is fault bounded along its southern and northern margins and is a graben type deposit (Figure 16). In this area, the basin is influenced by three major fault coal zones, the Eenzaamheid Fault delineating its southern limit, the Zoetfontein Fault near its northern limit, and the Daarby Fault, with a down-throw of approximately 350 m towards the northeast. The Daarby fault divides the coalfield into a deep lying north-eastern portion and a shallow south-western portion.

Sedimentological facies changes also influence the continuity of the coal zones, with deterioration in coal development. Mtimkulu, (2009) also describes how the depositional patterns in the Ellisras Basin were influenced by mobile geological structures such as lineaments or faults which were continuously active synsedimentary geological structures.

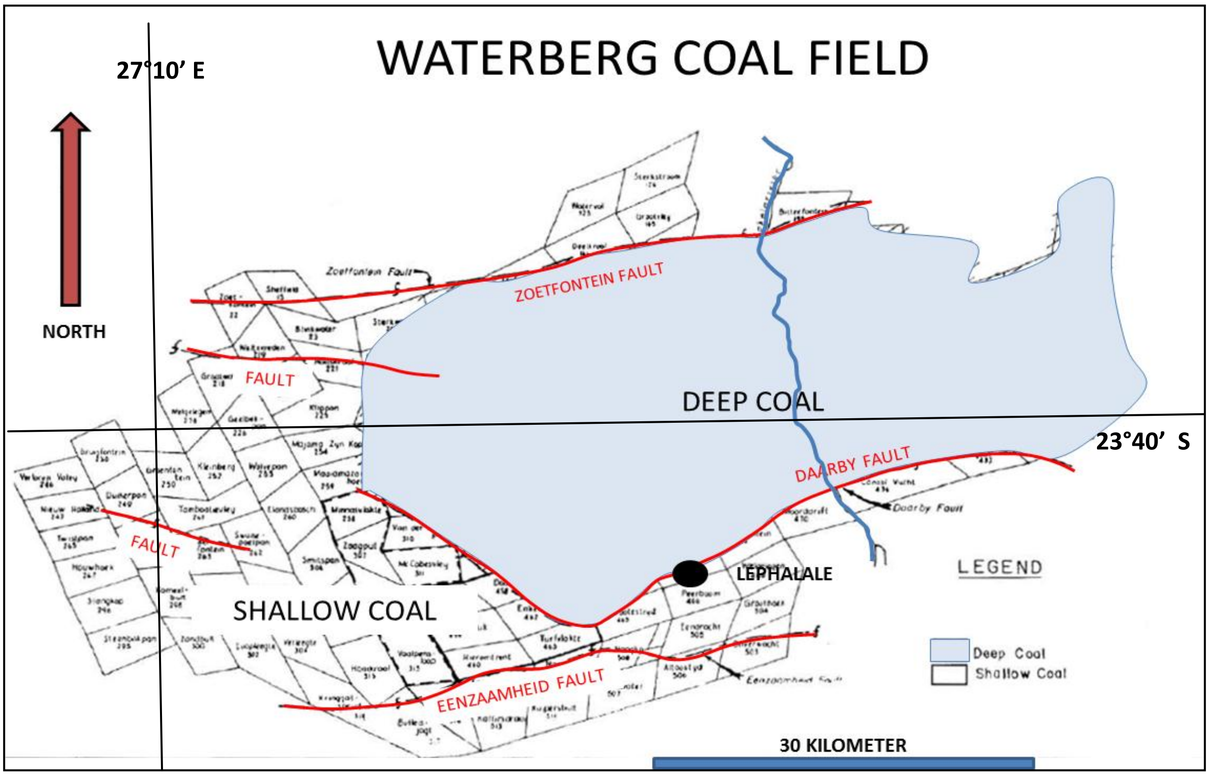

Figure 16 Sketch map of the Ellisras Basin showing major structural elements

The Ellisras, Mopane and Mmamabula (see Figure 15) coalfields formed within a larger intracratonic trough (Soutpansberg) and were subjected to tectonic/structural reactivation during Permian to early Triassic times, Arnot and Williams (2007). Several structural lineaments in the basement rocks to the Ellisras Basin were reactivated over time, probably due to the intrusion of the Bushveld Igneous Complex (ca. 2056 Ma), Buick et al (2001). Tectonic reactivation, caused in part by sediment loading, took place during the Karoo era and this controlled locally the sedimentation taking place within the basin. Energy levels influenced the types of sediments and this played a role in the formation of specific lithotypes. Coal formation took place during deposition of the Ecca Group (±280 Ma) and these are the Grootegeluk (Volksrust) and Swartrant Formations (Figure 17). Coal from the Grootegeluk Formation is considered to be autochthonous, while the coal from the Swartrant Formation is allochthonous, C. Dreyer, (2004, personal comment).

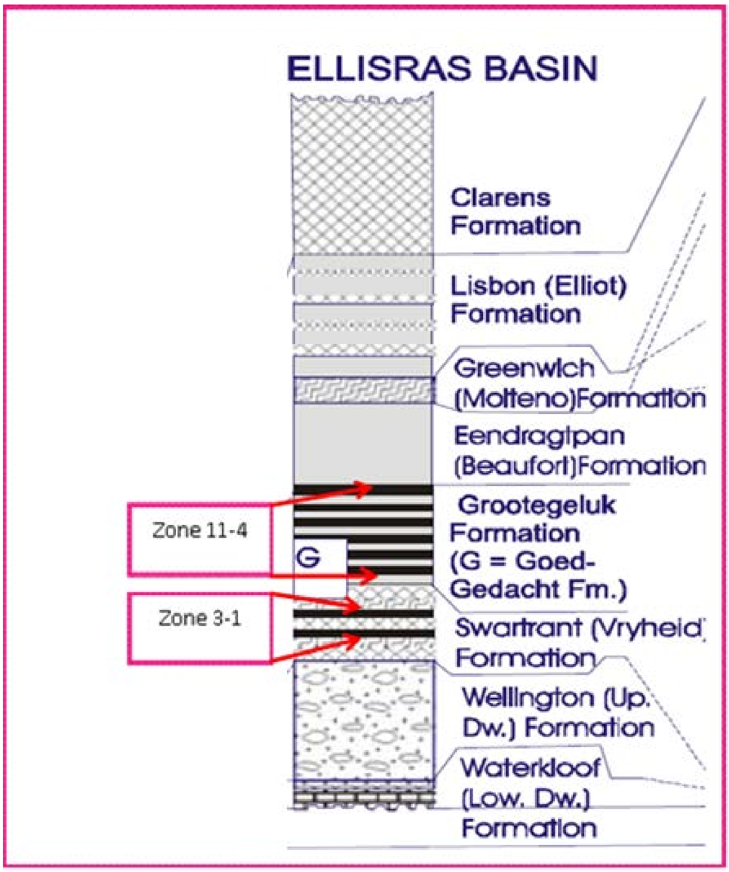

Figure 17 Coal-bearing formations within the stratigraphy of the Ellisras basin-fill, Bordy et al (2010). Coal zones 11-4 are of the thick interbedded coal type with Coal zones 3-1 being multiple seam deposits, according to SANS (2004)

4.2 Local structural setting

At the Study area, the northern boundary of the coal deposit (Figure 18) is formed by faulting that has a displacement of about 50 m towards the south, while the most southerly margin is delineated by a fault that has a throw of about 150 m to the north. Numerous smaller faults criss-cross the orebody; and most major faults strike roughly east-west and the minor faults strike north-east. There is a major northeast-southwest trending faulted coal zone in the southern part of the area.

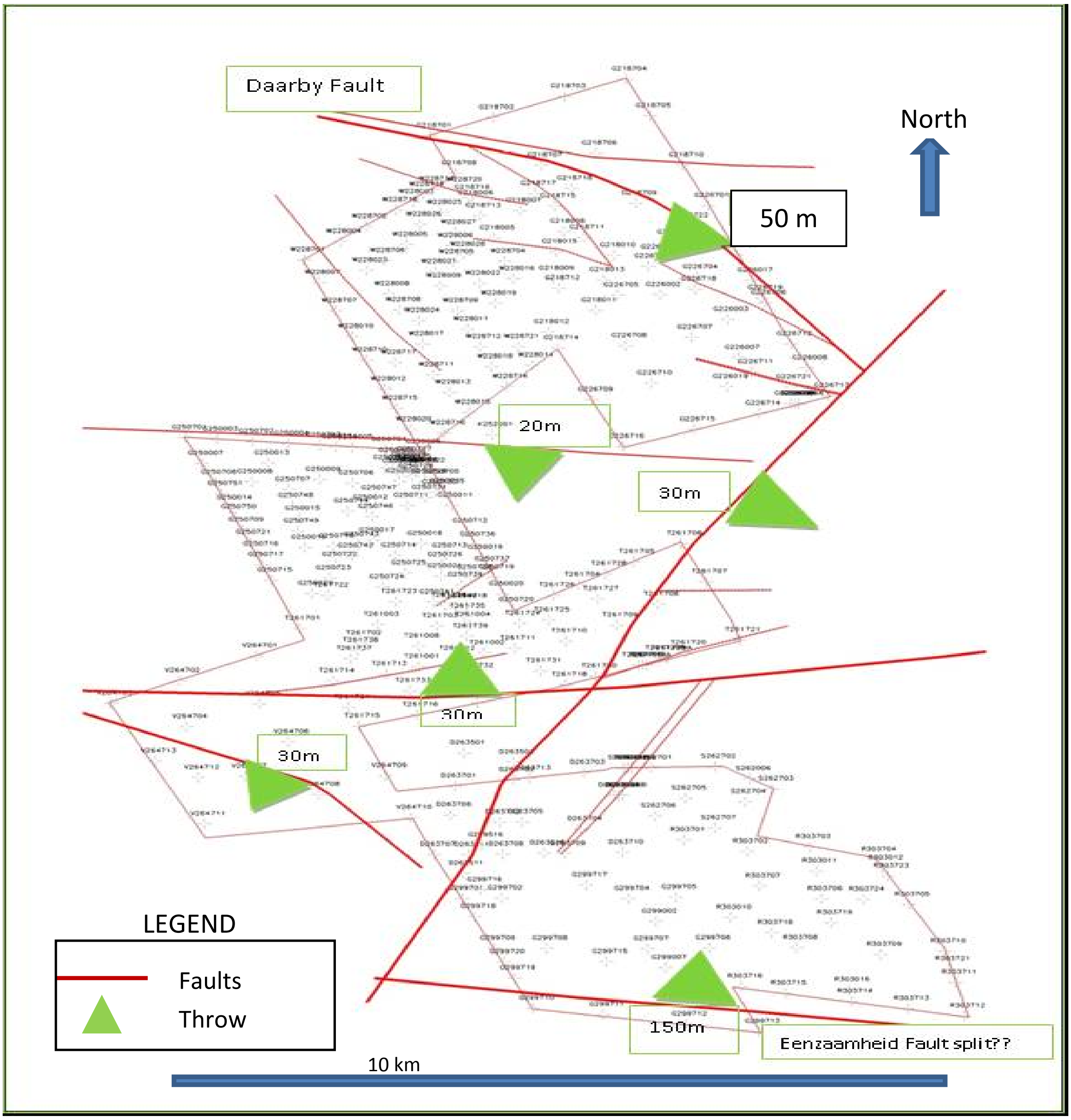

Figure 18 Local structural geology and borehole positions at the Study Area

4.3 Stratigraphy

The Ellisras Basin forms part of the Karoo Supergroup. Subdivision of the Karoo Supergroup as encountered in the Ellisras Basin is based mainly on lithological boundaries. All the “classic” units of the Karoo succession as found in the Main Karoo Basin Sequence are present in the basin area and hence, the same nomenclature is applied (Table 1). Local stratigraphic terminology for this basin (Figure 17) also shown, for comparison.. Only the Beaufort and Ecca Group rocks (highlighted in red) are found in the Study area

Table 1 SACS (1980) subdivision as used at the Groenfontein Area (highlighted in red).

GROUP	FORMATION (SACS – 1980)	FORMATION (Cilliers 1951)	Bordy et al Subdivision 2010	Representative Rock Type	Average Thickness
STORMBERG	Drakensberg Basalt	Drakensberg		Lava, purplish to red, amygdaloidal	95 m
	Clarens Sandstone	Cave Sandstone	Clarens Sandstone	Sandstone, fine grained, white to yellow-brown to reddish	80 m
	Elliot	Red Beds	Lisbon Formation	Mudstone, red to chocolate brown, clayey	90 m
	Molteno	Molteno	Greenwich Formation	Sandstone, white, medium to coarse grained, scattered pebbles	15 m
BEAUFORT	Beaufort	Beaufort	Eendragtpan Formation	Mudstone, purple and greenish grey, alternating at top, light grey at base	90 m
ECCA	Volksrust Mudstone	Upper Ecca	Grootegeluk Formation	Intercalated mudstone and bright coal	60 m
	Vryheid	Middle Ecca	Goedgedacht Formation	Sandstone and grit, intercalated carbonaceous mudstone, siltstone, few thick coal seams, mainly dull	55 m
	Pietermaritzburg Mudstone	Lower Ecca	Swartrant Formation	Mudstone and sandstone, grit in lower portions	150 m
DWYKA	Dwyka	Dwyka	Wellington and Waterkloof Formations	Tillite	3 m

4.4 Coal types and distribution

4.4.1.1 Grootegeluk Formation

The upper part of the coal deposit in the Study area, the Grootegeluk Formation (Figure 19), comprises intercalated mudstone and bright coal layers (Figure 20).

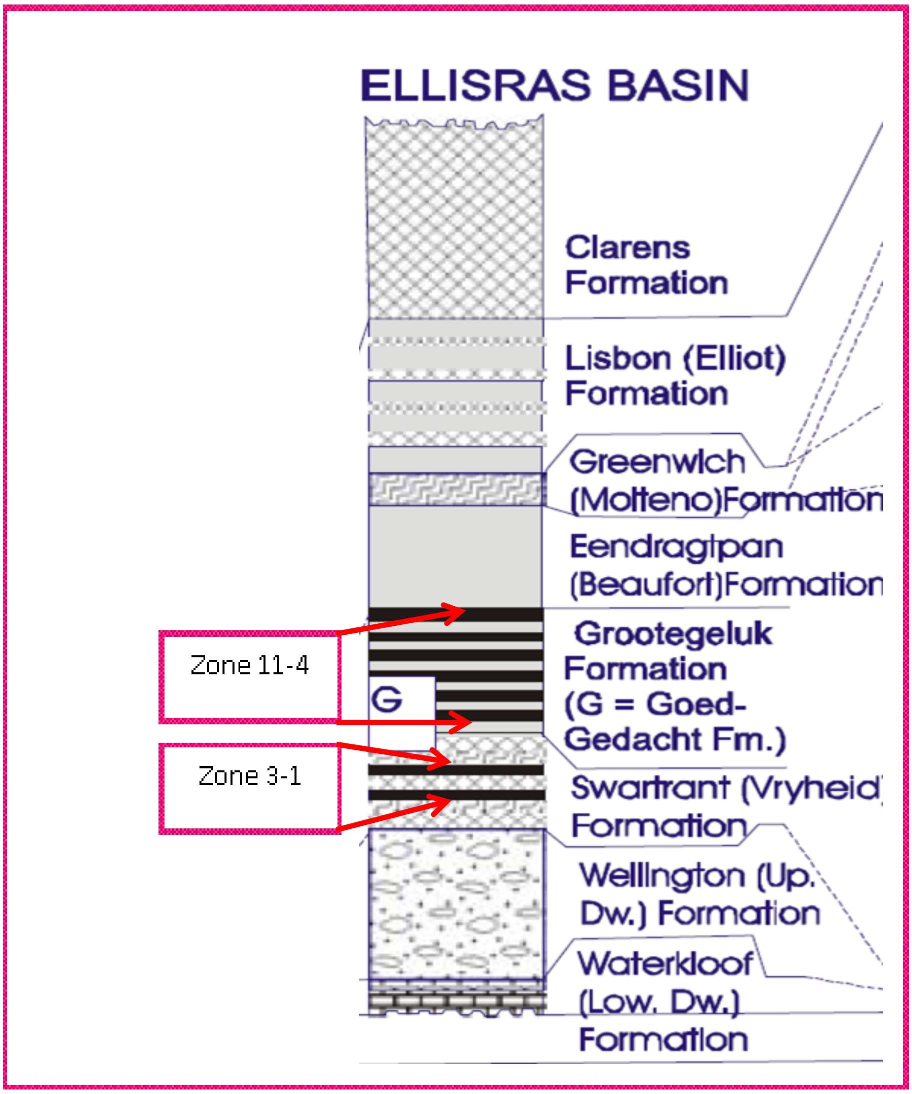

Figure 19 The Grootegeluk Formation coals at Groenfontein, adapted from Bordy et al (2010)

This formation has an average thickness of 72m ± 5m (Figure 21). It displays such a well-developed repetition of coal-mudstone assemblages that it can be divided into seven sedimentation cycles (Figure 27) or coal zones. Smaller sub-cycles (samples) are contained within these coal zones; these were sampled individually during exploration of the deposit.

Figure 20 Photograph of typical cores from Grootegeluk Formation coals. The yellow pencil marks are lithology boundaries with associated measured depths below surface. White pencil writing denotes sample numbers and the amount of plastic bags needed to place the material in weighing purposes

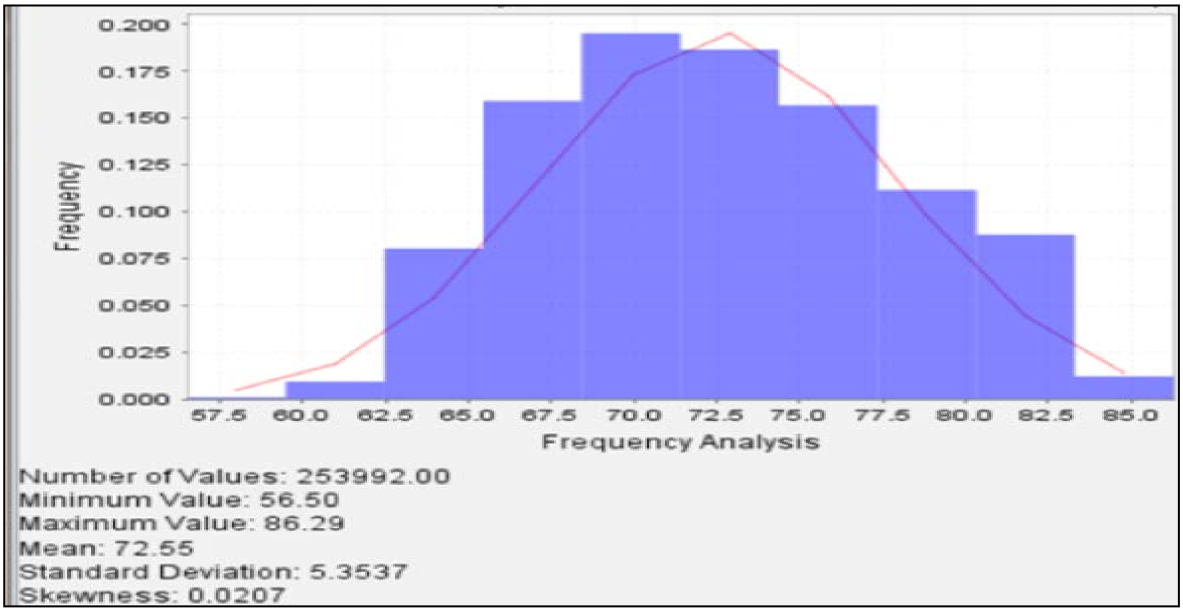

Figure 21 Thickness (general) statistics of the Grootegeluk Formation at the Study area

The Grootegeluk Formation (Figure 19) coal zones typically start with bright coal at the base, with the ratio of coal-mudstone decreasing from the base of each coal zone upwards (Figure 22).

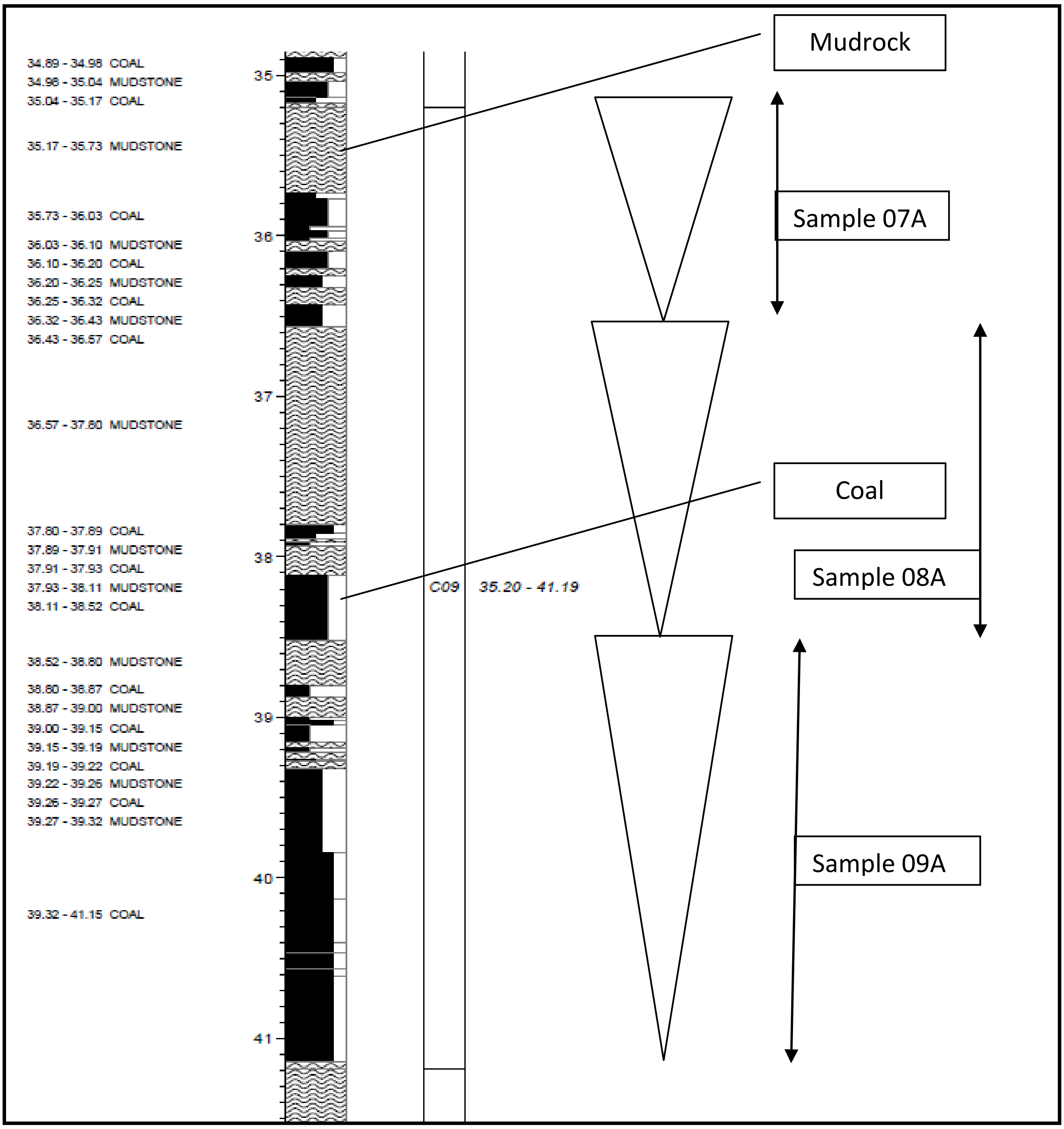

Figure 22 Typical upwards coarsening cycles on which sample boundaries are based. CO9 is coal Zone 09 and the other units are depth in meters

The Grootegeluk Formation mudstone shows an increase in carbon content with depth and range from a massive bluish-grey mudstone at the top to carbonaceous mudstone towards the

Basal coal zone. Although the thickness and coal quality of the Grootegeluk Formation is reasonably constant across the coalfield, a large variation in the yield of semi-soft coking coal occurs vertically in the coal succession, but the upper coals have a higher coking coal yield.

4.4.1.2 Swartrant Formation

The Swartrant Formation (± 55m thick) forms the lower part of the coal deposit. It consists of carbonaceous mudstone and sandstone with inter-bedded dull coal seams varying in thickness from 1.5 m to 17 m (Figure 23). The Swartrant Formation displays the characteristics of a Multiple Seam Deposit Type, according to the guidelines of the SANS 10320 standard.

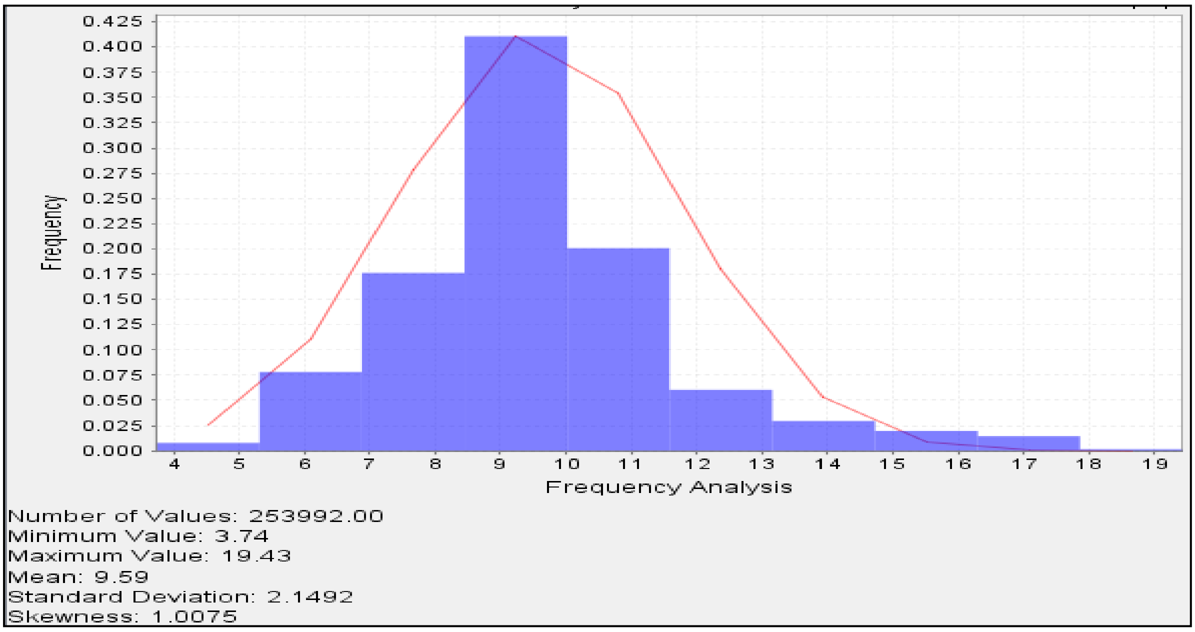

Figure 23 Thickness statistics (MINEX) of the thickness of the coal zones in the Swartrant Formation

There are three coal seams or coal zones in the Swartrant Formation, consisting predominantly of (Figure 25 and Figure 26) dull coal, with some bright coal and interbedded sandstones developed at the base of coal zones 1, 2, 3 (Figure 27). Due to lateral facies changes and changes in the depositional environment, these coal zones are characterized by a large variation in thickness and quality (Figure 24).

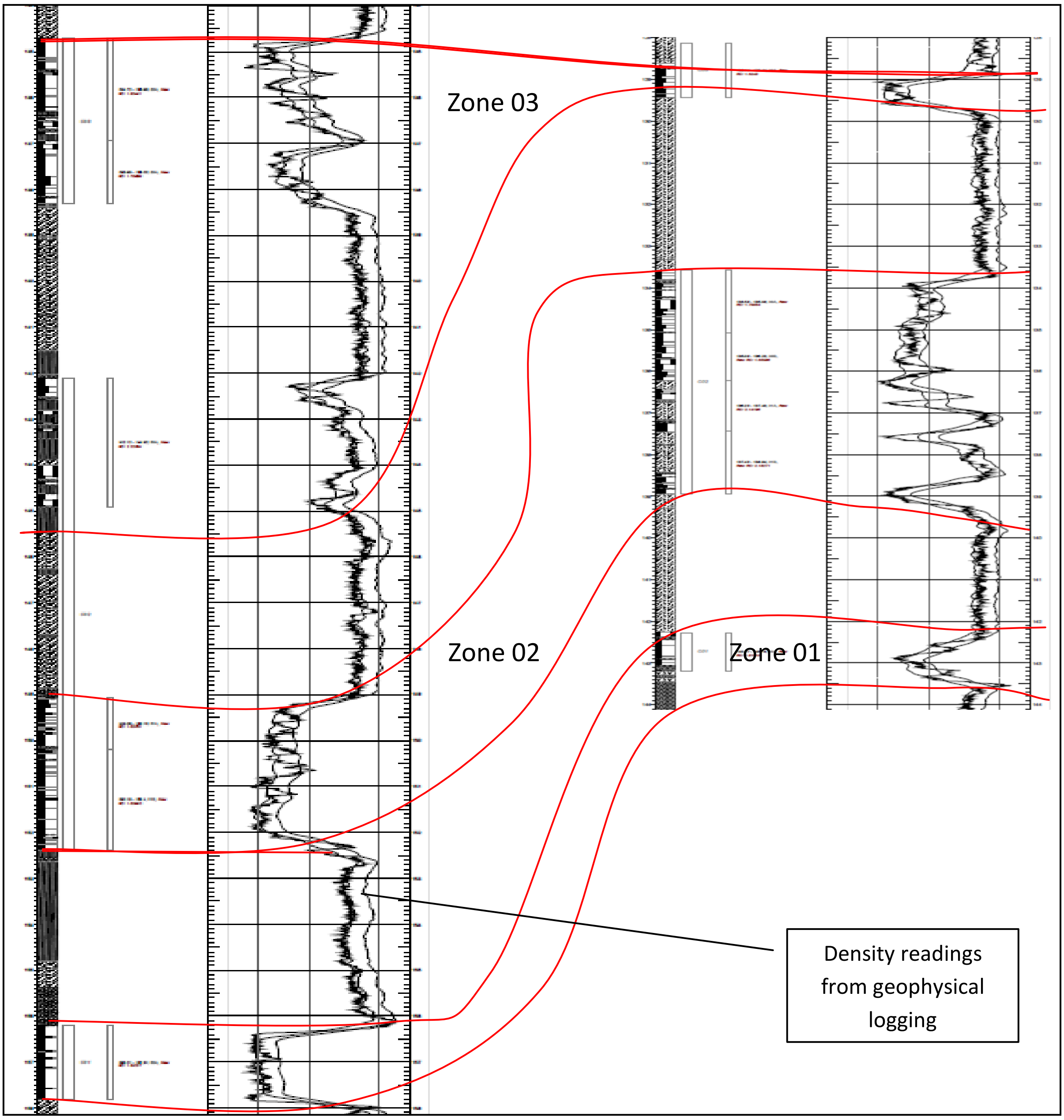

Figure 24 Variation in lithology of the Swartrant Formation coals seams. Red lines denote zone boundaries and the illegible writing on the left side of the lithology log and to the right of the geophysical log is the depth in one meter intervals

Figure 25 Swartrant coal seams with laminated siltstone

Figure 26 Swartrant coal seams, showing dull coal interbedded with sandstone (coarse, white rock) and mudrock (dark grey laminated rocks). The yellow pencil marks are lithology boundaries with associated measured depths below surface. White pencil writing denotes sample numbers

In the Waterberg Coalfield (Ellisras Basin) there is a convention on how to sub-divide coals into coal zones (Figure 28). This was done to find a logical scheme for creating benches in the mining operations as well as for aiding the mining of coal, as a specific unit then has certain characteristics. The numbering convention of the various coal zones as applied in the Ellisras basin sequence is shown in Figure 29.with the Study area on left and Grootegeluk mine on right.

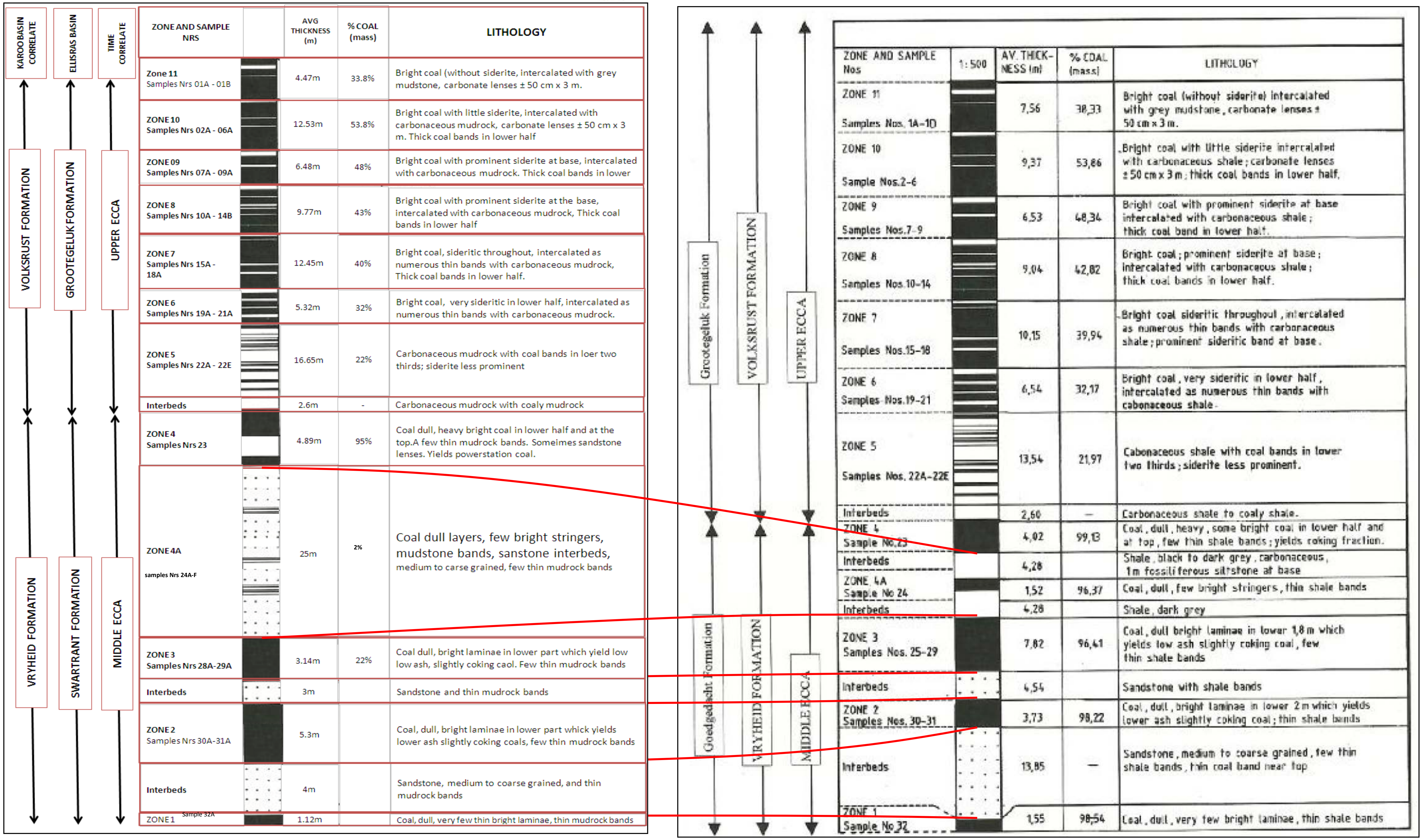

Figure 27 Sub-dividing the various coals into coal zones and samples in the Ellisras Basin. Study area on left and Grootegeluk mine on right

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As an example of how the coal zones can be mined is shown below (Figure 28). The Grootegeluk mine's mining benches are based on the coal zones and all the coal seams are mined except for the lowest coal seam in the succession (coal Zone 01 or sample 32A), as it is below a 10 m thick sandstone and is not currently economically viable.

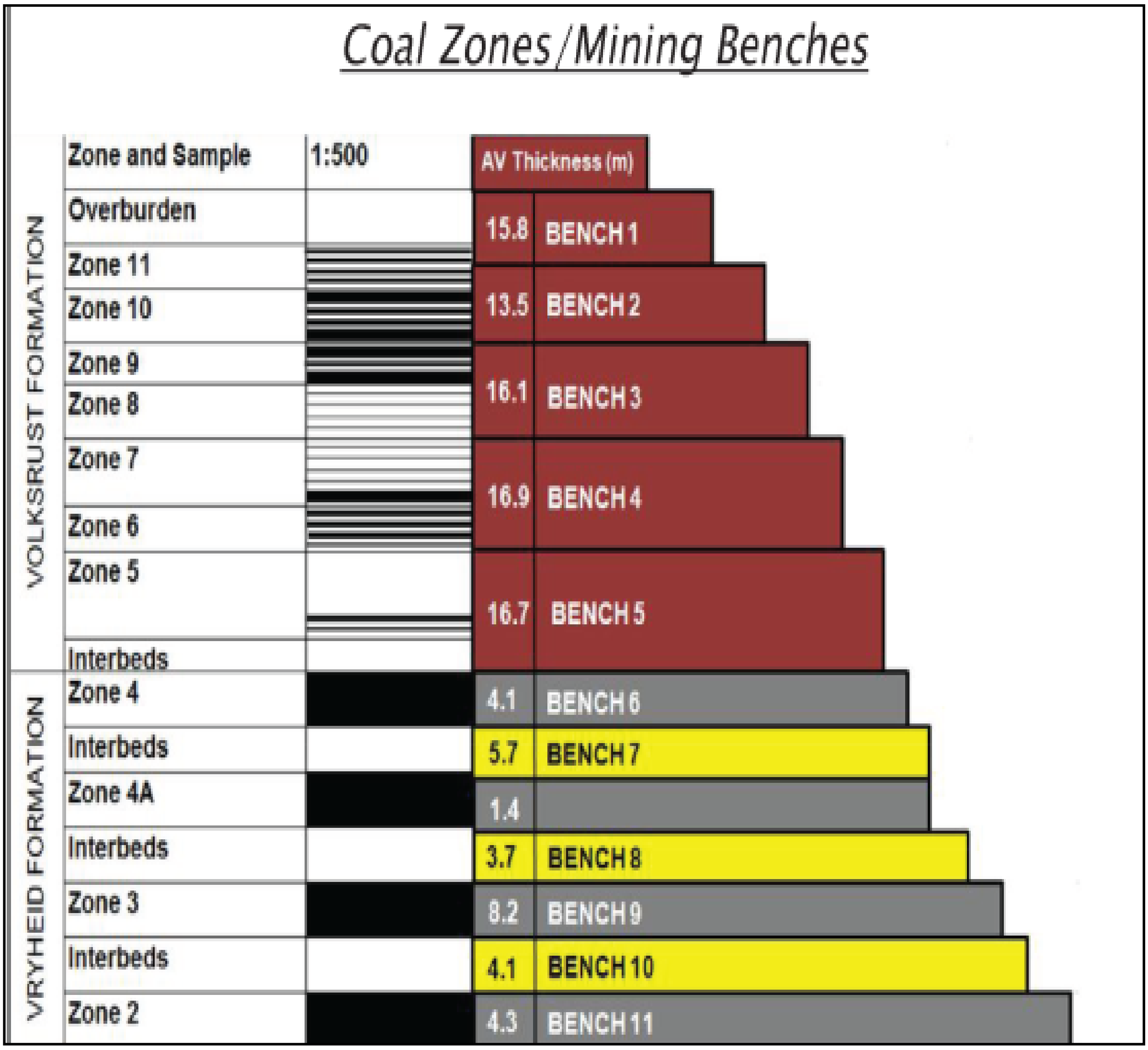

Figure 28 zones and mining benches as defined at Grootegeluk mine

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4.5 Sub-outcrop maps of the various coal zones

Figure 29 shows the position of the various areas identified for the purpose of illustrating the sub-outcrop positions of the various coal zones at the Study area.

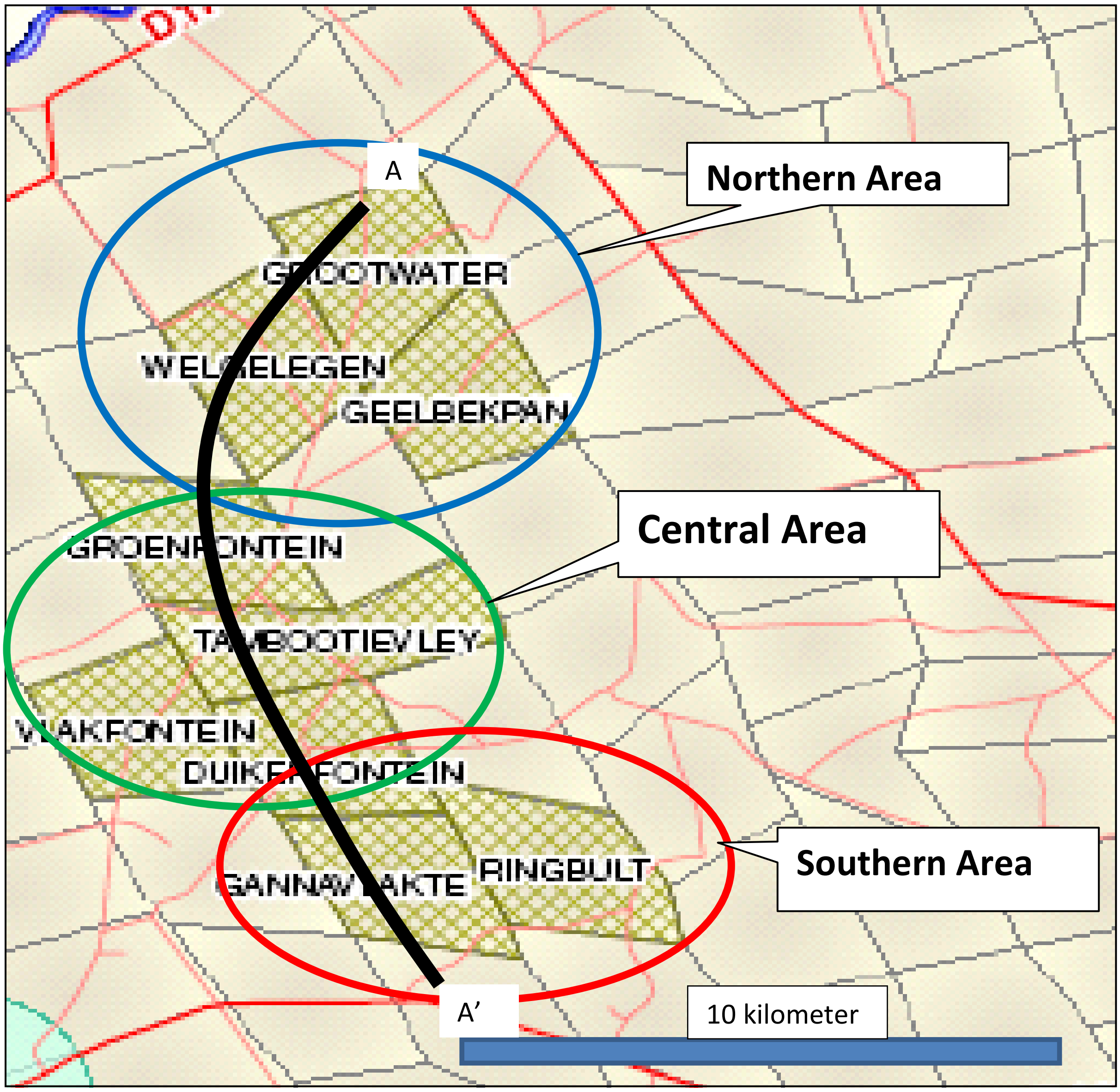

Figure 29 Geographical areas identified in the Study area

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The fault in the northern part of the Grootwater farms can be clearly seen (Figure 30) where the coal seams dip towards the South and West. The following sub-outcrop and section maps show the occurrence of the various upper coal zones in the Groenfontein area.

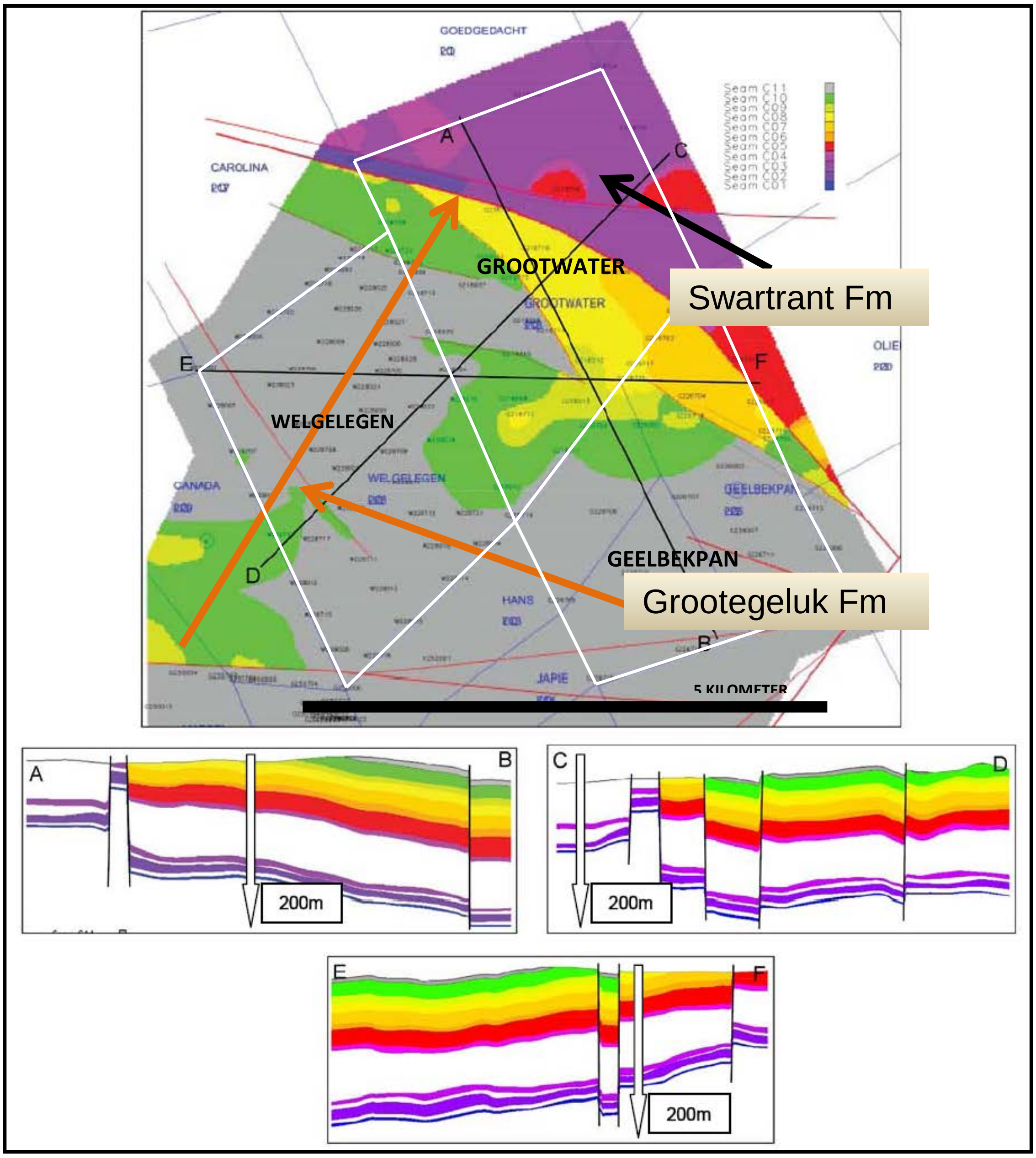

Figure 30 Northern Area coal zones. The top part is a plan showing the sub-outcrop positions of the coal zones and the bottom parts illustrates sections through the stratigraphy at various positions to illustrate faults and the dip of the rocks. Vertical exaggeration is ten times

In the central area, the extensive faulting in the eastern part is clearly visible (Figure 31). On Vlakfontein, the Swartrant Formation coals sub-outcrop against the overlying aeolian sand cover.

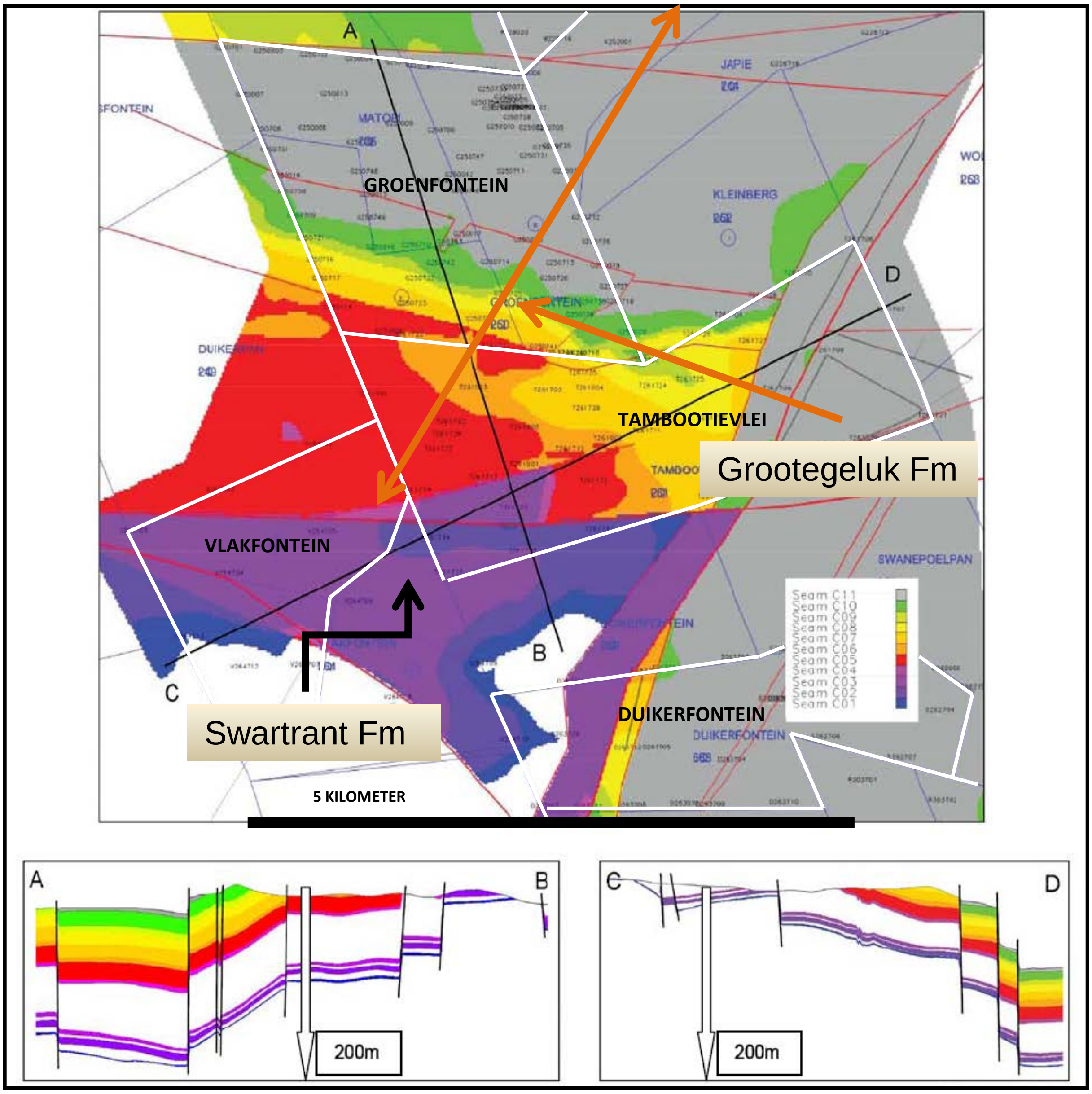

Figure 31 Central Area coal zones. The top part is a plan showing the sub-outcrop positions of the coal zones and the bottom parts illustrates sections through the stratigraphy at various positions to illustrate faults and the dip of the rocks. Vertical exaggeration is ten times

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In the southern area (Figure 32), the effect of the eastern part is clearly seen. It is interesting to note that on Vlakfontein, the Swartrant Formation coals occur in sub-outcrop west and is shallow dipping along a north-south profile.

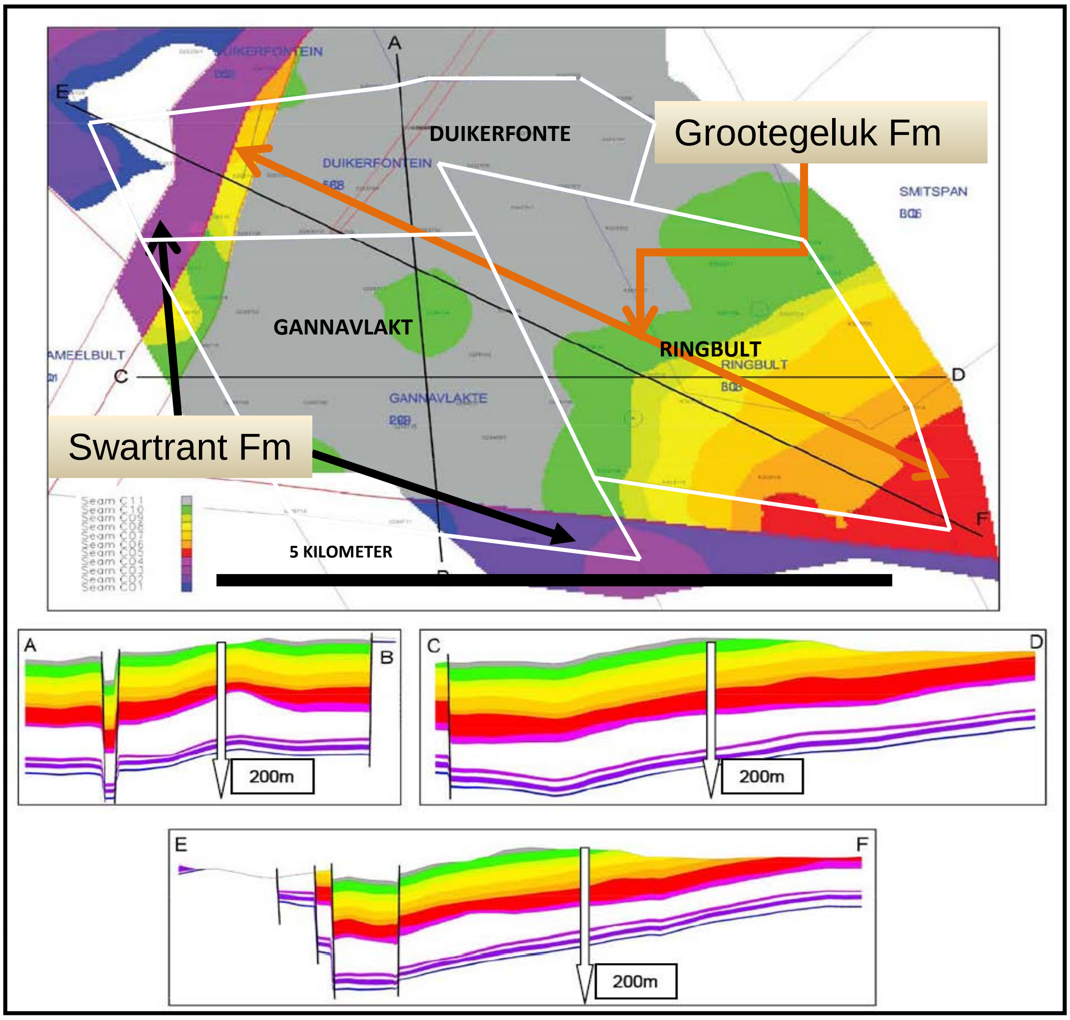

Figure 32 Southern Area top coal zones. The top part is a plan showing the sub-outcrop positions of the coal zones and the bottom parts illustrates sections through the stratigraphy at various positions to illustrate faults and the dip of the rocks. Vertical exaggeration is ten times

In the southern area (Figure 32) the effect of the Eenzaamheid fault is clearly seen. It is also interesting to note that the rocks dip towards the west and are shallow dipping along a north-south profile. A complete profile along A-A' is shown in Figure 33

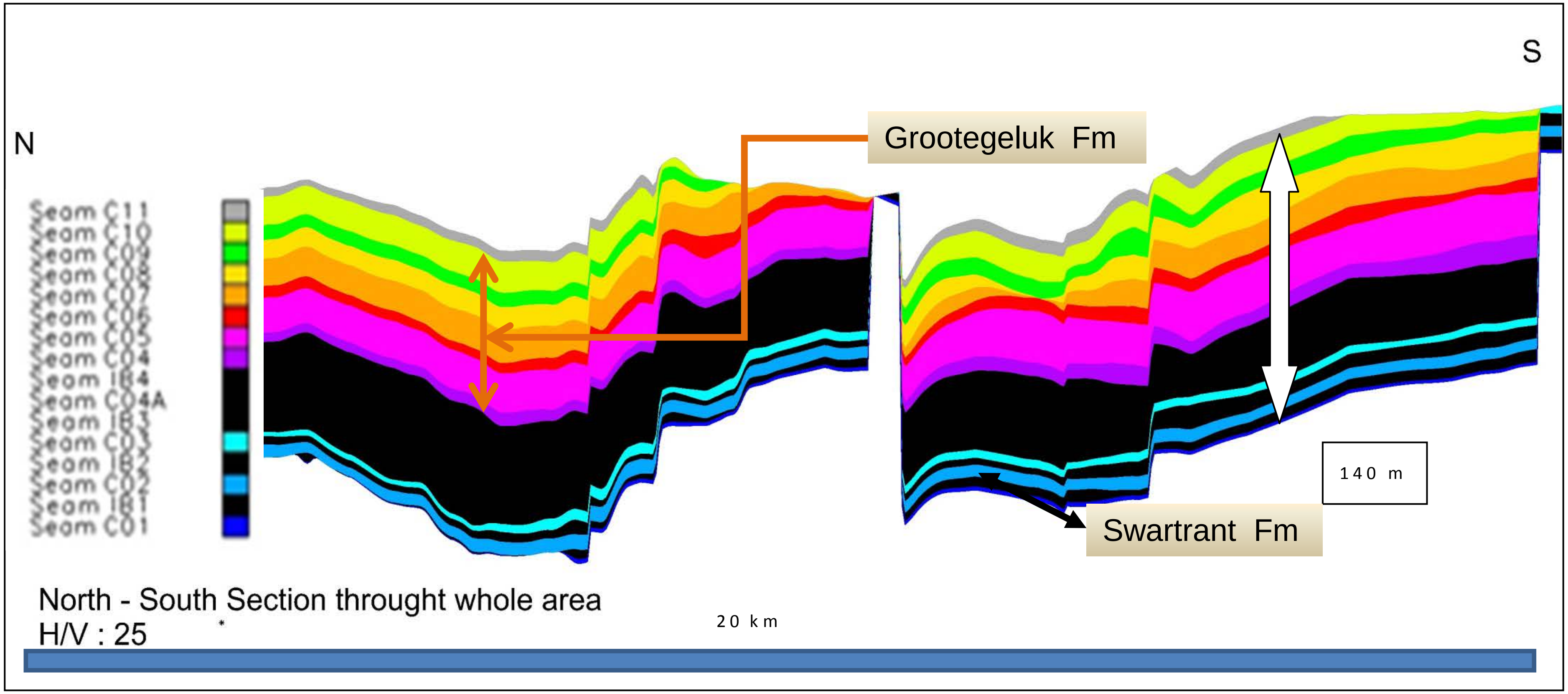

Figure 33 North-south section through all farms along line A-A' in Figure 29. Surface topography is not shown

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5 TECHNICAL INFORMATION RELATED TO THE PREPARATION OF THIS THESIS

5.1 Prospecting methods used at Groenfontein

The prospecting method used at Groenfontein comprised the drilling of cored exploration boreholes on a random spacing of ± 1 000 m x 1 000 m and infill percussion drilling, with the exception of Groenfontein where detailed cored drilling was done to delineate the deposit geometry in detail (as a bulk sample was mined from this area for gasification tests). All the boreholes lithologies were described in detail and the boreholes were geophysically logged. The coal samples recovered from the cored boreholes were analysed by Advanced Coal Technology (ACT) laboratory in Pretoria.

5.2 Drilling techniques, planning, control and material recovery

5.2.1 Cored drilling

Cored boreholes were drilled at the Study area by drilling the initial part of the borehole (piloting) through the loose overburden using tricone or similar methods. Initially (pre-2006), HQ/TNW boreholes, with percussion piloting through the overburden, were drilled at Groenfontein. Thereafter, all boreholes were drilled to large-diameter PQ (123 mm) coring to retrieve sufficient representative sample material to cater for the large suite of analyses to be performed. All holes were geophysically logged by Weatherford within a few hours or a day from being completed. All boreholes drilled after 2006, was done by one contractor, Diabor, and all percussion drilling by Ellisras Boorwerke, which has been drilling in the area for more than 20 years.

5.2.2 Percussion drilling

Percussion infill drilling (usually 115 mm in diametre) is geologically described within a few days of being completed and geophysical logging finished immediately after completion of

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the borehole. Percussion drilling is mostly used for structural delineation and determining the position of the coal seams. The geophysical logging is done for verification purposes and determining the position of the various samples in each borehole.

Cored boreholes were drilled at the Study area by drilling the initial part of the borehole (piloting) through the loose overburden using tricone or similar methods. According to contract, cored boreholes were only accepted for payment if:

- The core is clean;
- the depth of a borehole has been verified by a geologist; and
- core recovery for the coal seams has been confirmed to be 95% or higher.

Random depth checks are conducted during the drilling of each borehole and the geophysical logging is also used to verify reported drilling depths. Statistical analyses indicate that the reported drilling depths are within acceptable level of accuracy.

5.3 Geophysical density logging performed at the Study area

All boreholes were geophysically logged in the Study area. These included 164 cored and 261 percussion boreholes. Each of the cored boreholes had approximately 40 samples, consisting of about 4 bags each, which is a total of 25 760 bags that had to be weighed in water and in air, a total of 51 520 measurements. Five percent of these had to be reweighed making a total of 2576 samples; a grand total thus of 54 096 measurements. At an average of 150 m per borehole there were 24 600 m of geophysical logging that were completed and with the 261 percussion holes a further 39 150 m of logging were added, making the total logged length to 63 750m. Each centimeter of the total logged length has its own record making up for a dataset extending close to 6.4 million lines of information. This data was used in the compilation of this thesis.

Weatherford, the geophysical wireline logging company, used a DD 2 sonde which has a 7 cm vertical resolution. Figure 34 and Figure 35 illustrates the standard setup of equipment in the field.

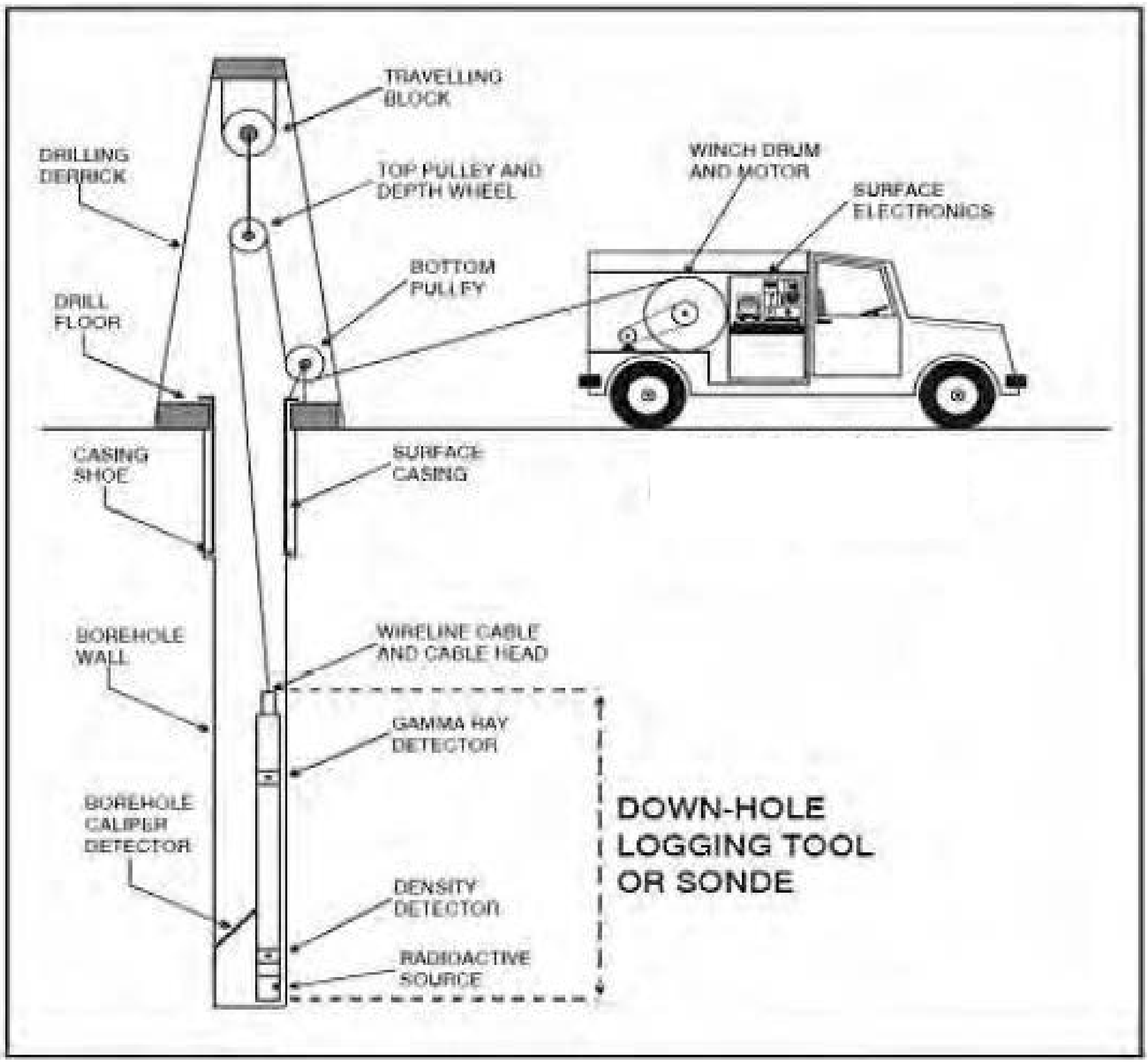

Figure 34 Standard setup of geophysical logging equipment in the field

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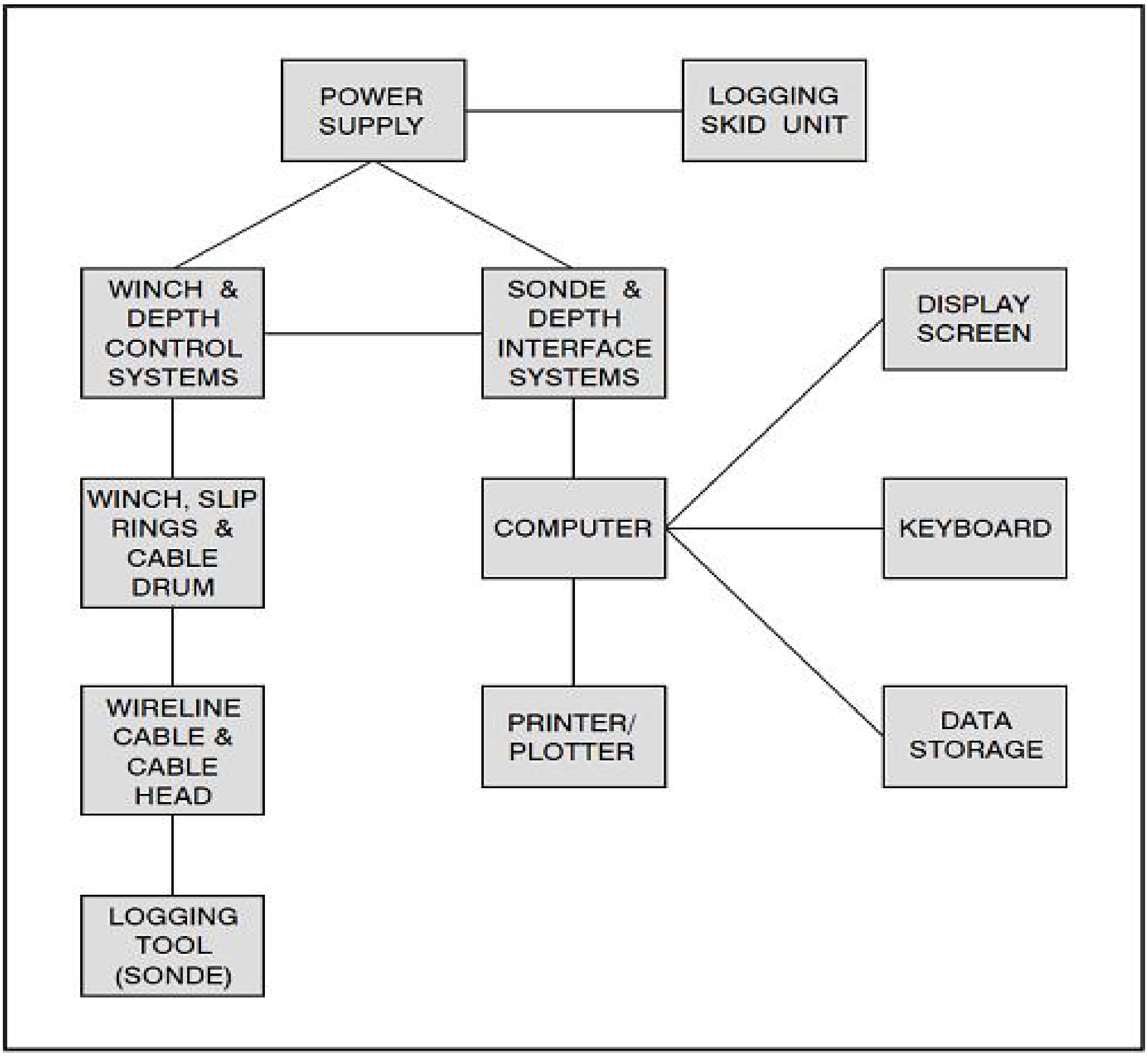

Figure 35 Diagram of setup of geophysical logging equipment in the field

The data received by the geologist in the field are usually supplied as a text file (Table 2) and typically contains tabulations of relevant readings of gamma, density types, porosity, depth and calliper width, which the geologist must interpret.

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Table 2 Typical geophysical las data supplied by Weatherford (units below in the table)

Depth	GRDE	CODE	CADE	DENL	DENB	DEPO	ADEN
160.210	88.732	2.385	120.933	2.353	2.270	15.774	2.370
160.200	80.265	2.389	121.055	2.357	2.295	16.328	2.380
160.190	79.588	2.392	121.182	2.362	2.337	15.891	2.424
160.180	106.342	2.395	121.215	2.366	2.275	15.031	2.370
160.170	100.585	2.401	121.244	2.372	2.338	15.252	2.422
160.160	103.294	2.403	121.371	2.375	2.317	14.791	2.401
160.150	103.633	2.402	121.498	2.377	2.278	14.444	2.362
160.140	102.278	2.402	121.557	2.379	2.317	15.439	2.380
160.130	81.620	2.399	121.760	2.379	2.370	15.296	2.428
160.120	80.604	2.397	121.887	2.380	2.333	15.151	2.388
160.110	76.201	2.401	121.986	2.385	2.429	15.639	2.470
160.100	78.571	2.409	122.027	2.392	2.311	15.115	2.354
160.090	77.217	2.411	122.099	2.396	2.326	14.249	2.375
160.080	79.926	2.421	122.127	2.405	2.321	12.898	2.384
160.070	78.571	2.426	122.254	2.411	2.407	14.620	2.436
160.060	75.185	2.423	122.301	2.411	2.338	12.500	2.396
160.050	70.105	2.423	122.346	2.413	2.386	13.593	2.419
160.040	70.443	2.426	122.376	2.417	2.368	15.262	2.365
160.030	78.910	2.426	122.574	2.419	2.374	12.949	2.403
160.020	80.604	2.428	122.599	2.422	2.409	13.499	2.426
160.010	87.377	2.439	122.799	2.431	2.434	12.625	2.458
160.000	87.038	2.435	122.868	2.430	2.422	13.055	2.435
159.990	81.281	2.436	123.018	2.432	2.421	11.895	2.452
159.980	71.798	2.430	123.009	2.428	2.419	13.969	2.413
159.970	72.814	2.418	123.290	2.419	2.459	13.226	2.466
159.960	72.814	2.404	123.494	2.408	2.439	14.374	2.432
159.950	82.297	2.396	123.888	2.401	2.506	16.780	2.465
159.940	102.278	2.382	124.200	2.388	2.492	16.164	2.474
159.930	110.745	2.367	124.460	2.375	2.528	16.460	2.513
159.920	116.164	2.355	124.632	2.362	2.534	17.573	2.513
159.910	125.308	2.338	124.795	2.345	2.479	18.907	2.452

```
#-------------------------------------
DEPT.   DEPTH
GRDE.   GAMMA FROM DENSITY TOOL
CODE.   COMPENSATED DENSITY
CADE.   CALIPER FROM DENSITY
DENL.   LONG SPACED DENSITY
DENB.   SHORT SPACED DENSITY
DEPO.   DENSITY POROSITY
ADEN.   VECTAR PROCESSED DENSITY
#
```

6 ACCURACY OF THE GEOPHYSICAL DATA IN PREDICTING THE RELATIVE DENSITY OF THE COAL SEAMS ON THE STUDY AREA

The following method was used:

- The lithological unit's intersected and other geological features are described from the cored or percussion cutting;
- the geological log as captured by the geologist of that borehole is depicted in SABLE (database program) next to the geophysical log received (Figure 36);
- the geophysical log versus the geological log is visually interpreted by the geologist, marked on the paper log and then the various samples marked out on the core in the field; and
- the samples are collected and weighed and the relative density of the coal samples determined.

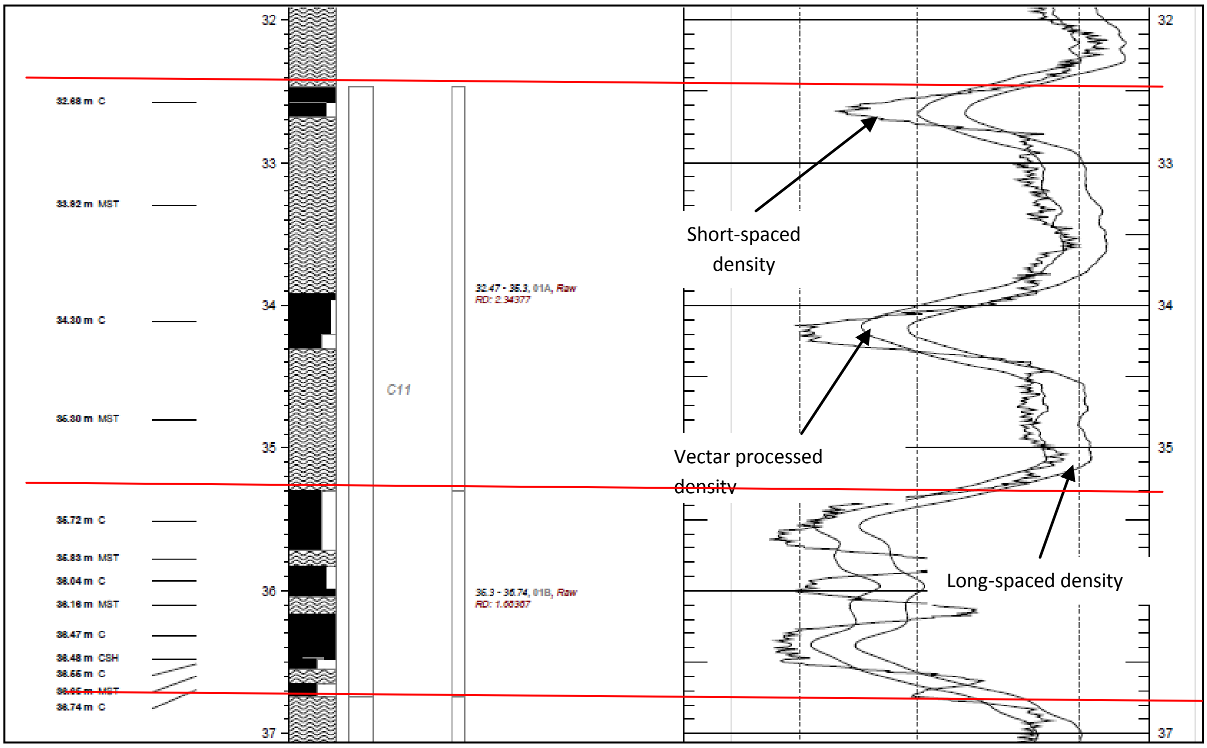

Figure 36 Plot of lithology and relative densities determined by geophysical logging. Three curves are long-spaced density (off-set for clarity), short-spaced density (serrated line) and Vectar processed density (smoothed line)

During 2009 and 2010, Sasol excavated a bulk sample at Groenfontein to determine if the coal could be gasified and used in the Sasol[TM] synfuels process. Figure 37 illustrates the correlation between the geophysical logging of a borehole drilled in the pit and the geology as found in the bulk sample site at Groenfontein.

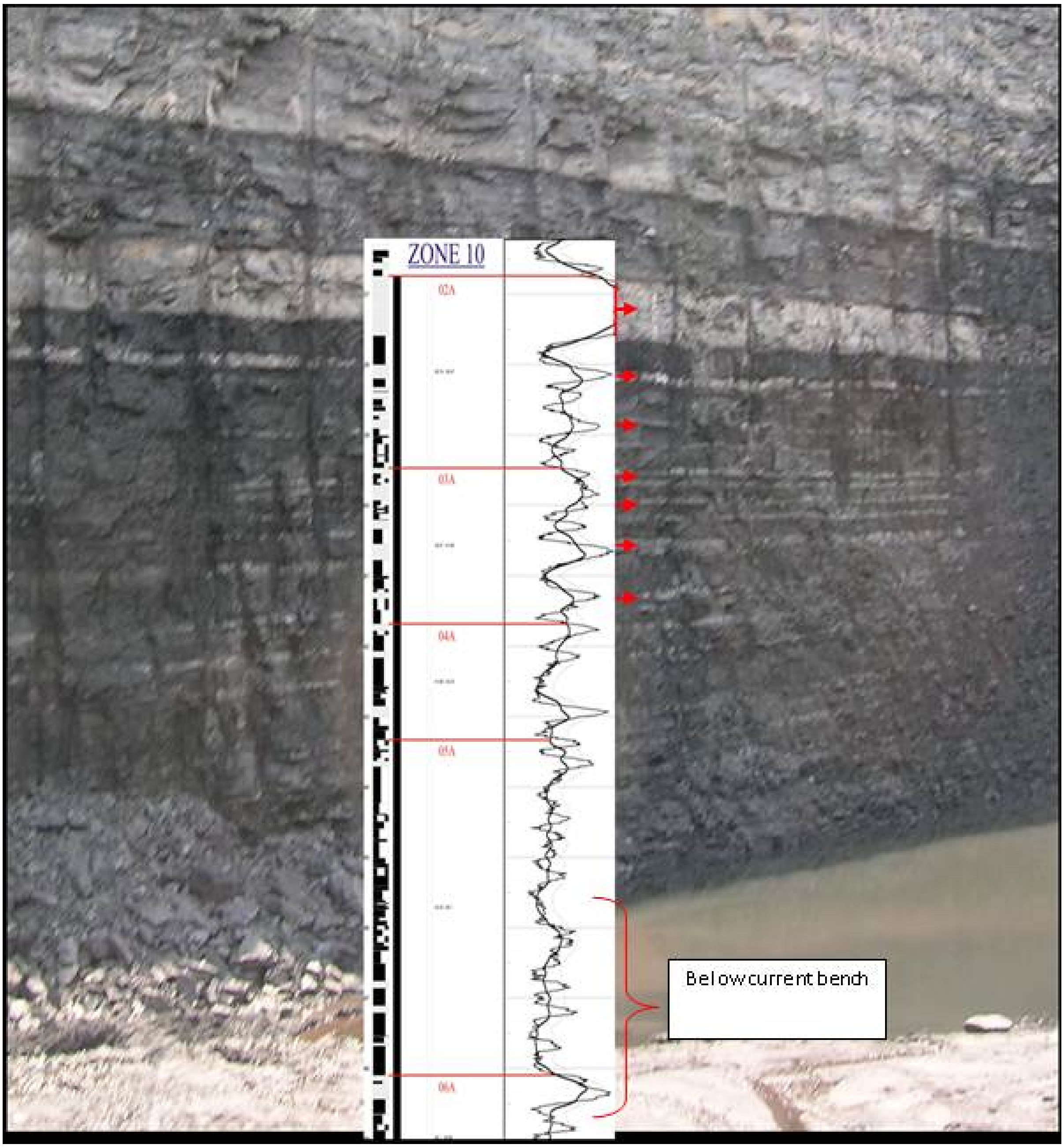

Figure 37 Photo of the local geology and a superimposed geophysical log of a borehole in a bulk sample pit illustrating the correlation between the geophysical logging and the lithotypes

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6.1 Statistical evaluation of the measured relative densities of cored material

The relative density of a sample is extremely important as it is used to determine the tonnage of that sample in the geological model. Relative density measurements are carried out per sample by weighing each sample in air and in water respectively, and dividing the weight obtained in air by the corresponding sample's weight obtained in water. The scale used for these measurements is calibrated using a control sample which has a known relative density.

An important requirement for SAMREC compliance is obtaining independent verification of the relative densities used for modelling purposes. This could have been done using traditional methods at the laboratory, or, as in the case of this study,, using the results from the geophysical logging done by Weatherford.

6.2 Reliability of measurements of sample masses

The reliability of weight measurements is checked in three ways, which indicate whether or not a weighing error has been made.

- The sample's relative density (Rd) measurements are compared with the core recovery recorded for each sample;
- the weight of each sample (in air) is measured again by ACT upon receipt of the sample at the laboratory in Pretoria. ACT's sample weight measurements are then compared with the original sample weights on the list which accompanied the samples to the laboratory, and should a significant discrepancy exist, the geology personnel at the field office is informed immediately. In general, only minimal weight measurement discrepancies were detected between the samples weights performed by the project team, and those performed by ACT; and
- all relative densities (Rd's) measured are compared to the geophysically derived values generated by Weatherford. The Rd's that are not within 95% of the theoretical values calculated by geophysical means are re-measured in the field. The overall correlation between the two values for Vectar processed density is 95% (Figure 38),

for compensated density it is 80.9% (Figure 39), for long spaced density 66.2% (Figure 40) and for short spaced density 81.3% (Figure 41).

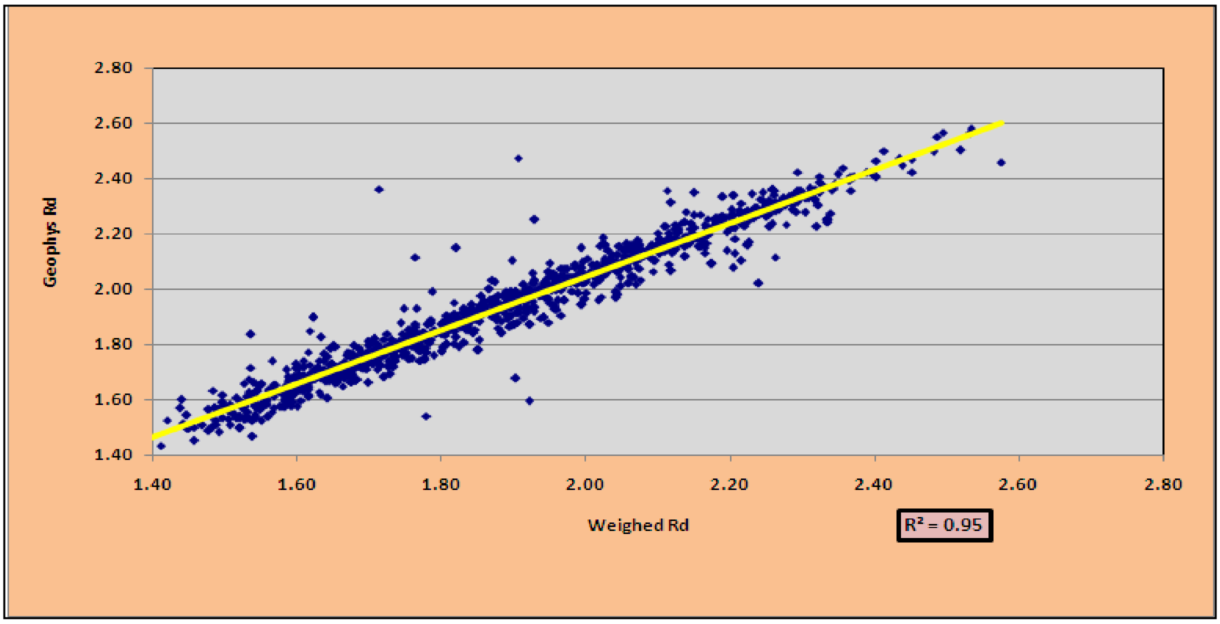

Figure 38 Regression plot of geophysically derived Vectar processed densities versus weighed densities

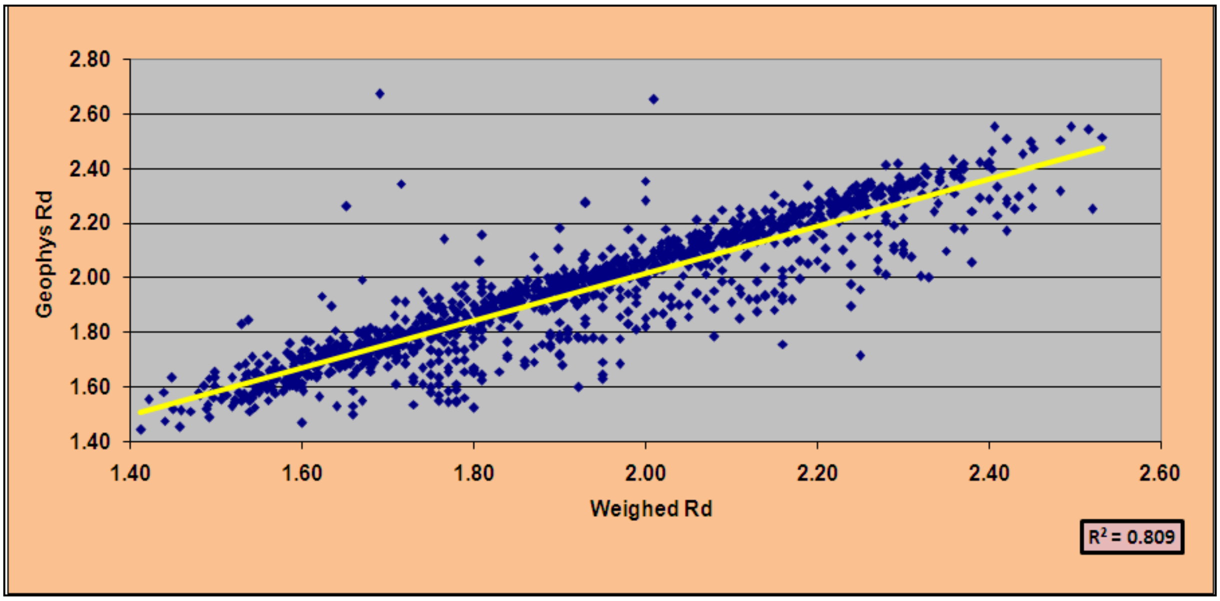

Figure 39 Regression plot of geophysically derived compensated densities versus weighed densities

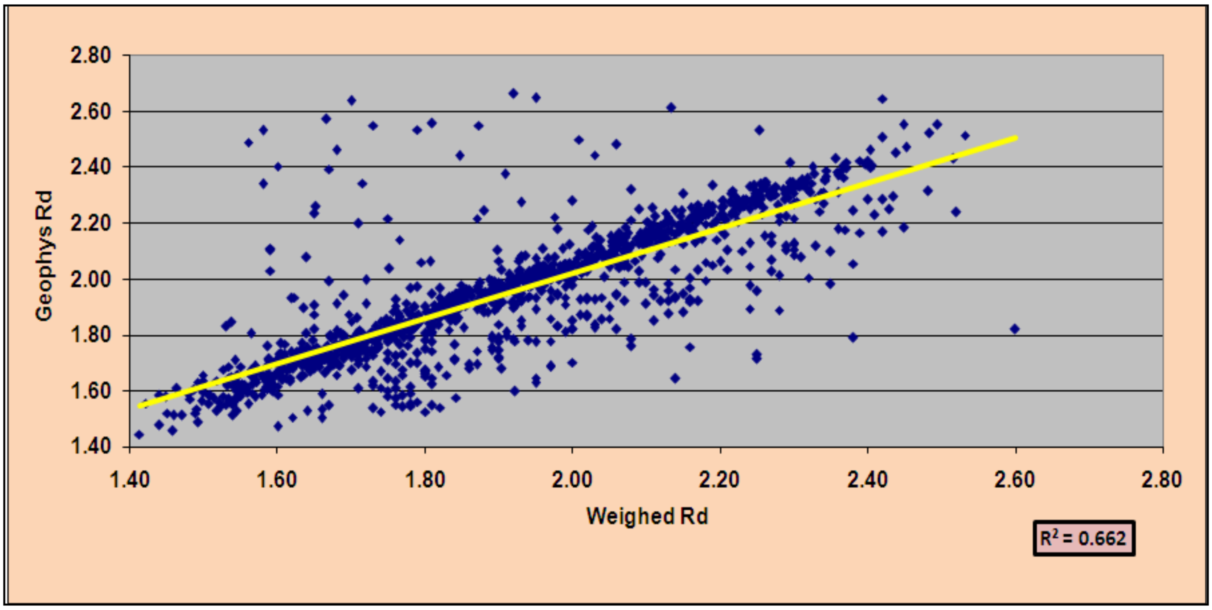

Figure 40 Regression plot of geophysically derived long-spaced densities versus weighed densities

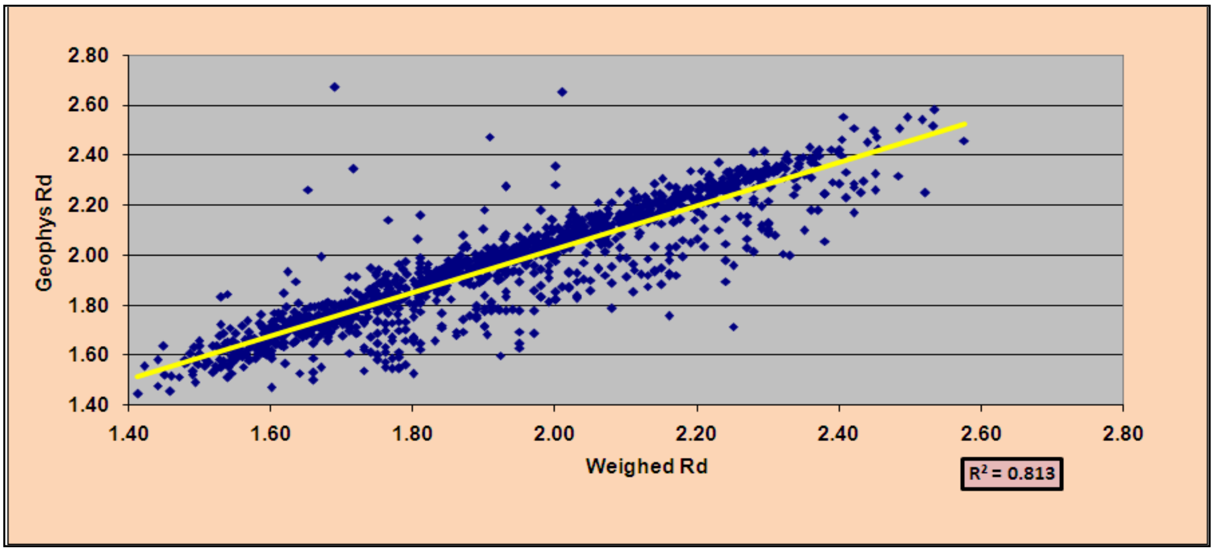

Figure 41 Regression plot of geophysically derived short-spaced density versus weighed density

It was found that the density determined empirically in the field was the most accurately mimicked by the densities determined by means of the Vectar processed density reported by Weatherford.

7 STATISTICAL DEPICTION OF THE GEOPHYSICAL DATA AND ASSOCIATED CALCULATIONS

7.1 Using the geophysical log to 'fingerprint' the various coal zones and specific parts (samples) of the coal seams.

A method (Geophysically Derived Cumulative Distribution Density - GDCDD-method) was devised by the author to determine how geophysical logs between two adjacent boreholes could be correlated. As an opening remark it must be noted that the depiction of the density per individual sample could be inaccurate due to the fact that, as the geophysical probe approaches a specific sample, it is at the same time detecting the influence of the surrounding lithological units as is illustrated below (Table 3).

Table 3 Reaction of geophysical probe over the contact between coal and mudrock for Sample 32A

Depth	32A Rd		3.00	2.30	2.25	2.20	2.15	2.10	2.05	2.00	1.95	1.90	1.85	1.80	1.75	1.70	1.65	1.60	1.55	1.50	1.45	1.40	1.35
	2.62			1																			
196.92	2.56			1																			
196.93	2.46			1																			
196.94	2.38			1																			
196.95	2.38			1																			
196.96	2.25				1																		
196.97	2.19						1																
196.98	2.11							1															
196.99	2.03									1													
197	2.01									1													
197.01	1.89												1										
197.02	1.69																1						
197.03	1.65																1						

The following must be taken into account when looking at the figure above:

- Coal (at a depth of 197,03 m) as a rock type has a Rd of 1.65;
- mudrock (at 196,92 m) as a rock type has a Rd of 2.56;
- as the probe moves from mudrock (at 196,92 m) towards coal (at 197,03 m) it gives readings between 2.56 and 1.65 depending on how close it is to the coal. When the probe reaches coal it reads 1.65;
- the inverse is true when the probe moves from coal to mudrock;
- this factor is common to all geophysical logs; and
- the actual Rd reading should be 2.3, 2.3 and 2.29 as it approaches the contact, and then 1.65, 1.65 etc. as the lithology changes to coal. A reading such as 1.80, is a calculated average between mudrock and coal as the probe moves from one rock type to the other (Table 3 and Figure 42).

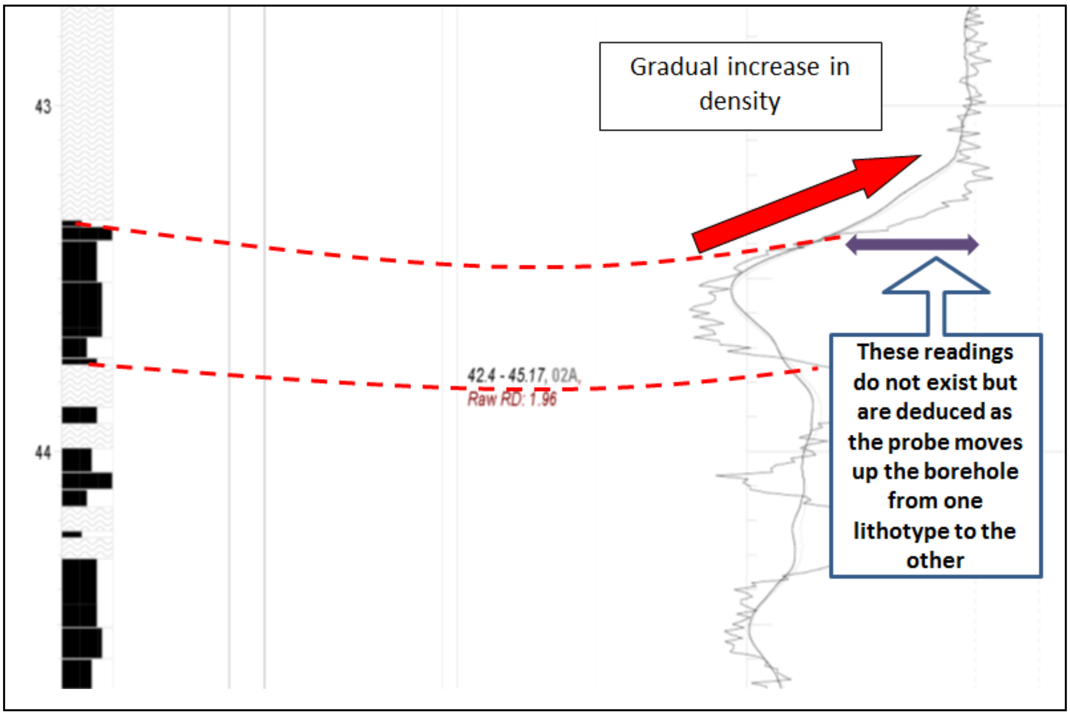

Figure 42 Detail illustration of gradual increase in Rd near the mudstone/coal contact as the probe moves upwards in the borehole. “Deduced” data is created in the process

When the geologist receives the geophysical log and starts correlating the various layers, he does so based on the visual characteristics of the geophysical graph. In the case of Figure 43 below it can be seen that the geophysical log, correlate with the lithology in the boreholes as well as between boreholes themselves.

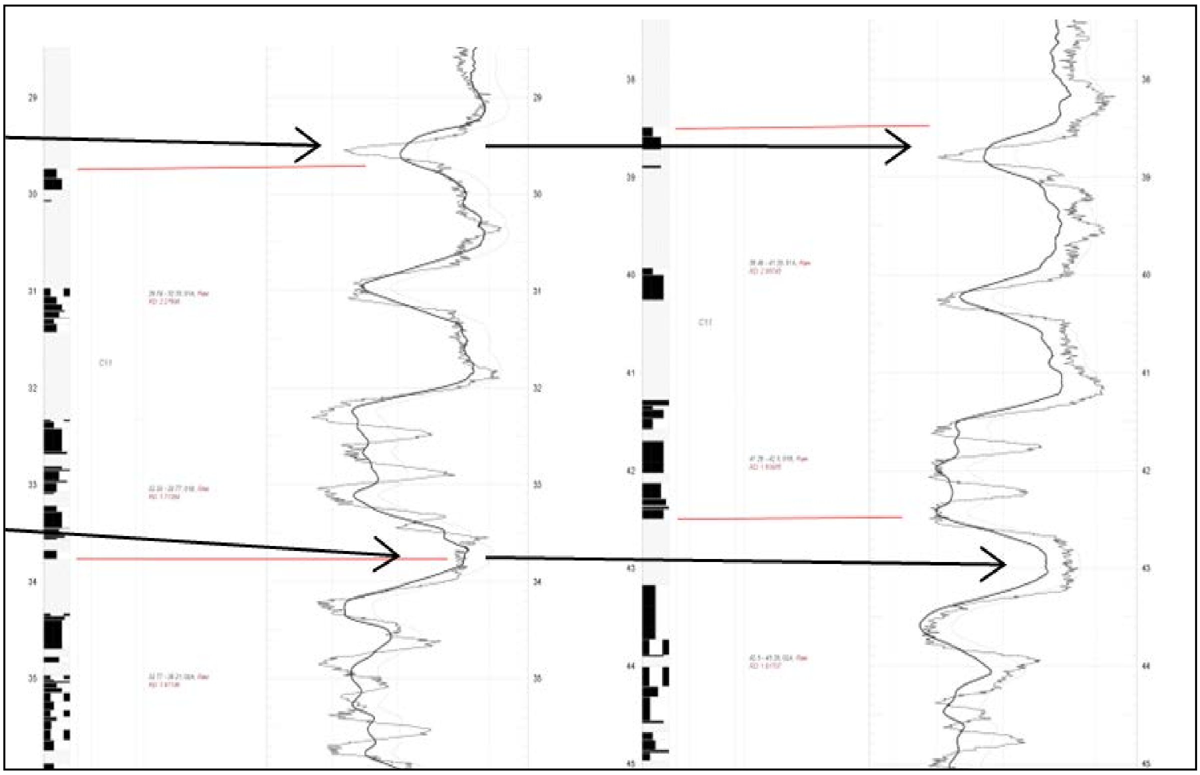

Figure 43 Correlation between boreholes using the geophysical profile

To what extent this visual, alignment takes place, is difficult to quantify. It is still unclear if one can prove, through some statistical process, that the two graphs are similar. Is it possible to know that the ‘fingerprint’ of the one graph is the same as the ‘fingerprint’ of the other graph, thereby proving that the rock types contained in that specific fingerprint are the same in terms of the lithology - a critical fact in coal geology and beneficiation?

A method of ‘fingerprinting’ the various coal samples was devised where it was decided to calculate the distribution of relative densities in the chosen geological intersection. As

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mentioned before in this chapter, an Excel spread sheet (Table 3) was used to give a value of 1 to each Rd, depending on in which class it reported to. From (Table 3) it can be noted that:

- The use of 0.05 relative density intervals (ie, 1.35, 1.40, 1.45 etc.) was used as the basis for distinction up to a Rd of 2.30. From a Rd of 2.3 to 3.0 no washability data were done at the laboratory and only a sink value was done at a Rd of 3.0;
- if a specific Rd value, at a specific depth, classified into a certain interval, then a value of 1 was inserted at that specific depth interval; for instance;
- at a depth of 196.92 m, the Rd reported was 2.56 and this was registered as a 1 in the column where the class interval is between 2.30 and 3.00;
- at a depth of 196.99 m, the Rd reported was 2.03 Rd. This triggered a 1 value in the in the column where the class interval is between 2.00 and 2.05; and
- the 1 value for the various class intervals was then summed to determine the distribution for the various classes of Rd's (Table 4).

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Figure 44 illustrates how a specific sample interval would be classified using the count of Rd's measured per Rd interval.

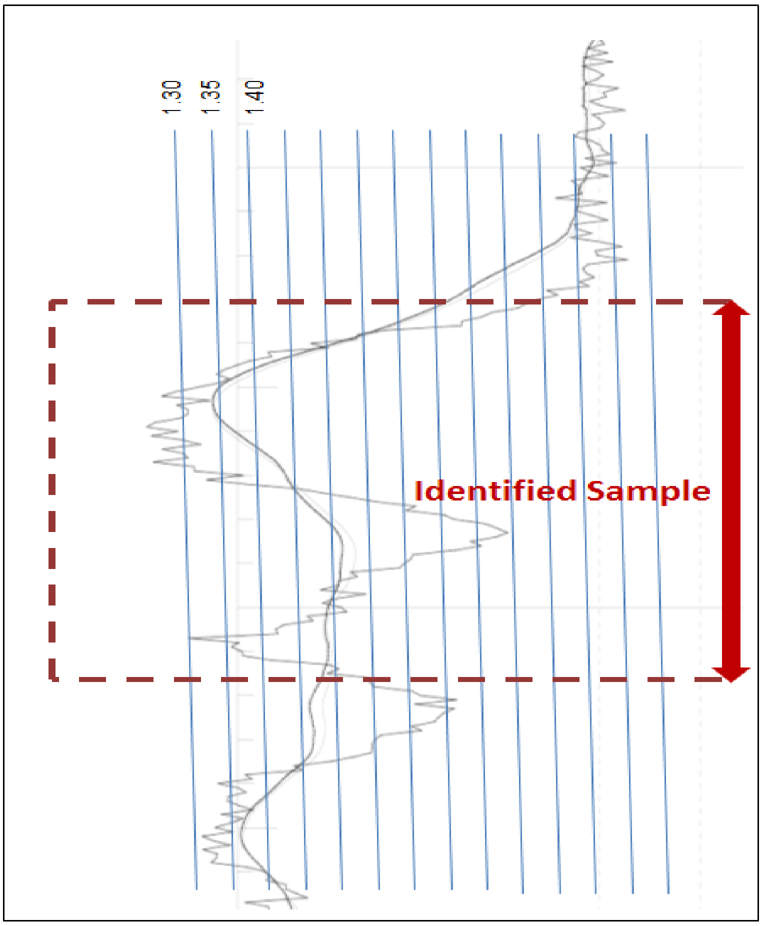

Figure 44 Detail illustration of how an identified sample would be classified using the various Rd intervals and counting the number of times a specific Rd value would fall in a specific class interval. The data of the graph is reported per centimeter and everything to the left of the vertical R 1,35 line would report to the 1,35 interval on the distribution diagram and so on

In the instance of Sample 1A in , this sample has a thickness of 4.23 m, the average Rd for the intersection was 2,26 and there were 288 Rd's in the intersection classed between 2.3 and 3.00. It had nine readings classing between 2.25 and 2.3, and four readings between 2.20 and 2.25.

Table 4 Distribution diagram of densities in borehole G250038 – for specific samples.

SampleNo	Thickness	Average RD	3.00	2.30	2.25	2.20	2.15	2.10	2.05	2.00	1.95	1.90	1.85	1.80	1.75	1.70	1.65	1.60	1.55	1.50	1.45	1.40	1.35
01A	4.23	2.26	0	288	9	4	5	6	6	4	9	4	6	6	3	4	8	10	17	18	10	7	1
01B	1.51	1.74	0	9	1	1	2	7	8	7	9	4	4	9	5	3	4	6	13	18	23	13	3
02A	2.90	2.00	0	95	4	8	6	8	8	8	13	12	8	14	10	12	16	11	20	19	15	6	0
03A	1.18	1.89	0	0	2	6	10	7	9	12	15	11	3	3	4	6	5	4	10	7	5	0	0
04A	2.32	1.74	0	0	6	5	8	8	4	8	8	9	15	15	12	13	13	20	22	34	19	11	3
05A	4.34	1.61	0	0	1	4	3	6	0	6	6	9	6	8	22	29	54	53	51	53	53	40	26
06A	1.65	1.62	0	0	0	0	0	1	1	0	1	7	7	6	12	19	14	20	15	18	21	13	8
07A	0.86	1.95	0	34	3	5	0	0	1	2	0	1	1	0	2	3	1	2	5	8	6	7	4
08A	1.93	2.25	0	124	7	10	5	5	5	3	2	6	2	2	3	2	6	3	1	7	1	0	0
09A	2.18	1.90	0	30	13	10	4	5	12	11	12	8	7	6	6	17	17	18	18	6	17	3	0
11A	2.08	2.29	0	153	2	4	3	4	2	3	5	8	2	1	2	3	0	5	13	0	0	0	0
12A	1.54	1.96	0	1	8	18	31	17	8	7	3	8	2	1	4	9	5	11	13	8	2	0	0

Variations in the shape and position of individual geophysical (Figure 43) graphs indicate the following:

- Faulting influences the relationship between the amount of coal and the amount of mudrock present in the specific intersection;
- if there are lateral facies variations, the shape of the graph, between boreholes also changes; and
- local post-depositional conditions, such as weathering and erosion, also change the shape of the density graph.

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The cumulative data derived, per sample, for all the boreholes in Figure 45 were used to portray geophysically derived cumulative distribution diagram (GDCDD) of the cumulative distribution of the relative density of the samples. As an example, a GDCDD was drawn for all the samples intersected in borehole G250038 (Figure 45).

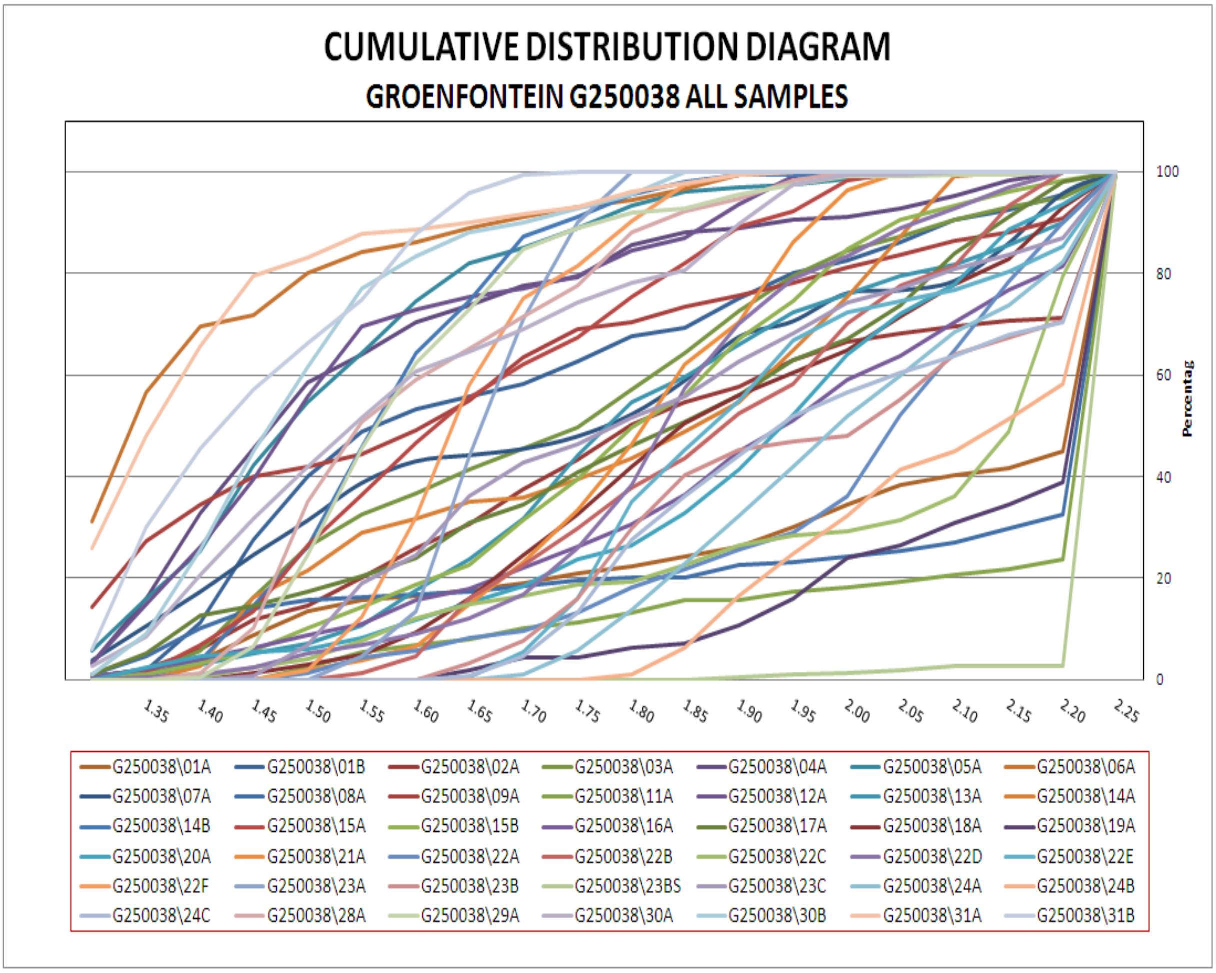

Figure 45 Geophysically derived cumulative distribution (GDCDD) line diagram for various samples in borehole G2500038 on Groenfontein. The horizontal axis depicts the relative density and the vertical axis the cumulative value of the density data per sample

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The method devised was used to compare the behaviour of a specific lithostratigraphic unit in adjacent boreholes (Figure 46).

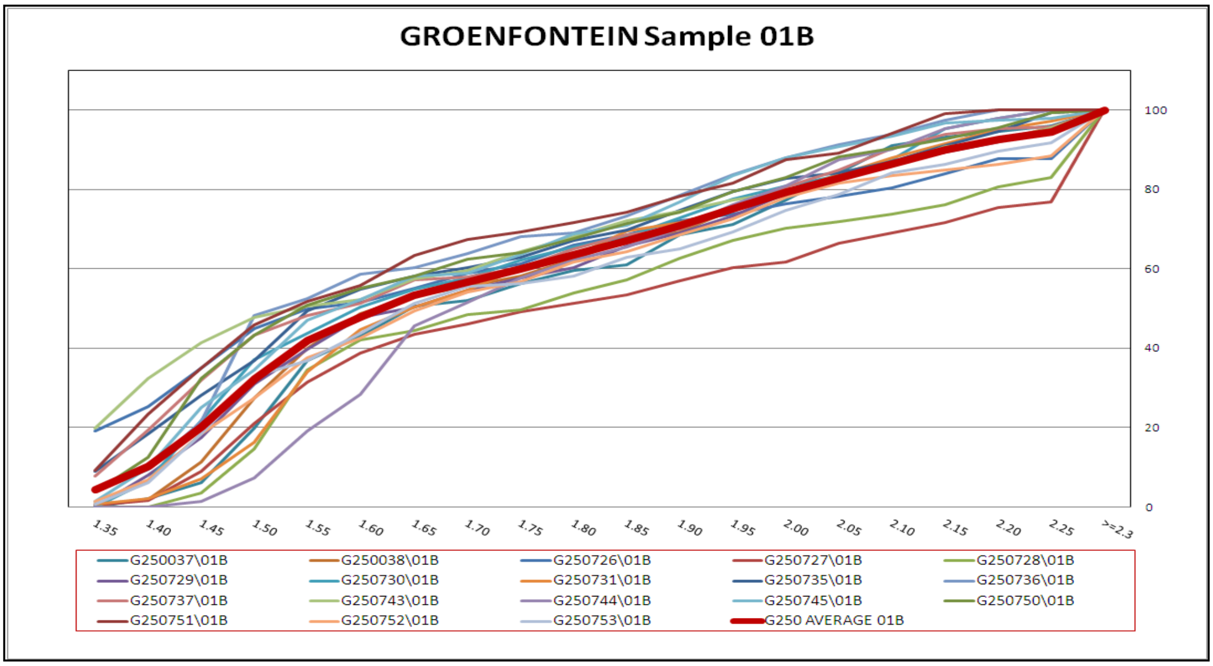

Figure 46 Geophysically derived cumulative distribution line diagram of Sample 01B in 18 boreholes . One line represents a cumulative distribution graph for a sample of a specific borehole

In Figure 46, the same sample (Sample 01B) is shown for 18 different boreholes . A different line colour is used in each instance. It can be seen that the derived curves have a similar pattern but are displaced vertically in relation to each other. This illustrates that there is a relatively good correlation between the same lithostratigraphic units between adjacent boreholes in which the stratigraphic unit occurs.

It was found that the method could also be used to check the accuracy of the raw data which the geologist uses to define the sub-units. The following example illustrates this. The Las file in the Las database gave the following information for the curve of Sample 08A for G250019 (Figure 47). From the figure it can be seen that the sample of G250019 reveals an anomalous trend.

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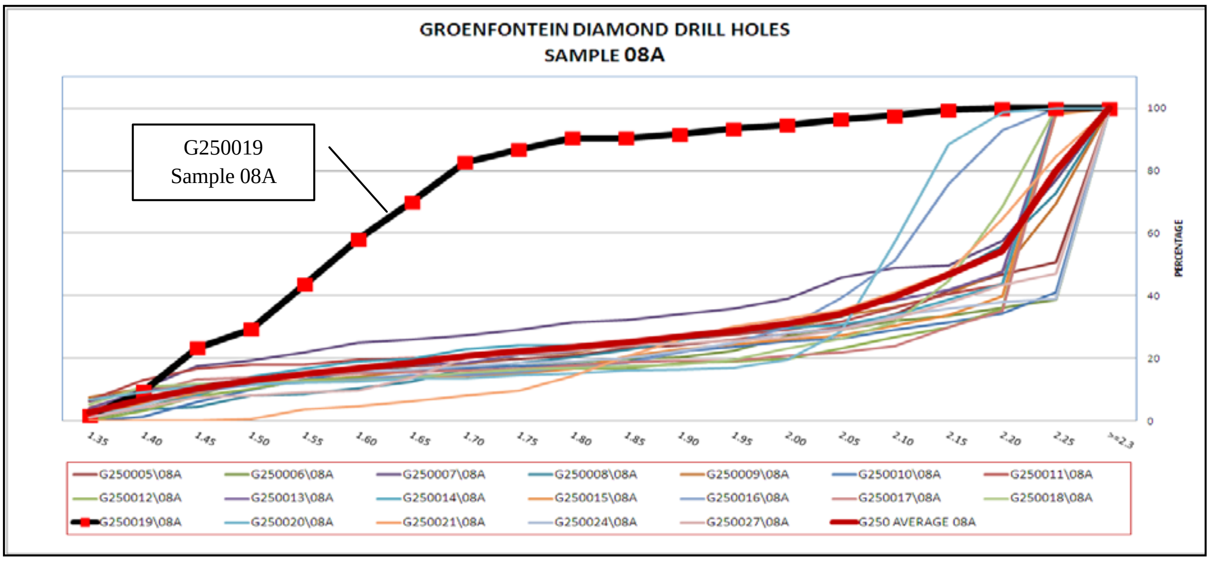
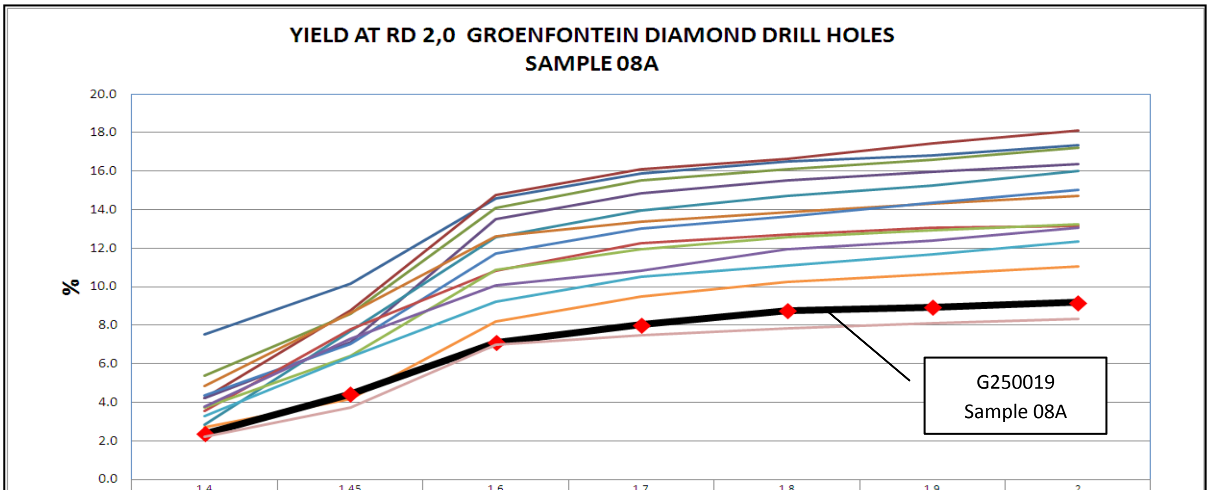


Figure 47 Anomalous curve for G250019 Sample 08A

The first part of the investigation into why this borehole appeared anomalous, consisted of interrogating the proximate analysis data. The proximate analysis data showed that G250019 had a very low yield (

Figure 48).



	1.4	1.45	1.6	1.7	1.8	1.9	2
G250014	7.5	10.2	14.6	15.9	16.5	16.8	17.4
G250005	4.2	8.8	14.8	16.1	16.7	17.4	18.1
G250030	5.4	8.6	14.1	15.5	16.1	16.6	17.2
G250008	4.2	7.1	13.5	14.8	15.5	16.0	16.4
G250010	2.8	7.7	12.6	14.0	14.7	15.3	16.0
G250015	4.9	8.6	12.6	13.4	13.9	14.3	14.7

Figure 48 Proximate information for the yield at various fractions for borehole G250019 Sample 08A.

The printed geology log from the database (Figure 49) revealed that Sample 08A consists of 90% mudstone (with a high Rd), and a small layer of coal at the bottom of the intersection. This distribution of the lithotypes makes it impossible for this Sample to have such high GDCDD graph while consisting of only 10% coal. Upon further investigation, it was found the Las data file in the database was incorrect.

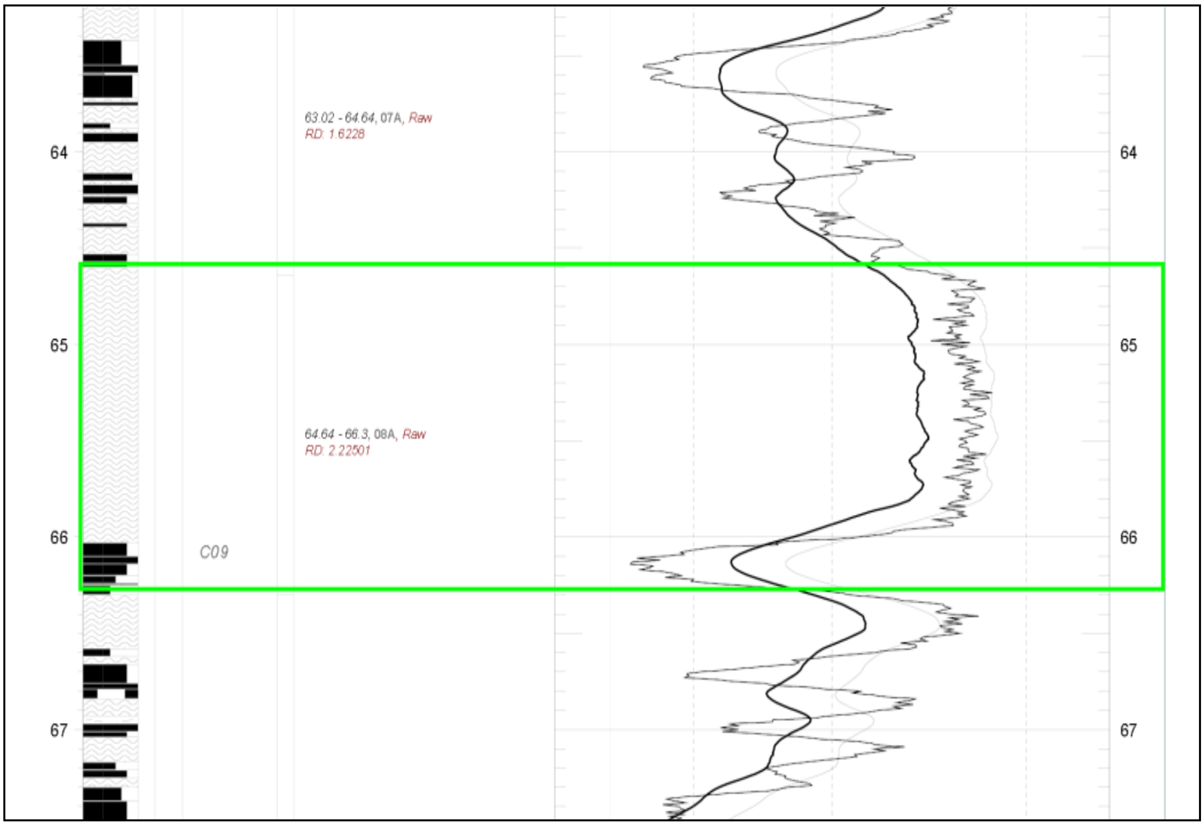


Figure 49 lithological/geophysical log for G250019 sample 08A

This method was easily applied to other anomalous GDCDD values and depending upon the outcome of such investigations, the database corrected accordingly. The database could thus be cleared of deduced data.

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8 DISCUSSION ON THE USE OF STATISTICALLY DERIVED GDCDD WHEN EVALUATING SAMPLES OVER THE STUDY AREA

The GDCDD method was tested in boreholes on four farms in the Study area along an irregularly-curved section line A-A’ (Figure 50). The farms were Geelbekpan – representing the northern part of the Study area (blue circle), Groenfontein representing the central Study area (green circle), and Gannavlakte/Ringbult – representing the southern part of the Study area (red circle in Figure 50). The test consisted of proving whether the sample lithology, determined in boreholes with continuous coring, could be reliably followed in the adjoining percussion boreholes along the section line to the detail required for mining purposes. If successful, this would confirm the practical usefulness of the method and result in considerable saving to the coal mining companies without compromising the results of the mining operations.

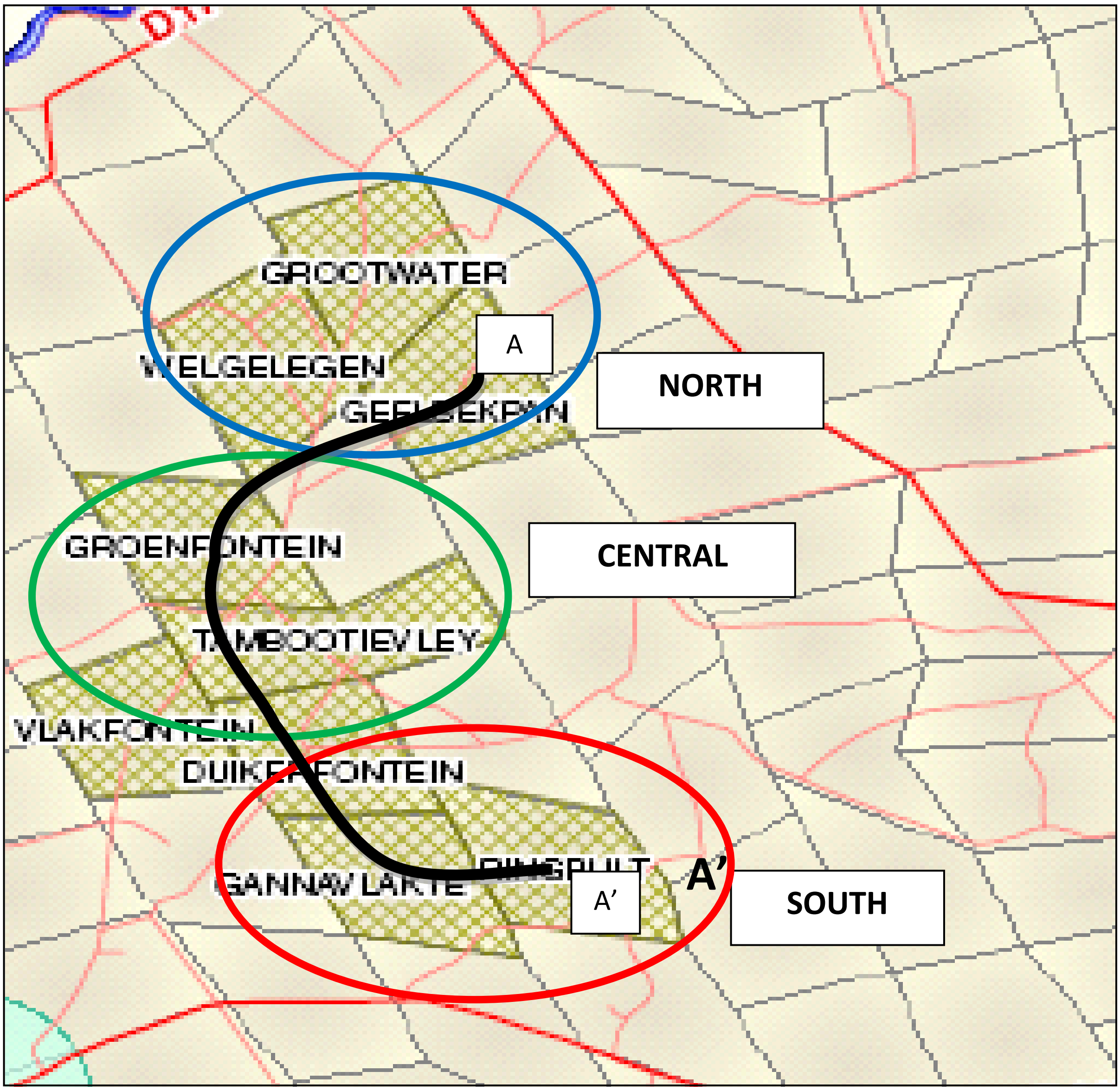

Figure 50 Four farms (Geelbekpan, Groenfontein, Gannavlakte and Ringbult) chosen to determine whether the method could be applied to more than one adjacent area

Figure 51 shows a profile of geophysically logged boreholes along the A-A’ line of Figure 50, which illustrates the lateral continuity of the coal zones.

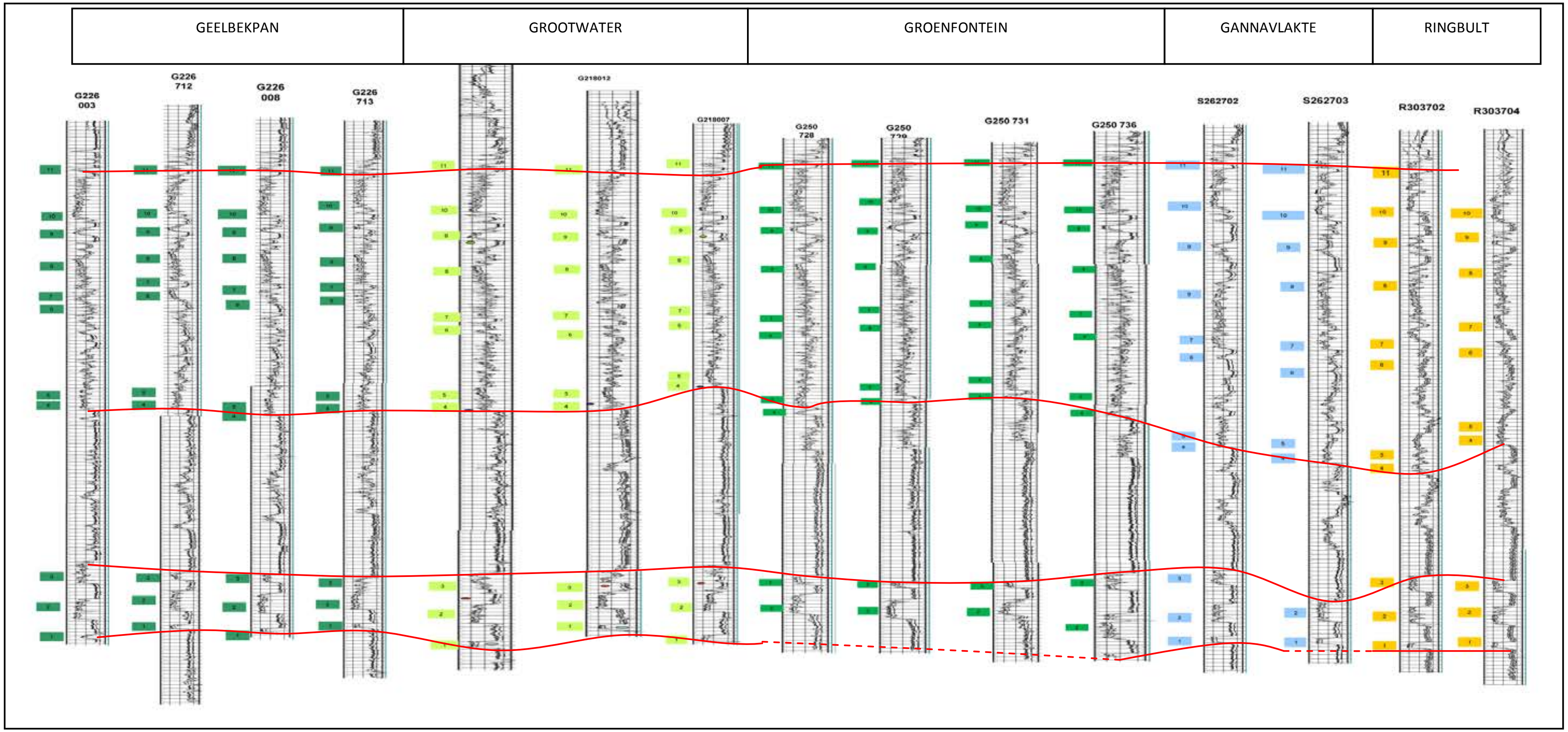

Figure 51 Geophysical profile along A-A' illustrating varying geology over the Study area. Coloured labels denote the bottom of coal zones. Red lines denote major stratigraphic boundaries

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8.1 Method for discussing the GDCDD of samples

The method explained in Chapter 7 was applied in the three non-immediately adjacent areas of the Study area (north, central and south). The parameters used in the description of the curves and significant results of the GDCDD graphs were condensed under a series of headings in relevant tables accompanying each graph. These headings with their meanings are listed below.

8.1.1 Graphs

Four graphs illustrating GDCDDs from the central area top left, the northern area, bottom left and the southern area, top right as well as a combined graph of all three areas, bottom right (Figure 53), are given and used as a base for a tabulated discussion of the selected samples.

8.1.2 Tables

A table consisting of thirteen points of discussion for each sample is given. The points of discussion in the tables are summarised below.

8.1.2.1 Angle of repose of graphs

The angle of a curve in a graph is the angle between the X-axis and the best-fitted straight line of the relevant curve. In the GDCDD graphs the wording "*angle of repose*" commonly refers to the percent value (read in the Y-axis) that the GDCDD curve assumes at a certain relative density (read in the X-axis). There are two significant angles of repose, one between Rd 1.35 (where the curve intersects the X-axis) and Rd 2.25 (portion one), which can be fitted with a straight line and a second one from Rd 2.25 to Rd 3.0 which could be fitted with another straight line at a different slope than the first one. The point of the curve at Rd 2.25 represents generally the inflexion point of the GDCDD curve for each sample. The second portion of the curve is sometimes very steep, and in any event, much steeper than the first portion and depends on the analytical yield of the sample. These Rd values are based on the

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standard used for the reporting of proximate data on the Study. No analysis is done on the fractions between 2.25 and 3.0.

The best indicator of angle of repose is the angle of the curve in portion one. A low angle of repose equates up to 40% increase over the first part of the curve (portion one, up to Rd 2.35). A medium angle of repose equates up to 80% increase over the same portion, while a high angle of repose would amount to an 80% increase (Figure 52).

8.1.2.2 Start point of graph

All the graphs start at a Rd of 1.35.

8.1.2.3 Spread

The spread indicates how spread the lines are from each other at a certain Rd. A Rd value of 2.0 was chosen as reference point as it is usually the cut point at which a typical power station product coal would be produced from the Ellisras Basin coals. In this thesis, a narrow spread signifies that the envelope of the GDCDD lines is within 20% at a Rd of 2.0. Narrowly spread data would indicate that the lithology is similar, while widely spread data would indicate larger variation in lithology.

8.1.2.4 Yield at a Rd 2.0

The analytical (proximate analysis) yield at a Rd of 2.0 is given. The Rd value of 2.0 was chosen as reference point as it is usually the cut point at which a typical power station product coal would be produced from the Ellisras Basin coals, as stated above.

8.1.2.5 Remarks – Yield at a Rd 2.0

General remarks regarding the yield at a Rd of 2.0 are discussed in the table.

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8.1.2.6 Raw Rd Sample

The raw Rd of the sample will be indicated in the table. This Rd is determined by weighing the sample in water and in air in the field and was discussed previously.

8.1.2.7 Thickness (in meter)

Thickness of the sample is reported in the table.

8.1.2.8 Remarks regarding raw Rd and thickness

Remarks regarding the data of the thickness and raw Rd are included in the table. There is an inverse correlation between the raw Rd and yields as a low raw Rd is a reflection of the high amount of low Rd material (coal) in the sample, and this would equate to a higher yield.

8.1.2.9 Standard deviation at a Rd of 1.60 and 2.0

The table will contain a tabulation of the standard deviations calculated at two Rd points namely 1.60 and 2.0. These two Rd points were chosen on the following basis;

- 1.60 = the cut point on the washtable, at which nearly all the vitrinite would be removed from the coal and 2.00 = the cut point at which powerstation coal can be produced from the Grootegeluk Formation coals.
- In order to quantify the standard deviation of the data, two reference points were chosen per graph and the standard deviation of the curve values at those points were calculated and compared. The two points of interest are at a Rd of 1.60 and at 2.0 (Figure 52).

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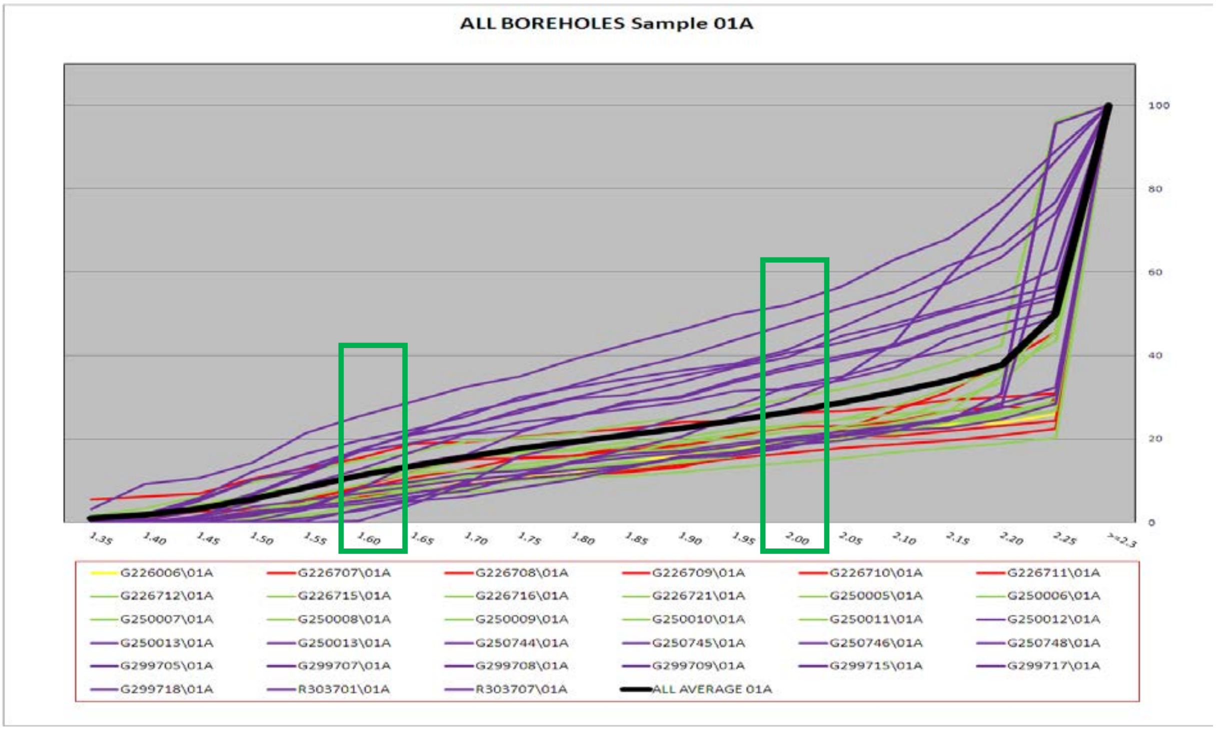

Figure 52 Standard deviation calculations at specific Rd's (1,60 and 2,0) - green blocks

8.1.2.10 Comments on standard deviation

General remarks regarding the standard deviation are dealt with. A higher standard deviation signifies a wider spread of the GDCDD envelope, as explained above. If the volume of mudrock increases in the stratigraphic unit in a specific borehole, as compared to neighbouring boreholes, then it has the effect of increasing the variance at the Rd 2.0 value.

8.1.2.11 Correlation accuracy by geologist

Comments, with a certain degree of subjectivity, concerning the complexity or otherwise at which a geologist could correlate the coal seams in different boreholes by means of geological and geophysical data, are included.

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8.1.2.12 Modelling accuracy

Comments, with a certain degree of subjectivity on the ease and accuracy at which a geologist could set up and maintain a geological model of the samples or zones, are included in the table.

8.1.2.13 Use as SANS 10320 data correlation point

In South Africa, the SAMREC code is the standard for reporting resources and reserves. For coal the reporting is based on the SANS 10320 standard. Therefore, a subjective comment on the adherence to the SANS 10320 standard, is included in the table. Although the comments are subjective, this does not imply non-adherence to the SANS 10320 standard. A Competent Person would necessarily be the final judge of any remark made in a report on resources and reserves.

8.2 Specific example from the study area

8.2.1 Sample 01A

In this chapter, Sample 01A is dealt with in detail with its relevant tabulation of comments as an example of the work undertaken to prove the usefulness of the method in interpreting the continuity of a coal seams (samples) or coal seam mining units (zones) in percussion holes. All the samples shown in the stratigraphic column (Figure 19) have already been dealt with in this thesis. Discussing the rest of the samples would merely be a repetitive exercise; all graphs of these samples and their relevant tabulations are shown in the Addendum on the attached CD.

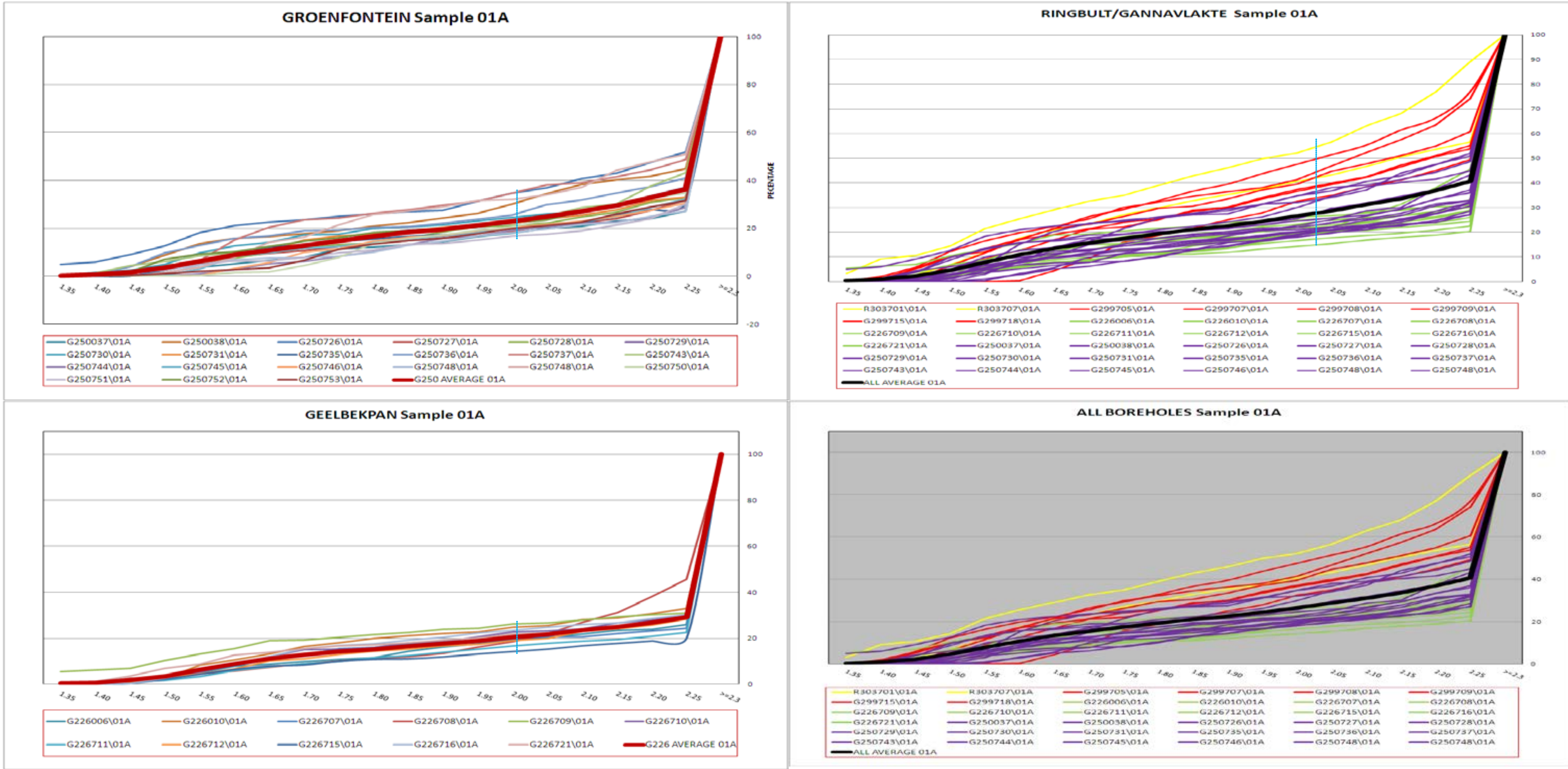


Figure 53 Combined GDCDD of Sample 01A (Spread at and Rd of 2.0 indicated with light blue dotted line)

Table 5 Summary of Sample 01A data.

BASIC INFORMATION ABOUT SAMPLE 01A	SUMMARY	GEELBEKPAN	GROENFONTEIN	RINGBULT	GANNAVLAKTE
Angle of repose of graphs	Sample 01A	Low	Low	Low	Low
	In the case of Sample 01A (Figure 53) the low angle of repose is due to the fact that there are not much low density material (coal) in this Sample (Figure 54), which would equate to a low yield.				
Start point of graphs at Rd 1.35	Data values start at the same point.				
Spread	In the south, the spread is ± 34% (between 18% and 52%) illustrating that the lithology is more variable in this area.				
Yield at Rd 2.0 – Sample 1A	Sample 01A	11.27	13.82	26.71	31.83
Remarks – Yield at Rd 2.0	The low yield can be seen for Groenfontein and Geelbekpan but towards the south - Ringbult and Gannavlakte – the yields are higher as shown above. Figure 58 (page 102) also illustrates that up to Rd 1.70 the higher values in the GDCDD graph correspond to higher yield values in the yield graph.				
Raw Rd Sample 01B	0,21 variance	2.23	2.27	2.02	2.09
Thickness (m)	0.93 m variance	3.82	2.89	3.33	3.29
Remarks on raw Rd and	There is an inverse correlation between the raw Rd and yields of Sample 01A. The thickness is reasonably				

thickness	constant (Figure 55, page 99), but for two very deep faulted boreholes in the central part of the Study area. On Geelbekpan Sample 01A is thicker due to the fact that an extra thin coal seam is developed above Sample 01A. These extra coal samples occur regularly at the Grootegeluk mine area.								
Standard deviation at a Rd of 1.60 and 2.0	**Relative density**	**1.6**	**2.0**	**1.6**	**2.0**	**1.6**	**2.0**	**1.6**	**2.0**
	Sample 01A	3.1	3.6	4.5	5.1	28.3	28.4	7.4	6.0
Comments on standard deviation	The standard deviation (σ) for Ringbult farm is about eight times higher than for the other farms in the Study area. The reason for this is the local weathering on this farm (Figure 59).								
Correlation accuracy by geologist	The degree to which the geologist can correlate Sample 01A is good and this sample is easy to correlate (Figure 54), but Ringbult/Gannavlakte is more difficult due to the fact that the geology varies more over this area. Problems with correlation, like faulting and correlation errors made by the geologist, would be prominent in the GDCDD curves. It can be seen from Figure 54 that although the thickness of the individual coal layers in Sample 01A varies a bit, the fact of the matter is that there are two coal seams in the sample and this can be followed over the whole Study area. At Geelbekpan, locally, a third coal seam is developed in Sample 01A.								
Modelling accuracy	Good correlation, easy to model. No factoring necessary to compensate for modelling accuracy at Groenfontein and Geelbekpan. Some factoring may be necessary at Ringbult/Gannavlakte due to the weathering of Sample 01a in this area.								
Use as SANS 10320 data correlation point	The use of the GDCDD proves that the method can be used to prove the continuity of Sample 01A in the area with a high measure of accuracy in the north and a good measure of accuracy in the south. Using the GDCDD method it is possible to correlate boreholes in a section and structural anomalies has a definite effect on the shape of the curves in the GDCDD diagrams. By comparing the shape of the various GDCDD diagrams of a chosen sample or								

	zone it is possible to see the effect of faulting and/or weathering on any specific borehole. The lateral variation of Sample 01A on Ringbult illustrates this fact clearly. The graphs for Sample 01A is closely spaced not showing large variation but for the north. The yields for the south are higher than those of the northern area. The thickness varies between 2,89 m and 3,82 m. Geelbekpan has the thickest Sample 01A of the farms as there is an extra thin coal seam developed in Sample 01A. It was also possible to note how the stratigraphy changes laterally from farm to farm or area to area. For Sample 01A the σ values are eight times higher in the south than that for the other farms. This is largely due to weathering in the south. There is a good correlation between yields and the GDCDD curves. This fact should be easily understood as the bases of the GDCDD is counting the various amounts of densities within a certain interval and the more dense material found in the interval the lower the yield. For modelling purposes, Sample 01A should be easy to model. No factoring necessary to compensate for modelling accuracy at Groenfontein and Geelbekpan. Some factoring may be necessary at Ringbult/Gannavlakte. The use of the GDCDD proves that the method can be used to prove the continuity of Sample 01A in the area with a high measure of accuracy in the north and a good measure of accuracy in the south.

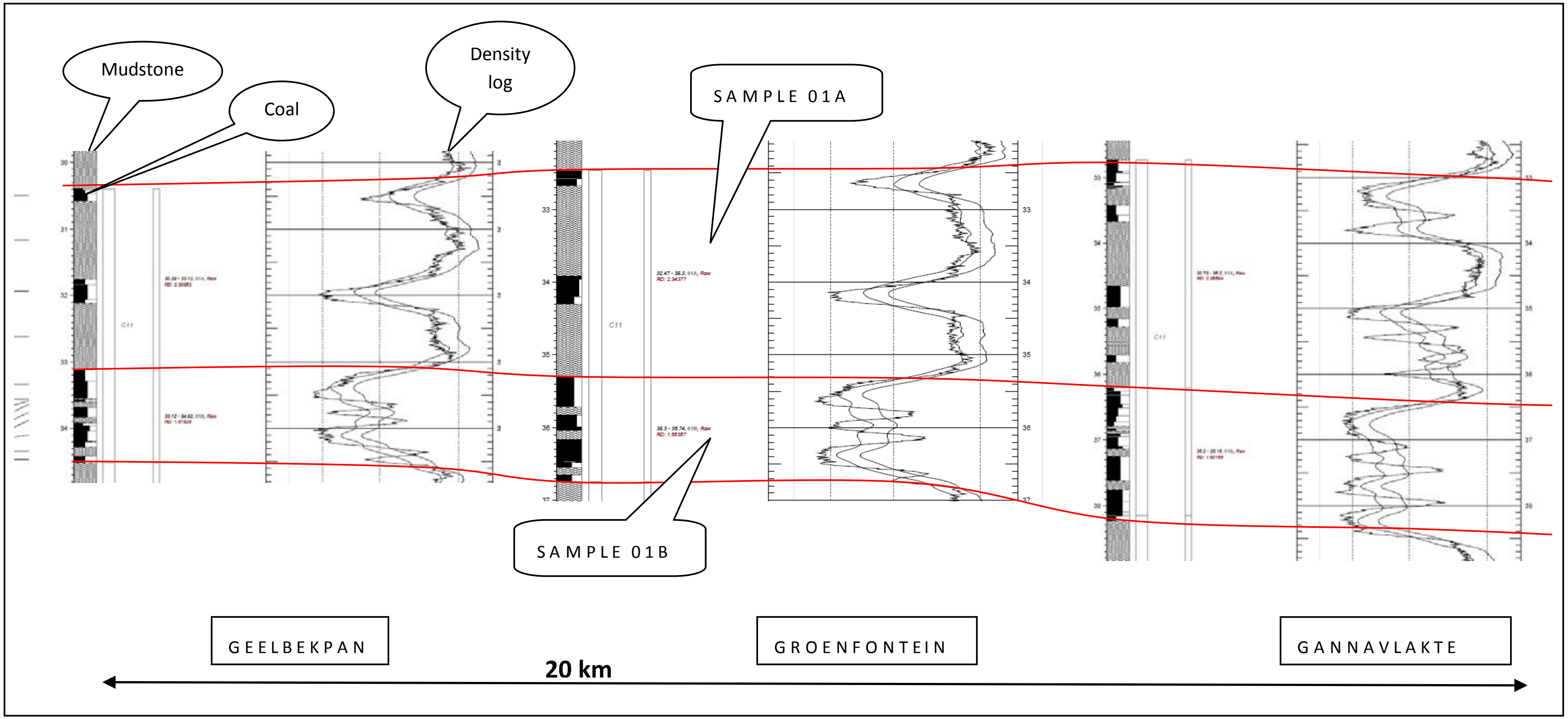


Figure 54 Graphical representation of Sample 01A and Sample 01B on the Study area illustrating the varying lithology of this sample over the Study area

Figure 54 graphically illustrates the lithology as described by the geologist and the associated geophysical log as captured by Weatherford, that illustrates the varying lithology. In Figure 55 the thickness of Sample 01A over the Study area indicates that the thickest development of Sample 01A is in the south (blue area).

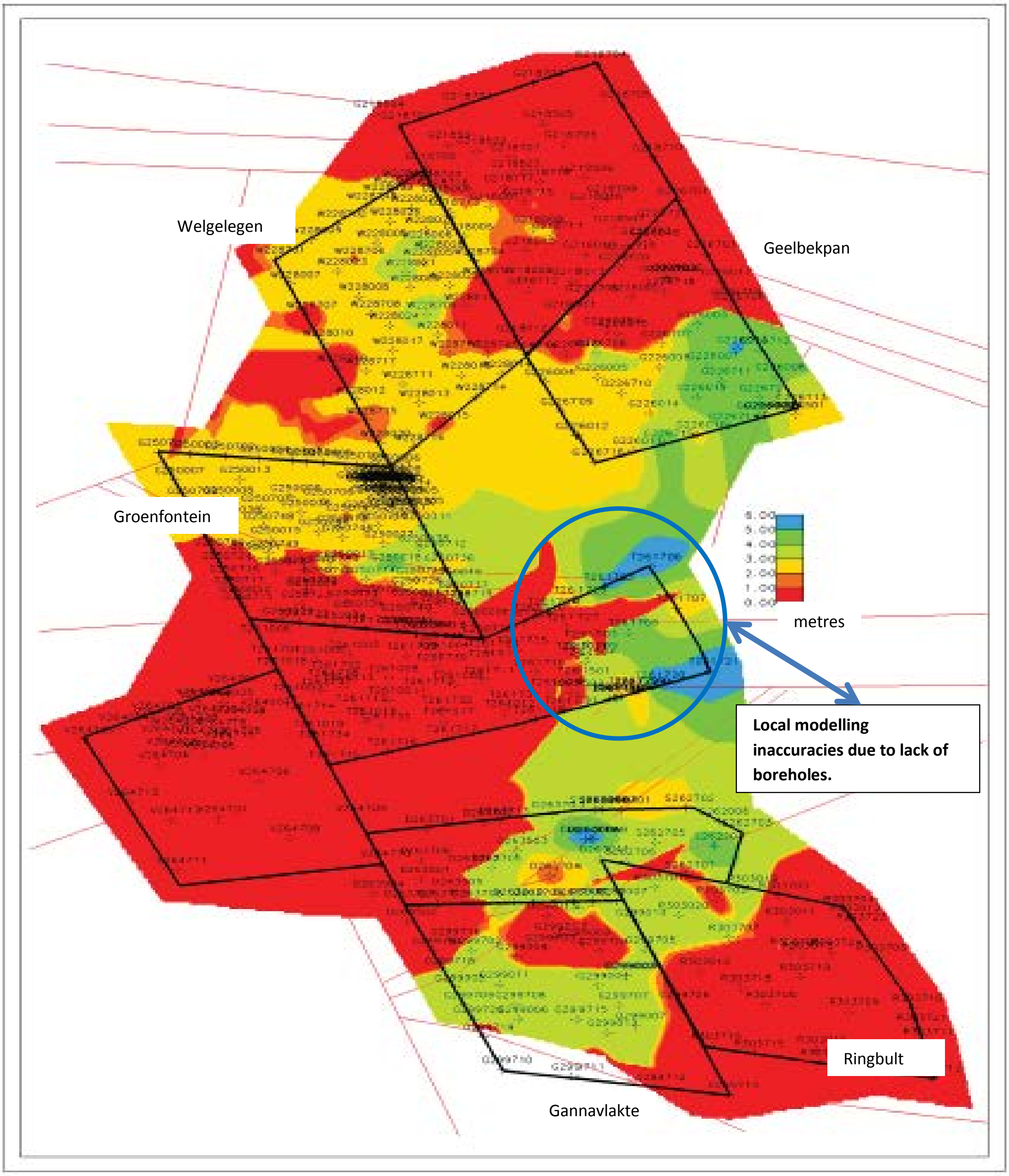


Figure 55 Thickness of Sample 01A over the Study area showing thickest development of Sample 01A in the in the south (blue area)

8.3 Relationship between GDCDD and yield calculated from proximate data and the relationship between cored and percussion boreholes' GDCDD curves

A specific section line (B-B') was chosen on the Study area to illustrate the concept of how the GDCDD curves compare with the actual proximate data for chosen samples (Figure 56). In this exercise both cored and percussion boreholes were selected along a section line. Furthermore, GDCDD curves were plotted for the two drilling methods (in the top part of Figure 58) in the same section line to find out what type of variation would occur in the same lithological unit when using a cored or a percussion borehole.

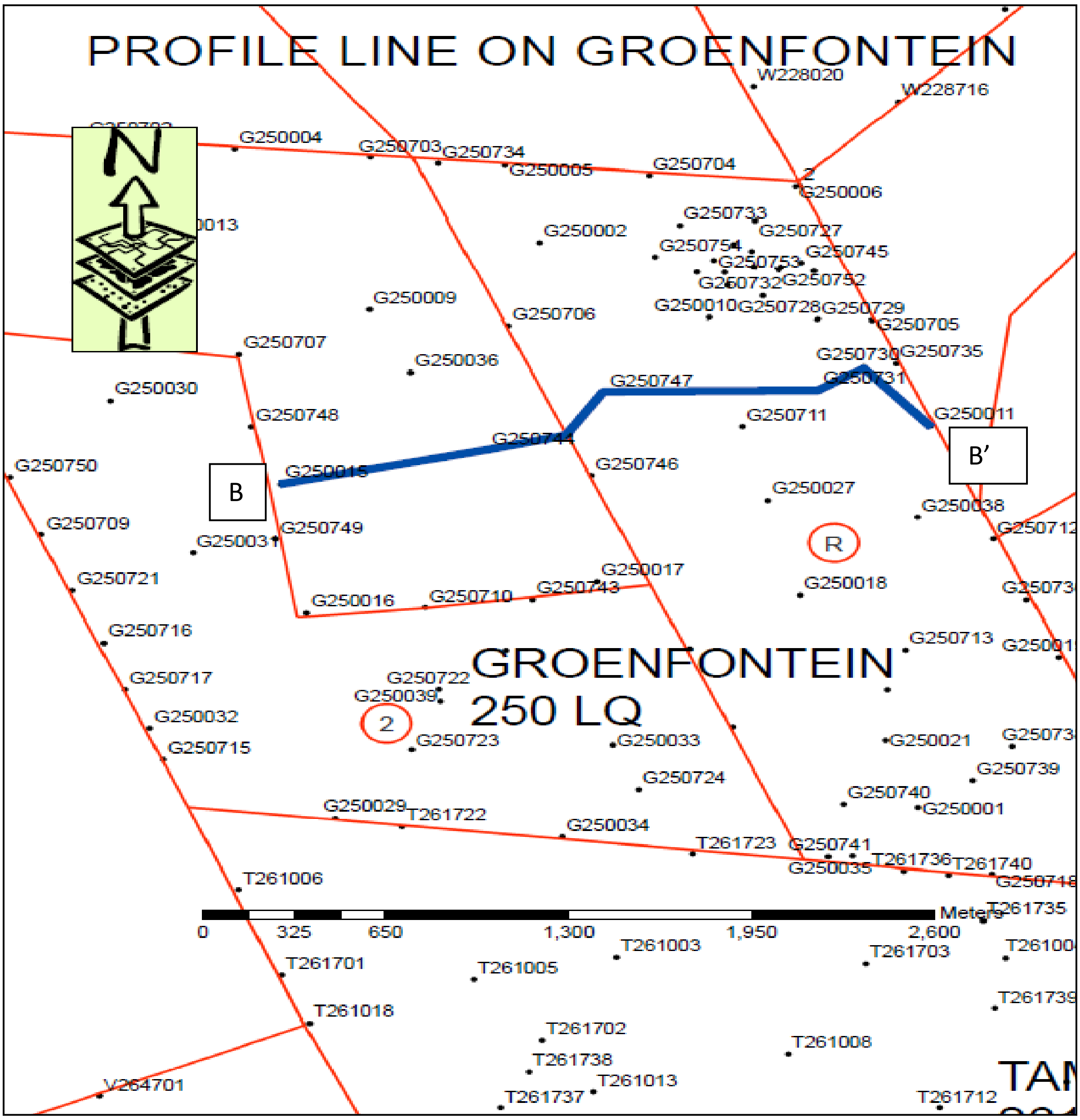


Figure 56 Plan of section line (B - B') on Groenfontein

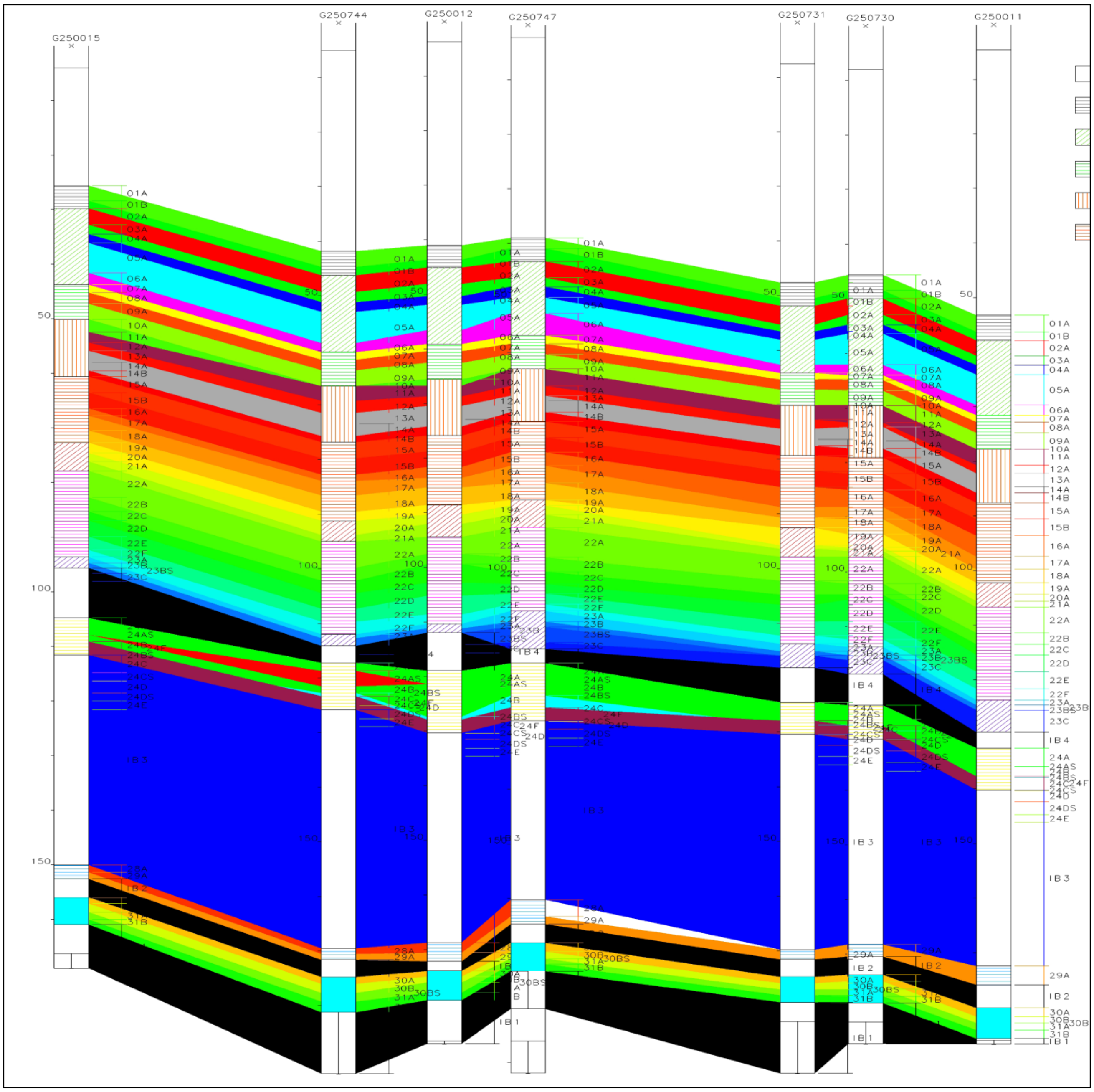
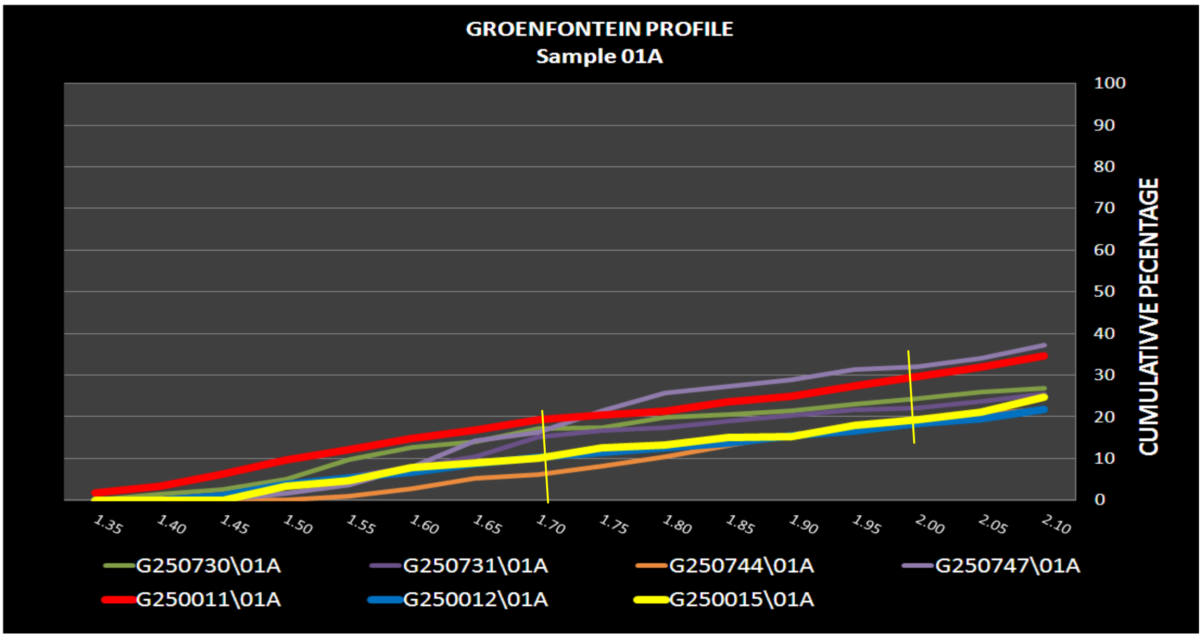
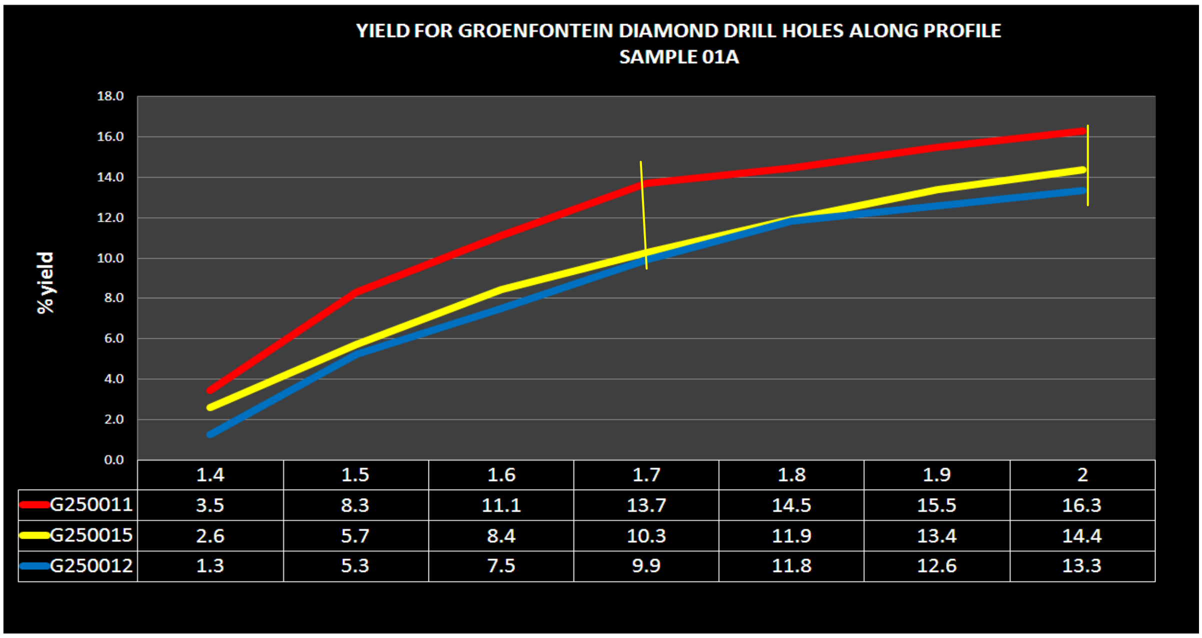


Figure 57 Profile along section B - B’ on Groenfontein, Different color represents different Samples

Figure 57 illustrates the stratigraphic position of the various samples in the boreholes. Each colour represents a sample. The sample cross-section was chosen to test whether percussion boreholes could be used as a data point as defined in SANS 10320. This was done for all the samples found in the Study area but only the following samples (01A, 01B, 02A, 03A, 04A, 05A, 7A and 11A) are reported here for the sake of simplicity and clarity.

It was found that the two drilling types yielded the same curves, in terms of position, angle of repose, start point etc. and whatever yield curves the cored boreholes has, the percussion drilling would replicate them (Figure 58). Figure 59 illustrates how local geological conditions influence the spatial distribution of coal seams over the whole Study area where G250736 is in the north and the other boreholes occur in the south.





	1.4	1.5	1.6	1.7	1.8	1.9	2
G250011	3.5	8.3	11.1	13.7	14.5	15.5	16.3
G250015	2.6	5.7	8.4	10.3	11.9	13.4	14.4
G250012	1.3	5.3	7.5	9.9	11.8	12.6	13.3

Figure 58 Sample 01A, GDCDD (on Groenfontein) at the top and yield curves along a selected profile at the bottom. Yellow vertical lines are discussed in point 8.4 on p. 104

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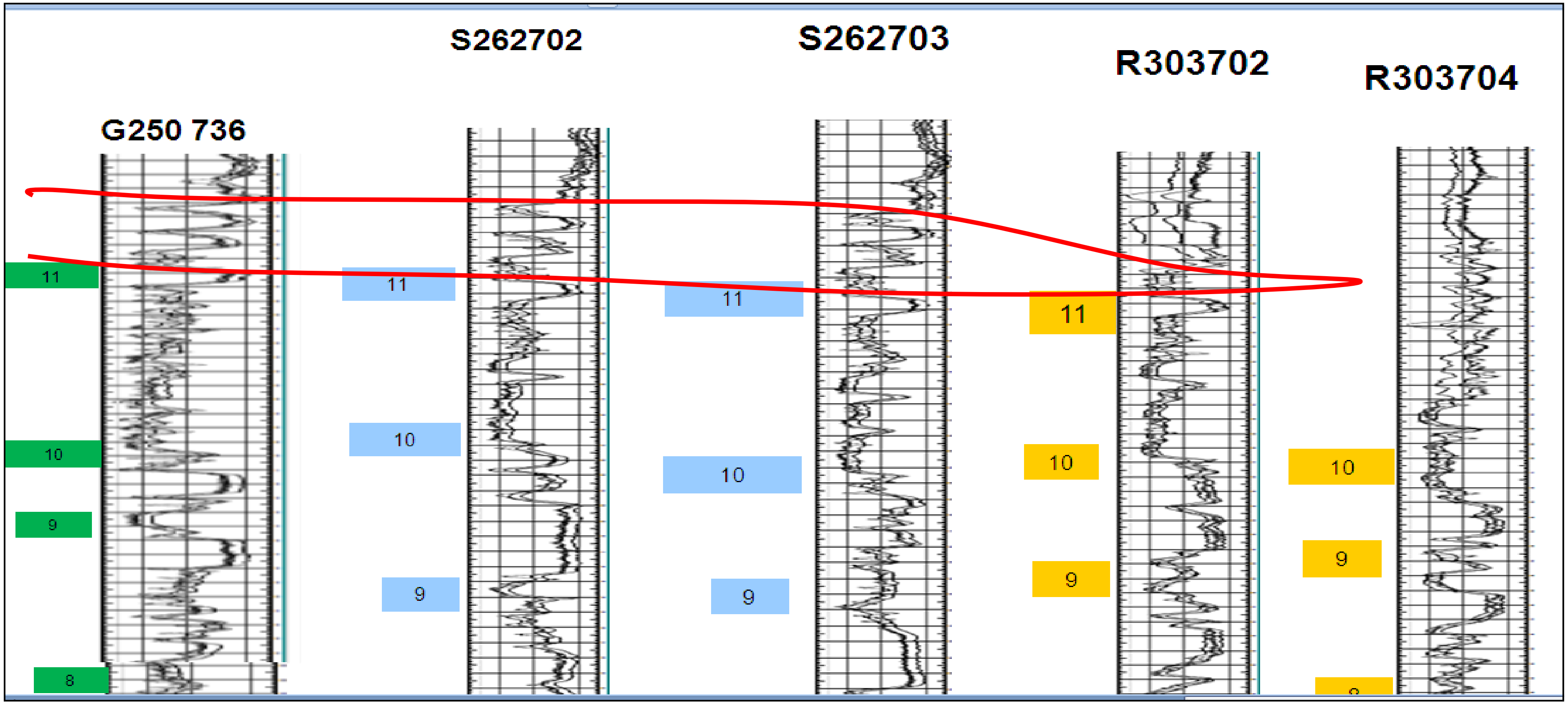

Figure 59 Local lithological variation, based on geophysical logging, from north to south in Sample 01A, ending on Ringbult (on the right of the figure). Colored labels denote the bottom of individual coal zones. Red line is the correlation of Zone 11

This figure shows how Sample 01A is influenced, primarily, by weathering due to the fact that it is the top coal seam in the area and that the rocks are not totally horizontal but influence by structural conditions in the Ellisras Basin.

8.4 Comparison between analytically derived yield and the GDCDD curves

It was previously mentioned in this thesis that the GDCDD method has a 'built in' error because the geophysical tool interprets relative densities as it moves, for instance, from mudrock to coal. These densities could not be an actual true reflection of the lithotype encountered, for instance Rd 2.7 for mudrock or Rd 1.6 for coal, but an interpreted Rd depending on the distance to the next lithotype encountered in the borehole, or if the probe is situated inside the lithotype then the actual relative densities is returned.

The method of comparing the CDCDD curves and actual proximate data yield (Figure 58) has illustrated that there was a specific correlation between the two values and that the GDCDD curves resemble the yield curves. The yellow vertical lines in Figure 58 are used to illustrate this point. In the lower part of the figure, the actual yield for Sample 01A, shows that at a Rd of 1.70 the yield is between 9,9 and 13,7, while in the upper figure (GDCDD curves) the values for all the boreholes are between 8 and 20. At a Rd of 2.0 the actual yield is between 13.3 and 16.3 while on the GDCDD curves the values are between 15 and 35 – nearly double those of the yield curves. In short the red line for borehole G250011 is higher up on the graph for both the yield graph and GDCDD.

After seeing these trends in the graphs a combined graph was then prepared to investigate this relationship in more detail (Figure 60). In this example the correlation between the two sets of data from the farm Welgelegen is shown and this figure illustrates the effect of the 'built in deduced' data (the deduced Rd values reported as the probe moves from coal to mudrock). How this comes about was discussed in detail in Chapter 7.1 (on p. 76) above.

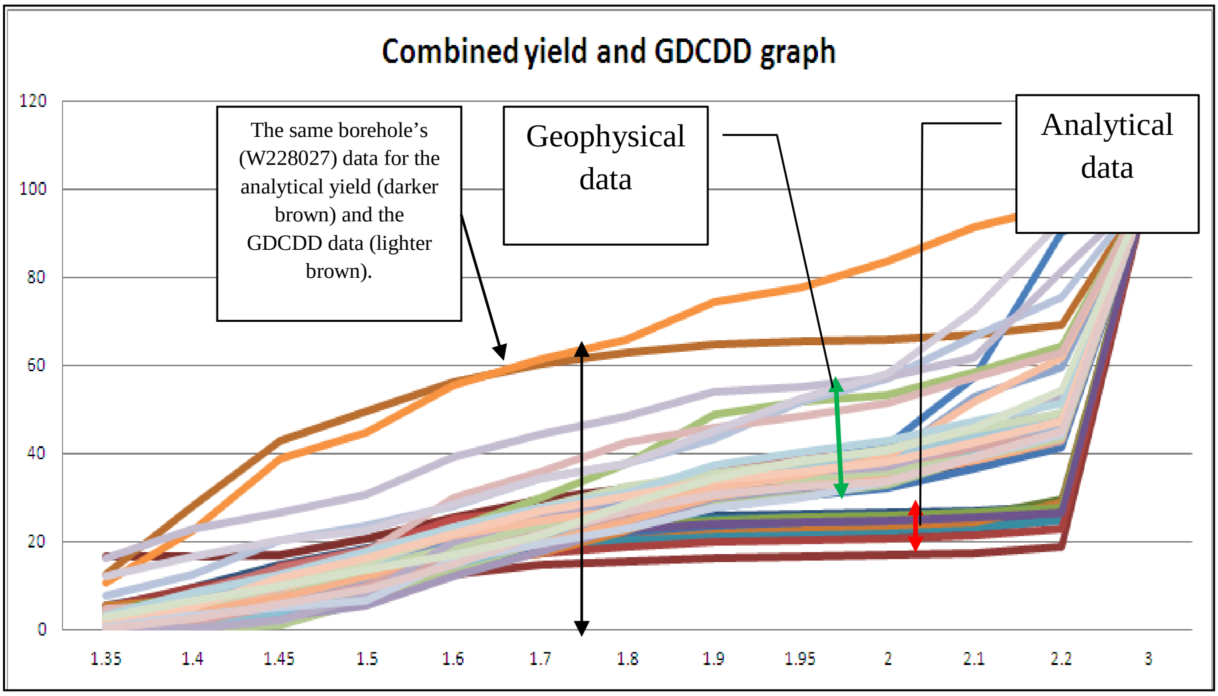

Figure 60 Combined actual yield and geophysically derived data for Welgelegen showing divergence starting at about an Rd of 1.75. Darker lines are usually actual analytical densities and lighter colored lines the GDCDD curves. Horizontal axis is relative density and vertical axis is percentage

It can be seen in the graph (Figure 60) that up to a Rd of 1.75 the curve envelope for the analytical yield and GDCDD envelope have a similar position on the graph. Above an Rd of 1.75 the two datasets diverge. The GDCDD shows an increase, at a higher trend, than the analytical yields. This divergence is caused by the derived "deduced" data.

The conclusion that can be drawn from Figure 60 is that the GDCDD curves mimic the actual analytical yield up to an Rd of 1.75.

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8.5 Anonymous check of information from neighbours

During the latter stages of this thesis the author was sent anonymous data from four boreholes by a friendly neighbour to determine whether the GDCDD method can be used on this data and expose any correlation problems.

Although the data differed from the Weatherford data in that the readings are taken 10 cm apart, it still clearly shows local variation in geology for Sample 32A (Figure 61) and Sample 2A (Figure 62).

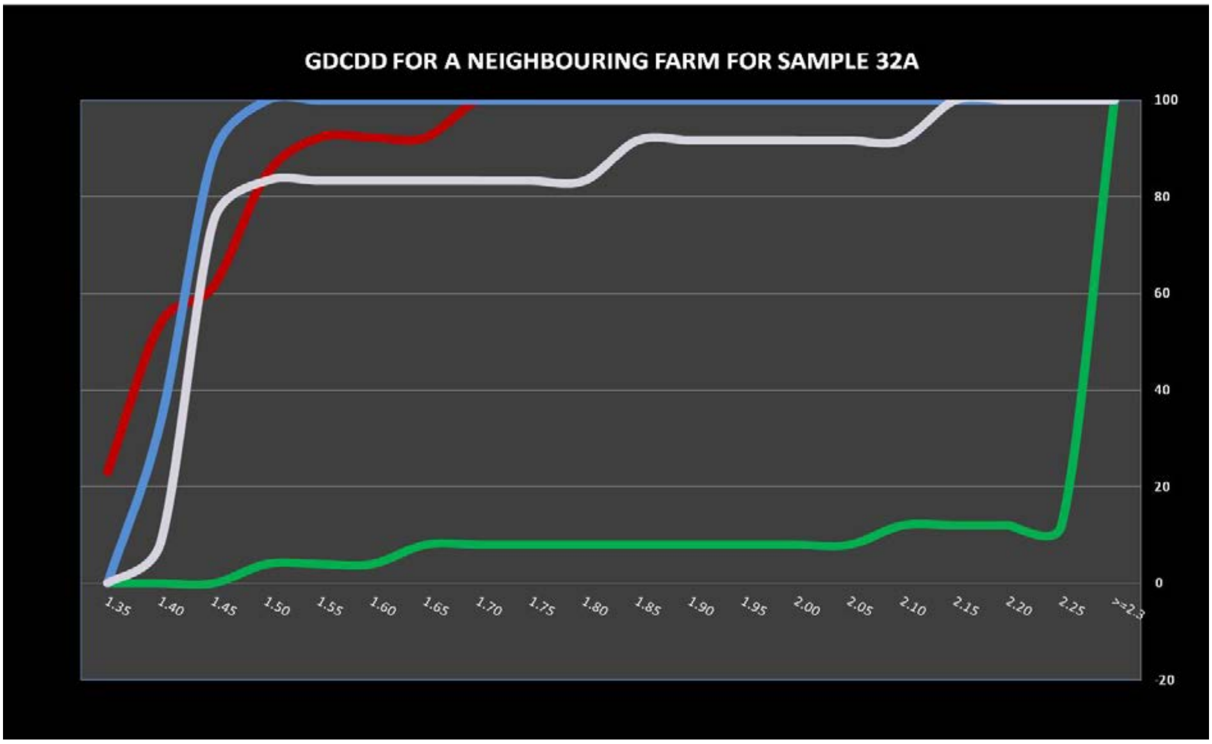

Figure 61 Anonymous data for Sample 32A illustrating faulting in the borehole with the green curve. Jumps in lines are a function of the data being collected in 10 cm intervals

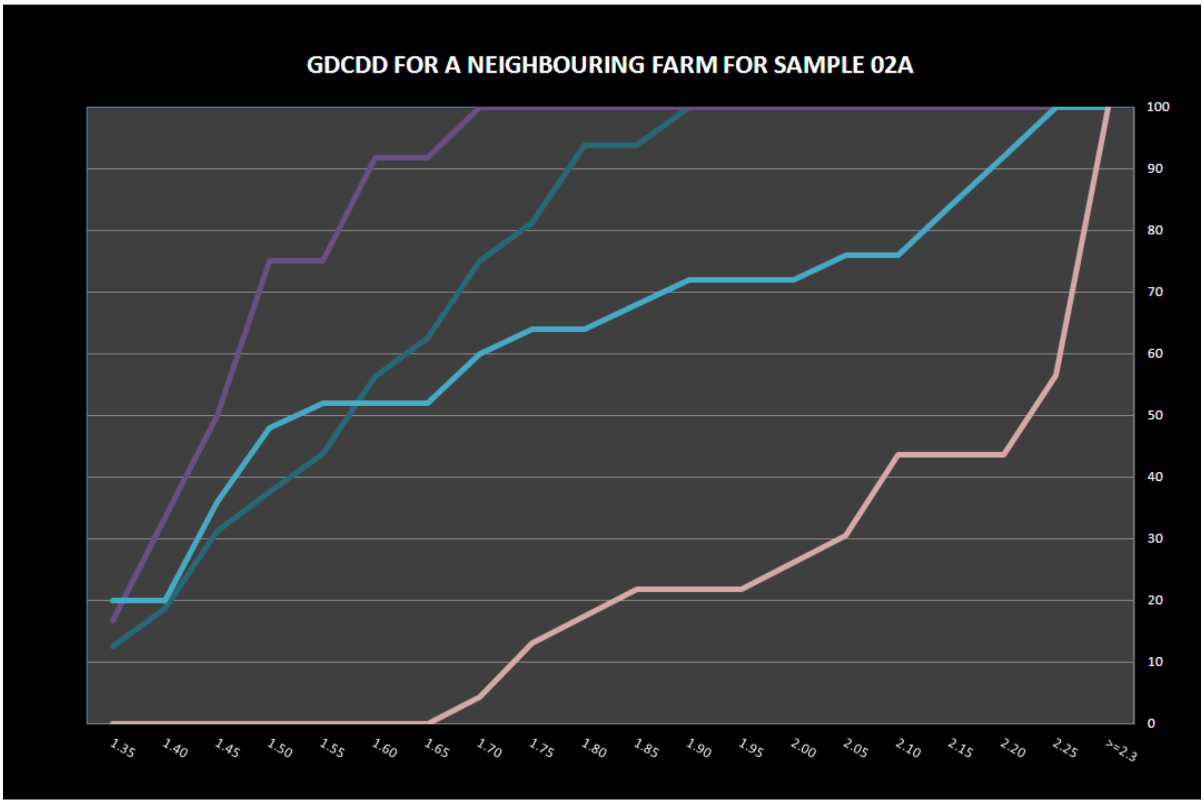

Figure 62 Anonymous data for Sample 02A illustrating effect of weathering in the area

The anomalous curves were queried at the source of the data. The reply, in all the cases where anomalous graphs were seen, was that those specific samples were influenced by local anomalous geology. In the case of Sample 32A – faulting (basically no coal left in the intersection) and in the case of Sample 02A – weathering (coal material weathered away and only higher density mudrock left behind).

8.6 Summary on the use of statistically derived GDCDD curves when evaluating samples over the Study area

When considering all the data discussed in this chapter on the application of the GDCDD method to the classification of samples in the Ellisras Basin coals, the following conclusions and observations can be made:

Angle of repose of graphs

- The angle of repose in the GDCDD was found to be similar to and indicative of the yield up to a Rd of 1.75, when 'deduced' readings start to play a role and the curves then deviate from the wash curves derived from the proximate analysis;
- the angle of repose of the GDCDD curves can be subdivided into high, medium or low and the amount to which this happens is a function of how much low density material there is in the sample. The more low density material (coaly material), the higher the angle of repose;
- the GDCDD for samples 28A to 32A has a very high angle of repose due to the inherent nature of these coals – having a low ash content and associated high yield; and
- the amount of interbedded waste material, like sandstone or mudstone, influences the shape of the curves.

Start point of graph at Rd 1.35

- The graphs do not have the same point of origin; and
- the more low density material, the higher up on the y-axis the curve starts which is indicative of the amount of coal found in the sample.

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Spread

- The GDCDD method allows the user to define spread in terms of percentage;
- the percentage spread for samples in individual geographical areas, depositional environments or simply various farms can be compared and quantified. The spread of the curves indicates how varying the depositional environments were; and
- the amount of mudrocks in the sample influences the spread for a specific sample and if the geologist does not take care when defining from-to depths of samples in boreholes accurately, it shows up as anomalous on the GDCDD curves for that specific sample.

Yield at 2.0

- The data for the analytically derived yield curves (proximate data) are mimicked by the values derived in the GDCDD curves;
- currently the yield at a specific ash product cannot be deduced for the GDCDD curves as a method for deducing the ash content from the density measurements has not yet been invented;
- the variance in yield is clearly shown by the GDCDD method;
- there are variances in yield due to the lithological changes in the area;
- when comparing the GDCDD curves for cored boreholes to those of the percussion boreholes it is clearly seen that there are no differences in the two drilling methods:
- the GDCDD method of evaluating the lithology is independent of the drilling method;
- the method allows a geologist to use the GDCDD curve as a method of comparing unknown boreholes with known boreholes and makes deductions about the lithological similarities; and
- when drilling at a certain grid spacing, it is possible to fill some of the drill points with percussion drilling and use that information, reworked by means of the GDCDD method, to come to a conclusion regarding the lateral continuity, thickness and to a certain extent yield, and form an opinion regarding the SAMREC status of the resources.

Raw Rd

- It has been shown that the geophysically derived (Vectar) density compares to within 95% and more of those measured with conventional methods;
- the geophysical data can give a geologist accurate predictions of the relative densities of any rock types or intersections chosen in the boreholes; and
- the geophysical measurements of the relative density can be used as an independent verification of the field Rd's.

Thickness

- The thickness of individual samples can vary significantly over the Study area;
- there are instances where the thickness varies very little over the Study area; and
- the thickness can vary due to the depositional environment or it can be caused by faulting and weathering.

Standard deviation

- By using the σ at two Rd points (1.60 and 2.0) it is possible to compare the σ between boreholes and to make some deduction regarding the accuracy of the correlation between boreholes;
- some samples, depending on the variations in lithology, has a small σ value and if there is a large variation in lithology a large σ results; and
- the Grootegeluk Formation samples – samples 01A to 22F has an average σ value of 10 (Figure 63) and the Swartrant Formation - Sample 28A to 32A has an average σ value of 14 (Figure 63). The reason for this is the fact that there are interbedded sandstones in these samples that complicate correlation.

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Correlation accuracy by geologist

- By using the GDCDD curves it is possible to clearly highlight anomalous geology like faulting and weathering;
- sample boundary, correlation errors is shown up in the GDCDD curves;
- deduced raw data captured in the database is highlighted in the GDCDD method;
- combining the standard deviation and GDCDD curves helps the geologist to decide on how accurately samples can be correlated; and
- it is shown that anonymous data can be correlated using the GDCDD method.

Modelling accuracy

- Factoring could be necessary to compensate for modelling accuracy in instances where there is a lot of local variation in lithology;
- care should be taken when doing correlation in some parts of the Study area (such as Gannavlakte and Ringbult);
- the inherent good lateral correlation would mean that modelling can be done to a high degree of accuracy; and
- In terms of modelling it was shown there is good lateral correlation between the samples on the various farms, which should make it easy to model the samples in the Study area.

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Use as SANS 10320 data correlation point

- The GDCDD method can be used to trace the lateral continuity of samples with a high degree of accuracy;
- percussion drilling has no detrimental effect on the shape of the GDCDD curve;
- there is no difference in the shape of the curves produced from percussion and cored boreholes. The two drilling methods are equally reliable with regard to their GDCDD curves;
- it is possible to make use of infill percussion drilling and use the GDCDD method to compare the results with known cored drilling boreholes; and
- there is a direct correlation between GDCDD curves and analytical yield curves below an Rd of 1.75.

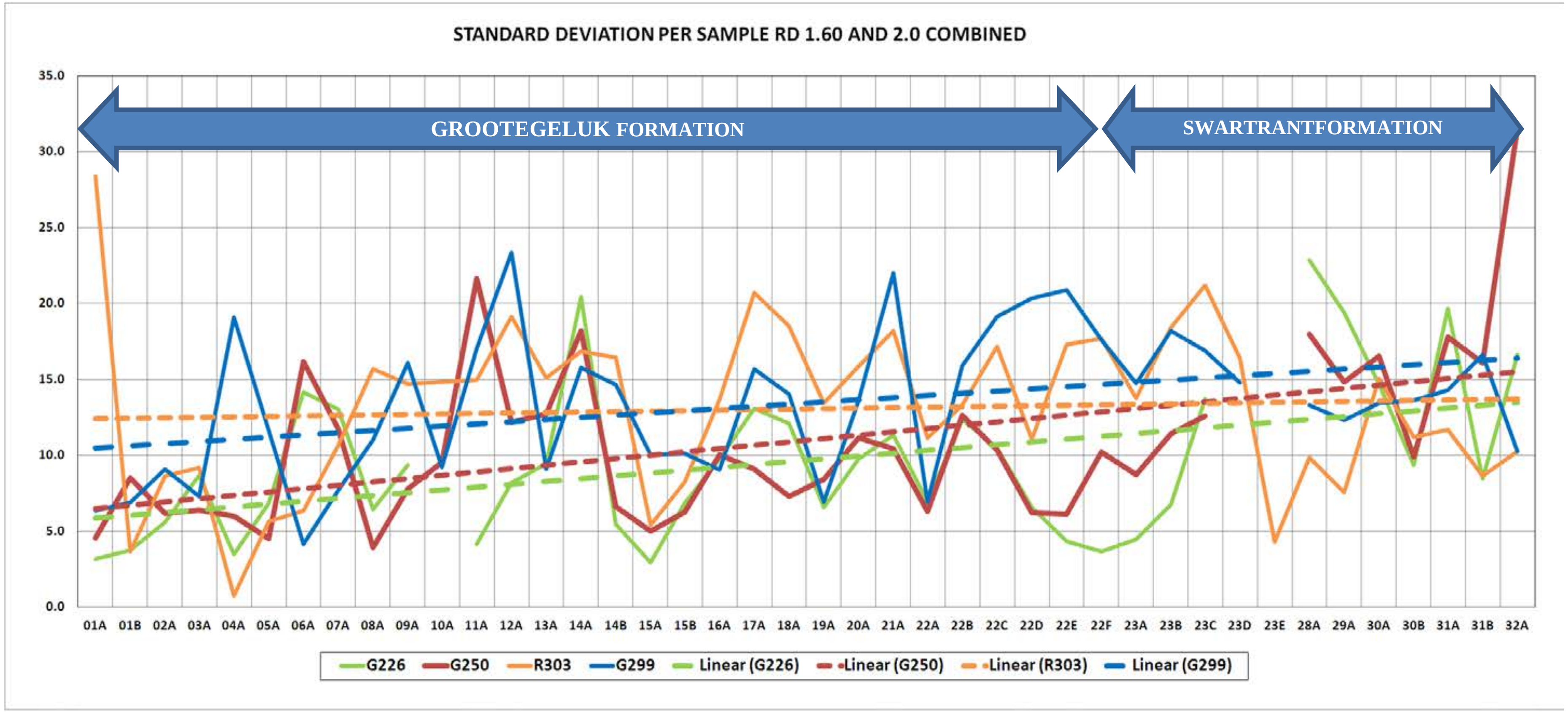

Figure 63 Standard deviation line graph for the combined average standard deviation of Rd 1.6 and 2.0, for all the samples in the Ellisras basin found in the Study area (per farm) and the associated trend lines

9 DISCUSSION ON THE USE OF STATISTICALLY DERIVED GDCDD WHEN EVALUATING COAL ZONES

At the only productive mine in the area, Grootegeluk, the coal is not mined on a per sample basis but per coal zone and these coal zones are divided into benches (Figure 64). The Study area subdivision for the zones is shown in Figure 65. The GDCDD method, used for evaluating the various coal samples in the Ellisras Basin area, was applied to the coal zones in the Study area to determine whether the method is applicable to these zones and could assist a Competent Person in classifying the resources.

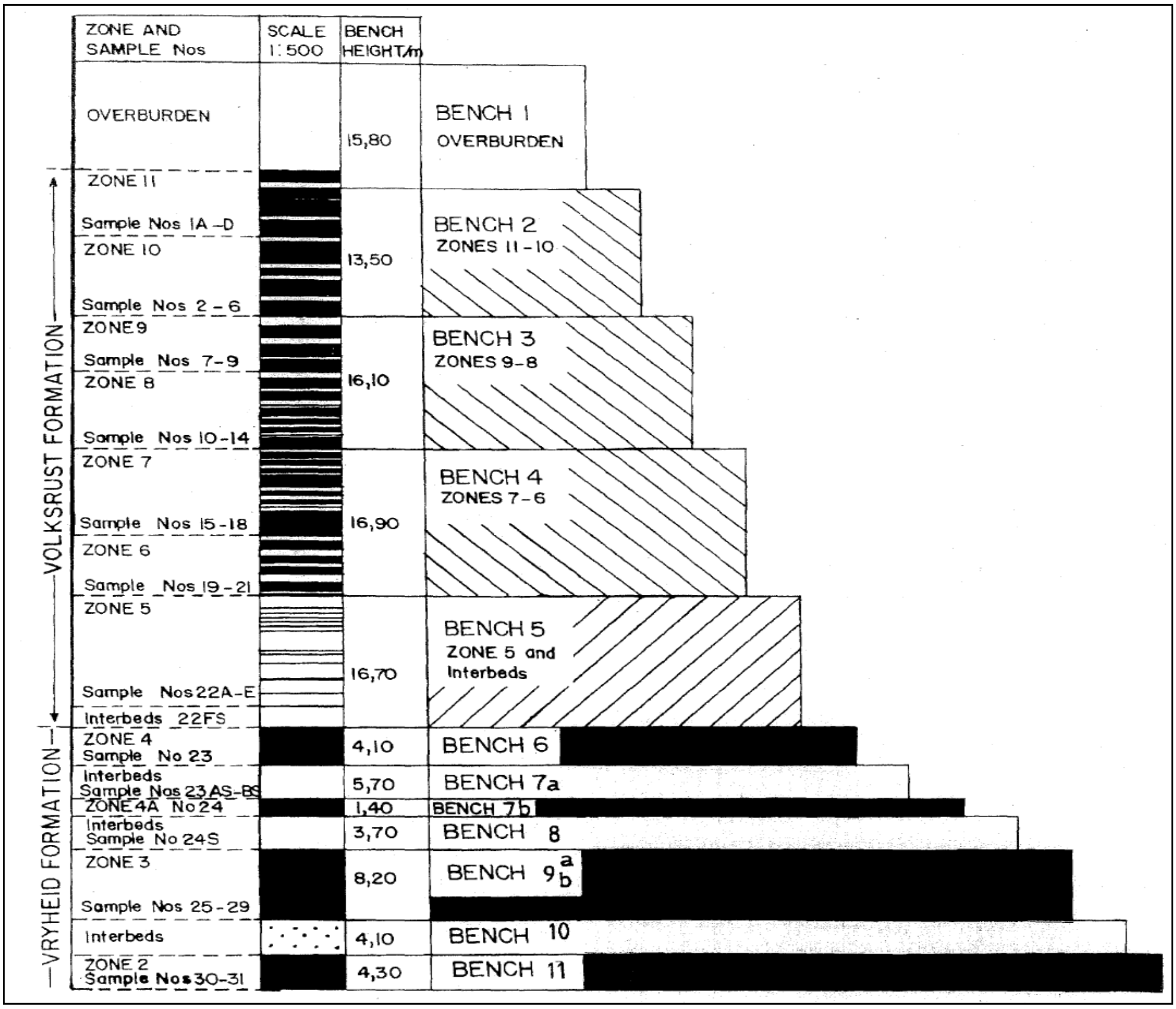

Figure 64 Grootegeluk subdivision of coal zones into mining benches, Dreyer (1994)

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KAROO BASIN CORRELATE	ELLISRAS BASIN	TIME CORRELATE	ZONE AND SAMPLE NRS	AVG THICKNESS (m)	% COAL (mass)	LITHOLOGY
VOLKSRUST FORMATION	GROOTEGELUK FORMATION	UPPER ECCA	Zone 11 Samples Nrs 01A - 01B	4.47m	33.8%	Bright coal (without siderite, intercalated with grey mudstone, carbonate lenses ± 50 cm x 3 m.
			ZONE 10 Samples Nrs 02A - 06A	12.53m	53.8%	Bright coal with little siderite, intercalated with carbonaceous mudrock, carbonate lenses ± 50 cm x 3 m. Thick coal bands in lower half
			ZONE 09 Samples Nrs 07A - 09A	6.48m	48%	Bright coal with prominent siderite at base, intercalated with carbonaceous mudrock. Thick coal bands in lower
			ZONE 8 Samples Nrs 10A - 14B	9.77m	43%	Bright coal with prominent siderite at the base, intercalated with carbonaceous mudrock, Thick coal bands in lower half
			ZONE 7 Samples Nrs 15A - 18A	12.45m	40%	Bright coal, sideritic throughout, intercalated as numerous thin bands with carbonaceous mudrock, Thick coal bands in lower half.
			ZONE 6 Samples Nrs 19A - 21A	5.32m	32%	Bright coal, very sideritic in lower half, intercalated as numerous thin bands with carbonaceous mudrock.
			ZONE 5 Samples Nrs 22A - 22E	16.65m	22%	Carbonaceous mudrock with coal bands in loer two thirds; siderite less prominent
			Interbeds	2.6m	-	Carbonaceous mudrock with coaly mudrock
VRYHEID FORMATION	SWARTRANT FORMATION	MIDDLE ECCA	ZONE 4 Samples Nrs 23	4.89m	95%	Coal dull, heavy bright coal in lower half and at the top.A few thin mudrock bands. Someimes sandstone lenses. Yields powerstation coal.
			ZONE 4A	25m	xxxx%	Coal dull layers, few bright stringers, mudstone bands, sanstone interbeds, medium to carse grained, few thin mudrock bands
			ZONE 3 Samples Nrs 28A-29A	3.14m	22%	Coal dull, bright laminae in lower part which yield low low ash, slightly coking caol. Few thin mudrock bands
			Interbeds	3m		Sandstone and thin mudrock bands
			ZONE 2 Samples Nrs 30A-31A	5.3m		Coal, dull, bright laminae in lower part which yields lower ash slightly coking coals, few thin mudrock bands
			Interbeds	4m		Sandstone, medium to coarse grained, and thin mudrock bands
			ZONE 1	1.12m		Coal, dull, very few thin bright laminae, thin mudrock bands

Figure 65 Study area subdivision of coal samples into coal zones

The Groenfontein and Welgelegen areas (Figure 14) were used as reference to evaluate the coal zones using the GDCDD method.

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9.1 Methodology used

In this investigation the depths of the top and bottom contacts of the coal zones were identified and used as basis for the GDCDD evaluation. The geophysical data were evaluated using the GDCDD method (Figure 66) and the curves were drawn. The values along the x-axis at two chosen cut-points, Rd 1.60 and 2.00, were tabled. These data were then processed using the general statistics function in Excel functions to determine the following:

- general statistics;
- the 2x standard deviation (2 σ) at the chosen Rd cut-points; and
- whether the standard deviation falls within the maximum and minimum values of the data range.

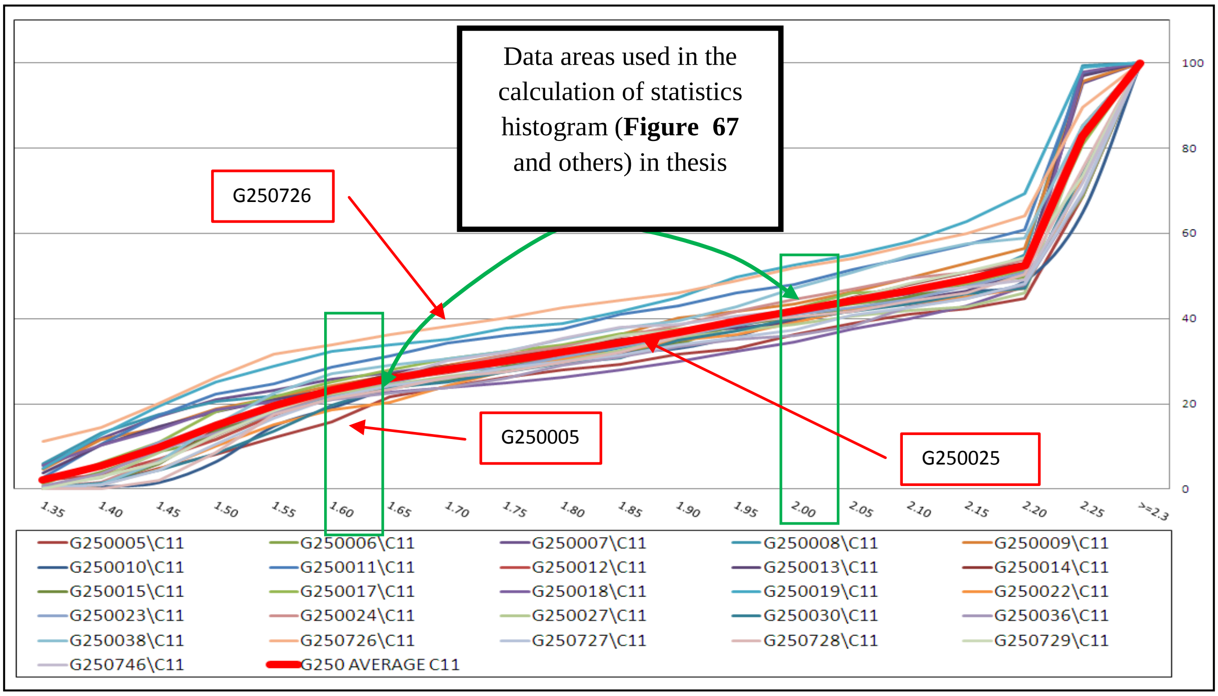

Figure 66 Trend of the GDCDD curves along profile A-A' for Zone 11 in the boreholes, on Groenfontein (borehole number listed below the graph). Each curve represents the GDCDD in one borehole. The average trend curve is also indicated (thick red line) for all the curves combined. The lowest (borehole G250005), highest (G250725) and mean (G250025) curves are indicated on the graph

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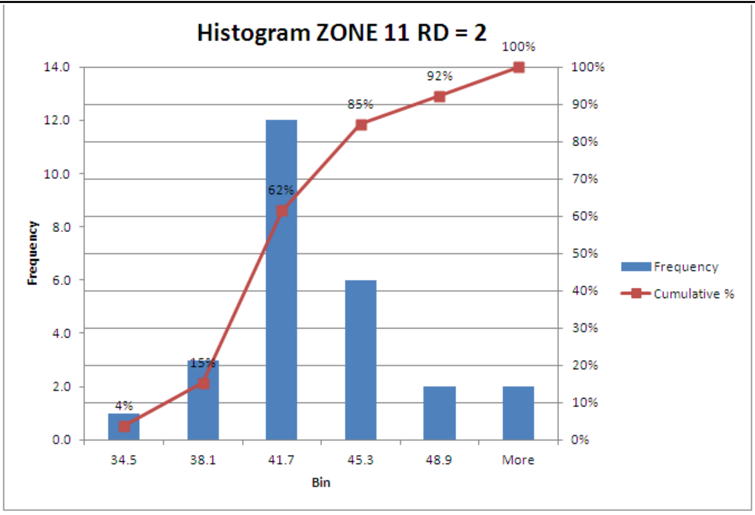
9.2 Coal Zone 11

Coal Zone 11, the uppermost coal zone in the stratigraphy, consists of Samples 01A and 01B. It has two bright coal seams of varying thickness and interbedded dark grey mudstones. On Geelbekpan there is, locally, a third coal seam developed. The general statistics of Zone 11 at the two chosen Rd's is shown in (Figure 67).

RD= 2	Frequency	Cumulative %
34.5	1.0	4%
38.1	3.0	15%
41.7	12.0	62%
45.3	6.0	85%
48.9	2.0	92%
More	2.0	100%

RD= 2				
Mean	41.7			
Standard Error	0.9			
Median	41.1			
Standard Deviation	4.3			
Sample Variance	18.8			
Kurtosis	1.3			
Skewness	1.0			
Range	18.0			
Minimum	34.5	<	33.01	-2σ
Maximum	52.5	>	50.3	+ 2σ
Sum	1083.7			
Count	26			
Confidence Level(95.0%)	1.75			



RD= 1.6	Frequency	Cumulative %
15.8	1.0	4%
19.5	2.0	12%
23.1	14.0	65%
26.7	5.0	85%
30.3	2.0	92%
More	2.0	100%

RD= 1.6				
Mean	23.2			
Standard Error	0.8			
Median	22.5			
Standard Deviation	3.9			
Sample Variance	15.3			
Kurtosis	2.0			
Skewness	1.1			
Range	18.0			
Minimum	15.8	<	15.36	-2σ
Maximum	33.9	>	31.0	+ 2σ
Sum	603			
Count	26.00			
Confidence Level(95.0%)	1.58			

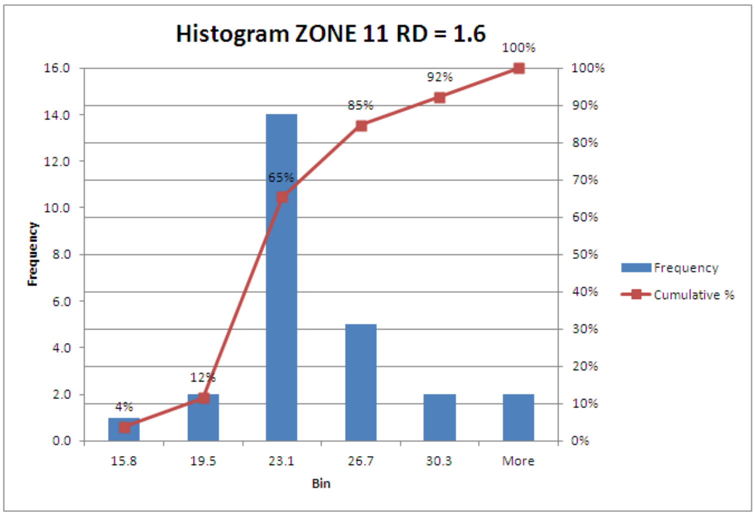


Figure 67 General statistics at a Rd of 2 and 1.6 of the GDCDD's of coal Zone 11 at Groenfontein, plus and minus two standard deviations (2σ) in yellow blocks

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The statistics were derived using the add-in function in Excel, giving a range of parameters in the reporting, including standard deviation (σ). In the yellow blocks on the graph (Figure 67), data for the 2σ (standard deviation $=\sigma$) is given. Comparing this value to the minimum and maximum values for all the data for Zone 11, it indicates that for an Rd of 2 the minimum value is within the mean - 2σ and the maximum value is outside the mean + 2σ. This would suggest that the Rd 1.60 values fall within the mean + 2σ, which is a narrow spread, and the Rd 2.0 values fall inside the mean + 2σ, which is a narrow spread as well. This equates to Zone 11not varying significantly over Groenfontein.

There is very little lithological variation in coal Zone 11 across Groenfontein in the GDCDD (Figure 68). However, due to a high incidence of faulting significantly influencing the dip and depth of the coal seams,

For illustrative purposes (Figure 69) the GDCDD curves for the same zone was plotted for an adjacent farm Welgelegen to prove the point that local geological conditions play a role in how the curves for the various boreholes present on the graph. In the case of Welgelegen there are boreholes of which the top part of Zone 11 has been weathered, and this shows up clearly on the GDCDD curves of the specific boreholes (W228015, W228713 and W228715) (Figure 69).

Figure 71 illustrates the section across some of the boreholes on Welgelegen to show how local weathering played a role in removing the top part of Zone 11 , so influencing the GDCDD of these boreholes.

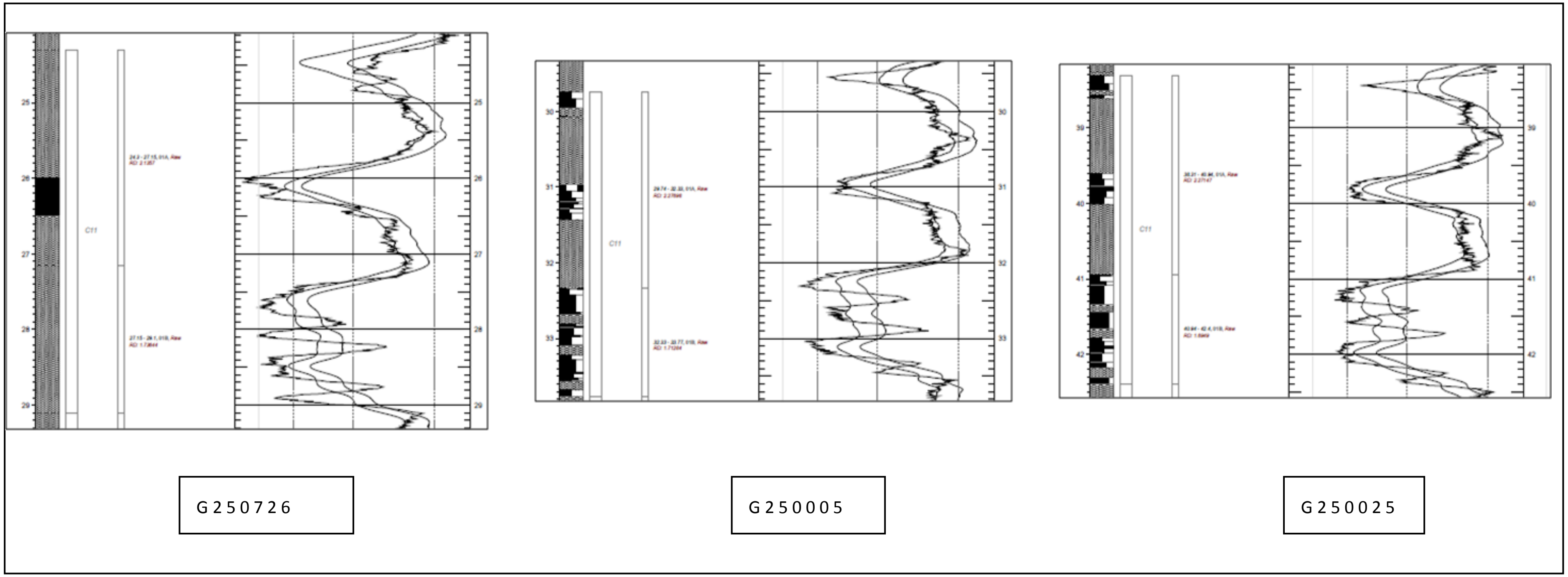


Figure 68 Coal Zone 11 geological/geophysical profile across Groenfontein. Note that the lithology in G250726 was inadequately logged, but the geophysical log has highlighted this fact

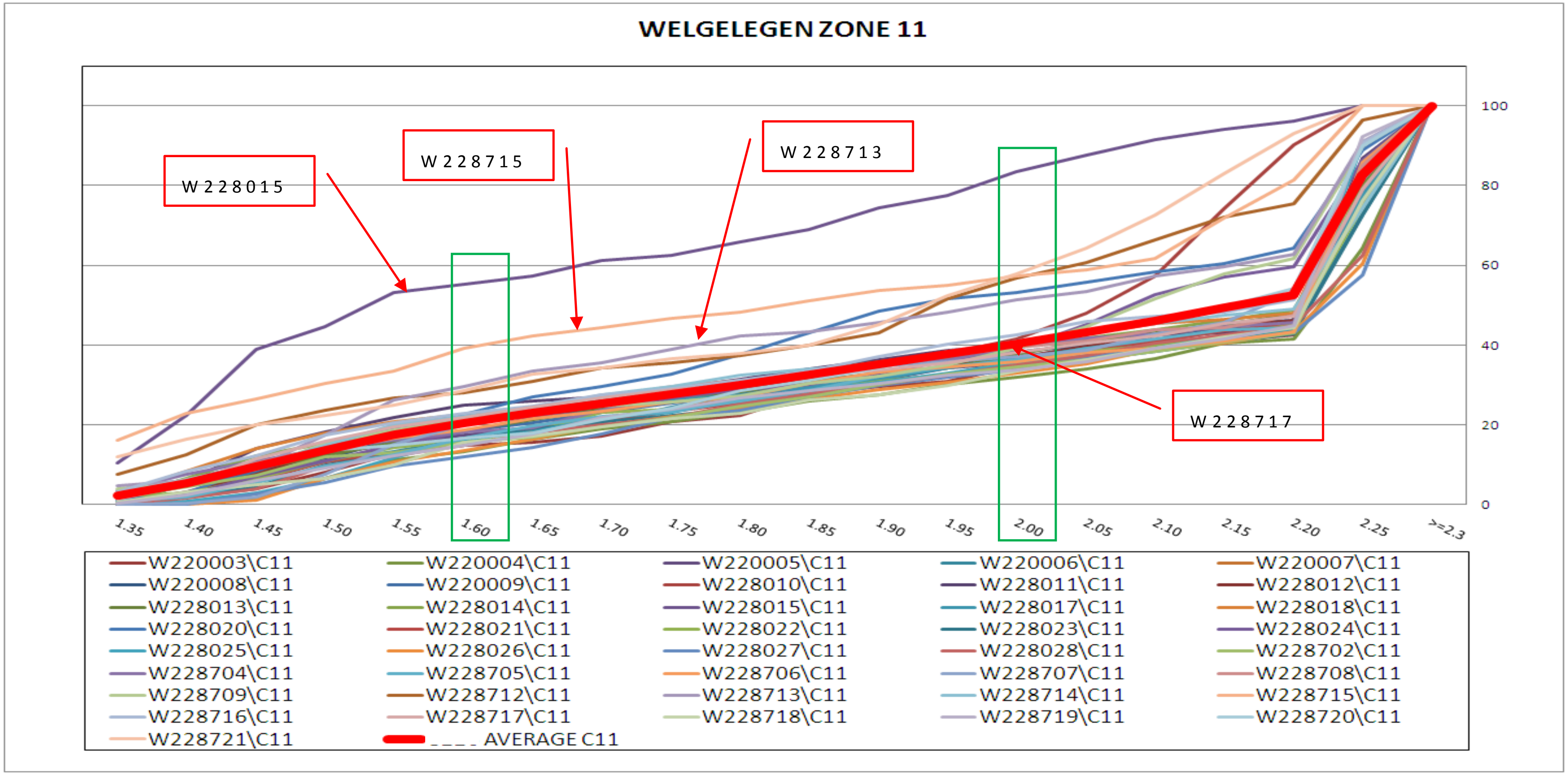
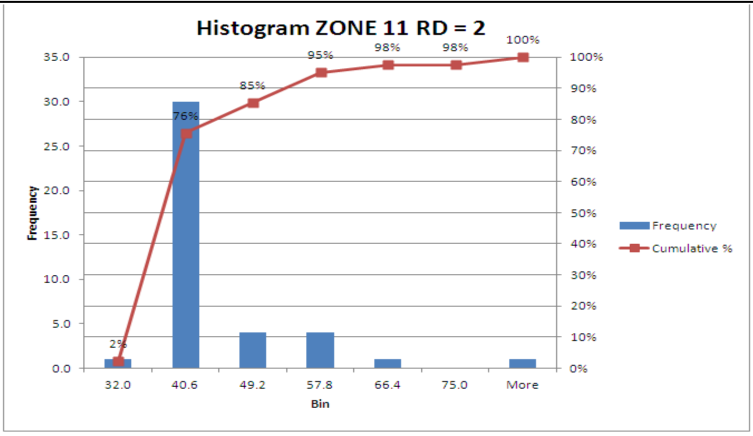


Figure 69 Combined GDCDD of Coal Zone 11 on Welgelegen illustrating the effect of erosion on coal Zone 11

RD= 2	Frequency	Cumulative %
32.0	1.0	2%
40.6	30.0	76%
49.2	4.0	85%
57.8	4.0	95%
66.4	1.0	98%
75.0	0.0	98%
More	1.0	100%

RD= 2				
Mean	40.4			
Standard Error	1.5			
Median	37.0			
Standard Deviation	9.6			
Sample Variance	91.4			
Kurtosis	10.0			
Skewness	2.9			
Range	51.6			
Minimum	32.0	>	21.23	-2σ
Maximum	83.6	>	59.5	+ 2σ
Sum	1654.4			
Count	41			
Confidence Level(95.0%)	3.017			



RD= 1.6	Frequency	Cumulative %
12.1	1.0	2%
19.3	21.0	54%
26.5	14.0	88%
33.7	3.0	95%
40.9	1.0	98%
48.1	0.0	98%
More	1.0	100%

RD= 1.6				
Mean	20.5			
Standard Error	1.2			
Median	18.4			
Standard Deviation	7.6			
Sample Variance	57.5			
Kurtosis	11.0			
Skewness	2.9			
Range	43.1			
Minimum	12	>	5.32	-2σ
Maximum	55.26	>	35.6	+ 2σ
Sum	839			
Count	41.00			
Confidence Level(95.0%)	2.392			

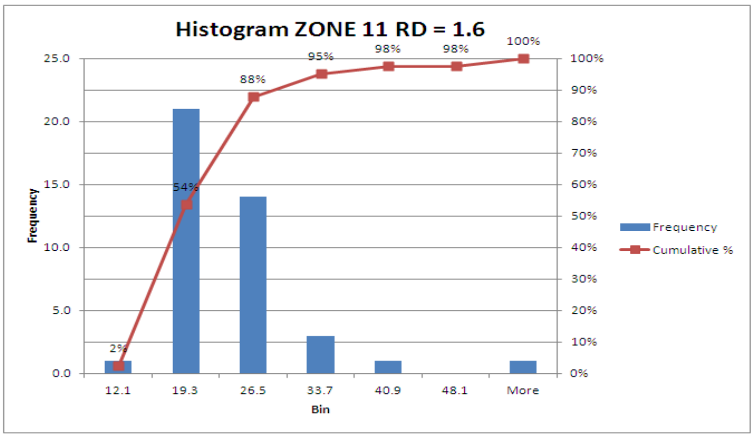


Figure 70 Statistics at a Rd of 2 and 1.6 of the GDCDD's of coal Zone 11 at Welgelegen. Plus and minus two standard deviations in yellow blocks

In Figure 70, the data in the yellow blocks, for the 2σ indicates, that for a Rd of 2.0, the minimum value is within the Mean - 2σ and the maximum value is also within the Mean + 2σ. This would suggest a narrow spread of the curves for both limits. The same is true for the RD 1.6 values. This is due to erosion and proves that more of the lower part of coal Zone 11 is preserved over Welgelegen. The lower curves, (Figure 69), are widely spread vertically while the upper curves (those above the mean) are spaced more widely apart indicating thicker and/or more numerous mudstone layers being present there.

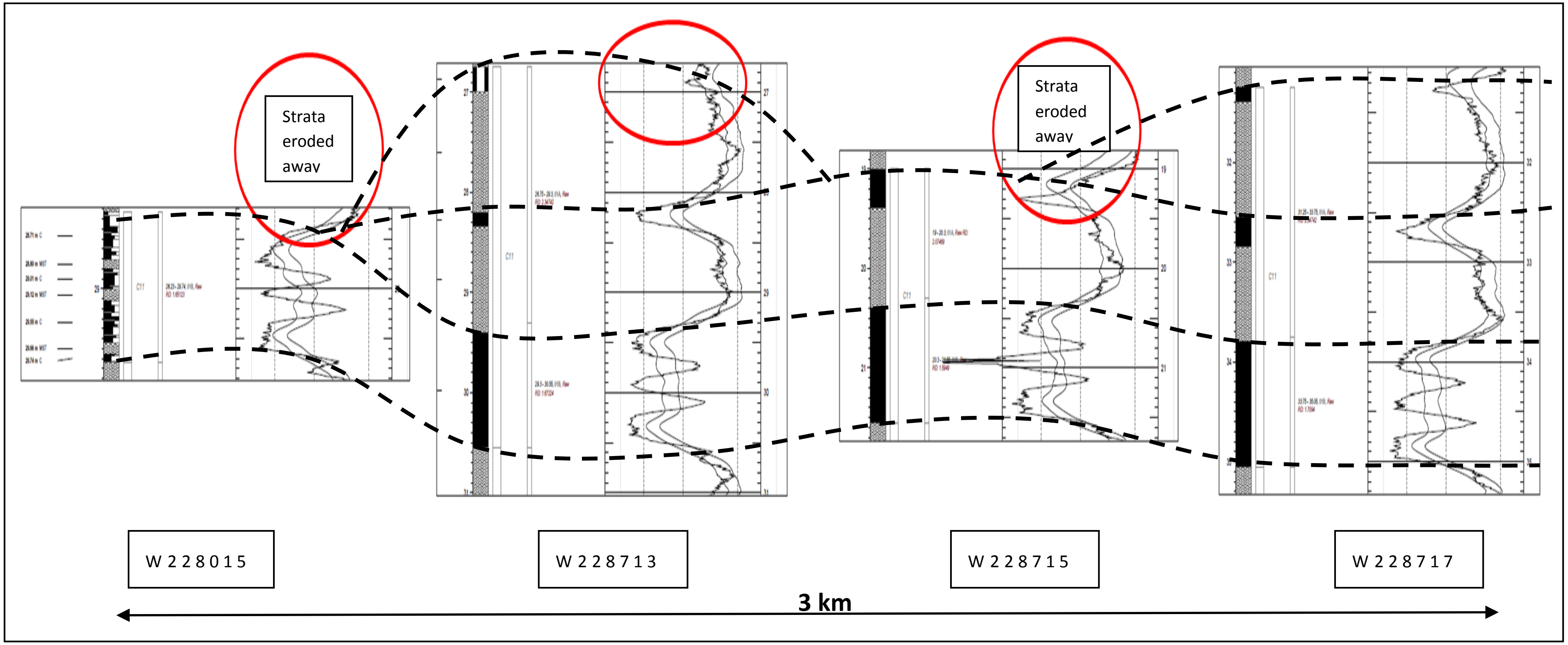


Figure 71 Coal Zone 11 profile, illustrating why low, high and average values occur in the GDCDD diagram on Welgelegen as a result of local geological conditions

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In Figure 71, borehole W228717 shows the normal development of Sample 01A, but in the other boreholes, the complete sequence of Sample 01A, is not present as the top coal seam has been eroded away. This has clearly affected the behaviour of the GDCDD curves of coal Zone 11 on Welgelegen (Figure 69). All the scattered graphs at the top of Figure 69 have been affected by erosion.

Based on the statistical method applied in Figure 69 and Figure 70 two tables of information were produced that give the σ values at a Rd of 1.60 and 2.0 for the eleven zones identified on the Study area. Table 6 was set up using the x-axis value of the GDCDD curves, while Table 7 shows the averaged σ values for the zones made up from the x-values of the individual samples that make up the various zones thus combining the individual sample values of each zone into a single value. The values in Table 7 reflect the variability of the individual samples making up the zones while the values in Table 6 reflect less variability, as they are based on total zone information.

The values of these two tables are illustrated figuratively for each farm in Figure 73 to Figure 78. All these figures illustrate that the σ values for the zones are lower than the σ values calculated for the zones based on the sample information. The lower variability of the Volksrust Formation (Zones 11 to 5) is clearly illustrated in all these figures. The average σ value for the Volksrust Formation is 8.0 while the σ value for the Vryheid Formation is 12.1 (Table 6) The average σ value for the zones, based on zone information is 9.2 while the average σ value for the zones, based on sample information is 13.1.These data confirm the fact that the individual samples are, clearly, more variable than the individual zones.

Zone 11 is the thickest developed over Geelbekpan where a third coal seam is developed in Sample 01A (Figure 72). This figure shows the thicker Zone 11 in a blue-green colour on the eastern side of Geelbekpan. The red parts in the figure is where Zone 11 has either been

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faulted out of the stratigraphy (and is not exposed in the area) or as in the case of the south – been eroded due to the dip of the coal seams.

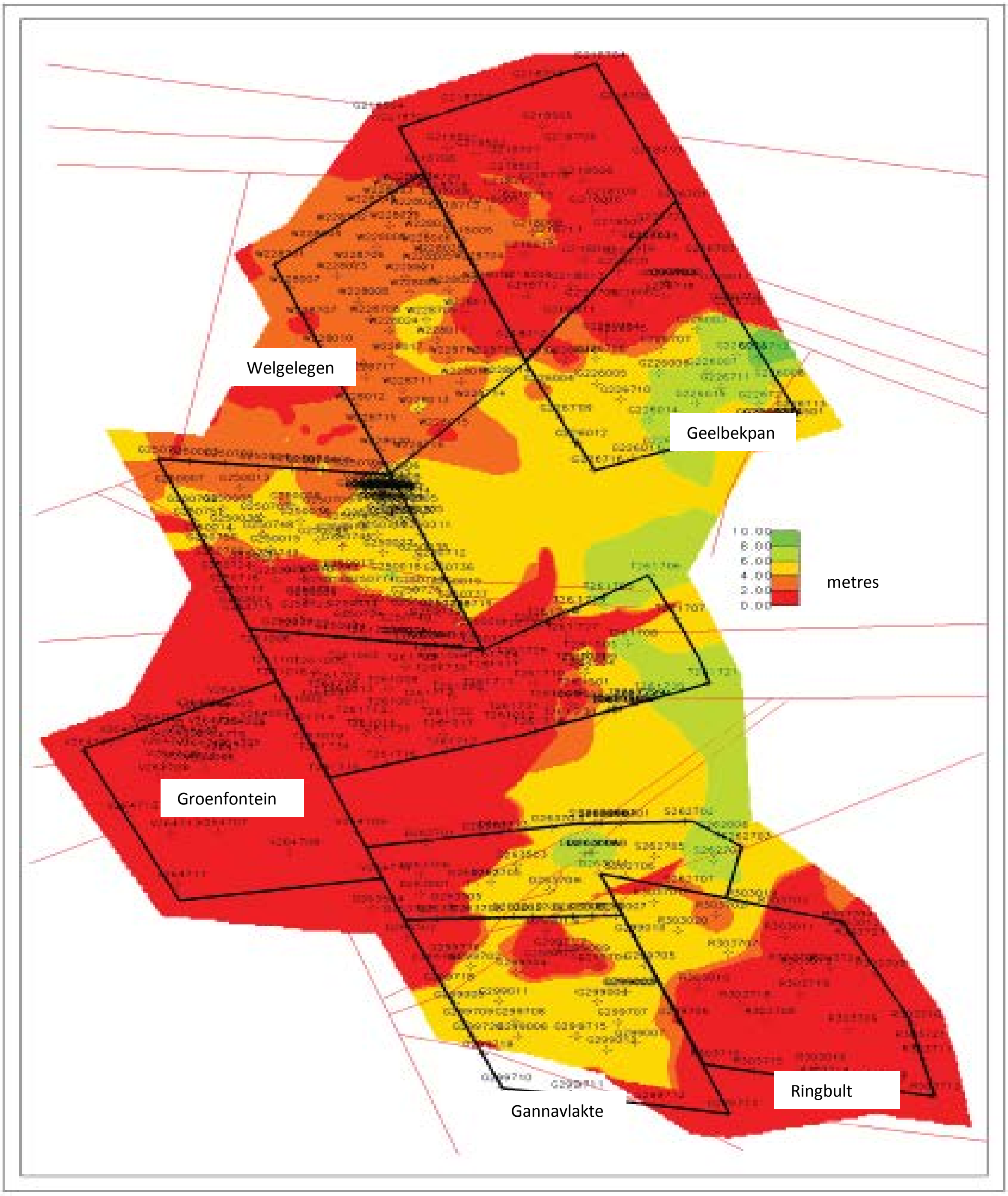

Figure 72 The lateral thickness variation of coal Zone 11 over the Study area

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9.3 The importance of the standard deviation when evaluating zones:

- **Geelbekpan** (Figure 73): The average σ value on this farm for zones 11 to 4 is between 4 and 7.1, (blue bars) and for zones 3 to 1 it is between 9.5 to 19.2.This would concur with the local geology where there is numerous thin sandstone layers within these coal zones. This would also concur with the SANS 10320 requirement that the multiple seam coal deposit needs to be drilled to a spacing that is closer than those of the thick interbedded coal seam deposit like the Volksrust Formation coals. What this figure also illustrates is that using samples to calculate zones directly returns a higher average σ value as the sample σ values is more variable than zones. The average σ for the zones based on the value for the samples (between 3.8 and 23.2).is nearly double those of the zones (between 4.0 and 19.2) (bars versus the lines).
- **Groenfontein** (Figure 74): The σ value on this farm for all the zones is between 4.1 and 15.5 with Zone 4 equals to 15.5 and Zone 3, 13. The reason for this is interbedded sandstones for Zone 3 and the 'separated' coal seam at the bottom of Zone 4. In the case of this farm it should be possible to use the borehole spacing of the thick interbedded coal seam deposit type to prove the classification of the resources on this farm. The average σ for the samples is nearly double those of the zones between 6.9 and 32.5.
- **Gannavlakte** (Figure 75): The σ value for this farm for zones, in general, is higher than that in the north (average = ±10) with values between 4.8 and 16.2. The samples has nearly double the σ value (average = ±15) than those of the zones. These two points proves that the lithology in the south is more variable than the north.
- **Ringbult** (Figure 76): The σ value for this farm, in general, is higher than that in the north (average = ±8) with values between 4.7 and 16.6. The samples also have nearly double the σ value (average = ±15) than that of the zones. These two points prove that the lithology in the south is more variable than the north and this is mostly due to the fact that the seams dip towards the north and over nearly half the total farm area the seams is subjected to weathering as they would sub-outcrop.

Table 6 Standard deviation calculated at two Rd's from the GCCD data for Zone 11 to Zone 01. Zone 05-11 forms the Volksrust Formation (highlighted in brown) whist the un-highlighted values of Zones 01-04 form part of the Vryheid Formation.

Standard deviation of zones as calculated from averaged Zone information															
FARM															
	GEELBEKPAN			GROENFONTEIN			GANNAVLAKTE			RINGBULT			TOTAL		
Zones	1.6	2.0	Avg	1.6	2.0	Avg	1.6	2.0	Avg	1.6	2.0	Avg	1.6	2.0	Avg
11	5.4	7.3	6.3	3.9	4.4	4.1	8.9	9.3	9.1	16.5	16.8	16.6	8.7	9.4	9.1
10	5.1	2.9	4.0	7.0	4.5	5.8	7.2	2.4	4.8	10.9	6.2	8.6	7.6	4.0	5.8
09	5.1	6.3	5.7	5.8	9.0	7.4	8.0	9.2	8.6	7.6	8.1	7.9	6.6	8.2	7.4
08	3.9	6.3	5.1	8.3	10.6	9.5	7.6	6.4	7.0	10.9	14.3	12.6	7.7	9.4	8.5
07	4.0	5.4	4.7	5.3	6.4	5.8	8.1	8.0	8.0	9.1	7.2	8.2	6.6	6.7	6.7
06	3.5	10.8	7.1	4.0	10.9	7.4	3.4	17.6	10.5	4.7	16.0	10.3	3.9	13.8	8.9
05	1.9	9.1	5.5	5.0	7.6	6.3	3.8	16.9	10.4	2.3	7.2	4.7	3.2	10.2	6.7
04	2.5	9.3	5.9	14.4	16.6	15.5	4.1	17.7	10.9	4.2	16.1	10.2	6.3	14.9	10.6
03	17.4	20.8	19.1	15.7	10.4	13.0	19.2	8.4	13.8	12.7	6.7	9.7	16.3	11.6	13.9
02	13.4	5.6	9.5	9.7	4.3	7.0	17.0	5.1	11.0	10.5	6.5	8.5	12.6	5.4	9.0
01	29.3	9.1	19.2	12.2	6.7	9.4	16.0	16.3	16.2	14.9	15.0	14.9	18.1	11.8	14.9
Grand Total	**7.8**	**7.9**	**8.4**	**7.7**	**7.8**	**8.3**	**8.7**	**10.0**	**10.0**	**8.8**	**10.2**	**10.2**	**8.3**	**8.9**	**9.2**

Table 7 Standard deviation calculated at two Rd's from the GCCD data for Zone 01 to Zone 11 as deduced from combined individual sample information. Zone 05-11 forms the Volksrust Formation (highlighted in brown) whist the un-highlighted values of Zones 01-04 form part of the Vryheid Formation.

Standard deviation of zones as calculated from averaged individual Sample information															
FARM															
	GEELBEKPAN			GROENFONTEIN			GANNAVLAKTE			RINGBULT			TOTAL		
Zones	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**
11	3.5	4.0	3.8	6.8	7.0	6.9	7.8	5.9	6.9	16.0	16.0	16.0	8.5	8.2	8.4
10	9.6	7.4	8.5	10.4	6.5	8.4	14.4	7.2	10.8	7.9	6.2	7.1	10.6	6.8	8.7
09	7.9	12.1	10.0	7.4	9.3	8.3	10.2	14.4	12.3	13.1	16.3	14.7	9.7	13.0	11.4
08	10.1	11.2	9.5	13.3	16.3	13.5	14.1	16.7	14.7	16.0	18.3	16.5	13.4	15.6	13.5
07	9.2	11.0	10.1	7.2	9.6	8.4	14.9	10.9	12.9	15.3	13.6	14.4	11.6	11.3	11.5
06	5.6	14.8	10.2	7.5	14.9	11.2	7.4	25.4	16.4	8.0	25.8	16.9	7.1	20.2	13.7
05	3.4	12.9	8.2	8.3	10.9	9.6	7.6	28.1	17.9	7.5	23.8	15.7	6.7	18.9	12.8
04	3.2	14.7	8.9	11.9	12.4	12.1	9.9	25.8	17.8	12.9	25.0	19.0	9.5	19.5	14.5
03	21.5	24.8	23.2	19.0	16.9	17.9	23.1	5.7	14.4	15.3	4.1	9.7	19.7	12.9	16.3
02	17.9	10.4	14.2	20.2	12.9	16.6	25.5	7.3	16.4	19.1	6.7	12.9	20.7	9.3	15.0
01	26.3	8.9	17.6	35.4	29.6	32.5	13.5	8.5	11.0	13.5	8.3	10.9	22.2	13.8	18.0
Grand Total	**10.7**	**12.0**	**11.3**	**13.4**	**13.3**	**13.2**	**13.5**	**14.2**	**13.8**	**13.1**	**14.9**	**14.0**	**12.7**	**13.6**	**13.1**

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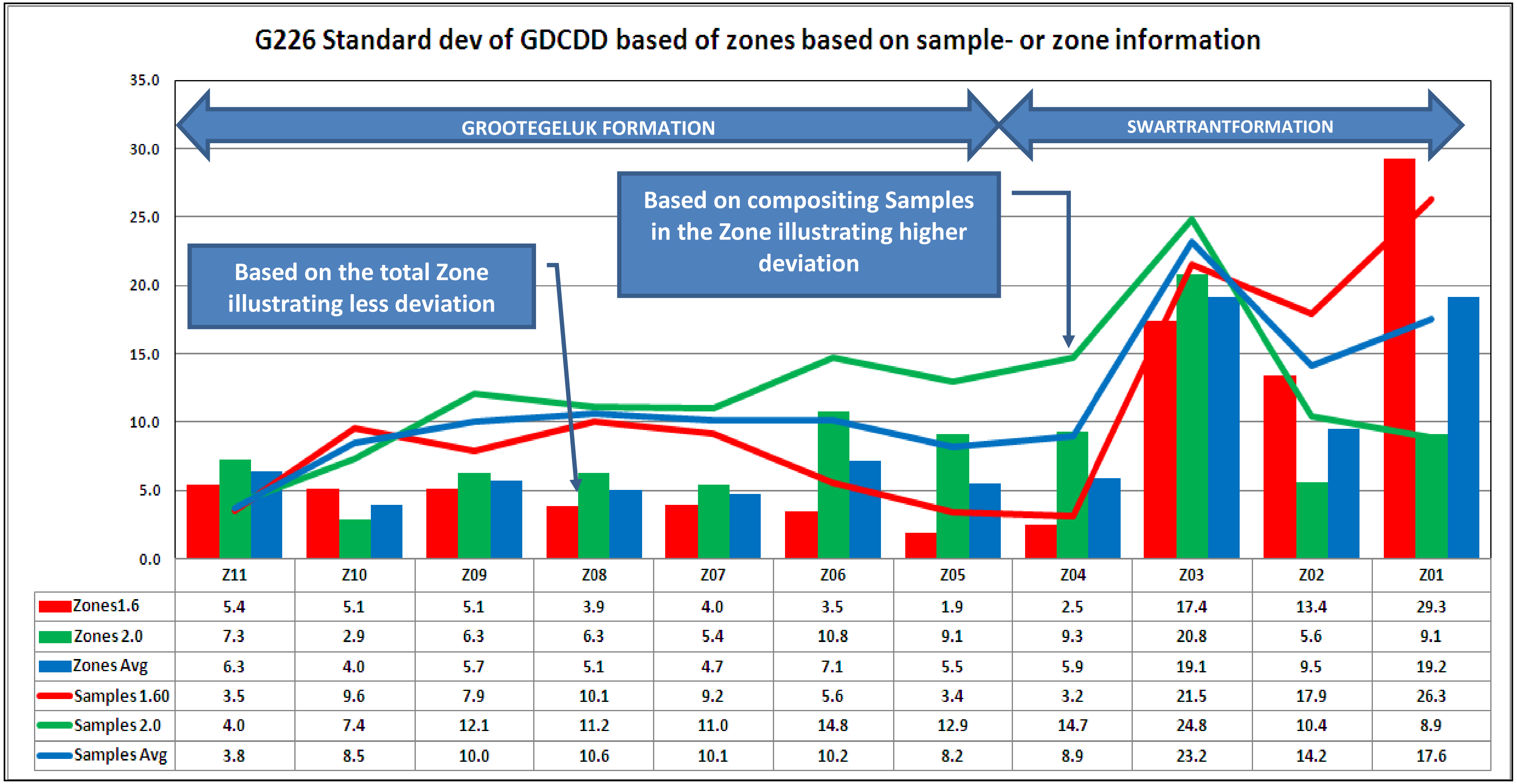
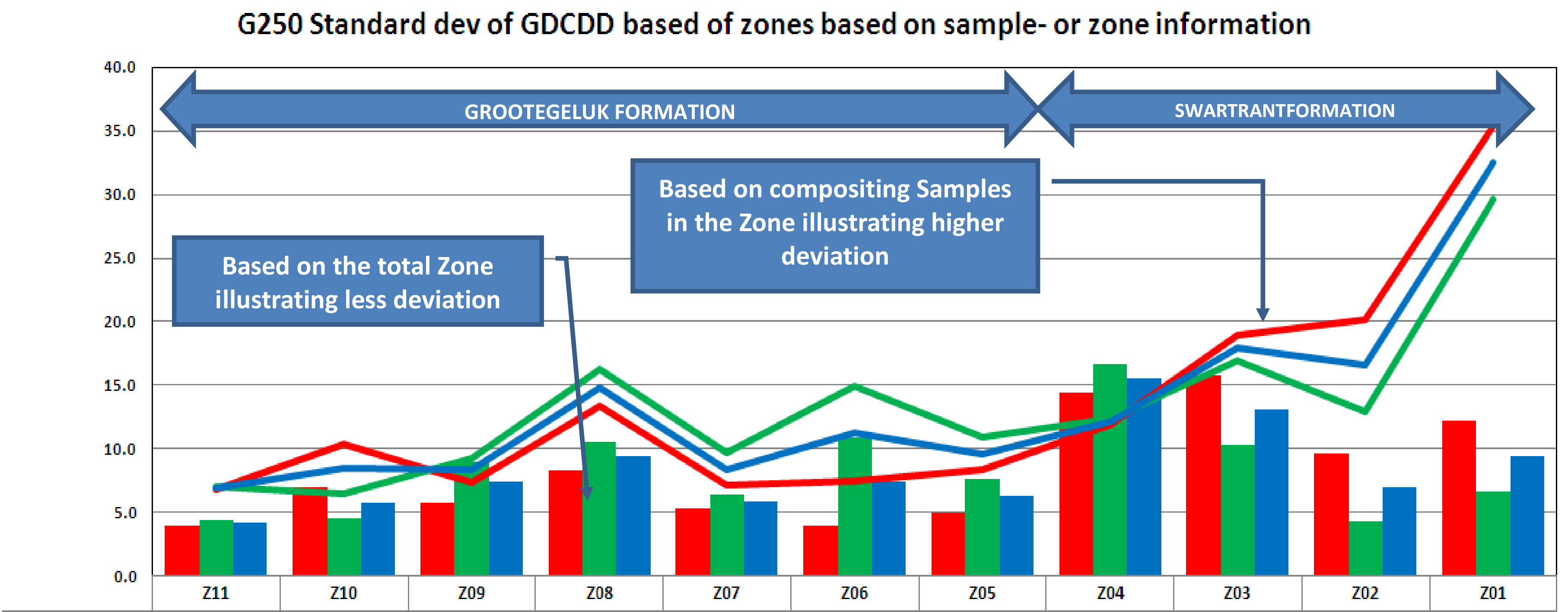


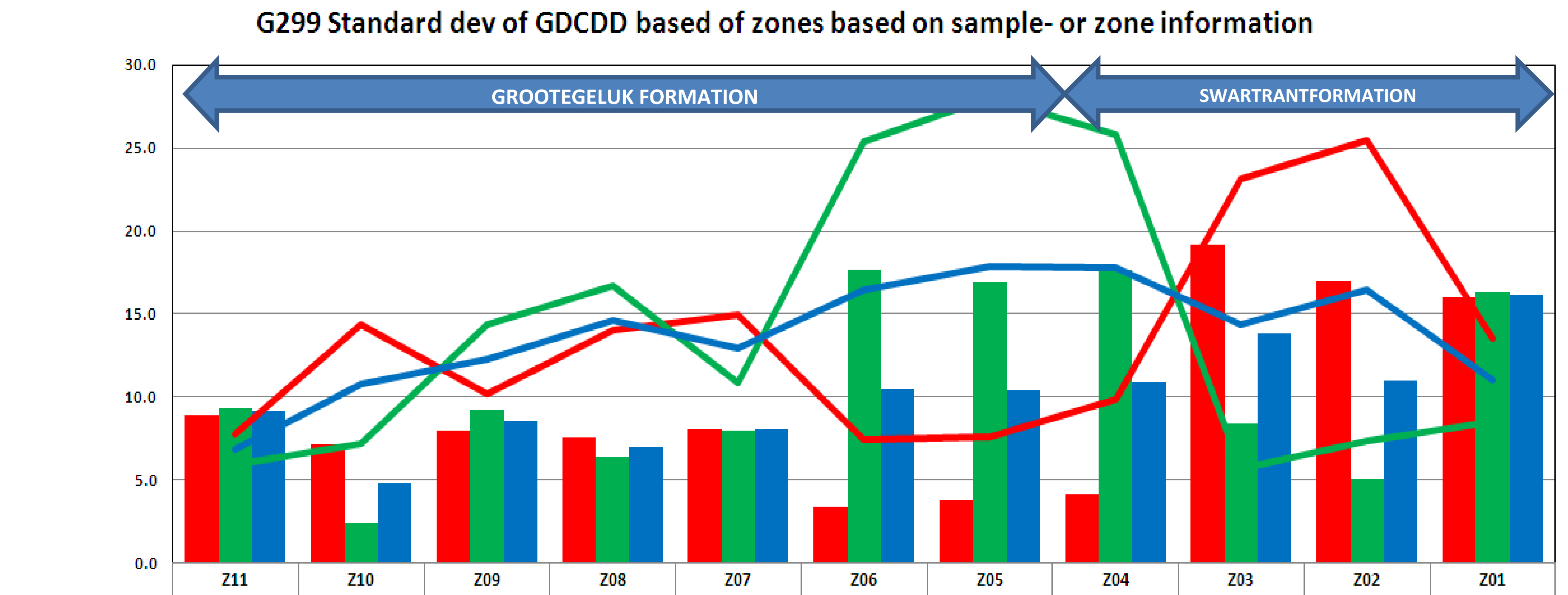
	Z11	Z10	Z09	Z08	Z07	Z06	Z05	Z04	Z03	Z02	Z01
Zones1.6	5.4	5.1	5.1	3.9	4.0	3.5	1.9	2.5	17.4	13.4	29.3
Zones 2.0	7.3	2.9	6.3	6.3	5.4	10.8	9.1	9.3	20.8	5.6	9.1
Zones Avg	6.3	4.0	5.7	5.1	4.7	7.1	5.5	5.9	19.1	9.5	19.2
Samples 1.60	3.5	9.6	7.9	10.1	9.2	5.6	3.4	3.2	21.5	17.9	26.3
Samples 2.0	4.0	7.4	12.1	11.2	11.0	14.8	12.9	14.7	24.8	10.4	8.9
Samples Avg	3.8	8.5	10.0	10.6	10.1	10.2	8.2	8.9	23.2	14.2	17.6

Figure 73 The standard deviation of the GDCDD for the zones at a Rd of 1.60 and 2.0 based on sample and zone information for Geelbekpan



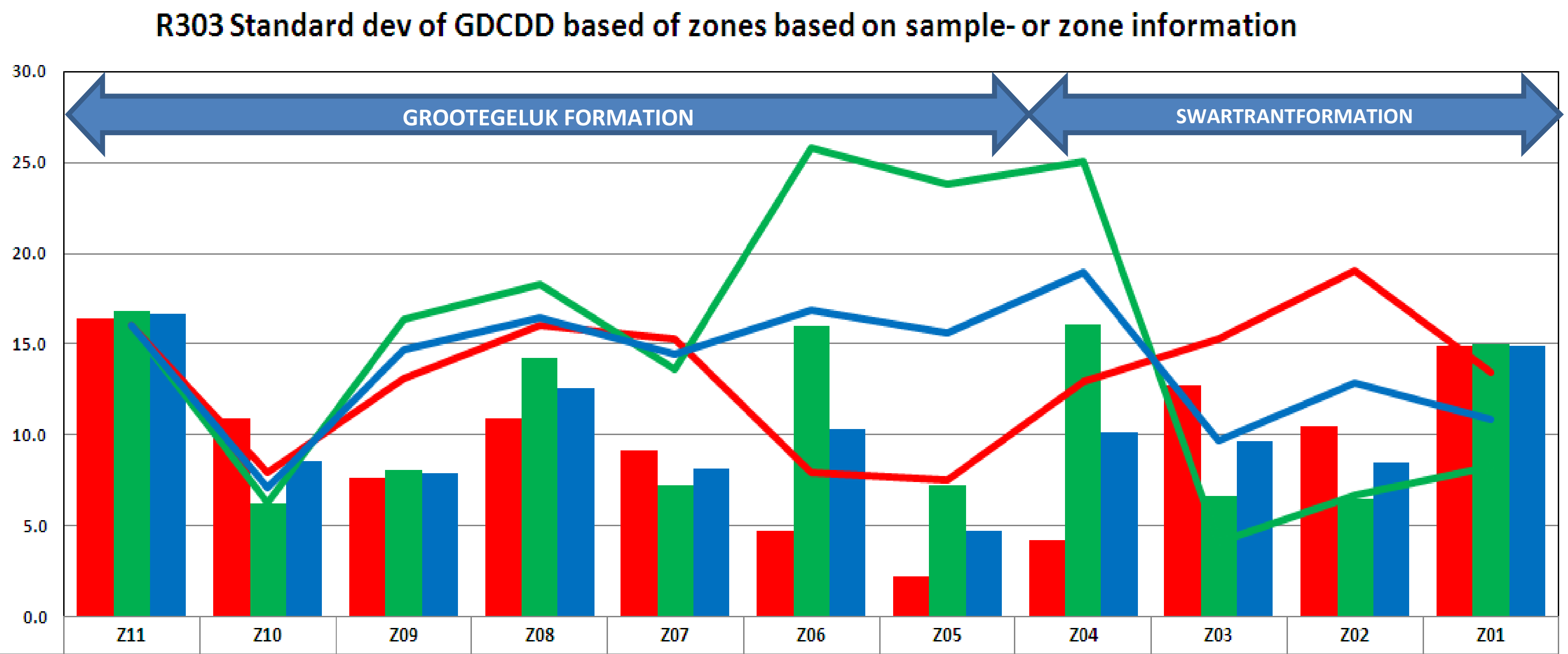
	Z11	Z10	Z09	Z08	Z07	Z06	Z05	Z04	Z03	Z02	Z01
Zones1.6	3.9	7.0	5.8	8.3	5.3	4.0	5.0	14.4	15.7	9.7	12.2
Zones 2.0	4.4	4.5	9.0	10.6	6.4	10.9	7.6	16.6	10.4	4.3	6.7
Zones Avg	4.1	5.8	7.4	9.5	5.8	7.4	6.3	15.5	13.0	7.0	9.4
Samples 1.60	6.8	10.4	7.4	13.3	7.2	7.5	8.3	11.9	19.0	20.2	35.4
Samples 2.0	7.0	6.5	9.3	16.3	9.6	14.9	10.9	12.4	16.9	12.9	29.6
Samples Avg	6.9	8.4	8.3	14.8	8.4	11.2	9.6	12.1	17.9	16.6	32.5

Figure 74 The standard deviation of the GDCDD for the zones at a Rd of 1.60 and 2.0 based on sample and zone information for Groenfontein



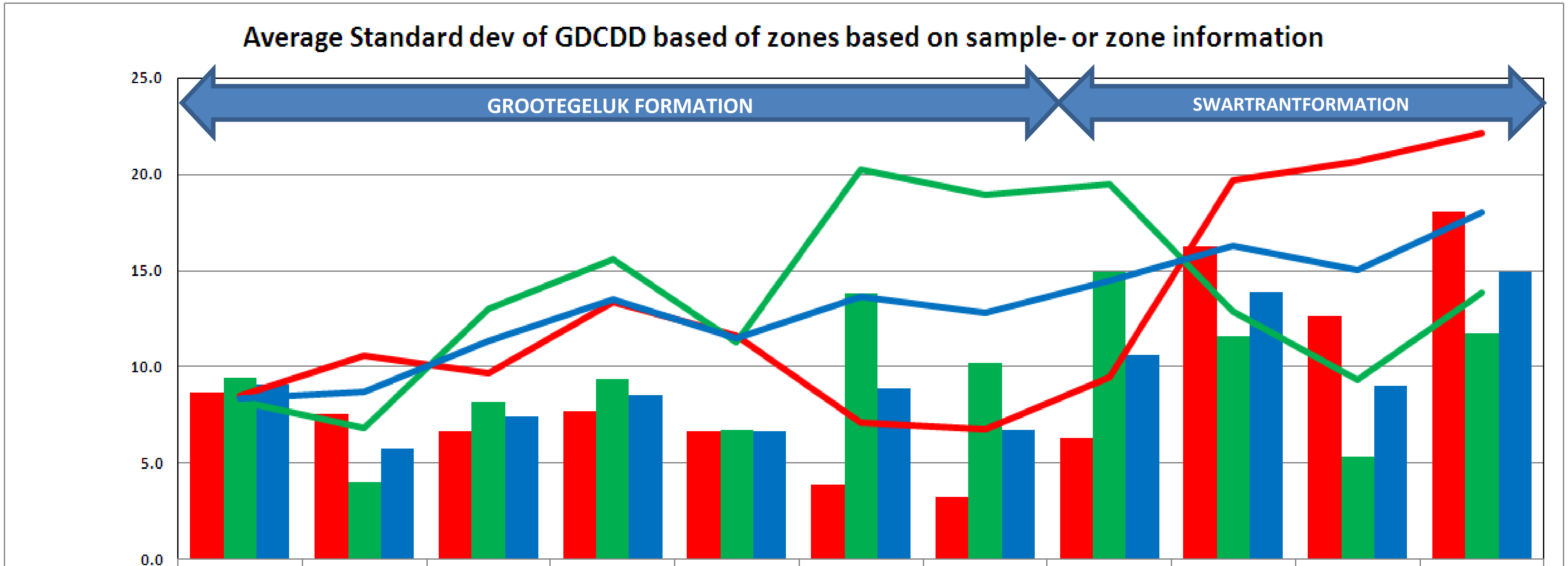
	Z11	Z10	Z09	Z08	Z07	Z06	Z05	Z04	Z03	Z02	Z01
Zones1.6	8.9	7.2	8.0	7.6	8.1	3.4	3.8	4.1	19.2	17.0	16.0
Zones 2.0	9.3	2.4	9.2	6.4	8.0	17.6	16.9	17.7	8.4	5.1	16.3
Zones Avg	9.1	4.8	8.6	7.0	8.0	10.5	10.4	10.9	13.8	11.0	16.2
Samples 1.60	7.8	14.4	10.2	14.1	14.9	7.4	7.6	9.9	23.1	25.5	13.5
Samples 2.0	5.9	7.2	14.4	16.7	10.9	25.4	28.1	25.8	5.7	7.3	8.5
Samples Avg	6.9	10.8	12.3	14.7	12.9	16.4	17.9	17.8	14.4	16.4	11.0

Figure 75 The standard deviation of the GDCDD for the zones at a Rd of 1.60 and 2.0 based on sample and zone information for Gannavlakte



	Z11	Z10	Z09	Z08	Z07	Z06	Z05	Z04	Z03	Z02	Z01
Zones1.6	16.5	10.9	7.6	10.9	9.1	4.7	2.3	4.2	12.7	10.5	14.9
Zones 2.0	16.8	6.2	8.1	14.3	7.2	16.0	7.2	16.1	6.7	6.5	15.0
Zones Avg	16.6	8.6	7.9	12.6	8.2	10.3	4.7	10.2	9.7	8.5	14.9
Samples 1.60	16.0	7.9	13.1	16.0	15.3	8.0	7.5	12.9	15.3	19.1	13.5
Samples 2.0	16.0	6.2	16.3	18.3	13.6	25.8	23.8	25.0	4.1	6.7	8.3
Samples Avg	16.0	7.1	14.7	16.5	14.4	16.9	15.7	19.0	9.7	12.9	10.9

Figure 76 The standard deviation of the GDCDD for the zones at a Rd of 1.60 and 2.0 based on sample and zone information for Ringbult



	Z11	Z10	Z09	Z08	Z07	Z06	Z05	Z04	Z03	Z02	Z01
Zones1.6	8.7	7.6	6.6	7.7	6.6	3.9	3.2	6.3	16.3	12.6	18.1
Zones 2.0	9.4	4.0	8.2	9.4	6.7	13.8	10.2	14.9	11.6	5.4	11.8
Zones Avg	9.1	5.8	7.4	8.5	6.7	8.9	6.7	10.6	13.9	9.0	14.9
Samples 1.60	8.5	10.6	9.7	13.4	11.6	7.1	6.7	9.5	19.7	20.7	22.2
Samples 2.0	8.2	6.8	13.0	15.6	11.3	20.2	18.9	19.5	12.9	9.3	13.8
Samples Avg	8.4	8.7	11.4	13.5	11.5	13.7	12.8	14.5	16.3	15.0	18.0

Figure 77 The standard deviation of the GDCDD for the zones at a Rd of 1.60 and 2.0 based on sample and zone information for all farms

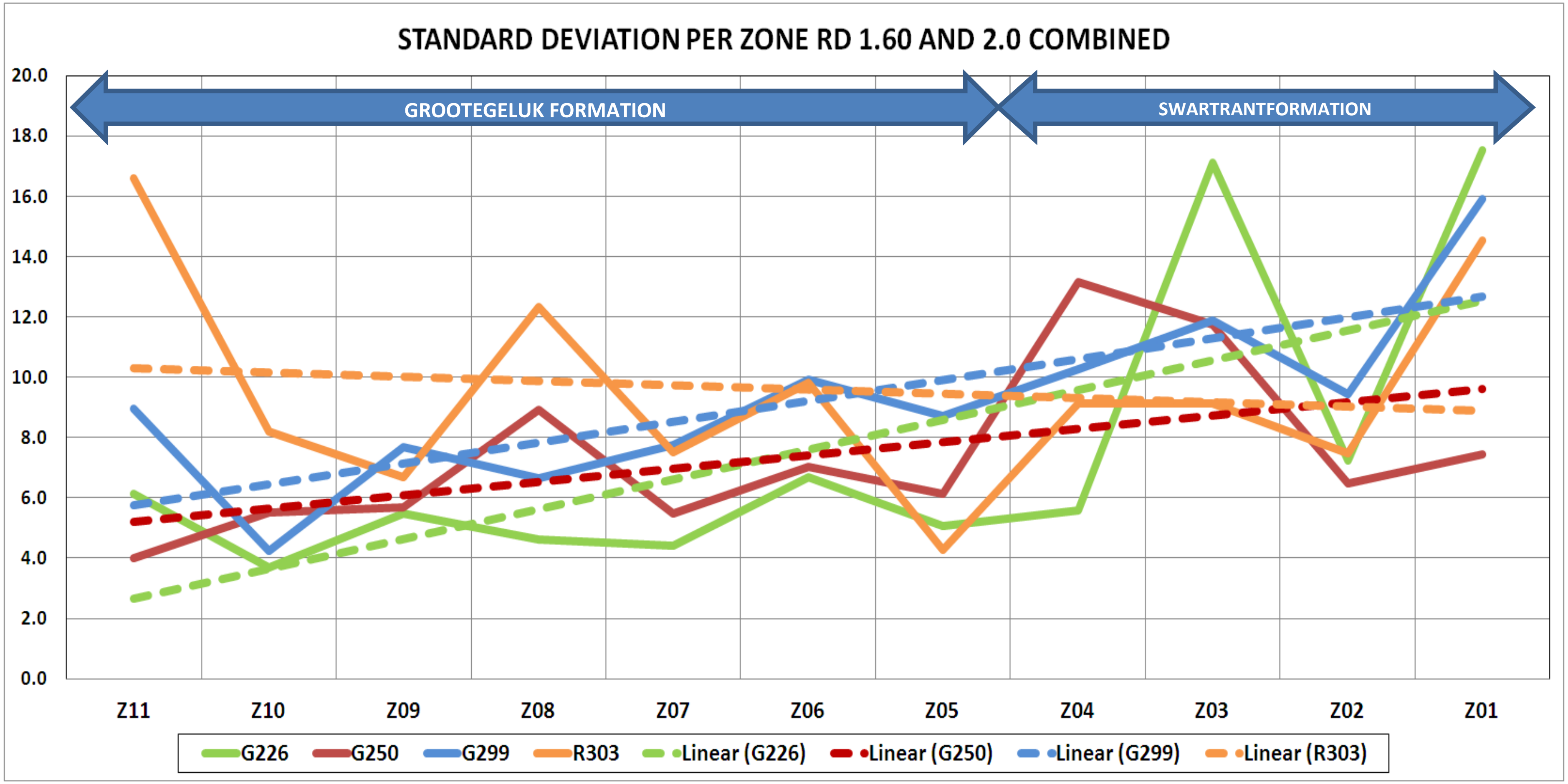


Figure 78 Graph of the averaged and combined standard deviation at a Rd of 1.6 and 2.0, for all the zones. (Trend lines are dashed)

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9.4 Discussion on the use of GDCCD when evaluating the coal zones of the Study Area.

By combining the standard deviation values at a Rd of 1.60 and 2.0 and averaging the two values, the graph in Figure 78 can be drawn. The graph illustrates the following points previously made:

- The large variation in σ values for Zone 11 is due to the fact that weathering in the south plays a role in altering the nature of Zone 11 (Figure 68);
- the uncertainty about the 'separated' bottom coal layer developed in Zone 4 (displayed in the Addendum) influences the σ values of Zone 4 on Groenfontein in as much as the average σ values for the preceding zones hovers around 6 and then it increases to 13 at Zone 4.
- Interbedded sandstone plays a role in elevating the σ values for zones 1 to 3 on all the farms;
- the σ value increase from Zone 11 to Zone 1 for three of the four areas investigated (Geelbekpan, Groenfontein and Gannavlakte), but shows a decrease for Ringbult (Table 6);
- on Geelbekpan (G226) the σ value increases three-fold (3 to 12), on Groenfontein (G250), doubles (5-10), on Ringbult (R303) it shows a slight a decrease (10-9) and doubles on Gannavlakte (G299) (6-12);
- the variability of Zone 01 is seen on all the farms (Figure 78). Interbedded sandstone plays a role in elevating the σ values for zones 1 to 3 on all the farms;
- the Vryheid Formation (Zones 11 to 05) is less variable than the Volksrust Formation (Zones 04 to 01) as can be seen in Table 6 and Table 7;
- the σ value for the zones are generally less variable than the σ value for the zones made up of σ values combined from individual samples making up the zones (Figure 73 to Figure 77);

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- Figure 69 illustrates that there are six boreholes on Welgelegen that are influenced by anomalous local conditions, but the other 35 boreholes are closely spaced around the average.

- The GDCDD curves can be used to determine whether the geology in the percussion holes are the same as those of the cored boreholes.

- The GDCDD curves clearly indicated anomalous geology of the zone in specific boreholes (W228015, W227715, W228713 in Figure 69).

- The Competent Person can make up his/her mind about variability of the geology on this farm by using the GDCDD curves of all the boreholes (cored and percussion).

- Figure 66 illustrates that there are possibly two slightly anomalous intersections of Zone 10 (G250726 and G250005) on Groenfontein out of 30 boreholes. Zone 10 is thus very regular over the farm and should not present any great challenges when interpreting the lateral extent of Zone 10 on Groenfontein. Percussion boreholes confirm the geology of Zone 10 in collaboration with cored boreholes.

- The GDCDD curves for Zone 09 on Groenfontein (displayed in the Addendum on CD) shows that there are two boreholes with anomalous GDCDD curves (G250721 and G250726) when compared to the average curve of G250020. When observing the section drawn through the mentioned boreholes it can be conclusively seen that G250721 was subjected to faulting that removed the top part of Zone 09 and that G250726 is anomalously thin with the lower portion on Zone 09 only developed to half of the "normal" Zone 09 illustrated in G250020.

  There are two anomalous boreholes for Zone 09 on Groenfontein and they have been clearly identified by the anomalous GDCDD curves they present (displayed in the Addendum on CD). The other 29 boreholes have closely grouped GDCDD curves which illustrates that the lithologies of Zone 09 is very regular over the whole farm. Percussion boreholes confirm the geology of Zone 09 in collaboration with cored boreholes.

10 CONCLUSION

The first geophysical tools were placed in a borehole in 1927 and the use thereof in the next 50 years was based, primarily, in the oil industry. In the 1960's major technological advances included transistors and integrated circuits while the 1970's brought computers to process the data quickly and efficiently.

The use of down-hole logging is standard practice by mining companies in the area and the use of geophysics is absolutely essential in some large coal basin deposits. Without using geophysics as correlation aid, it would often be very difficult for even the most competent of geologists to define the exact roof and floor of the various coal Samples and/or Zones. With slimline geophysical logging, the various coal Samples and Zones can be correlated to a high degree and discrepancies easily identified. In the remote chance that the drilling company tries to hide core losses in the coal, the slimline logging would show exactly where the floor and roof contacts are and the discrepancy can then be taken up with the drilling company.

The relative densities of the various coal samples were determined by means of the Archimedes method. The relative density of the same samples were predicted by means of the geophysically determined relative density and it was found that an accuracy of more than 95% was achieved when predicting the relative density by means of the Vectar processed derived densities..

The graphical representation of the relative density of the rocks, by means of a line graphs showing many different traces, does not adequately indicate lithology variation. A method was then devised by the author that enables the scientist to portray the graphical data of the geophysically derived density log, in a derived cumulative distribution diagram line diagram (GDCDD) curves.

- It was possible to use the method to check on the accuracy of the database and errors made during the capture of geophysical data.
- It was also possible to use the method to check on the accuracy of the database and errors made during the capture of geological data.
- It was found that the method enables the scientist to produce similar curves for specific Samples or Zones chosen in the stratigraphy.
- The line curves (which equate to an easily understood depiction) of any Sample or Zone can be correlated accurately over the area of the investigation (200 km^2).
- Any geological dissimilarity, in any chosen Sample or Zone, produces anomalies in the shape or position of the GDCDD curve of that anomalous Sample or Zone.
- The lateral correlation between lithologies can be described accurately and this would be beneficial to a Competent Person and demonstrates that this method is valuable in classifying coal resources in large coal occurrences.
- It would enable the scientist to accurately portray any chosen coal intersection's relative density distribution when measured by geophysical means and compare that to those measured in adjacent boreholes.

The GDCDD method was further refined to calculate the standard deviation at the two chosen relative density points of 1.6 and 2.0 and the derived values can be used as basis for evaluating how the various Samples and Zones vary laterally.

Geophysical logging is thus an essential aid when evaluating where the various Samples or Zones occur in the stratigraphy. Although pictures say a thousand words, some mathematical method had to be found to persuade a Competent Person that the curves tell a convincing scientific story as the following points illustrate.

- The use of geophysics, and in particular the slimline down-hole logging used in the Study area, has proved that the relative densities derived by the Vectar processed method, can be used to control and improve the field measurement of the relative densities. Accuracies of more than 95% are the norm.

- By evaluating the density readings of a specific sample or zone boundary in the stratigraphy by means of a cumulative distribution line diagram, it can be shown that any local variation in the seam structure is immediately noticeable when combining the curves of the area/farm as it modifies either the origin of the curve on the Y-axis, its inclination and/or shape.

- Weathering and/or faulting changes the local composition and the associated relative density of the lithologies in that specific sample or zone and this has a clear impact on the GDCCD curves. Zone 11, the top coal zone in the stratigraphy, is sometimes influenced by weathering and even the loss of 30 cm of this zone, significantly modifies the shape and position of the GDCDD curve of that zone. This proves the high sensitivity of the GDCDD method.

By combining cored and percussion drilling for a specific area or farm it was illustrated that there is a clear, close relationship between the shapes of the GDCDD curves for that area/farm independent of the drilling method used.

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With regards to the spacing of boreholes, the SAMREC Code (and thus the SANS 10320 standard) prescribes a specific drilling density based on the thickness of the coal seams. Barring special conditions such as structural complexity, the spacing of boreholes is prescribed as 350 m between boreholes to conform to Measured Mineral Resource status for thick interbedded coal seam deposits such as those in the Ellisras Basin.

- The SANS committee made the classification of measured Mineral resource the same for both the multiple coal seam deposits (Witbank coal basin types in South Africa) and the thick interbedded coal seam type deposits (Ellisras basin types in South Africa).
- For Indicated and Inferred Resource classification, in thick interbedded deposits, wider borehole spacing is allowed which could be in the order of three times that allowed for the multiple coal seam deposit resources.
- The reason for this decision was based on conservatism due to a lack of quantifiable data at that time. In the meanwhile, new data emerged as other role players became involved in exploration activities in the Ellisras basin and this new data should be recognized.
- Structurally complex areas can be evaluated in detail by means of infill percussion drilling and the lithology accurately compared to adjacent cored boreholes.
- Evaluating the additional percussion boreholes in combination with original boreholes by using the GDCDD method leads to quantifiable information which is as accurate in interpreting the lithology as would have been the case with additional core drilling. The advantage of using percussion drilling is that it is considerably cheaper than core drilling.
- In the latest update of the SANS 10320 standard, in its final draft stage, the 350 m borehole spacing requirement has been altered to a recommended 500 m.

The issue of drilling density is a critical issue all over the world where the classification of resources needs to be done. By applying the GDCDD method, in coal deposits, to both percussion and cored boreholes in a specific project, a Competent Person is able to reliably decide to which category the Resources can be assigned.

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ADDENDUM 1

Samples 01B and 02A

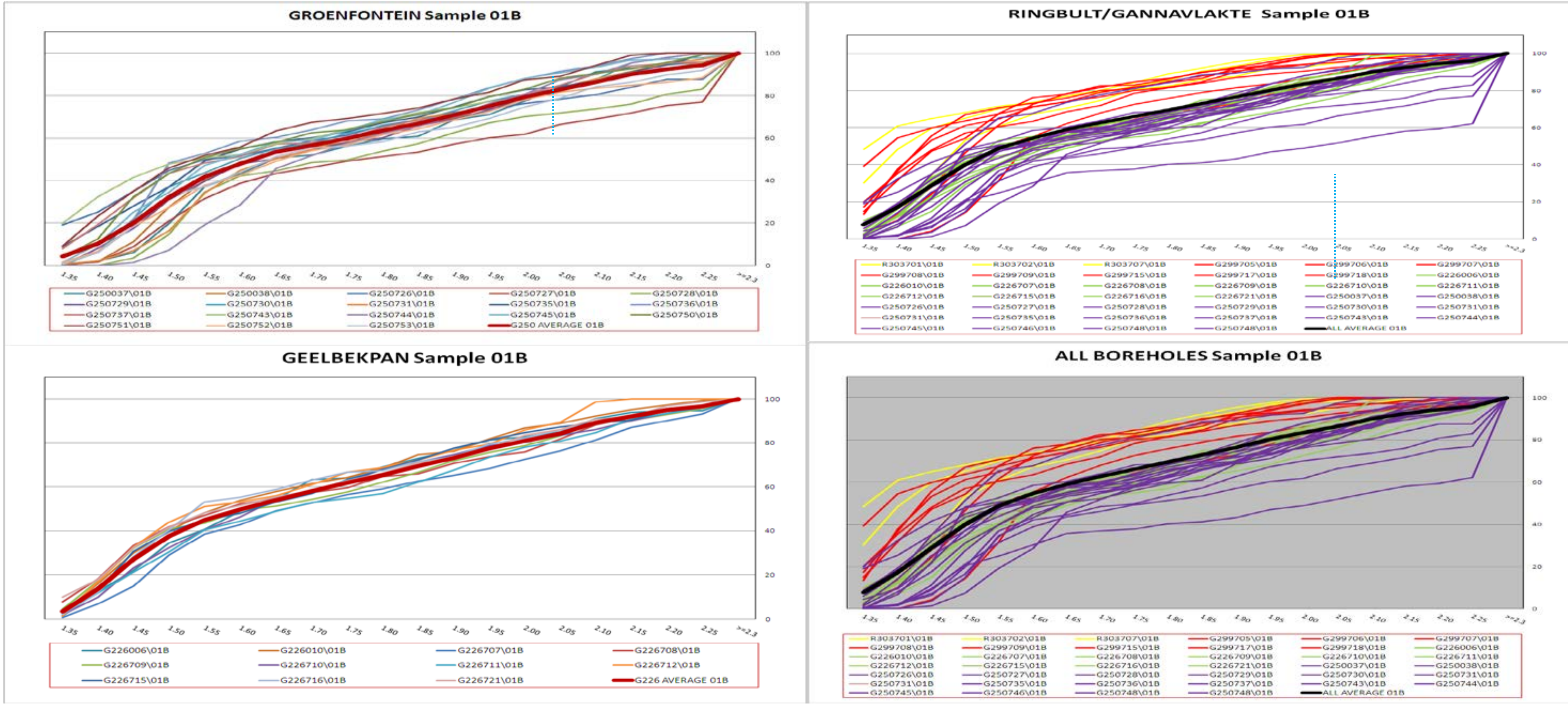


Figure 1 Combined GDCDD of Sample 01B (Spread at a Rd of 2.0 indicated by light blue dotted line)

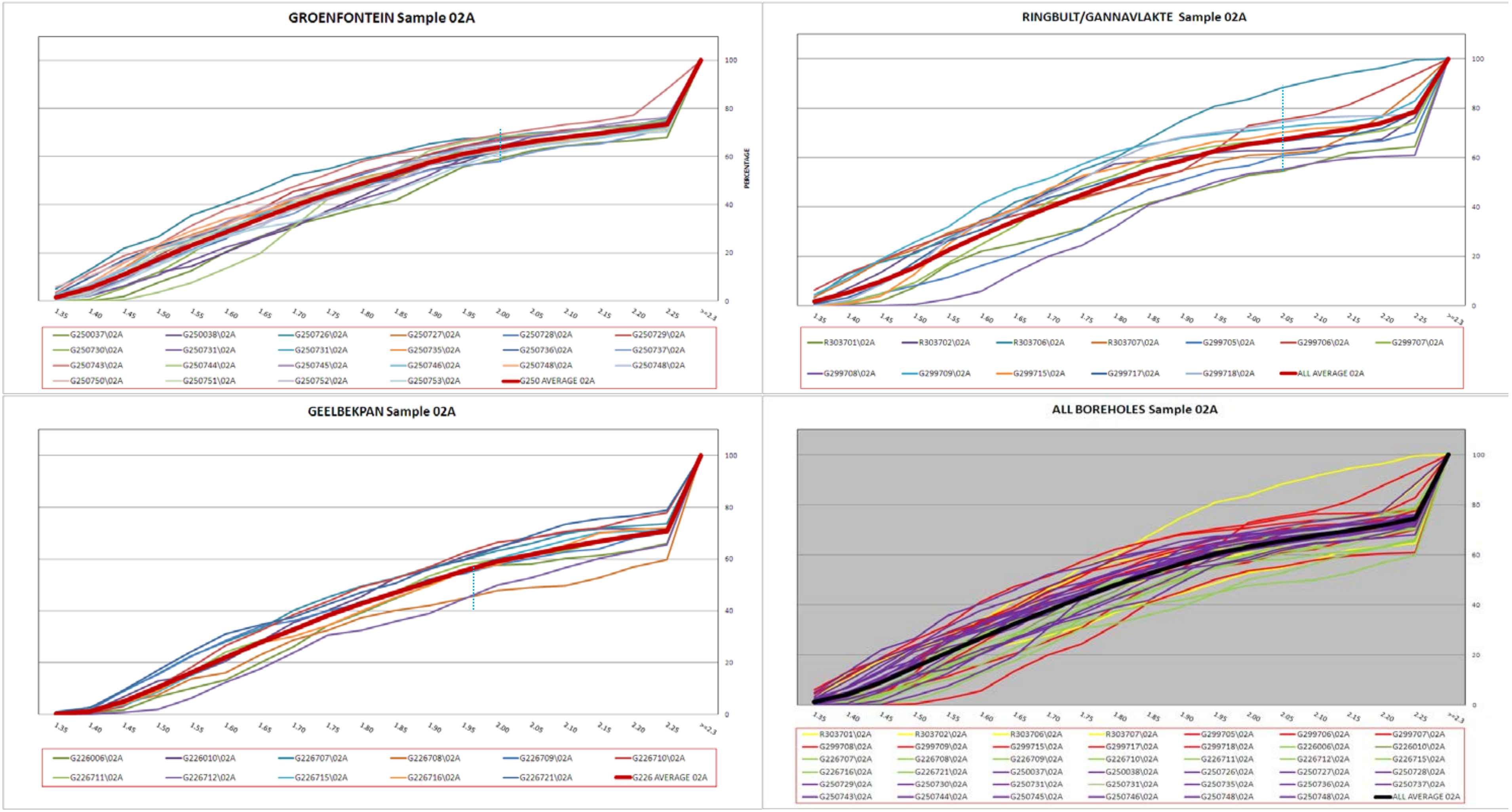


Figure 2 Combined GDCDD of Sample 02A (Spread at a Rd of 2.0, indicated by light blue dotted line)

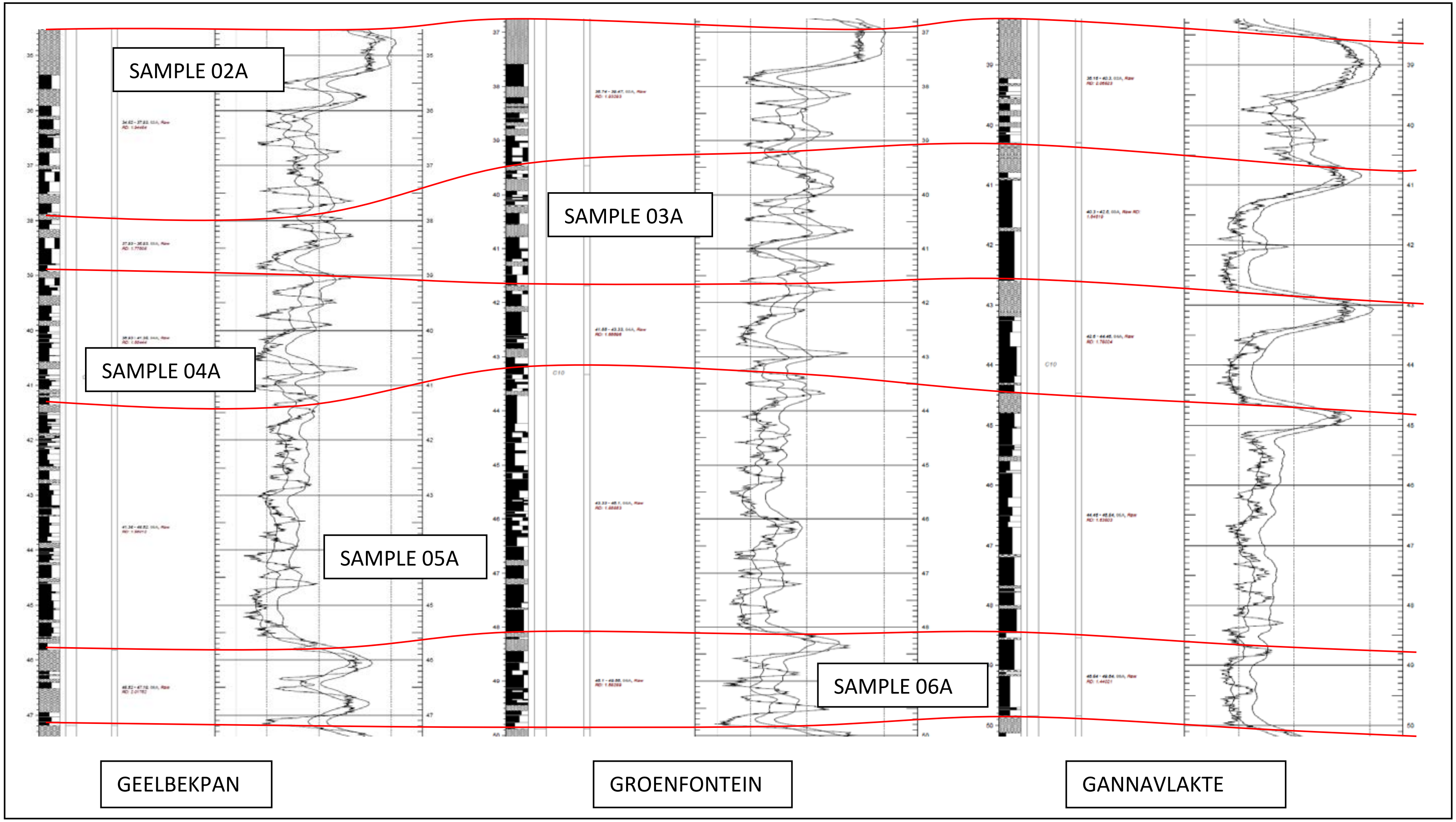


Figure 3 Graphical representation of Sample 02A to Sample 06A making up coal Zone 10 on the Study area

Table 1 Summary of Sample 01B and 02A data.

BASIC INFORMATION ABOUT SAMPLE 01B AND 02A.	SUMMARY	GEELBEKPAN	GROENFONTEIN	RINGBULT	GANNAVLAKTE
Angle of repose of graphs	Sample 01B	Medium	Medium	Medium to high	Medium to high
	Sample 02A	Medium	Medium	Medium	Medium
	The angle of repose is indicative of the high yield of these specific samples.				
Start point of graphs at Rd 1.35	Data values do not have the same point of origin for sample 01B (Figure 78) but for sample 02 they have the same start point (Figure 79). Gannavlakte and Ringbult start at a higher point of origin (more values at the lower Rd range.				
Spread	Groenfontein has a slightly wider spread of 25% for Sample 01B, but a narrow spread for Sample 02A. Geelbekpan has a narrow spread for both samples and Ringbult/Gannavlakte the widest spread (up to 40%) illustrating the varying conditions towards the south and the regularity in the north.				
Yield at Rd 2.0 – Sample 1B	11.6% variance	68.9	69.2	80.7	75.0
Yield at Rd 2.0 – Sample 2A	8.3% variance	39.6	42.2	40.8	33.9
Remarks – yield at 2.0	For Sample 01B, the data shows that the yields for Ringbult and Gannavlakte are higher than the other sample areas. For Groenfontein, the higher values in the GDCDD graph corresponds to a higher yield value in the yield data.				

	There is a 12% variation over the whole area. In the case of Sample 02A, there is an 8,3% variation over the whole area. The GDCDD curves for Sample 02A along the Groenfontein profile shows very narrow correlation between the known yield boreholes and the unknown boreholes (Figure 83 and Figure 84).								
Raw Rd Sample 01B	0.09 variance	1.64		1.64		1.55		1.59	
Raw Rd Sample 02A	0.09 variance	1.92		1.91		1.92		2.00	
Remarks on raw Rd	The south has the lowest raw Rd for Sample 01B, and Groenfontein has the lowest raw Rd for Sample 02A and								
Thickness Sample 01B	0.77 meter variance	1.44		1.38		2.15		1.92	
Thickness Sample 02A	0.32 meter variance	2.80		2.91		2.87		2.59	
Remarks on thickness	The thickness of Sample 01B varies in thickness (Figure 58), but Sample 02A has less variation of thickness (Figure 80, Figure 81, Figure 82 and Figure 86) and does not occur everywhere, due to geological variations, such as faulting.								
Standard deviation at a Rd of 1.60 and 2.0	**Relative density**	**1.6**	**2.0**	**1.6**	**2.0**	**1.6**	**2.0**	**1.6**	**2.0**
	Sample 01B	4.0	4.3	9.1	8.9	3.7	3.7	8.2	5.8
	Sample 02A	6.2	5.9	7.3	6.4	5.9	13.2	11.4	7.1
Comments on standard deviation	It can be seen that the σ for Groenfontein is higher than for the other areas in the Study area for Sample 01B. Ringbult and Gannavlakte have higher values for Sample 02A.								
Correlation accuracy by geologist	Good, easy to correlate. Problems with correlation, like faulting and correlation errors, will be prominent.								
Modelling accuracy	Good correlation, easy to model. No factoring necessary to compensate for modelling accuracy at Geelbekpan. Groenfontein has to be investigated in more detail due to some erosion of this sample in the southern part of the								

	sampled area. (Figure 31). The south shows that care should be taken when doing correlation and factoring will probably be necessary.
Use as SANS 10320 data correlation point	The use of the GCCD proves that the method can be used to prove the continuity of Sample 01B with a good measure of accuracy. Figure 85 illustrates that the coal seam next to the green 11 label in the figure has a varying thickness and this results in the variance illustrated in the GDCDD (Figure 78). Ringbult has some variance, but this can be geologically declared (Figure 67). The spacing in the GDCDD graphs for Sample 01B is very narrow for Geelbekpan, wider for Groenfontein and wide for the graphs in the south (Ringbult and Gannavlakte). Sample 01B is easy to correlate over the Study area, but it is somewhat variable in the south. There is an 11.6% variance in yield over the Study area and a thickness variation of 0,77 m. For modelling purposes, there is good lateral correlation. No factoring necessary to compensate for modelling accuracy at Geelbekpan. Groenfontein has to be investigated in more detail due to some erosion of this sample in the southern part of this farm. The south shows that care must be taken when doing correlation and factoring will probably be necessary. There is a direct correlation between GDCDD's and yield curves. In terms of modelling, there is good lateral correlation, which should make modelling straightforward.. The south shows that care should be taken when doing correlation and factoring will probably be necessary. The use of the GCCD proves that the method can be used to prove the continuity of these samples with a good measure of accuracy, as a SANS data point. Ringbult has some variance but these can be geologically declared.

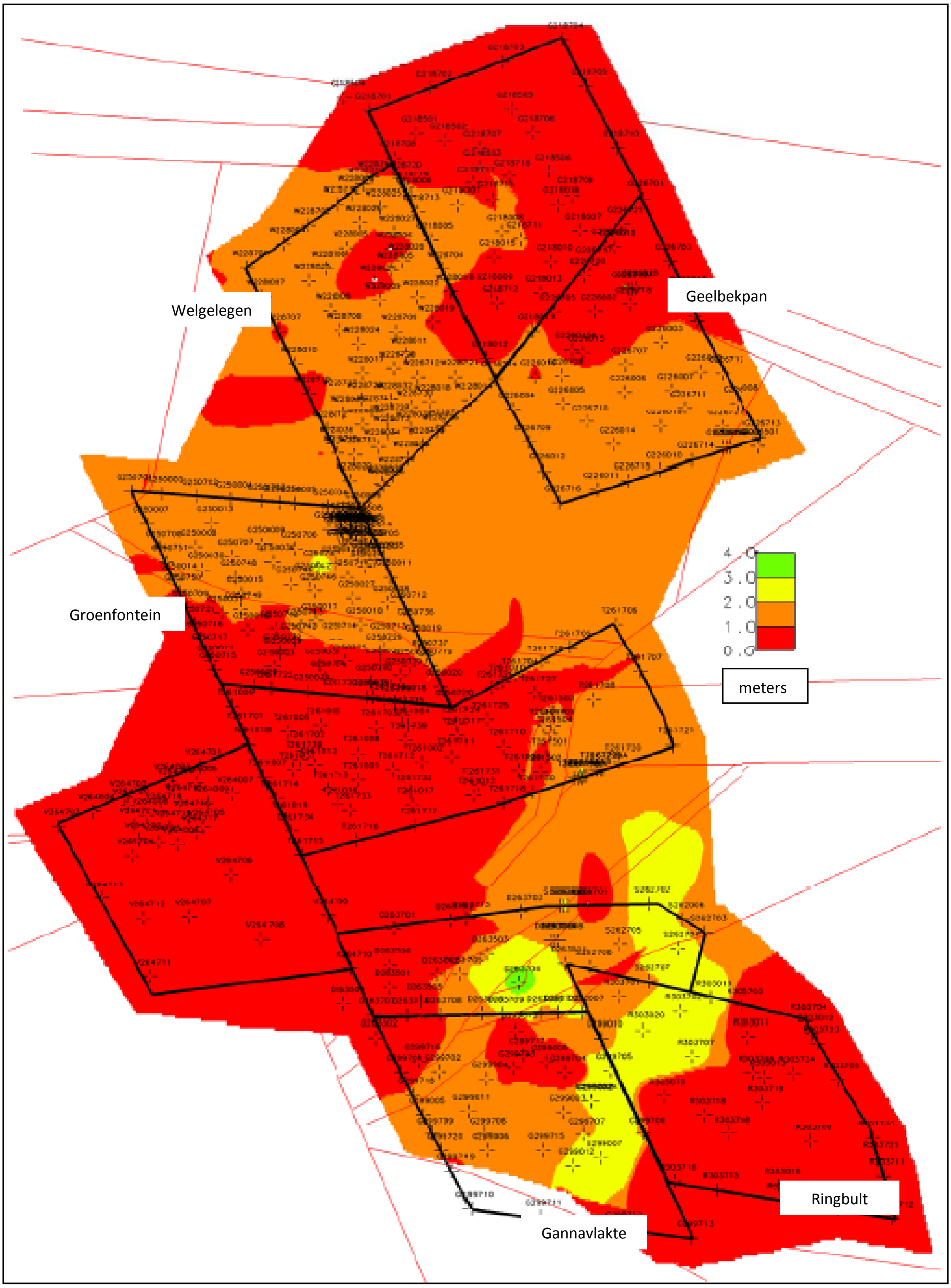


Figure 4 Thickness of Sample 01B over the Study area

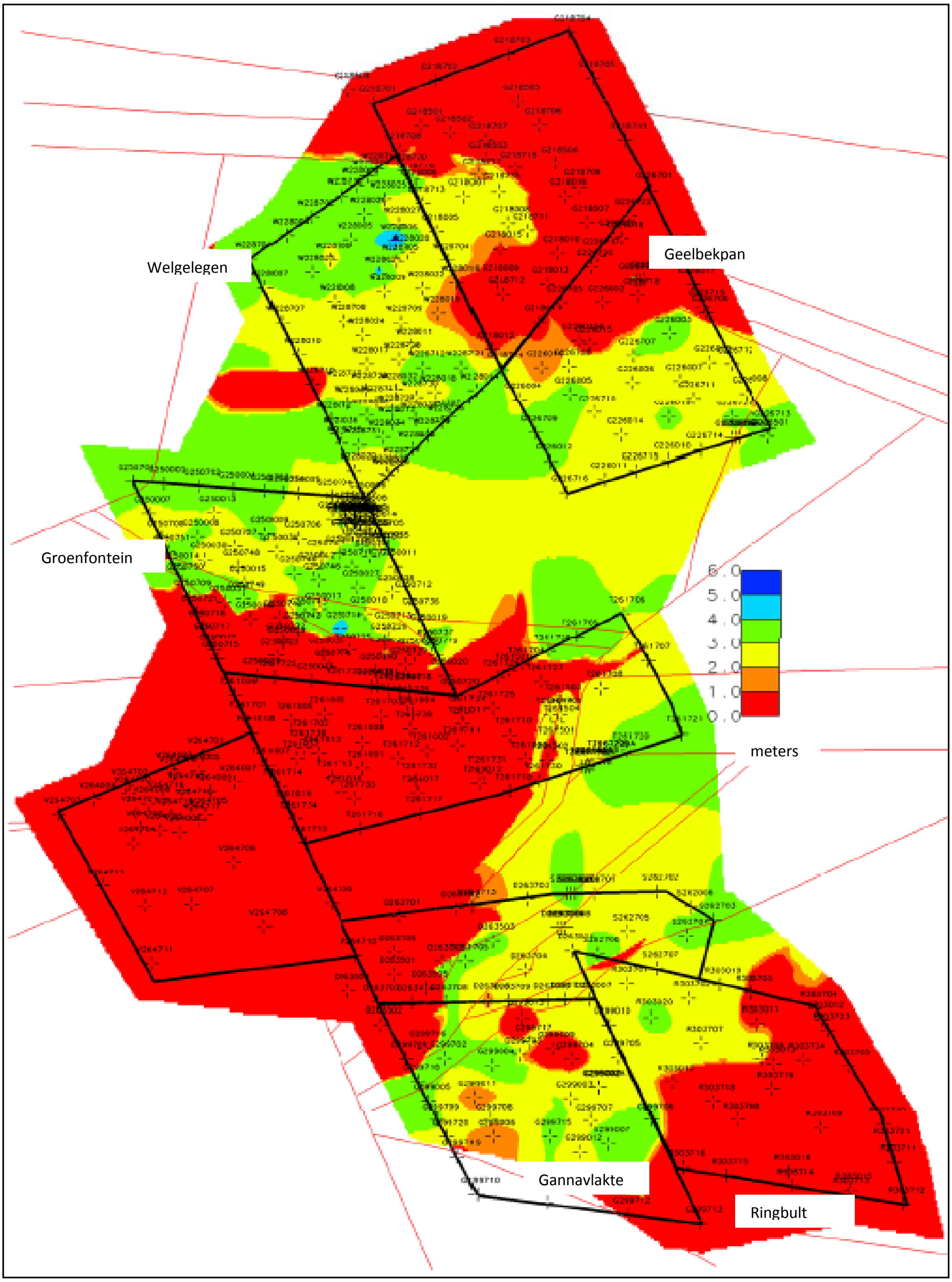
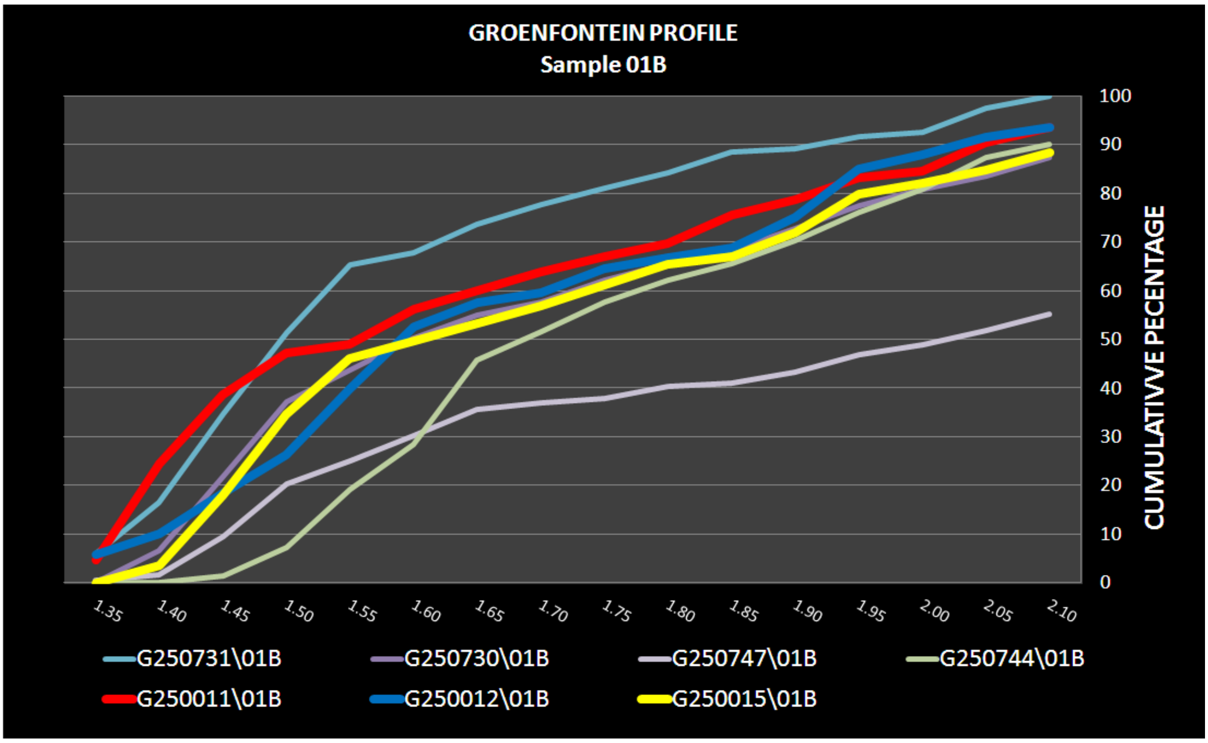
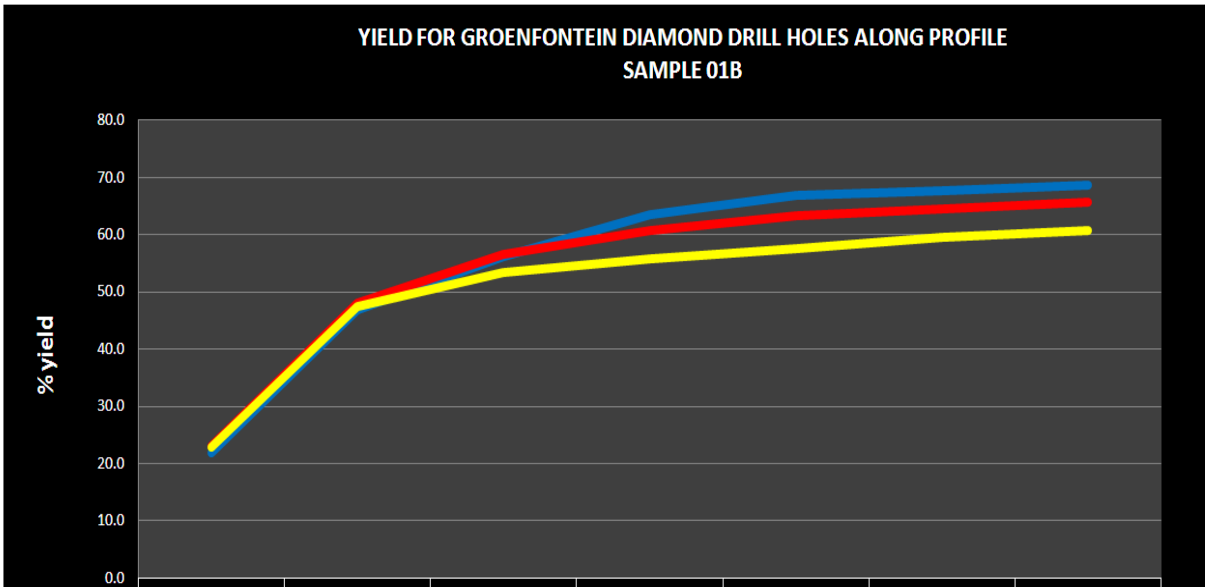


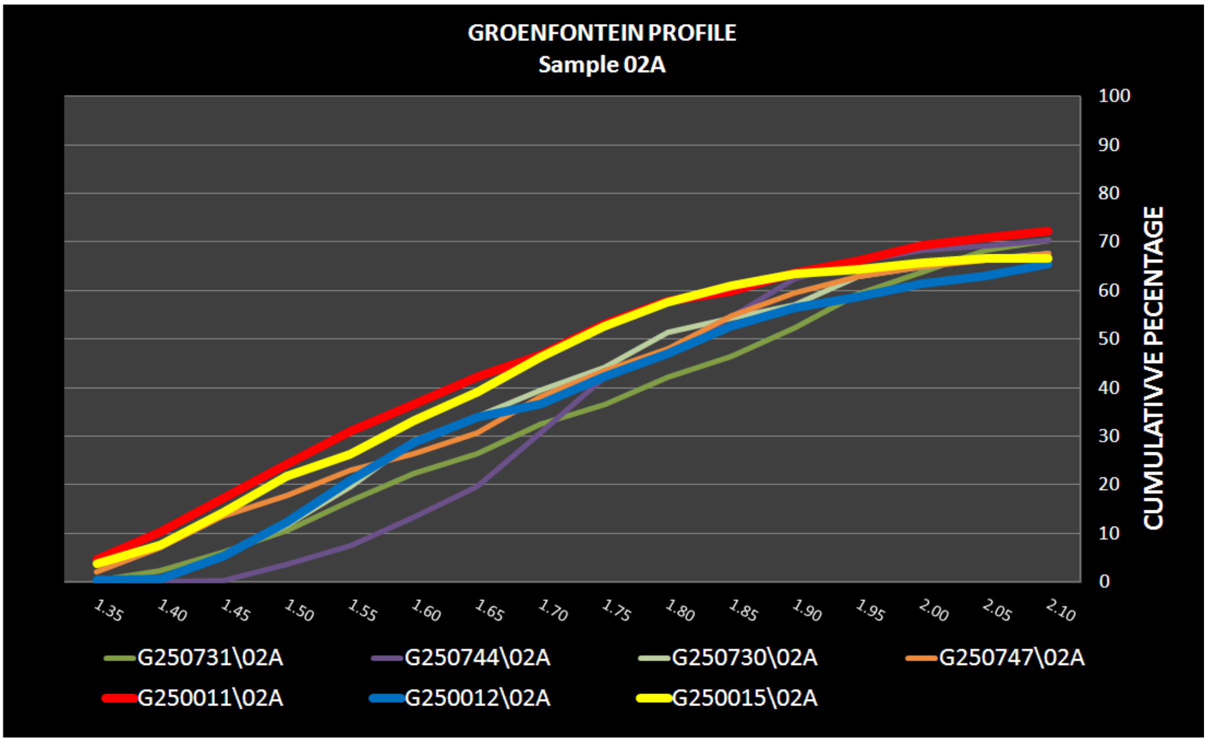
Figure 5 Thickness of Sample 02A over the Study area

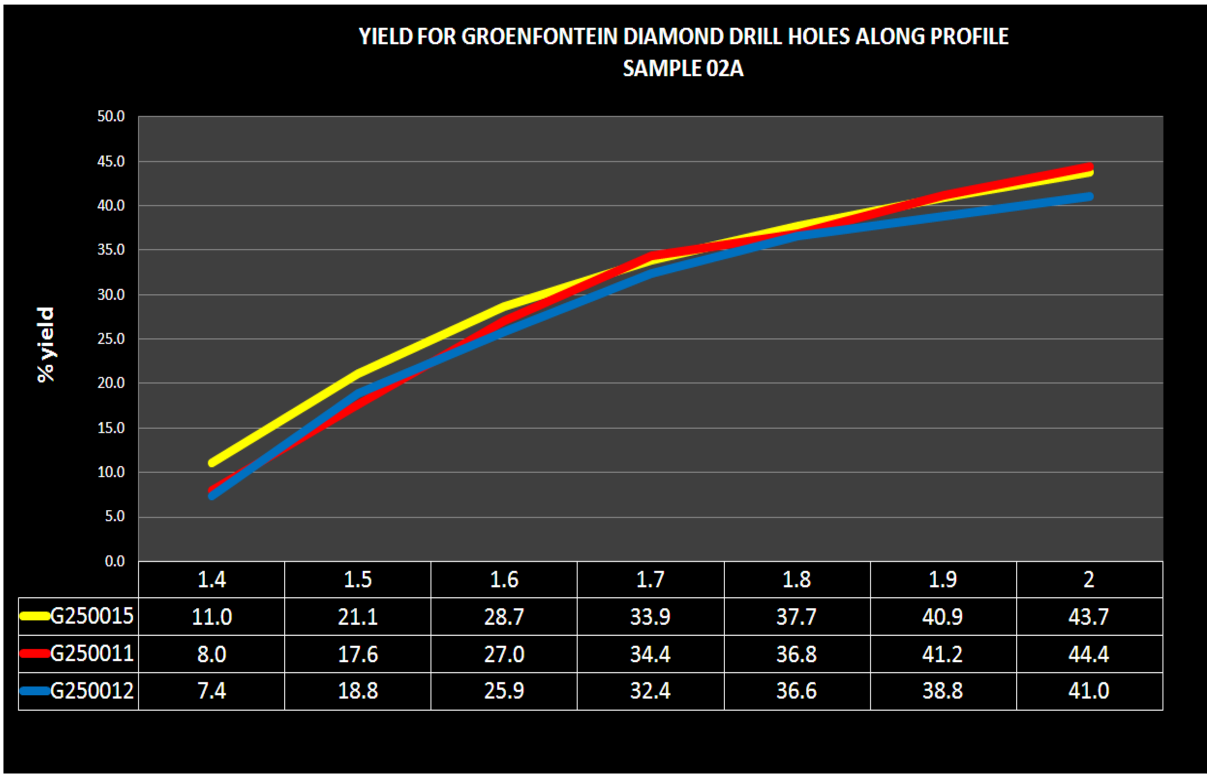




	1.4	1.5	1.6	1.7	1.8	1.9	2
G250012	21.9	46.9	56.2	63.5	66.8	67.6	68.7
G250011	23.0	48.0	56.5	60.7	63.3	64.4	65.6
G250015	22.8	47.5	53.5	55.8	57.6	59.5	60.7

Figure 6 Groenfontein Sample 01B, GDCDD at the top and yield curves along a selected profile. (Illustrated in Figure 55)





	1.4	1.5	1.6	1.7	1.8	1.9	2
G250015	11.0	21.1	28.7	33.9	37.7	40.9	43.7
G250011	8.0	17.6	27.0	34.4	36.8	41.2	44.4
G250012	7.4	18.8	25.9	32.4	36.6	38.8	41.0

Figure 7 Groenfontein Sample 02A GDCDD at the top and yield curves along a selected profile. (Illustrated in Figure 55)

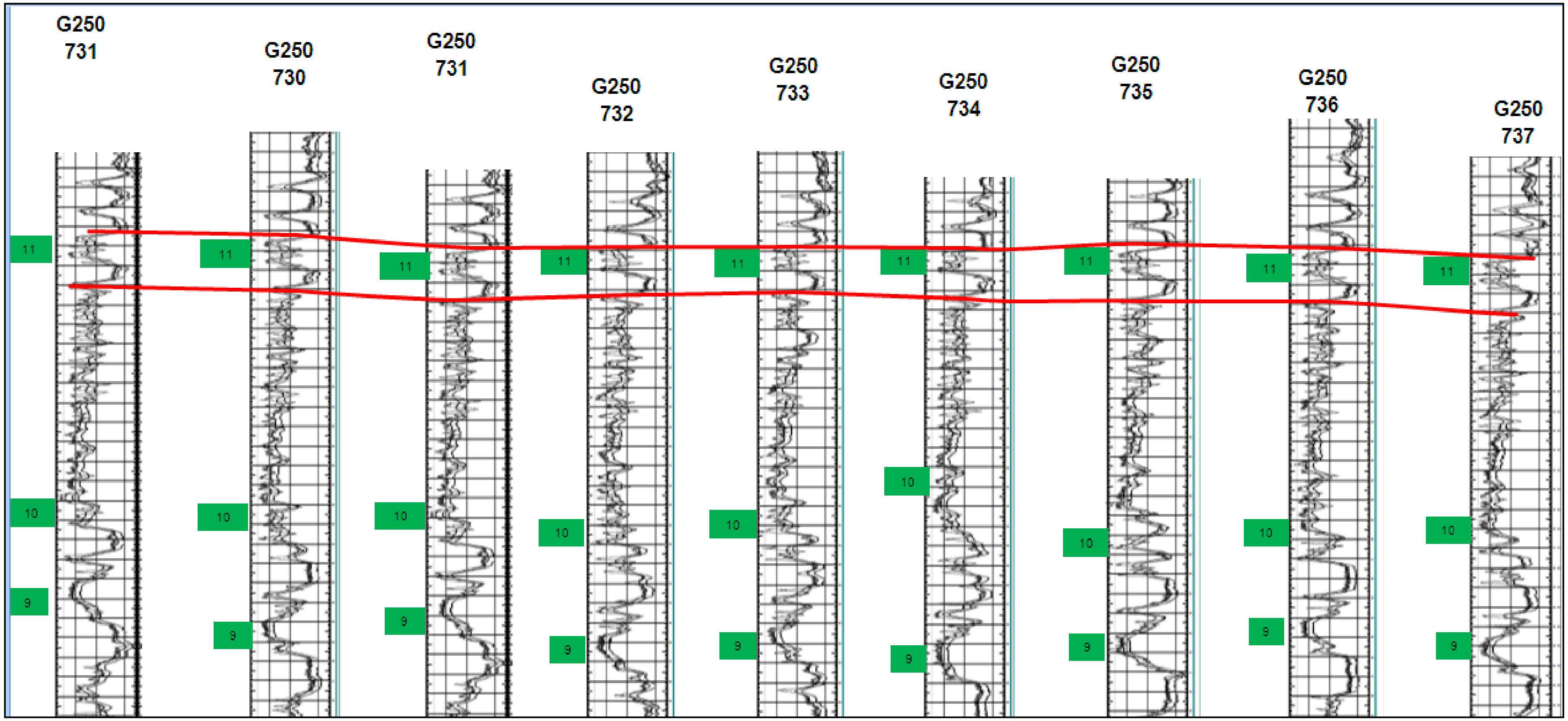


Figure 8 Occurrence of Sample 01B on Groenfontein, illustrating variances in Sample 01B. Green labels denote bottom of coal zones

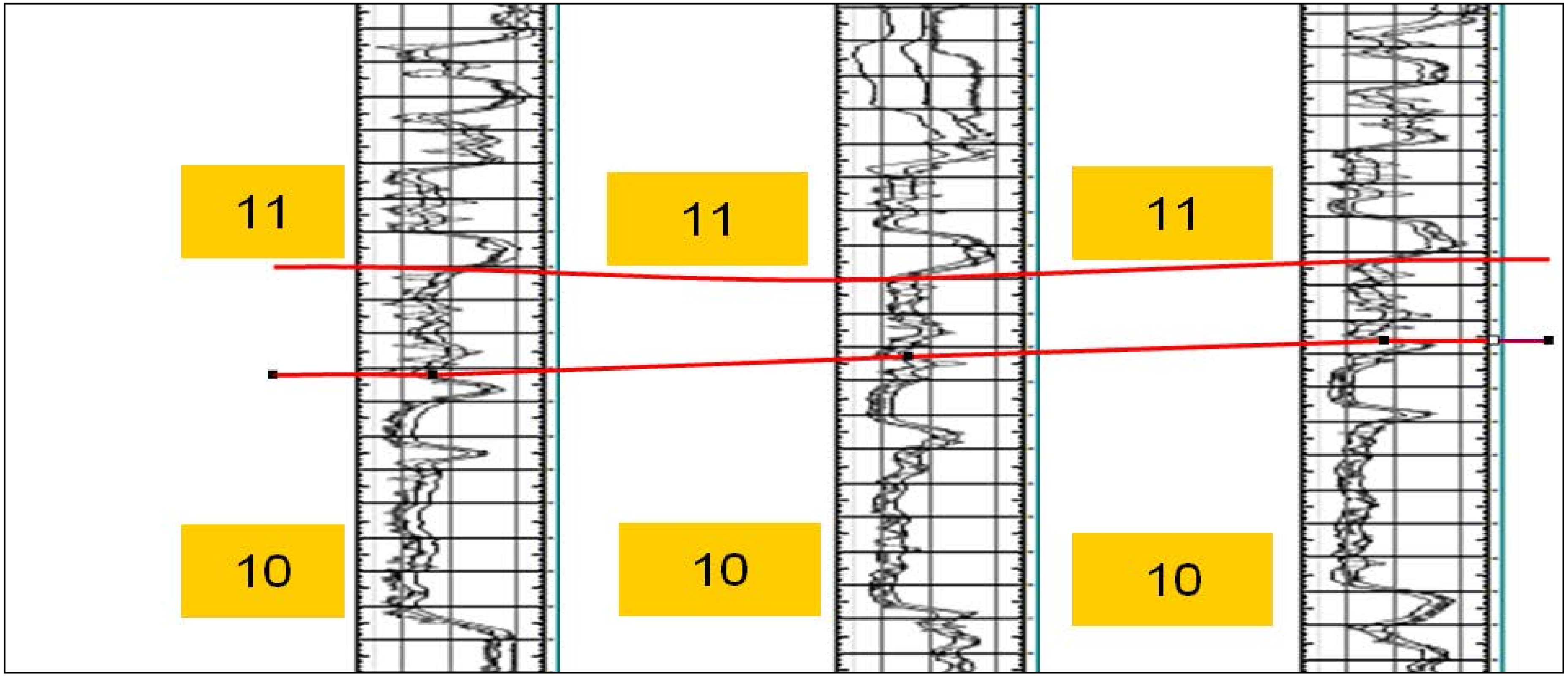


Figure 9 Occurrence of Sample 02A on Ringbult, illustrating variances in Sample 02A. The yellow labels denote bottom of coal zones (From geophysical data)

Samples 03A, 04A and 05A

Figure 87 to Figure 89

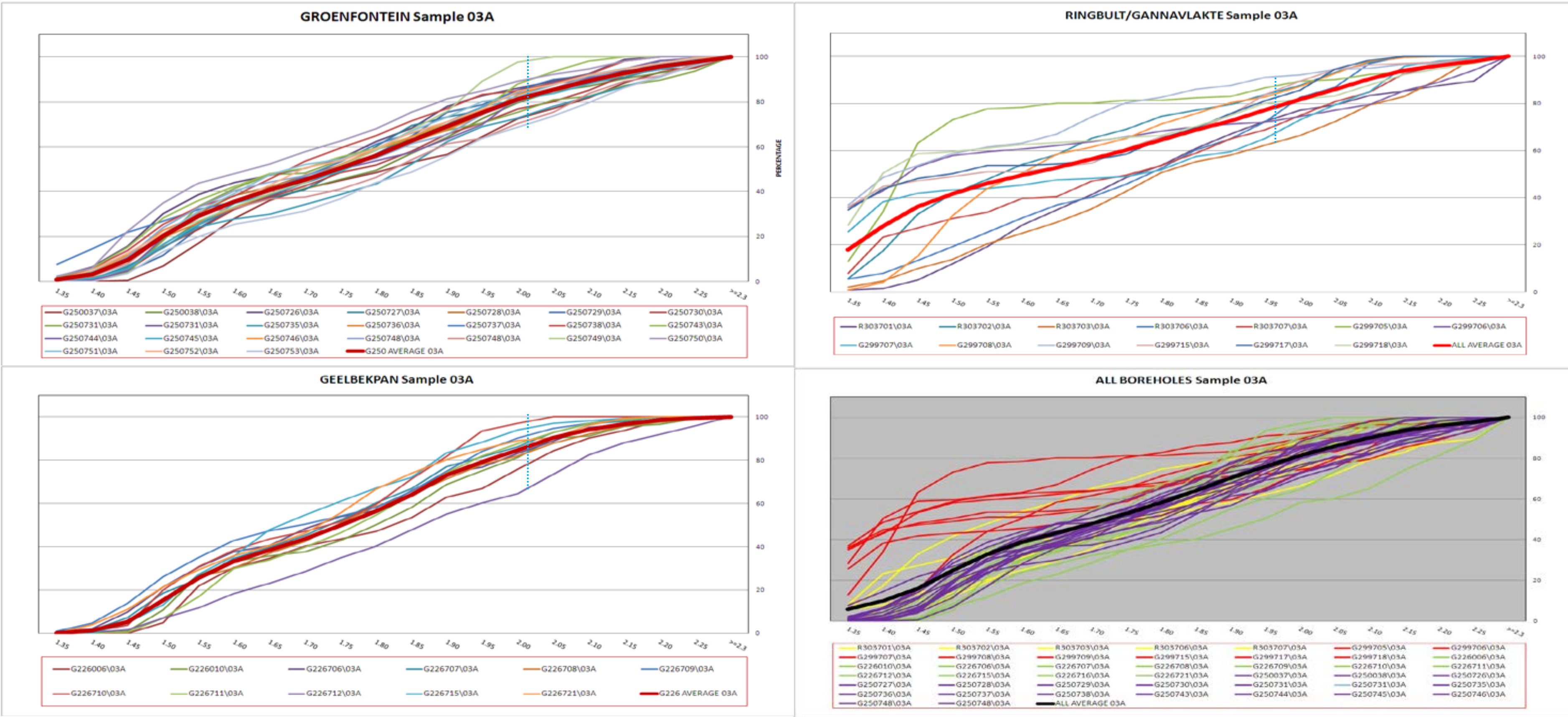


Figure 10 Combined GDCDD of Sample 03A (Spread at a Rd of 2.0, indicated by light blue dotted line)

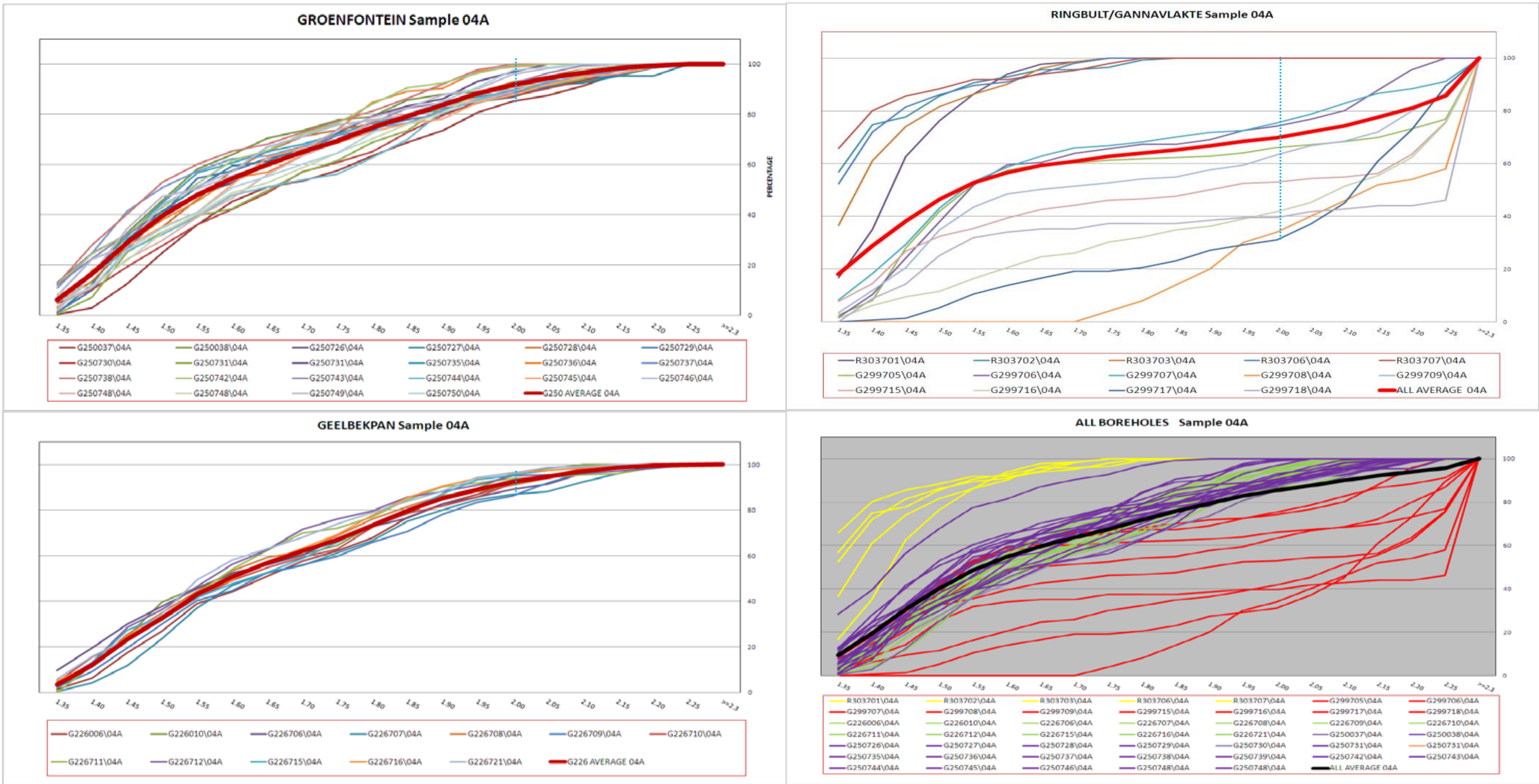


Figure 11 Combined GDCDD of Sample 04A (Spread at a Rd of 2.0, indicated by light blue dotted line)

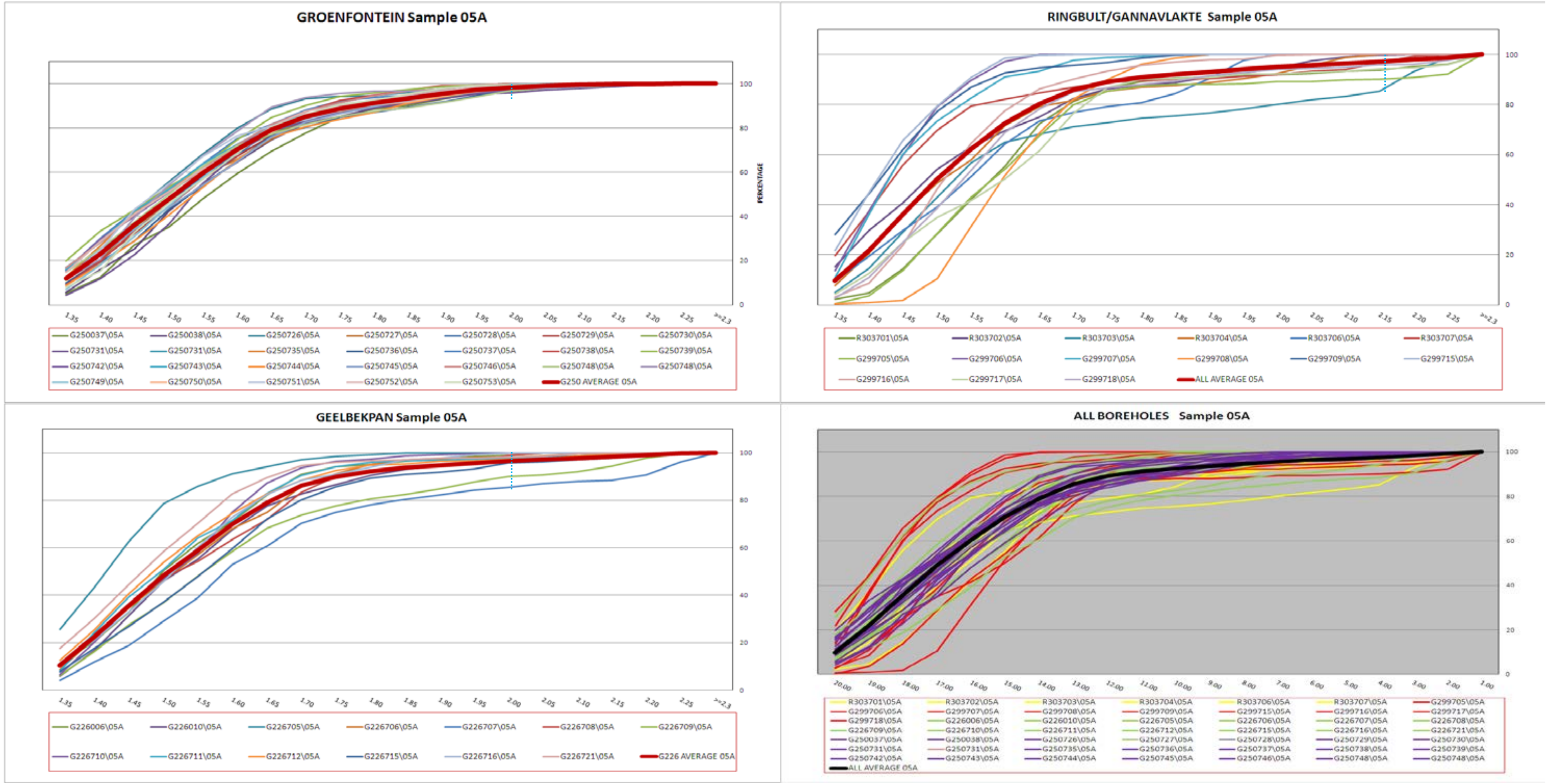


Figure 12 Combined GDCDD of Sample 05A (Spread at a Rd of 2.0, indicated by light blue dotted line)

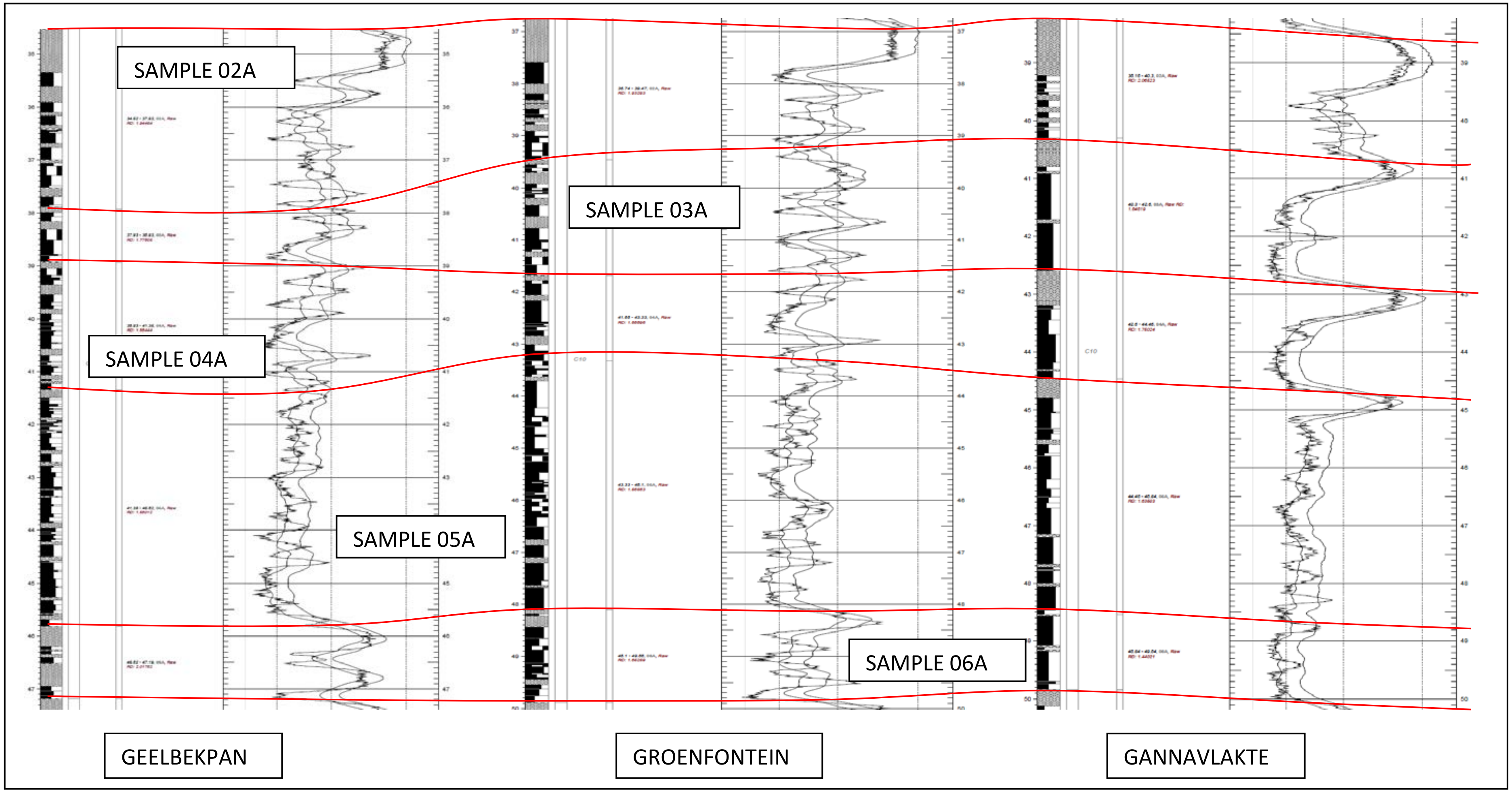


Figure 13 Graphical representation of Sample 02A to Sample 06A on the Study area

Table 2 Summary of Sample 03A, 04A and 05A data.

BASIC INFORMATION ABOUT SAMPLE 03A, 04A AND 05A	SUMMARY	GEELBEKPAN	GROENFONTEIN	RINGBULT	GANNAVLAKTE
Angle of repose of graphs	Sample 03A	High	High	High and medium	High and medium
	Sample 04A	High	High	High and medium	High and medium
	Sample 05A	High	High	High	High
	High angles of repose for the various areas and associated higher yields. The amount of interbedded inorganic material in the south (in certain areas) influences the angle of repose of some graphs (Figure 87 to Figure 89).				
Start point of graphs at Rd 1.35	Data values do not start at the same point of origin, illustrating the variable amount of low density material in the various areas.				
Spread	For Sample 03A (Figure 87), the spread is around 30% for all the areas; for the south, the yields vary considerably. For Sample 04A (Figure 88), the spread for the south is very wide (55%) due to mudstones on top and at the bottom of this sample (Figure 90). Sample 05A is narrowly spread for Groenfontein and Geelbekpan (± 10%), but only slightly wider in the south due to one borehole (Figure 89).				
Yield at Rd 2.0 -Sample 03A	14.9% variance	57.4	55.7	53.1	68.0
Yield at Rd 2.0 - Sample 04A	18.8% variance	73.2	68.9	64.8	54.4
Yield at Rd 2.0 - Sample 05A	5.1% variance	86.3	82.8	83.7	81.2

Remarks- Yield	The lowest yield is found in sample 03A. Sample 04A has the highest variance in yield and Sample 05A the lowest. The highest yield is found in Sample 05A.								
Raw Rd Sample 03A	0.45 variance	1.72		1.95		1.82		1.50	
Raw Rd Sample 04A	0.12 variance	1.64		1.66		1.67		1.76	
Raw Rd Sample 05A	0.08 variance	1.55		1.56		1.59		1.63	
Remarks on raw Rd	Highest variance is found in Sample 03A, due to the lateral facies changes and the lowest variance in Sample 05A, with the least lateral facies variance. The lower yield are reflected in the higher raw Rd value for Sample 03A.								
Thickness Sample 03A	0.18 meter variance	1.79		1.78		1.75		1.61	
Thickness Sample 04A	0.36 meter variance	2.07		1.69		2.02		1.71	
Thickness Sample 05A	0.93 meter variance	4.29		4.73		4.03		3.80	
Remarks on thickness	Sample 04A varies between 1 m and 3 m (Figure 93). Good correlation of thickness for all three samples. The south is thinner than the north for Sample 03A (Figure 92) and Sample 05A (Figure 94). Sample 05A is quite thick in the Groenfontein area.								
Standard deviation at a Rd of 1.60 and 2.0	**Relative density**	**1.6**	**2.0**	**1.6**	**2.0**	**1.6**	**2.0**	**1.6**	**2.0**
	Sample 03A	6.6	11.4	5.9	7.6	11.7	8.0	10.4	7.1
	Sample 04A	4.4	3.6	9.3	4.5	1.5	0.0	21.6	17.2
	Sample 05A	10.2	4.3	8.2	1.2	8.9	6.5	20.1	4.2
Comments on standard deviation	The standard deviation varies between 0.0 and 21.6, averaging around 8.0%.								

Correlation accuracy by geologist	Good, easy to correlate, except for the south. Problems with correlation, such as faulting and correlation errors, will be prominent. The variation in yields in the south may be ascribed to the geological variations (Figure 90 and Figure 91). The σ for Gannavlakte (Sample 04A) is high and care should thus be taken when correlating.
Modelling accuracy	Good correlation, easy to model, except for the south. Here some factoring would be necessary to compensate for modelling accuracy.
Use as SANS 10320 data correlation point	The use of the GCCD proves that the method can be used to prove the continuity of Sample 03A and Sample 04A in the north with a good measure of accuracy; except for the south where care has to be taken when correlating the geology. The reason is that Sample 03A and Sample 04A have to a large extent, been weathered away (Figure 32). There is a narrow correlation between the various graphs for Groenfontein and Geelbekpan, except for the south which is slightly wider spaced. The start-point of the graphs for the south in particular, shows a variable amount of low density material in the samples, with Sample 04A being especially variable. The raw Rd for Sample 03A is also quite variable (0.45), but the thickness is remarkable even (0.28 m over the Study area). Sample 05A varies by 0.93 m, but this Sample is quite thick (+3.80 m). The standard deviation for Sample 04A is the highest (17.2) because of the inclusion of high density material in this sample in the south. Of the three samples, Sample 05A has the lowest variance in yield. The lower yields for the south resulted because the south has a higher raw Rd, in particular, Sample 04 for Gannavlakte. When comparing the yield with the GDCDD curves with the analytical yield along a specific profile they show that high values for the GDCDD curves corresponds with a higher value in the analytical yield (for sample 03A-Figure 95, for sample 04A-Figure 96 and for sample 05A-Figure 97).There is good correlation of thickness for all three samples. The south is thinner

	than the north for Sample 03A and Sample 05A. The thickness of Sample 03A is remarkably even over the whole area, having only a 0.18 cm variance. The lateral lithofacies correlation over the whole area of these three samples is constant, and it is relatively easy to correlate, except for the south. Problems with correlation, such as faulting and correlation errors, will be prominent. The variation in yields in the south can be ascribed to the geological variations. The comparison between the yield and the GDCDD shows a clear relationship between the derived curves and the yield where the curves with the higher value correlate well to the higher yield curves (Figure 95 to Figure 97).The σ for Gannavlakte Sample 04A is high and care should be taken when correlating. In terms of modelling accuracy, the use of the GCCD demonstrates that the method can be used to prove the continuity of Sample 03A and Sample 04A in the north with a good measure of accuracy; except for the south where care has to be taken when correlating the geology. The reason being that Sample 03A and Sample 04A have been weathered to a large extent.

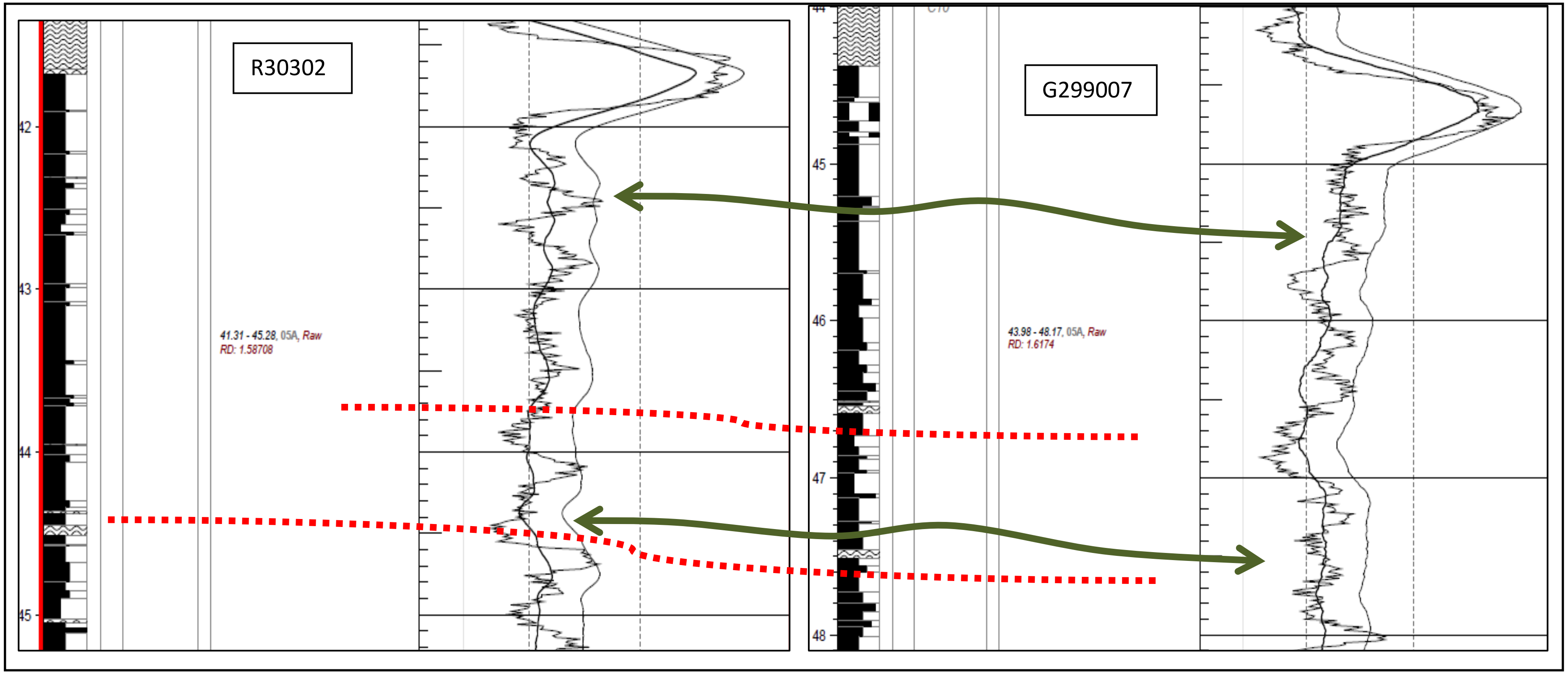


Figure 14 The lateral lithological variation in Sample 05A in the south. The geophysical graphs look dissimilar and mudstone lenses are not laterally consistent

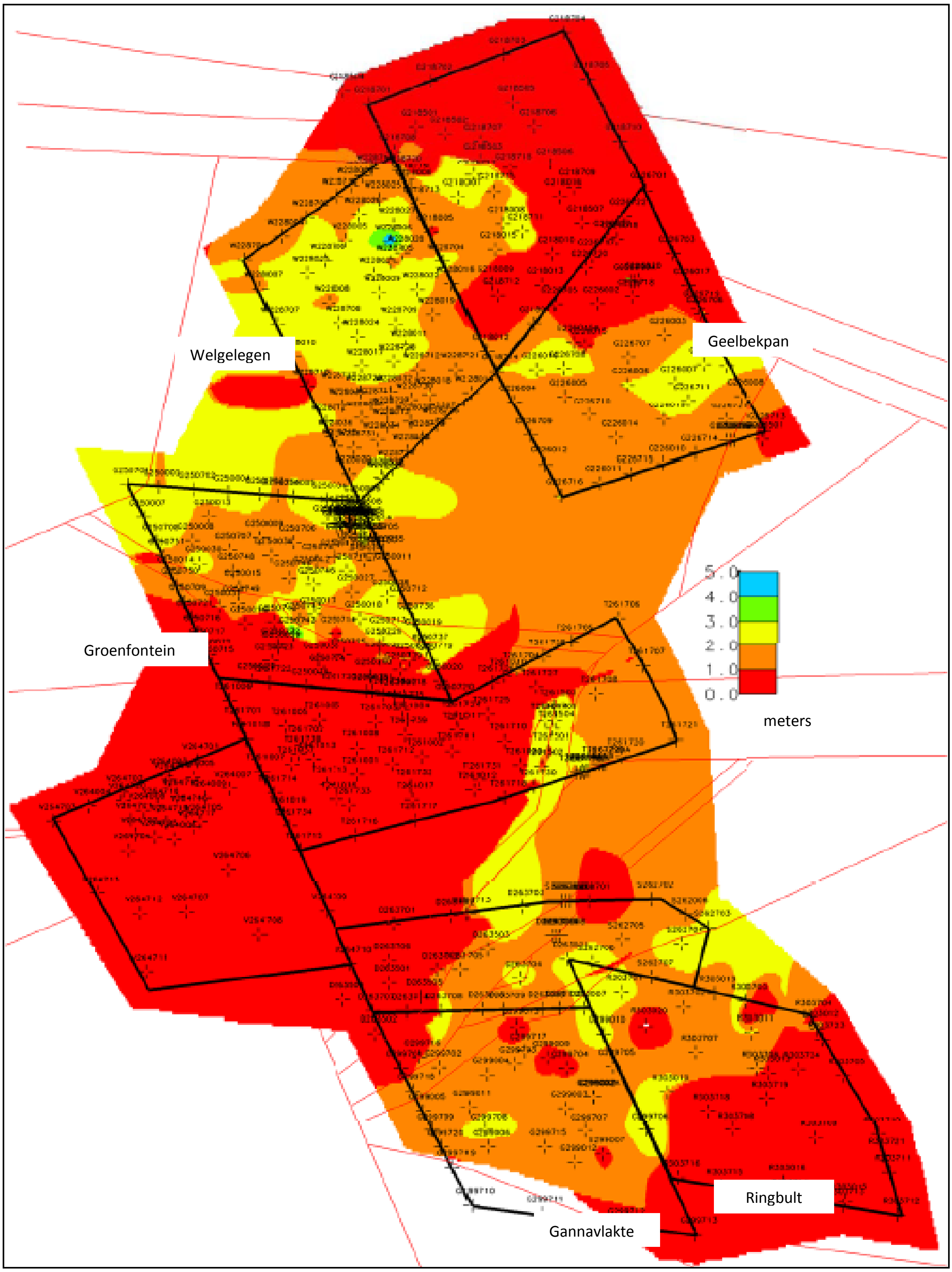


Figure 15 Thickness of Sample 03A over the Study area

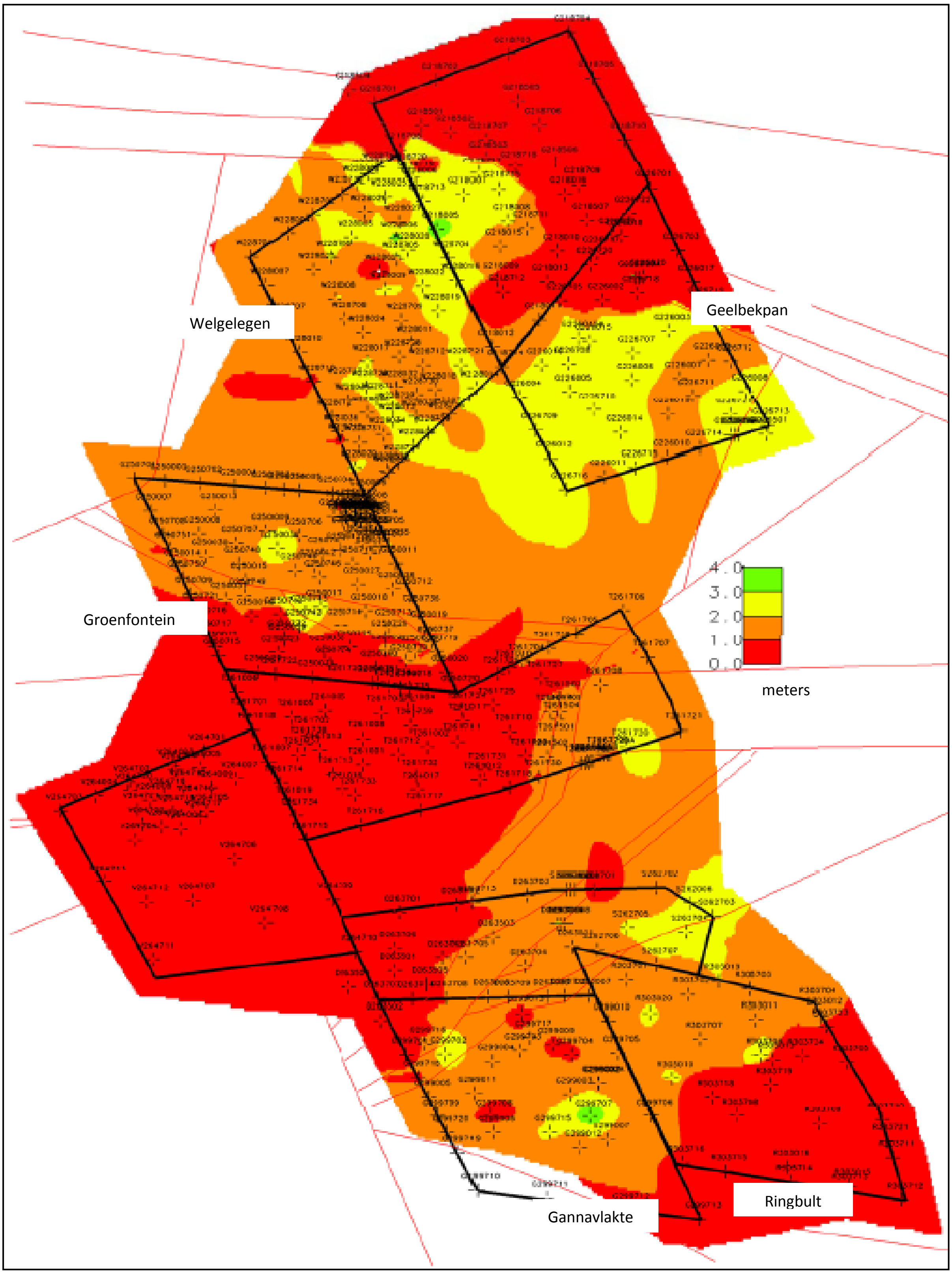


Figure 16 Thickness of Sample 04A over the Study area

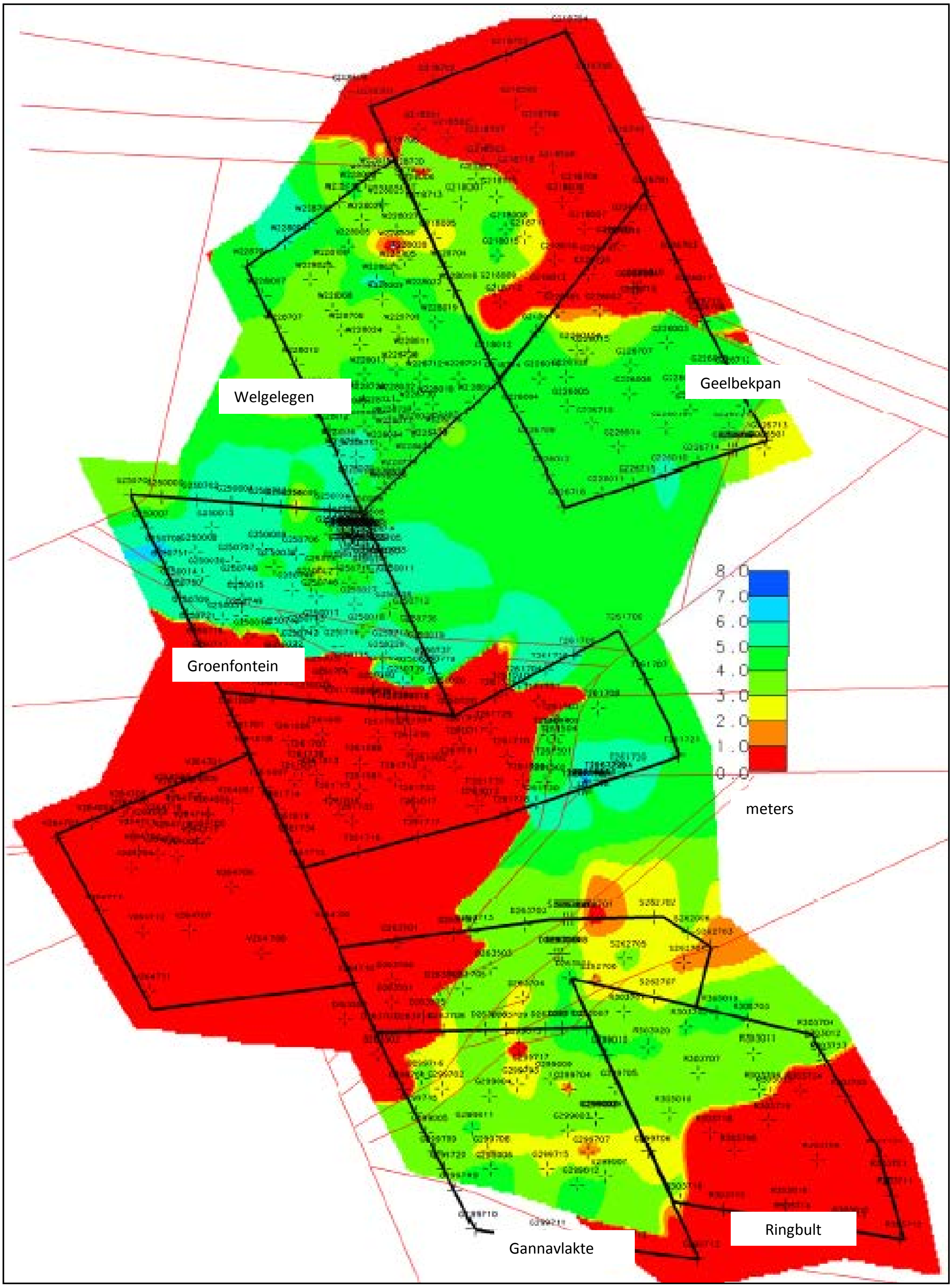
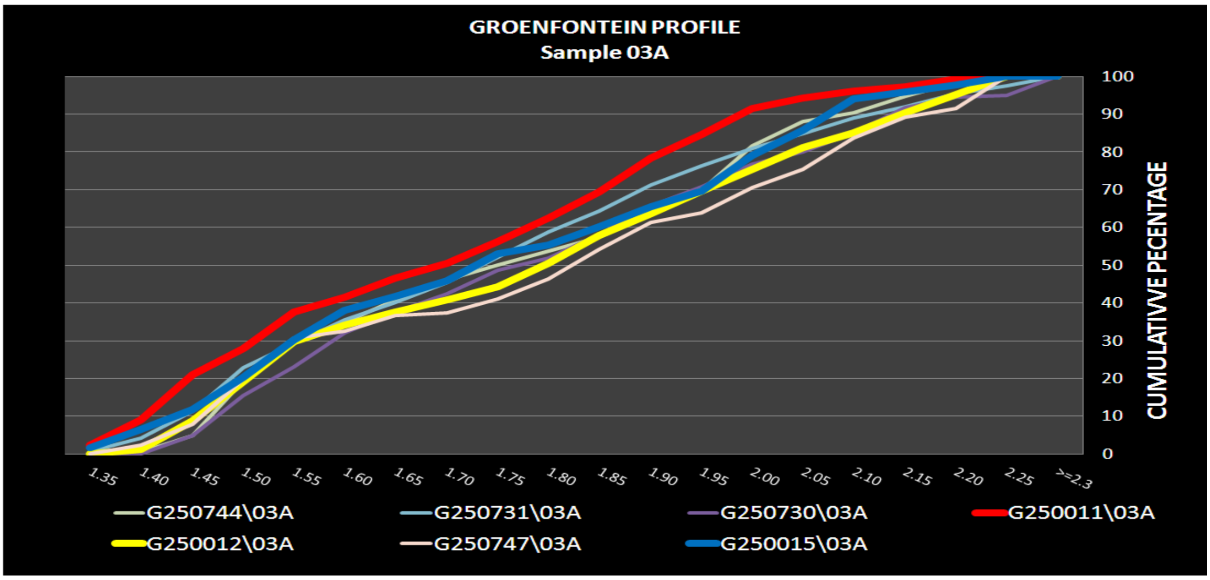


Figure 17 Thickness of Sample 05A over the Study area

Table 3 Standard deviation calculated at two RDs from the GCCD data for Sample 03A to Sample 05A.

FARM															
	GEELBEKPAN			**GROENFONTEIN**			**GANNAVLAKTE**			**RINGBULT**			**TOTAL**		
Sample	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**
03A	6.6	11.4	9.0	5.9	7.6	6.8	10.4	7.1	8.8	11.7	8.0	9.8	8.6	8.6	8.6
04A	4.4	3.6	4.0	9.3	4.5	6.9	21.6	17.2	19.4	1.5	0.0	0.8	9.2	6.3	7.8
05A	10.2	4.3	7.3	8.2	1.2	4.7	20.1	4.2	12.2	8.9	6.5	7.7	11.9	4.1	8.0



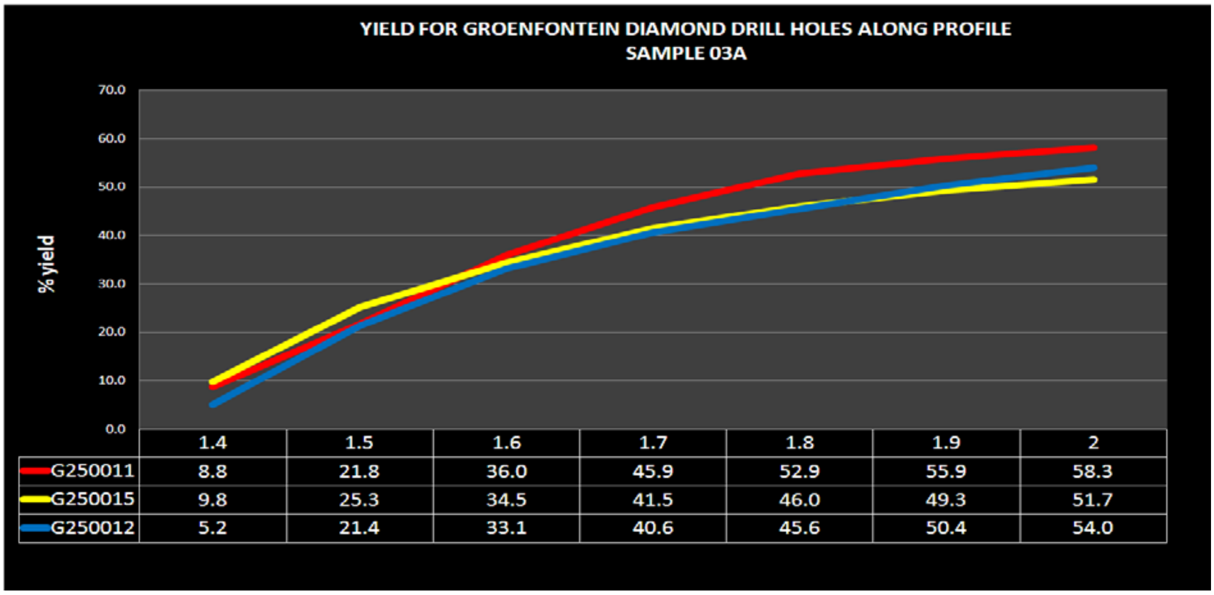
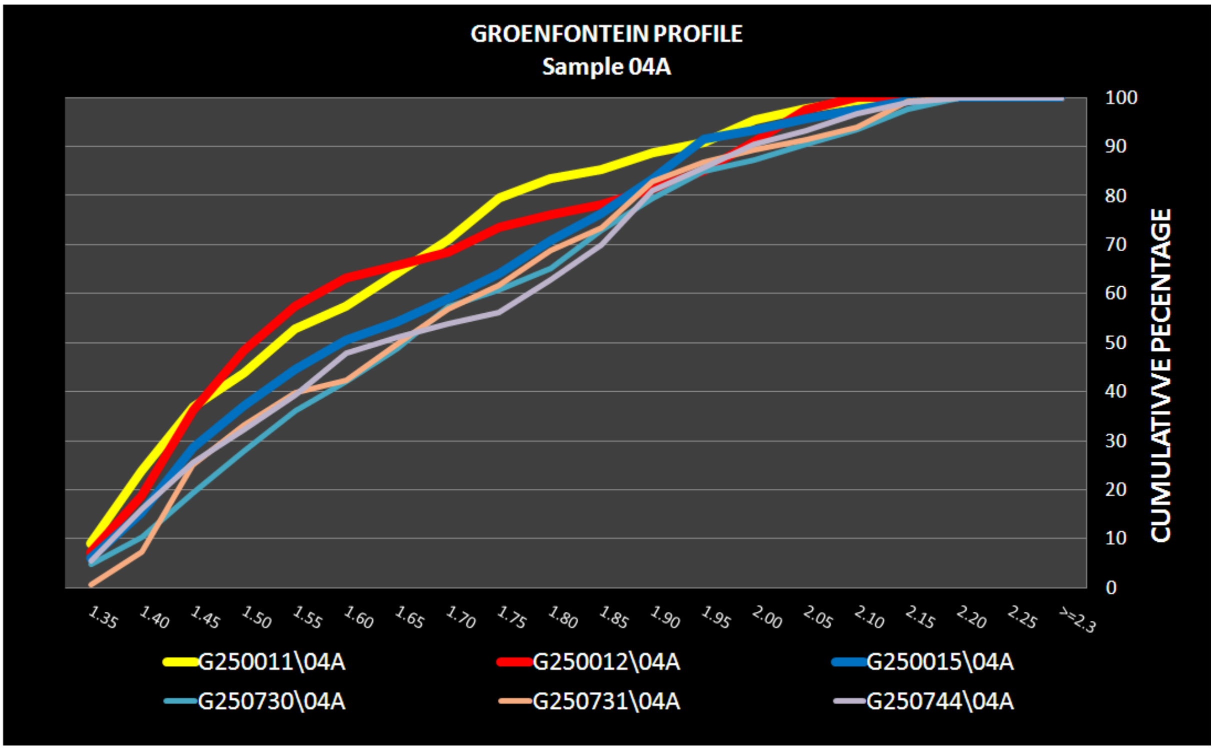
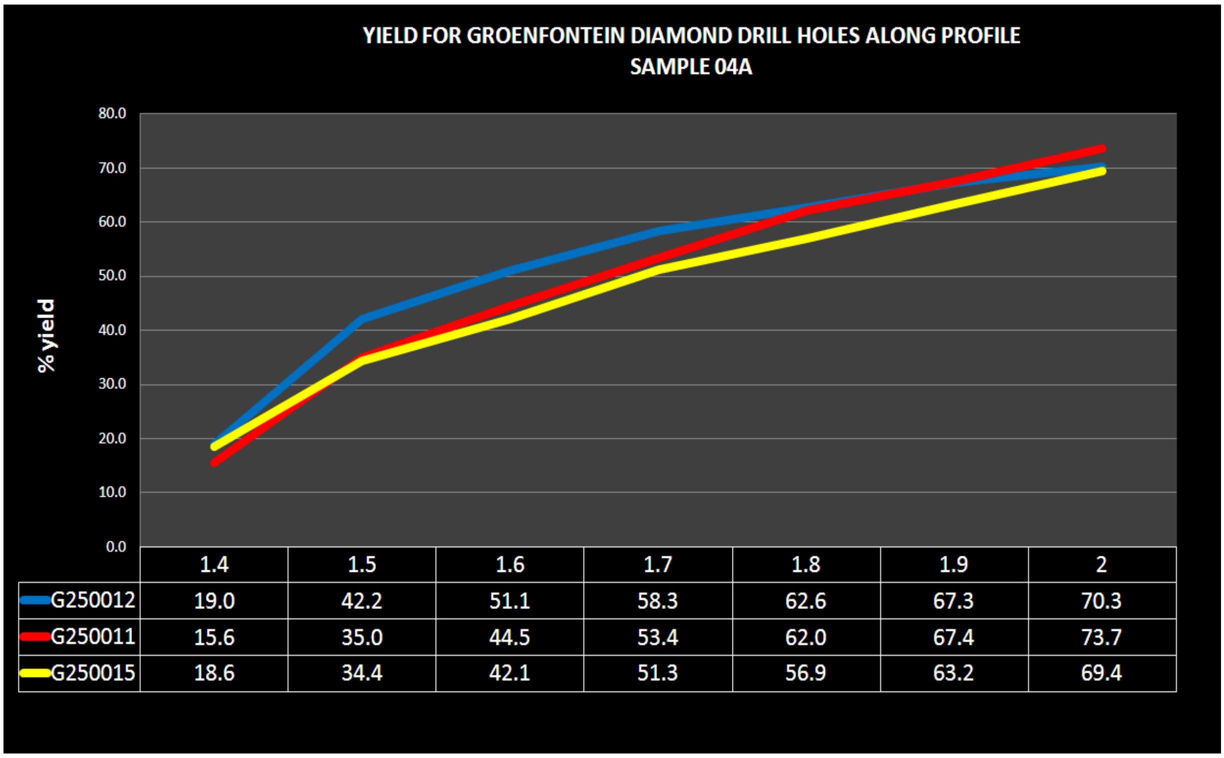


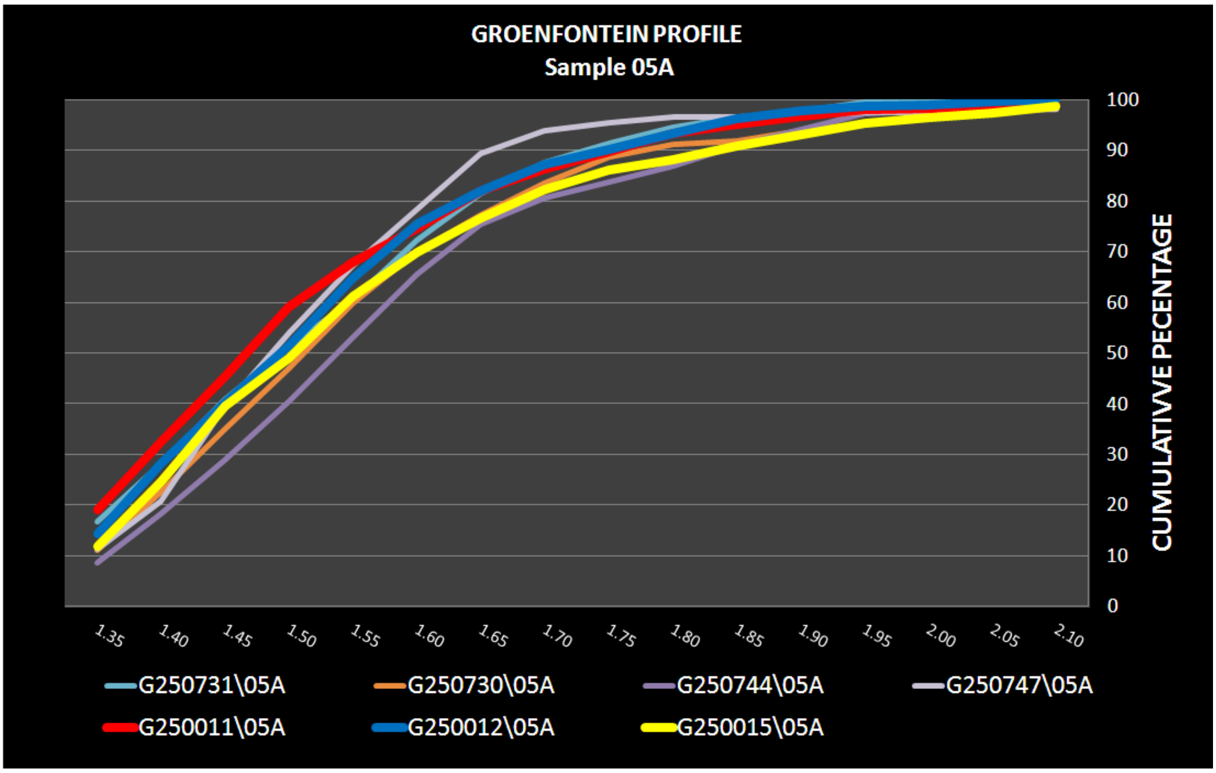
Figure 18 Groenfontein Sample 03A GDCDD at the top and yield curves along a selected profile (illustrated in Figure 55)

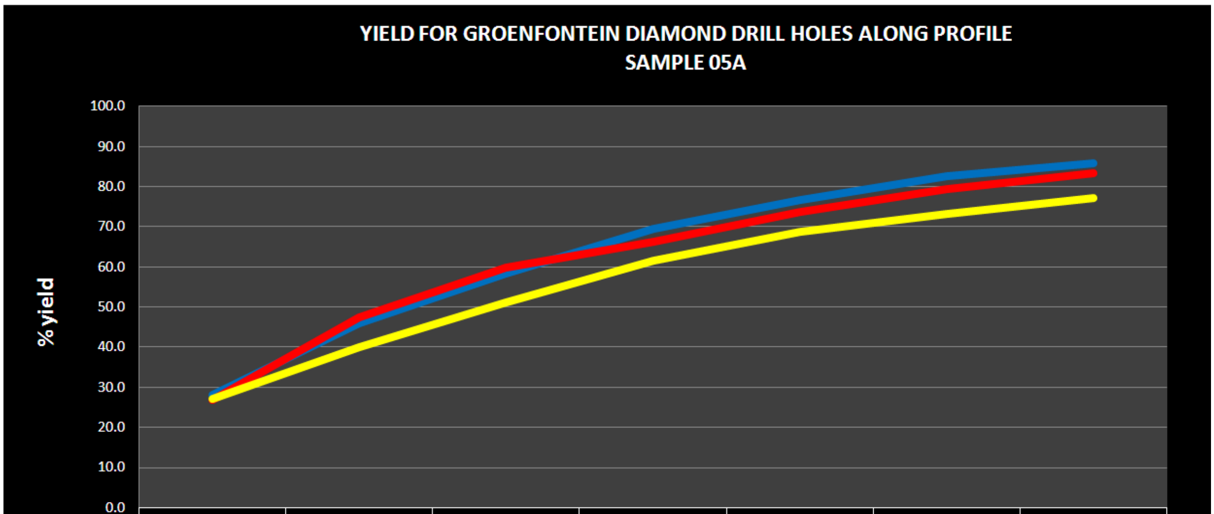




	1.4	1.5	1.6	1.7	1.8	1.9	2
G250012	19.0	42.2	51.1	58.3	62.6	67.3	70.3
G250011	15.6	35.0	44.5	53.4	62.0	67.4	73.7
G250015	18.6	34.4	42.1	51.3	56.9	63.2	69.4

Figure 19 Groenfontein Sample 04A GDCDD at the top and yield curves along a selected profile (illustrated in Figure 55)





	1.4	1.5	1.6	1.7	1.8	1.9	2
G250012	28.2	45.8	58.3	69.6	76.7	82.7	85.9
G250011	26.9	47.4	59.8	66.2	73.7	79.3	83.2
G250015	27.1	40.1	51.1	61.4	68.6	73.1	77.2

Figure 20 Groenfontein Sample 05A GDCDD at the top and yield curves along a selected profile (illustrated in Figure 55)

Sample 06A and Sample 07A

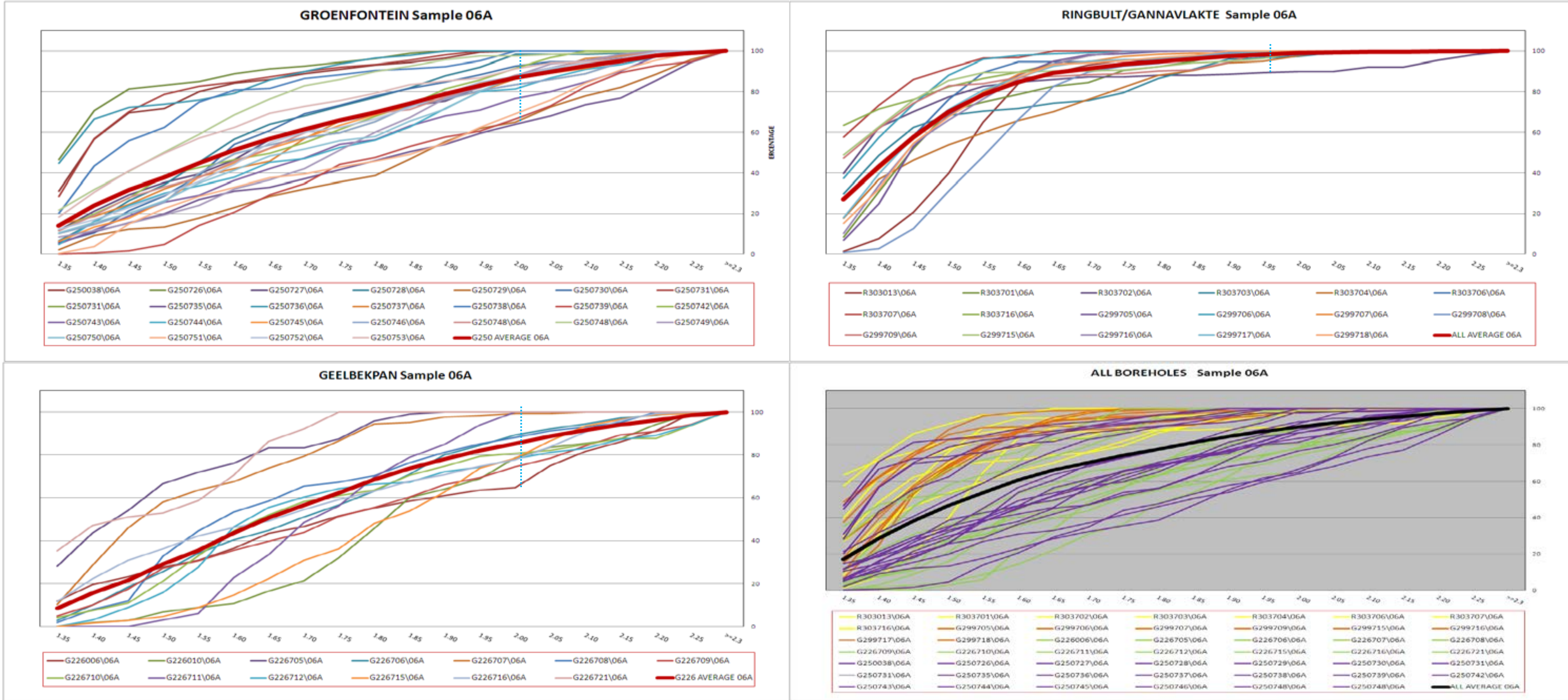


Figure 21 Combined GDCDD of Sample 06A (Spread at a Rd of 2.0, indicated by light blue dotted line)

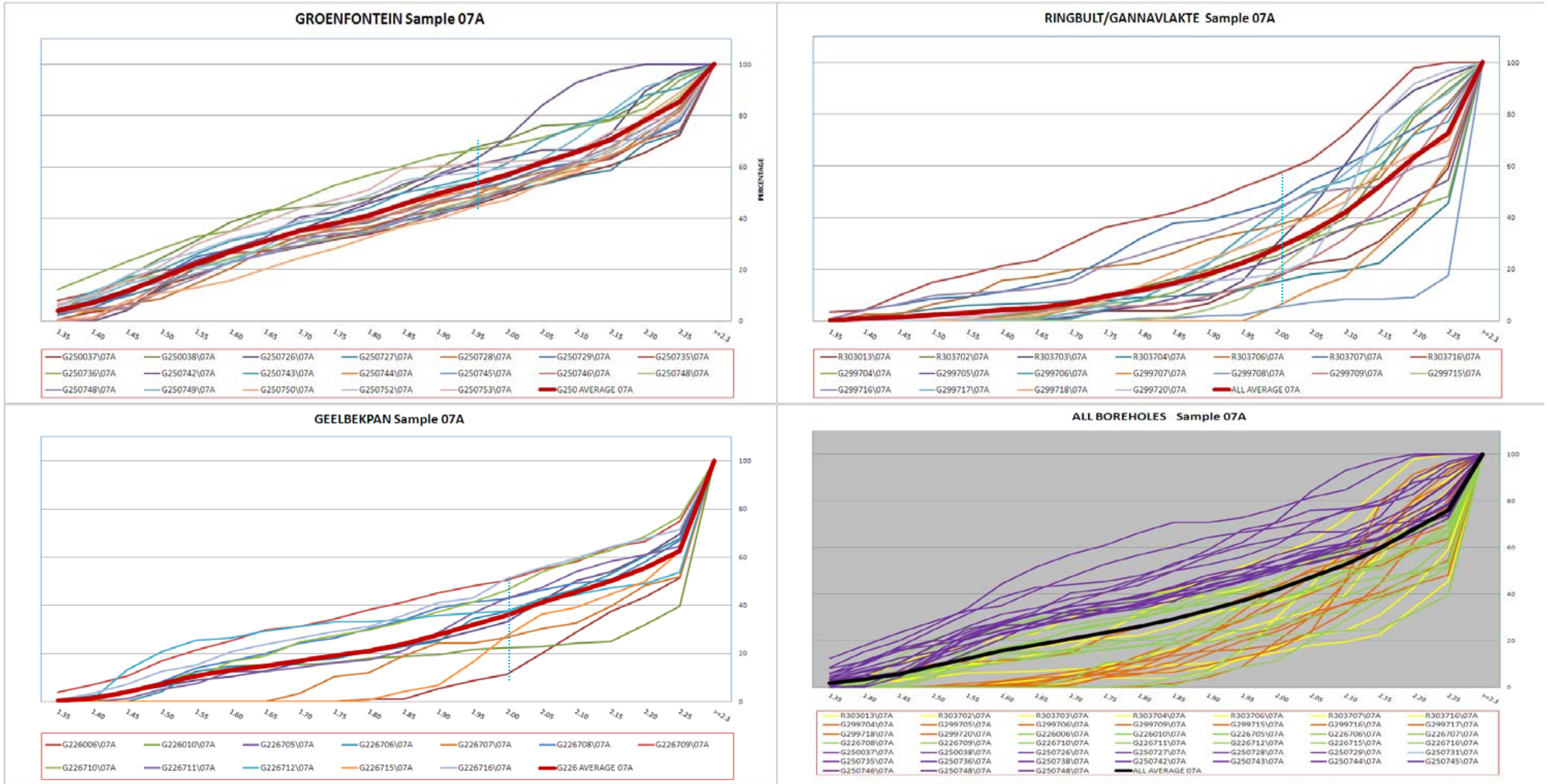


Figure 22 Combined GDCDD of Sample 07A (Spread at a Rd of 2.0, indicated by light blue dotted line)

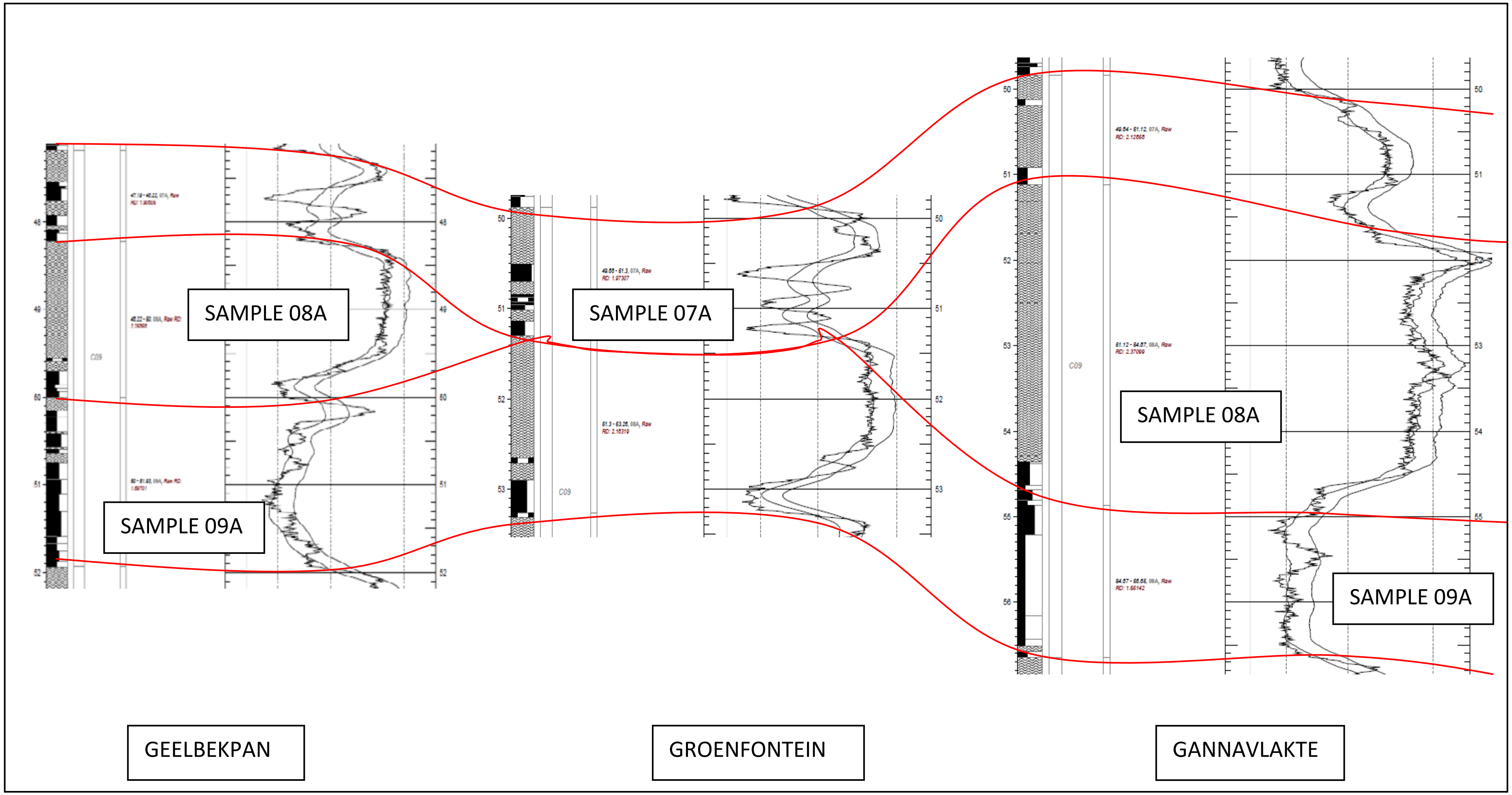


Figure 23 Graphical representation of Sample 07A to Sample 09A. Sample 08A not present in this specific Groenfontein borehole

Table 4 Summary of Sample 06A and Sample 07A data.

<table>
<tr><th>BASIC INFORMATION ABOUT SAMPLE 06A AND SAMPLE 07A.</th><th>SUMMARY</th><th>GEELBEKPAN</th><th>GROENFONTEIN</th><th>RINGBULT</th><th>GANNAVLAKTE</th></tr>
<tr><td rowspan="3">Angle of repose of graphs</td><td>Sample 06A</td><td>High</td><td>High</td><td>High</td><td>High</td></tr>
<tr><td>Sample 07A</td><td>Medium</td><td>Medium</td><td>Medium</td><td>Medium and high</td></tr>
<tr><td colspan="5">The angle of repose in all the areas varies. The Ringbult/Gannavlakte graph has a high angle of repose and a kink at a Rd of 1.45 (Figure 99).</td></tr>
<tr><td>Start point of graphs at Rd 1.35</td><td colspan="5">Data values do not start at the same point. Gannavlakte and Ringbult start higher (more values at the lower Rd range.</td></tr>
<tr><td>Spread</td><td colspan="5">For Sample 06A, the south has the narrowest spread of 10% (Figure 98). For Sample 07A, the south has a wide spread of 55% (Figure 99). These two samples, in general, have a wider spread than the previous samples, illustrating varying lithology over the Study area.</td></tr>
<tr><td>Yield at Rd 2.0-Sample 06A</td><td>25.9% variance</td><td>58.4</td><td>57.9</td><td>83.8</td><td>86.7</td></tr>
<tr><td>Yield at Rd 2.0 - Sample 07A</td><td>13.5% variance</td><td>23.0</td><td>30.4</td><td>20.6</td><td>16.9</td></tr>
<tr><td>Remarks - Yield</td><td colspan="5">The graph (Figure 98) shows that the GDCDD curve data for the south reaches about 80% at a Rd of 1.60, and this</td></tr>
</table>

<table>
<tr><td></td><td colspan="9">is 30 percent higher than the north. This is supported by the proximate data (yields at a Rd of 2.0) for these areas in the table. The low angle of repose for Sample 07A in the Ringbult/Gannavlakte GDCDD is reflected in the low yield of 16.9%.</td></tr>
<tr><td>Raw Rd-Sample 06A</td><td>0.22 variance</td><td colspan="2">1.72</td><td colspan="2">1.68</td><td colspan="2">1.51</td><td colspan="2">1.50</td></tr>
<tr><td>Raw Rd-Sample 07A</td><td>0.28 variance</td><td colspan="2">2.05</td><td colspan="2">1.91</td><td colspan="2">2.08</td><td colspan="2">2.19</td></tr>
<tr><td>Remarks on raw Rd</td><td colspan="9">The raw Rd values are echoed in the yield values. The south has a higher Rd value for Sample 07A and corresponding lower yield at a Rd of 2.0.</td></tr>
<tr><td>Thickness-Sample 06A</td><td>0.70 meter variance</td><td colspan="2">1.20</td><td colspan="2">1.90</td><td colspan="2">1.28</td><td colspan="2">1.89</td></tr>
<tr><td>Thickness-Sample 07A</td><td>1.52 meter variance</td><td colspan="2">1.42</td><td colspan="2">1.42</td><td colspan="2">1.86</td><td colspan="2">2.94</td></tr>
<tr><td>Remarks on thickness</td><td colspan="9">The prominent lateral variation in Sample 06A thickness and geology over the whole area is shown in Figure 101. The south is nearly double the thickness of the north for Sample 07A and there is quite a big lateral variation (Figure 102). Figure 103 indicates the thickest Sample 06A on Groenfontein (Figure 104) indicates that Sample 07A is best developed on Gannavlakte.</td></tr>
<tr><td rowspan="3">Standard deviation at a Rd of 1.60 and 2.0</td><td>Relative density</td><td>1.6</td><td>2.0</td><td>1.6</td><td>2.0</td><td>1.6</td><td>2.0</td><td>1.6</td><td>2.0</td></tr>
<tr><td>Sample 06A</td><td>20.3</td><td>11.6</td><td>21.2</td><td>12.7</td><td>11.7</td><td>3.5</td><td>8.3</td><td>0.3</td></tr>
<tr><td>Sample 07A</td><td>10.5</td><td>16.7</td><td>9.2</td><td>15.0</td><td>8.2</td><td>14.5</td><td>3.4</td><td>13.6</td></tr>
<tr><td>Comments on standard deviation</td><td colspan="9">The σ value for samples 06 is high in the north and central areas. The table also shows that at a Rd of 1.60, the σ value is smaller than for the σ value at a Rd of 2.0. There is a gradual decrease in σ towards Ringbult for both samples. The average σ vale for Sample 06A = 11.2, for Sample 07A = 11.4 and for Sample 08A = 10.5.</td></tr>
<tr><td>Correlation accuracy by</td><td colspan="9">Sample 6A would be more difficult to correlate in the north as it is just over one metre thick. Local variation and any</td></tr>
</table>

geologist	degree of faulting would make it difficult to identify. Correlation would then be based on the samples surrounding Sample 6A and not so much Sample 6A in itself. Sample 07A would be easy to identify in the north, but care must be taken as the sandstone in Sample 07A varies in thickness in the south. Identification is relatively easy on Ringbult due to the increased thickness of the sandstone.
Modelling accuracy	Sample 06A would be more difficult to correlate and care should be taken when doing correlation. Factoring will probably be necessary to compensate for modelling accuracy at Geelbekpan and Groenfontein.
Use as SANS 10320 data correlation point	The use of the GCCD proves that the method can be used to prove the continuity of Sample 06A and Sample 07A with some measure of accuracy. The three samples are variable over the thesis area and in places either faulted away or poorly developed. For Sample 06A, the variance in thickness is about 60% of the total thickness, while the thickness variation for Sample 07A is greater than the thickness of this sample in the north. Sample 06A has higher yields in the south and Sample 7A has higher yields in the north. There are prominent lateral variation in Sample 06A thickness and geology over the whole area. The south is nearly double the thickness of the north for Sample 07A and there is quite a big lateral variation. The thickest occurrence of Sample 06A occurs on Groenfontein and the thickest Sample 07A is found on Gannavlakte. Sample 6A would be more difficult to correlate in the north as it is just over one metre thick. Local variation and any degree of faulting would make it difficult to identify. Correlation would then be based on the samples surrounding Sample 6A and not so much Sample 6A itself. Sample 07A would be easy to identify in the north, but care must be taken as the sandstone in Sample 07A varies in thickness in the south. Identification is relatively easy on the farm Ringbult due to the increased thickness of the sandstone. When modelling, Sample 06A would be more difficult to

	correlate and care should be taken when doing correlation. Factoring will probably be necessary to compensate for modelling accuracy at Geelbekpan and Groenfontein. The use of the GCCD demonstrates that the method can be used to prove the continuity of Sample 06A and 07A with a good measure of accuracy.

Table 5 Standard deviation calculated at two Rd's from the GCCD data for samples 06A and Sample 07A on the various farms.

VRYHEID FORMATION															
FARMS															
	GEELBEKPAN			**GROENFONTEIN**			**GANNAVLAKTE**			**RINGBULT**			**TOTAL**		
Sample	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**
06A	20.3	11.6	16.0	21.2	12.7	17.0	8.3	0.3	4.3	11.7	3.5	7.6	15.4	7.0	11.2
07A	10.5	16.7	13.6	9.2	15.0	12.1	3.4	13.6	8.5	8.2	14.5	11.4	7.8	14.9	11.4

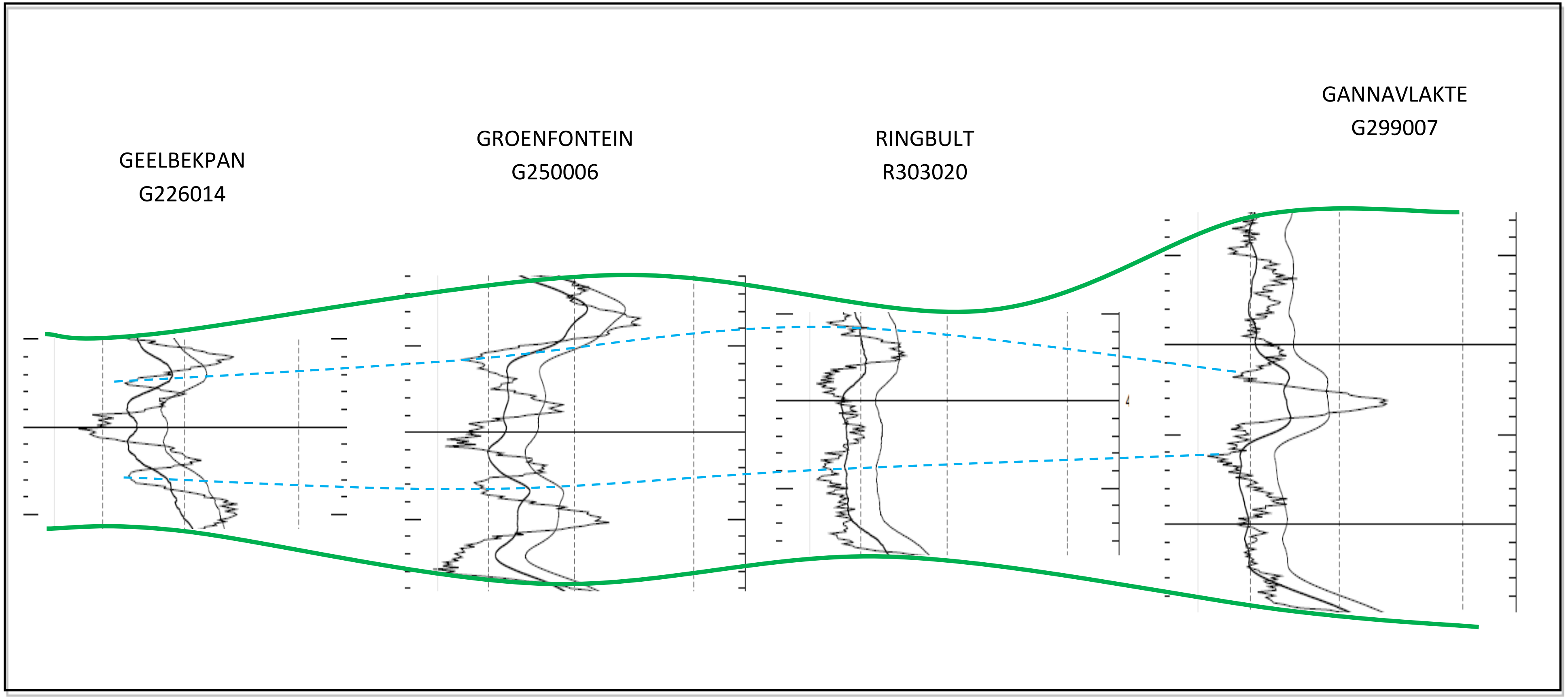


Figure 24 Lateral variation of Sample 06A over the Study area. Blue line denotes possible correlation points, but this is uncertain

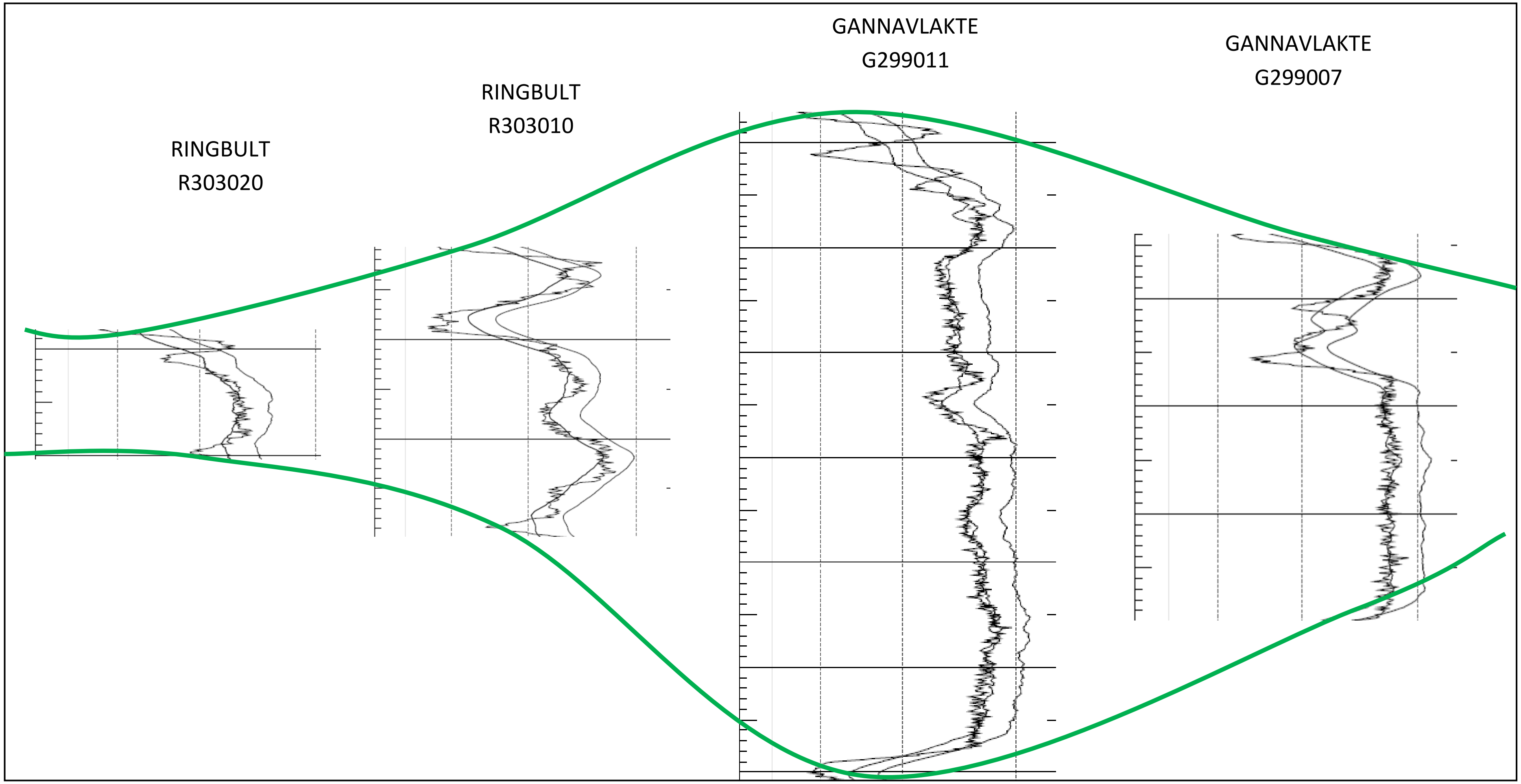


Figure 25 Lateral variation of Sample 07A in the south

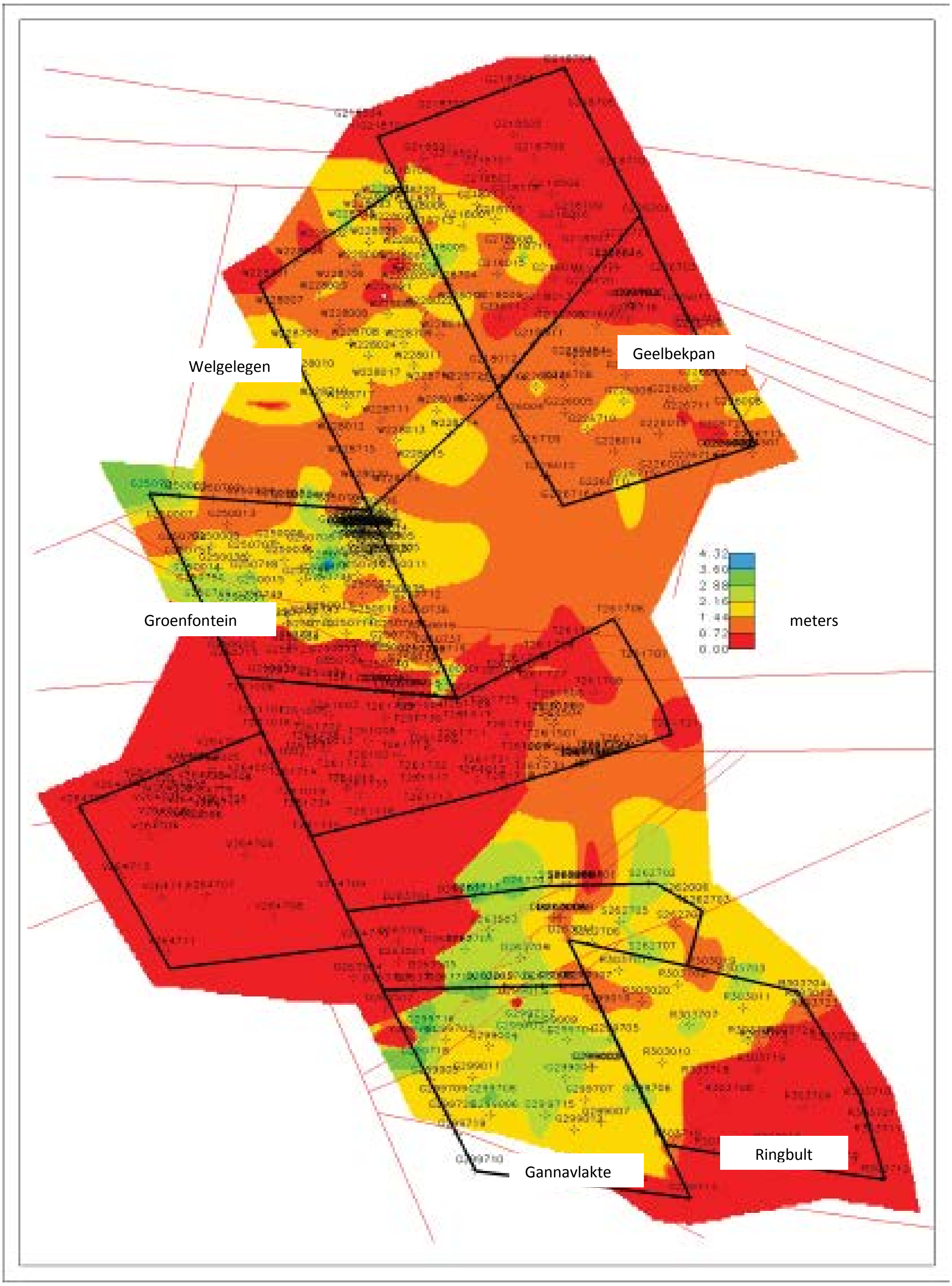


Figure 26 The lateral variation of Sample 06A over the Study area

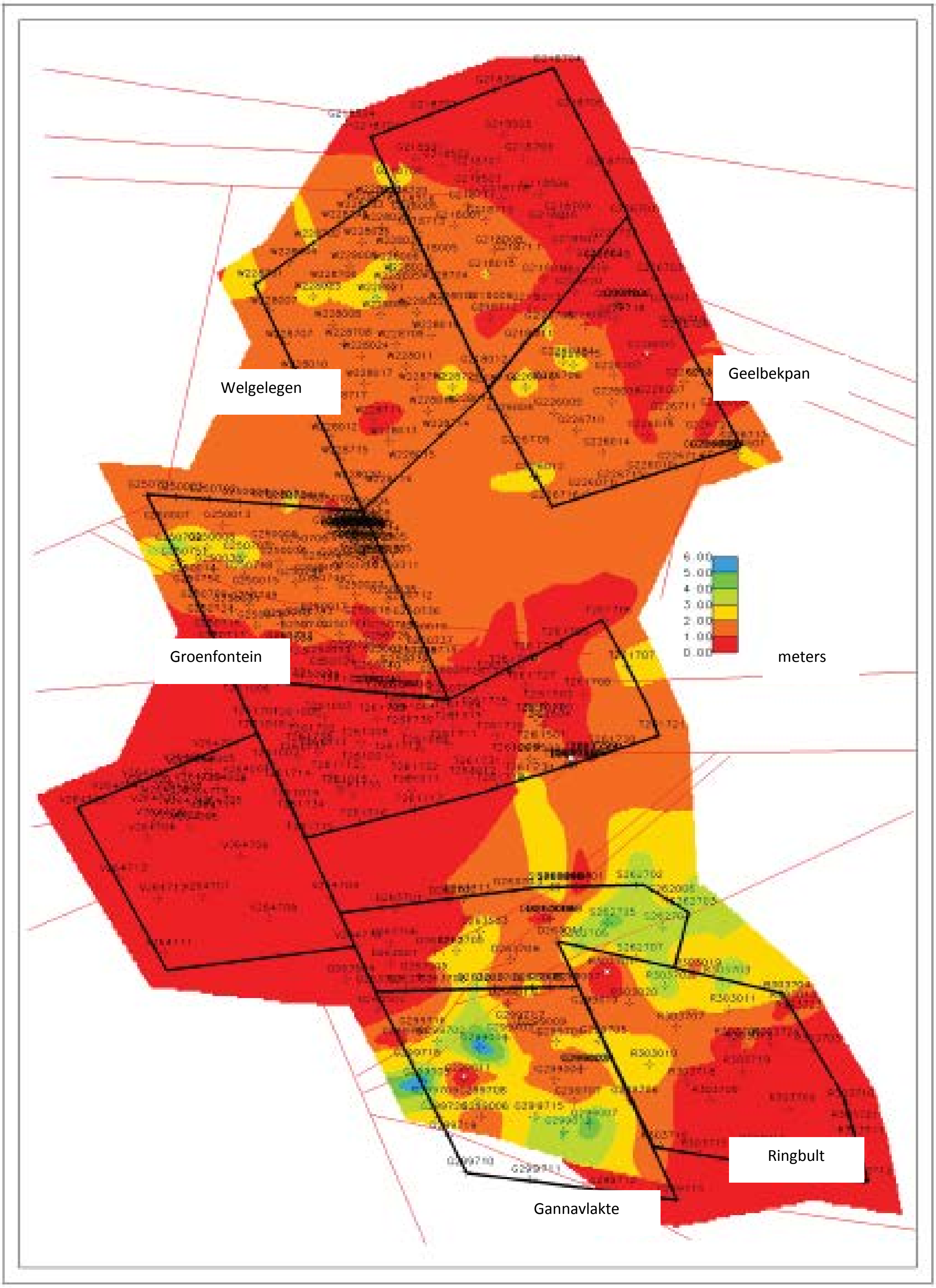


Figure 27 The lateral thickness variation of Sample 07A over the Study area

Samples 08A, to 14A

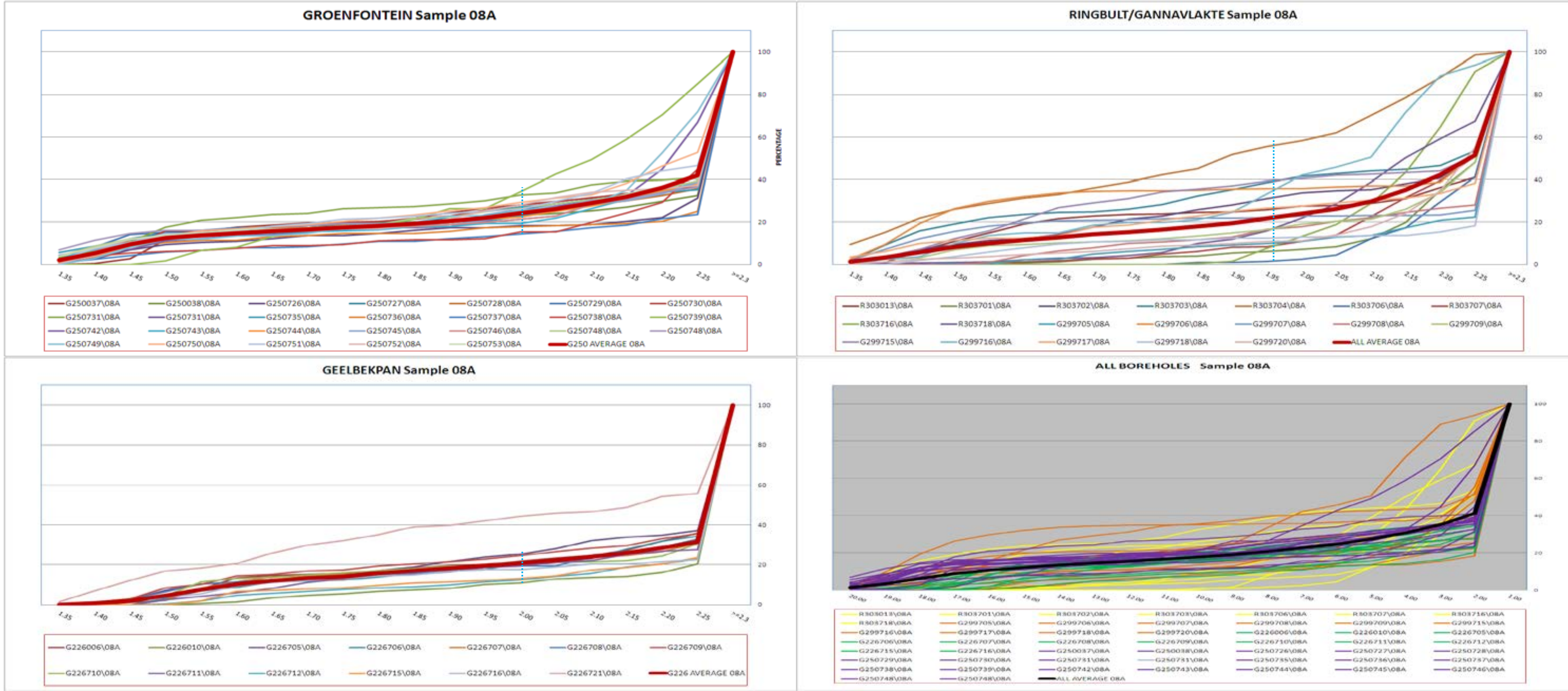


Figure 28 Combined GDCDD of Sample 08A (Spread at a Rd of 2.0, indicated by light blue dotted line)

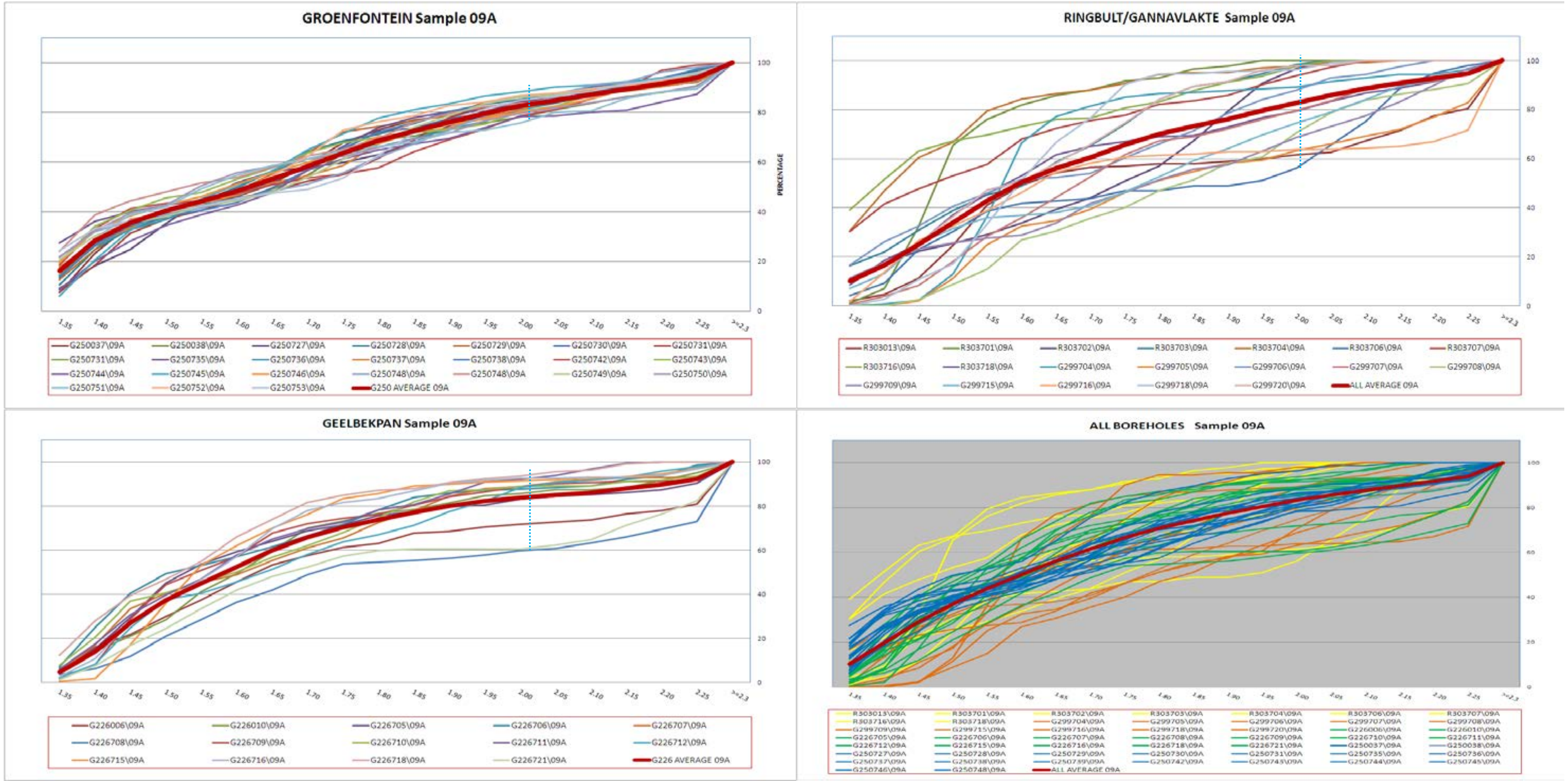
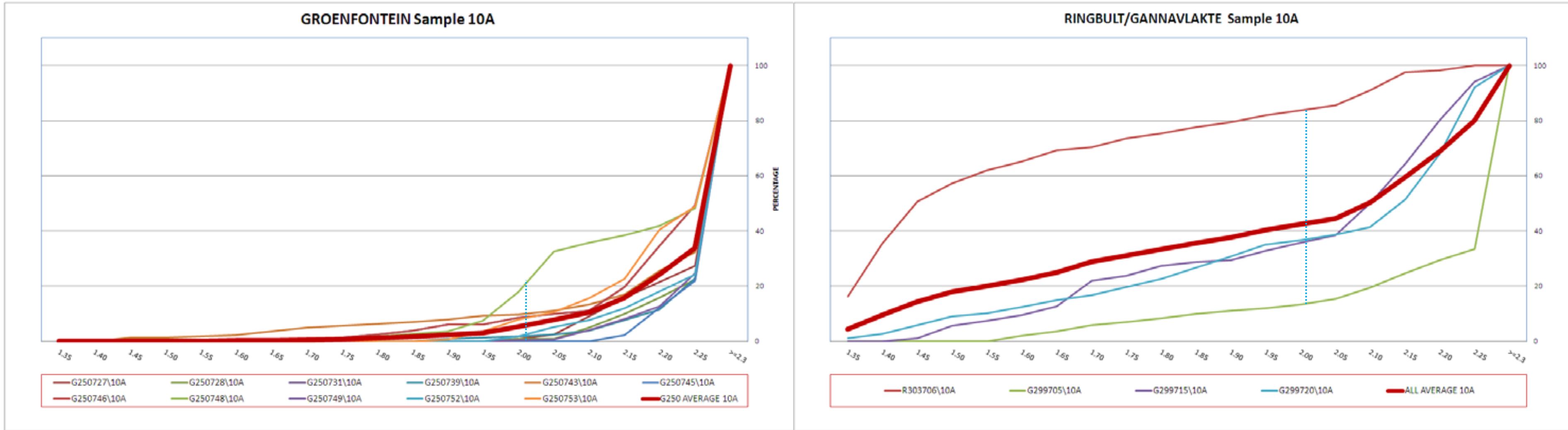


Figure 29 Combined GDCDD of Sample 09A (Spread at a Rd of 2.0, indicated by light blue dotted line)



GEELBEKPAN has no Sample 10A coals

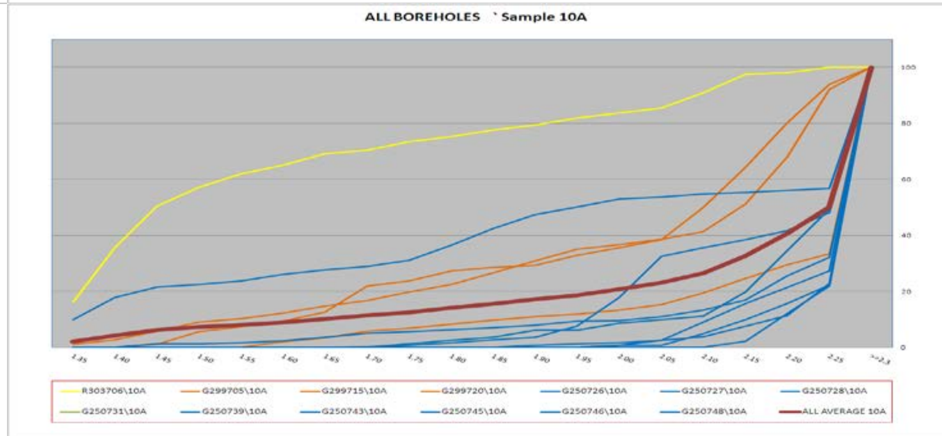


Figure 30 Combined GDCDD of Sample 10A (Spread at a Rd of 2.0, indicated by light blue dotted line)

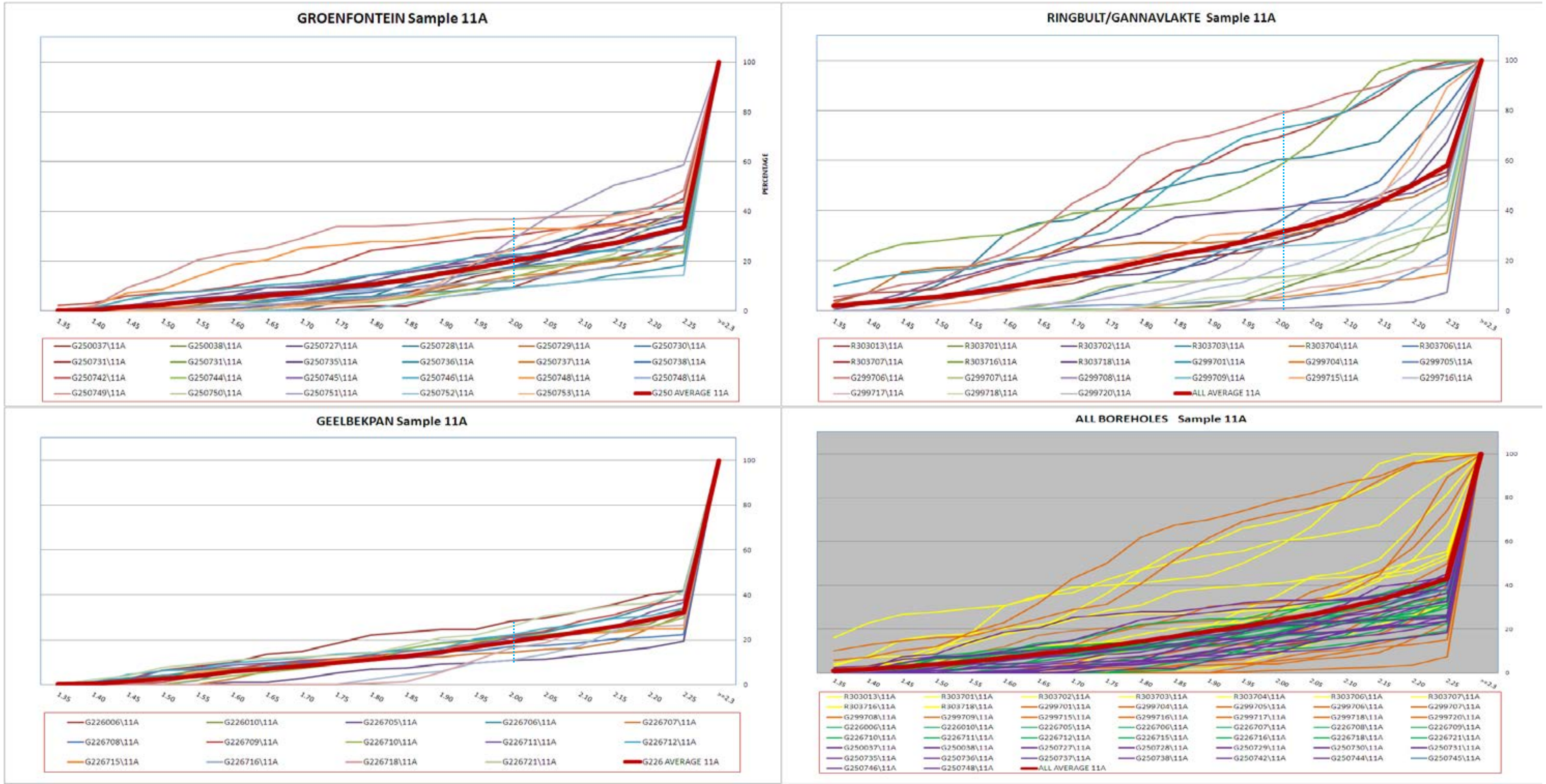


Figure 31 Combined GDCDD of Sample 11A (Spread at a Rd of 2.0, indicated by light blue dotted line)

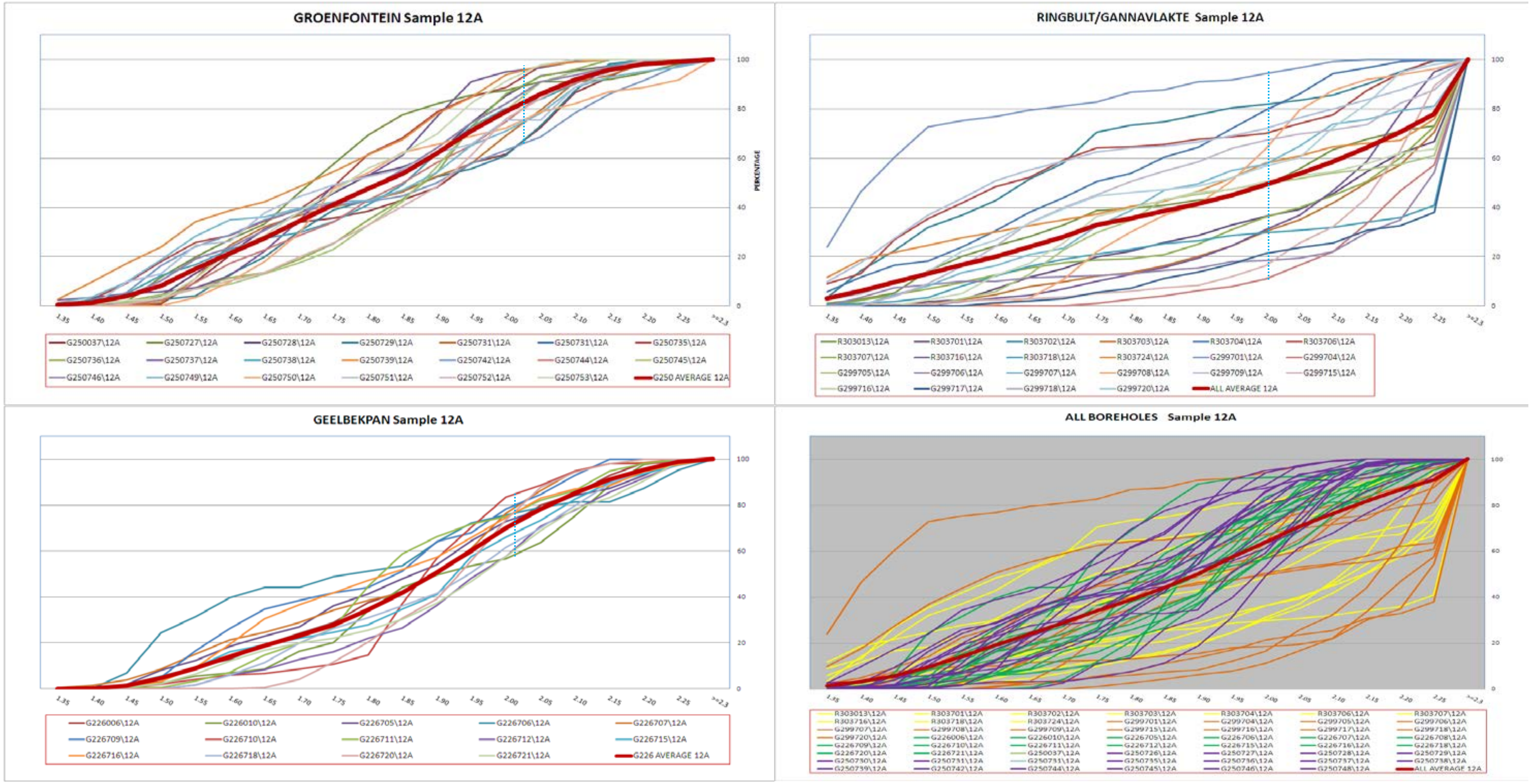


Figure 32 Combined GDCDD of Sample 12A (Spread at a Rd of 2.0, indicated by light blue dotted line)

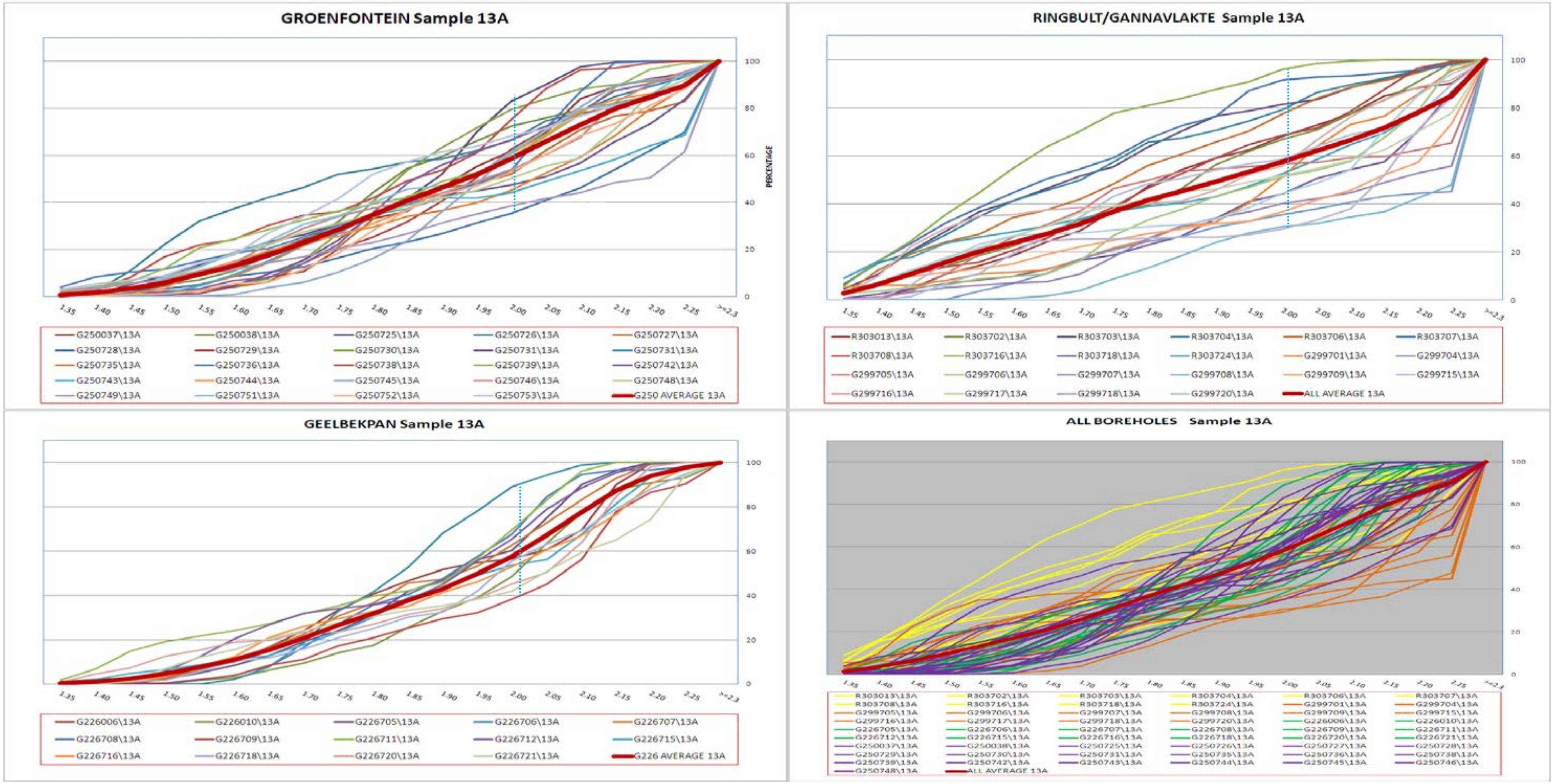


Figure 33 Combined GDCDD of Sample 13A (Spread at a Rd of 2.0, indicated by light blue dotted line)

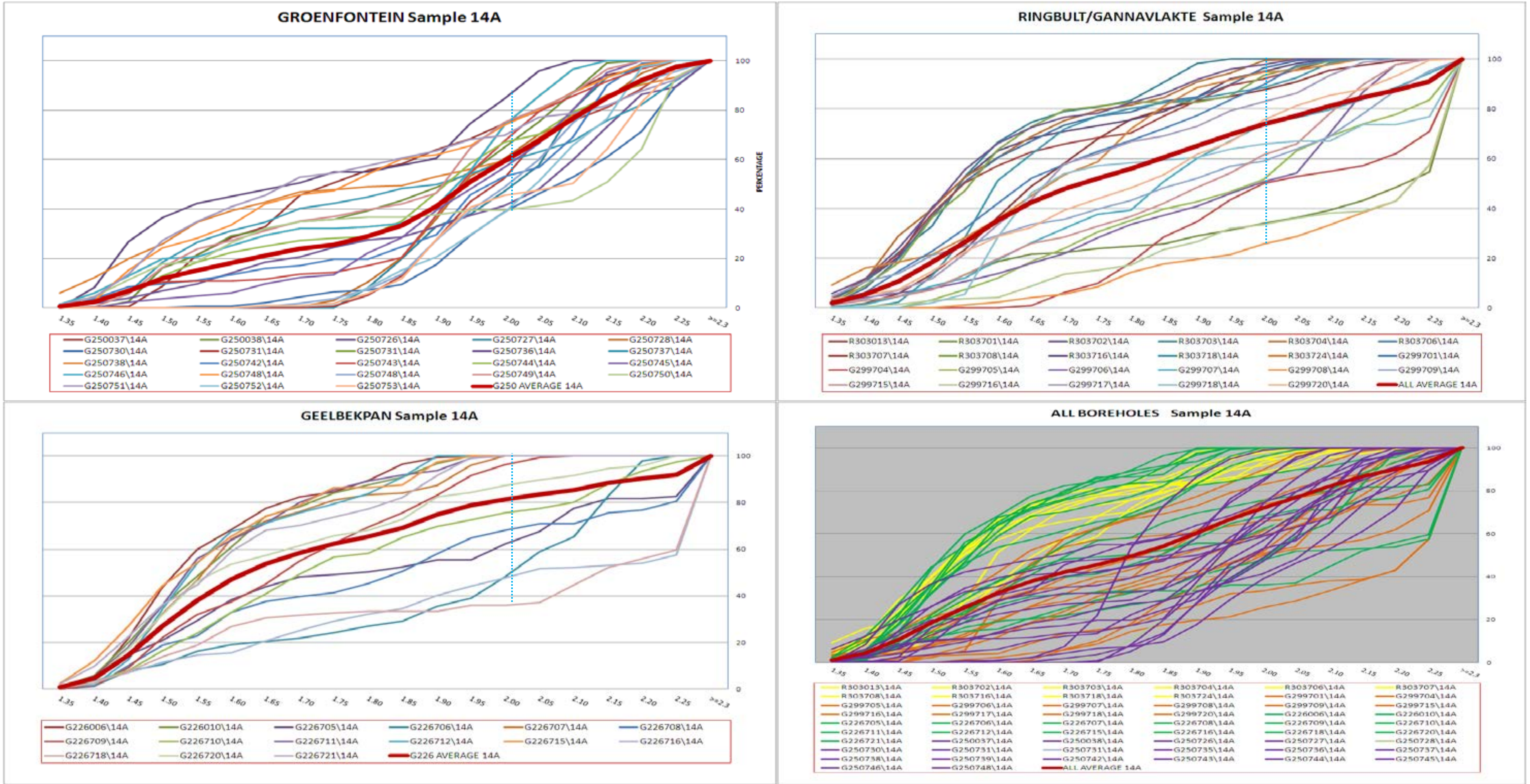


Figure 34 Combined GDCDD of Sample 14A (Spread at a Rd of 2.0, indicated by light blue dotted line)

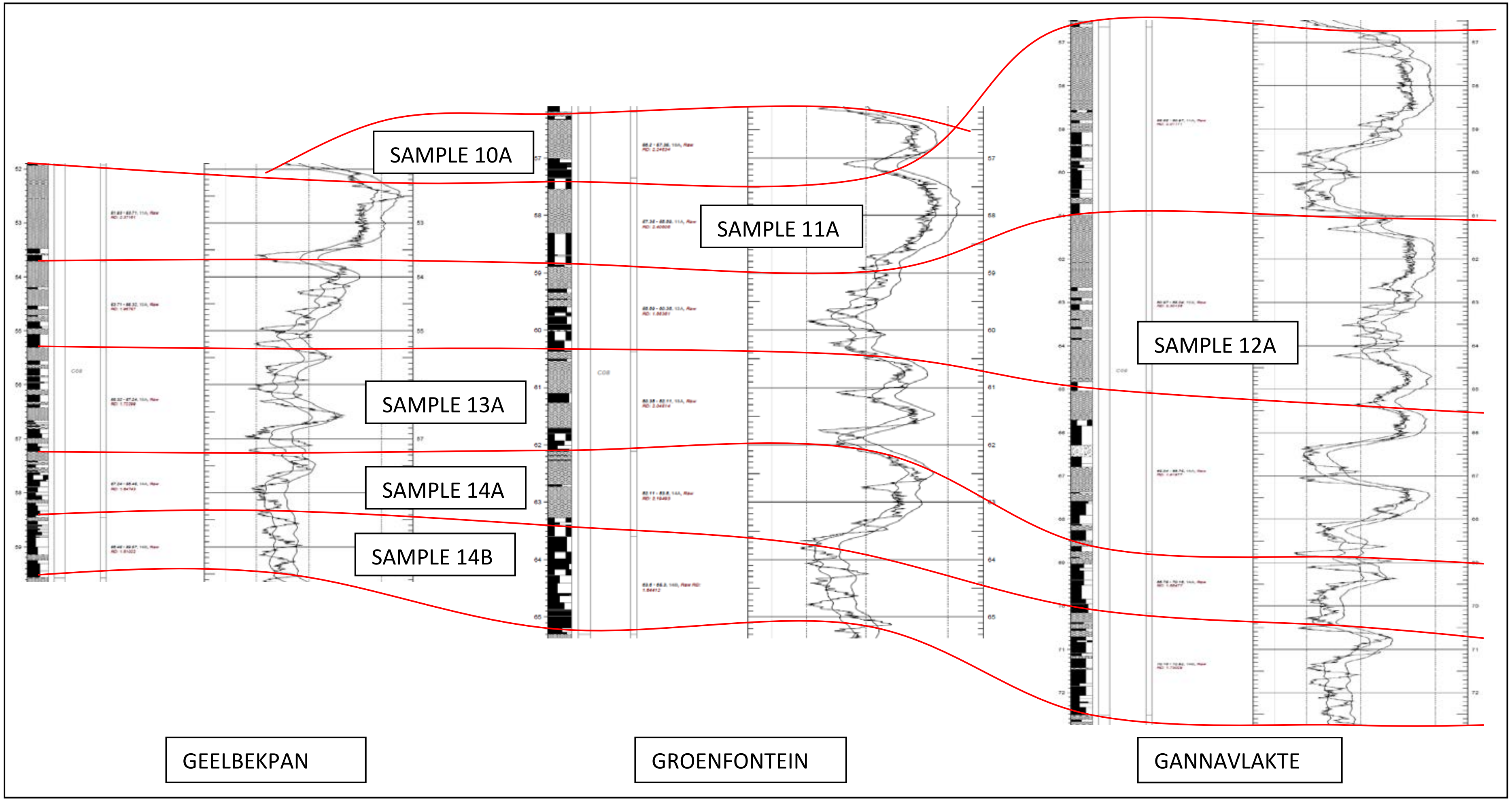


Figure 35 Graphical representation of Sample 10A to Sample 14B

Table 6 Summary of Sample 08A, 09A, 10A, 11A, 12A, 13A and 14A data.

BASIC INFORMATION ABOUT SAMPLE 08A, 09A, 10A, 11A, 12A, 13A AND 14A DATA	**SUMMARY**	**GEELBEKPAN**	**GROENFONTEIN**	**RINGBULT**	**GANNAVLAKTE**
Angle of repose of graphs	Sample 08A	Low	Low	Low to high	Low to high
	Sample 09A	Medium to high	High	Medium to high	Medium to high
	Sample 10A	N/A	Low	Low to high	Low to high
	Sample 11A	Low	Low	Low to high	Low to high
	Sample 12A	High	High	Low to high	Low to high
	Sample 13A	High	Med to high	Low to high	Low to high
	Sample 14A	Med to high	High	Med to high	Med to high
	The graphs in this selection all exhibit a lower angle of repose with a variable rise (Figure 105, Figure 106, Figure 107, Figure 108, Figure 109, Figure 110 and Figure 111). Ringbult/Gannavlakte illustrates the variability of the geology in the south. This low angle is reflected in the yields which is quite low, except for two samples, 09A (Figure 106) and 14A, (Figure 111) which have yields higher than 50%. The yield for Sample 10A (Figure 107) is the lowest of this group and this Sample is not developed on Geelbekpan (Figure 112).				

Start point of graphs at Rd 1.35	Data values for all the graphs (Figure 105 to Figure 111) start at the same point, except for Ringbult/Gannavlakte in the south, Sample 11A (Figure 108) and Sample 12A (Figure 109).				
Spread	For Sample 08A, the graphs are narrowly spread, except for Ringbult/Gannavlakte which has a 40% spread. For Sample 09A, Geelbekpan and the south, has about a 40% spread. Sample 10A does not occur on Geelbekpan, but the south has a spread of about 70%. Sample 11A has an 80% spread in the south, 30% on Groenfontein and 20% on Geelbekpan. Sample 12A has a 30% spread for Geelbekpan and Groenfontein and 80% for the south. Sample 13A has a 50% spread, and the south a 70% spread. For Sample 14A, all the graphs show a wide spread between 45% and 75%. All these graphs are indicative of the variability of the geology in the south (Figure 112).				
Yield at Rd 2.0 -Sample 08A	4.1% variance	12.8	14.8	15.8	16.9
Yield at Rd 2.0 - Sample 09A	16.2% variance	66.4	63.6	53.9	50.2
Yield at Rd 2.0 - Sample 10A	8.4% variance	Na	9.4	6.6	15.0
Yield at Rd 2.0 -Sample 11A	7.1% variance	13.4	20.4	19.3	15.8
Yield at Rd 2.0 - Sample 12A	9.7% variance	37.1	39.5	37.3	29.8
Yield at Rd 2.0 - Sample 13A	8.0% variance	35.4	39.0	31.0	37.0
Yield at Rd 2.0 -Sample 14A	37.2% variance	74.3	37.1	63.8	58.5
Remarks- Yield	The highest yields are found in Sample 09A and Sample 14A, while the lowest yield is found in Sample 10A. The largest variance in yield is found in Sample 14A and the smallest variation in Sample 08A. The variance in Sample 14A is due to geological variances in this sample.				
Raw Rd Sample 08A	0.11 variance	2.24	2.13	2.21	2.22

<table>
<tr><td>Raw Rd Sample 09A</td><td>0.15 variance</td><td colspan="2">1.69</td><td colspan="2">1.69</td><td colspan="2">1.76</td><td colspan="2">1.84</td></tr>
<tr><td>Raw Rd Sample 10A</td><td>0.10 variance</td><td colspan="2">Na</td><td colspan="2">2.31</td><td colspan="2">2.26</td><td colspan="2">2.21</td></tr>
<tr><td>Raw Rd Sample 11A</td><td>0.10 variance</td><td colspan="2">2.17</td><td colspan="2">2.16</td><td colspan="2">2.12</td><td colspan="2">2.22</td></tr>
<tr><td>Raw Rd Sample 12A</td><td>0.11 variance</td><td colspan="2">1.92</td><td colspan="2">1.90</td><td colspan="2">1.96</td><td colspan="2">2.01</td></tr>
<tr><td>Raw Rd Sample 13A</td><td>0.11 variance</td><td colspan="2">1.90</td><td colspan="2">1.88</td><td colspan="2">1.98</td><td colspan="2">1.99</td></tr>
<tr><td>Raw Rd Sample 14A</td><td>0.27 variance</td><td colspan="2">1.66</td><td colspan="2">1.93</td><td colspan="2">1.72</td><td colspan="2">1.77</td></tr>
<tr><td>Remarks on raw Rd</td><td colspan="9">The highest Rd is found on the farm Groenfontein, Sample 10A, and the lowest Rd on Geelbekpan, Sample 14A.</td></tr>
<tr><td>Thickness Sample 08A</td><td>1.69 meter variance</td><td colspan="2">1.84</td><td colspan="2">2.03</td><td colspan="2">3.53</td><td colspan="2">3.53</td></tr>
<tr><td>Thickness Sample 09A</td><td>0.78 meter variance</td><td colspan="2">2.12</td><td colspan="2">2.82</td><td colspan="2">2.04</td><td colspan="2">2.47</td></tr>
<tr><td>Thickness Sample 10A</td><td>1.39 meter variance</td><td colspan="2">Na</td><td colspan="2">1.95</td><td colspan="2">1.98</td><td colspan="2">3.34</td></tr>
<tr><td>Thickness Sample 11A</td><td>0.94 meter variance</td><td colspan="2">2.40</td><td colspan="2">2.18</td><td colspan="2">2.77</td><td colspan="2">3.12</td></tr>
<tr><td>Thickness Sample 12A</td><td>1.63 meter variance</td><td colspan="2">1.51</td><td colspan="2">1.62</td><td colspan="2">3.14</td><td colspan="2">2.22</td></tr>
<tr><td>Thickness Sample 13A</td><td>0.81 meter variance</td><td colspan="2">1.78</td><td colspan="2">1.75</td><td colspan="2">2.50</td><td colspan="2">2.56</td></tr>
<tr><td>Thickness Sample 14A</td><td>0.55 meter variance</td><td colspan="2">1.38</td><td colspan="2">1.42</td><td colspan="2">1.22</td><td colspan="2">1.77</td></tr>
<tr><td>Remarks on thickness</td><td colspan="9">The lateral variation in thickness of Sample 14A is shown in Figure 112. The reason why Sample 19A does not occur in some areas on Geelbekpan, is due to a small coal seam that is not developed below Sample 09A; this is illustrated in Figure 100. The 1.63 metre variance in thickness for Sample 12A is more than the thickness of this sample on Geelbekpan.</td></tr>
<tr><td>Standard deviation at a Rd of</td><td>Relative density</td><td>1.6</td><td>2.0</td><td>1.6</td><td>2.0</td><td>1.6</td><td>2.0</td><td>1.6</td><td>2.0</td></tr>
</table>

1.60 and 2.0	Sample 08A	4.9	8.3	3.9	5.4	12.3	19.3	9.7	13.4
	Sample 09A	8.4	11.4	9.1	7.5	18.9	15.1	17.6	16.0
	Sample 10A			5.9	14.5			5.3	13.2
	Sample 11A	3.7	5.0	14.5	30.1	12.0	20.1	8.6	25.8
	Sample 12A	10.0	10.1	13.9	15.2	17.0	22.0	23.4	26.1
	Sample 13A	7.2	16.1	13.8	15.0	13.9	17.0	10.5	10.4
	Sample 14A	18.7	23.2	19.1	21.1	15.5	19.7	13.4	19.1
Comments on standard deviation	The σ values for samples 08A to 11A are quite variable. For Sample 12A, there is a gradual increase in σ value. Sample 11A to Sample 14A have higher σ values than Sample 08A to Sample 10A. The average σ for Sample 08A = 9.7, for Sample 11A = 15.0, Sample 12A = 17.2, Sample 13A = 12.9 Sample 14A = 18.7. The combined average is 13.2 (Figure 115).								
Correlation accuracy by geologist	Good, easy to correlate, but for the south. Problems with correlation, such as faulting and correlation errors, would be prominent on the GDCCD plot. The best correlation for all the graphs in this series is found on the farm Groenfontein(Sample 09A)(Figure 106). The variation in yields in the south can be ascribed to the local geological variation (Figure 100).								
Modelling accuracy	Good correlation, easy to model, but for the south. Here some factoring would be necessary to compensate for modelling accuracy, in particular, Sample 14A (Figure 113). There is a general increase in thickness of the samples towards the south, but the yields are generally lower. The thicknesses of interbedded mudstones is generally greater towards the south.								

Use as SANS 10320 data correlation point	The use of the GDCCD proves that this method can be used to prove the continuity of Sample 08A to Sample 14A in the north with a good measure of accuracy; except for the south where care has to be taken when correlating the geology. Sample 14A has a large variance in yield and care must be taken when using data from this sample for correlation purposes and sample 10A, which is a this sample is not laterally continuous over the Study area (Figure 114).

Table 7 Standard deviation calculated at two RDs from the GCCD data for samples 08A to Sample 14A.

VRYHEID FORMATION															
FARM															
	GEELBEKPAN			**GROENFONTEIN**			**GANNAVLAKTE**			**RINGBULT**			**TOTAL**		
Sample	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**
08A	4.9	8.3	6.4	3.9	5.4	3.9	9.7	13.4	11.0	12.3	19.3	15.7	7.7	11.6	9.7
09A	8.4	11.4	9.4	9.1	7.5	7.8	17.6	16.0	16.1	18.9	15.1	14.7	13.5	12.5	13.0
10A				5.9	14.5	9.5	5.3	13.2	9.2				5.6	13.8	9.7
11A	3.7	5.0	4.2	14.5	30.1	21.6	8.6	25.8	17.0	12.0	20.1	15.0	9.7	20.3	15.0
12A	10.0	10.1	8.2	13.9	15.2	12.2	23.4	26.1	23.3	17.0	22.0	19.1	16.1	18.4	17.2
13A	7.2	16.1	9.5	13.8	15.0	12.7	10.5	10.4	9.1	13.9	17.0	15.1	11.4	14.6	13.0
14A	18.7	23.2	20.4	19.1	21.1	18.2	13.4	19.1	15.8	15.5	19.7	16.9	16.7	20.8	18.7

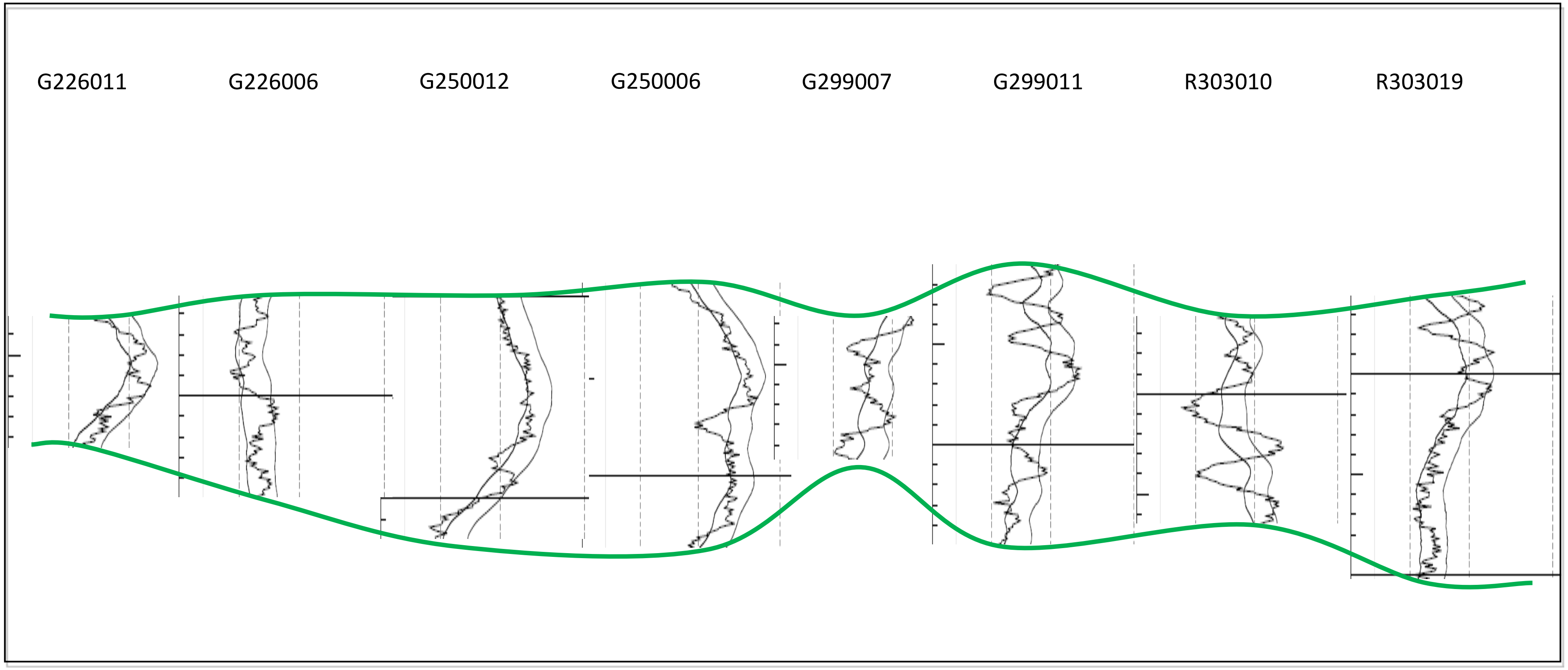


Figure 36 Lateral variation of Sample 14A over the Study area

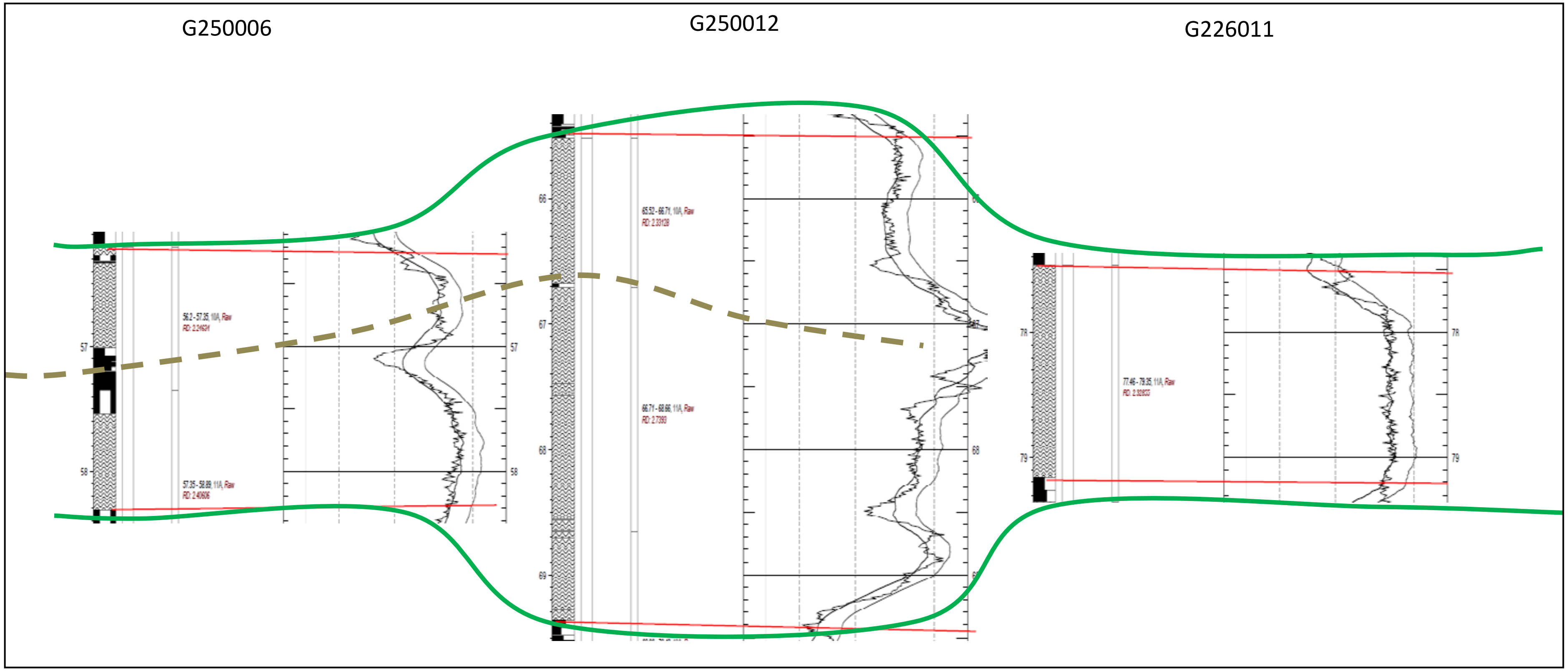


Figure 37 The small coal seam in Sample 10A on Groenfontein is not present on Geelbekpan

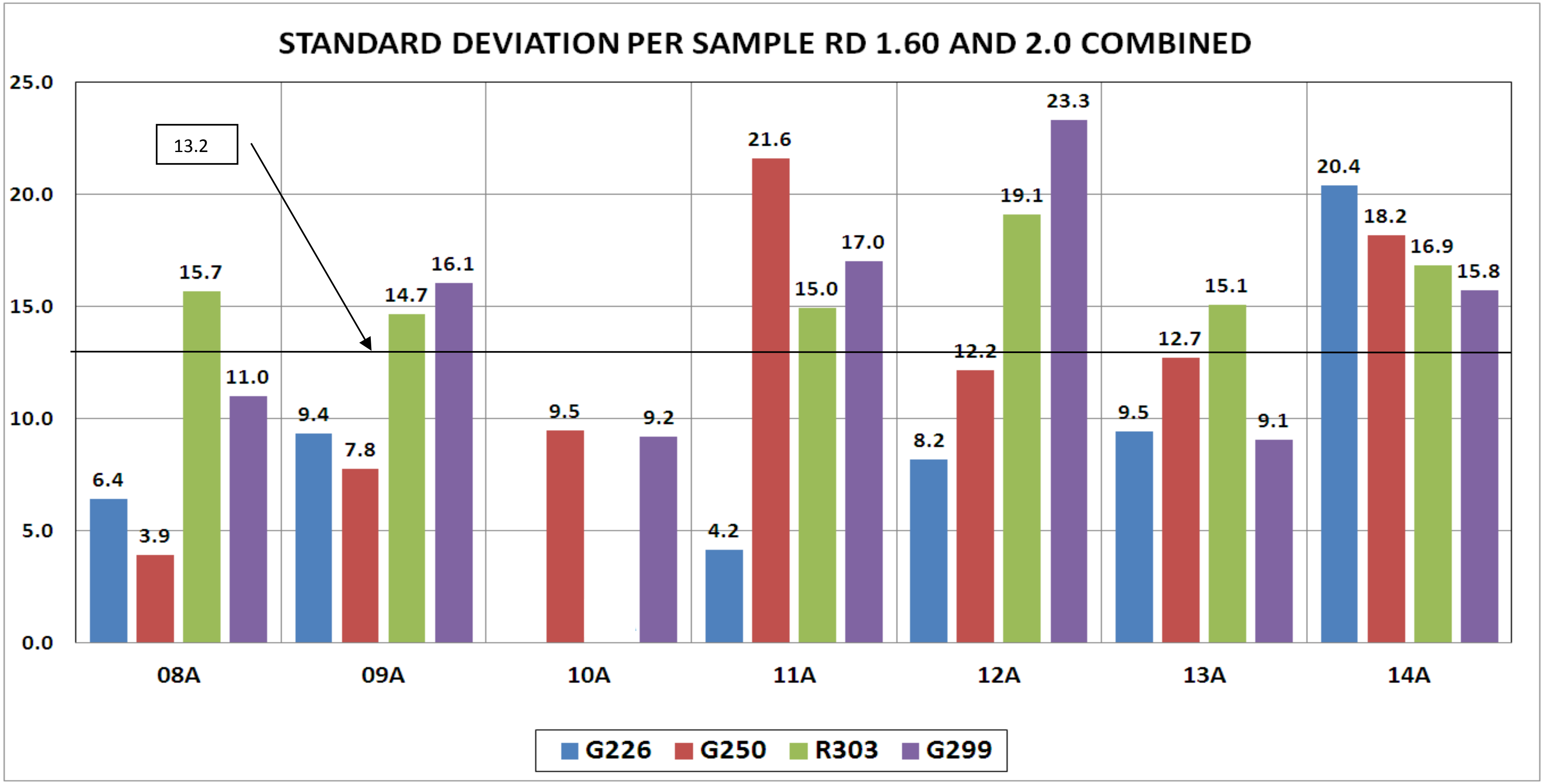


Figure 38 Standard deviation graph at Rd 1.6 and Rd 2.0, combined and averaged, for Sample 08A to Sample 14A

Samples 14B to 23D

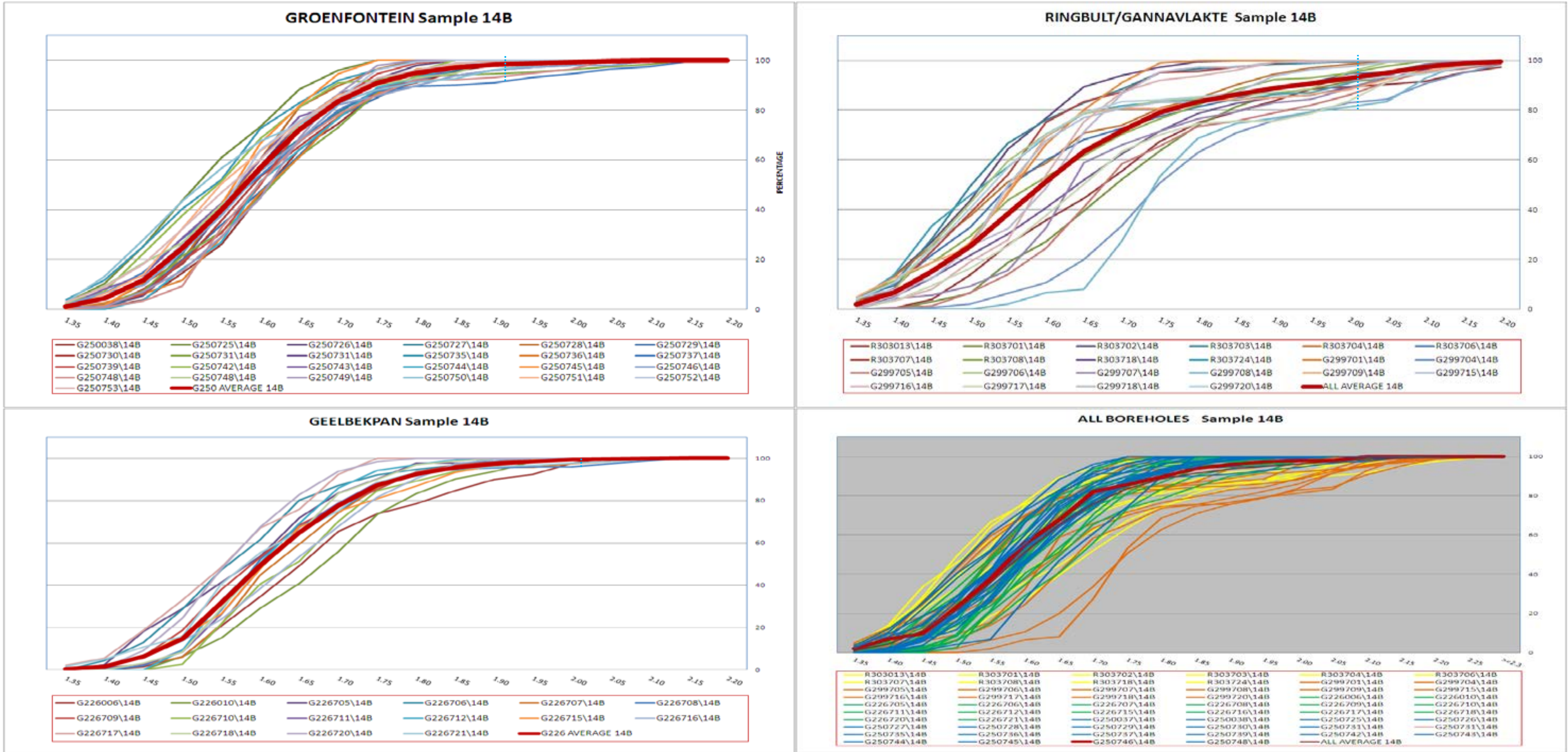


Figure 39 Combined GDCDD of Sample 14B (Spread at a Rd of 2.0, indicated by light blue dotted line)

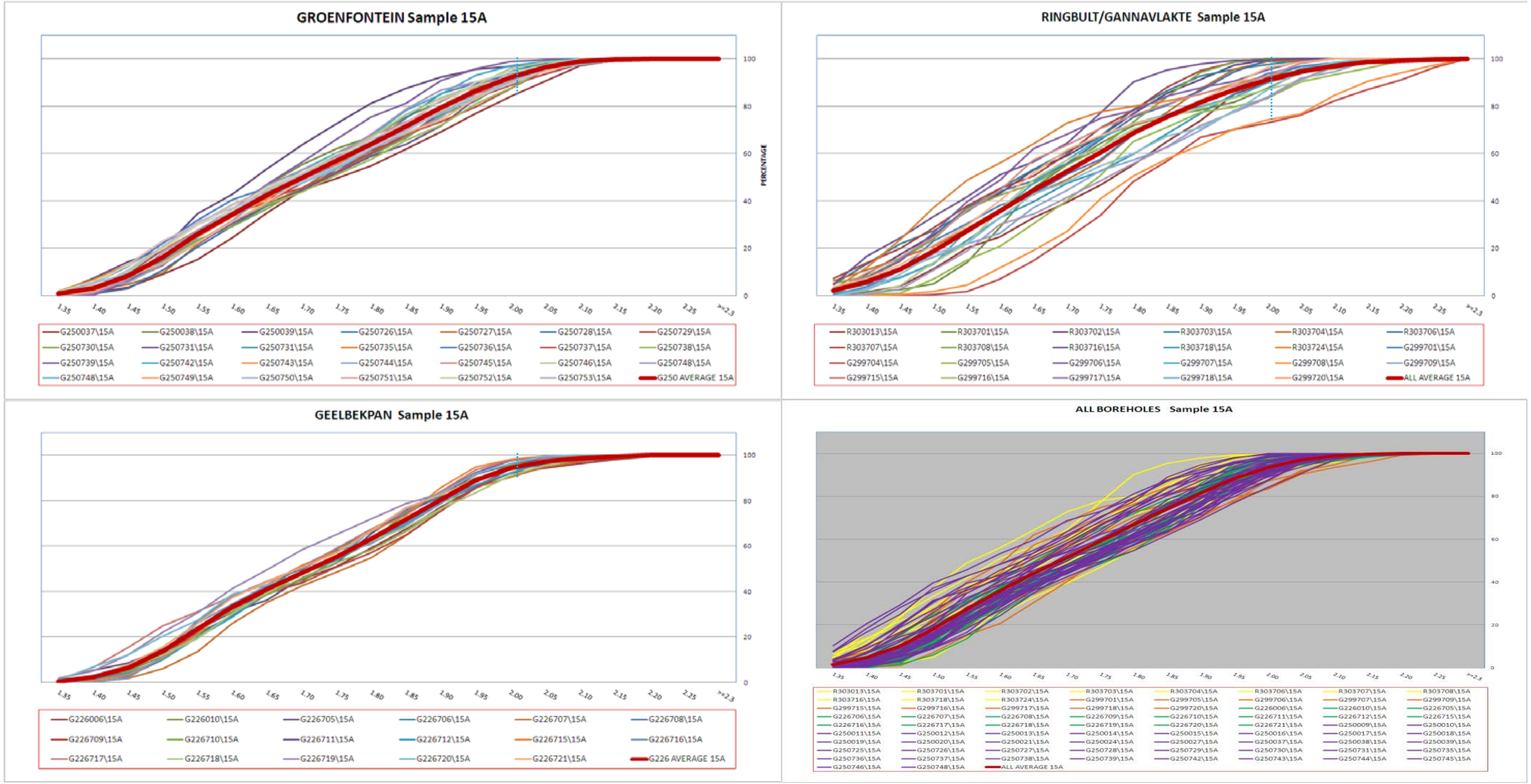


Figure 40 Combined GDCDD of Sample 15A (Spread at a Rd of 2.0, indicated by light blue dotted line)

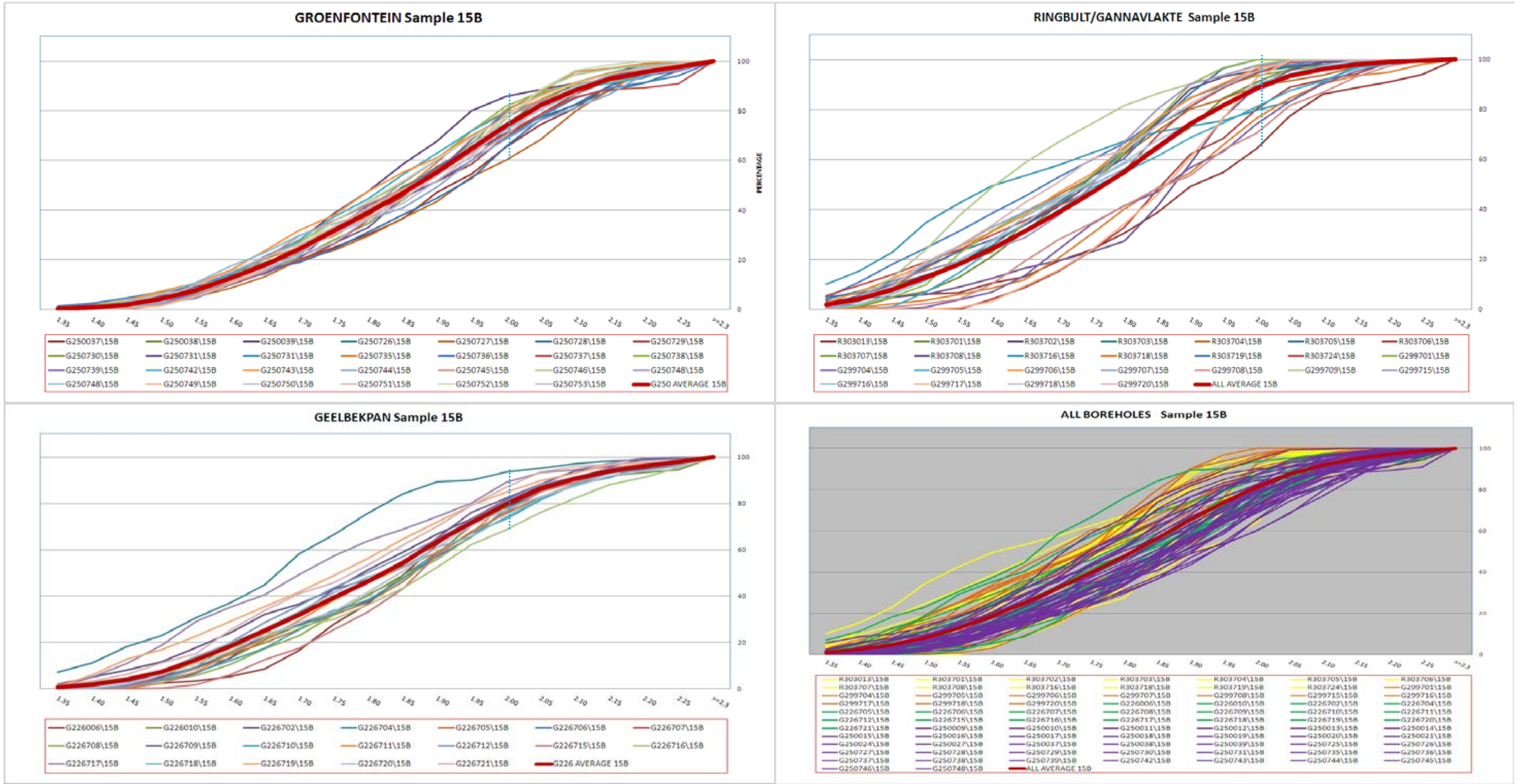


Figure 41 Combined GDCDD of Sample 15B (Spread at a Rd of 2.0, indicated by light blue dotted line)

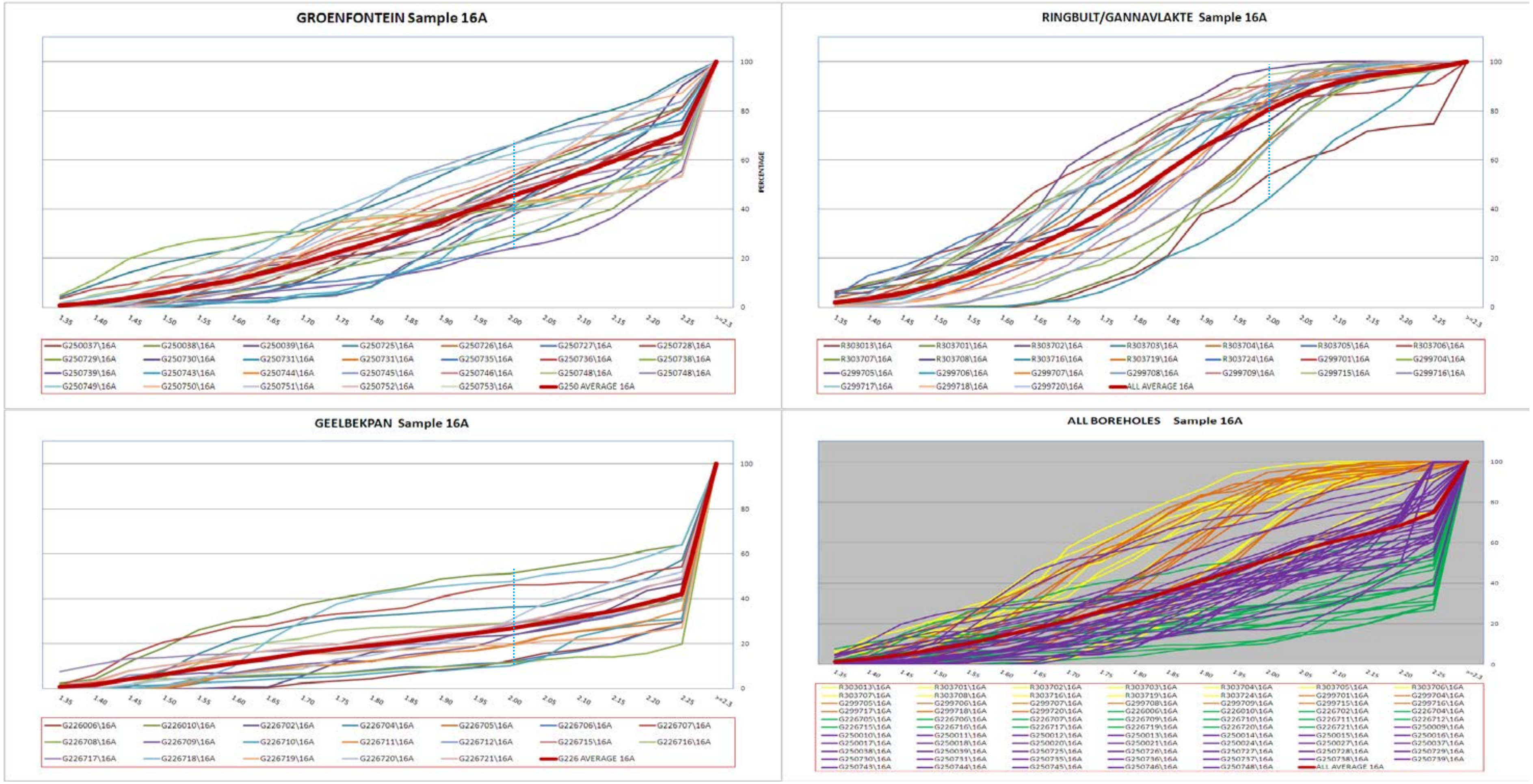


Figure 42 Combined GDCDD of Sample 16A (Spread at a Rd of 2.0, indicated by light blue dotted line)

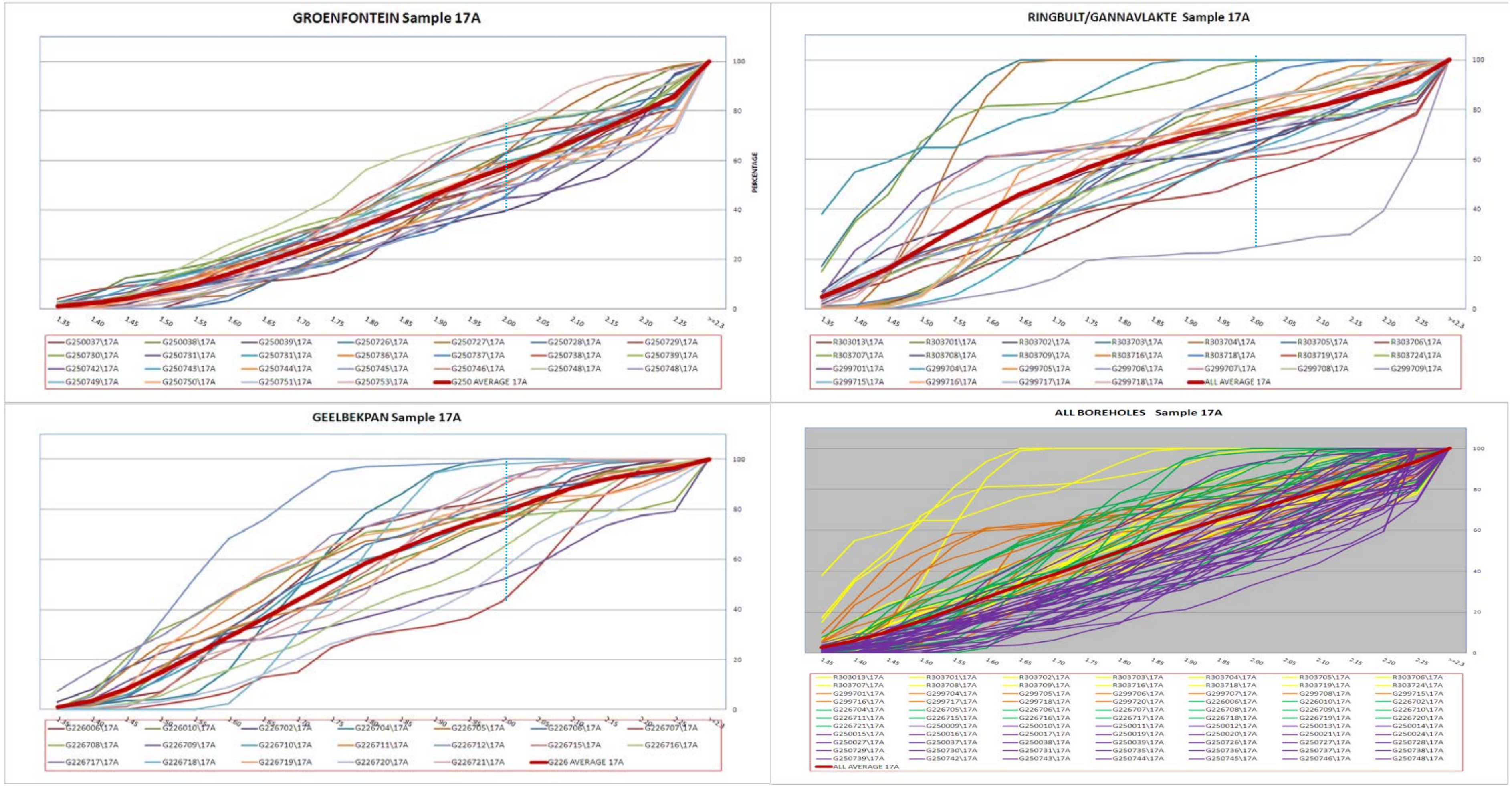


Figure 43 Combined GDCDD of Sample 17A (Spread at a Rd of 2.0, indicated by light blue dotted line)

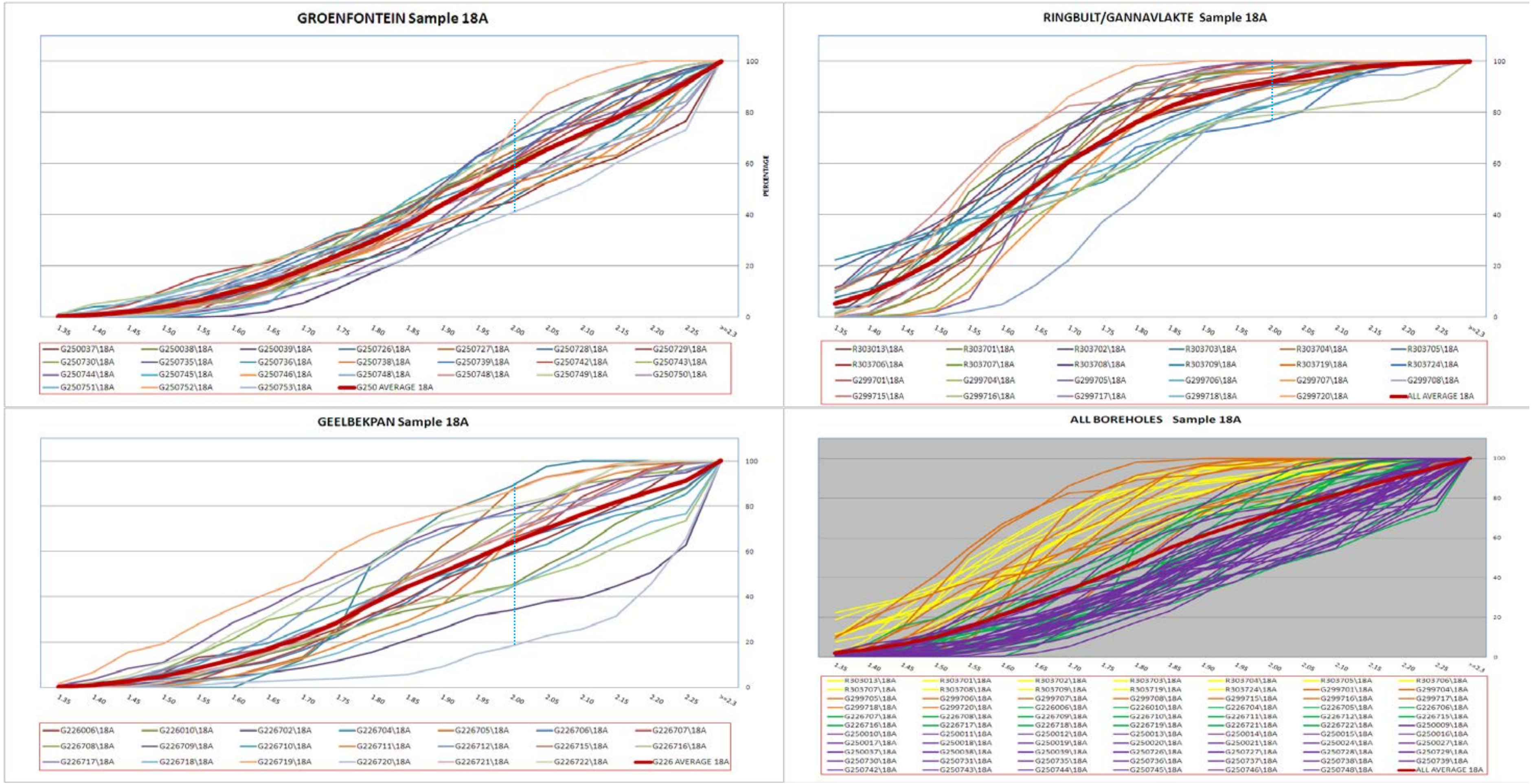


Figure 44 Combined GDCDD of Sample 18A (Spread at a Rd of 2.0, indicated by light blue dotted line)

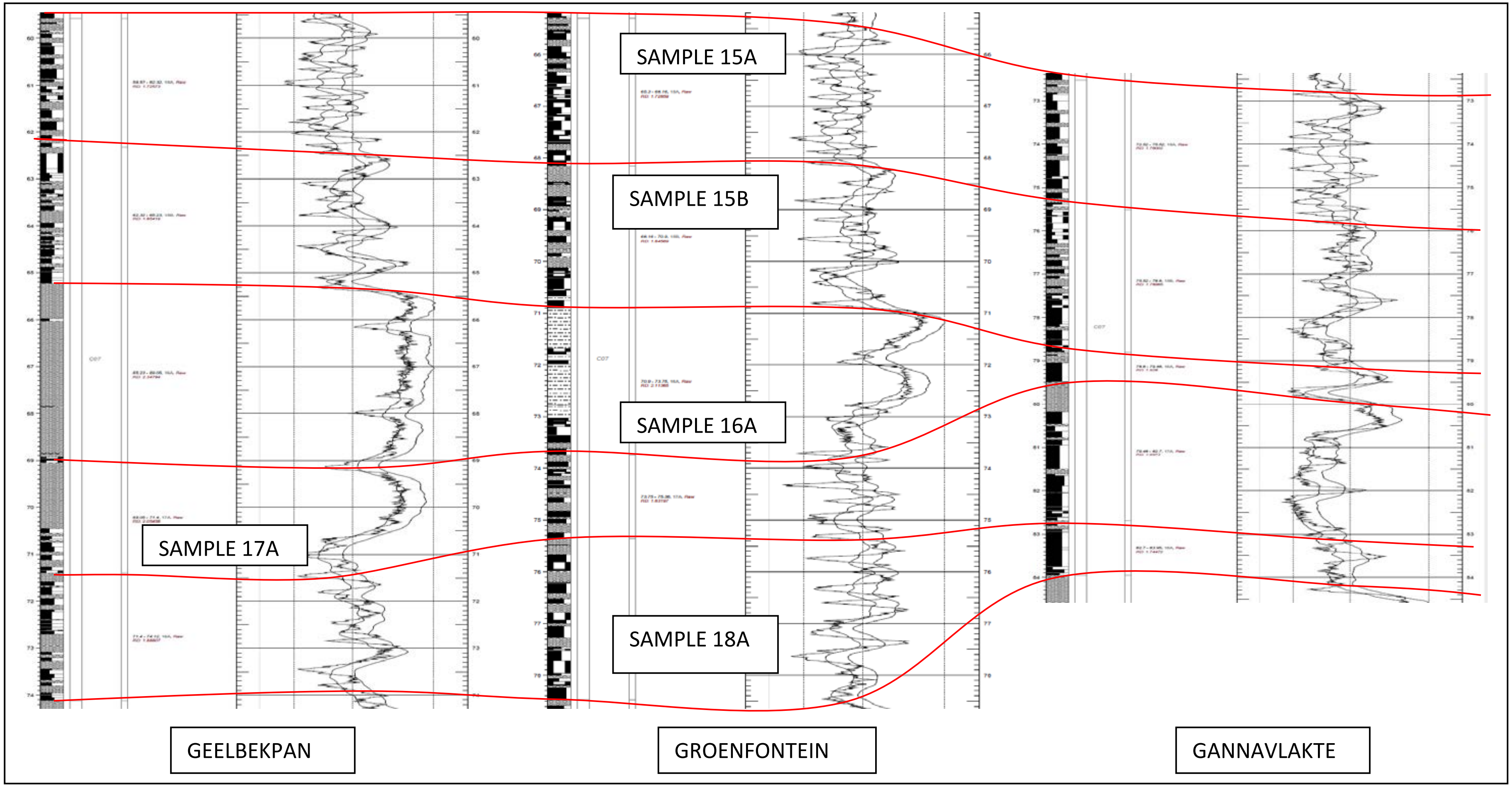


Figure 45 Graphical representation of Sample 15A to Sample 18A

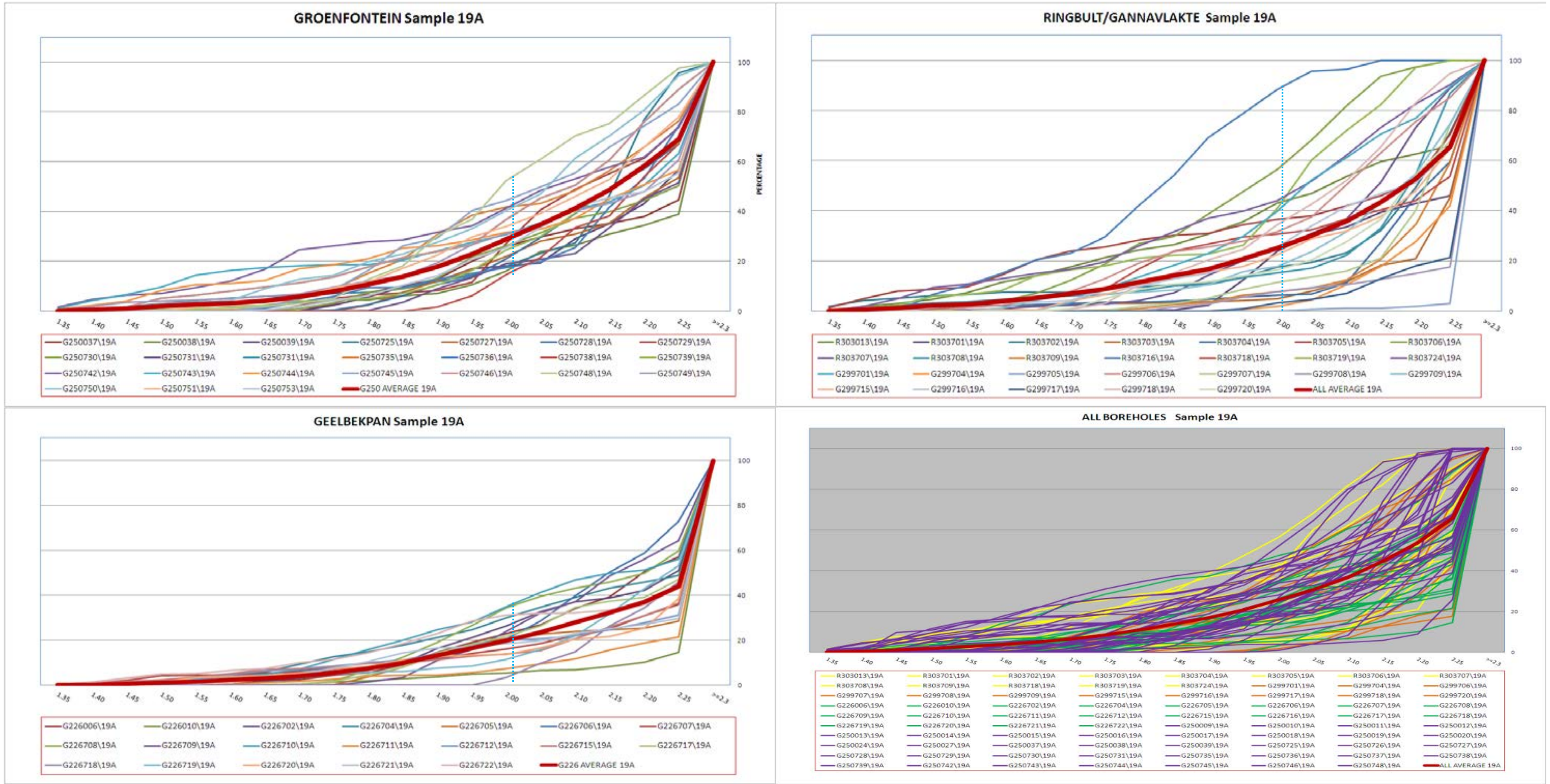


Figure 46 Combined GDCDD of Sample 19A (Spread at a Rd of 2.0, indicated by light blue dotted line)

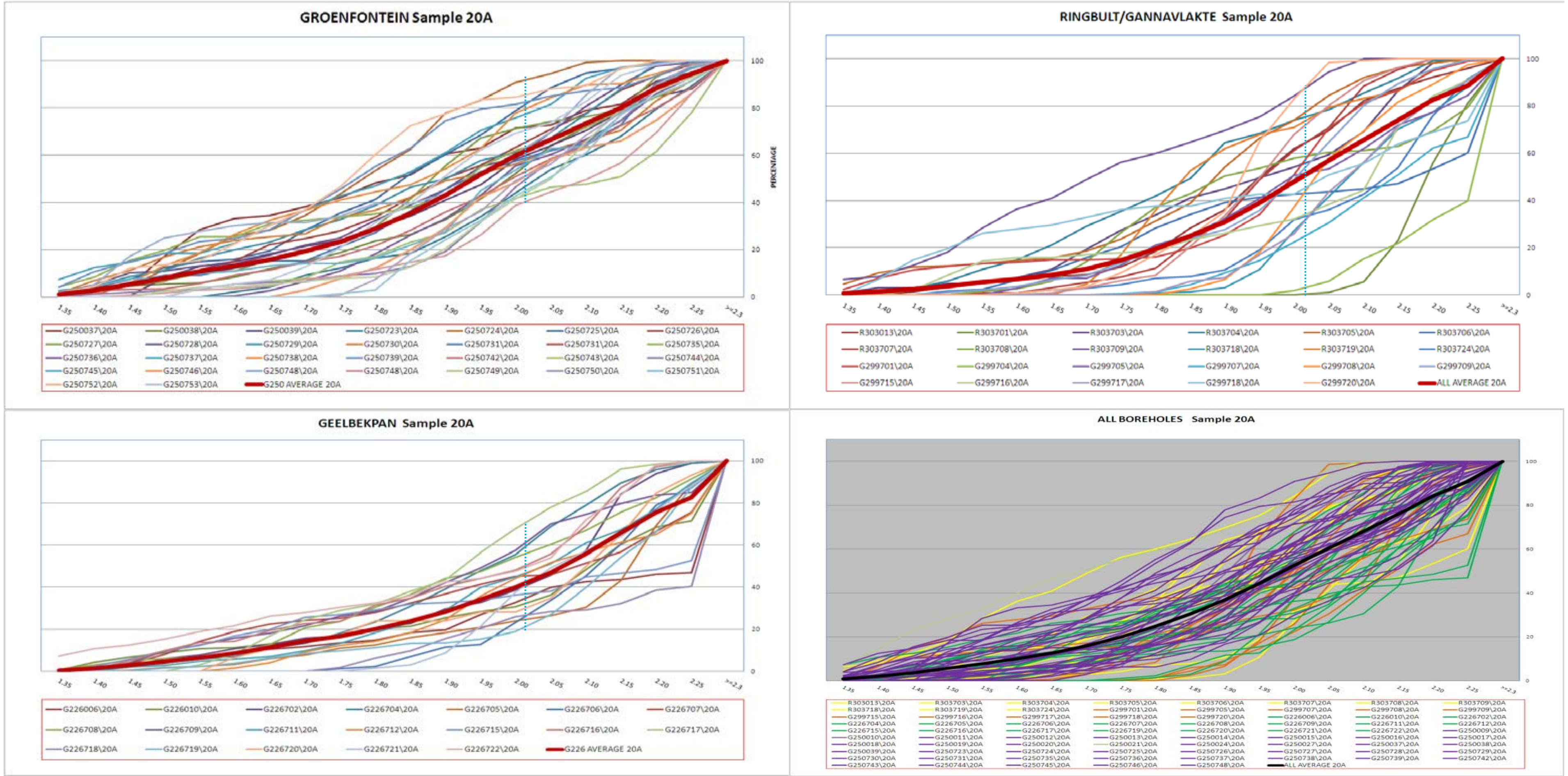


Figure 47 Combined GDCDD of Sample 20A (Spread at a Rd of 2.0, indicated by light blue dotted line)

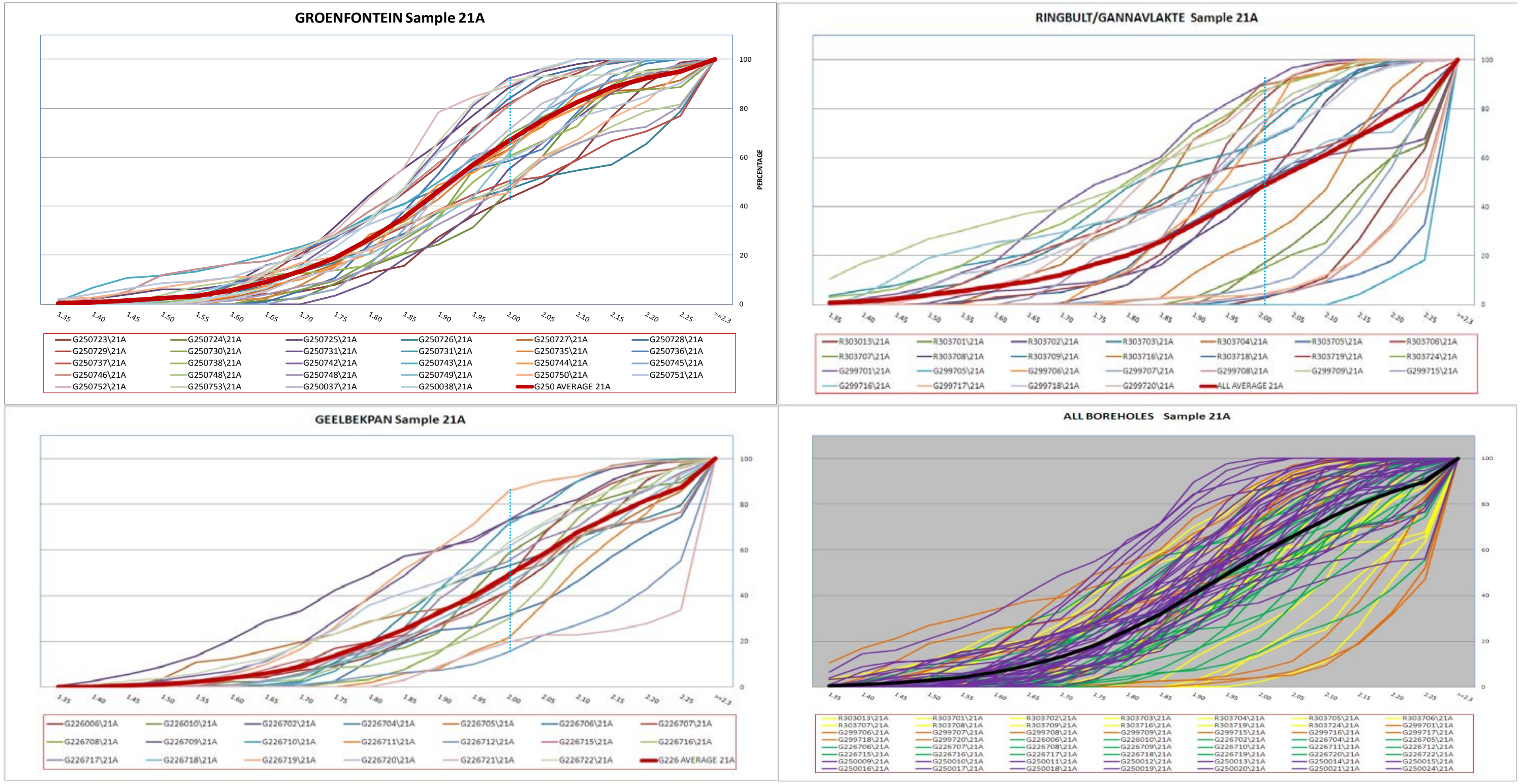


Figure 48 Combined GDCDD of Sample 21A (Spread at a Rd of 2.0, indicated by light blue dotted line)

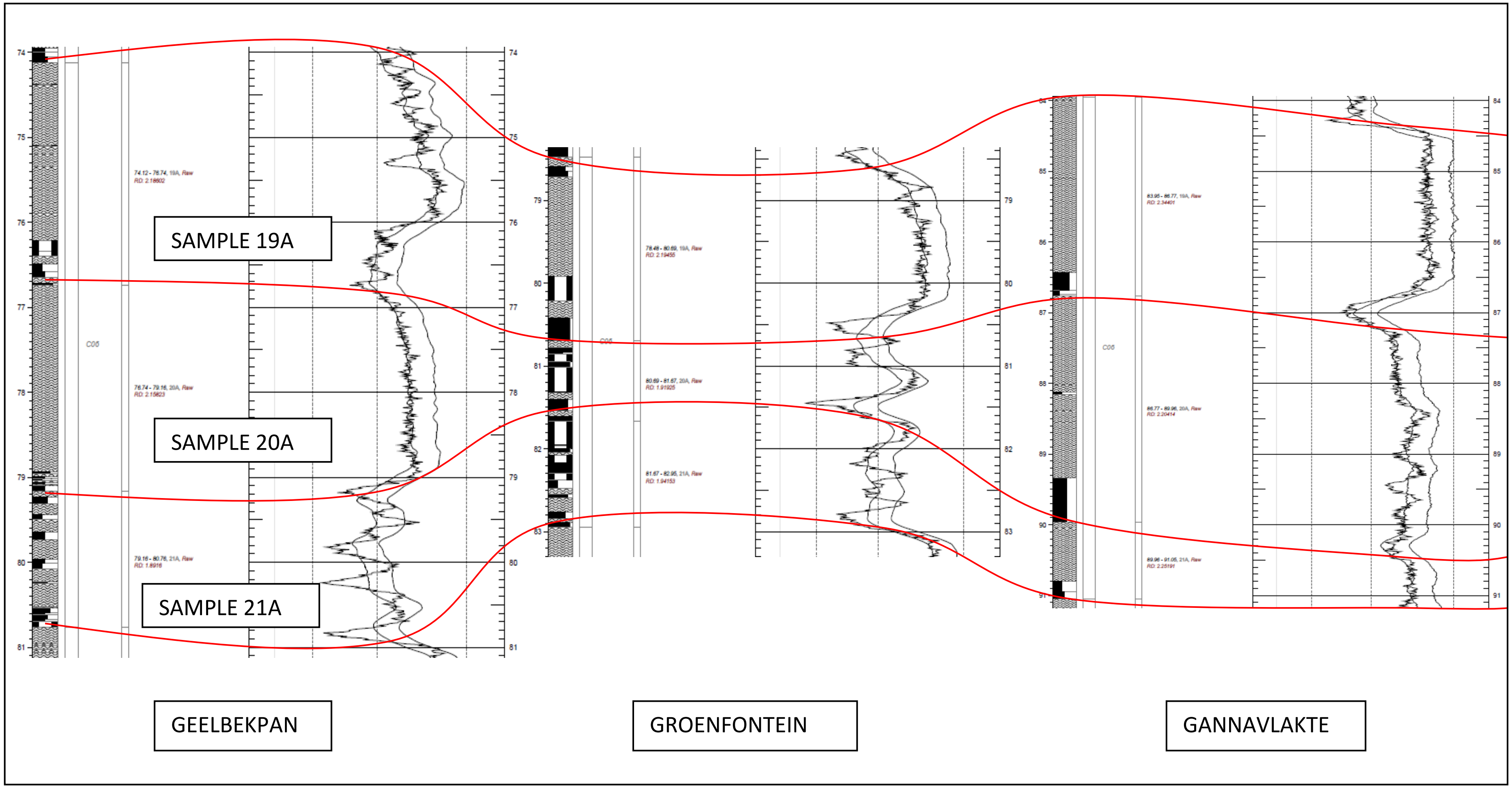


Figure 49 Graphical representation of Sample 19A to Sample 21A

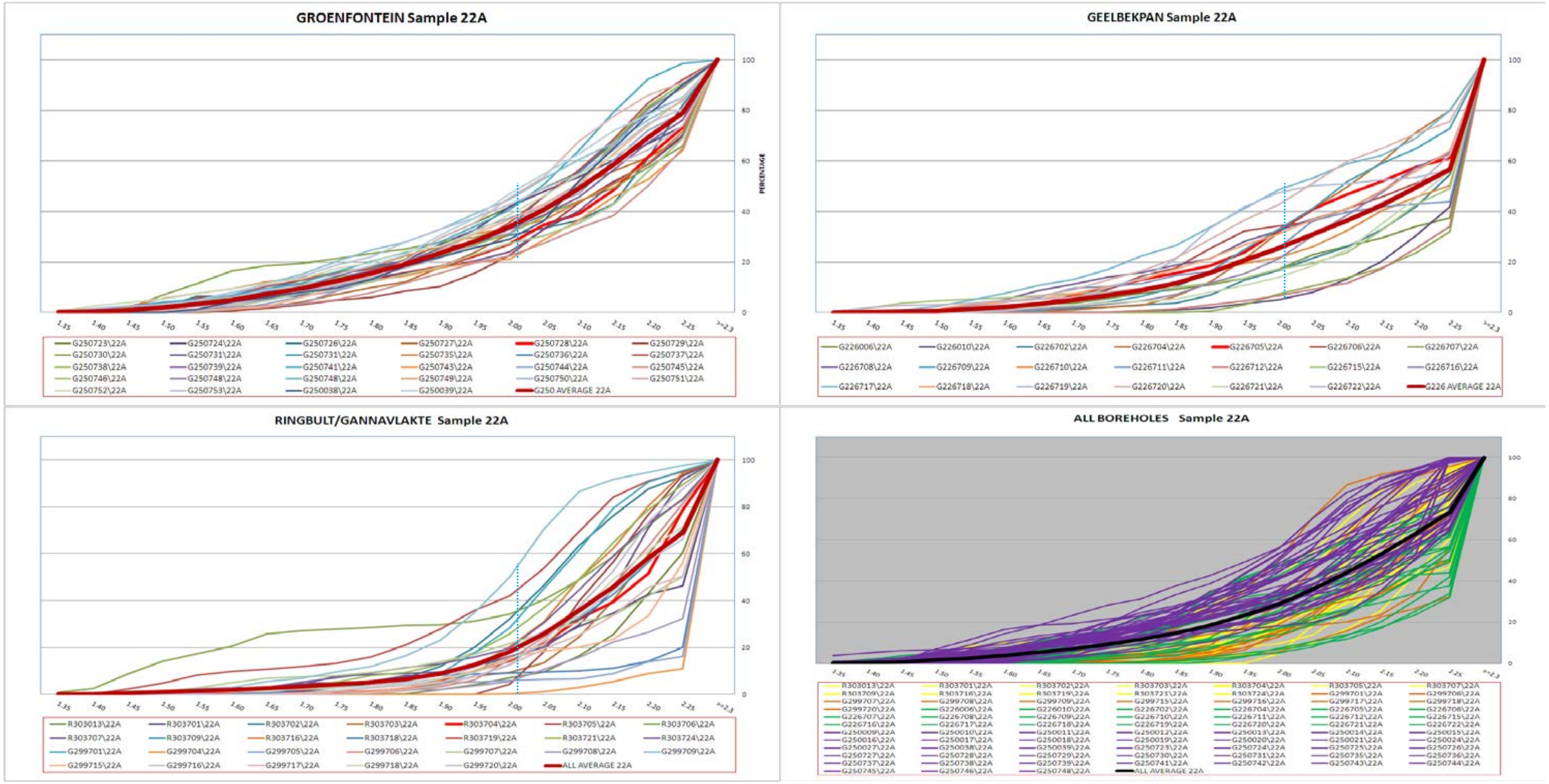


Figure 50 Combined GDCDD of sample 22A (Spread at a Rd of 2.0, indicated by light blue dotted line)

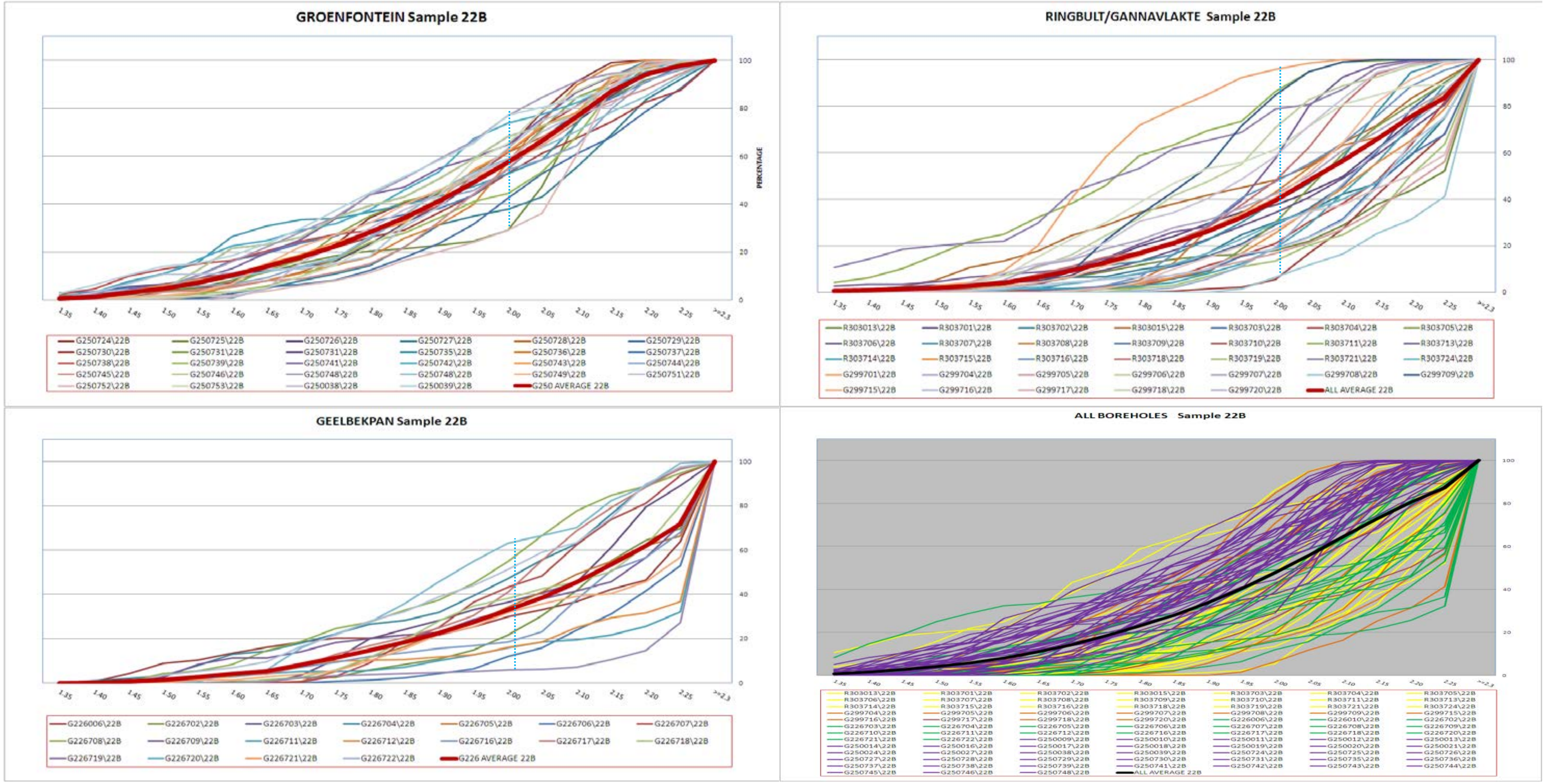


Figure 51 Combined GDCDD of Sample 22B (Spread at a Rd of 2.0, indicated by light blue dotted line)

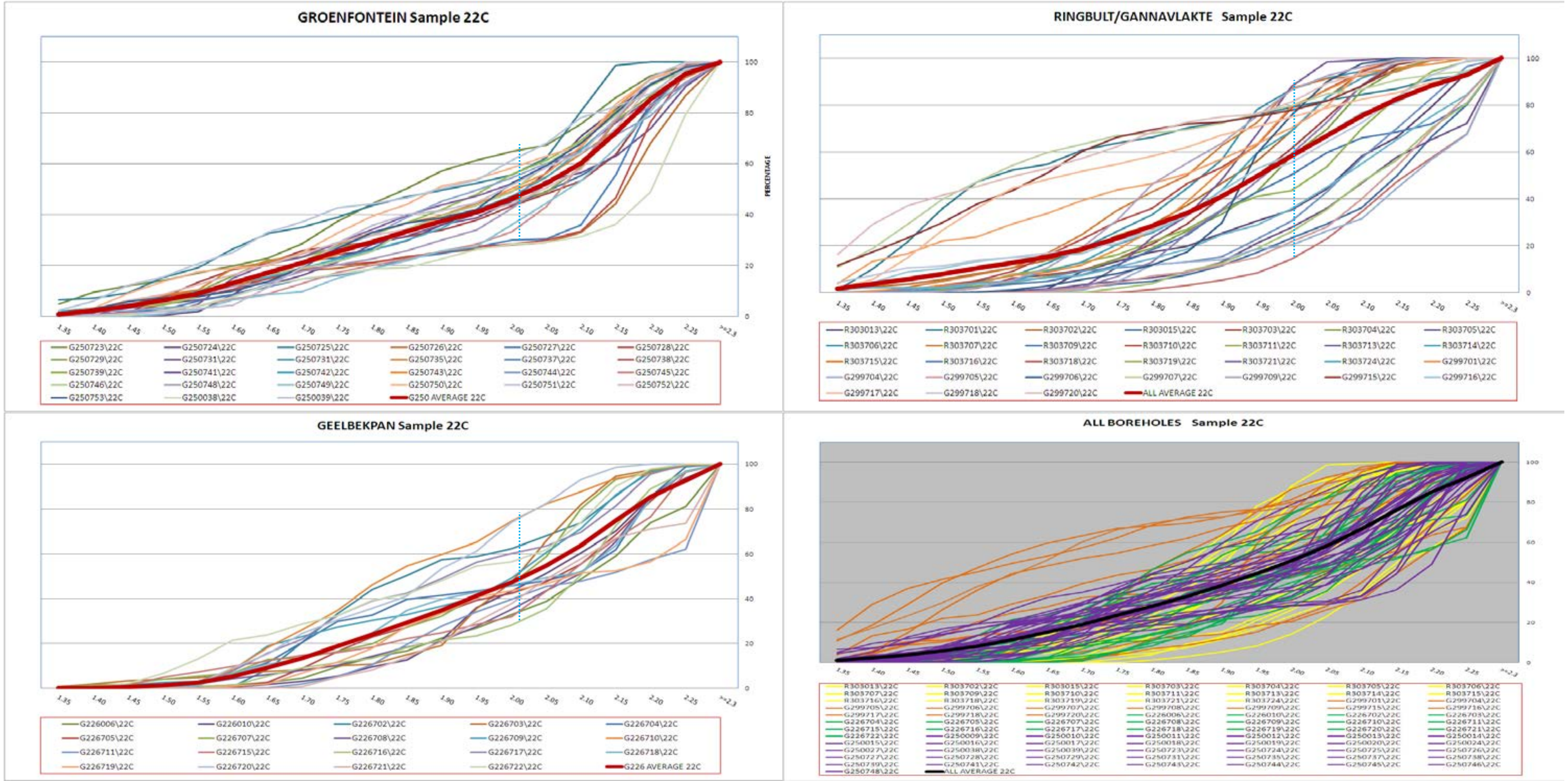


Figure 52 Combined GDCDD of Sample 22C (Spread at a Rd of 2.0, indicated by light blue dotted line)

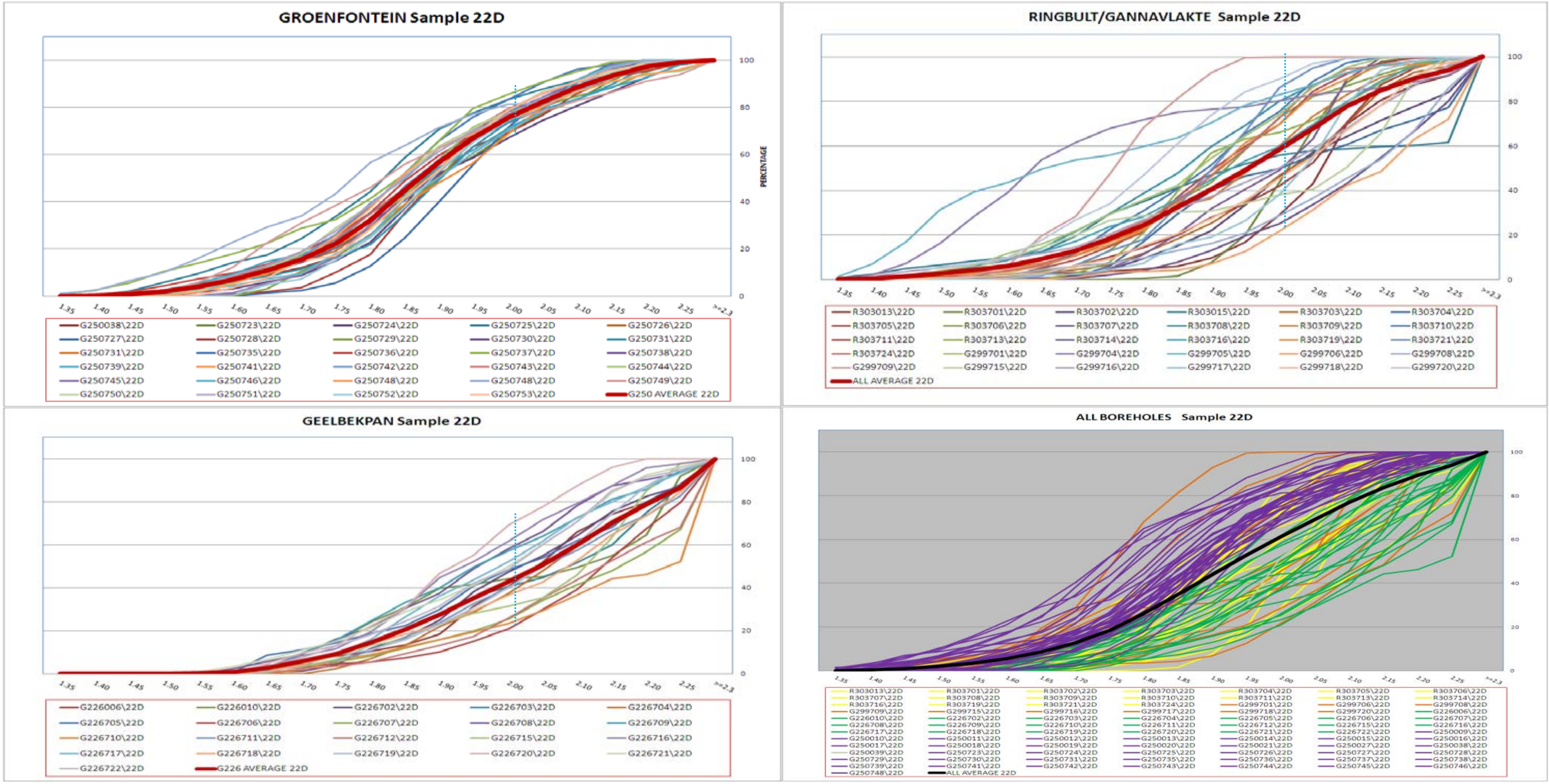


Figure 53 Combined GDCDD of Sample 22D (Spread at a Rd of 2.0, indicated by light blue dotted line)

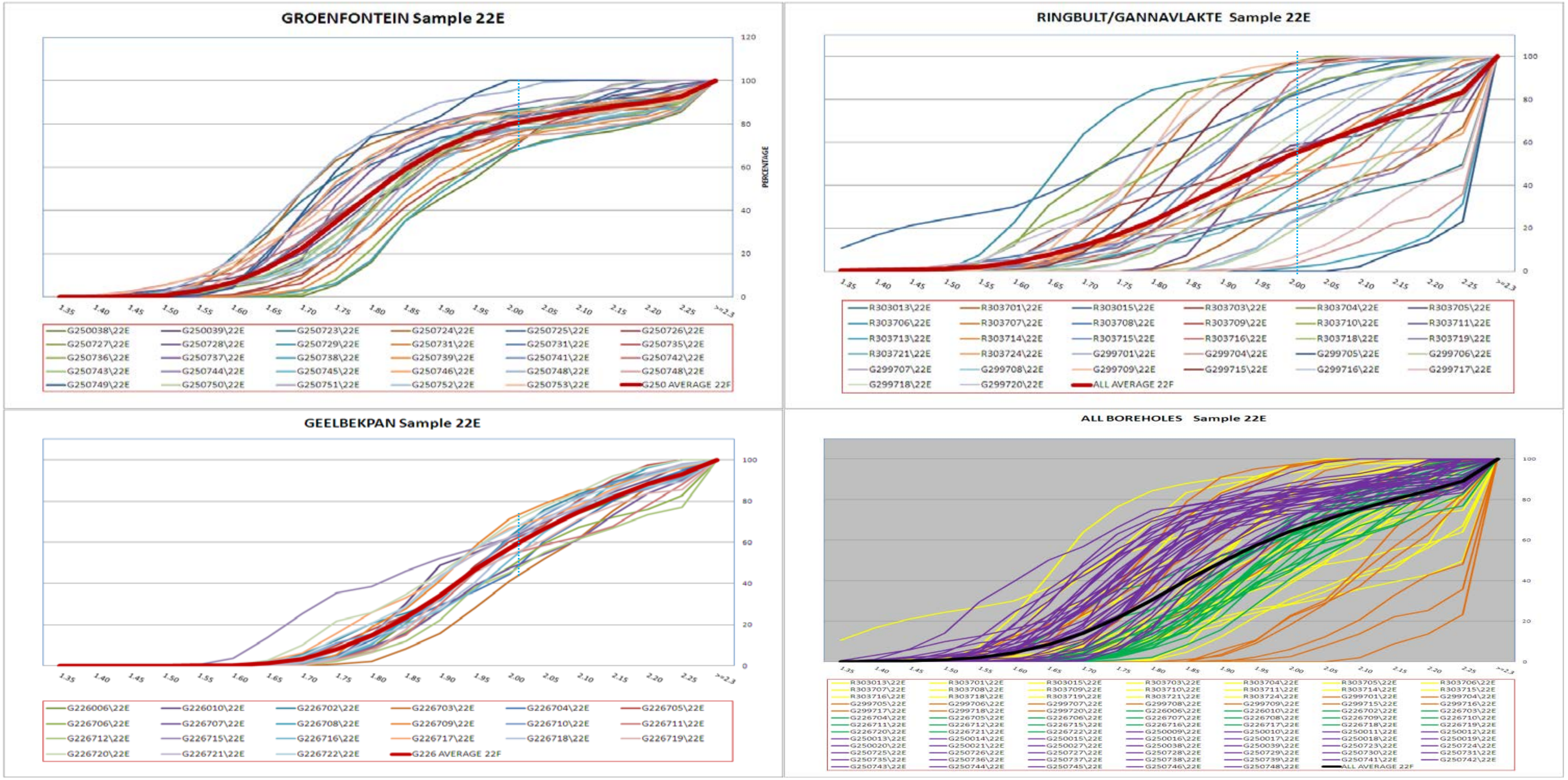


Figure 54 Combined GDCDD of Sample 22E (Spread at a Rd of 2.0, indicated by light blue dotted line)

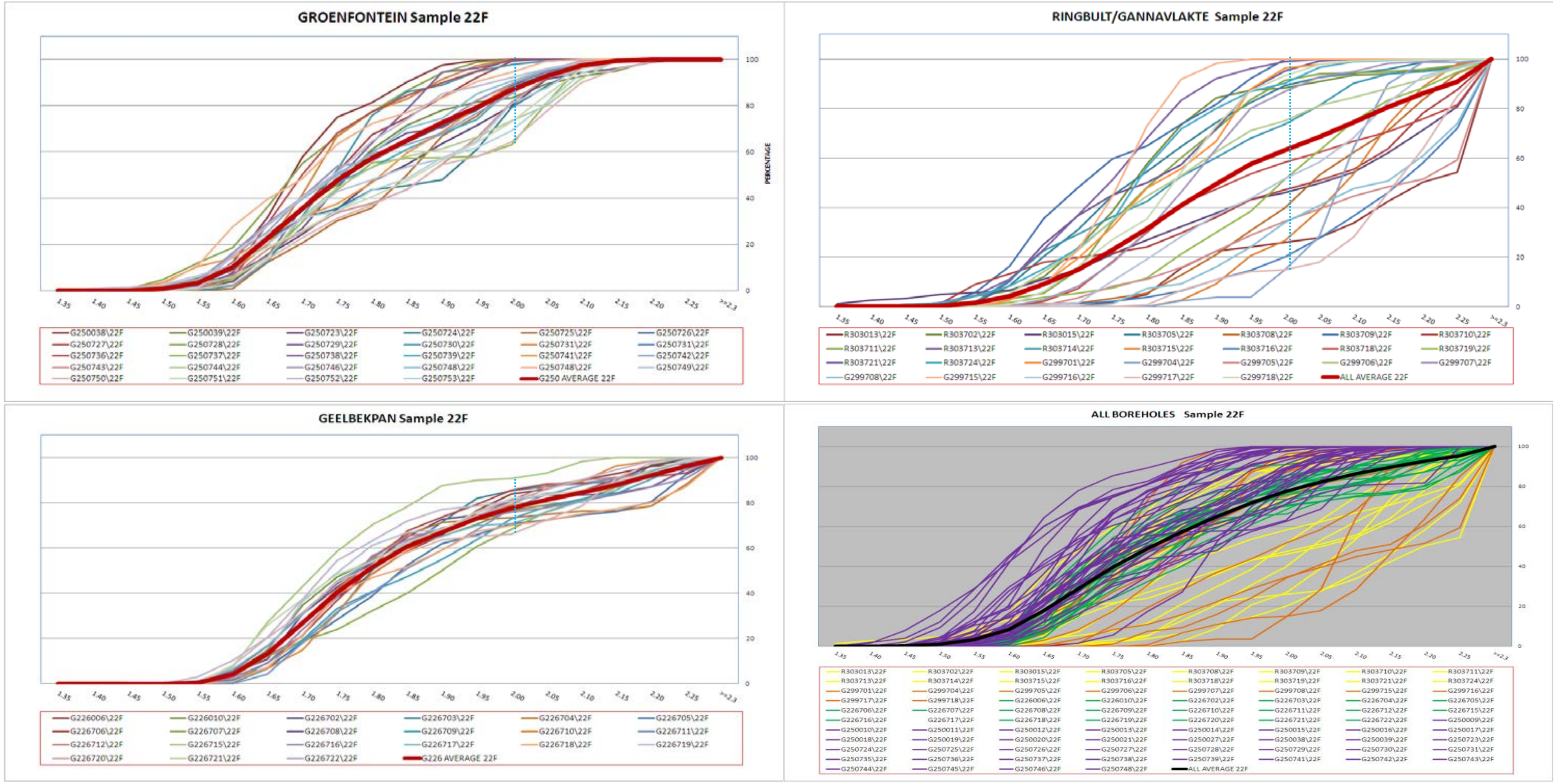


Figure 55 Combined GDCDD of Sample 22F (Spread at a Rd of 2.0, indicated by light blue dotted line)

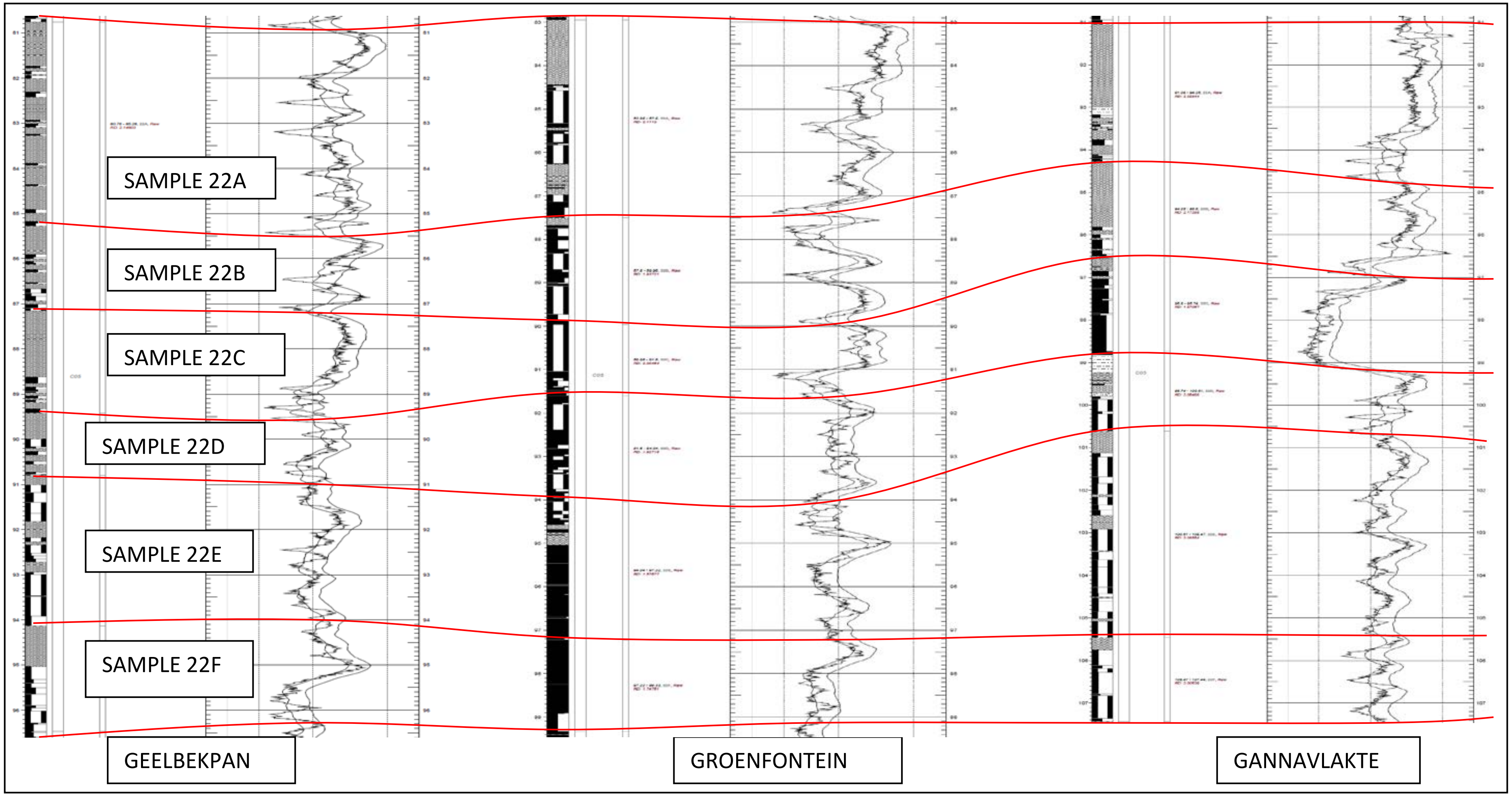


Figure 56 Graphical representation of Sample 22A to Sample 22F

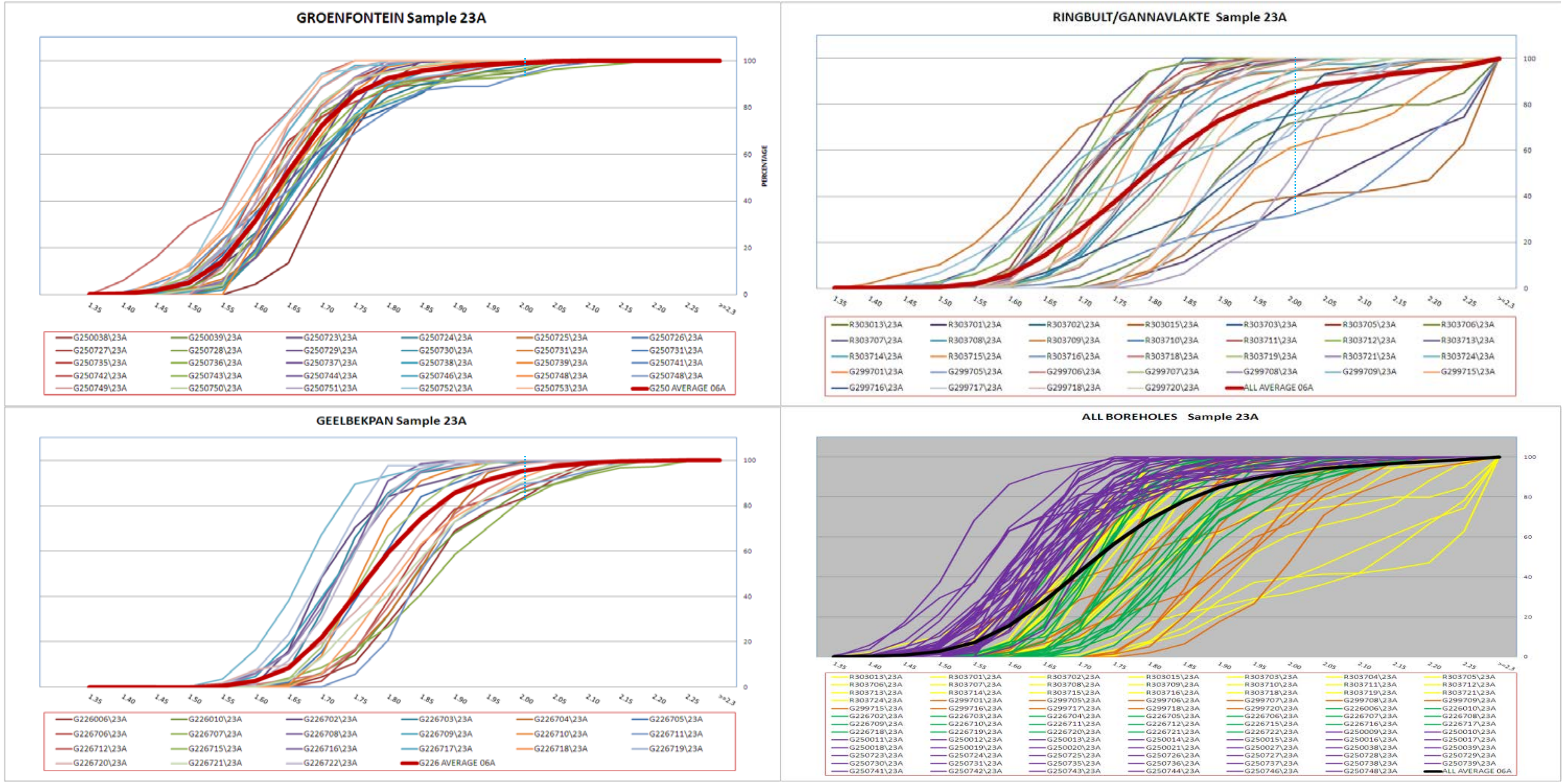


Figure 57 Combined GDCDD of Sample 23A (Spread at a Rd of 2.0, indicated by light blue dotted line)

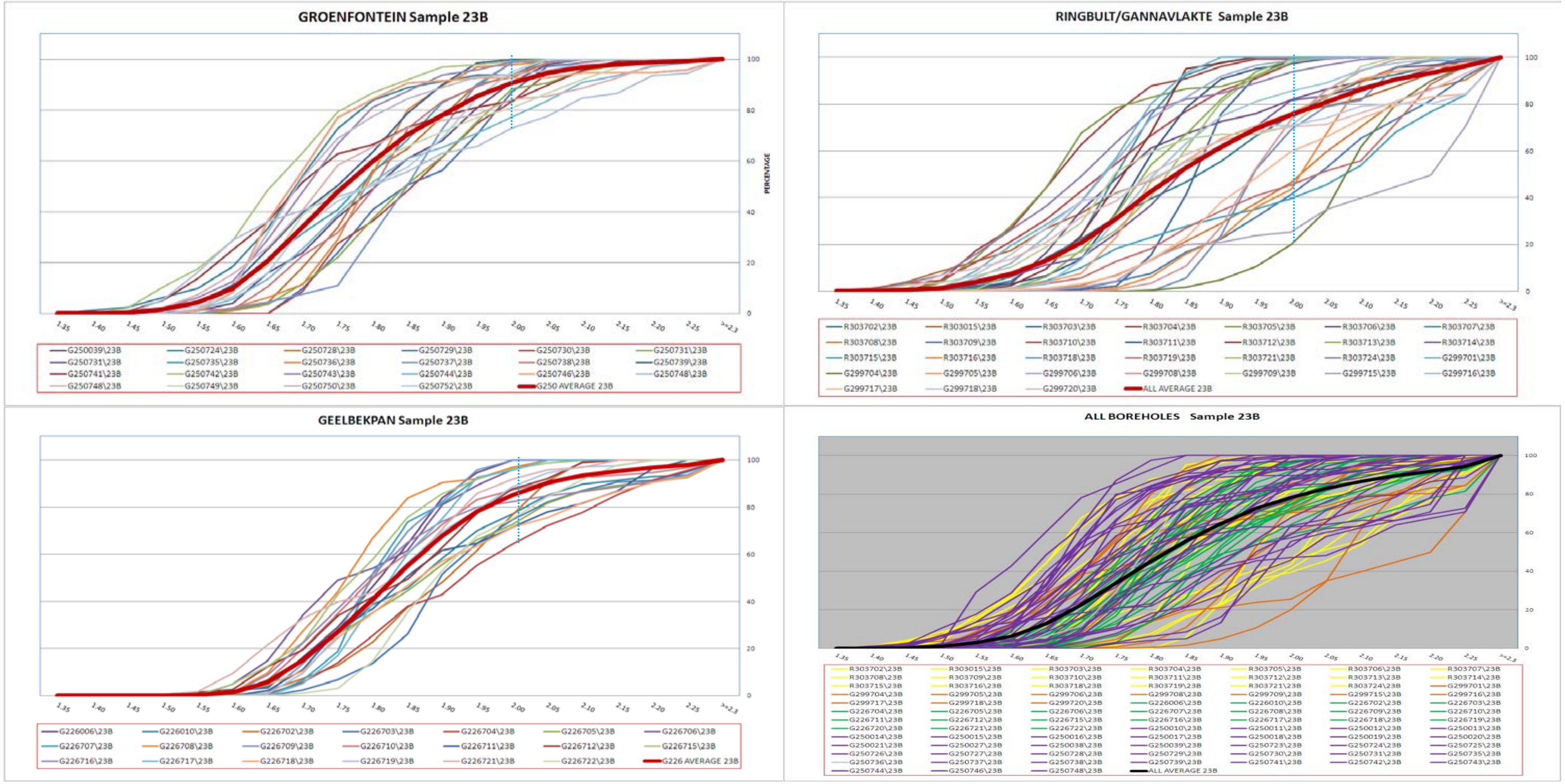


Figure 58 Combined GDCDD of Sample 23B (Spread at a Rd of 2.0, indicated by light blue dotted line)

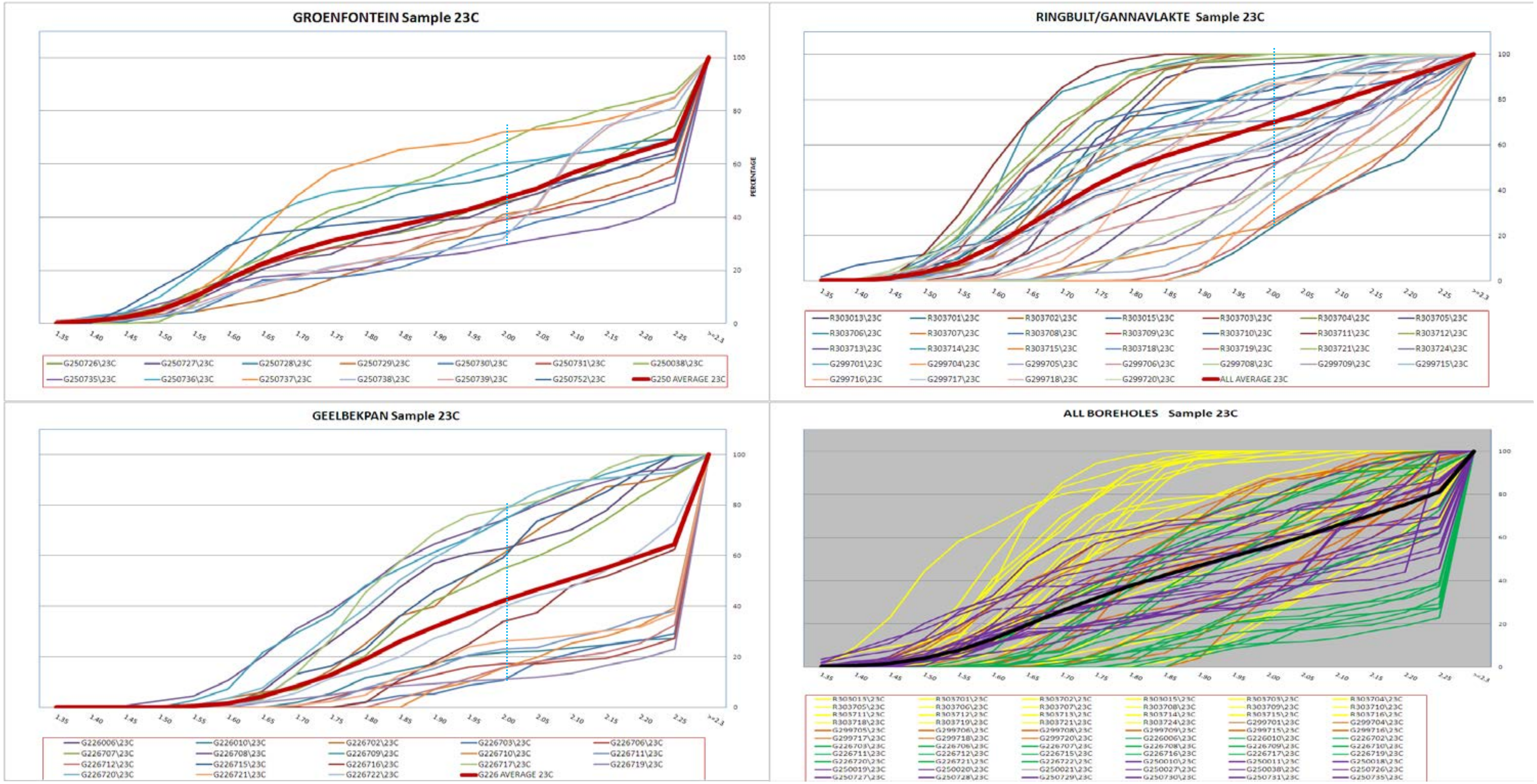


Figure 59 Combined GDCDD of Sample 23C (Spread at a Rd of 2.0, indicated by light blue dotted line)

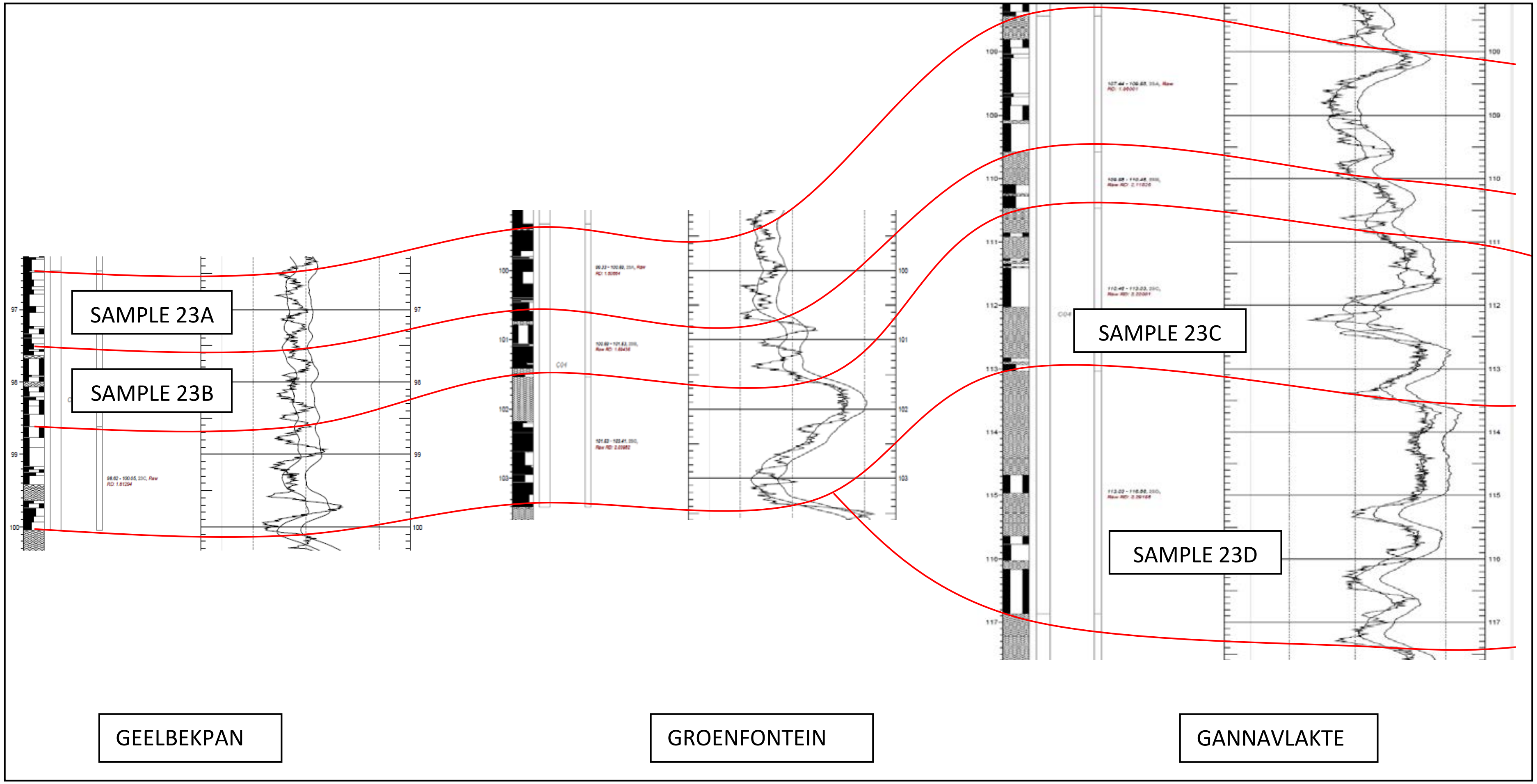


Figure 60 Graphical representation of Sample 23A to Sample 23D

Table 8 Summary of Sample 14B to Sample 23C data.

BASIC INFORMATION ABOUT SAMPLE 14C tot 23C DATA	**SUMMARY**	**GEELBEKPAN**	**GROENFONTEIN**	**RINGBULT**	**GANNAVLAKTE**
Angle of repose of graphs	Sample 14B	High	High	High	High
	Sample 15A	High	High	High	High
	Sample 15B	High	High	High	High
	Sample 16A	Low to med	Med	High	High
	Sample 17A	Med to high	Med	Med to high	Med to high
	Sample 18A	Med to high	Med to high	High	High
	Sample 19A	Low to med	Low to high	Low to high	Low to high
	Sample 20A	Med to high	Med to high	Med to high	Med to high
	Sample 21A	Low to high	Med to high	Low to high	Low to high
	Sample 22A	Low to high	Med to high	Low to med	Low to med
	Sample 22B	Low to high	High	Low to high	Low to high
	Sample 22C	Med to high	High	Med to high	Med to high
	Sample 22D	Med to high	High	Med to high	Med to high
	Sample 22E	High	High	Low to high	Low to high
	Sample 22F	High	High	Low to high	Low to high

	Sample 23A	High	High	Med to high	Med to high
	Sample 23B	High	High	Low to high	Low to high
	Sample 23C	Low to high	Med to high	Low to high	Low to high
	The angle of repose varies over these samples, and it is clear from the graphs, that the lithology in the south is more variable than in the north (Figure 116, Figure 117, Figure 118,Figure 119, Figure 120, Figure 121, Figure 123, Figure 124, Figure 125, Figure 127, Figure 128, Figure 129, Figure 130, Figure 131, Figure 132, Figure 134, Figure 135 and Figure 136).				
Start point of graphs at Rd 1.35	Data values start at the same point, except for Ringbult/Gannavlakte in the south: Sample 17A (Figure 120) and Sample 18A (Figure 121).				
Spread	For Sample 14B and Sample 15A, the spread for Groenfontein and Geelbekpan is very narrow (<10%), while in the south it is ±25%. Sample 15B and Sample 16A have a spread of 25% for the north and ±40% for the south. Sample 17A has a spread of 35% on Groenfontein, 60% on Geelbekpan and 75% in the south. Sample 18A has the narrowest spread in the south and Geelbekpan has the widest distribution. Sample 19 has a 40% spread in the north and 93% in the south. Sample 20A has a 50% spread for the north and 90% for the south. Sample 21A has a 50% spread for Groenfontein, 65% for Geelbekpan and 93% for the south. Sample 22A has a spread of 25% for Groenfontein, 55% for Geelbekpan and the south. Sample 22B has a spread of 50% for Groenfontein, 65% for Geelbekpan and 85% for the south. Sample 22C has a spread of 40% for Groenfontein, 50% for Geelbekpan and 80% for the south. Sample 22D has a 20% spread for Groenfontein, 45% for Geelbekpan and 78% for the south. Sample 22E				

	has a spread of 25% for the north and 100% for the south. Sample 22F has a spread of 38% for Groenfontein, 25% for Geelbekpan and 85% for the south. Sample 23A has a very narrow spread for Groenfontein, a narrow spread for Geelbekpan and a 68% spread for the south. Sample 23B has as spread of about 35% for the north and 80% for the south. Sample 23C has a spread of 45% for Groenfontein, 70% for Geelbekpan and 75% for the south. The data as a whole indicates that the lithology in the south is more variable than on the northern farms.				
Yield at Rd 2.0 -Sample 014B	24.8 % variance	89.9	85.0	82.0	65.1
Yield at Rd 2.0 - Sample 15A	8.2 % variance	61.9	58.0	64.9	56.7
Yield at Rd 2.0 - Sample 15B	8.6 % variance	49.4	42.9	51.4	51.5
Yield at Rd 2.0 -Sample 16A	26.7 % variance	20.9	26.1	40.7	47.6
Yield at Rd 2.0 - Sample 17A	34.1 % variance	48.5	33.6	53.3	67.7
Yield at Rd 2.0 - Sample 18A	27.1 % variance	34.5	34.2	53.9	61.3
Yield at Rd 2.0 -Sample 19A	6.3 % variance	16.2	16.8	14.3	10.5
Yield at Rd 2.0 -Sample 20A	11.2 % variance	23.2	27.7	16.5	22.0
Yield at Rd 2.0 - Sample 21A	22.2 % variance	37.3	36.7	20.1	15.1
Yield at Rd 2.0 - Sample 22A	10.4 % variance	17.4	19.8	9.4	9.8
Yield at Rd 2.0 -Sample 22B	18.2 % variance	22.2	35.2	22.0	25.2
Yield at Rd 2.0 - Sample 22C	14.0 % variance	28.3	28.1	38.9	42.1
Yield at Rd 2.0 - Sample 22D	21.9 % variance	32.1	47.5	25.6	36.6

Yield at Rd 2.0 -Sample 22E	17.6 % variance	46.8	58.5	42.8	40.9
Yield at Rd 2.0 -Sample 22F	10.9 % variance	67.5	69.6	58.7	62.1
Yield at Rd 2.0 - Sample 23A	21.5 % variance	80.4	85.6	64.1	64.6
Yield at Rd 2.0 - Sample 23B	34.9 % variance	72.9	68.4	56.5	38.0
Yield at Rd 2.0 -Sample 23C	18.5 % variance	52.9	34.4	39.8	36.4
Remarks- Yield	The largest variation in yield is found in Sample 17A and Sample 23B, and the highest yield in Sample 14B on Geelbekpan and Sample 23A on Groenfontein.				
Raw Rd Sample 14B	0.12 variance	1.62	1.62	1.65	1.74
Raw Rd Sample 15A	0.03 variance	1.73	1.72	1.72	1.75
Raw Rd Sample 15B	0.06 variance	1.80	1.86	1.80	1.82
Raw Rd Sample 16A	0.28 variance	2.12	2.02	1.87	1.84
Raw Rd Sample 17A	0.21 variance	1.83	1.93	1.80	1.72
Raw Rd Sample 18A	0.14 variance	1.91	1.92	1.80	1.78
Raw Rd Sample 19A	0.16 variance	2.12	2.10	2.20	2.26
Raw Rd Sample 20A	0.15 variance	2.04	2.00	2.09	2.13
Raw Rd Sample 21A	0.40 variance	1.78	1.89	2.09	2.18
Raw Rd Sample 22A	0.17 variance	2.08	2.08	2.21	2.25
Raw Rd Sample 22B	0.21 variance	2.07	1.90	2.11	2.10
Raw Rd Sample 22C	0.13 variance	2.02	1.97	1.96	1.89

Raw Rd Sample 22D	0.21 variance	2.01	1.89	2.10	1.97
Raw Rd Sample 22E	0.16 variance	1.95	1.87	2.03	2.03
Raw Rd Sample 22F	0.15 variance	1.84	1.81	1.96	1.93
Raw Rd Sample 23A	0.20 variance	1.78	1.70	1.89	1.90
Raw Rd Sample 23B	0.24 variance	1.87	1.82	1.92	2.06
Raw Rd Sample 23C	0.16 variance	1.95	2.01	2.05	2.11
Remarks on raw Rd	The largest variance in yield occurs in Sample 21A and the smallest variance in raw Rd in Sample 15A.				
Thickness Sample 14B	0.7 meter variance	1.14	1.53	1.71	1.90
Thickness Sample 15A	0.49 meter variance	2.87	3.06	2.67	2.57
Thickness Sample 15B	0.23 meter variance	3.12	2.92	2.94	2.89
Thickness Sample 16A	0.59 meter variance	2.54	2.13	1.95	2.03
Thickness Sample 17A	0.90 meter variance	1.95	2.21	2.85	2.21
Thickness Sample 18A	0.88 meter variance	2.18	2.47	2.54	1.66
Thickness Sample 19A	1.07 meter variance	2.69	1.80	2.47	2.87
Thickness Sample 20A	0.23 meter variance	1.67	1.61	1.84	1.69
Thickness Sample 21A	0.77 meter variance	1.53	1.60	2.22	1.45
Thickness Sample 22A	0.95 meter variance	3.86	4.38	4.07	3.43
Thickness Sample 22B	0.69 meter variance	2.90	2.47	3.16	2.77
Thickness Sample 22C	0.32 meter variance	2.32	2.25	2.55	2.23

Thickness Sample 22D	0.79 meter variance	2.62		2.85		2.51		2.06	
Thickness Sample 22E	0.35 meter variance	3.06		2.74		2.86		3.09	
Thickness Sample 22F	0.55 meter variance	2.10		1.95		2.50		2.24	
Thickness Sample 23A	0.56 meter variance	1.26		1.18		1.74		1.63	
Thickness Sample 23B	1.03 meter variance	1.31		1.06		1.37		2.09	
Thickness Sample 23C	0.55 meter variance	1.49		2.04		1.97		1.83	
Remarks on thickness	Sample 14B has a fairly constant thickness (Figure 112).The thickness of sample 15A, 15B and 17A is fairly constant (Figure 122), while the thickness of sample 16A and 18A becomes thinner towards Gannavlakte (Figure 122). The largest variance in thickness occurs in Sample 19A and the smallest variance in Sample 15B and Sample 20A. To have only a maximum variance in thickness of 1.07 m over a few hundred square km is remarkable (Figure 126). Figure 139, which shows the thickness contours of Sample 15B, shows an equal thickness over the area. The purple circle shows modelling inaccuracies which are caused by a lack of borehole information. The thickness of sample 22A to 22F id constant over the whole area (Figure 133). Sample 23D only occurs in the south ().Figure 137								
Standard deviation at a Rd of 1.60 and 2.0	**Relative density**	**1.6**	**2.0**	**1.6**	**2.0**	**1.6**	**2.0**	**1.6**	**2.0**
	Sample 14B	10.7	1.3	12.7	2.0	21.8	12.7	23.7	7.1
	Sample 15A	4.2	2.4	6.6	3.9	8.1	4.4	12.7	7.6
	Sample 15B	8.6	5.9	4.7	8.3	12.5	7.5	12.8	9.6

	Sample 16A	8.4	12.2	9.3	13.2	12.5	17.6	10.0	9.6
	Sample 17A	15.7	15.9	8.8	12.4	27.4	16.5	18.8	16.3
	Sample 18A	9.1	18.7	6.6	10.4	15.8	22.2	20.3	11.3
	Sample 19A	3.4	11.0	5.7	13.6	5.4	22.8	1.2	13.3
	Sample 20A	7.9	14.0	9.9	14.3	10.5	24.0	9.0	26.5
	Sample 21A	5.4	19.3	6.9	16.8	8.0	30.5	12.1	36.4
	Sample 22A	2.4	12.8	3.4	10.5	7.4	15.9	1.6	12.9
	Sample 22B	8.6	18.9	12.8	14.7	7.2	20.2	3.5	29.0
	Sample 22C	5.2	18.1	7.4	15.5	13.7	25.1	20.4	22.8
	Sample 22D	0.9	13.0	5.7	7.7	3.3	20.8	14.8	30.4
	Sample 22E	0.8	8.5	8.1	6.2	8.2	29.4	3.8	39.3
	Sample 22F	2.8	6.4	12.6	10.9	5.4	31.4	1.8	34.1
	Sample 23A	4.1	6.3	17.2	2.2	9.1	22.7	6.4	27.7
	Sample23B	2.4	12.5	9.8	17.4	9.8	31.0	7.5	31.4
	Sample 23C	10.7	1.3	12.7	2.0	21.8	12.7	23.7	7.1
Comments on standard deviation	The largest σ value, of 39.3, can be found at a Rd of 2.0 in Sample 22E on Gannavlakte, and the smallest σ value at a Rd of 1.60 for Sample 22E on Geelbekpan The σ value in the south are generally higher than in the central and northern areas. In general, Geelbekpan has the lowest σ value of all the samples and Ringbult and Gannavlakte the highest σ value. When combining the σ values of 1.60 an d 2.0 it can be clearly seen that the south has higher value than the north for all the samples (Figure 138). On this graph								

	(Figure 138) it is illustrated that basically all the samples in the north has a σ value of less than 10 and the south and average of about 12.5.
Correlation accuracy by geologist	Correlation is good and easy to do, but care will have to be taken in the southern part of the Study area.
Modelling accuracy	Care must be taken in modelling these samples, as there is some variation on a per sample basis.
Use as SANS 10320 data correlation point	Sample 14B to Sample 15B are very closely spaced and very similar for the north and only slightly wider for the south. From Sample 16A to Sample 23B, the graphs illustrate a wider association of the graphs and the south is quite wide to haphazard in places, based on the local geology. Sample 23C is influenced by the mudrock parting below the coal sample; where the parting was greater than 2 m, the coal seams below were added to Sample Zone 04 in which Sample 23 occurs. The angle of repose of the graphs is influenced by the amount of low density material (coal) present in the sample. Sample 23B and Sample 17A have the highest variance in yield and Sample 14B and Sample 23A some of the highest yields. Sample 22A has the lowest yields. Sample 21A has the highest variance in raw Rd because it consists virtually of only of mudrock material in places. Sample 15A has the lowest variance with a Rd of only 0.03. In term of thickness, Sample 15B has the least variance in thickness and Sample 19A the highest variance. Sample 22A is the thickest individual sample and Sample 23A on Groenfontein the thinnest sample. It should be a simple matter for a geologist to correlate these samples over the Study area, but when modelling, care must be taken with some of the samples. In general, the lithology variation in the south is higher than in the north.

Table 9 Standard deviation calculated at two RDs from the GCCD data for Sample 14B to Sample 23C.

VRYHEID FORMATION															
FARM	**GEELBEKPAN**			**GROENFONTEIN**			**GANNAVLAKTE**			**RINGBULT**			**TOTAL**		
Sample	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**
14B	10.7	1.3	6.0	12.7	2.0	7.3	23.7	7.1	15.4	21.8	12.7	17.3	17.2	5.8	11.5
15A	4.2	2.4	3.3	6.6	3.9	5.3	12.7	7.6	10.2	8.1	4.4	6.2	7.9	4.6	6.2
15B	8.6	5.9	7.3	4.7	8.3	6.5	12.8	9.6	11.2	12.5	7.5	10.0	9.7	7.8	8.7
16A	8.4	12.2	10.3	9.3	13.2	11.2	10.0	9.6	9.8	12.5	17.6	15.0	10.0	13.1	11.6
17A	15.7	15.9	15.8	8.8	12.4	10.6	18.8	16.3	17.6	27.4	16.5	21.9	17.7	15.3	16.5
18A	9.1	18.7	13.9	6.6	10.4	8.5	20.3	11.3	15.8	15.8	22.2	19.0	12.9	15.7	14.3
19A	3.4	11.0	7.2	5.7	13.6	9.7	1.2	13.3	7.3	5.4	22.8	14.1	3.9	15.2	9.6
20A	7.9	14.0	10.9	9.9	14.3	12.1	9.0	26.5	17.7	10.5	24.0	17.3	9.3	19.7	14.5
21A	5.4	19.3	12.4	6.9	16.8	11.8	12.1	36.4	24.3	8.0	30.5	19.3	8.1	25.8	16.9
22A	2.4	12.8	7.6	3.4	10.5	7.0	1.6	12.9	7.2	7.4	15.9	11.6	3.7	13.0	8.3
22B	8.6	18.9	13.7	12.8	14.7	13.8	3.5	29.0	16.3	7.2	20.2	13.7	8.0	20.7	14.4
22C	5.2	18.1	11.6	7.4	15.5	11.5	20.4	22.8	21.6	13.7	25.1	19.4	11.7	20.4	16.0
22D	0.9	13.0	7.0	5.7	7.7	6.7	14.8	30.4	22.6	3.3	20.8	12.0	6.2	18.0	12.1
22E	0.8	8.5	4.7	8.1	6.2	7.1	3.8	39.3	21.5	8.2	29.4	18.8	5.2	20.8	13.0
22F	2.8	6.4	4.6	12.6	10.9	11.7	1.8	34.1	17.9	5.4	31.4	18.4	5.6	20.7	13.2
23A	4.1	6.3	5.2	17.2	2.2	9.7	6.4	27.7	17.1	9.1	22.7	15.9	9.2	14.7	12.0
23B	2.4	12.5	7.4	9.8	17.4	13.6	7.5	31.4	19.4	9.8	31.0	20.4	7.4	23.1	15.2
23C	3.0	25.4	14.2	8.7	17.5	13.1	11.1	26.2	18.6	18.5	27.0	22.8	10.3	24.0	17.2

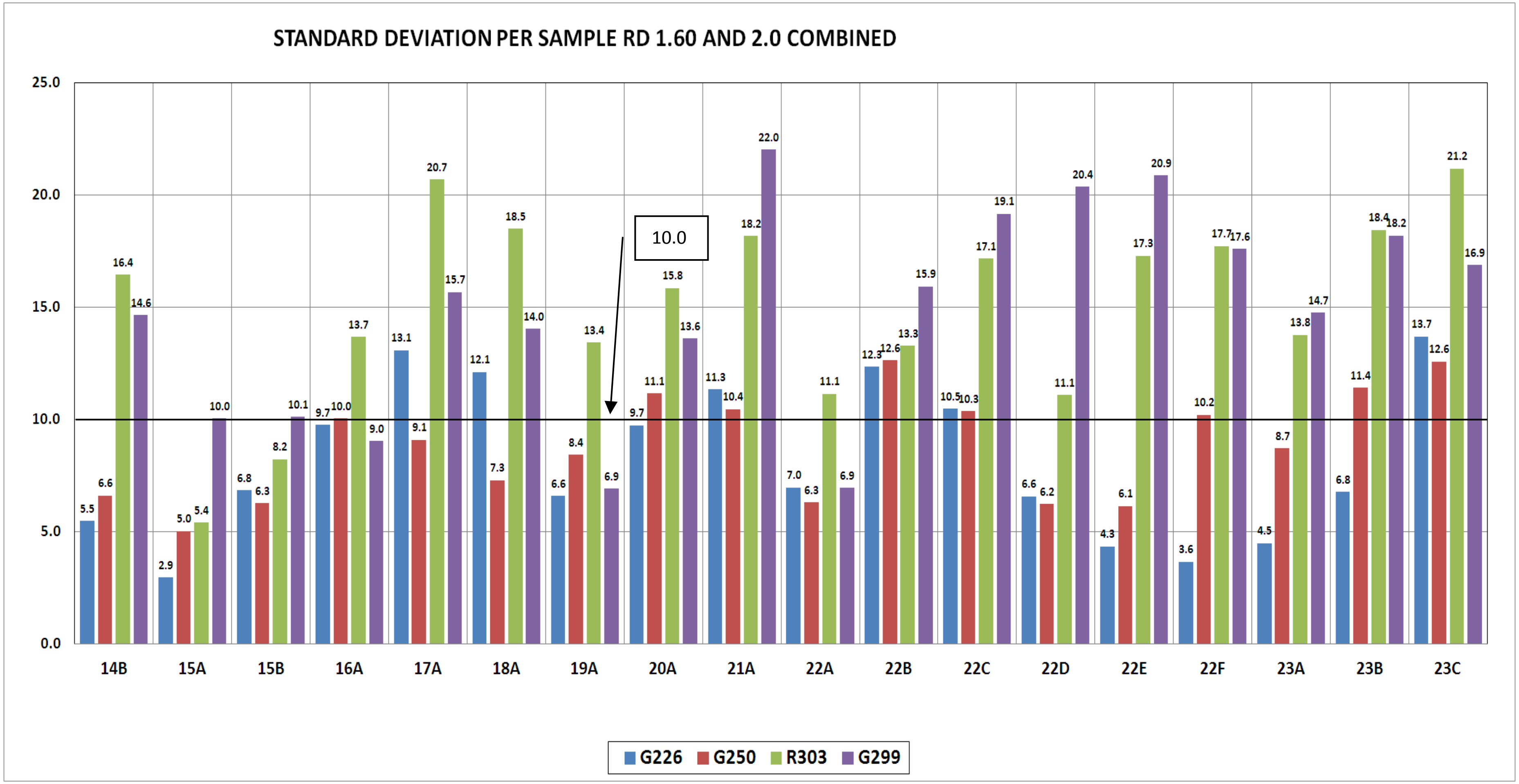


Figure 61 Standard deviation graph at of Rd 1.6 and 2.0, combined and averaged, for Sample 14C to Sample23C

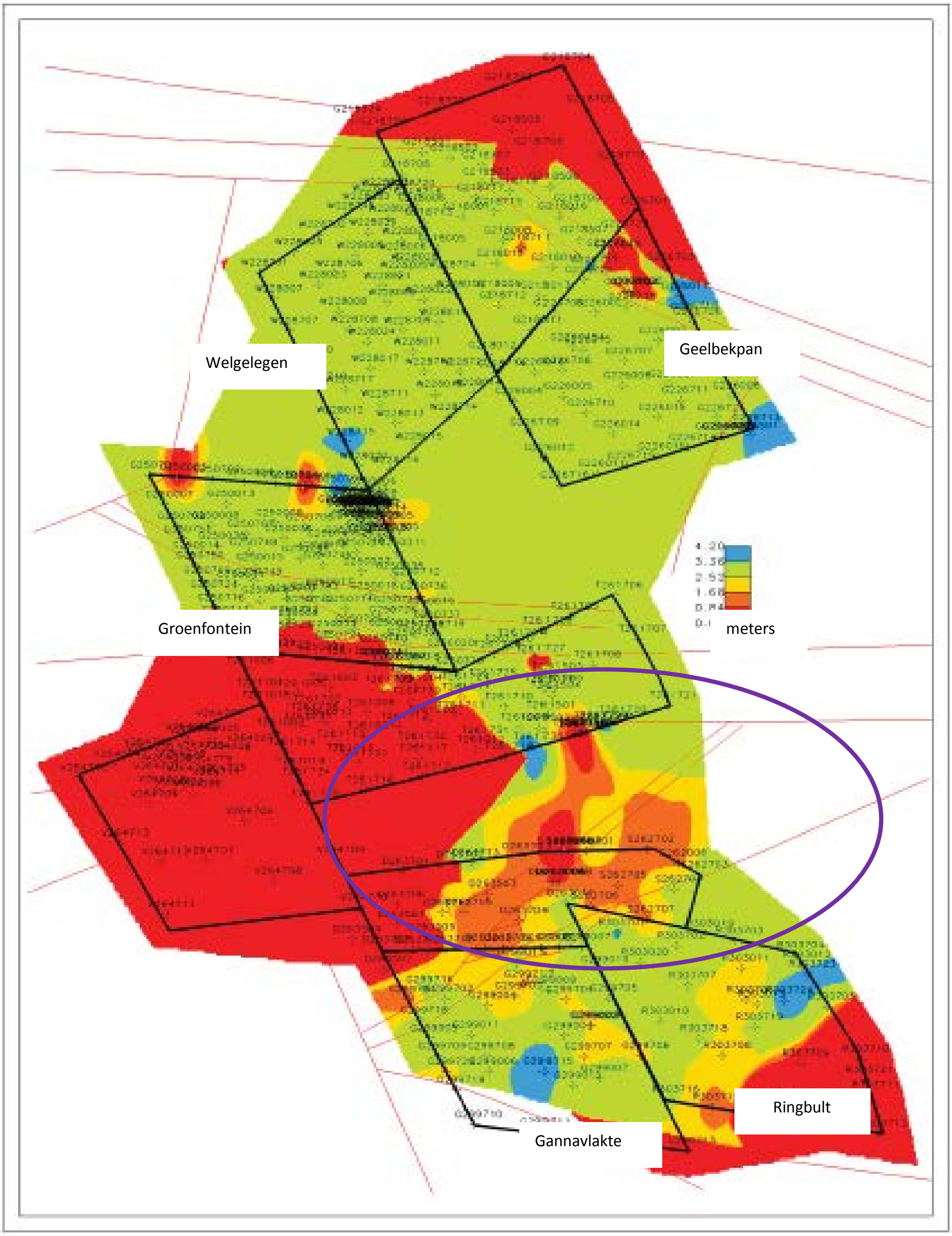


Figure 62 The lateral thickness variation of Sample 15B over the Study area. Purple circle delineates area of modelling inaccuracies due to lack of information

Samples 28A to 32B

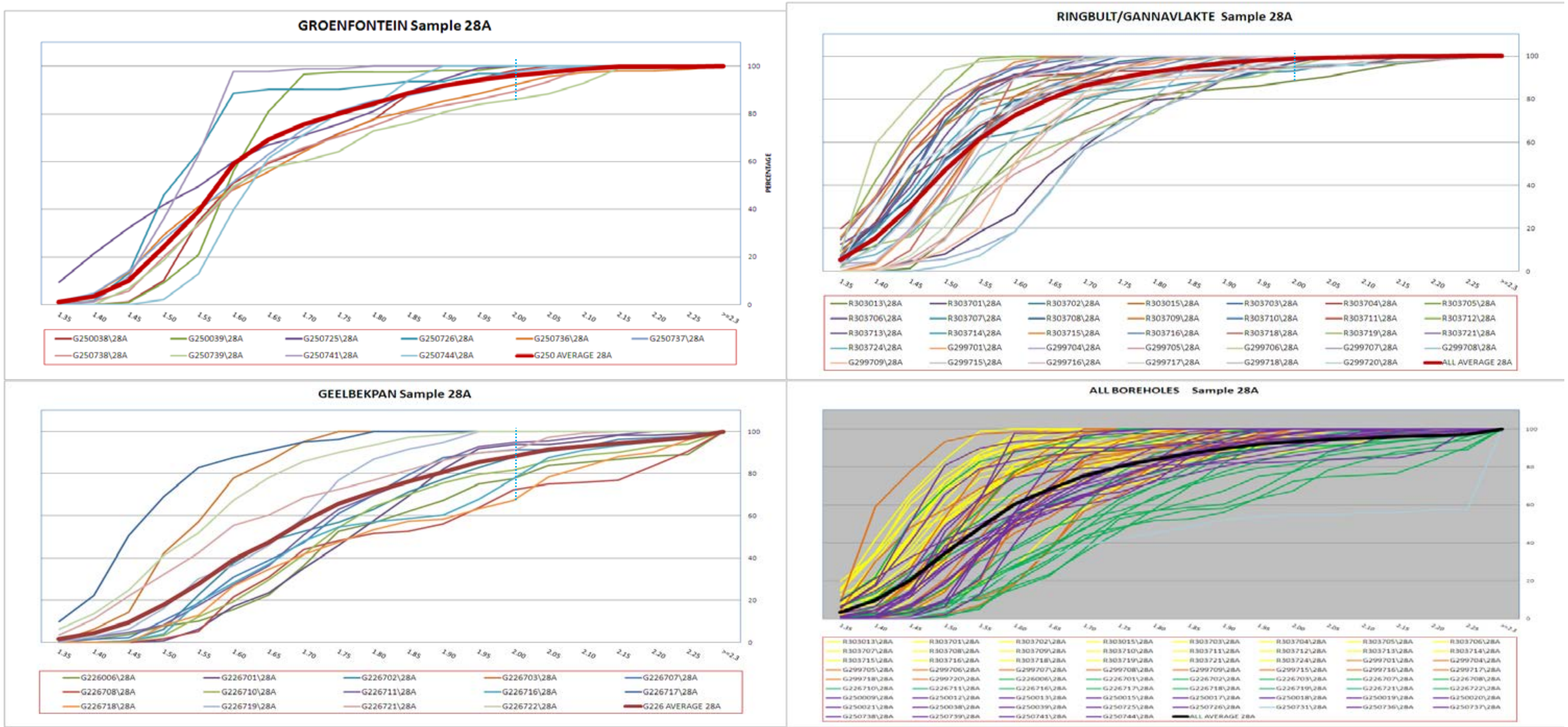


Figure 63 Combined GDCDD of Sample 28A (Spread at a Rd of 2.0, indicated by light blue dotted line)

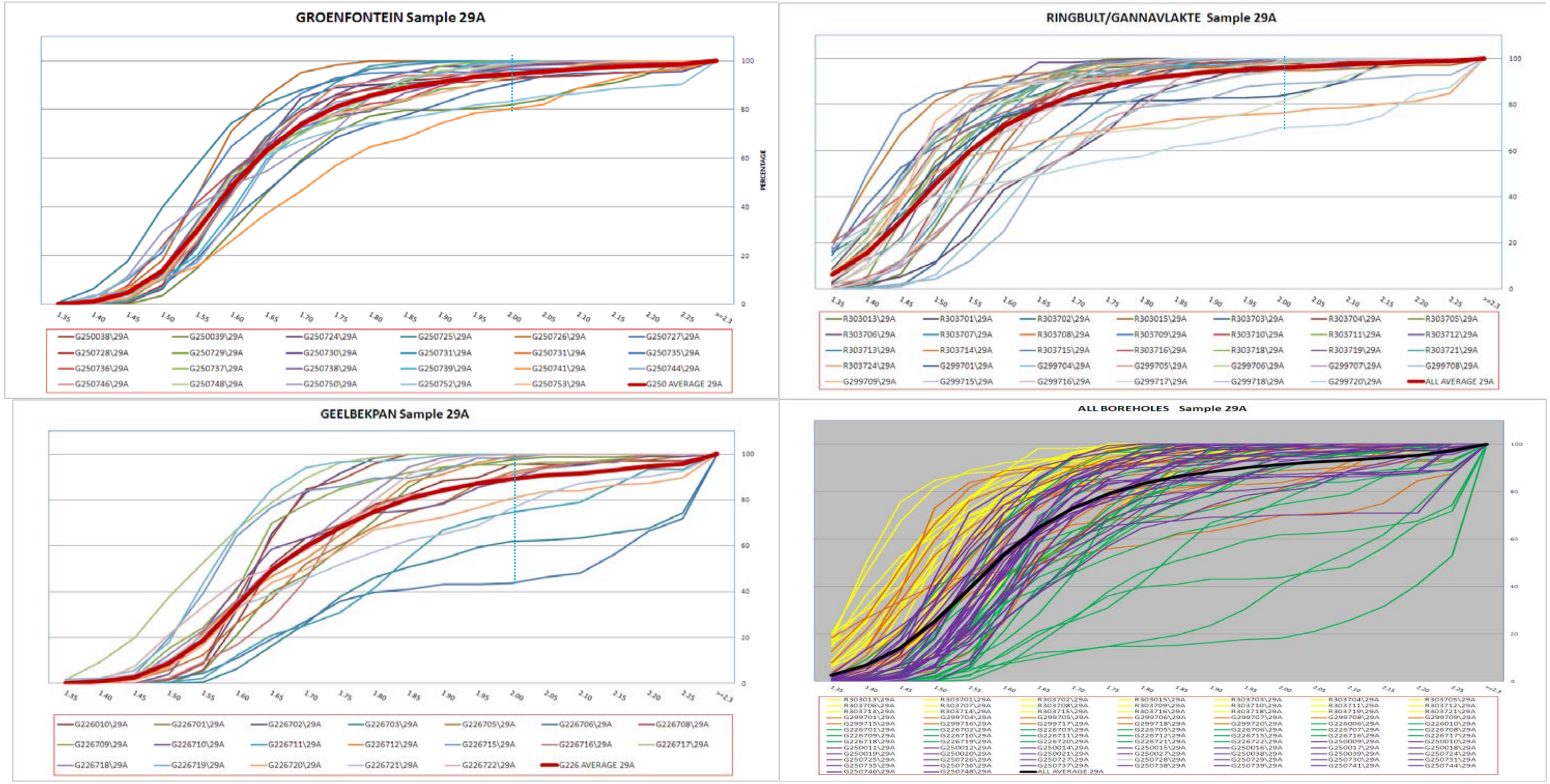


Figure 64 Combined GDCDD of Sample 29A (Spread at a Rd of 2.0, indicated by light blue dotted line)

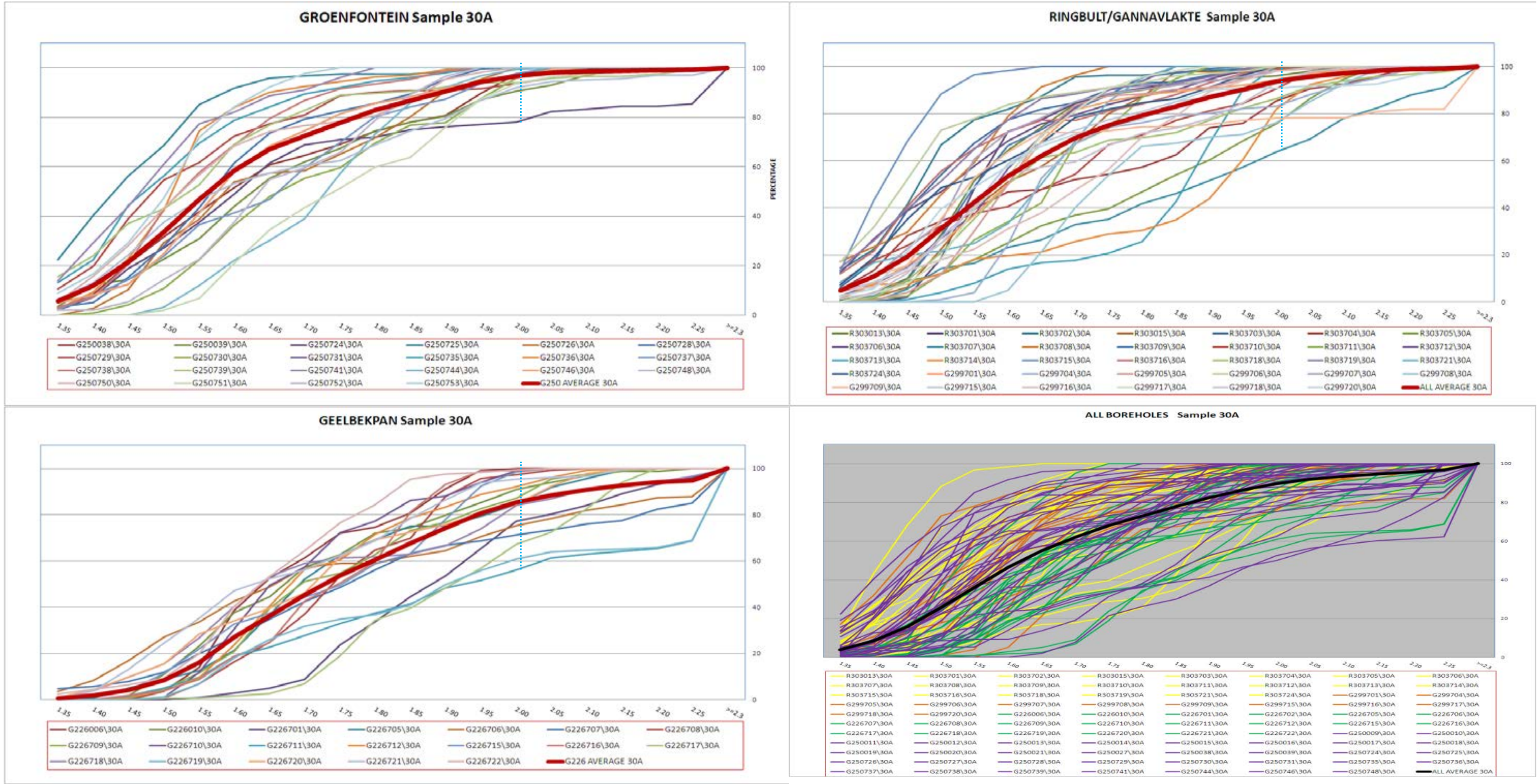


Figure 65 Combined GDCDD of Sample 30A (Spread at a Rd of 2.0, indicated by light blue dotted line)

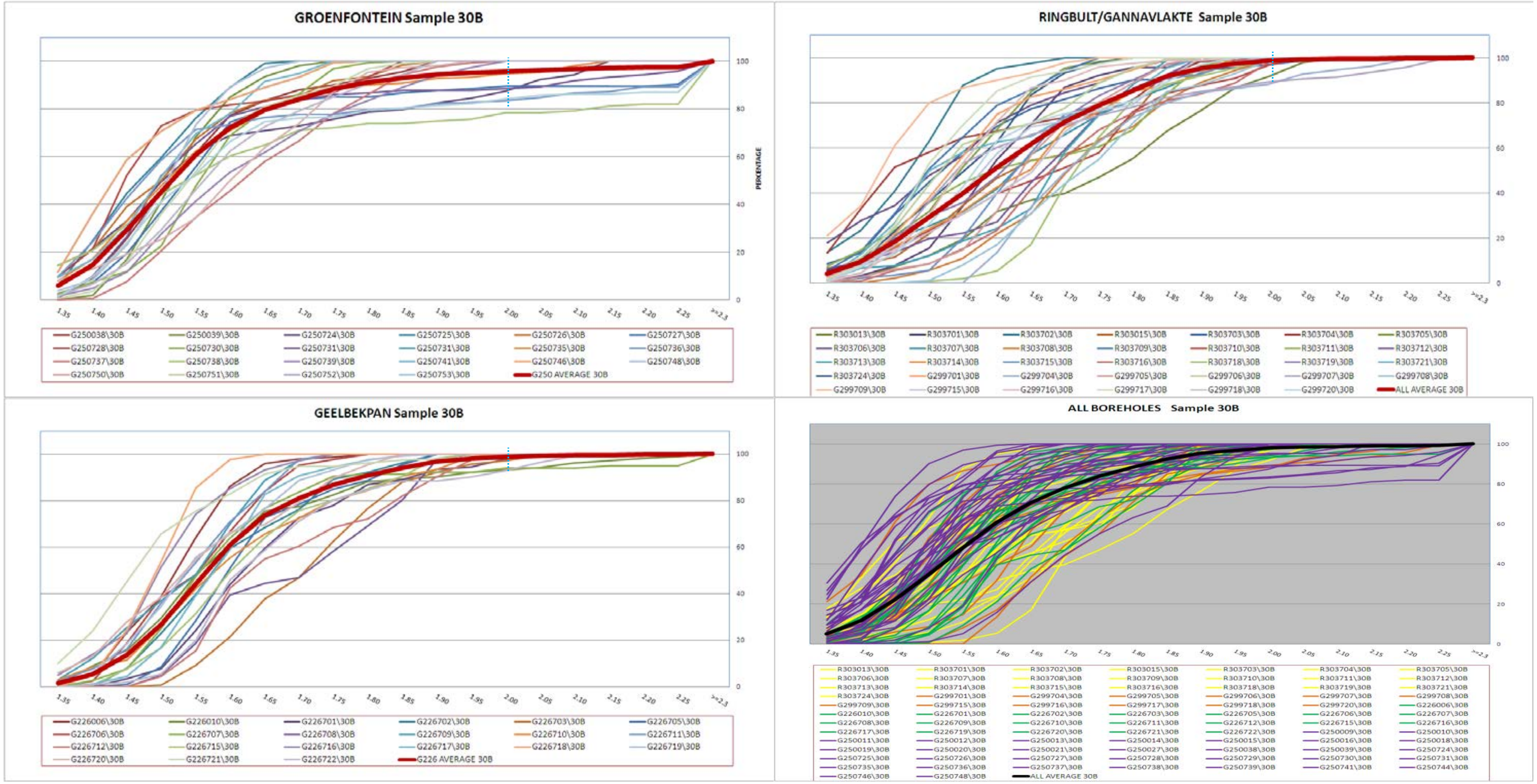


Figure 66 Combined GDCDD of Sample 30B (Spread at a Rd of 2.0, indicated by light blue dotted line)

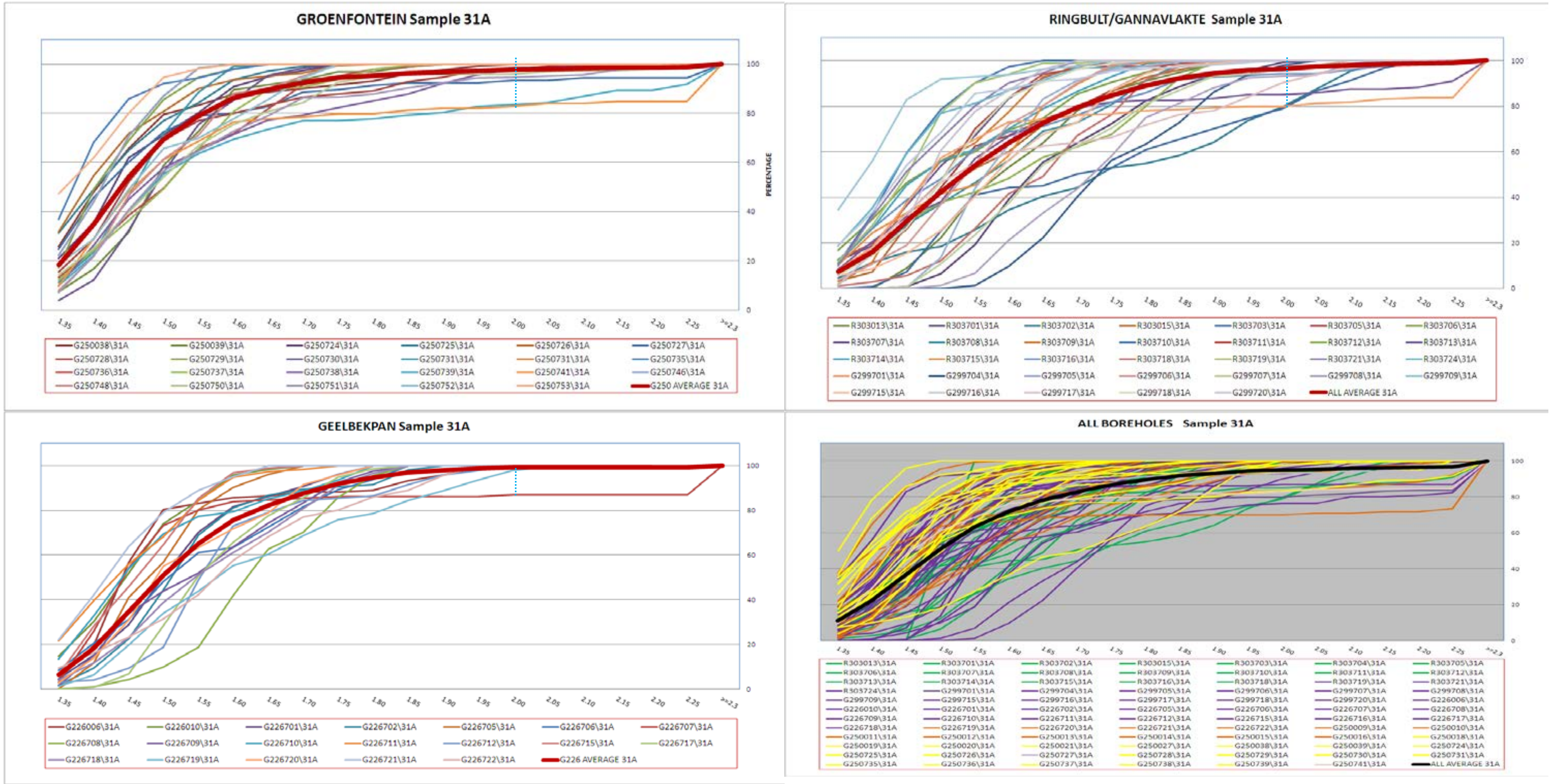


Figure 67 Combined GDCDD of Sample 31A (Spread at a Rd of 2.0, indicated by light blue dotted line)

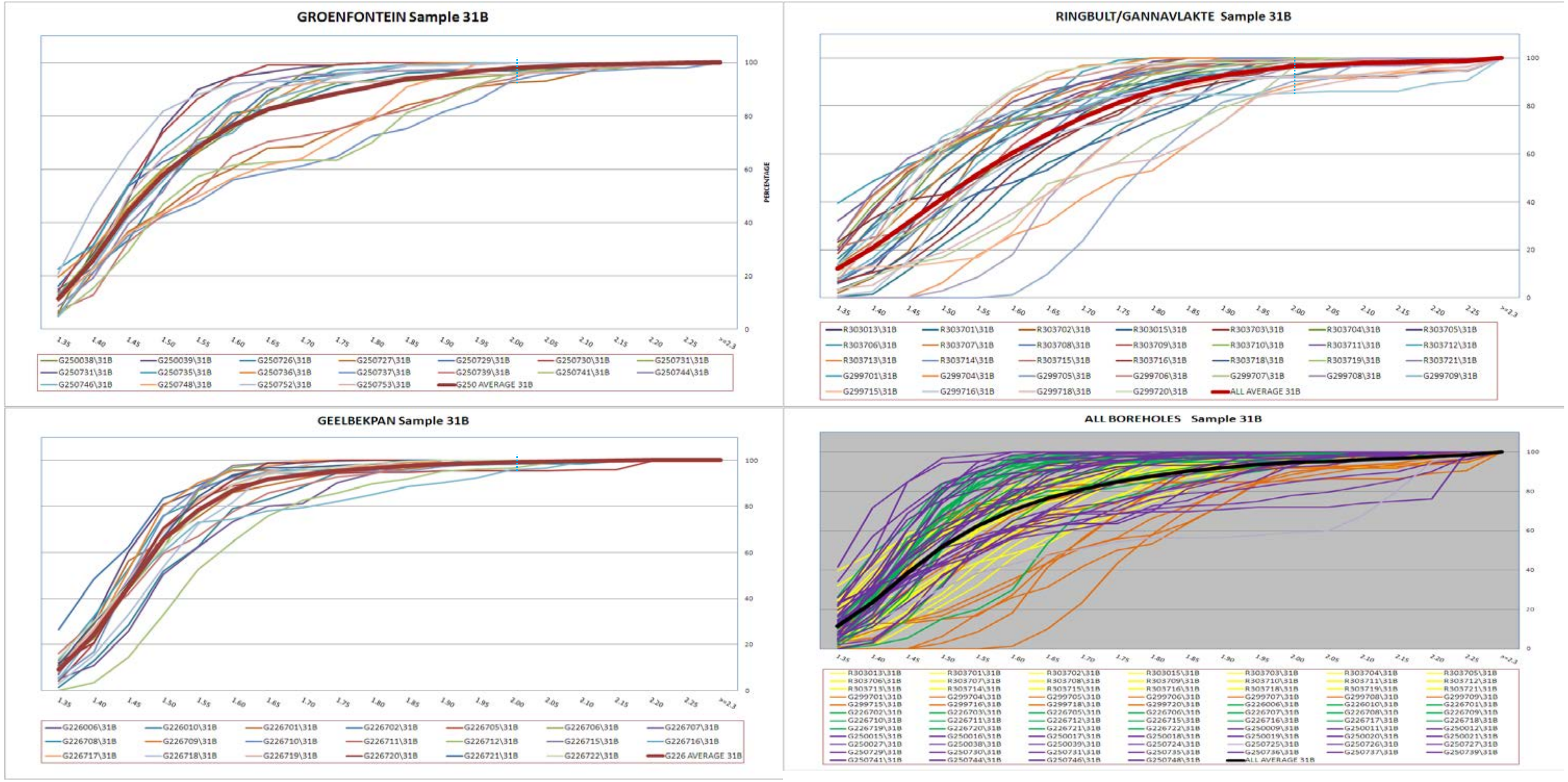


Figure 68 Combined GDCDD of Sample 31B (Spread at a Rd of 2.0, indicated by light blue dotted line)

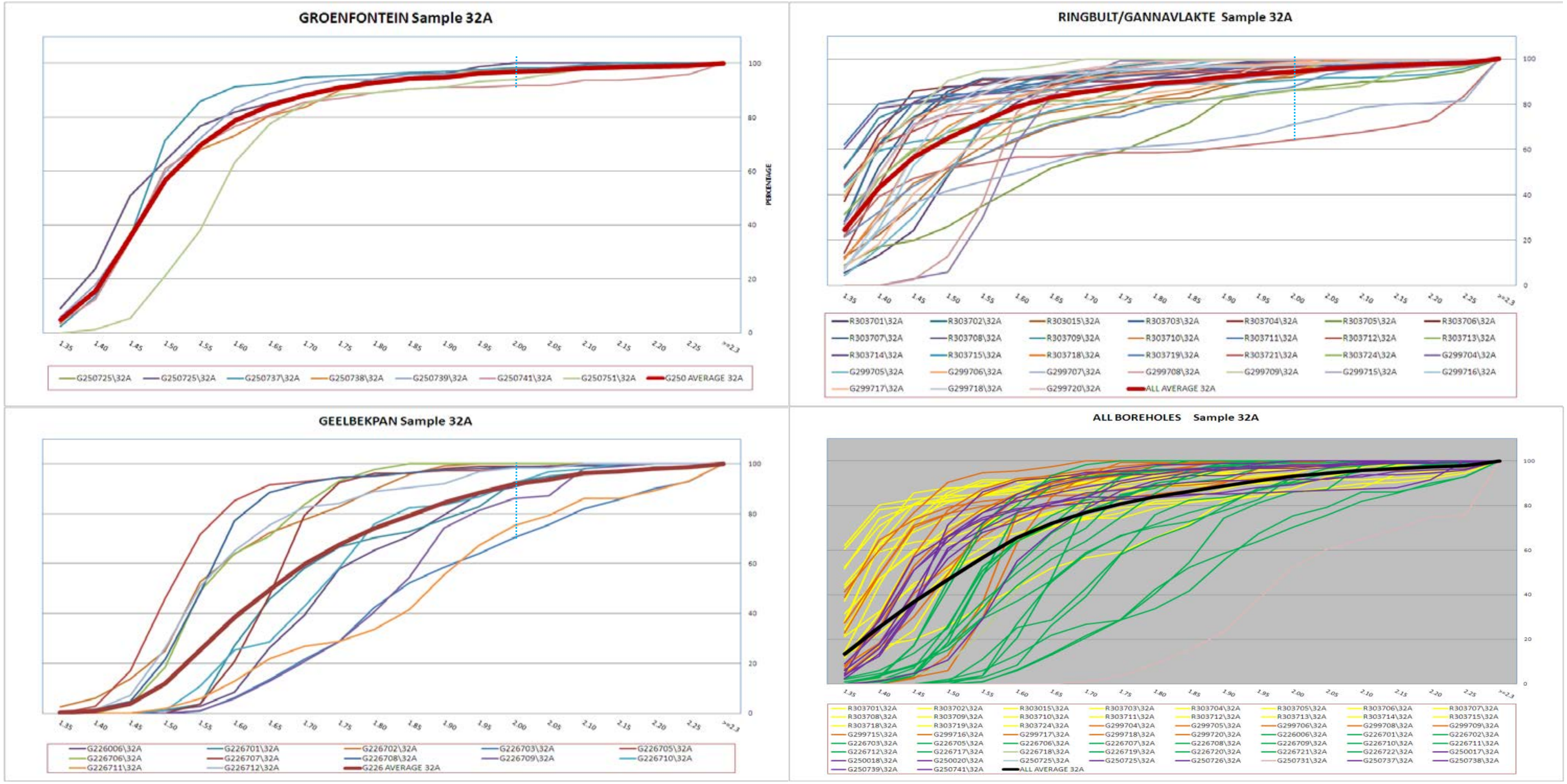


Figure 69 Combined GDCDD of Sample 32A (Spread at a Rd of 2.0, indicated by light blue dotted line)

Table 10 Summary of Sample 28A to Sample 32A data.

BASIC INFORMATION ABOUT SAMPLE 28A tot SAMPLE 32A DATA	**SUMMARY**	**GEELBEKPAN**	**GROENFONTEIN**	**RINGBULT**	**GANNAVLAKTE**
Angle of repose of graphs	Sample 28A	High	High	High	High
	Sample 29A	Med to high	High	High	High
	Sample 30A	Med to high	High	High	High
	Sample 30B	High	High	High	High
	Sample 31A	High	High	High	High
	Sample 31B	High	High	High	High
	Sample 32A	High	High	Med to high	Med to high
	The nature of the coals in these samples has changed to a mat coal, and these coals are low ash, high yield coals which is reflected in the GDCDD curves (Figure 140, Figure 141, Figure 142, Figure 143, Figure 144, Figure 145 and Figure 146). The lower curves in Sample 32A, for the south, are those reflected by the inclusion of interbedded sandstones in the samples.				
Start point of graphs at Rd 1.35	The graphs do not have a common starting point at the origin of the graph but it varies quite a lot and this is because of the varying quality of the coal in the samples				
Spread	Sample 28A and Sample 29A have a narrow spread for Groenfontein and the south, but the presence of interbedded sandstones makes the spread at Geelbekpan wider. Sample 30A has similar spreads for Geelbekpan				

	and the south of 35% - 45%. samples 30B, 31A and 31B have a narrow spread for all samples, while Sample 32A has a spread of 30% plus for Geelbekpan and the south. This narrow spread is indicative of the type of coals found in these samples.				
Yield at Rd 2.0 -Sample 28A	19.7% variance	71.2	85.7	89.6	90.9
Yield at Rd 2.0 - Sample 29A	21.6% variance	66.7	82.3	88.2	79.4
Yield at Rd 2.0 - Sample 30A	5.2% variance	78.5	82.6	79.4	83.7
Yield at Rd 2.0 -Sample 30B	9.0% variance	86.1	86.3	77.3	84.0
Yield at Rd 2.0 - Sample 31A	8.3% variance	89.2	87.2	89.7	81.4
Yield at Rd 2.0 - Sample 31B	17.0% variance	90.9	89.4	78.4	73.9
Yield at Rd 2.0 -Sample 32A	9.0% variance	80.4	87.1	89.4	85.1
Remarks- Yield	The largest variation in yield is found in Sample 29A and the highest yield in Sample 31B.				
Raw Rd Sample 28A	0.17 variance	1.76	1.66	1.60	1.59
Raw Rd Sample 29A	0.18 variance	1.77	1.70	1.59	1.67

<table>
<tr><td>Raw Rd Sample 30A</td><td>0.07 variance</td><td colspan="2">1.70</td><td colspan="2">1.67</td><td colspan="2">1.63</td><td colspan="2">1.64</td></tr>
<tr><td>Raw Rd Sample 30B</td><td>0.12 variance</td><td colspan="2">1.61</td><td colspan="2">1.61</td><td colspan="2">1.70</td><td colspan="2">1.73</td></tr>
<tr><td>Raw Rd Sample 31A</td><td>0.16 variance</td><td colspan="2">1.54</td><td colspan="2">1.53</td><td colspan="2">1.63</td><td colspan="2">1.69</td></tr>
<tr><td>Raw Rd Sample 31B</td><td>0.20 variance</td><td colspan="2">1.67</td><td colspan="2">1.53</td><td colspan="2">1.68</td><td colspan="2">1.73</td></tr>
<tr><td>Raw Rd Sample 32A</td><td>0.23 variance</td><td colspan="2">1.72</td><td colspan="2">1.60</td><td colspan="2">1.49</td><td colspan="2">1.58</td></tr>
<tr><td>Remarks on raw Rd</td><td colspan="9">The largest variance in yield occurs in Sample 32A and the smallest variance in raw Rd in Sample 30A.</td></tr>
<tr><td>Thickness Sample 28A</td><td>0.17 meter variance</td><td colspan="2">1.49</td><td colspan="2">1.50</td><td colspan="2">1.36</td><td colspan="2">1.33</td></tr>
<tr><td>Thickness Sample 29A</td><td>0.57 meter variance</td><td colspan="2">1.65</td><td colspan="2">1.51</td><td colspan="2">1.38</td><td colspan="2">1.08</td></tr>
<tr><td>Thickness Sample 30A</td><td>0.15 meter variance</td><td colspan="2">1.33</td><td colspan="2">1.29</td><td colspan="2">1.20</td><td colspan="2">1.35</td></tr>
<tr><td>Thickness Sample 30B</td><td>0.11 meter variance</td><td colspan="2">1.31</td><td colspan="2">1.36</td><td colspan="2">1.25</td><td colspan="2">1.36</td></tr>
<tr><td>Thickness Sample 31A</td><td>0.18 meter variance</td><td colspan="2">1.34</td><td colspan="2">1.36</td><td colspan="2">1.15</td><td colspan="2">1.18</td></tr>
<tr><td>Thickness Sample 31B</td><td>0.13 meter variance</td><td colspan="2">1.31</td><td colspan="2">1.32</td><td colspan="2">1.29</td><td colspan="2">1.19</td></tr>
<tr><td>Thickness Sample 32A</td><td>0.51 meter variance</td><td colspan="2">1.30</td><td colspan="2">1.53</td><td colspan="2">1.53</td><td colspan="2">1.81</td></tr>
<tr><td>Remarks on thickness</td><td colspan="9">The largest variance in thickness occurs in Sample 29A and the smallest variance in Sample 31B. Sample 32A has a scattered occurrence, in particularly on Groenfontein, but does not occur over a large area. Geelbekpan’s Sample 32A also has a variable thickness as depicted in Figure 150.
The σ value increases to the south on the right of the figure when interbedded sandstone begins to play a role in the subdivision of the samples.</td></tr>
<tr><td rowspan="2">-Standard deviation at a Rd of 1.60 and 2.0</td><td>Relative density</td><td>1.6</td><td>2.0</td><td>1.6</td><td>2.0</td><td>1.6</td><td>2.0</td><td>1.6</td><td>2.0</td></tr>
<tr><td>Sample 28A</td><td>24.4</td><td>26.1</td><td>20.7</td><td>18.8</td><td>17.9</td><td>3.1</td><td>25.9</td><td>2.1</td></tr>
</table>

	Sample 29A	18.7	23.5	17.3	15.0	12.7	5.2	20.3	9.4
	Sample 30A	15.8	17.5	23.3	13.4	23.2	9.9	21.4	8.5
	Sample 30B	18.0	2.4	17.9	6.1	21.8	1.9	25.2	4.3
	Sample 31A	22.6	19.7	20.3	17.4	19.7	6.7	27.0	6.2
	Sample 31B	15.3	2.0	19.3	14.8	11.7	8.2	28.5	10.3
	Sample 32A	26.3	8.9	35.4	29.6	13.5	8.3	13.5	8.5
Comments on standard deviation	The σ value in the north and central areas are generally higher than in the south. The lowest σ per sample is found in Sample 30B. The bar chart in Figure 147 shows that Geelbekpan and Groenfontein, in general, have a higher σ value than the other two sampled areas and that the Volksrust Formation has a higher σ value that that of the Vryheid Formation.								
Correlation accuracy by geologist	Care will have to be taken when correlating Sample 28A to Sample 32B due to the presence of interbedded sandstones in certain areas (Figure 148 and Figure 149).								
Modelling accuracy	Care must be taken when modelling these samples, as there is some variation on a per sample basis.								
Use as SANS 10320 data correlation point	Care must be taken when correlating these samples, as there is some variation on a per sample basis.								

Table 11 Standard deviation calculated at two RDs from the GCCD data for Sample 28A to Sample 32A.

VOLKSRUST FORMATION															
Farm															
	GEELBEKPAN			GROENFONTEIN			GANNAVLAKTE			RINGBULT			TOTAL		
Sample	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**	**1.6**	**2.0**	**Avg**
28A	24.4	26.1	25.3	20.7	18.8	19.7	25.9	2.1	14.0	17.9	3.1	10.5	22.2	12.5	17.4
29A	18.7	23.5	21.1	17.3	15.0	16.2	20.3	9.4	14.9	12.7	5.2	8.9	17.2	13.3	15.3
30A	15.8	17.5	16.6	23.3	13.4	18.3	21.4	8.5	14.9	23.2	9.9	16.5	20.9	12.3	16.6
30B	18.0	2.4	10.2	17.9	6.1	12.0	25.2	4.3	14.8	21.8	1.9	11.9	20.7	3.7	12.2
31A	22.6	19.7	21.2	20.3	17.4	18.9	27.0	6.2	16.6	19.7	6.7	13.2	22.4	12.5	17.4
31B	15.3	2.0	8.7	19.3	14.8	17.1	28.5	10.3	19.4	11.7	8.2	9.9	18.7	8.8	13.8
32A	26.3	8.9	16.6	35.4	29.6	32.5	13.5	8.5	11.0	13.5	8.3	10.9	22.2	13.8	18.0
Avg	**20.2**	**14.3**	**17.1**	**22.0**	**16.4**	**19.2**	**23.1**	**7.0**	**15.1**	**17.2**	**6.2**	**11.7**	**20.6**	**11.0**	**15.8**

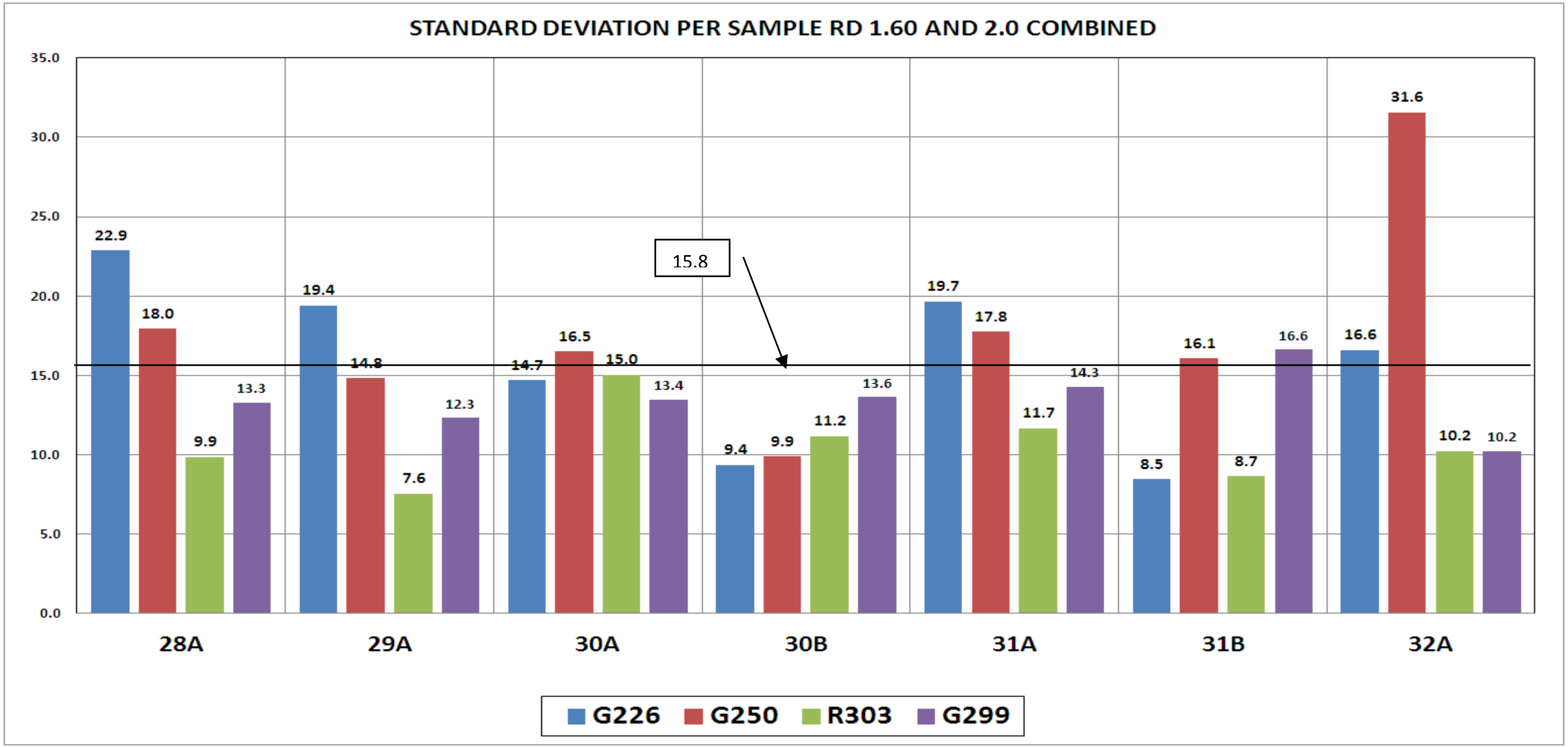


Figure 70 Standard deviation bar graph at a Rd of 1.6 and 2.0, combined and averaged, for Sample 28A to Sample 32B

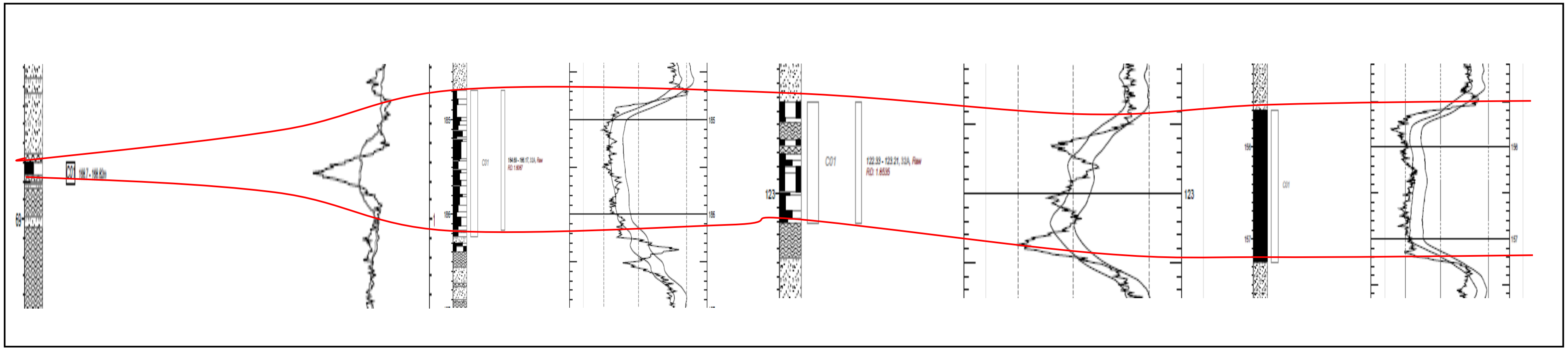


Figure 71 Profile on Geelbekpan for Sample 32A, illustrating variability. Boreholes in no specific order

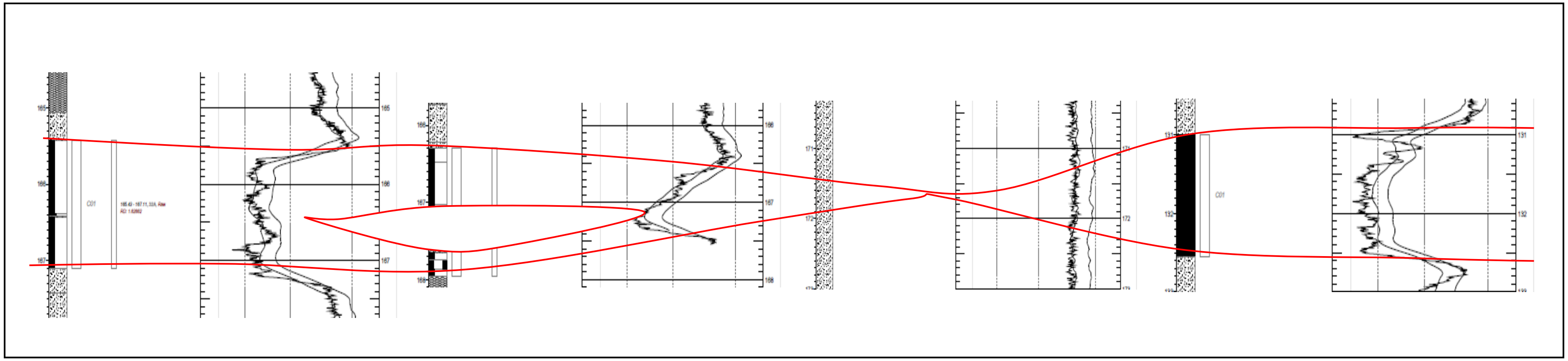


Figure 72 Profile on Groenfontein for Sample 32A, illustrating variability. Boreholes in no specific order

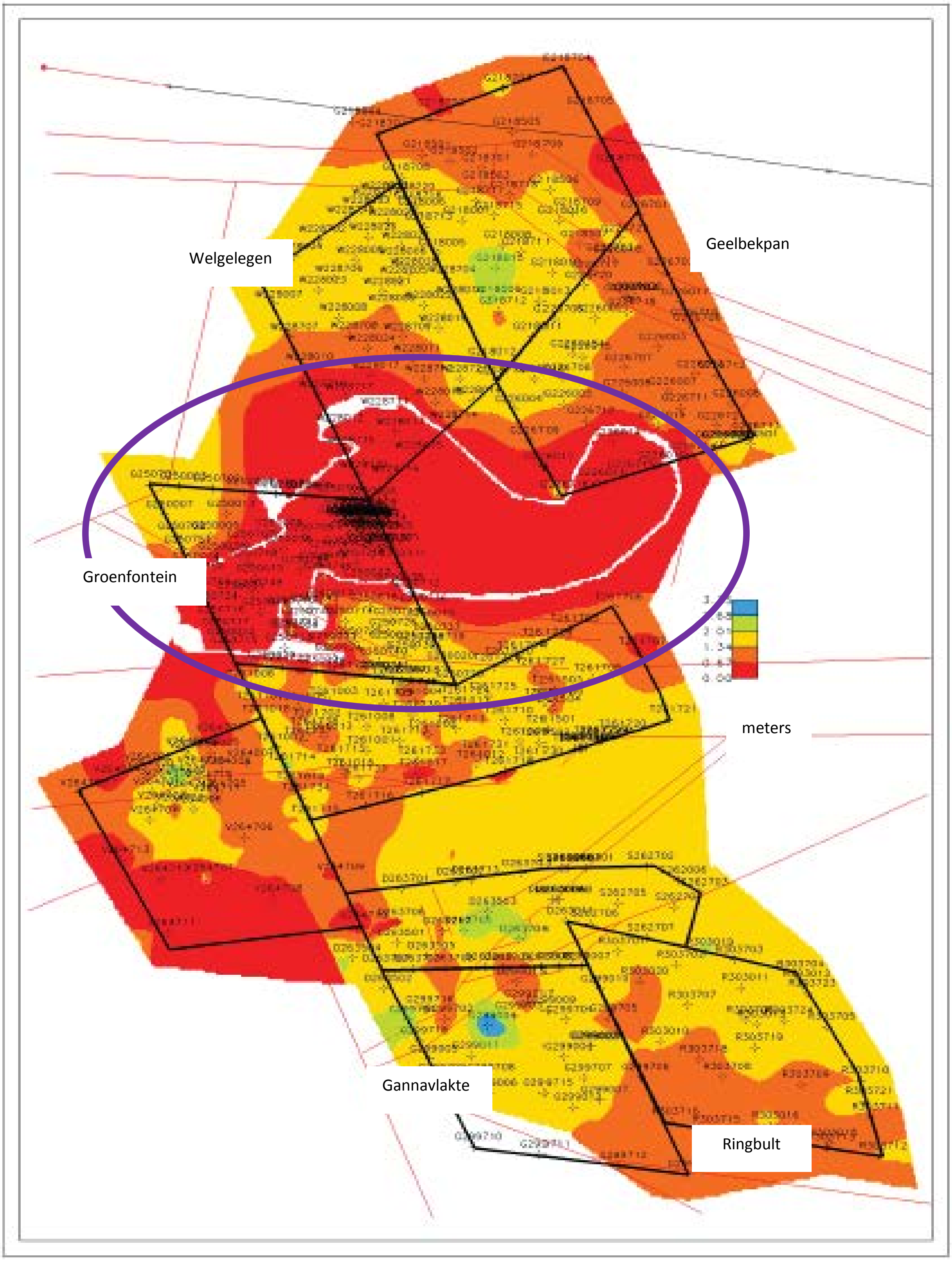


Figure 73 The lateral thickness variation of Sample 32A over the Study area. The purple oval is a function of the modelling package and does not denote anything in particular

Coal Zone 10

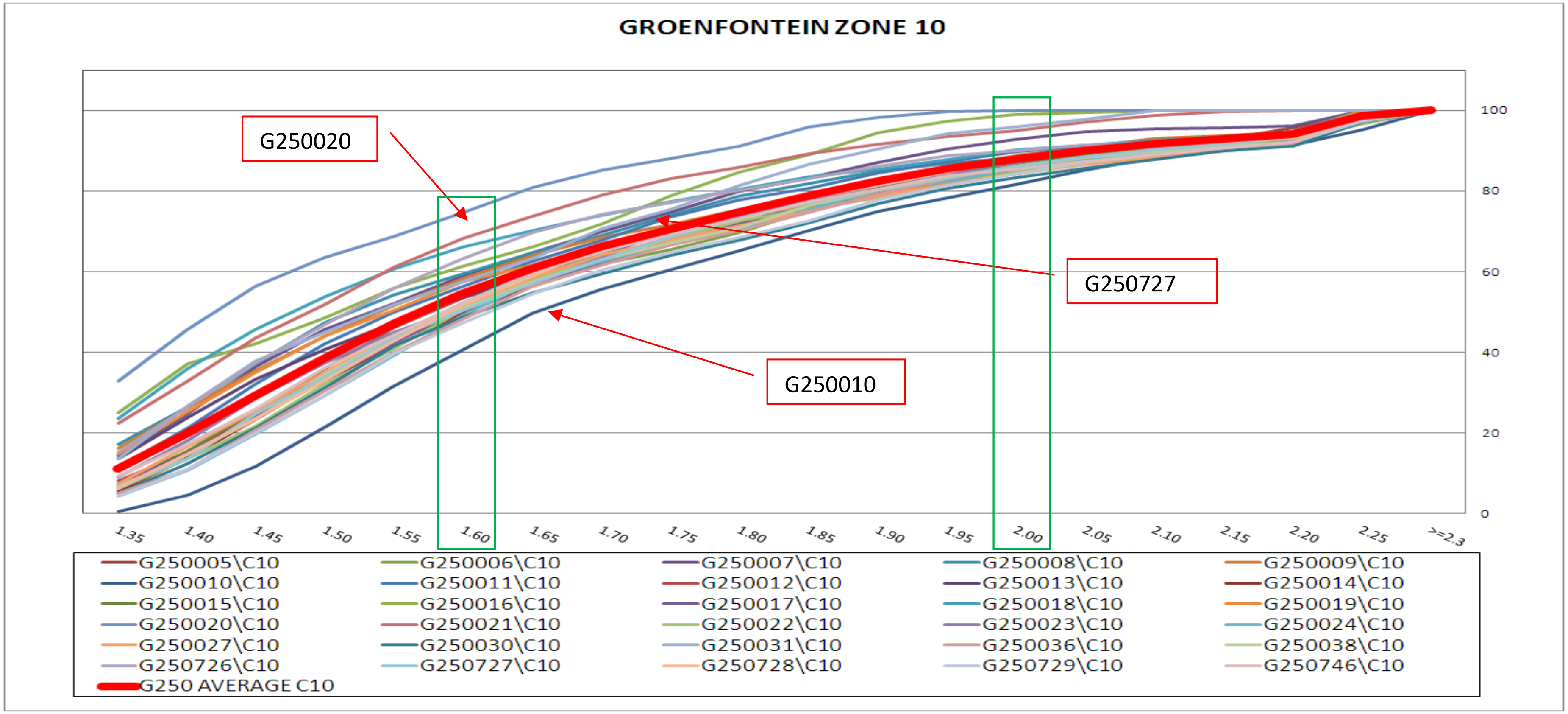
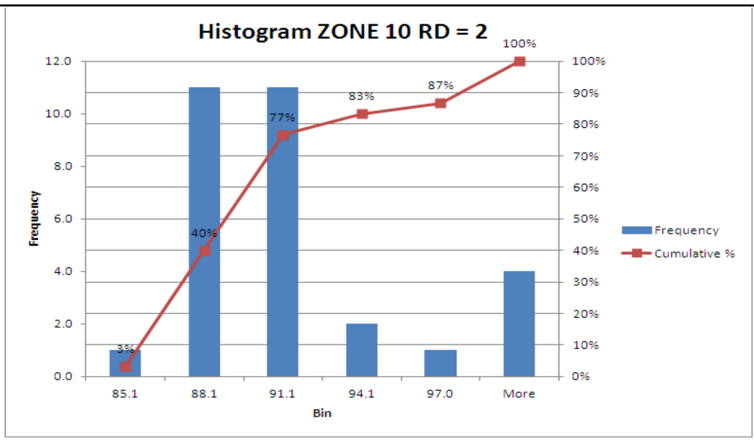


Figure 74 Combined GDCDD of Zone 10

The high values (upper line in the graph) in Figure 151 are represented by G250020, in which the upper coal zones have been eroded away (Figure 153).

RD= 2	Frequency	Cumulative %
85.1	1.0	3%
88.1	11.0	40%
91.1	11.0	77%
94.1	2.0	83%
97.0	1.0	87%
More	4.0	100%

RD= 2				
Mean	89.9			
Standard Error	0.7			
Median	88.6			
Standard Deviation	4.0			
Sample Variance	16.0			
Kurtosis	1.1			
Skewness	1.4			
Range	14.9			
Minimum	85.1	>	81.94	-2σ
Maximum	100.0	>	97.9	+ 2σ
Sum	2698.2			
Count	30			
Confidence Level(95.0%)	1.494			



RD= 1.6	Frequency	Cumulative %
40.8	1.0	3%
47.6	1.0	7%
54.3	17.0	63%
61.1	6.0	83%
67.9	3.0	93%
More	2.0	100%

RD= 1.6				
Mean	54.5			
Standard Error	1.3			
Median	52.1			
Standard Deviation	7.0			
Sample Variance	49.4			
Kurtosis	1.4			
Skewness	1.0			
Range	33.9			
Minimum	41	>	40.48	-2σ
Maximum	74.67	>	68.6	+ 2σ
Sum	1636			
Count	30.00			
Confidence Level(95.0%)	2.625			

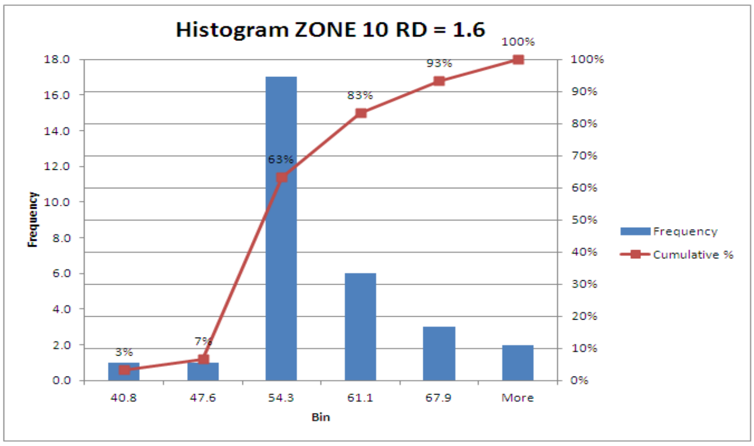


Figure 75 Statistics at a Rd of 2 and 1.6 of the GDCDD's of Zone 11 at Groenfontein. Plus and minus two standard deviations in yellow blocks

In Figure 152, the data in the yellow blocks, for 2σ, indicates that for a Rd of 2, the minimum value is outside 2σ and the maximum value is outside the 2σ. This would suggest that the lower value fall outside 2σ, which is a wide spacing, but that the maximum value fall outside the 2σ which also illustrates a wide distribution. The same is true for the RD 1.6 value. This is a result of erosion and that more of the lower part of coal Zone 11 is preserved over Welgelegen. The central curves (Figure 151) are closely spaced and the upper and lower curves are spaced more widely apart. There is some variability in the lithotypes.

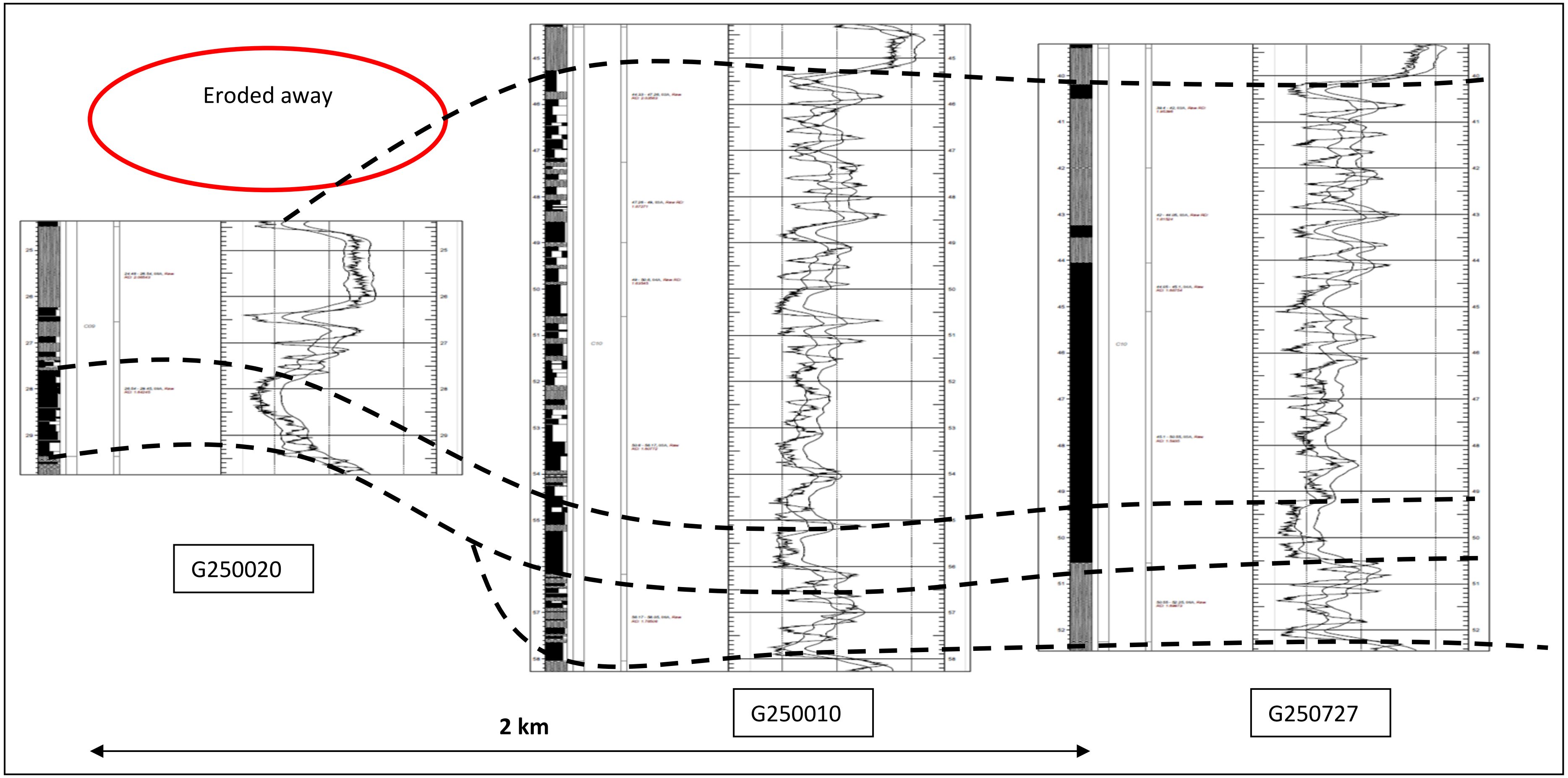


Figure 76 Zone 10 geological profile below illustrating why low, high and average values occur in the GDCDD diagram

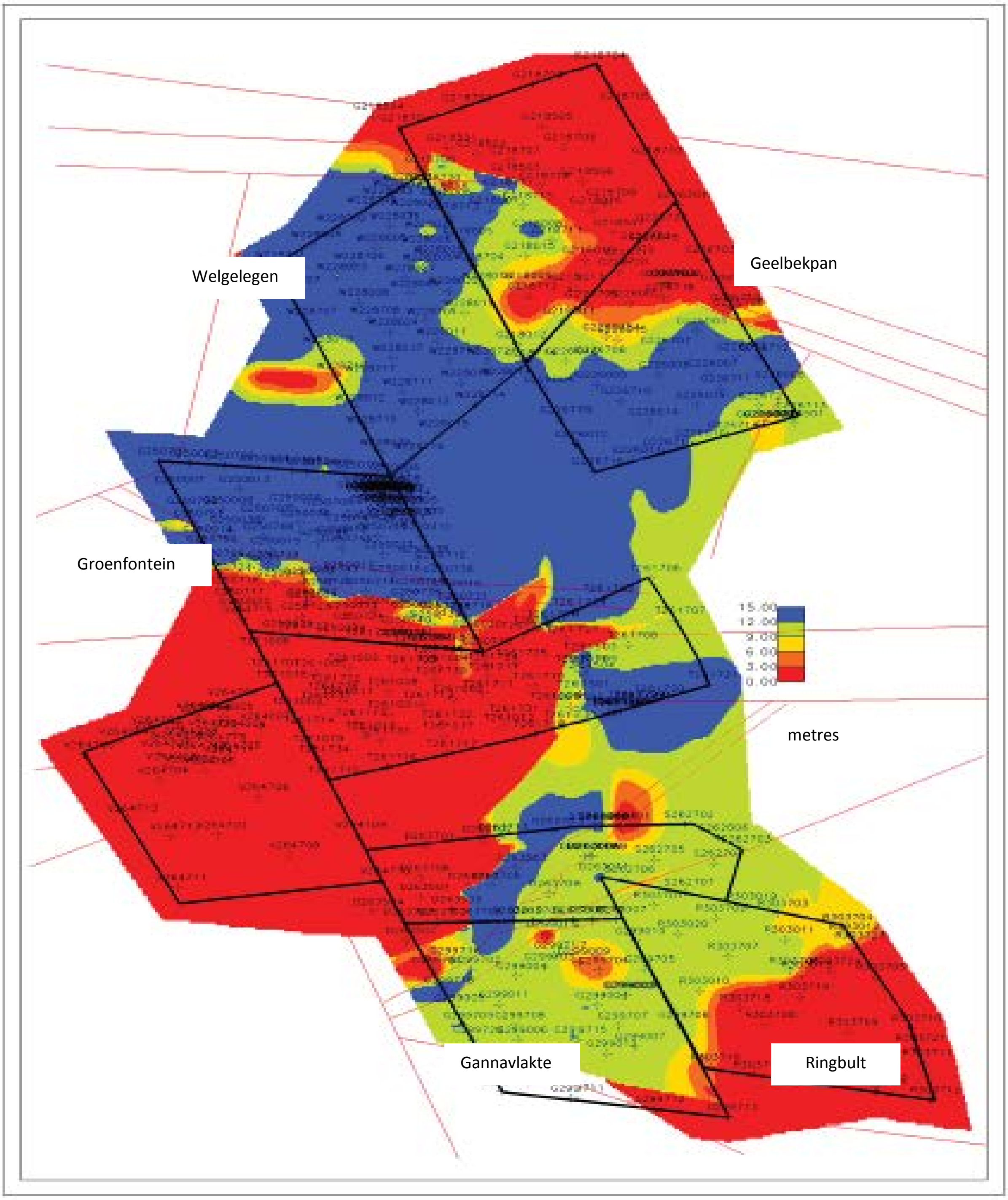


Figure 77 The lateral thickness variation of Zone 10 over the Study area

Zone 10 is the thickest on Groenfontein and Welgelegen (Figure 154).

Coal Zone 09

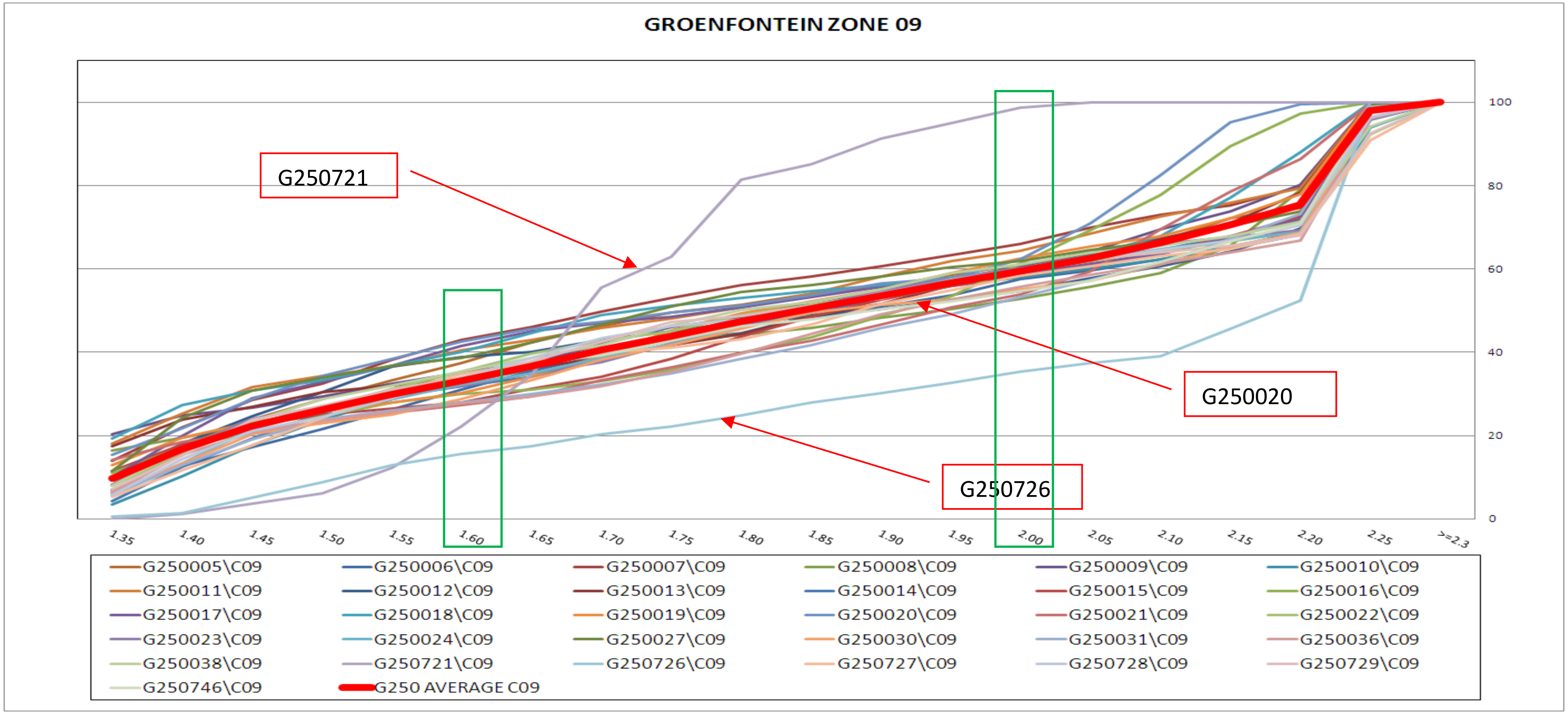


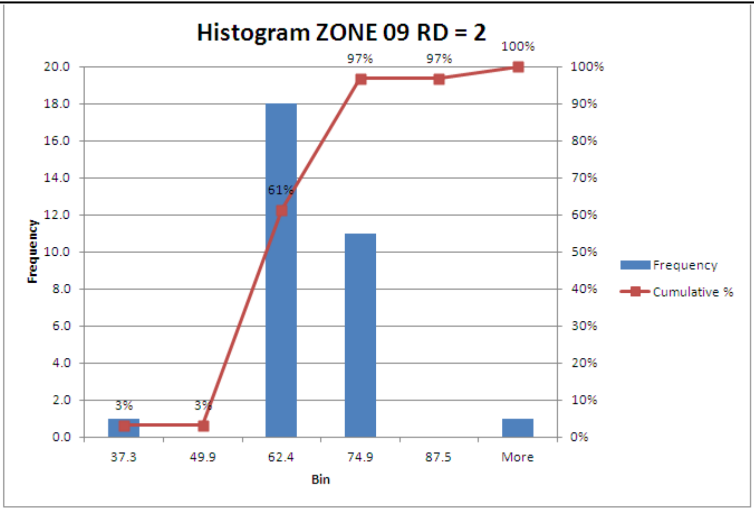
Figure 78 Combined GDCDD of Zone 09

The GDCDD of coal Zone 09 is illustrated in Figure 155. This figure illustrates that two boreholes (G250721 and G250726) are far removed from the other graphs. In the case of G250721, the top of coal Zone 09 has been weathered away (Figure 157). Using only the lower part of the coal zone leads to an erroneous interpretation of coal Zone 09 as an entity. G250020 has thick sandstone developed in Sample 09A and the total thickness of coal Zone 09 for this borehole is 5,5 m compared to a normal 3,5 m for the coal zone (as represented by borehole G250726) (Figure 157).

In Figure 156, the data in the yellow blocks, for 2σ, indicates that for a Rd of 2, the minimum value is inside 2σ and the maximum value is outside 2σ. This would suggest that the lower values fall inside 2σ, which is a narrow spacing, but that the maximum values fall outside 2σ which also illustrates a wide distribution. For a Rd of 1.6, both the minimum and maximum value are inside 2σ. This would suggest that there is a narrow spacing between the individual line graphs. Figure 156 illustrates that the few outlying data points does not influence the statistical result too much at a Rd 1.6, but at a Rd of 2 it has an impact. The lithotypes are reasonably constant throughout coal Zone 09.

RD= 2	Frequency	Cumulative %
37.3	1.0	3%
49.9	0.0	3%
62.4	18.0	61%
74.9	11.0	97%
87.5	0.0	97%
More	1.0	100%

RD= 2				
Mean	62.6			
Standard Error	1.6			
Median	62.2			
Standard Deviation	8.9			
Sample Variance	79.5			
Kurtosis	11.4			
Skewness	1.8			
Range	62.7			
Minimum	37.3	<	44.80	-2σ
Maximum	100.0	>	80.5	+ 2σ
Sum	2004.2			
Count	32			
Confidence Level(95.0%)	3.22			



RD= 1.6	Frequency	Cumulative %
15.7	1.0	3%
21.1	0.0	3%
26.6	1.0	6%
32.1	10.0	39%
37.5	12.0	77%
More	7.0	100%

RD= 1.6				
Mean	33.2			
Standard Error	1.1			
Median	33.7			
Standard Deviation	5.9			
Sample Variance	34.8			
Kurtosis	1.4			
Skewness	-0.7			
Range	27.3			
Minimum	15.7	<	21.39	-2σ
Maximum	43.0	<	45.0	+ 2σ
Sum	1029			
Count	31.00			
Confidence Level(95.0%)	2.16			

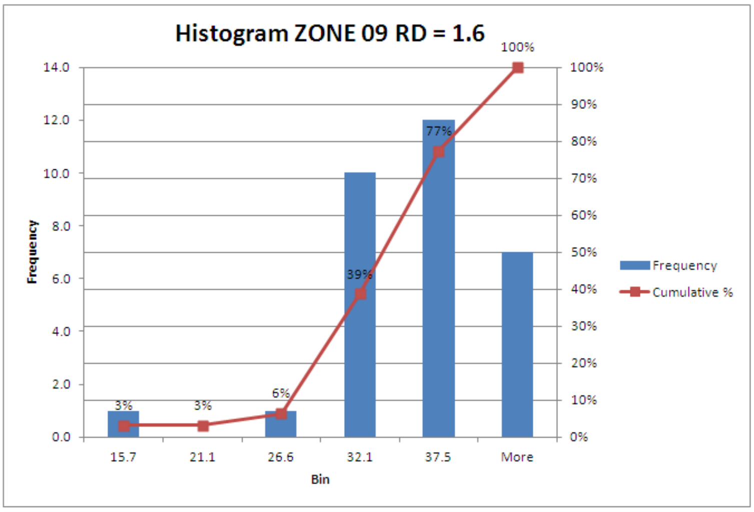


Figure 79 Statistics at a Rd of 2 and 1.6 of the GDCDD's of Zone 09 at Groenfontein. Plus and minus two standard deviations in yellow blocks

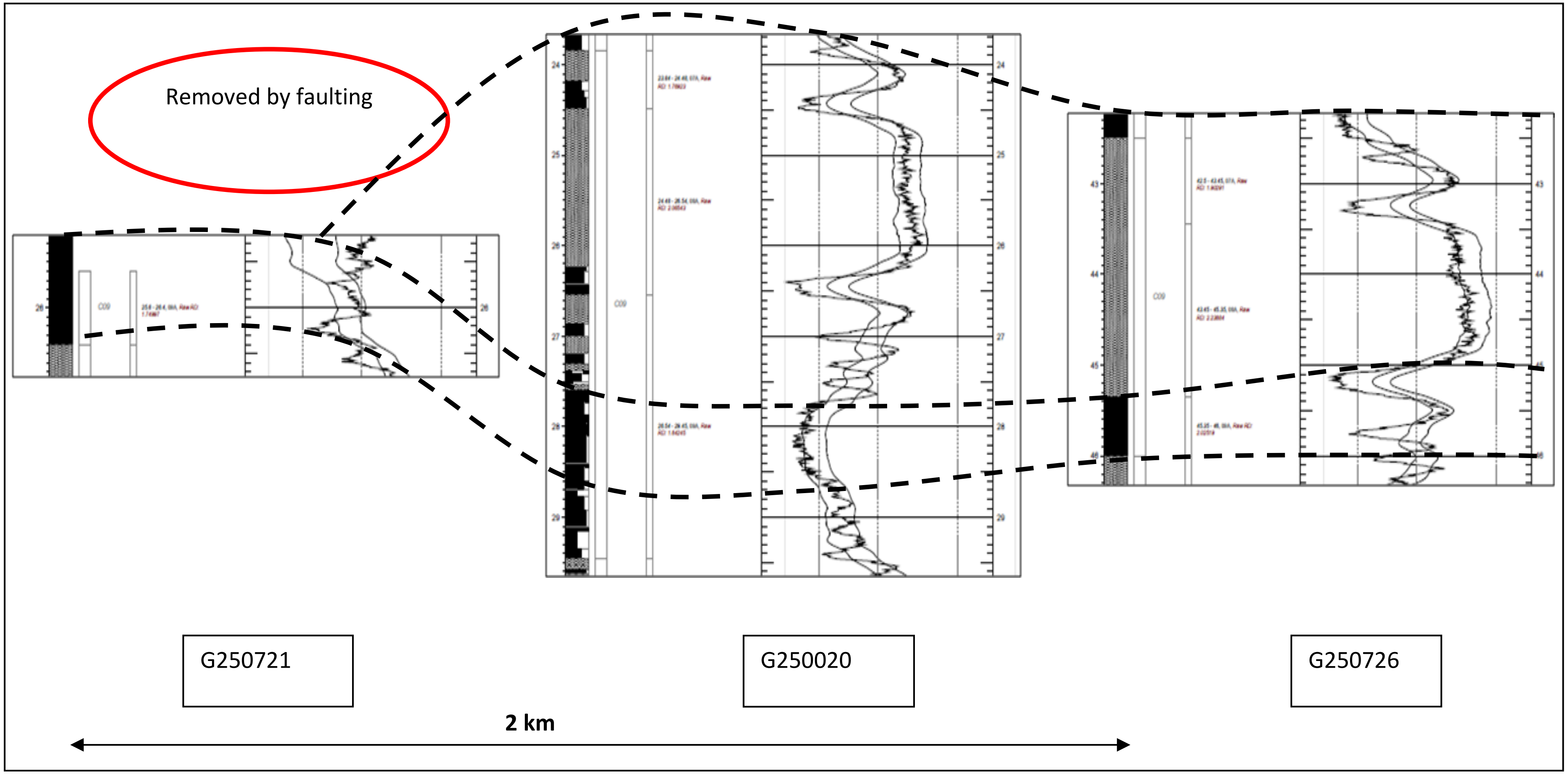


Figure 80 Zone 09 geological profile illustrates why low, high and average values occurs in the GDCDD diagram

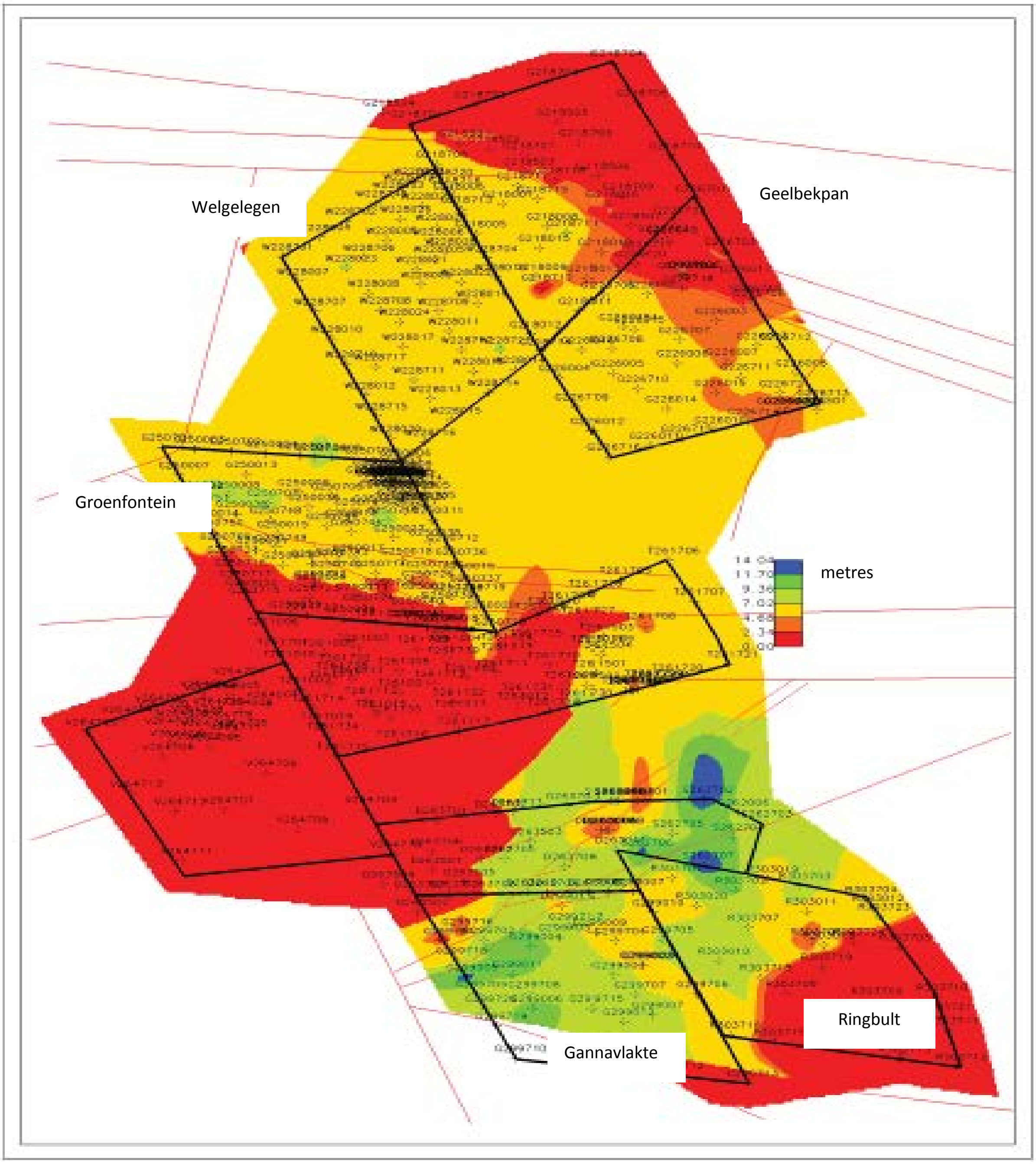


Figure 81 The lateral thickness variation of Zone 09 over the Study area

Zone 09 is the thickest developed over Gannavlakte and Ringbult (Figure 158).

Coal Zone 08

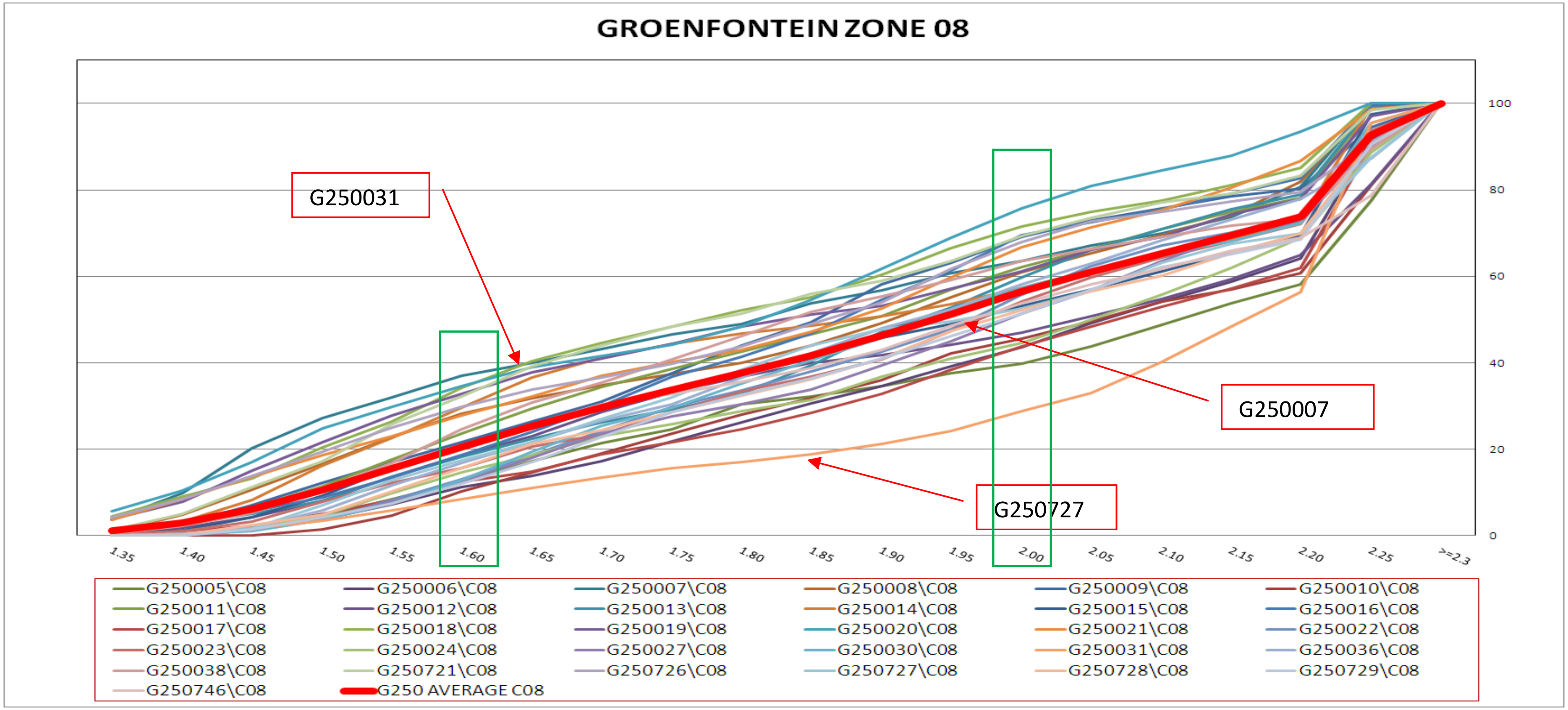
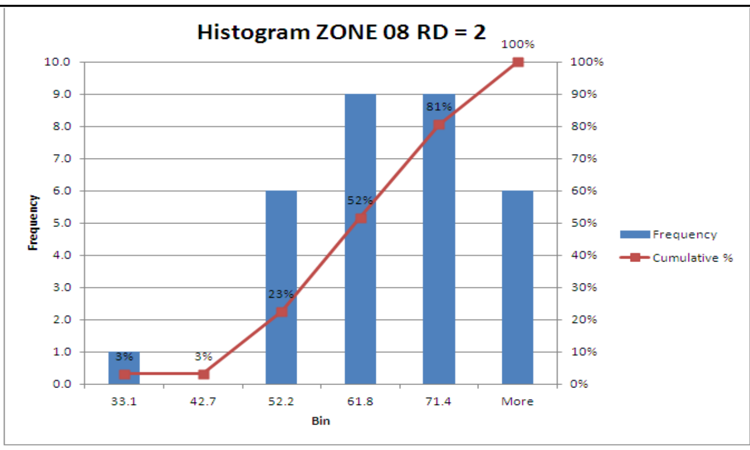


Figure 82 Combined GDCDD of Zone 08

RD= 2	Frequency	Cumulative %
33.1	1.0	3%
42.7	0.0	3%
52.2	6.0	23%
61.8	9.0	52%
71.4	9.0	81%
More	6.0	100%

RD= 2				
Mean	61.0			
Standard Error	1.9			
Median	61.3			
Standard Deviation	10.4			
Sample Variance	109.1			
Kurtosis	0.4			
Skewness	-0.5			
Range	47.9			
Minimum	33.1	<	40.10	-2σ
Maximum	81.0	<	81.9	+ 2σ
Sum	1890.9			
Count	31			
Confidence Level(95.0%)	3.83			



RD= 1.6	Frequency	Cumulative %
8.5	1.0	3%
14.2	8.0	29%
19.9	8.0	55%
25.6	5.0	71%
31.3	4.0	84%
More	5.0	100%

RD= 1.6				
Mean	20.6			
Standard Error	1.5			
Median	18.6			
Standard Deviation	8.3			
Sample Variance	69.6			
Kurtosis	-1.0			
Skewness	0.5			
Range	28.5			
Minimum	8.5	>	3.90	-2σ
Maximum	37.0	<	37.3	+ 2σ
Sum	638			
Count	31.00			
Confidence Level(95.0%)	3.06			

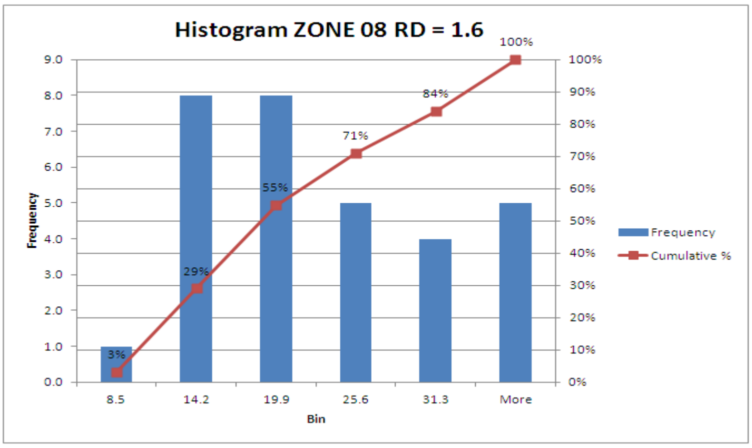


Figure 83 Statistics at a Rd of 2 and 1.6 of the GDCDD's of Zone 08 at Groenfontein. Plus and minus two standard deviations in yellow blocks

In Figure 160, the data in the yellow blocks, for 2σ, indicates that for a Rd of 2, the minimum and maximum value are inside 2σ. This would suggest a narrow spacing for the σ value. For the Rd 1.6 values, the minimum value is outside 2σ and the maximum value is just inside 2σ. This would suggest that the lower values have a wider spacing, but that the maximum values fall inside 2σ, which also illustrates a narrow distribution. All this evidence suggests that there is a wider spacing between the individual line graphs. Figure 160 illustrates that the one or two outliers do not influence the statistical result too much at a Rd of 1.6, but at a Rd of 2.0, it has an impact. The lithotypes in this Zone vary to some extent.

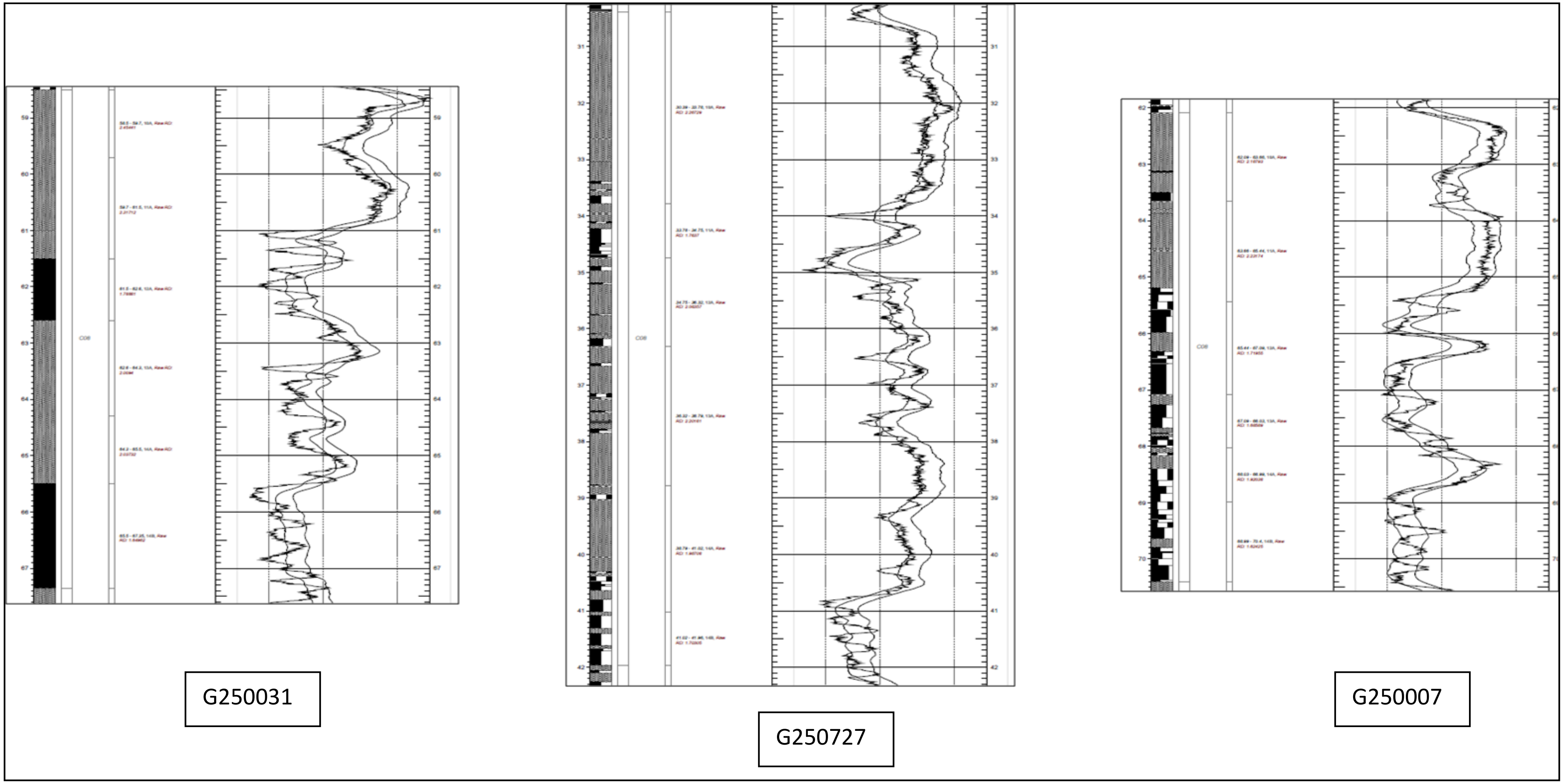


Figure 84 Zone 08 geological profile illustrates why low, high and average values occur in the GDCDD diagram)

G250727 has a thick coal zone, Zone 08, with thick sandstone near the top (Figure 161) leading to low GDCDD values (Figure 159)

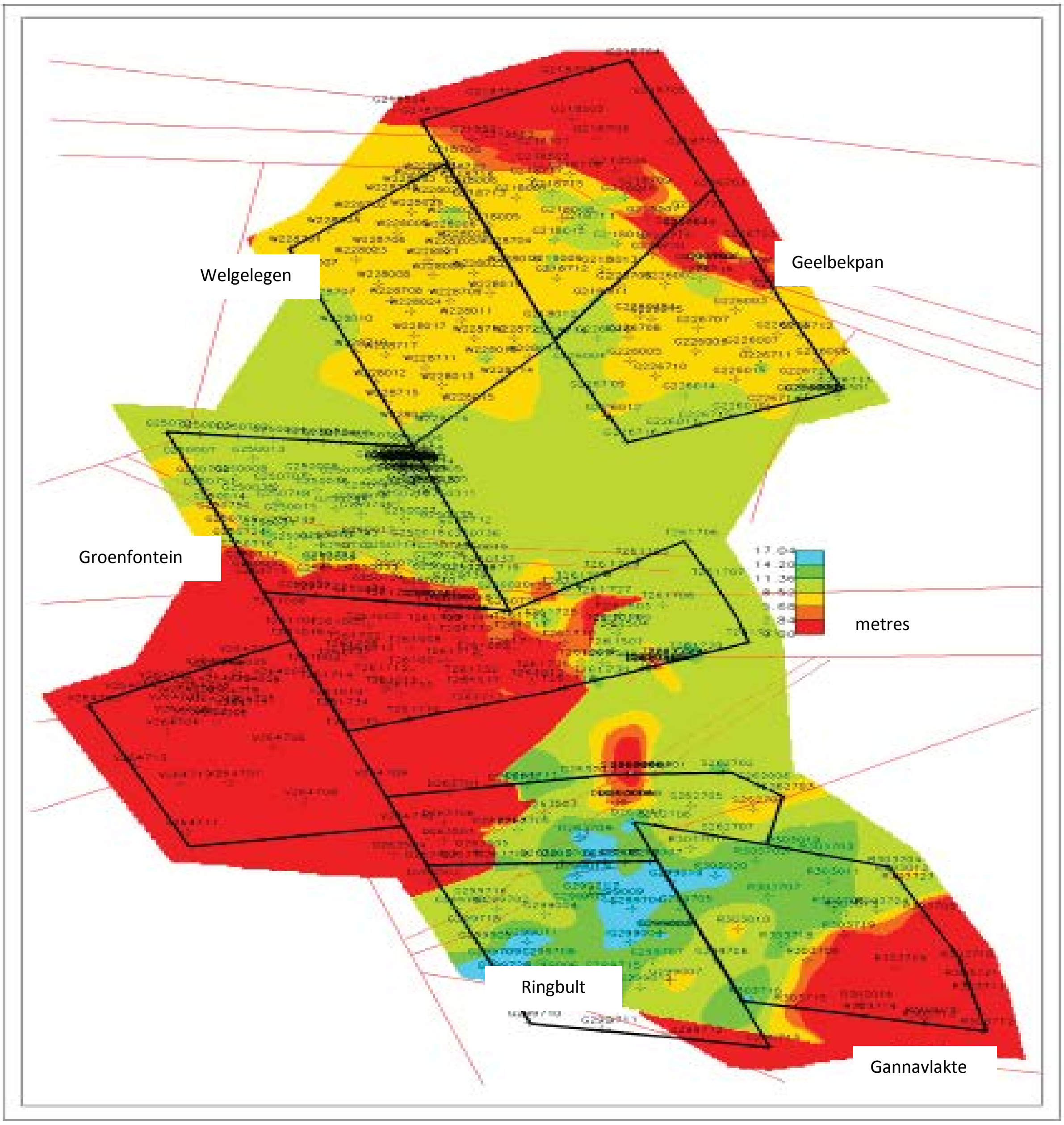


Figure 85 The lateral thickness variation of Zone 08 over the Study area

Zone 08 is the thickest developed over Gannavlakte (Figure 162).

Coal Zone 07

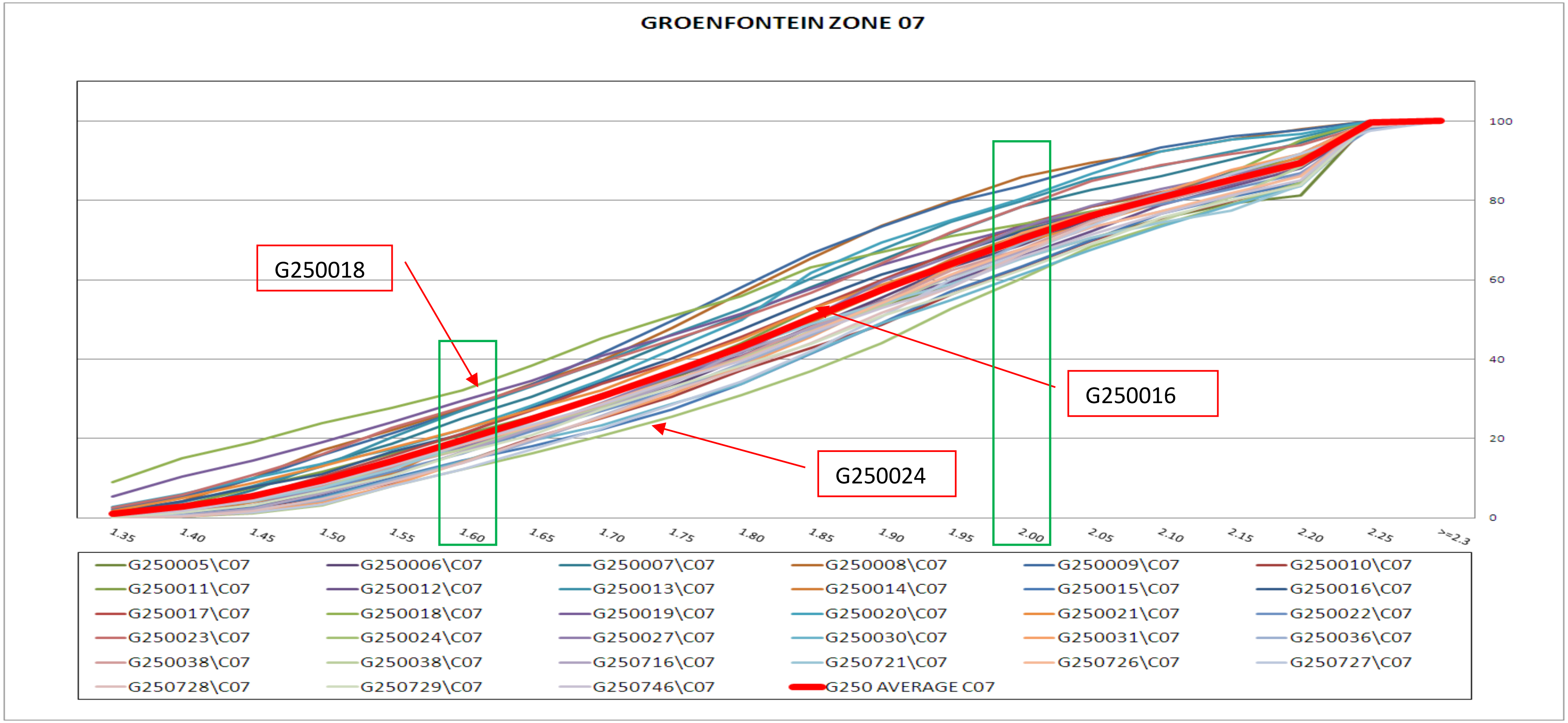
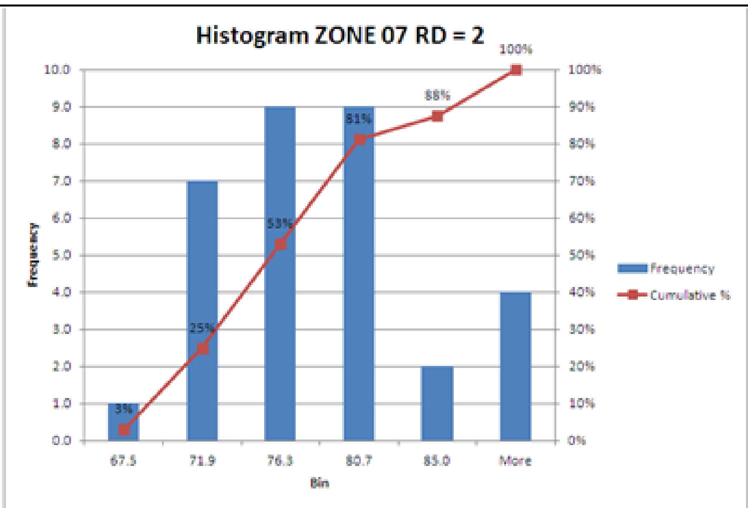


Figure 86 Combined GDCDD of Zone 07

RD= 2	Frequency	Cumulative %
67.5	1.0	3%
71.9	7.0	25%
76.3	9.0	53%
80.7	9.0	81%
85.0	2.0	88%
More	4.0	100%

RD= 2				
Mean	76.0			
Standard Error	1.0			
Median	75.5			
Standard Deviation	5.9			
Sample Variance	34.4			
Kurtosis	0.0			
Skewness	0.8			
Range	21.9			
Minimum	67.5	>	64.32	-2σ
Maximum	89.4	>	87.8	+ 2σ
Sum	2509.3			
Count	33			
Confidence Level(95.0%)	2.08			



RD= 1.6	Frequency	Cumulative %
0.0	2.0	6%
3.1	4.0	18%
6.2	9.0	45%
9.2	9.0	73%
12.3	7.0	94%
More	2.0	100%

RD= 1.6				
Mean	19.5			
Standard Error	0.9			
Median	18.4			
Standard Deviation	5.3			
Sample Variance	28.3			
Kurtosis	-0.3			
Skewness	0.7			
Range	20.1			
Minimum	12.1	>	8.90	-2σ
Maximum	32.2	>	30.2	+ 2σ
Sum	645			
Count	33.00			
Confidence Level(95.0%)	1.89			

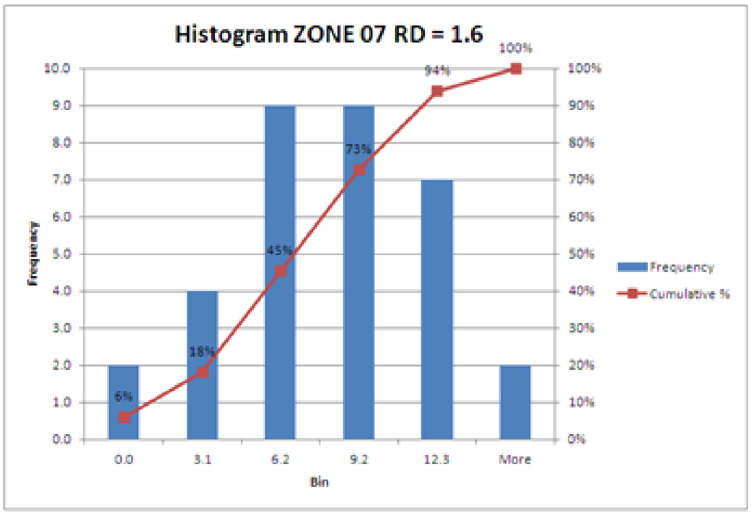


Figure 87 Statistics at a Rd of 2 and 1.6 of the GDCDD's of Zone 07 at Groenfontein. Plus and minus two standard deviations in yellow blocks

In Figure 164, the data in the yellow blocks, for 2σ, indicates that for a Rd of 2, the minimum and maximum value is inside 2σ. This suggests a narrow spacing for the σ value. For the Rd 1.6 value, the minimum and maximum value is inside 2σ. All the evidence suggests that there is a narrow spacing between the individual line graphs. Figure 163 illustrates that the line graphs have a narrow spacing, meaning that the lithotypes are similar.

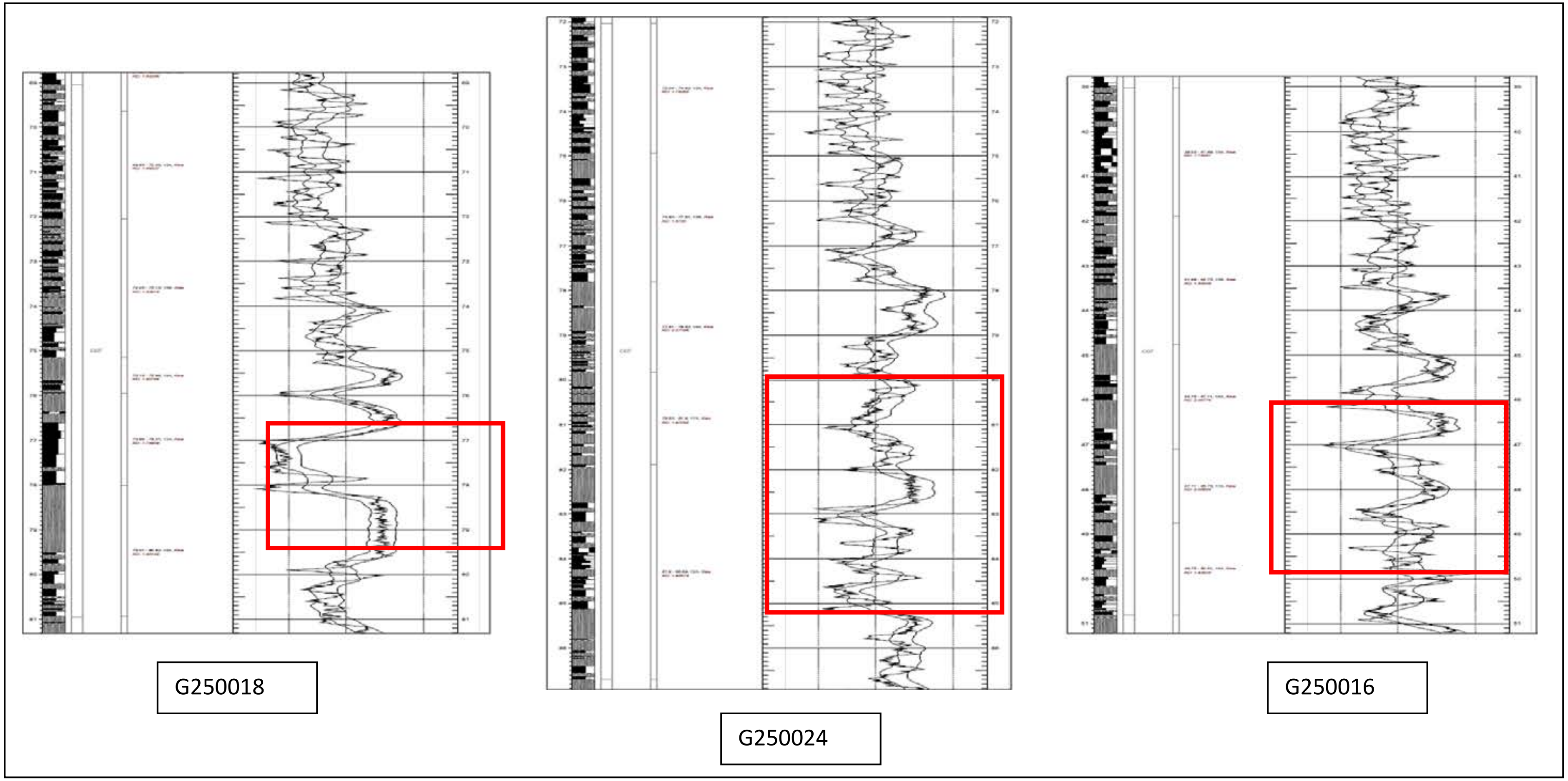


Figure 88 Zone 07 geological profile illustrating why low, high and average values occur in the GDCDD diagram

The lower part of G250018 is not well developed (Figure 165) which leads to higher values in the GDCDD for Zone 07 (Figure 163).

Zone 07 is the best developed over the north (Figure 166) while the area in the purple circle is a modelling inaccuracy due to the absence of boreholes.

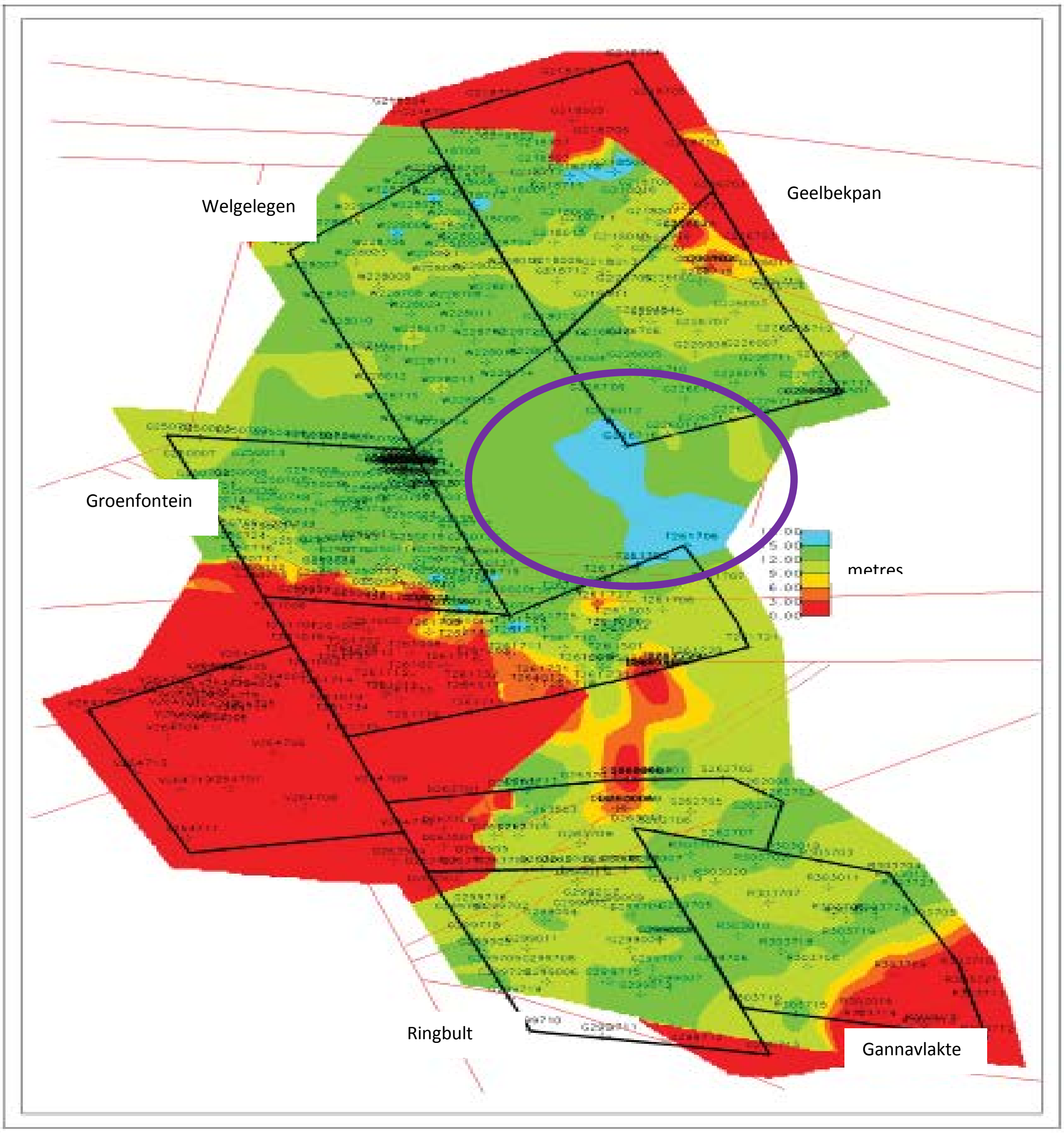


Figure 89 The lateral thickness variation of Zone 07 over the Study area

Coal Zone 06

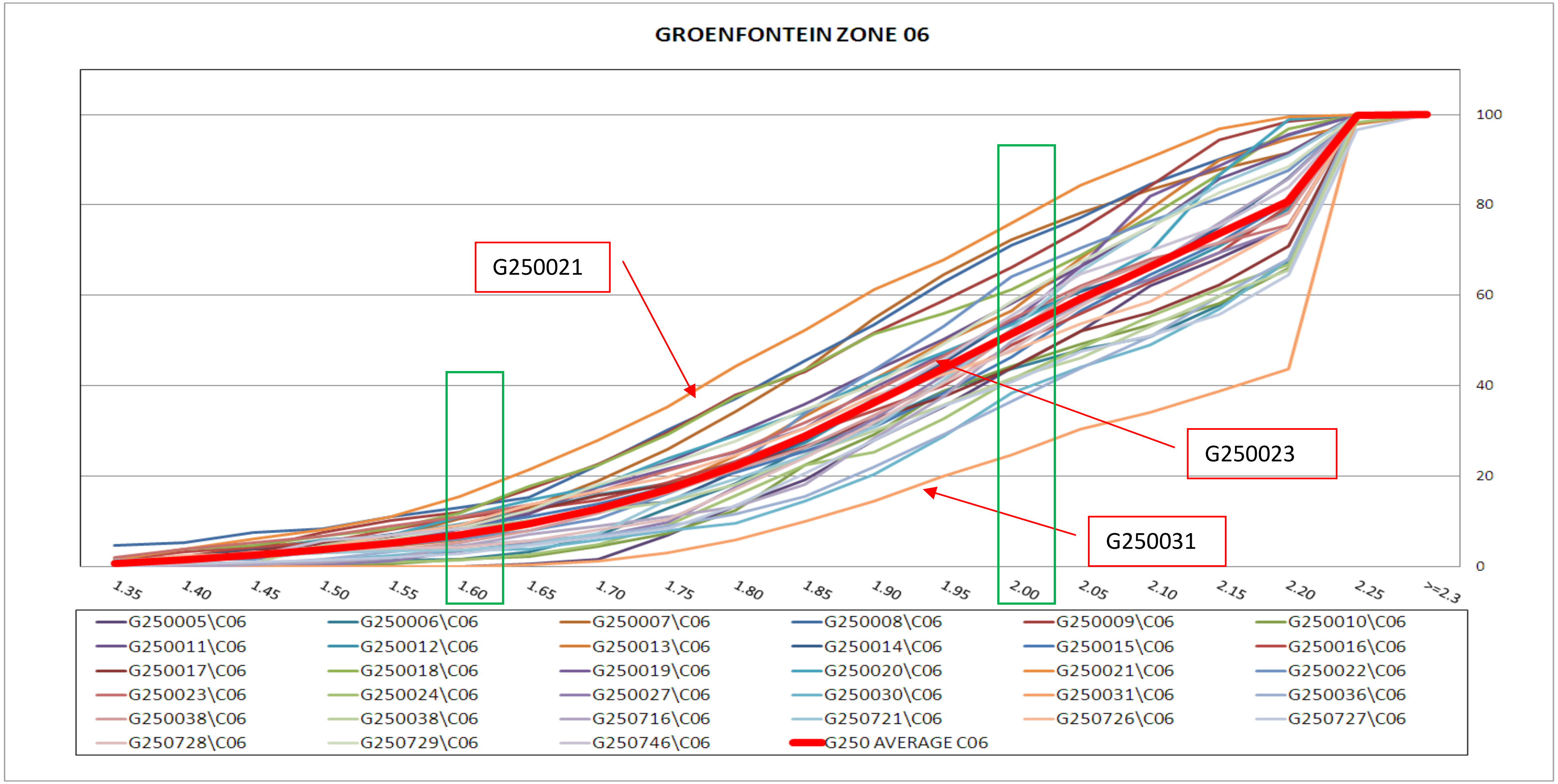
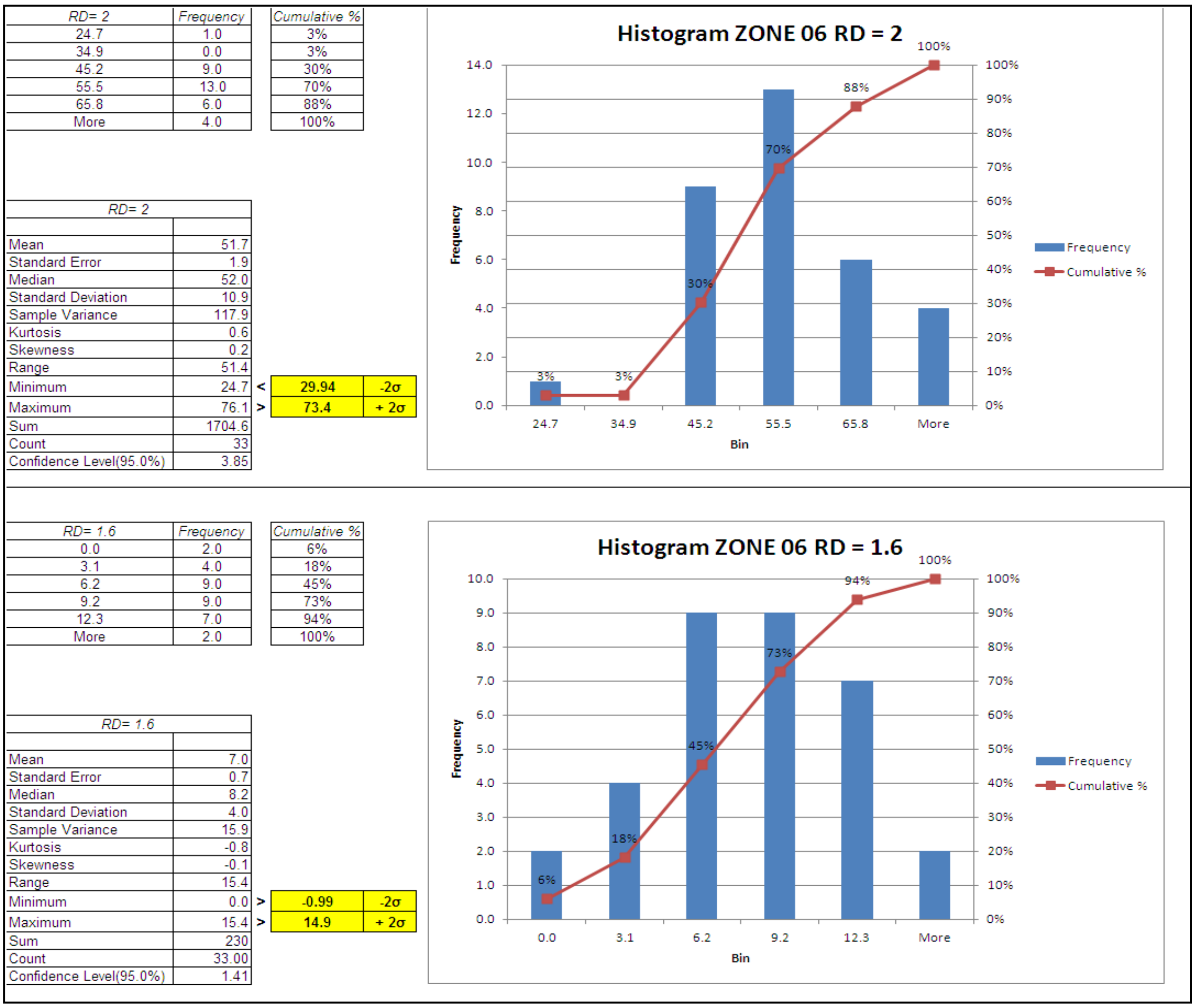


Figure 90 Combined GDCDD of Zone 06

In Figure 168, the data in the yellow blocks, for 2σ, indicates that for a Rd of 2, the minimum value falls inside the 2σ and the maximum value is just outside 2σ. This suggests a narrow spacing for the σ value.



RD= 2	Frequency	Cumulative %
24.7	1.0	3%
34.9	0.0	3%
45.2	9.0	30%
55.5	13.0	70%
65.8	6.0	88%
More	4.0	100%

RD= 2				
Mean	51.7			
Standard Error	1.9			
Median	52.0			
Standard Deviation	10.9			
Sample Variance	117.9			
Kurtosis	0.6			
Skewness	0.2			
Range	51.4			
Minimum	24.7	<	29.94	-2σ
Maximum	76.1	>	73.4	+ 2σ
Sum	1704.6			
Count	33			
Confidence Level(95.0%)	3.85			

RD= 1.6	Frequency	Cumulative %
0.0	2.0	6%
3.1	4.0	18%
6.2	9.0	45%
9.2	9.0	73%
12.3	7.0	94%
More	2.0	100%

RD= 1.6				
Mean	7.0			
Standard Error	0.7			
Median	8.2			
Standard Deviation	4.0			
Sample Variance	15.9			
Kurtosis	-0.8			
Skewness	-0.1			
Range	15.4			
Minimum	0.0	>	-0.99	-2σ
Maximum	15.4	>	14.9	+ 2σ
Sum	230			
Count	33.00			
Confidence Level(95.0%)	1.41			

Figure 91 Statistics at a Rd of 2 and 1.6 of the GDCDD's of coal Zone 06 at Groenfontein. Plus and minus two standard deviations in yellow blocks

For the Rd 1.6 value, the minimum and maximum value is just outside 2σ. This suggests that the values have a wider distribution. All the evidence suggests that there is a wider spacing between the individual line graphs. Figure 167 illustrates that the line graphs have a wider spacing. This suggests varying geological lithotypes in this Zone, which is supported by the profile in Figure 169.

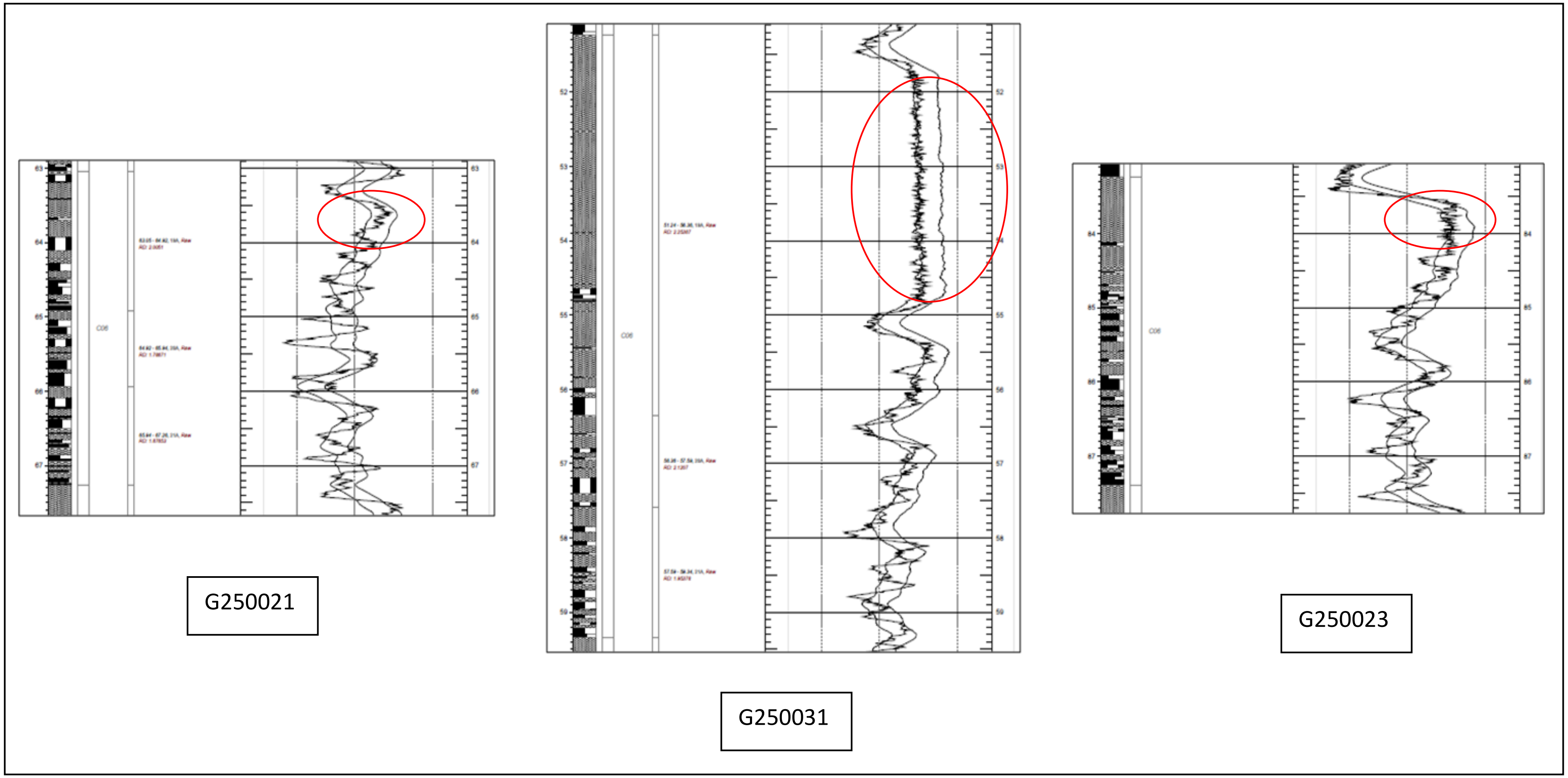


Figure 92 Zone 06 geological profile illustrating why low, high and average values occur in the GDCDD diagram

Figure 170 shows that G250021 has no thin mudrock near the top of coal Zone 06 as in the other two boreholes. G250031 has low GDCDD values (Figure 167) as it has a very thick mudrock developed at the top of coal Zone 06 (Figure 169).

Zone 06 is the thickest developed on Geelbekpan (Figure 170).

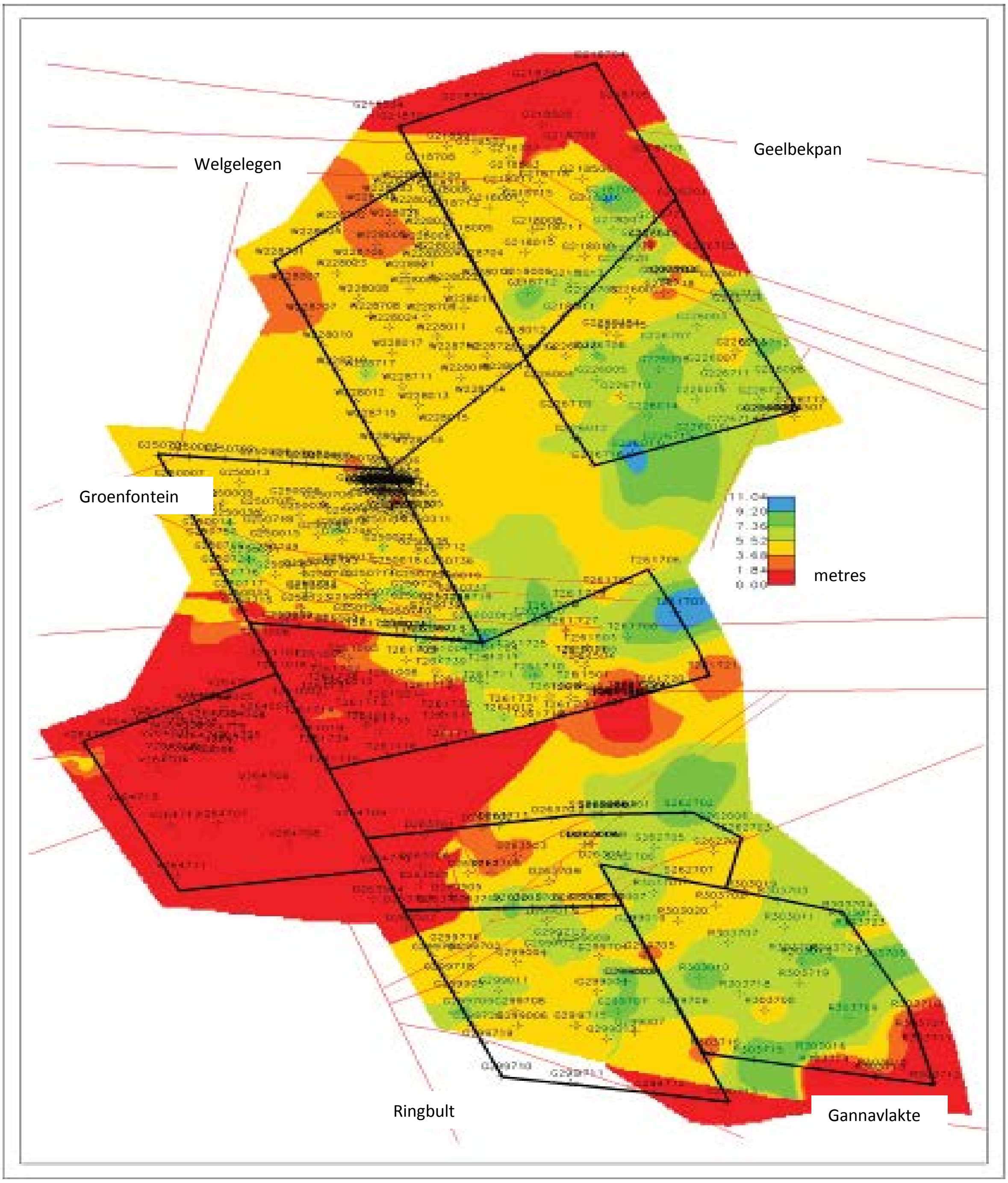


Figure 93 The lateral thickness variation of Zone 06 over the Study area

Coal Zone 05

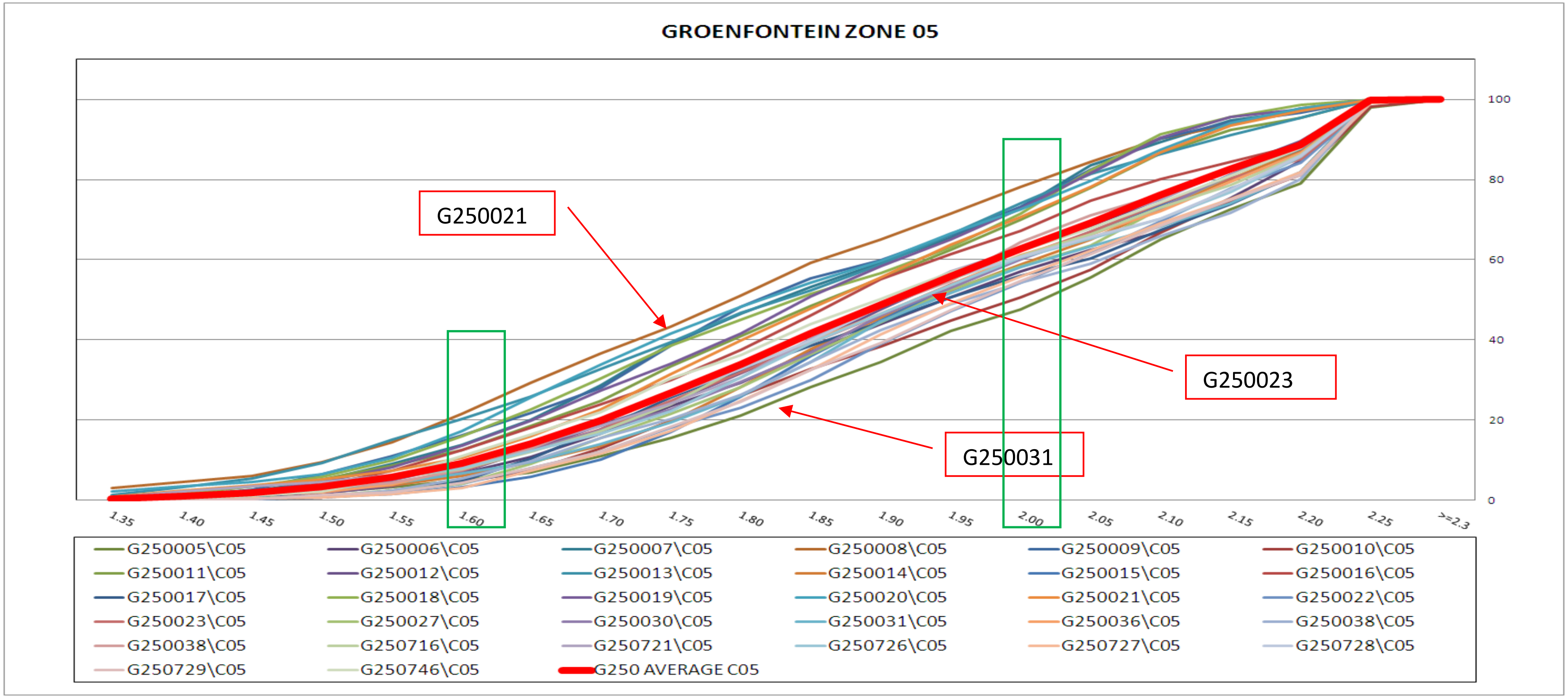
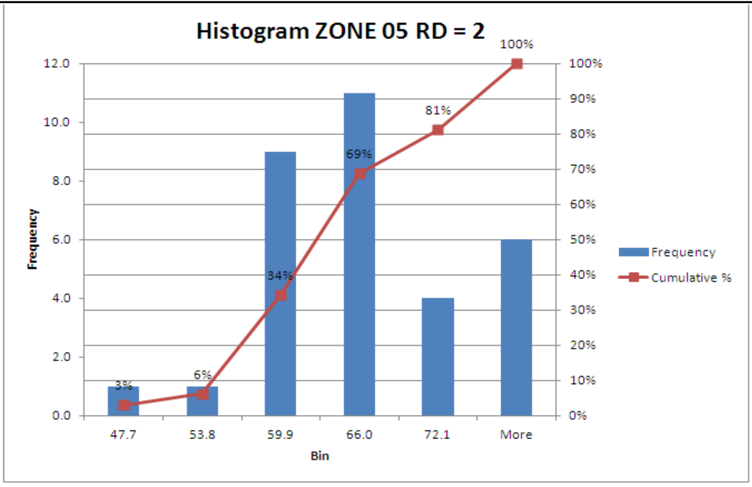


Figure 94 Combined GDCDD of Zone 05

In Figure 172 , the data in the yellow blocks, for 2σ, indicate that for a Rd of 2, the minimum value falls inside the 2σ and maximum value is outside 2σ.

RD= 2	Frequency	Cumulative %
47.7	1.0	3%
53.8	1.0	6%
59.9	9.0	34%
66.0	11.0	69%
72.1	4.0	81%
More	6.0	100%

RD= 2				
Mean	9.2			
Standard Error	0.9			
Median	7.8			
Standard Deviation	5.0			
Sample Variance	24.8			
Kurtosis	0.2			
Skewness	1.0			
Range	18.6			
Minimum	3.1	<	-0.73	-2σ
Maximum	21.6	>	19.2	+ 2σ
Sum	295.2			
Count	32			
Confidence Level(95.0%)	1.79			



RD= 1.6	Frequency	Cumulative %
3.1	1.0	3%
6.8	11.0	38%
10.5	9.0	66%
14.2	6.0	84%
17.9	3.0	94%
More	2.0	100%

RD= 1.6				
Mean	9.2			
Standard Error	0.9			
Median	7.8			
Standard Deviation	5.0			
Sample Variance	24.8			
Kurtosis	0.2			
Skewness	1.0			
Range	18.6			
Minimum	3.1	<	-0.73	-2σ
Maximum	21.6	>	19.2	+ 2σ
Sum	295			
Count	32.00			
Confidence Level(95.0%)	1.79			

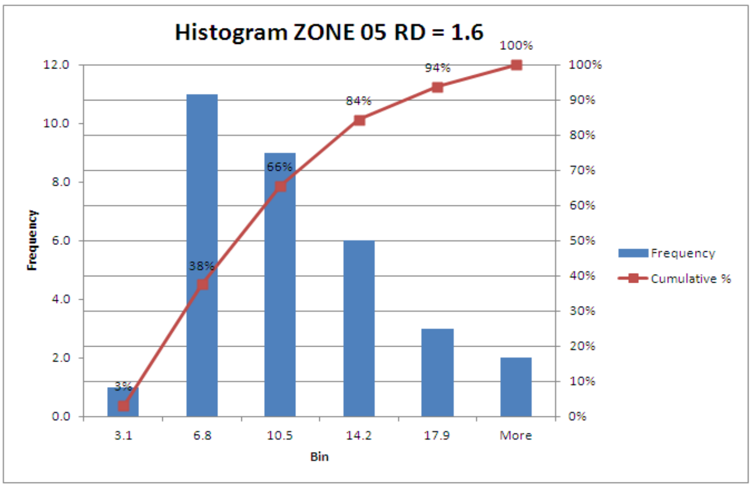


Figure 95 Statistics at a Rd of 2 and 1.6 of the GDCDD's of Zone 05 at Groenfontein. Plus and minus two standard deviations in yellow blocks

This suggests a narrow spacing for the σ value. For the Rd 1.6 value, the minimum value is inside 2σ, while the maximum value is outside 2σ. All the evidence suggests that there is a wider spacing between the individual line graphs. Figure 171 illustrates that the line graphs have a slightly wider spacing. This suggests slightly varying geological lithotypes in this Zone, which is supported by the profile in Figure 173.

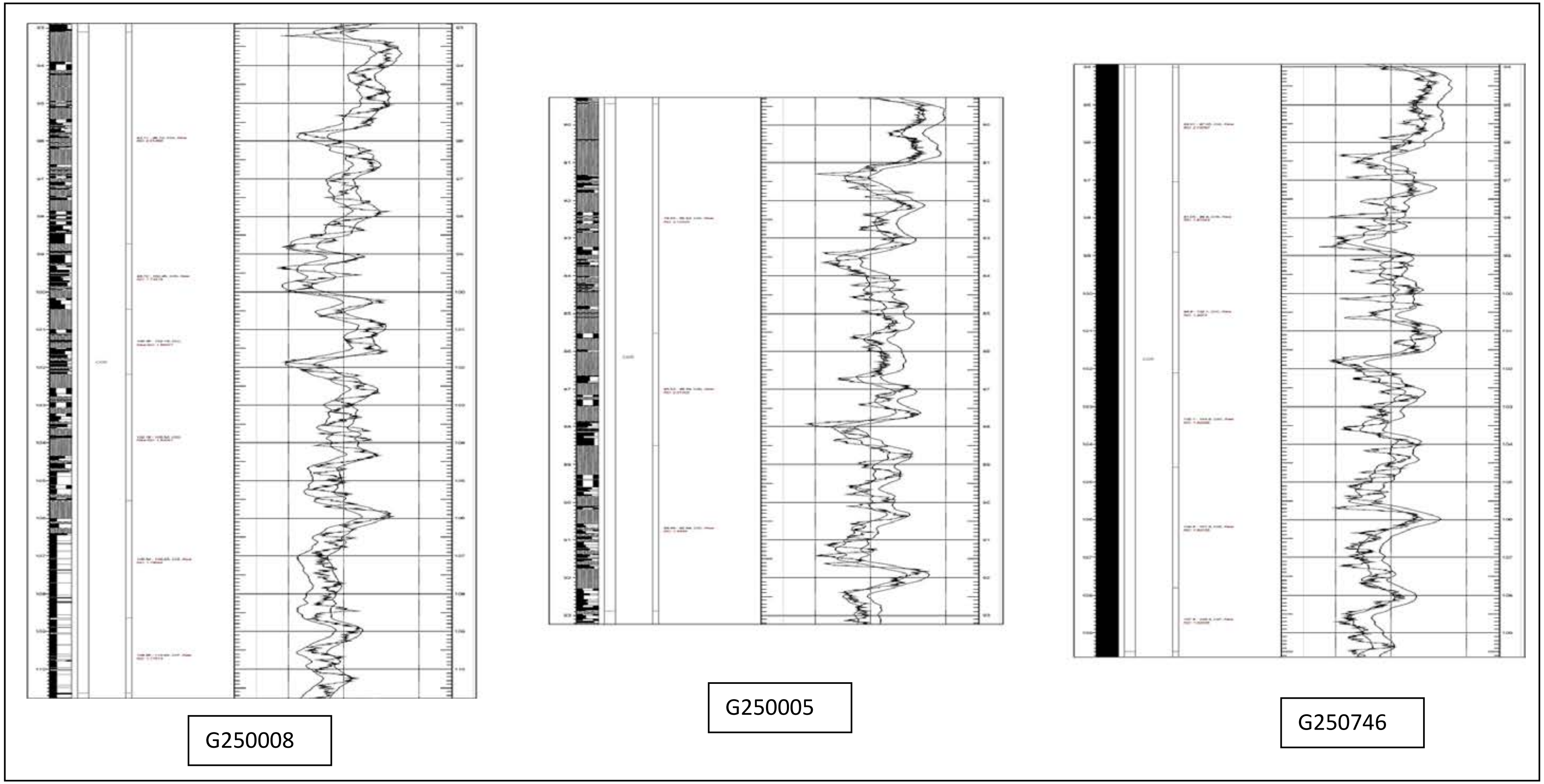


Figure 96 Zone 05 geological profile below illustrating why low, high and average values occurs in the GDCDD diagram

There is little variation in the geology of Zone 05 (Figure 171 and Figure 173) except for thickness.

Zone 05 is the thickest developed over the south and on Geelbekpan Figure 174).

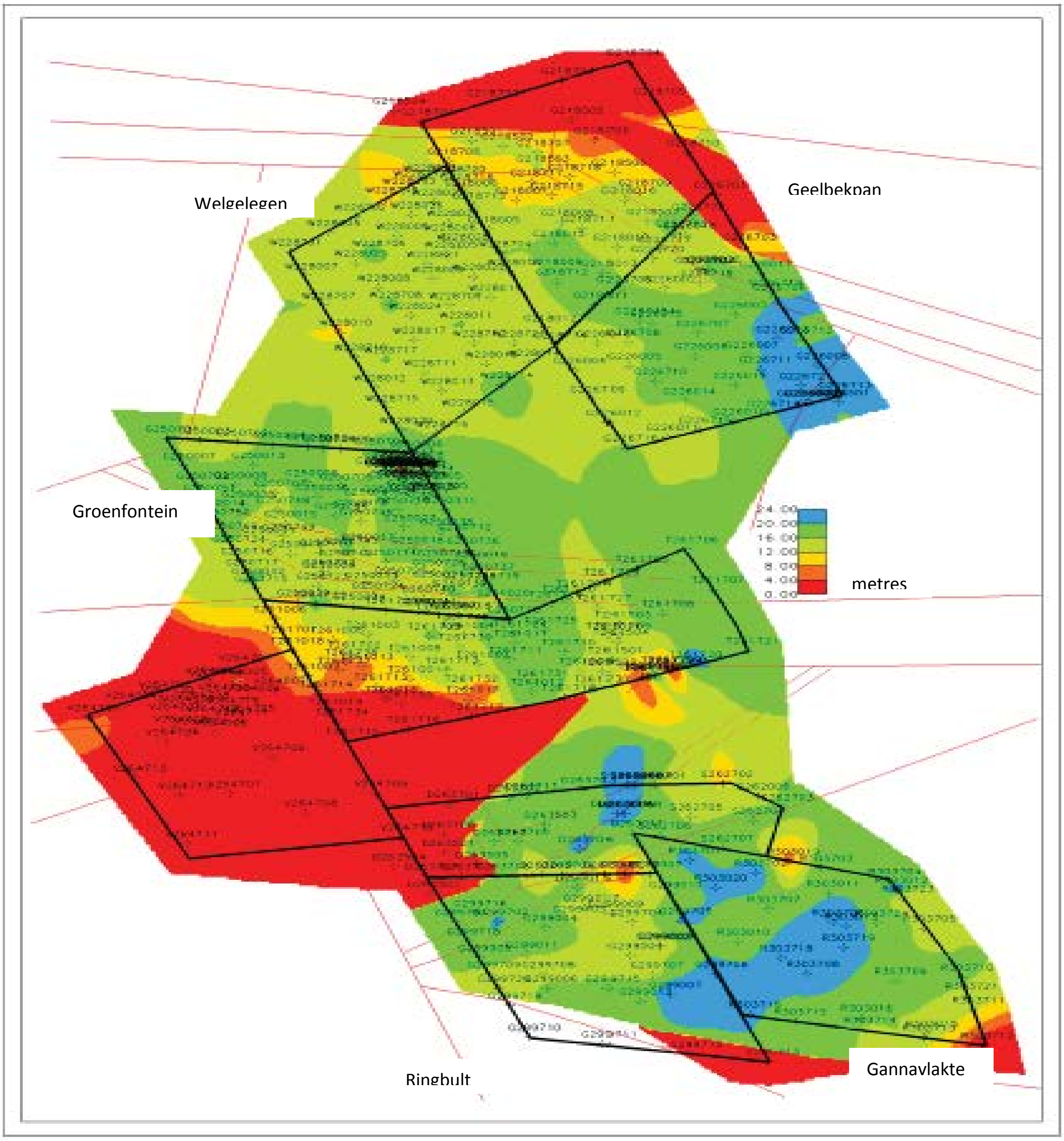


Figure 97 The lateral thickness variation of Zone 05 over the Study area

Coal Zone 04

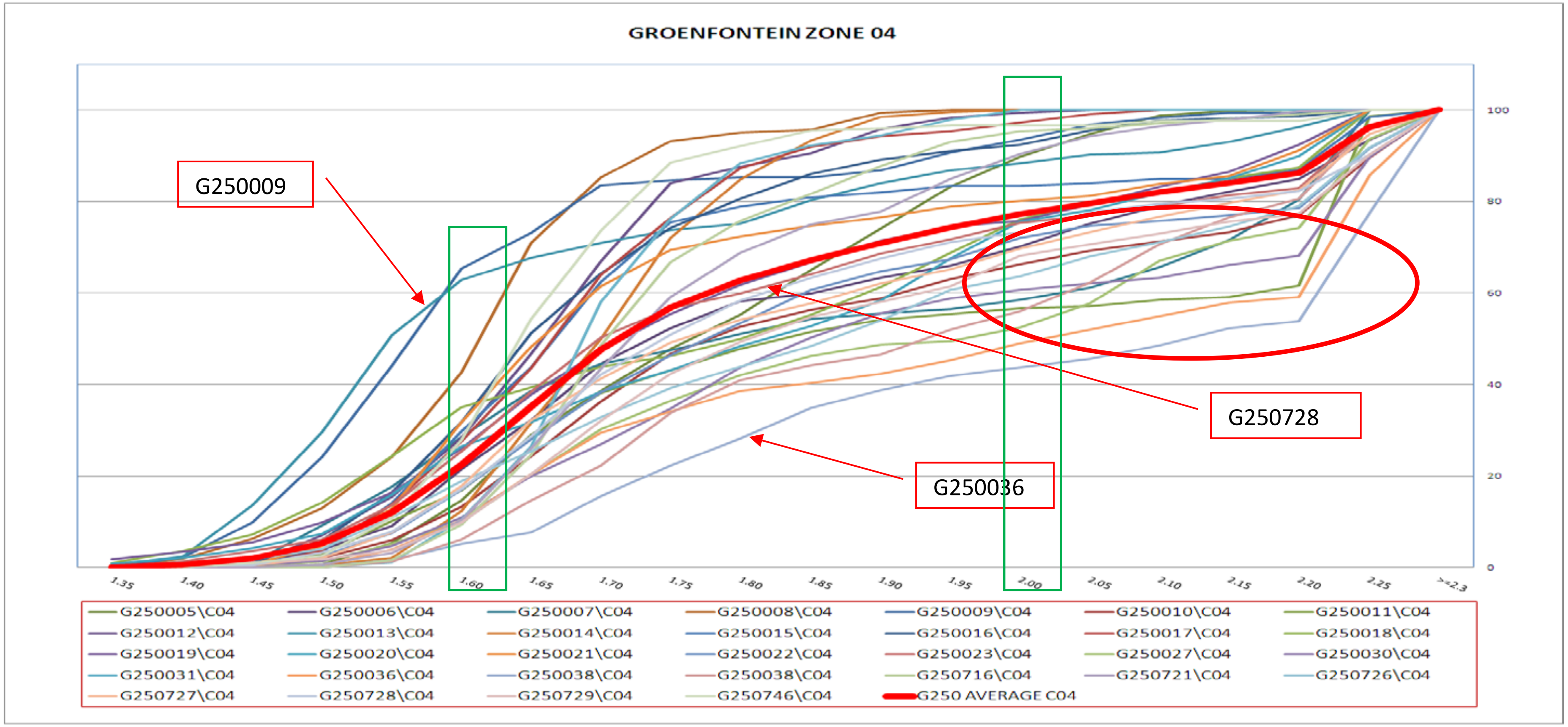
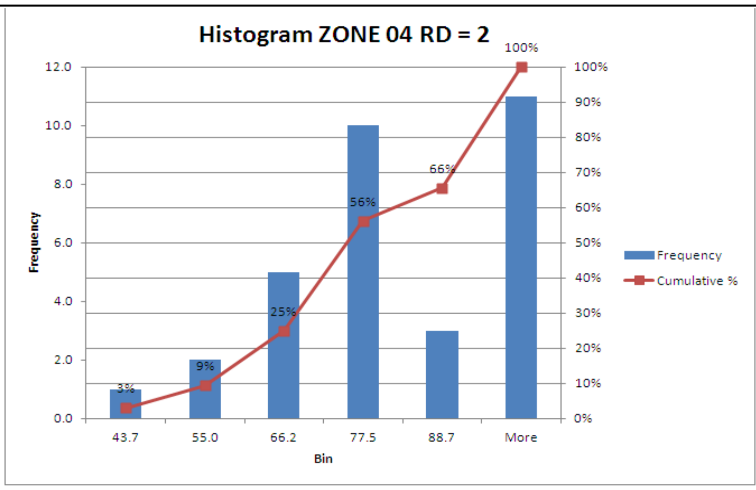


Figure 98 Combined GDCDD of Zone 04. Red oval denotes second population which is influenced by sandstones included in the zone

In Figure 176, the data in the yellow blocks, for 2σ, indicate that for a Rd of 2, the minimum and maximum value fall inside 2σ as the data is very widely spaced and the σ value is three times greater than most of the previous σ values.

RD= 2	Frequency	Cumulative %
43.7	1.0	3%
55.0	2.0	9%
66.2	5.0	25%
77.5	10.0	56%
88.7	3.0	66%
More	11.0	100%

RD= 2				
Mean	77.2			
Standard Error	3.0			
Median	75.7			
Standard Deviation	16.8			
Sample Variance	280.9			
Kurtosis	-1.1			
Skewness	-0.2			
Range	56.3			
Minimum	43.7	<	43.63	-2σ
Maximum	100.0	<	110.7	+ 2σ
Sum	2469.0			
Count	32			
Confidence Level(95.0%)	6.04			



RD= 1.6	Frequency	Cumulative %
5.1	1.0	3%
17.1	13.0	44%
29.2	11.0	78%
41.3	4.0	91%
53.3	1.0	94%
More	2.0	100%

RD= 1.6				
Mean	22.5			
Standard Error	2.5			
Median	18.3			
Standard Deviation	14.4			
Sample Variance	207.4			
Kurtosis	2.7			
Skewness	1.5			
Range	60.3			
Minimum	5.1	<	-6.28	-2σ
Maximum	65.4	>	51.3	+ 2σ
Sum	721			
Count	32.00			
Confidence Level(95.0%)	5.19			

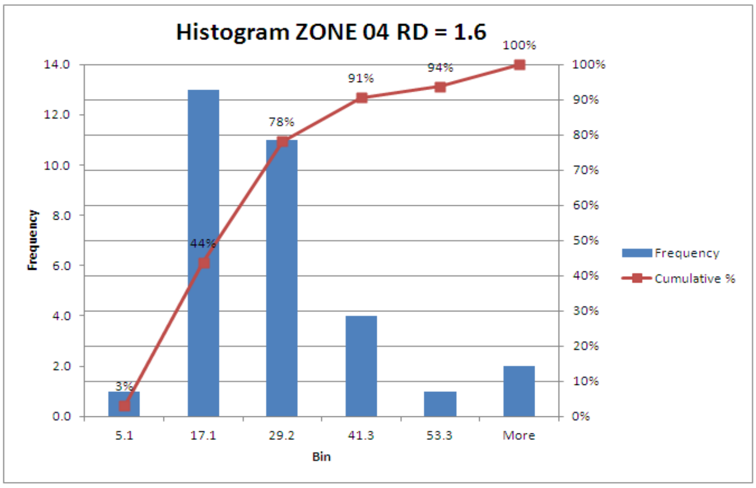


Figure 99 Statistics at a Rd of 2 and 1.6 of the GDCDD's of Zone 04 at Groenfontein. Plus and minus two standard deviations in yellow blocks

This would suggest that a wide spacing exists for these values. For the Rd of 1.6 value, the minimum value is inside 2σ, while the maximum value is outside 2σ. The evidence suggests that there is a wider spacing between the individual line graphs. Figure 175 illustrates that the line graphs have a wider spacing. This suggests varying geological lithotypes in this zone, which is supported by the profile in Figure 177.

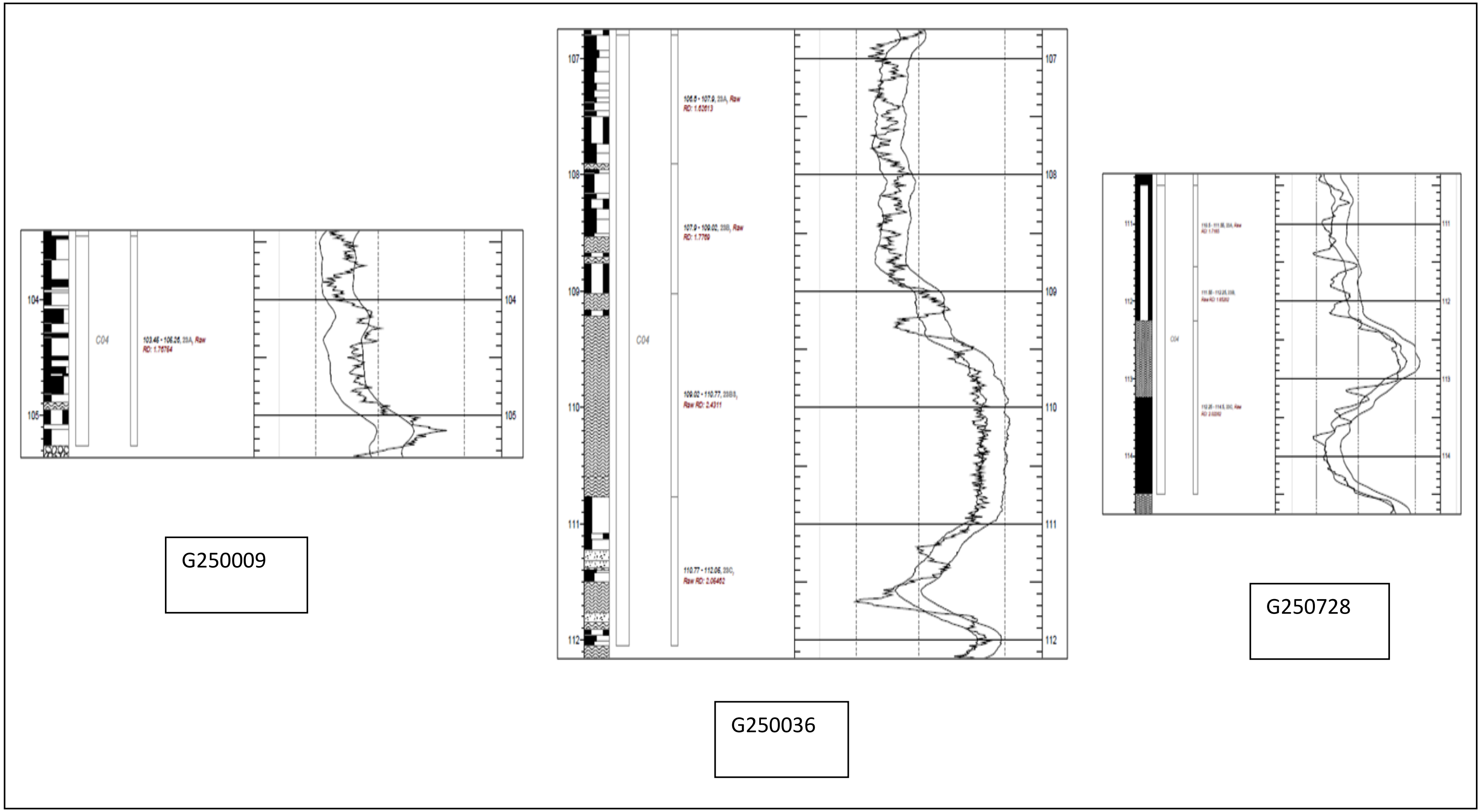


Figure 100 Zone 04 lithological profile illustrates why low, high and average values occurs in the GDCDD diagram

Zone 04 has layers of coal of varying thickness at the bottom of the zone. How thick the interbedded mud/sandstone was, determined whether the separated lower coal layer was included in Zone 04 or whether it was disregarded and made part of Zone 04A. As Zone 04A's distribution is random and thus of no economic interest, it was not included in this study. Zone 04 consists of Sample 24A to Sample 24D which occurs randomly throughout the thesis area. In Figure 178 the circle denotes a second population in the GDCDD of Zone 04. This population is based on the amount of interbedded waste in Zone 04. G250036 in Figure 177 illustrates this clearly.

There is another identified coal zone in the stratigraphy that occurs between coal Zone 04 and coal Zone 03, namely coal Zone 04A. This zone consists of dull coals, like Zone 04 and the lower coal zones, but because the coal are so irregularly distributed, they are not discussed in this thesis. This zone is illustrated in Figure 179 but not discussed in any detail.

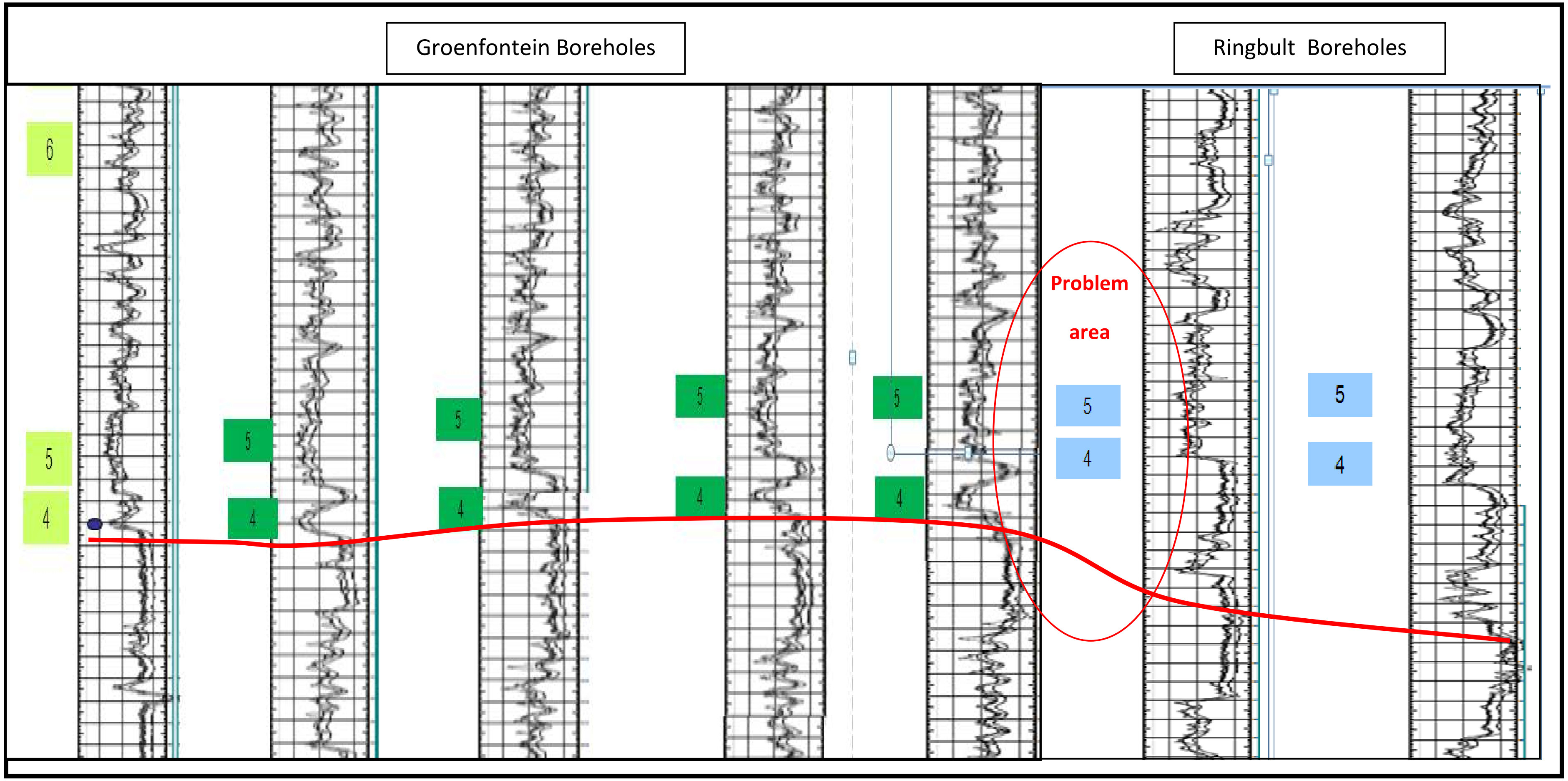


Figure 101 'Separated' coal at the bottom of Zone 04 (above thick red line). The area in which the geologist will have difficulty in determining the floor of Zone 04, is shown in the red circle. Horizontal lines on graph are at one metre intervals

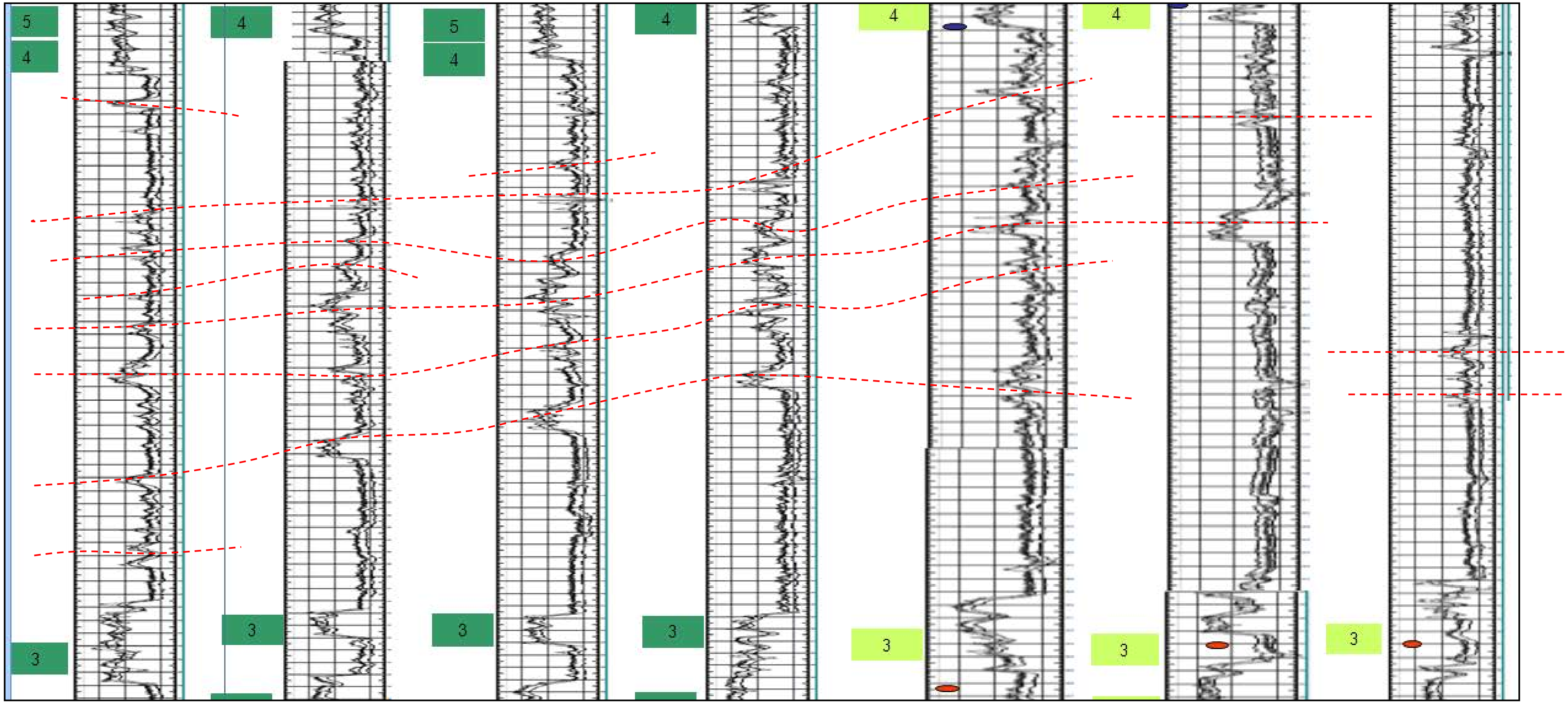


Figure 102 Irregular occurrence of the coals of Sample 24A to Sample 24D in coal Zone 04A, which is not discussed in this thesis due to their irregular nature

Zone 04 is the thickest developed in the south (Figure 180).

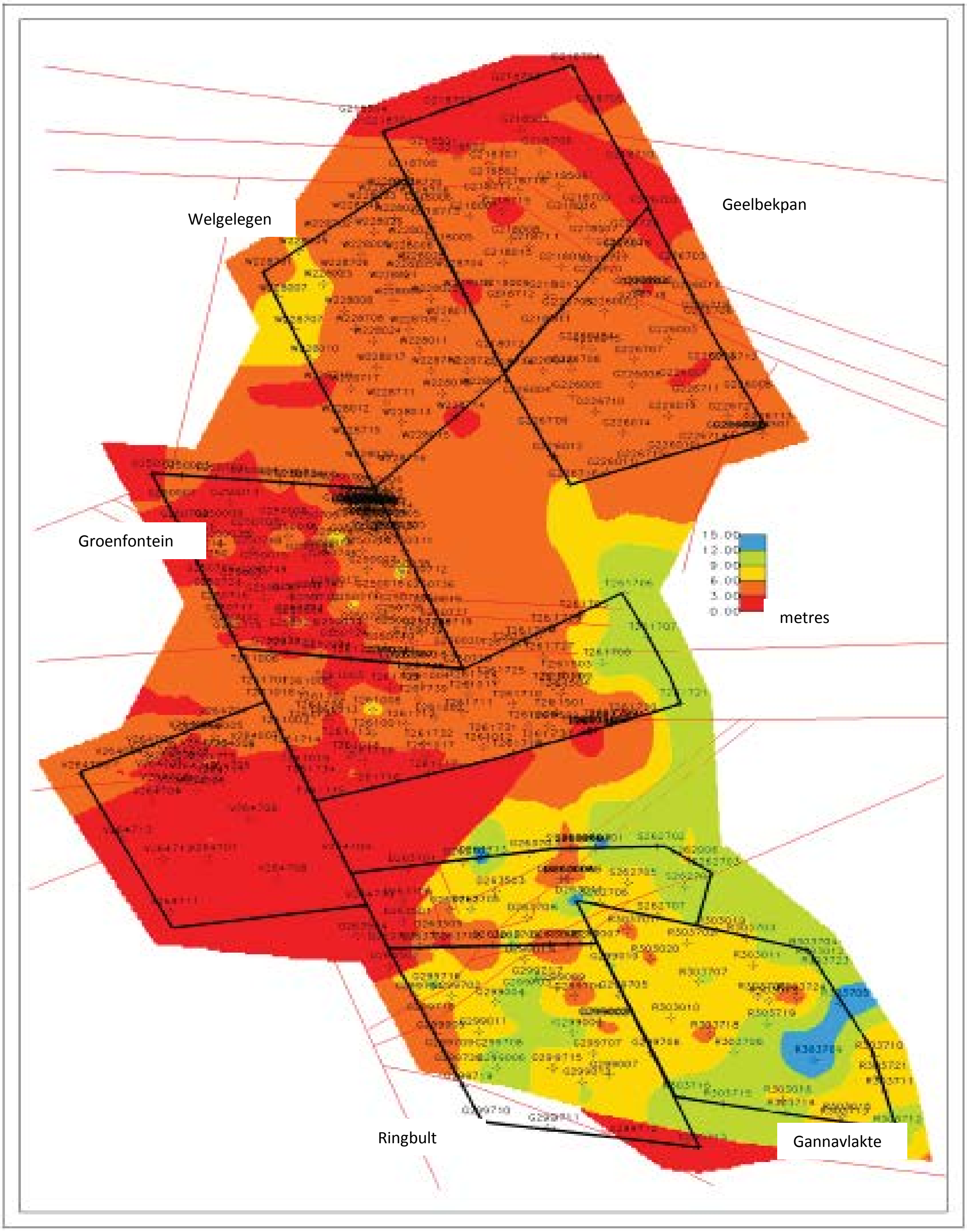


Figure 103 The lateral thickness variation of Zone 04 over the Study area

Coal Zone 03

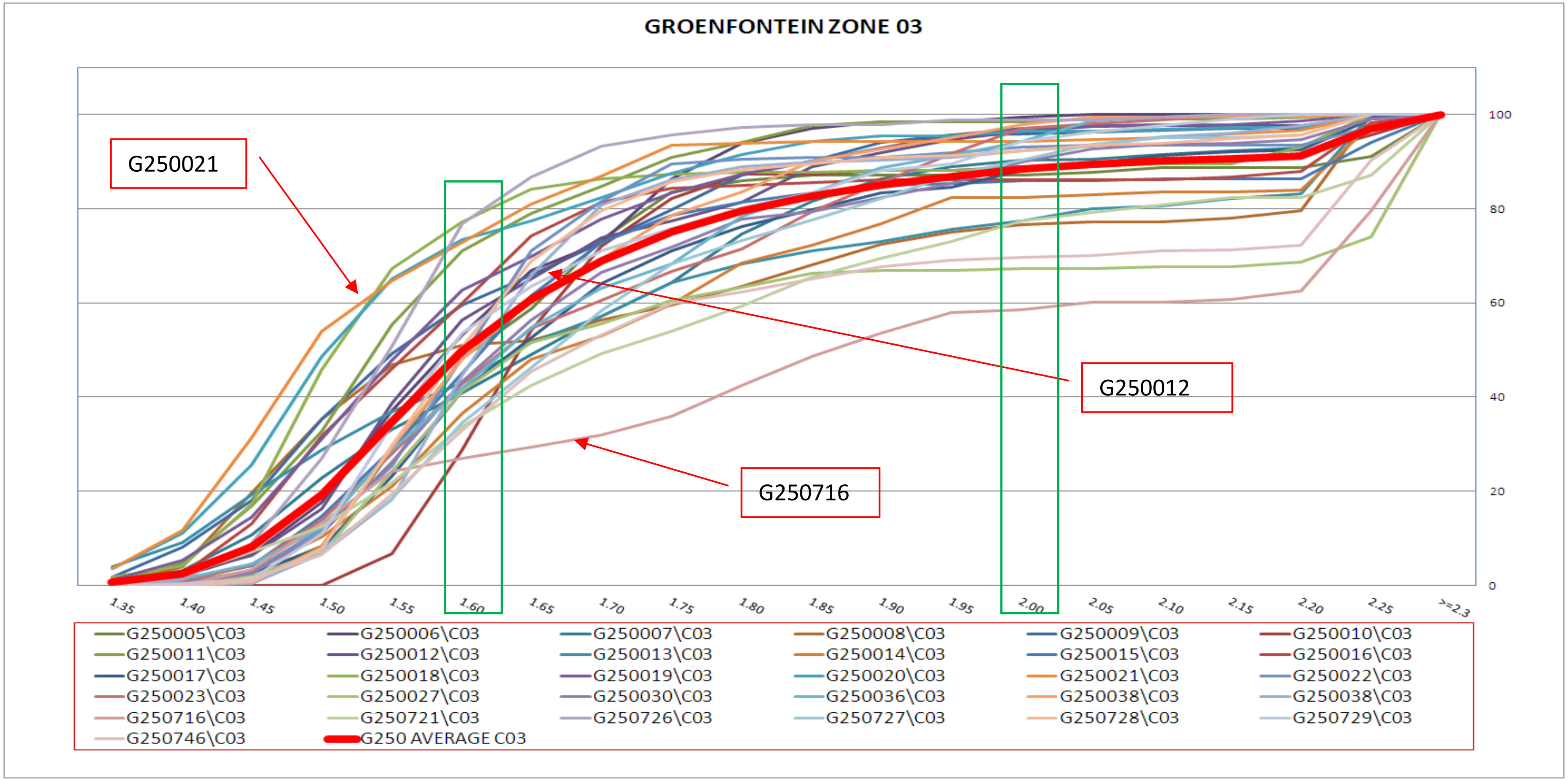
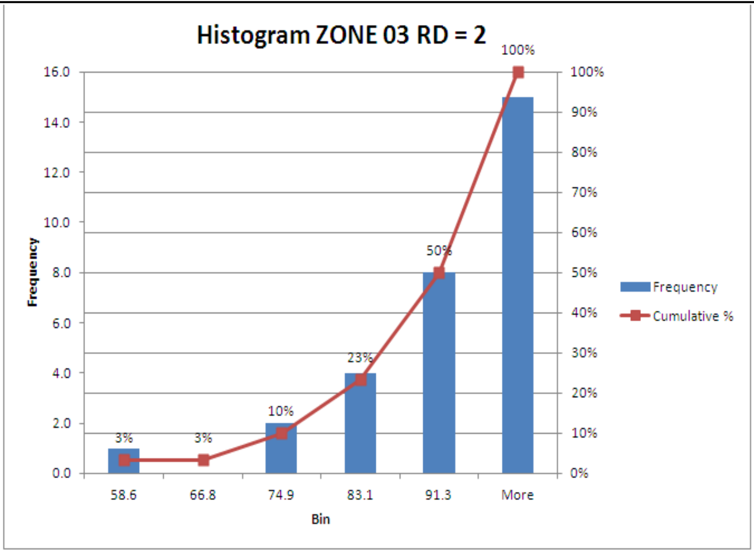


Figure 104 Combined GDCDD of Zone 03

In Figure 182, the data in the yellow blocks, for 2σ, indicates that for a Rd of 2, both the minimum and maximum values fall inside the 2σ as that the data is very widely spaced and the σ value is two times greater than most of the previous σ values.

RD= 2	Frequency	Cumulative %
58.6	1.0	3%
66.8	0.0	3%
74.9	2.0	10%
83.1	4.0	23%
91.3	8.0	50%
More	15.0	100%

RD= 2				
Mean	88.5			
Standard Error	1.8			
Median	90.4			
Standard Deviation	10.1			
Sample Variance	101.3			
Kurtosis	1.6			
Skewness	-1.4			
Range	40.9			
Minimum	58.6	<	68.37	-2σ
Maximum	99.5	<	108.6	+ 2σ
Sum	2743.5			
Count	31			
Confidence Level(95.0%)	3.69			



RD= 1.6	Frequency	Cumulative %
27.1	1.0	3%
37.1	5.0	19%
47.2	9.0	48%
57.2	8.0	74%
67.2	3.0	84%
More	5.0	100%

RD= 1.6				
Mean	49.7			
Standard Error	2.5			
Median	47.9			
Standard Deviation	14.0			
Sample Variance	194.9			
Kurtosis	-0.4			
Skewness	0.6			
Range	50.2			
Minimum	27.1	>	21.79	-2σ
Maximum	77.3	<	77.6	+ 2σ
Sum	1541			
Count	31.00			
Confidence Level(95.0%)	5.12			

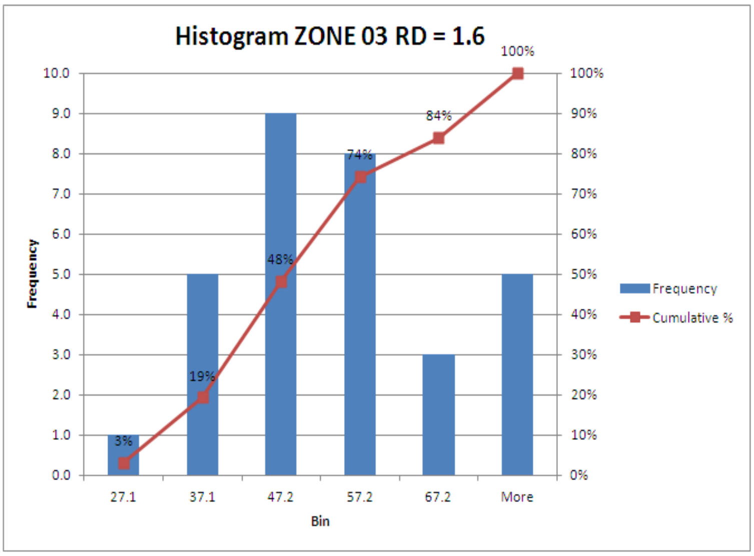


Figure 105 Statistics at a Rd of 2 and 1.6 of the GDCDD's of Zone 03 at Groenfontein . Plus and minus two standard deviations in yellow blocks

For the Rd 1.6 value, the minimum value is inside 2σ, while maximum value is outside 2σ. The evidence suggests that there is a wider spacing between the individual line graphs. Figure 181 illustrates that the line graphs have a wider spacing. This suggests varying geological lithotypes in this zone, which is supported by the profile in Figure 183.

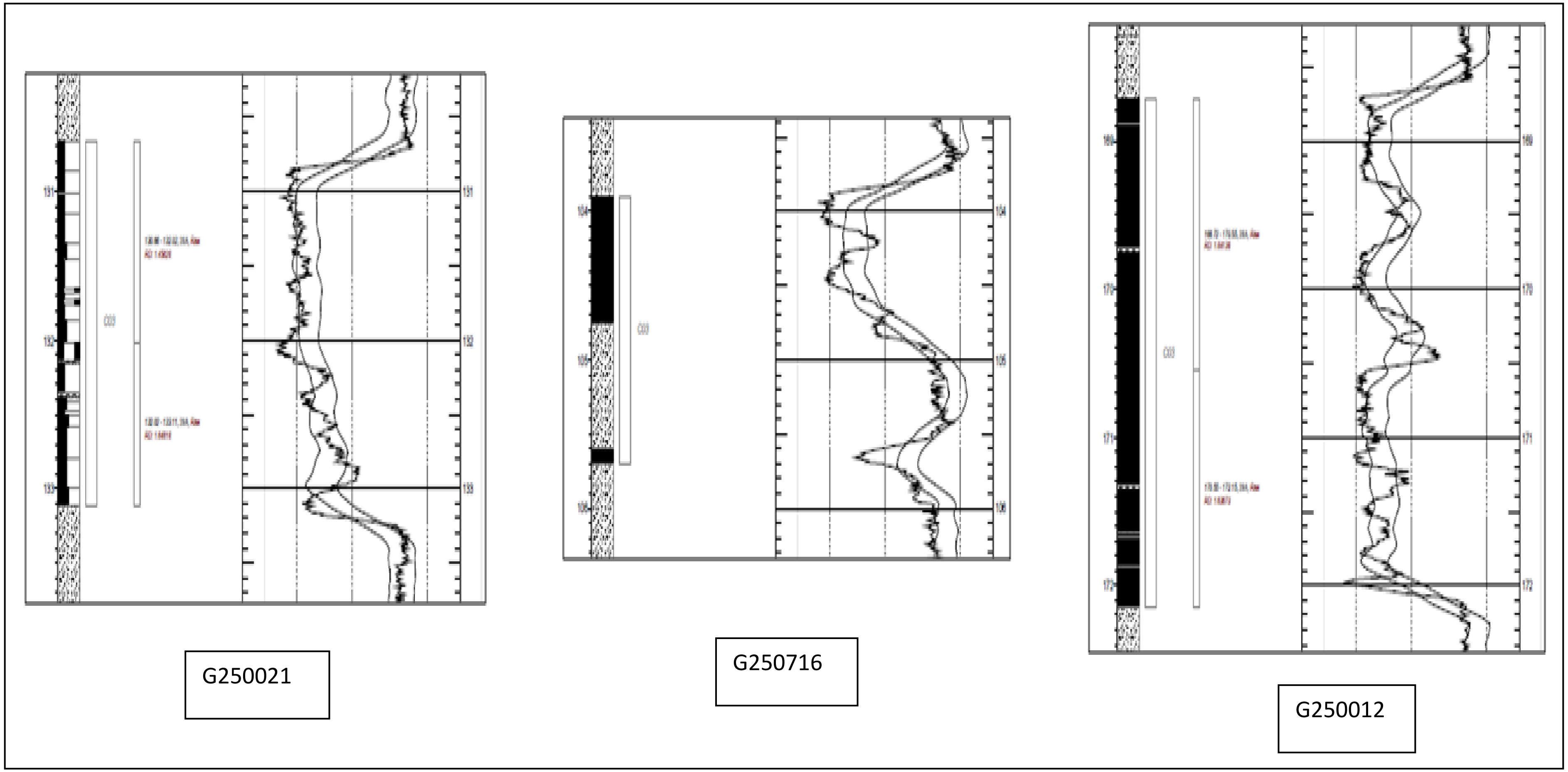
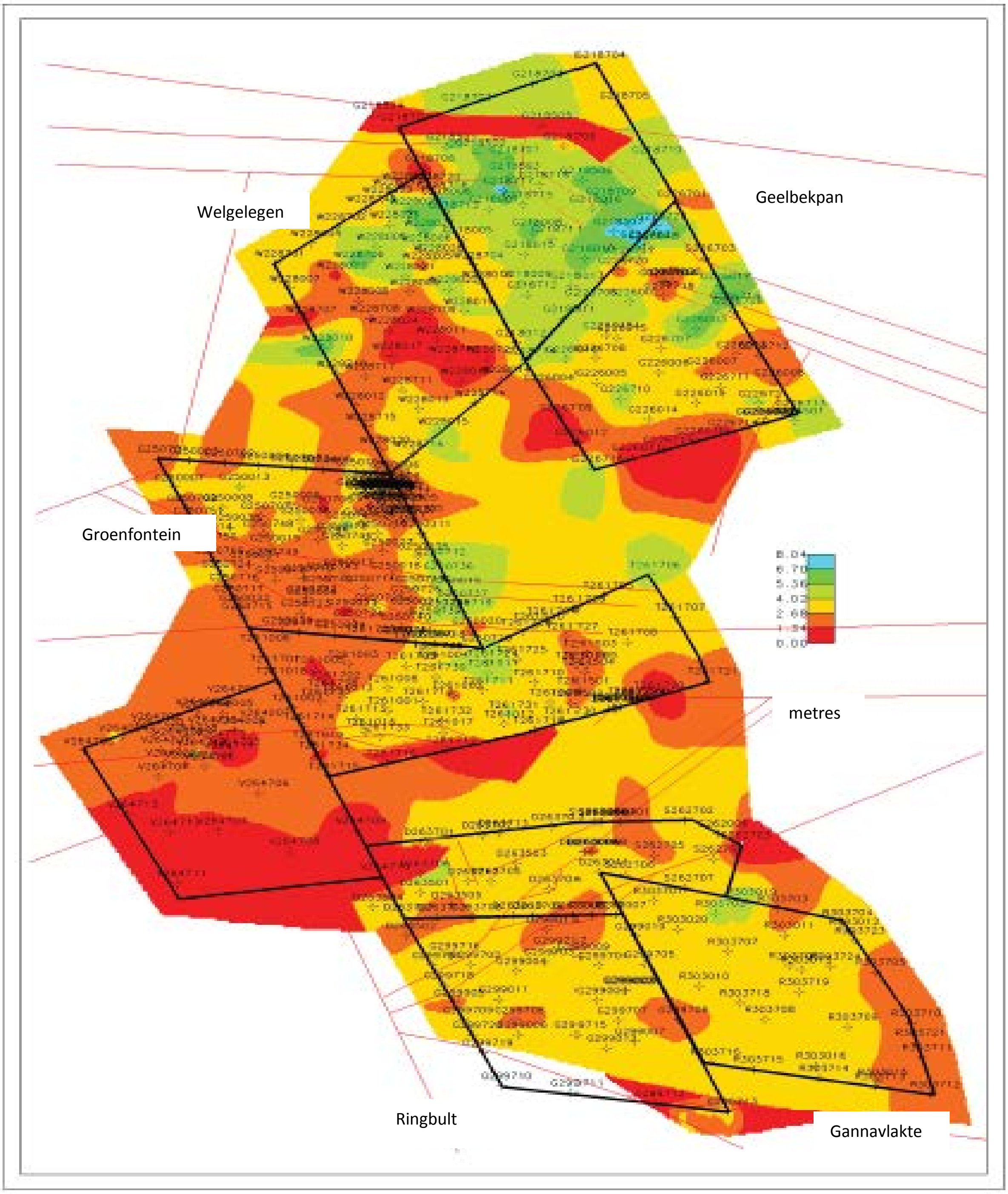


Figure 106 Zone 03 lithological profile, illustrating why low, high and average values occurs in the GDCDD diagram

Zone 03 is the thickest developed over the north (Grootwater) (Figure 184) due to the presence of interbedded sandstones.



Zone 03 is the thickest developed over the north (Grootwater) (Figure 184) due to the presence of interbedded sandstones.

Coal Zone 02

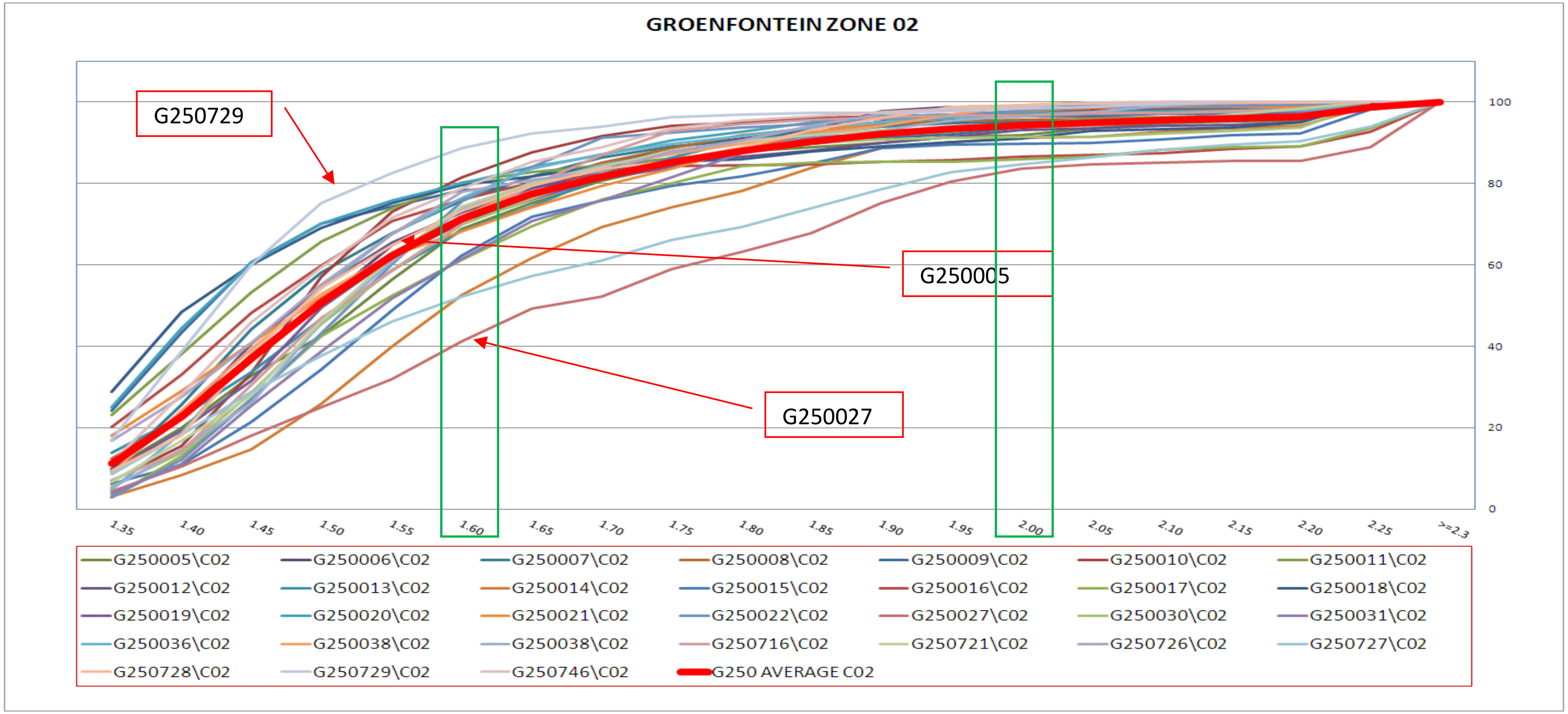
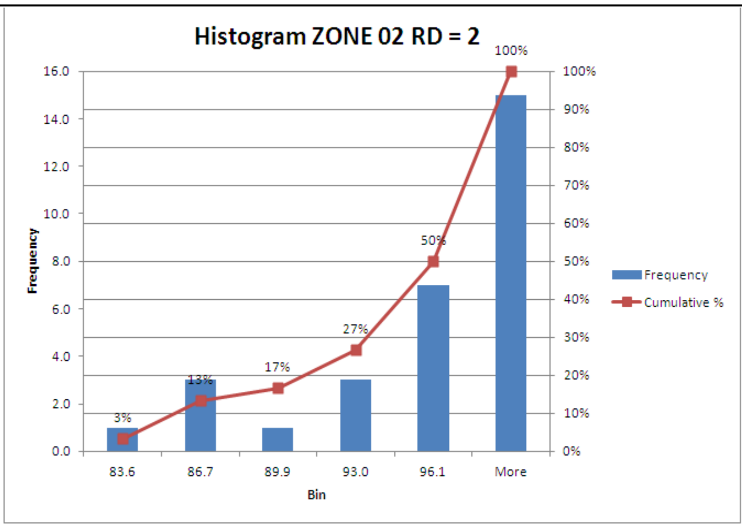


Figure 108 Combined GDCDD of Zone 02

In Figure 186, the data in the yellow blocks, for 2σ, indicate that for a Rd of 2 and Rd 1.6, both the minimum and maximum value fall inside 2σ as the data is widely spaced.

RD= 2	Frequency	Cumulative %
83.6	1.0	3%
86.7	3.0	13%
89.9	1.0	17%
93.0	3.0	27%
96.1	7.0	50%
More	15.0	100%

RD= 2				
Mean	94.2			
Standard Error	0.9			
Median	96.5			
Standard Deviation	4.8			
Sample Variance	22.8			
Kurtosis	-0.2			
Skewness	-0.9			
Range	15.7			
Minimum	83.6	<	84.60	-2σ
Maximum	99.3	<	103.7	+ 2σ
Sum	2448.1			
Count	26			
Confidence Level(95.0%)	1.93			



RD= 1.6	Frequency	Cumulative %
41.3	1.0	3%
50.7	0.0	3%
60.2	2.0	10%
69.7	6.0	29%
79.2	17.0	84%
More	5.0	100%

RD= 1.6				
Mean	94.2			
Standard Error	0.9			
Median	96.5			
Standard Deviation	4.8			
Sample Variance	22.8			
Kurtosis	-0.2			
Skewness	-0.9			
Range	15.7			
Minimum	83.6	<	84.60	-2σ
Maximum	99.3	<	103.7	+ 2σ
Sum	2448			
Count	26.00			
Confidence Level(95.0%)	1.93			

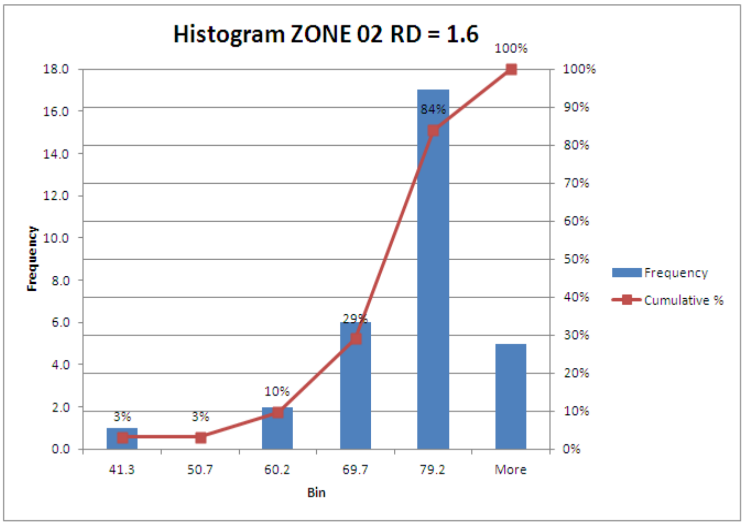


Figure 109 Statistics at a Rd of 2 and 1.6 of the GDCDD's of Zone 02 at Groenfontein. Plus and minus two standard deviations in yellow blocks

The evidence suggests that there is a wider spacing between the individual line graphs. Figure 185 illustrates that the line graphs have a wider spacing. This suggests some variance in geological lithotypes in this zone, which is supported by the profile in Figure 187. Figure 188 illustrates that the line graphs have a wider spacing.

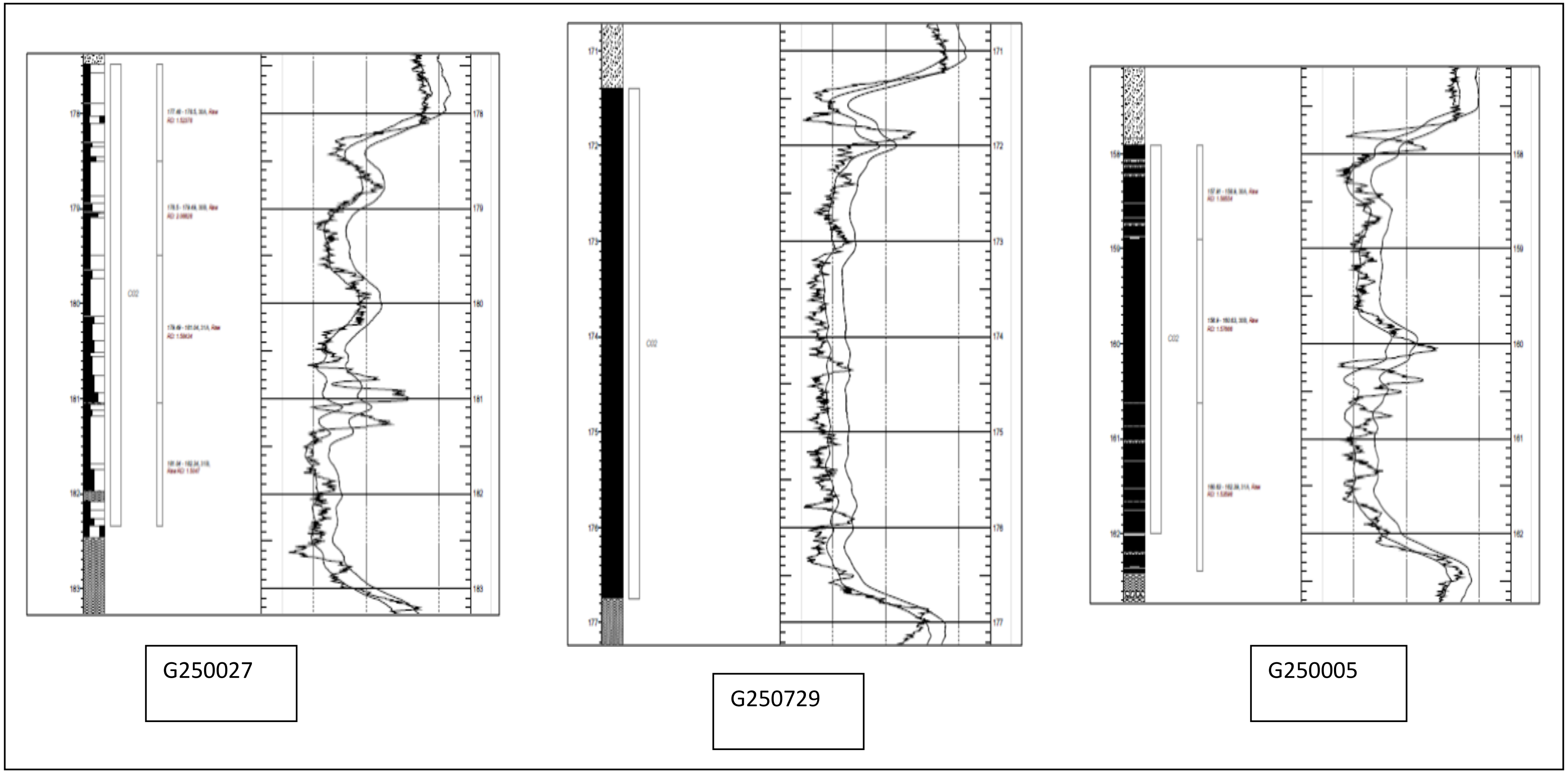


Figure 110 Zone 02 lithological profile illustrates why low, high and average values occur in the GDCDD diagram

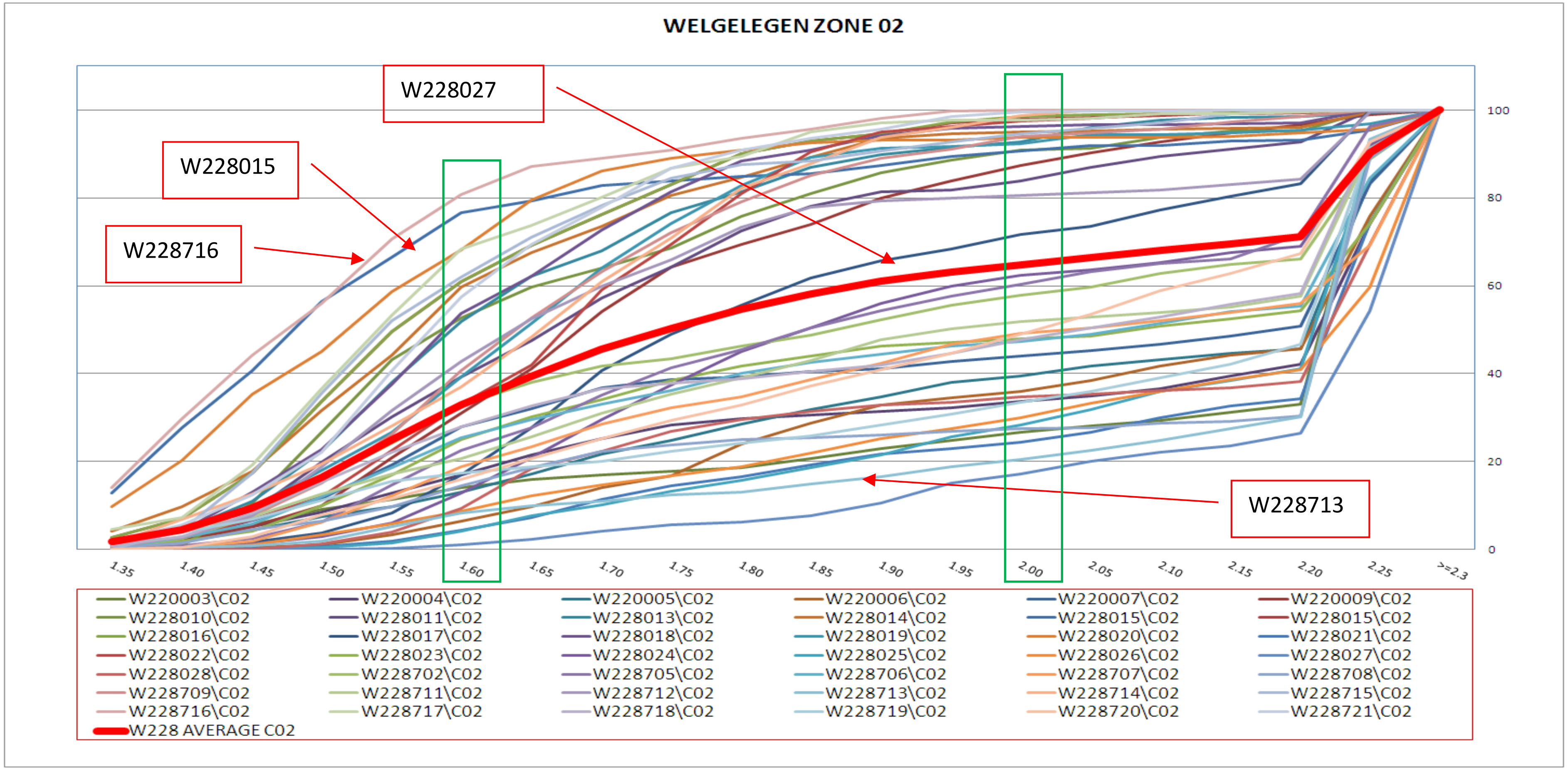


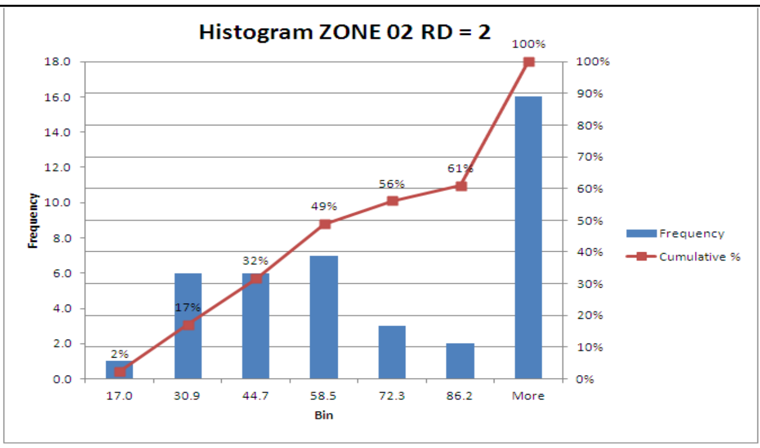
Figure 111 Combined GDCDD of Zone 02 on Welgelegen, illustrating the presence of interbedded sandstones

The higher σ value illustrated in Figure 185 are due to the amount of inorganic material found in the coals of Zone 02 (Figure 187). On Welgelegen, north-east of Groenfontein, the variance in Zone 2 is even more prominent.

In Figure 189, the data in the yellow blocks, for 2σ, indicates that for a Rd of 2, the minimum values fall outside 2σ and maximum values fall inside 2σ, as the data is very widely spaced and the σ value is 28.7, which is very high. For the Rd 1.6 value, the minimum and maximum values are inside 2σ.

RD= 2	Frequency	Cumulative %
17.0	1.0	2%
30.9	6.0	17%
44.7	6.0	32%
58.5	7.0	49%
72.3	3.0	56%
86.2	2.0	61%
More	16.0	100%

RD= 2				
Mean	64.0			
Standard Error	4.5			
Median	60.2			
Standard Deviation	28.7			
Sample Variance	826.1			
Kurtosis	-1.6			
Skewness	-0.1			
Range	83.0			
Minimum	17.0	>	6.52	-2σ
Maximum	100.0	<	121.5	+ 2σ
Sum	2624.4			
Count	41			
Confidence Level(95.0%)	9.072			



RD= 1.6	Frequency	Cumulative %
1.0	1.0	2%
14.3	9.0	24%
27.6	10.0	49%
40.8	9.0	71%
54.1	4.0	80%
67.4	4.0	90%
More	4.0	100%

RD= 1.6				
Mean	32.2			
Standard Error	3.4			
Median	27.8			
Standard Deviation	22.0			
Sample Variance	483.6			
Kurtosis	-0.7			
Skewness	0.6			
Range	79.8			
Minimum	1.0	>	-11.80	-2σ
Maximum	80.73	>	76.2	+ 2σ
Sum	1319			
Count	41.00			
Confidence Level(95.0%)	6.941			

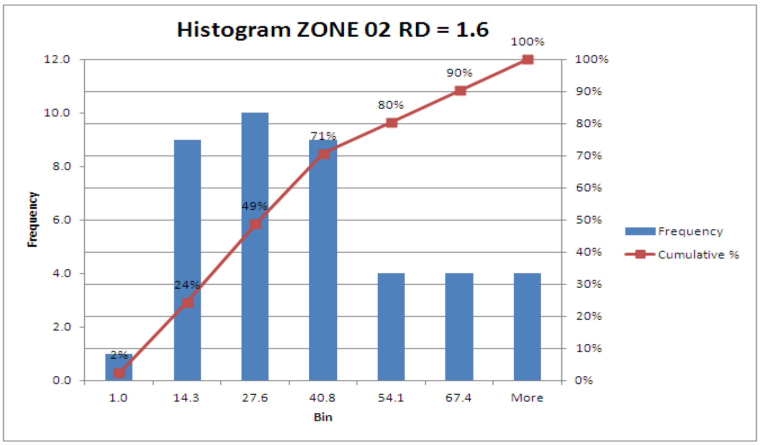


Figure 112 Statistics at a Rd of 2 and 1.6 of the GDCDD's of Zone 02 at Welgelegen. Plus and minus two standard deviations in yellow blocks

This suggests varying geological lithotypes in this zone, which is supported by the profile in Figure 190.

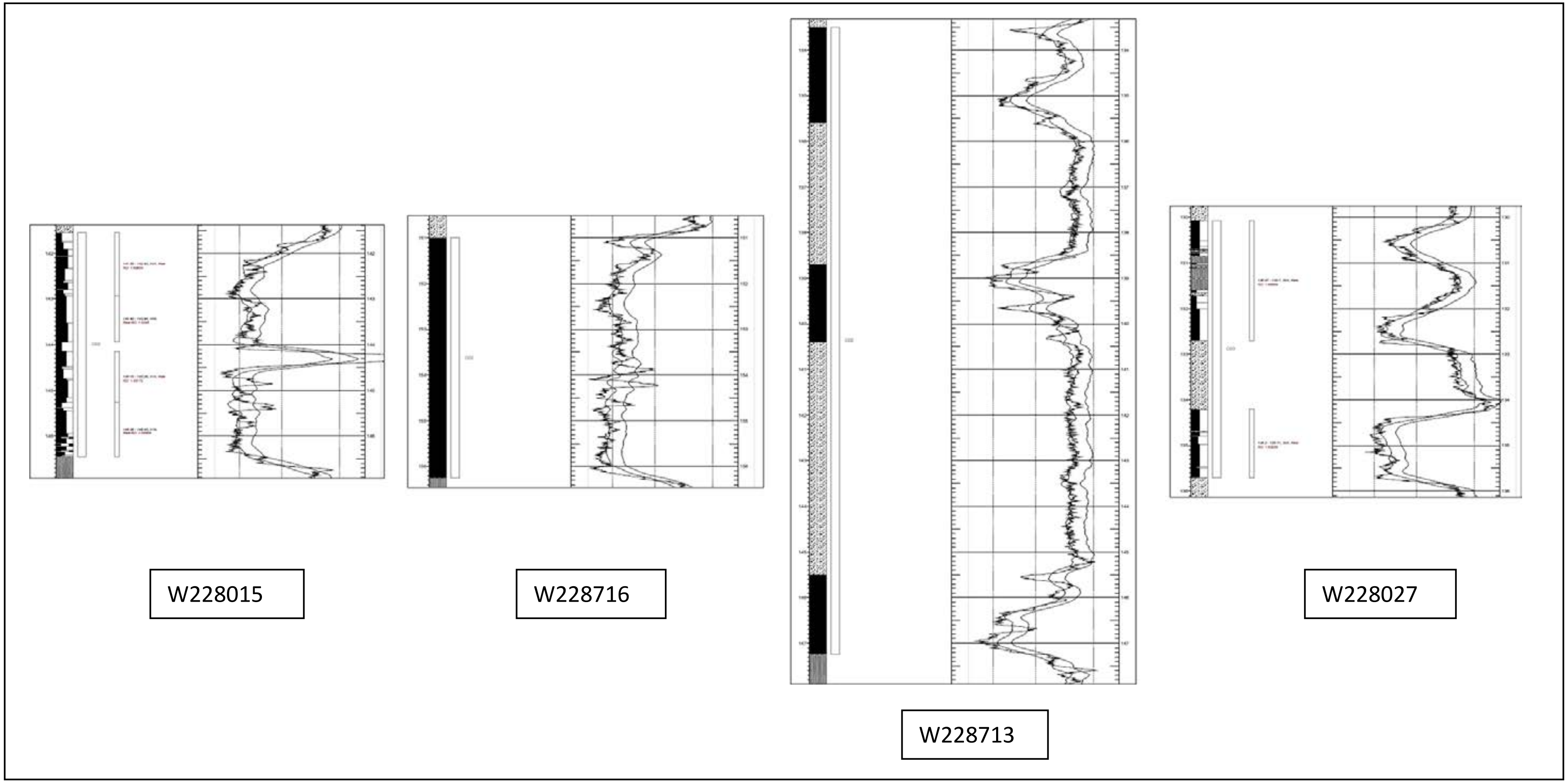


Figure 113 Zone 02 lithological profile illustrates why low, high and average values occur in the GDCDD diagram on Welgelegen

Zone 02 is the thickest developed over Welgelegen (Figure 191), due to the presence of interbedded sandstones.

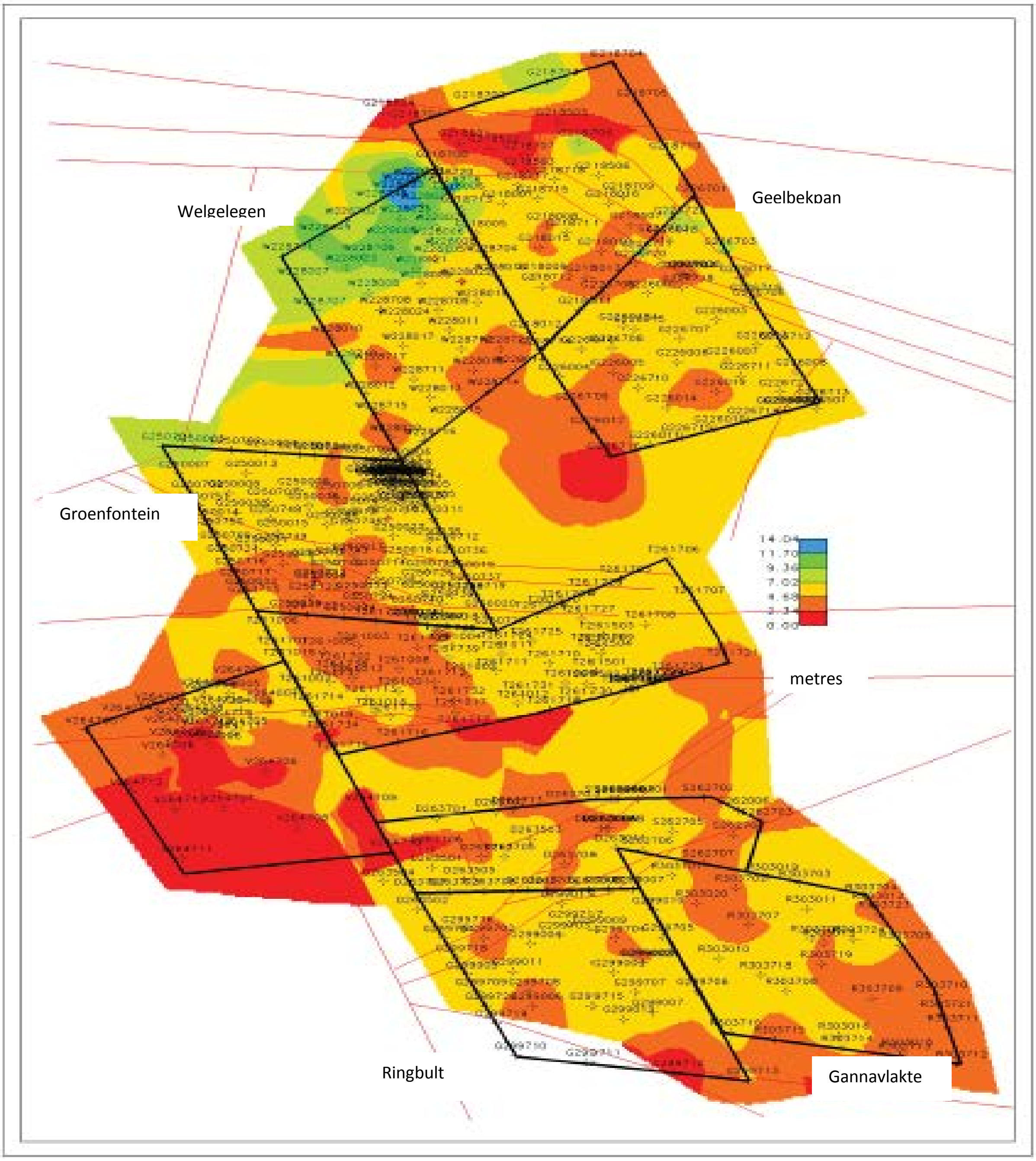


Figure 114 The lateral thickness variation of Zone 02 over the Study area

Coal Zone 01

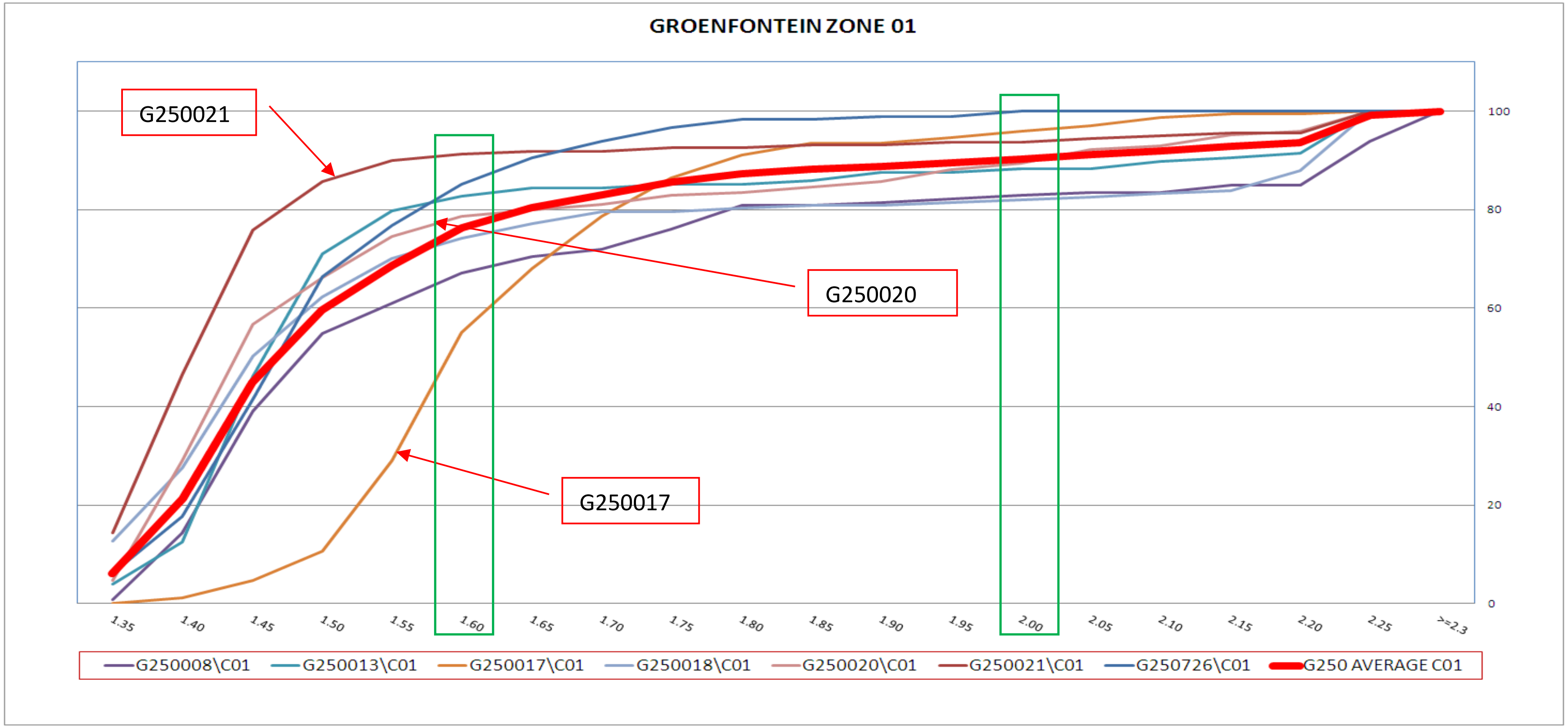
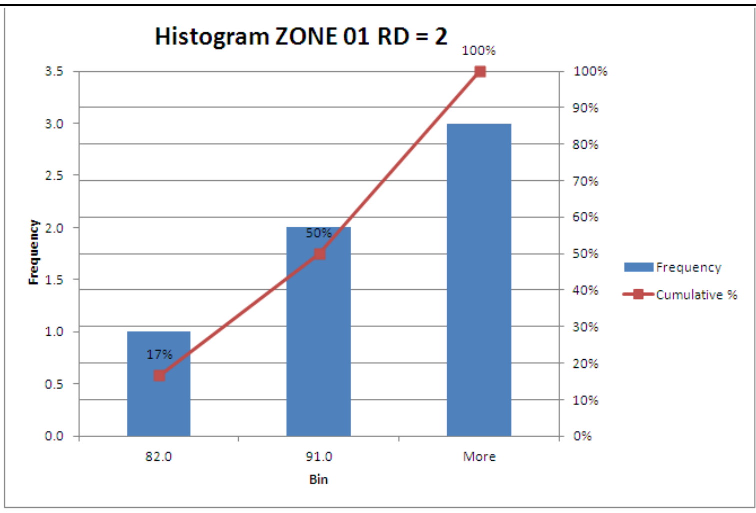


Figure 115 Combined GDCDD of Zone 01

Coal Zone 01 is not developed over the whole Study area and on a large part of Groenfontein , not developed. Due to its thickness of, mostly, less than 2 meters it consists only of one sample (32A) and is not influenced by interbedded sandstones in the way Zone 02 is influenced. In only limited instances has a geologist included a small coal seam above Zone 01 that is separated by a thin sandy layer from Zone 01 (Figure 194) and the influence of this is shown upon the GDCDD of the borehole in Figure 192 (borehole G250017). In Figure 193, the data in the yellow blocks, for 2σ, indicates that for a Rd of 2 and Rd 1.6, both the minimum and maximum values fall inside 2σ as the data is widely spaced.

RD= 2	Frequency	Cumulative %
82.0	1.0	17%
91.0	2.0	50%
More	3.0	100%

RD= 2				
Mean	88.5			
Standard Error	1.8			
Median	90.4			
Standard Deviation	10.1			
Sample Variance	101.3			
Kurtosis	1.6			
Skewness	-1.4			
Range	40.9			
Minimum	58.6	<	68.37	-2σ
Maximum	99.5	<	108.6	+ 2σ
Sum	2743.5			
Count	31			
Confidence Level(95.0%)	3.69			



RD= 1.6	Frequency	Cumulative %
55.0	1.0	14%
73.2	1.0	29%
More	5.0	100%

RD= 1.6				
Mean	76.3			
Standard Error	4.6			
Median	78.7			
Standard Deviation	12.2			
Sample Variance	148.5			
Kurtosis	0.3			
Skewness	-0.8			
Range	36.3			
Minimum	55.0	<	51.95	-2σ
Maximum	91.3	<	100.7	+ 2σ
Sum	534			
Count	7.00			
Confidence Level(95.0%)	1.79			

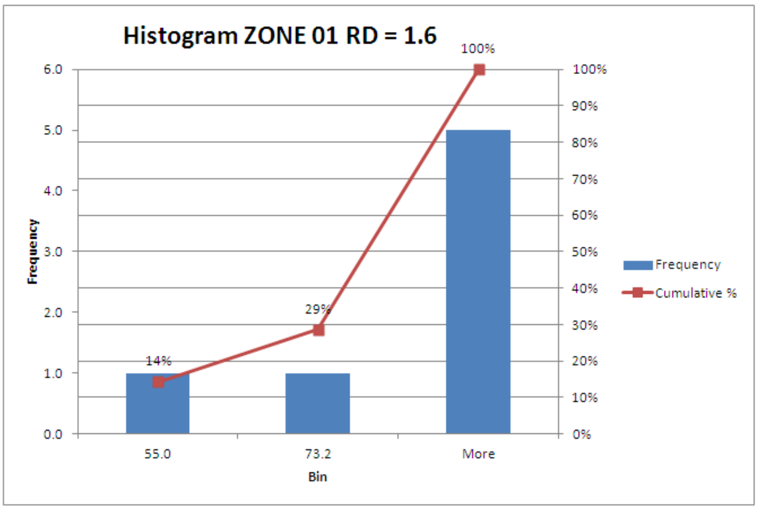


Figure 116 Statistics at a Rd of 2 and 1.6 of the GDCDD's of Zone 01 at Groenfontein. Plus and minus two standard deviations in yellow blocks

The suggests that there is a wider spacing between the individual line graphs. Figure illustrates that the line graphs have a narrower spacing. This suggests some variance in geological lithotypes in this zone, which is supported by profile in Figure 194.

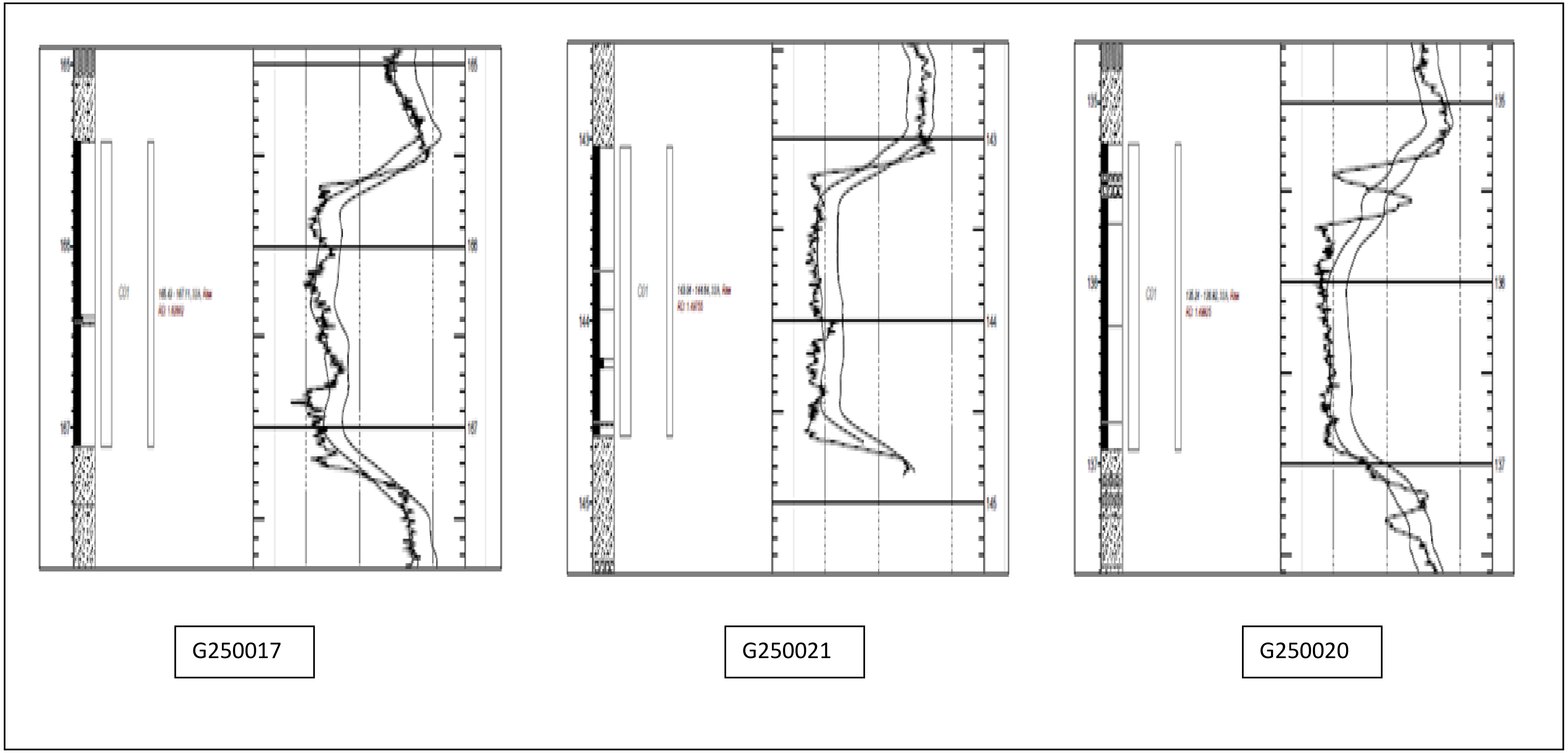


Figure 117 Zone 01 lithological profile illustrates why low, high and average values occur in the GDCDD diagram

Zone 01 is the not developed over most of the Groenfontein area (Figure 195).

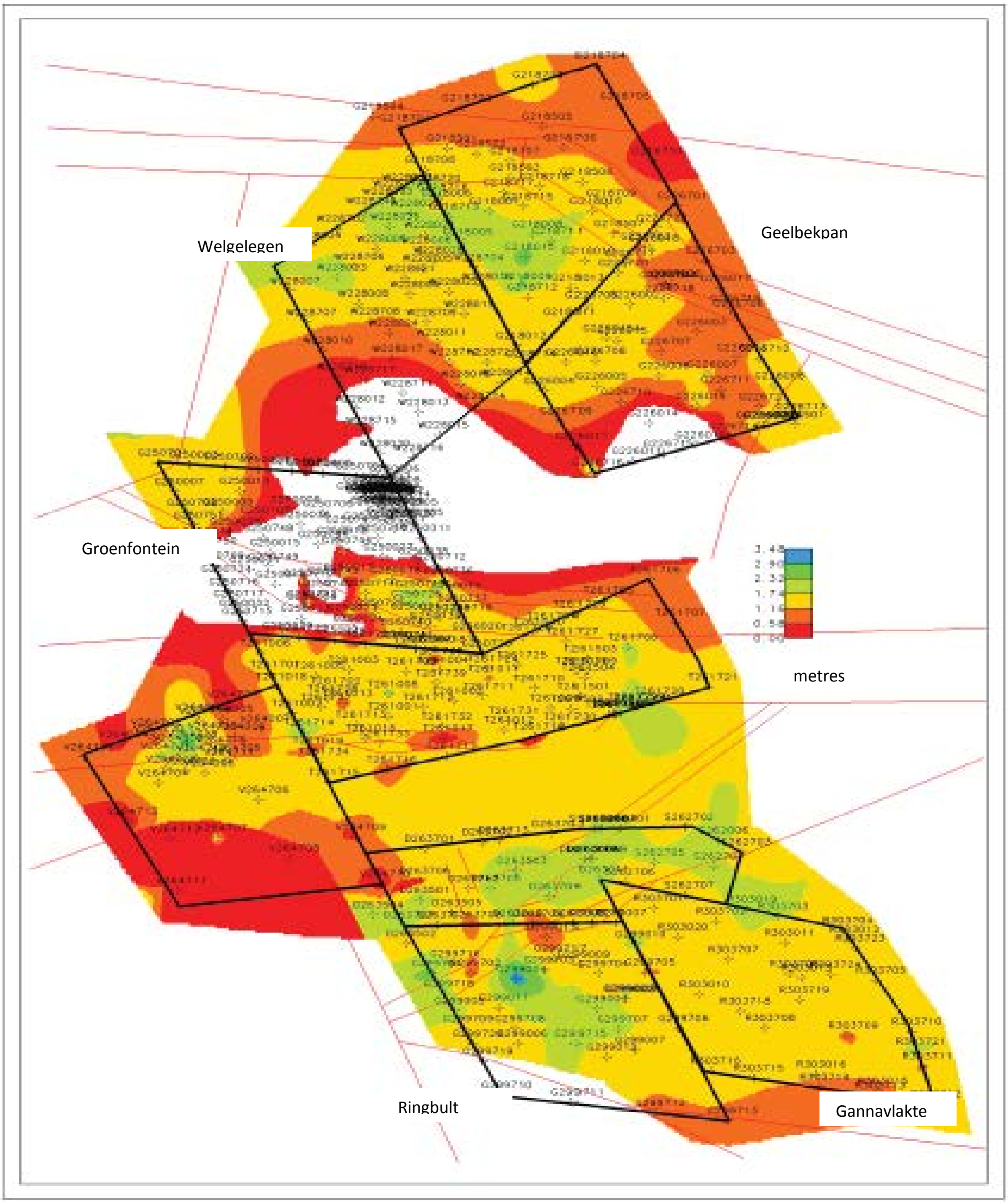


Figure 118 The lateral thickness variation of Zone 01 over the Study area