An investigation of key seismic attribute analysis of the Whitehill Formation in the Karoo Basin

A mini thesis in Petroleum Geology

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ABSTRACT

The object of this study is to determine the thickness of the Whitehill formation based on historic seismic data provided by the Council for Geoscience (CGS). The thickness of the Whitehill was determined through the development of a velocity model and extraction of velocities at each picked location for the horizon in question. Amplitudes data was also extracted to determine if the data could be used to establish possible anomalies that could represent hydrocarbon prospects in the Whitehill formation.

Ninety nine seismic lines were selected for the purpose of this study in the south western part of the Karoo Basin. It has been noted that due to the lack of velocity logs and sonic logs that a velocity model was created to determine depth conversion.

This has been used to create depth and time variation maps, amplitude variation maps and isopach maps across the Whitehill formation.

Essentially the data proved acceptable in establishing the topographical shape and depth of the Whitehill but lacked in estimating the thickness, due to the base of the Whitehill being difficult to discern.

It was concluded that the results produced acceptable results for estimating the depth of the Whitehill and in some areas the thickness of the Whitehill but due to the poor quality of the data it could not produce accurate results from the HVA and the amplitude variation maps.

DECLARATION

I declare that my research entitled “An investigation of key seismic attribute analysis of the Whitehill formation in the Karoo Basin” is my work and it has not been submitted before for any degree or examination in any other university and that all the sources used have been referenced/ quoted and acknowledged.

1. I know that plagiarism means taking and using the ideas, writings, works or inventions of another as if they were one's own. I know that plagiarism not only includes verbatim copying, but also the extensive use of another person's ideas without proper acknowledgement (which includes the proper use of quotation marks). I know that plagiarism covers this sort of use of material found in textual sources and from the Internet.
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Ms. Wahiebah Hoosain (student number: 3420627)

Date: 08 January 2016

"Be grateful for your life, every detail of it, and your face will come to shine like a sun and everyone who sees it will be made glad and peaceful." – Jalal u-deen Rumi

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1.1 SEISMIC ATTRIBUTES

Seismic attributes are physical scientific parameters/ characteristics of seismic waves which can be derived from seismic data. It utilised complex mathematical principles such as geometry, kinematics, dynamics and statistics to identify the geometric and structural characteristics of the subsurface (Li & Zhao, 2014). A seismic attribute is defined as quantity derived from either pre-stack or post-stack seismic data with the use of a mathematical transformation / formula. This would allow the data to be enhanced for better geological interpretation. Some attributes are used to define lithological boundaries and other attributes can be used as direct hydrocarbon indicators.

The use of seismic data initially was used only for lining up of seismic waves to identify structural traps, which could possibly contained trapped oil and gas prospects. However, it was soon discovered that seismic data contained valuable information regarding rock properties such as lithology, fluid composition and physical properties of the rock/sediment.

Seismic attribute analysis is used by Geoscientist to calibrate seismic data in order to reduce noise and provide information regarding lithological properties.

1.2 STUDY AREA

In 1965 SOEKOR was founded to establish the presence of economic oil prospects in the Karoo (Roswell & De Swardt, 1976). This led to the acquisition of several seismic lines and the drilling of boreholes in the Southern part of the Karoo Basin as mentioned previously (Roswell & De Swardt, 1976). The target then was the Bokkeveld and Table Mountain sandstones as well as the Ecca and Beaufort sandstones with fractured Dwyka tillite as a secondary target (Roswell & De Swardt, 1976).

For the purpose of this study the seismic lines in Figure 1.5 have been selected for interpretation and analysis. The quality of the data is poor and for this reason there is significant error associated with the results. Also the quality of the seismic sections varies due to the presence of dykes in the areas. The data in the north is nosier than the data in the south although some seismic lines in the south particularly line BV03 shows anomalous behaviour which is not consistent and that will be seen later on.

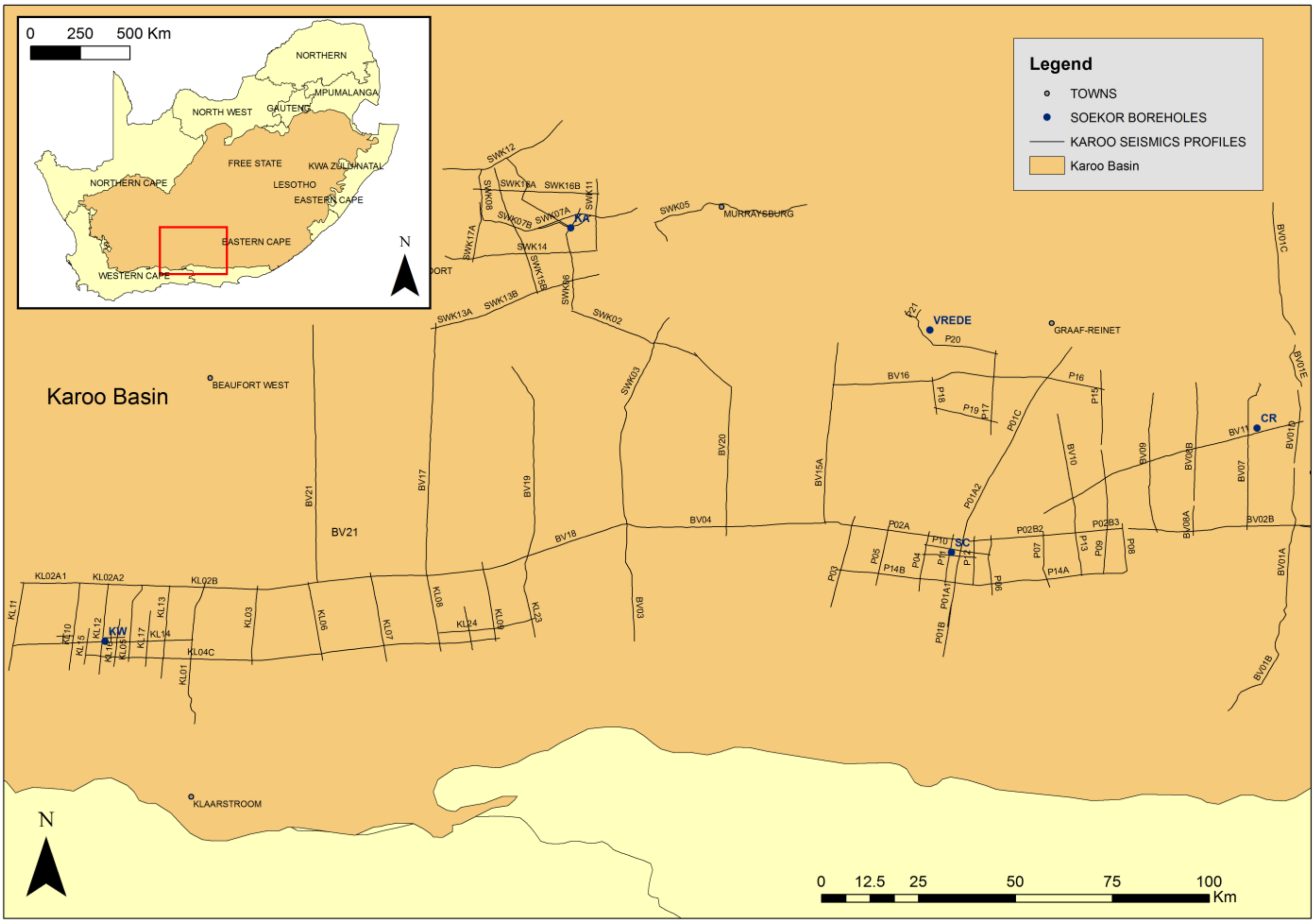


Figure 1.1 Area and seismic lines outlined in the SW part of the Karoo basin for examination

The area depicted in Figure 1.1 illustrates the SOEKOR seismic lines that have been acquired in 1965 and the data selected for this study is in the south western part of the Karoo Basin bounded by Leeu Gamka in the west, Somerset East in the east and in the south Prince Albert and north of Murraysburg. The seismic lines have not been acquired in any gridded style but in single 2D survey lines across the locations of interest.

The exploration wells that were drilled mostly exhibited minor high-pressure low-volume gas shows except for CR1/68 where methane gas was observed flowing strongly from the fractured Upper Ecca shales for a short period (Roswell & De Swardt, 1976). While drilling and field work commenced preliminary studies was done on the source rock and reservoir potential and diagenesis (Roswell & De Swardt, 1976).

The results from this were disappointing and this prompted from 1969 onward SOEKOR began to focus its resources on the Northern Karoo Basin and on Cretaceous Basins (Roswell & De Swardt, 1976). Many of the wells drilled in the Northern Karoo were sunk by mining companies exploring for minerals (Roswell & De Swardt, 1976).

This data has, since SOEKOR became PETROSA, been stored at the CGS in paper format. It has recently been converted from paper into .sgy format by Falcon Oil and Gas which propositioned the CGS to scan and digitise the data on the basis that Falcon Oil and gas get to keep the seismic data (Schreiber-Enslin, et al., 2014).

With the recent interest in the Karoo there has been a movement to re-evaluate the data and look at the Karoo in a petroleum context once again. The data has also been used to address scientific research questions and has led to various research papers, M.Sc.'s Or PhD's.

1.3 Focus of study

The aim of this study will be to look at the key seismic attributes and well information available in the South West (SW) Karoo and interpret the Whitehill formation top and base and depth conversion, extract velocity changes and amplitude variation across the Whitehill formation.

This focused seismic attribute analysis of these seismic lines will be used and examined to establish a velocity model for the data and whether the horizon velocity analysis applied to this data can be used as a hydrocarbon indicator.

1.4 Research limitations

There are 99 seismic lines in total that this study will be looking at for interpretation and analysis. The challenges associated with this study are listed below:

1. No actual velocity data/ Check shot data is available for the seismic data.
2. No well-to-seismic tie could accurately be done.
3. Only one sonic log was successfully done at well SP1/69 (which is not in the area selected)
4. Only one velocity profile was done for CR1/68 (is in the area selected)

5. The poor quality of the data because of it being collected in the 1960's as well as the degradation of the paper records over time in storage.
6. The inability to re-process the data due to them being scanned and digitised paper records

These challenges make it considerably difficult to conclusively establish the results as being accurate and for this reason the results are not conclusive.

1.5 HYPOTHESIS AND RESEARCH QUESTION

Utilising the relevant seismic lines and well information in the Karoo basin, this study aims to identify potential sites within the seismic data that may be sites of possible hydrocarbon prospects. Focusing on the Whitehill formation and the seismic attributes displayed by its seismic signature. Horizon velocity analysis and amplitude variation will be used to establish if the velocity data can be effectively used to identify regions or areas of good porosity and hydrocarbon potential.

1.5.1 QUESTIONS:

i. What is the depth variation and/or topographic shape of the Whitehill formation below the surface?

ii. What is the depth and thickness of the Whitehill formation

iii. What is the amplitude variation (AV) for the Whitehill formation?

iv. What is the horizon velocity analysis (HVA) for the Whitehill formation?

1.6 DEPOSITIONAL ENVIRONMENTS

The Karoo Basin is made up of two Supergroups the Karoo Supergroup and the older Cape Supergroup. The Cape Supergroup forms part of the Greater Cape Basin which exhibit more a shallow marine, deltaic and fluvial setting which thickens southwards. This developed an east-west trending depositional axis (from Early Ordovician to Early Carboniferous). The Cape Supergroup is made up of the TMG (Table Mountain Group), Bokkeveld Group and the Witteberg Group (Geel, et al., 2013).

The Karoo Supergroup consists of the Dwyka, Ecca and Beaufort Groups. These groups are about 550m deep and comprise of deep marine to fluvial deposits which are aged between the late Carboniferous to the early Jurassic (Flint, et al., 2011).

The Dwyka is estimated to be deposited when Gondwana drifted over the South Pole and the formation of glaciers and sheet ice deposited successions of diamictites, varves and glacio-fluvial deposits (Geel, et al., 2013). The Ecca Group is mainly siliciclastic sediments topped with fluvial sediments of the Beaufort Group (Geel, et al., 2013).

There is a growing consensus that the diamictites in the Dwyka and lower Karoo have been deposited in an open marine environment, whereas others suggest a marine-lacustrine type of setting (Geel, et al., 2013). This setting evolved due to a prograding of basin sediments and this cause deposition of delta-slope sediments resulting in a more fluvial environment during the deposition of sediments in the Beaufort Group (Geel, et al., 2013).

The progression of the Cape Fold Belt in the north promoted intruding of the mountain range inland this facilitated the deposition of the fluvial deposits of the Stromberg Group to be deposited further north (Geel, et al., 2013). At this time the climate changed and became semi-arid resulting in the deposition of coarser grained clastic sediments as seen in the Katberg and Molteno formations (Geel, et al., 2013). The last phase of deposition exhibits wadii and playa lake type Facies producing the Elliot Formation and the sand dunes associated with the Clarens Formation there after (Geel, et al., 2013).

CHAPTER TWO:

2 LITERATURE REVIEW

2.1 KAROO BASIN: GEOLOGICAL BACKGROUND

The Karoo Basin covers a considerable amount of South Africa spanning more or less 700 000km² area (Catuneanu, et al., 1998) (Schreiber-Enslin, et al., 2014). The basin is hypothesised to have formed during the Late Carboniferous-Middle Jurassic retroact foreland basin which developed in front of the Cape Fold Belt (CFB) (Catuneanu, et al., 1998).

The CFB resulted from the subduction zone which formed at the time when the Paleo Pacific Plate was subducted underneath the Gondwana plate (Catuneanu, et al., 1998). This however is disputed by Tankard et al. 2012 who proposes that it was a strike-slip tectonic regiem that formed the CFB and the Karoo Basin is a resulting felxural foreland basin. Lindeque et al. 2011 apposes both theories and advised that the CFB could be a Jura-type fold belt where it formed due to arc-continent collision with a subduction zone in the south (Lindeque, et al., 2011). Figure 1.2 is an image which illustrates what type of tectonic environment and land structure existed at the time of Gondwana's formation (Tankard, et al., 2009).

Figure 1.2 Reconstruction of what the tectonic environment and continental morphology looked like at the time Gondwana existed (Tankard, et al., 2009).

At the time of deposition it is believed that the Karoo basin covered a greater area than which it does today and the sediments which make up the Karoo Basin are direct evidence of their depositional environment (Catuneanu, et al., 1998).

The sediments associated with the Karoo Basin are in the Karoo Supergroup and are illustrated in the stratigraphic column and the summary of tectonic history of the Karoo Basin in Figure 1.3. The sediments observed are mostly controlled by orogenic cycles defining episodes of loading and unloading in the CFB (Catuneanu, et al., 1998).

Deposition occurred at the onset of the late Carboniferous across what was the supercontinent Gondwana and the time of this deposition proceeded until the break-up of Gondwana in the Middle Jurassic approximately 183 Ma (Geel, et al., 2013).

The Karoo basin is topped by Basaltic lava flows (i.e. Drakensberg Group) and it also has a network of dolerite dykes and sills that have been of much interest over the years with the highest concentration of these dykes being in the eastern part of the basin. A detailed illustration of the stratigraphic formations that make up the Karoo Basin can be seen in Figure 1.4.

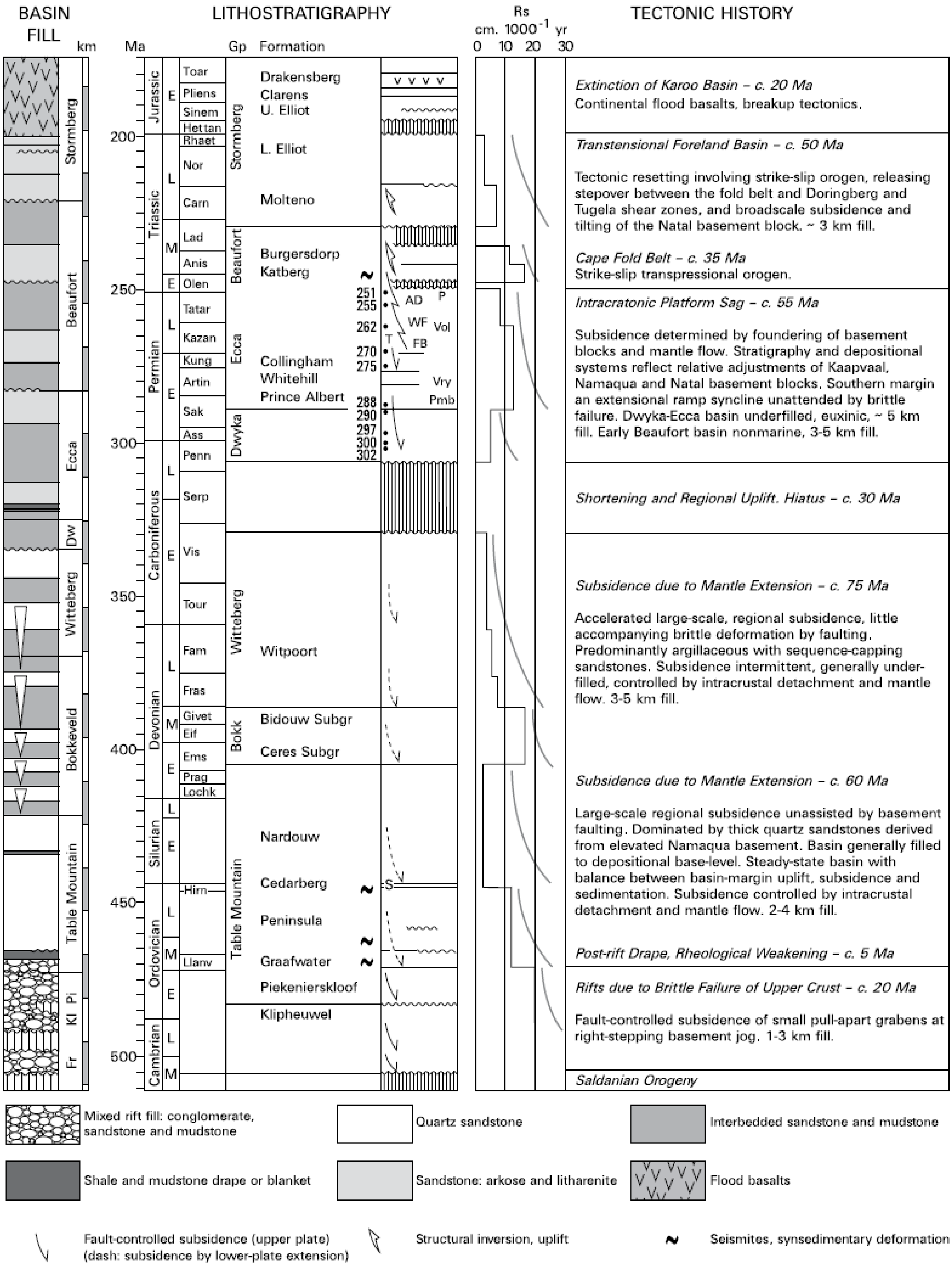


Figure 1.3 Stratigraphic and Tectonic evolution of the Karoo Basin (Tankard, et al., 2009).

Group	Formation		Depositional Environment
Drakensberg			Lavas
Stromberg	Clarens Frm.		Aeolian and playa
	Elliot Frm.		Meandering rivers and playa
	Molteno Frm.		Braided rivers
Upper Beaufort	Tarkastad Subgroup:		
	Burgersdorp Frm.		Alluvial fan and braided rivers
	Katberg Frm.		Meandering rivers
Lower Beaufort	Adelaide Subgroup:		}
	Southwestern Karoo	*South-eastern Karoo*	
	Teekloof	Balfour	Meandering RIvers
	Abrahamskraal	Middleton	
		Koonap	
Upper Ecca	Waterford		Delta front sands
	Fort Brown		Prodelta slop muds
	Southwestern Karoo	*South-eastern Karoo*	
	Laingsburg	Ripon	Basin Turbidites
	Vsichkuil		
Lower Ecca	Collingham		Marine shales
	Whitehill		Carbonaceous black shale layer consisting of alternating chert lenses
	Prince Albert		Fine grained silt and sandstones with gradational contact
Dwyka (Tillite)			Glacial diamictites and muds

Figure 1.4 Stratigraphic column and depositional environment for the Karoo basin South-east and Southwestern regions (Schreiber-Enslin, et al., 2014 modified).

2.2 PREVIOUS RESEARCH IN THE KAROO

There has been various research work in the Karoo basin that have been done in the past such as Hughton et.al (1953), Kingston et.al (1961), Henson et.al (1965), Burollet (1966), Oomkens (1967), Mingramm (1968), Habicht (1974), Busch (1974) and Wopfner (1974). All these authors did the preliminary research such as the general qualifications of hydrocarbon prospects in the Cape-Karoo Basin prior to the seismic surveying for the Karoo Basin.

The consensus from all these research papers is that the Cape-Karoo sediments are unlikely to contain any oil. This later after much investigation in the Karoo basin has proven to be true at that time (Roswell & De Swardt, 1976).

Pysklywec and Mitrovica in 1999 looked at the tectonic evolution of the Karoo Basin and put forward that the long wavelength factor of the basin subsidence was a result of the deflection of the lithosphere due to mantle flow added with the adjacent subduction which resulted in the present day elevated topography (Pysklywec, et al., 1999). They also developed numerical models for mantle convection to display that a shallow dipping slab is able to resolve and explain the long-wavelength subsidence of the Karoo Basin (Pysklywec, et al., 1999).

Tankard et.al (2009) also evaluated the tectonic evolution of the Cape and Karoo Basins and the paper stipulated that a three-stage tectonic evolution of the crust and long periods of regional subsidence associated with faulting and erosional truncation took place (Tankard, et al., 2009). A seismic evaluation of the Karoo basin using seismic reflection data and deep –burial diagenesis studies conducted by Tankard (et. al 2009) indicated that the Cape Fold belt orogeny started in the Early Triassic.

Branch et.al (2007), which formed part of the Inkaba ye Afrika project, examined magnetotelluric data for three profiles across the Karoo Basin and concluded that the high conductivity layer is an effective marker horizon for the lower Karoo (Ecca Group) and an indirect marker to the top of the Namaqua basement (Branch, et al., 2007).

Flint et.al (2010) looked at the depositional architecture of the Karoo stratigraphy in the Laingsburg area or depocentre. There are two known depocentres in the Karoo Basin the Laingsburg depocentre and the Tanqua depocentre. The two depocentres differ in structure where the Tanqua is relatively flat and un-deformed the Laingsburg strata are folded and faulted (Flint, et al., 2011).

Lindeque et.al (2011) and Lindeque (2008) accessed a deep crustal profile across the Southern Karoo seismic line (IyA-200501) which was acquired via an alliance between the Inkaba yeAfrika project and the Council for Geoscience (Lindeque, 2008).

Lindeque's interpretation showed sub-horizontal Cape Supergroup sediments overlying uncomformably flat and shallow south dipping NNMB (Namaqua Natal Metamorphic Belt)for approximately more than 100km as seen in Figure 1.5 (Lindeque, et al., 2011). Lindeque further interpreted the structure and structural evolution of the Karoo sediments related to the upper crust, middle crust and lower crust which was relevant for the deep crustal seismic line she based her work on (Lindeque, et al., 2011).

Lindeque's seismic line could not be not be utilised in this study due to the deep crustal type resolution used for acquiring her seismic data which would have not been relevant for the scale this project is focused on.

Also in line with the Inkaba ye Africa collaboration between the Council for Geoscience and GeoForschungsZentrum (GFZ) in Potsdam Lettica Loots also looked at seismic data in the Karoo sub parallel to Lindeque's line and closer to Beaufort West (the town) (Loots, 2014). Loots processed the raw data and did a structural and stratigraphic interpretation of the line SAG03-92. The line was approximately 100km long and was collected by the South African National Geophysics Programme (Loots, 2014).

Most recently Scheiber-Enslin et.al (2014) & (2015) have revived the old seismic data that SOEKOR (Southern Oil Exploration Company (Pty.) Ltd) collected in the 1960's which is almost 5 decades later. This research produced by Scheiber-Enslin has opened the door to more stratigraphic and structural research in the Karoo basin using the archived data (Schreiber-Enslin, et al., 2014). The research involved mapping the prominent horizons in the seismic data and also developing a depth conversion for the data which lacked accurate velocity data in order to produce depth maps for the Karoo basin (Schreiber-Enslin, et al., 2014).

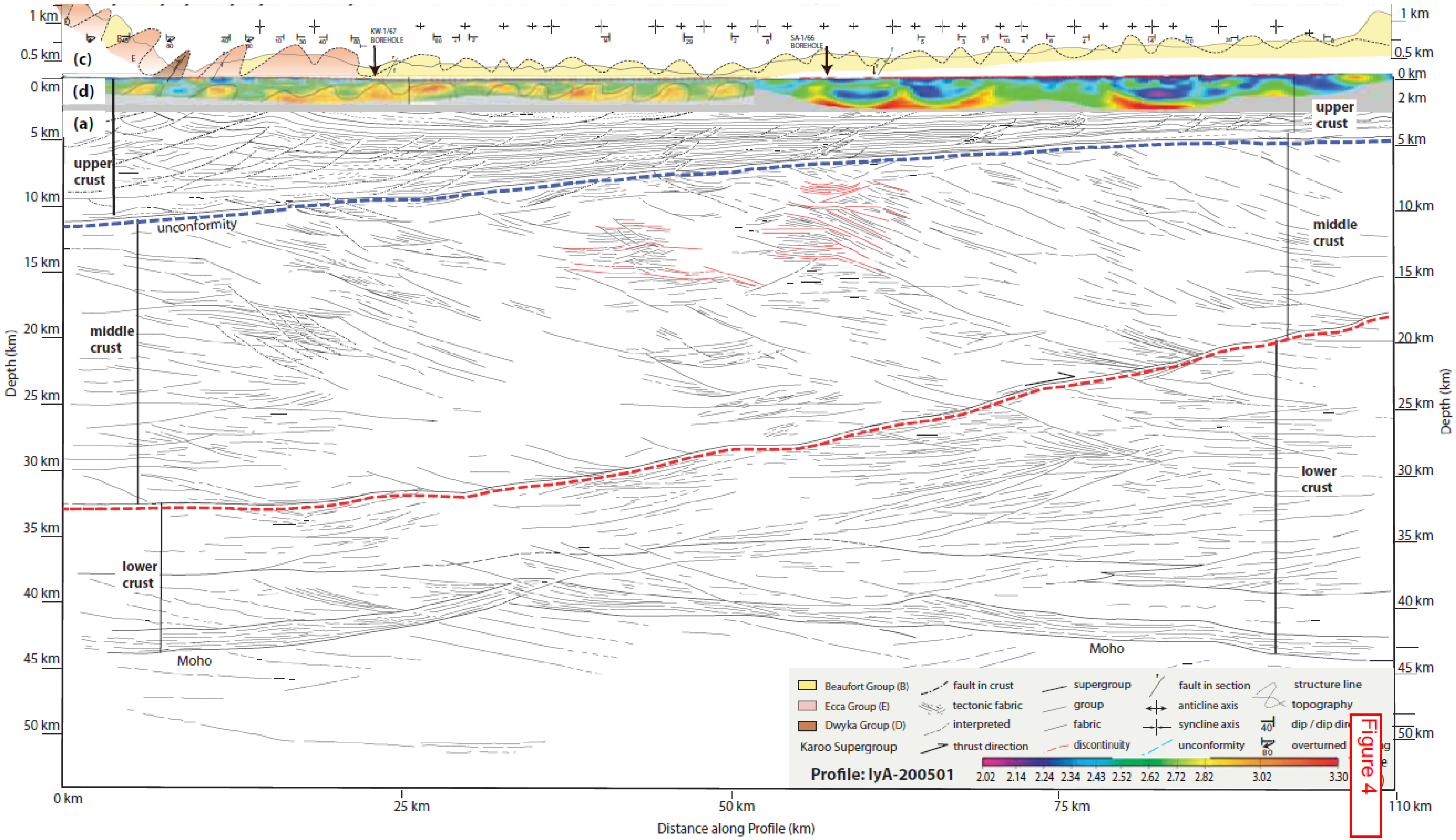


Figure 1.5 Lindeque's interpretation of the seismic profile IyA-200501 cutting across the Karoo from North to South (Lindeque, et al., 2011)

2.3 HYDROCARBON EXPLORATION

Haughton et al (1953) theorised that the prior oil accumulations that could have once been in the Karoo Basin must have dissipated along fractures that developed at the time of the Cape Folding event. Kingston et.al (1961) stated that the upper Dwyka shales are good source rocks and the middle Ecca sandstones which are fair reservoirs. This has since then been re-evaluated and currently the Whitehill and Prince Albert shales are the most likely reservoirs and sources for shale gas instead of oil (Geel, et al., 2013) (Shell South Africa, 2015) (Cole, et al., 1994).

It was in 1965 that SOEKOR began exploring for oil in the South African Karoo Basin four years after Kingston Kingston et al. (1961). This prompted the drilling of exploration wells and the acquiring of seismic surveys in the South Western Karoo, which at the time was estimated to be the best location for possible oil prospects. SOEKOR found gas instead of oil and in the form of tight shale gas in the Ecca formations (Fatti & Du Toit, 1970). Fatti & Du Toit (1970) and Fatti (1978) detailed the field techniques, results, data quality and an interpretation depth section for the SW Karoo of this data (FATTI, et al., 1970).

The results from Fatti (1970) revealed that the seismic data acquired in the SW Karoo by SOEKOR deteriorated in quality northwards as the number of dolerite sills increased, however the data is still sufficient for mapping (Fatti, 1970).

Also two prominent reflectors could be mapped in the data which is the top of the Dwyka formation and base of the Table Mountain Formation (Fatti & Du Toit, 1970) and the top of the Whitehill in the most of the profiles (Schriber-Enslin, et al., 2015) (Schreiber-Enslin, et al., 2014).

At this time in the 1970's shale gas was not economical to produce and the money and resources required to produce it would have been to costly and this resulted in most of the wells to be abandoned and the seismic data was given to SOEKOR and then later when SOEKOR underwent transition and became PETROSA the data was handed over the South African Geological Survey at the time now the Council for Geoscience.

Cole and McLachlan (1994) did a detailed petroleum analysis of the Whitehill for the Karoo Basin from the SOEKOR cores. They did Rock-Eval analysis, thermal maturation, and Pyrolysis and vitrine reflectance for the cores and recovered core for the Whitehill, Tierberg shales, Prince Albert Shales, Dwyka formation and the Karoo sequence (Cole, et al., 1994).

They concluded that the Whitehill formation can be considered as a "marginally economic resource" and that the Whitehill may have had oil generating potential around borehole DP1 north east of Hopetown but this was destroyed by burial and thermal maturation of the Whitehill in the southern part of the area (Cole, et al., 1994).

Vermeulen (2012) commented on the perspective on the hydraulic fracturing of the potential shale gas in the Karoo. This method of hydraulic fracturing has been under much scrutiny in South Africa since the interest in shale gas has surfaced. A nation-wide debate has been sparked as to whether the Karoo Basin has shale gas or not and what environmental implications would it have on the ground water in the Karoo (Erismann, 2011) (deWit, 2011).

Vermeulen (2012) concluded that shale gas may be a large part of the USA energy production but in South Africa there needs to be significant amount of issues resolved before we can invest in shale gas and make it work for South Africa.

Geel et.al (2013) delved into the shale gas characteristics of the Permian black shales in South Africa with detailed lithological, sedimentological, petrographical and geochemical analyses of the three lower formations of the Ecca Group in the Eastern Cape. Geel et.al (2013) stated that the TOC of the Whitehill averaged at 4.5% and this satisfied conditions for gas bearing shales.

Presently at the turn of the new millennium there has been an increased interest in the Karoo because shale gas has become more and more economical in countries such as the USA and Canada. There are however many different schools of thought on whether the Karoo actually has gas or if the gas can even be extracted and some also dispute the estimated volumes that have been brought to the fore (Vermeulen, 2012) (de Wit, 2011) (Shell South Africa, 2015).

This has all sparked a new found interest in the Karoo as a possible resource for South Africa, a country with serious energy issues. Many believe that this will solve the economic instability the country has been experiencing. Companies such as Shell, EXXON Mobile and Total have been looking to South Africa as a possible country with un-discovered petroleum prospects.

Shell was awarded a Technical Cooperation Permit by the Petroleum Agency of South Africa in 2009 to enable them to examine the Karoo and establish the gas potential it has (Shell South Africa, 2015). This base line study then resulted in Shell applying for three separate exploration license areas in the Karoo in December 2010 (Shell South Africa, 2015). These three areas were in the Western Cape, Eastern Cape and Northern Cape and constituted approximately 30 000 km² each (Shell South Africa, 2015). This application process requires that an EMP (Environmental management plan) be included which requires that public consultations be done (Shell South Africa, 2015).

Since then gas exploration in the Karoo has had heavy opposition from land owners and concerned citizens regarding the environmental impacts and ground water contamination that could occur in the Karoo. Many people think that even if there is gas beneath the Karoo it might not be worth the environmental damage that could result from it.

The most recent estimate of shale gas in the Karoo was done by Decker and Marot in 2012 and they estimate that the Southern Karoo could have reserves from 32Tcf to approximately 485Tc f (Geel, et al., 2013). This estimate is based on the analysis that the Karoo formations thin toward the north (Geel, et al., 2013).

In a summary the Whitehill may have been an unfavourable target for oil shale in the past potential for shale gas is more promising with the developments of recent research (Geel, et al., 2013)(Cole & McLachlan, 1994). There has also been some speculation that the Dolerites may not even hinder the potential of the source rock but may be creating trapping mechanisms for the gas to be trapped below.

2.4 SHALE GAS POTENTIAL OF THE KAROO: SOURCE AND RESERVOIR

Shale gas formations are termed “unconventional” reservoirs and in comparison to “conventional reservoirs they are low permeability reservoirs such as shale and coal. Conventional reservoirs are gas or oil reservoirs that are either sand or carbonates which have a good permeability for flow and conventional reservoirs are easier to drill and extract hydrocarbons whereas the unconventional reservoirs because of the low permeability this type of reservoir needs to be stimulated to extract the hydrocarbons (U.S. Geological Survey Powell Center for Analysis and Synthesis, 2010).

Shale gas a term widely used to describe natural gas that is essentially “trapped” in tight organic carbon-rich shale layers below the subsurface. Previously, these type reservoirs have been overlooked due to the high economic implications in the extraction there of recently, however there has been a reawakening and many exploration companies are now looking for hydrocarbon prospects in places they termed unfavourable before (Arthur, et al., 2008).

In the case of shale gas the common method of stimulation is hydraulic fracturing which comprises of pressurized fluids being injected into the shale formations and creating fractures within the shale for the gas to flow out into. Sand with fluid is pumped into the fractures to keep them open and composition and volume of this fluid depends on the geological structure and make up (see Figure 1.6).

The method of hydraulic fracturing has been used for decades in limestone and sandstone reservoirs but it was not till the 1970’s that great efforts were made to apply the technology to shale gas reservoirs (U.S. Geological Survey Powell Center for Analysis and Synthesis, 2010).

Horizontal drilling is also a method largely associated with shale gas reservoirs. This horizontal drilling is used to achieve the maximum amount of fractures in the shale and they provide extra passage ways for the gas to flow out into (U.S. Geological Survey Powell Center for Analysis and Synthesis, 2010).

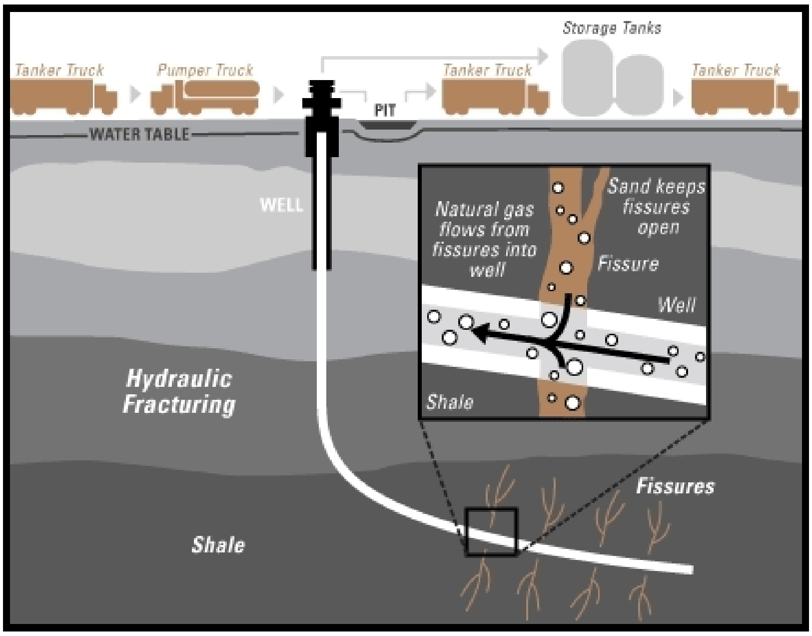


Figure 1.6 Schematic Diagram of the process of Hydraulic Fracturing of shale gas reservoirs (Anna, 2014)

The focus on the Karoo Basin in South Africa has been largely based on previous exploration in the Karoo by SOEKOR and this has created a justification for the further research, exploration and the improvement of the data and knowledge in the Karoo.

The discovery of shale gas has erupted in many countries such as the U.S., Canada, and Japan. The promise of possible hydrocarbon riches means a great deal to the economic progression and development of a country (BELLELLI, 2013). Shale gas has been termed “unconventional” because of the unconventional techniques that are required to extract the gas which would require hydraulic fracturing (BELLELLI, 2013).

In the respect to oil and gas exploration there are always environmental impacts and with hydraulic fracturing there have been several concerns from the public in a region where shale gas exploration has been proposed (Arthur, et al., 2008). The Karoo is no different there are concerns of contamination of groundwater, damaging the property of farmers in the Karoo and even the geological heritage sites that exist there (Erismann, 2011).

Intially the Whitehill formation in the Ecca Group has been predimonintley looked at as a source rock for shale gas. It has recently, however been undertaken to look at the Prince Alber Formation, which also has a high organic content (Cole & McLachlan, 1994).

The Whitehill was looked at in as an oil shale reservoir in the past. An oil shale by definition contains very liitle “free oil” and needs to be heated artifically to convert the kerogen to oil(Cole & McLachlan, 1994). The Whitehill has been characterised and termed as “siliceous” shale or “sapropelic-humic “ shale or “marinite” (Cole & McLachlan, 1994).

Essentially based on previous research the Whitehill is the most likely formation to contain shale gas, but more research and investigation needs to be done to accurately establish this.

2.5 SEISMIC ATTRIBUTES

2.5.1 WHAT IS SEISMIC ATTRIBUTE ANALYSIS

Seismic attributes are categorised in to two physical and geometrical attributes. Physical attributes are determined by wave propagation, lithology etc. which can be then classified into pre-stack and post-stack attributes and each of these have subdivisions for instantaneous and wavelet. Where instantaneous are computed sample by sample and show continuous changes of attributes in time and space. Wavelet attributes in contrast represent characteristics of the wavelet and the amplitude spectrum. (Subrahmanyam & Rao, 2008)

Geometrical attributes are features such as dip, azimuth and discontinuity. For example he dip attribute/ amplitude of the data would correspond to the dip of seismic events, which means that they dip helps to identify faults. The amplitude of the data corresponds to the azimuth attribute which helps discern the azimuth of the max dip direction of a seismic feature (Subrahmanyam & Rao, 2008).

There are various seismic attributes such as post-stack, instantaneous phase, instantaneous frequency and post stack attributes such as RMS velocities, Geometrical attributes which can all be derived from seismic data to help us better interpret the data (Subrahmanyam & Rao, 2008).

2.5.2 AMPLITUDE VARIATION

Amplitude data was first used in the 1970’s as hydrocarbon indicators and this is how it was established that there was a relationship between amplitude “bright” spots and hydrocarbon traps (Avseth, et al., 2010). This was when amplitude data became important and it was noted that amplitudes changed with rock lithology and pore fluids (Avseth, et al., 2010).

The presence of light oil in soft sand causes the compressibility of a rock to increase significantly and associated with this is a drop in velocity resulting in the amplitude decreasing to a negative “bright spot” (Avseth, et al., 2010). Alternately, if the sand is hard and saturated with brine this could also produce a bright spot.

In the case of tight shale gas characterising a shale gas reservoir can be done using geophysical methods although the methodology is rather different compared to conventional reservoirs. The characterisation of a shale gas reservoir requires the application of particular tools and need to be applied with caution. The characterisation of shale gas reservoirs are still evolving and developing to combat the pitfalls with regard exploration of unconventional reservoirs.

The extraction of amplitudes for the purpose of this study was done in the name of scientific interest. Although the values achieved for bight and dim spots could not be conclusively be stated these ranges differ from area to area based on the regional geology.

2.6 VELOCITY MODELLING

Seismic velocity is a key attribute in petroleum exploration and can be used as a direct hydrocarbon indicator (DHI). Velocity data from seismic data and well logs are vital in differentiating lithologies, facies and extracting information regarding fluid types, reservoir attributes, burial and thermal history and even generating synthetic sections used for interpreting seismic data (Hongtao, et al., 2009).

There are several factors that affect velocity anomalies such as a) Fluid Density, b) Matrix Density, c) Water Saturation, d) Porosity, e)Effective Pressure, f) Rock Composition, g) Granularity, h) Cementation, i) Temperature and j) age /depth. According to Hongtao et al.(2009) it is suggested that the dominant factors that enfluence velocities vary from area to area.

According to Strovoll et.al (2005) it was established the relationship between velocity and depth does not follow a linear relationship as is normally assumed with acoustic velocities of sedimentary rocks and their burial depth. In essence he concluded that general linear velocity depth function is not an accurate analysis of the depth conversion, pore-pressure prediction or even basin modelling.

This in mind it must be noted that for the purpose of this study we are estimating the value in creating a general velocity model and from this a depth conversion to estimate the depth of the Whitehill in the Karoo Basin. There will be associated error but the data in the area is limited and it will be considerably costly to acquire more data. Also previous well data namely CR and WE both take into account a linear relationship and to avoid more error a linear relationship has been utilised for this study.

Japsen (2006) contrary to Strovoll et al (2005) did advocate that a general velocity depth function could be utilised for seismic analysis of sedimentary rocks. This has started a debate on whether there is value in generating a general velocity –depth function.

The bright spot technique for velocity data has been successfully applied as a DHI in parts of the world, but this method has been seen to only be effective in shallow gas reservoirs no deeper than 2100 meters (Hongtao, et al., 2009). The bright spot technique is mainly controlled by velocity parameters and for this it is vital to understand how velocities change in your geological setting. The effects of seismic velocity for identifying hydrocarbon prospects require scrutinising to provide accurate estimation for future exploration in a basin (Hongtao, et al., 2009).

The Karoo Basin is a special case due to the fact that the seismic data available in the Karoo Basin was acquired 50 years ago and this is the reason for the poor quality. This along with the failure of SOEKOR to log the sonic and velocity logs for most of the wells in the Karoo has made it considerably difficult to achieve accurate results.

CHAPTER THREE:

3 METHODOLOGY

3.1 SOEKOR DATA

3.1.1 SOEKOR WELLS

The SOEKOR wells used in this study have been listed below:

1. AB1/65
2. CR1/68
3. SA1/66
4. KA1/66
5. KL1/65
6. KW1/67
7. OL1/6
8. QU1/65
9. SC3/67
10. VR1/66
11. WE1/66
12. SP1/69

Wells AB1/65, KW1/67, CR1/68, SC3/67, KA1/66 and VR1/66 are wells that are in the area of interest in Figure 1.1 and wells WE1/66, OL1/65, QU1/65, SA1/66, KL1/65, SC3/67 and SP1/69 are outside the area but relevant for the production of a general velocity model for the seismic data. Wells WE1/66 and CR1/68 had some velocity data in the form of a velocity profile of sonic log. This data was incorporated to establish a better velocity model for the data.

Schreiber-Enslin, et al., 2014 created a velocity model for the depth conversion for the data using only well data from WE1/66 where as in this study we utlised the sonic log from WE1/66 and the velocity profile from CR1/68.

3.1.2 SOEKOR SEISMIC PROFILE DATA

3.1.2.1 DATA ACQUISITION

The seismic reflection technique was used due to it being the most accurate and reliable geophysical tool at the time (1965) (Fatti, 1987). There had been little or none seismic reflection surveying done in the

Karoo basin as there had been some limited reflection work done by the Geological Survey of South Africa (currently the Council for Geoscience) on an experimental basis in the extreme western part of the basin (Fatti, 1987).

A three month contract was signed between SOEKOR and the British geophysical contracting company called Seismograph Service Limited. They then went ahead and did some experimental reconnaissance traverses in the southern Karoo (Fatti & Du Toit, 1970). The first line was shot between November 1965 and February 1966. This line was a north-south trending traverse shot through Beaufort West and southward past Seekgat across outcropping Dwyka tillite and north almost to Loxton (Fatti & Du Toit, 1970).

A dynamite source of 50lb was used in 15-18m deep hole and some of the lines in the eastern Free-State were shot using vibrosies and some using weight drop methods (Fatti, 1987). A majority of the lines are single fold with an average of 24 traces per shot point. Although there are a few 3 and 6 fold stacks which was used in areas with reduced quality (Fatti, 1987).The quality of the data deteriorates northwards as the concentration of dolerite sills increases (Fatti, 1987).

13000 line kilometres of seismic data was shot between 1966 and 1971 with most of the lines in the Southern part of the Karoo Basin the lines used for this study form part of those lines as seen in Figure 1.1. A conventional split spread was used with a standard array of 24 groups of geophones and after a series of experiments a consensus was reached on the spread arrangement (see Figure 1.7). The distance between each group of geophones was set as 165 ft. (British feet) or approximately 50.29 m. This gives a distance of 1898 ft. (578.51 m) between the shot point and the centre of the furthest geophone group and 1980 ft. (603.5 m) between adjacent shot points (Fatti, 1987).

Twelve geophones per group of geophones were used. Theoretically the complete cancellation of the ground –roll or any other coherent shot generated noise travelling radially outwards from a shot may be done by using the twelve geophone array, where the geophones are laid in a straight line along the direction of the propagation of the noise. Meaning the total length of the group is equal to 11/2 λ (wavelength of the noise). In order to determine the wavelength of the noise a “noise spread” was shot, which using the formula Wavelength = velocity X period determined the period and horizontal velocity of the noise (Fatti, 1987).

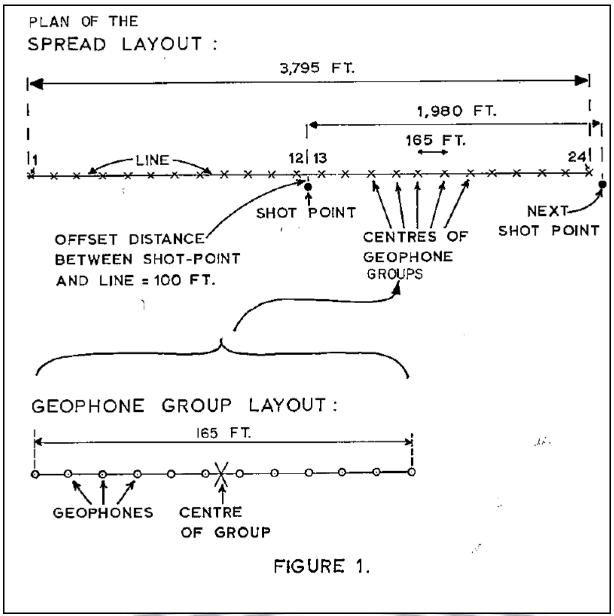


Figure 1.7 Spread layout used by surveyor at the time of seismic line acquisition (source: Fatti, 1970)

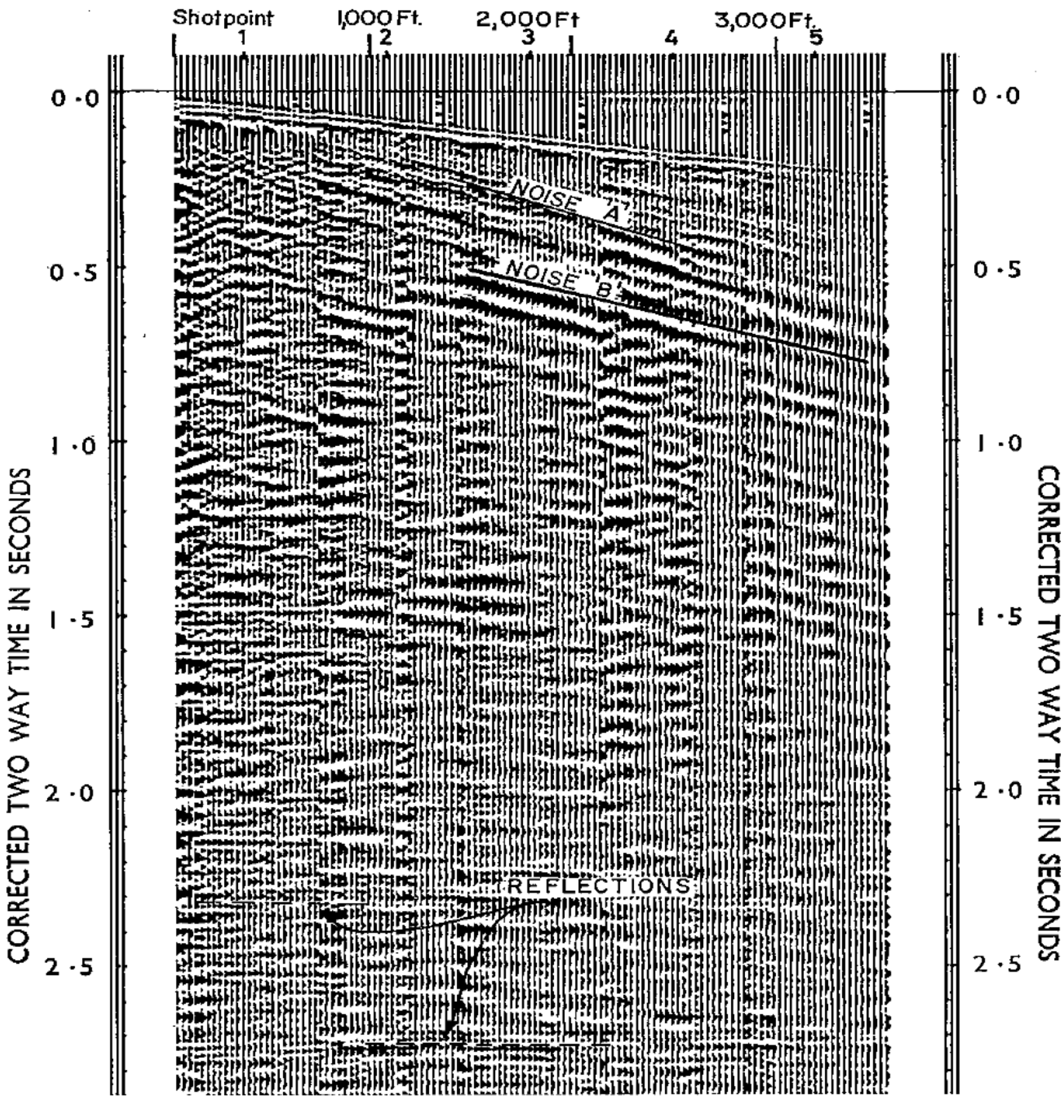
Shot points consisted of single holes which were 50-60 ft. deep and a Failing rotary drill was used which is standard equipment used by oil prospecting seismic crews. This drill was later found unsuitable for the very hard formations and a pneumatic down-the-hole hammer was used to complete the line. The type of explosive used was "GEOPHEX", which is specifically designed for seismic operations and an average charge of 50 lb was used (Fatti, 1970) (Fatti & Du Toit, 1970).

3.1.2.2 DATA PROCESSING

Miniature HS-J geophones were used with a resonant frequency of 14 Hz and the amplifiers used were Geospace model GSC 111 and the recording was done on a Techno-type analogue magnetic tape with was amplitude modulated. For the recording a broad band filter of 22-108 Hz was applied with a cut-off of 36 dB/ octave. These tapes were then played back through various narrow pass-band filters (22-60 Hz) to remove the high and low frequency noise. The seismic recorded section produced in the field was in the form of a variable area display (Fatti, 1970).

It was established that a vague layer near the surface of varying thickness, which was termed a "Low-Velocity Layer" (average thickness ~50 ft. with a velocity of 7000ft/sec). Travel times were corrected for this layer using the "up-hole time" method which took the time of the first energy arrival from the charge to the surface and on this principle the reflection time is recorded to remove the effect of this low velocity layer (providing that the charge is below the low velocity layer) (Fatti, 1970) (Fatti & Du Toit, 1970).

A datum of 3200ft. above sea level was incorporated into the results using a velocity of 15000 ft/sec and a corrected record section was produced (Fatti, 1970).



NOISE EVENT	VELOCITY(Ft/sec.)	PERIOD (seconds)	FREQUENCY(Hz)	WAVELENGTH(Ft)
A	5900	0·07	14·3	410
B	7300	0·04	25·0	290

Figure 1.8 Noise spread shot south of Graaff-Reinet in the Karoo from Fatti & Du Toit (1970)

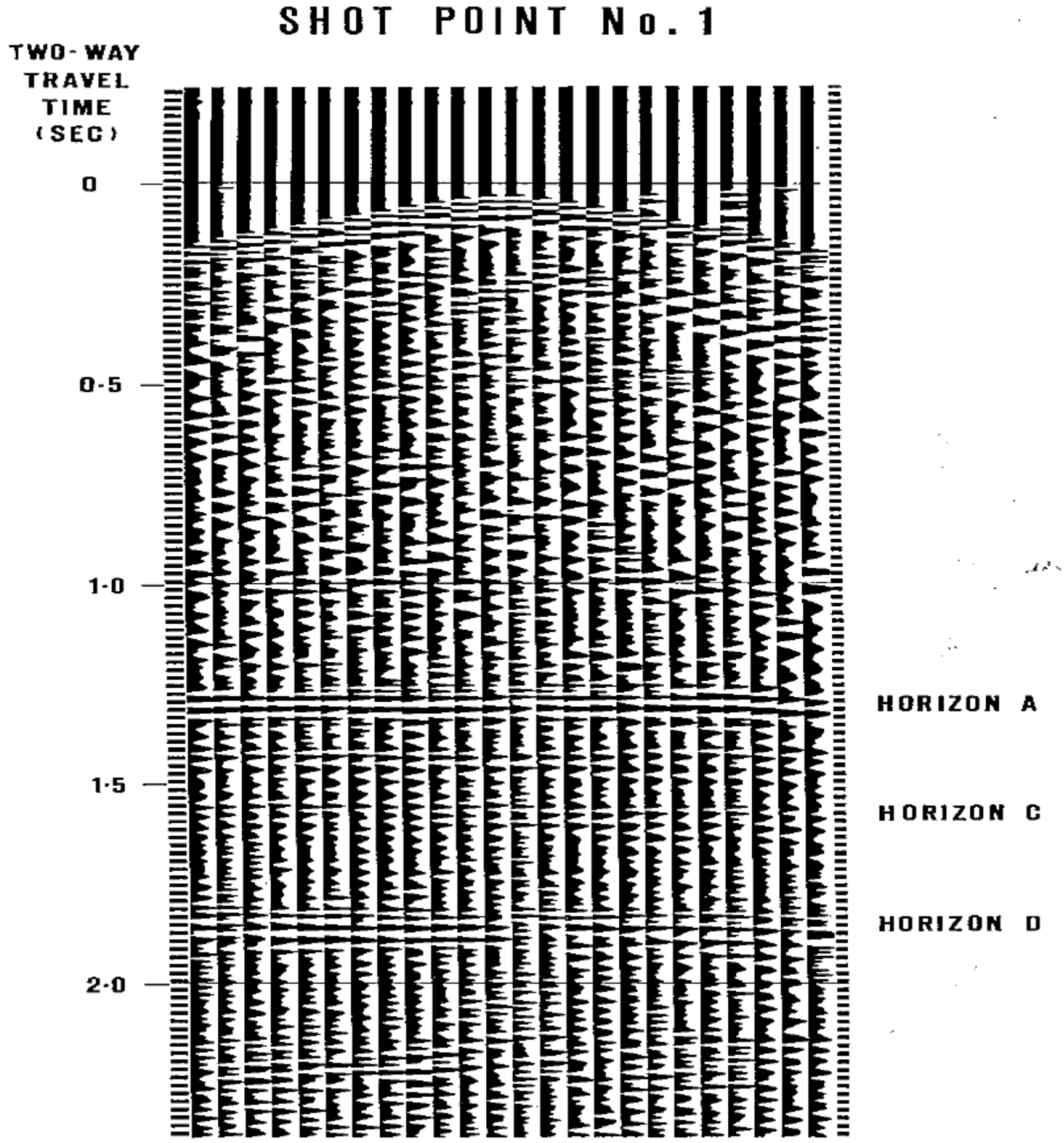


Figure 1.9 Field record of shot point No.1 played back with 22-60 Hz pass-band filter from Fatti & Du Toit (1970)

RESULTS OBTAINED FROM 1965/1966 SURVEY

There were two very continuous horizons “A” and “D” and two less continuous horizons “B” and “C” depicted in Figure 1.9 (Fatti & Du Toit, 1970). Horizon has been termed “old Faithful” because of its continuous character and horizon A was formally identified as the top of the Dwyka tillite but is now known to represent the Whitehill (Fatti & Du Toit, 1970) (Schreiber-Enslin, et al., 2014). Horizon “D” has been allocated to the base of the Cape System of Cape Supergroup (Fatti & Du Toit, 1970).

3.1.2.3 DATA FORMAT AND QUALITY

These TIFF images are scans of large plotted paper sections and others are scanned films. The quality of the originals, colour depth and plotting parameters vary and some of the paper sections have been folded and wrinkled and the colours have faded in the past 40 years. There are some of the regional lines that have been scotch taped together from shorter lines. Also some of the lines have been interpreted using colour pencils. A majority of the seismic lines are single fold and a few are three fold stacks.

The shot point for the lines were also scanned paper plots or films (High resolution TIFF files), original scales which vary between 1:100000 and 1:250000. The originals were drawn by hand. The shot point locations, numbers, line names and wells have been plotted on these hand drawn maps. In many of these maps the geographical co-ordinates are indicated besides the projection coordinates. The shot points were digitized by TMX using Global Mapper 11.

The scanned maps were georeferenced using geographical co-ordinates stipulated on the plots. Navigation files were created for the seismic sections were produced using these shot points. In the last phase of data transfer the Petroleum Agency of South Africa (PASA) provided Falcon Oil and Gas with digital navigation files for a few lines. These, however revealed that the digitized shot points may have an error of a few hundred of meters (but most likely less). Digital navigational data were used for the corresponding lines.

3.1.2.4 NAVIGATION DATA: PROJECTION, CO-ORDINATE SYSTEM, SHOT POINTS AND META DATA

The Hartebeesthoek 94 co-ordinate system (WGS84 ellipsoid) as of January 1999 became the official system in South Africa this replaced the previous Cape Datum system (which was a modified Clarke 1880 ellipsoid).

The shot maps used Cape Datum geographical co-ordinates and the Gauss Conform Projection (two degree longitude belts with the origin of each belt at the intersection of the central meridian and the Equator; e.g. Lo. 25°).Rectification was based on geographical coordinates using Global Mapper.

After consulting Dr. Manie Barnard (Spatial Management, Council for Geoscience, South Africa) all the co-ordinates were transformed to Albers Equal Area grid with the following parameters:

First Parallel	:	20°S
Second Parallel	:	30°S
Central meridian	:	24°E
False Easting	:	0
False Northing	:	0
WGS84 Ellipsoid		
Hartebeesthoek 94 datum		

These parameters were also used to define the XY projection method in SMT Kingdom.

3.1.2.5 SMT (KINGDOM SUITE) IMPORT OF SEISMIC DATA

All the reconstructed seismic lines could be imported into SMT. Initially the shot point number distribution of the original lines- far from linear and monotonous- which made it impossible for SMT to locate the traces properly (therefore re-numbering shot points were necessary for several of the lines).

Assigning shot points to traces was done either by two points (first and last trace and shot point numbers) or by a table. The two shot endpoints of each line were assigned to "half" shot points (i.e. 1st trace SP 9.5 last trace SP125.5). In average 24 traces belonged to one shot point, however, it was consistent, partly due to the reconstruction process and partly due to data acquisition.

The datum level of the original seismic lines varied between 488m and 1651m above sea-level. We selected 700 m above sea level as seismic reference datum for the SMT project. Initial static shift of imported seismic files were based on the original seismic datum and elevation velocity.

Refinements were done with interactive Mistie Analysis. Mostly no phase rotation was applied during mistie corrections. The original seismic datum levels and elevation velocity data can be found under survey details/ processing in SMT. Description of the mistie values is in file Karoo MISTIE Table.xlsx

A navigation file called Karoo_navigation.nav was provided by PASA.

CHAPTER FOUR:

4 INTERPRETATION

4.1 INTERPRET THE WHITEHILL FORMATION FROM SOEKOR SEISMIC DATA

The Whitehill formation is the most prominent reflector across the seismic data available in the Karoo Basin and for this reason it has been chosen (Fatti, 1987) (Schriber-Enslin, et al., 2015). The Whitehill will be interpreted across the 99 seismic section illustrated in Figure 1.1. The geological setting for the area selected varies gradually across the seismic lines. In the north there concentrations of dolerite dykes occur and cause the quality of the data to diminish where as in the south the data is less noisy. The strata dip southwards where the Whitehill gets deeper in the south.

4.2 EXTRACT AMPLITUDE DATA

The amplitude data for the Whitehill formation in SMT Kingdom can be extracted using the export data option under the Horizon Tab in the main Kingdom window. This opens a window which allows the extraction of the X and Y co-ordinate, line name, time and amplitude of the Whitehill horizon that has been picked. This data is then written in the format of .txt file and can be opened in Excel and be edited for Surfer and then in Surfer the amplitude data is gridded according to the appropriate gridding algorithm and then plotted as a map. Further information regarding gridding parameters have been detailed under the results section.

4.3 VELOCITY MODELLING

The Velocity data will be calculated in the following fashion due to the fact that there was no available check shot data for the seismic data and there were only two wells within the Karoo that have velocity data. Wells CR1/68 and WE1/66 have velocity profiles and from these velocity profiles and plotting them together it was calculated that both wells display a common trend and the trend line derived from this and equation would be used to calculate the depth variation of the seismic data. This was used to tie all the other wells to the seismic lines by creating a generic Depth to Time plot that would allow all the well tops to plot relatively in the correct location.

4.4 EXTRACT VELOCITY DATA (INSTANTANEOUS VELOCITY)

Due to the fact that most of the wells have not had successful sonic logs or velocity data it has been a challenge to develop a generic depth –time plot to enable the wells to tie to the seismic data. This has allowed better interpretation of the seismic horizons.

The interpretation of the Whitehill formation top and bottom) onto the Seismic data in Kingdom SMT will allow us to extract the time at each picked point and this can be converted into depth using the equation in Figure 1.12. and using the depth in meters and TWT it is possible then to calculate velocity (instantaneous velocity) at a point picked on a horizon and then derive Horizon lateral velocity variation.

All these calculations for velocity and depth were done using Excel. The extracted data from Kingdom SMT was tabulated and used to define velocity values and depth values for the Whitehill top and base. The resulting gridded maps were created in Surfer 8.

CHAPTER FIVE:

5 RESULTS

5.1 VELOCITY MODEL

The equation for the depth conversion for the seismic data from time to depth in meters differs from the equation generated by Schreiber-Enslin et al. (2014)($\textit{Measured Depth} = 231.5\ (TWT)^2 + 2022.6(TWT)$) where as Schriber-Enslin created a binomial equation where as this study utliised a linear realtionship for the depth to time plot for the generic velocity data. This proved to provide better results than the Schriber-Enslin equation for the top of the Whitehill formation. However, there was some discrepancies in results received for the base of the Whitehill its was more assocaited with the poor quality of the data and thus affecting the picking of the base accurately. Schriber-Enslin communicated that she found it difficult to disern the base and could not comment on my results.

All depths have been converted for subsea values for the depth maps using a refernce datum of 700 m above sea level which is what was used for the SOEKOR survey (Schriber-Enslin, et al., 2015).

EQUATION FOR DEPTH CONVERSION

Depth= 2523.6(TWT) - 66.171 → (A1)

*Depth is in meters *Time is in seconds

EQUATION FOR DEPTH TO TWT CONVERSION

TWT= 0.0004(Depth) + 0.0277 → (B1)

*Depth is in meters *Time is in seconds

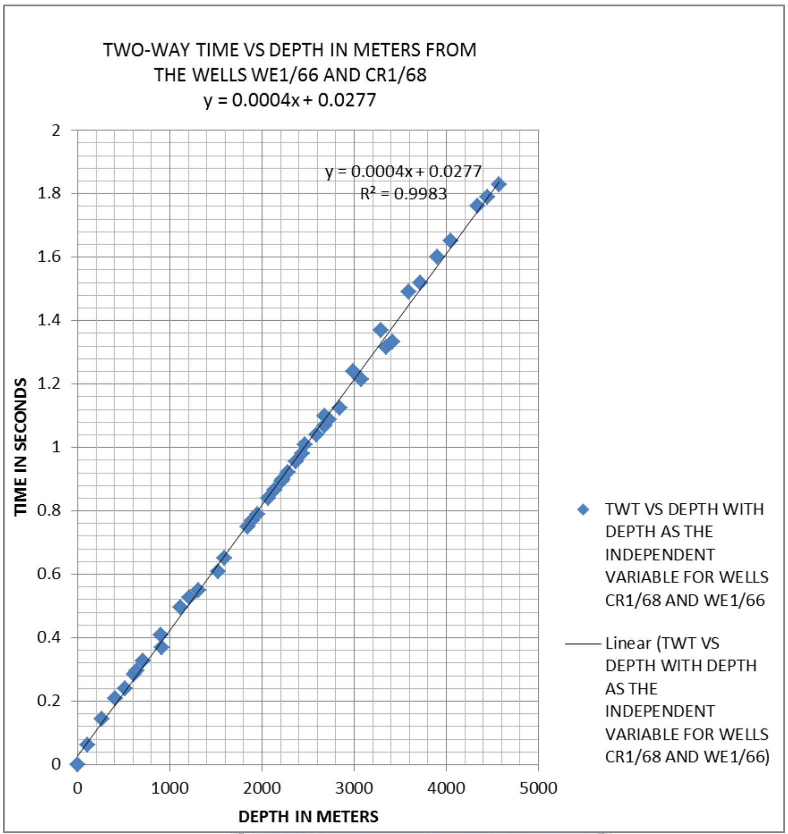


Figure 1.10 TWT vs Depth in meters to calculate TWT to tie well tops from wells to the seismic data y = 0.0004x + 0.0277

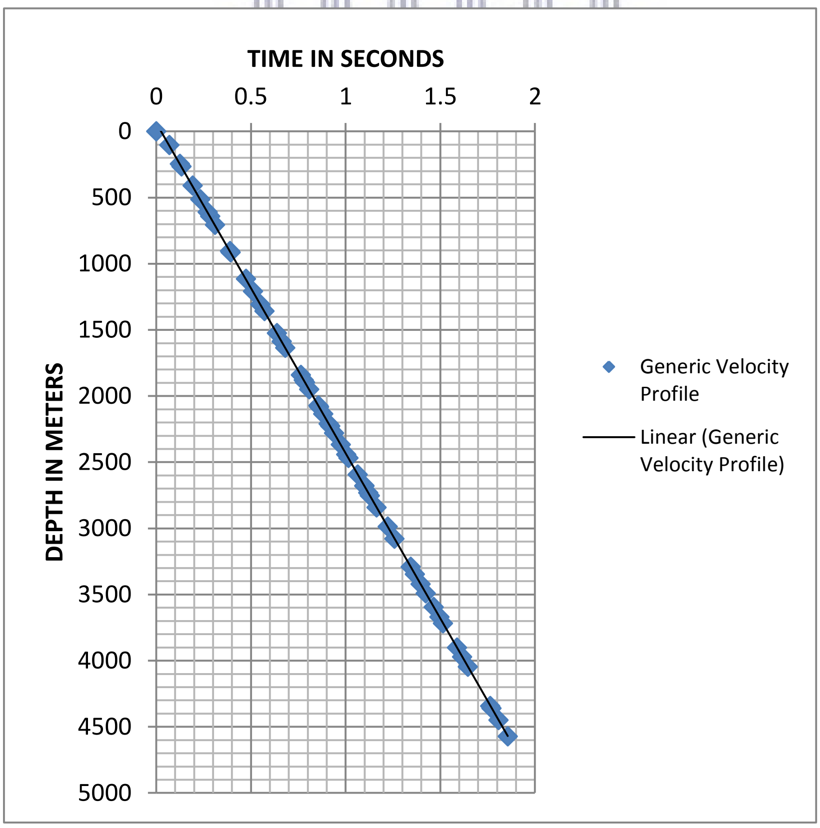


Figure 1.11 Generic velocity profile created from equation y = 0.0004x + 0.0277, where y is depth in meters and x is TWT in seconds. Each TWT value was calculated from the equation y = 0.0004x + 0.0277

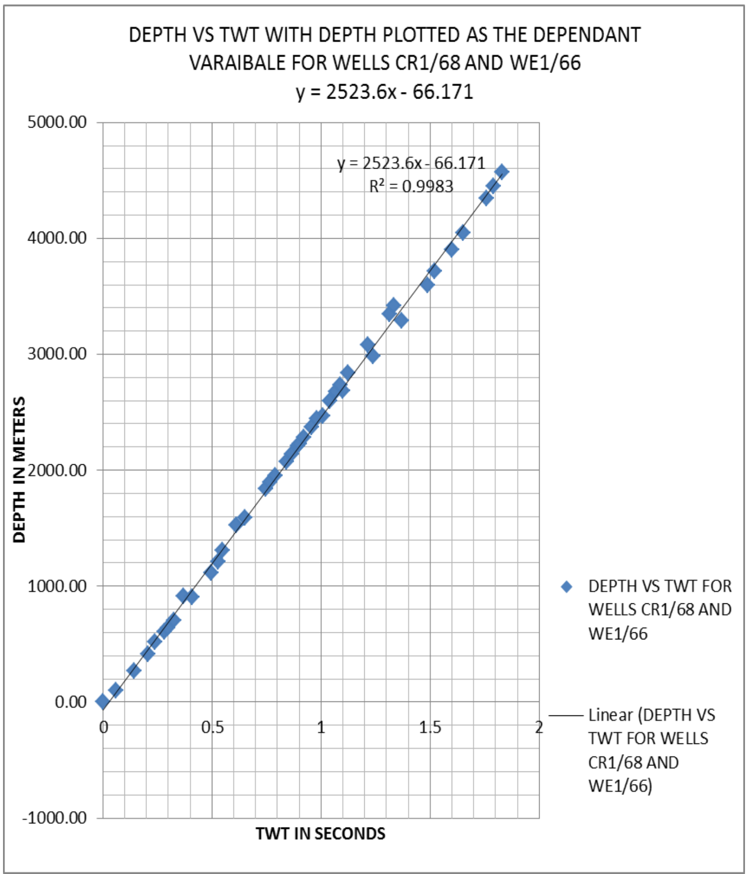


Figure 1.12 Depth vs TWT plotted to derive an equation of Depth conversion of the seismic data y = 2523.6x - 66.17

5.2 TIME AND DEPTH MAPS (WHITEHILL TOP & BASE)

The time and depth variation maps for the top and base of the Whitehill was generated from the data extracted from the interpretation of the 99 line previously mentioned and seen in Figure 1.1. This depth is corrected to a datum of 700m and the gridded data has been blanked to only include data closest to the intersecting 2D seismic lines. Figure 1.13, Figure 1.15, Figure 1.16 and Figure 1.17 show a general character of deepening of the Whitehill in the South and shallowing to the north.

The grids for these maps were created using the Nearest Neighbour gridding method in Surfer 8 Golden Software. Also all the data was corrected to a subsea datum of 700m above sea level which was taken in to account by Kingdom Suite when creating the project. The depth in time was extracted from Kingdom Suite and then converted into meters using the equation derived in Figure 1.12 in excel and then gridded in Surfer using the natural neighbour gridding algorithm with a grid size of 61X100.

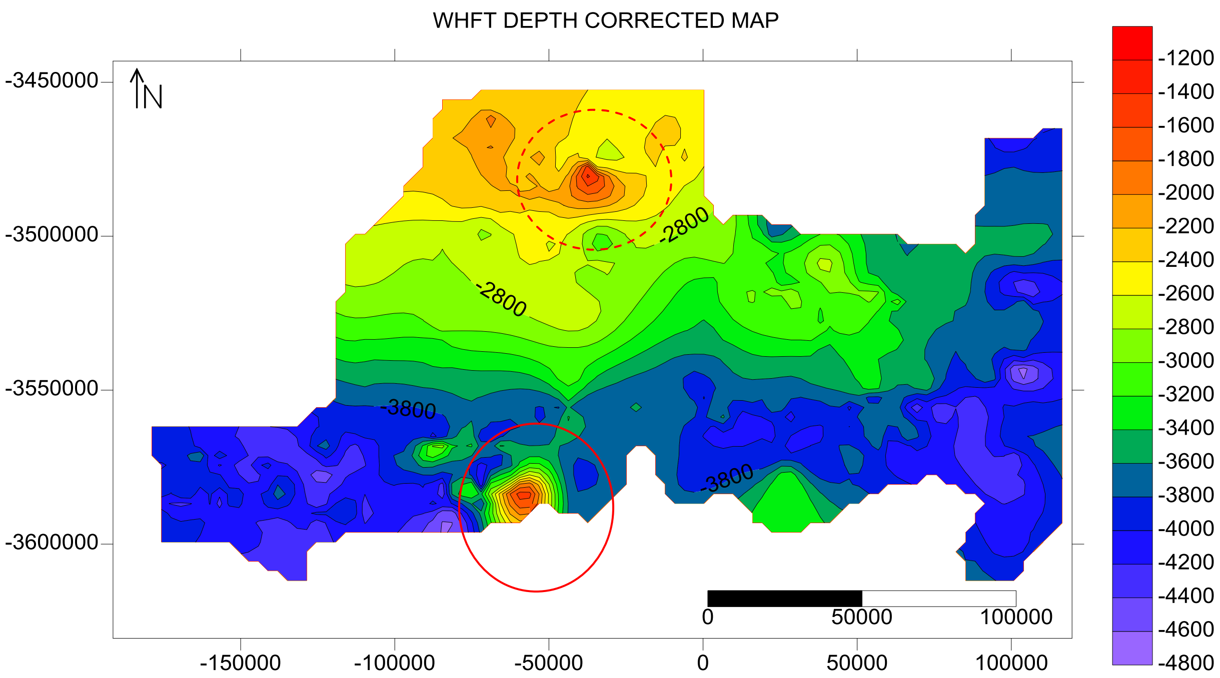


Figure 1.13 Whitehill formation top depth corrected map in meters (corrected to seismic datum of 700m)

The Top of the Whitehill across the seismic lines selected has a range of approximately 1200m to 4800m in depth and there is some shallowing in the north which appears unusual but consistent with the reflectors on the intersecting seismic line of BV03 seen in Figure 1.13 highlighted by the solid red circle in the south of the mapped area. There is also some anomalous behaviour in the north of the area highlighted by a dashed red circle.

According to Schriber-Enslin, et al. (2015) the Whitehill reaches a maximum depth of approximately 3000 meters in the sout- west and 4000 meters in the south-east and does not extend into the north eastern part of the basin, this estimation was however done over a larger area for the Karoo where as this study has focused on a more localised area within the Karoo Basin.

The anomaly in the south of line BV03 is inconsistent with the trend of the top of the Whitehill for the rest of the BV03 line. On close inspection of that seismic line (see Figure 1.13) it was observed that during the gridding process in Kingdom there was a false interpolation of the Whitehill top and base reflectors. This means that the data in the South of this line is not reliable. This is also seen in the North in the SWK lines which have also associated error with them due the presence of dolerites and the bad quality of the seismic data in the Karoo.

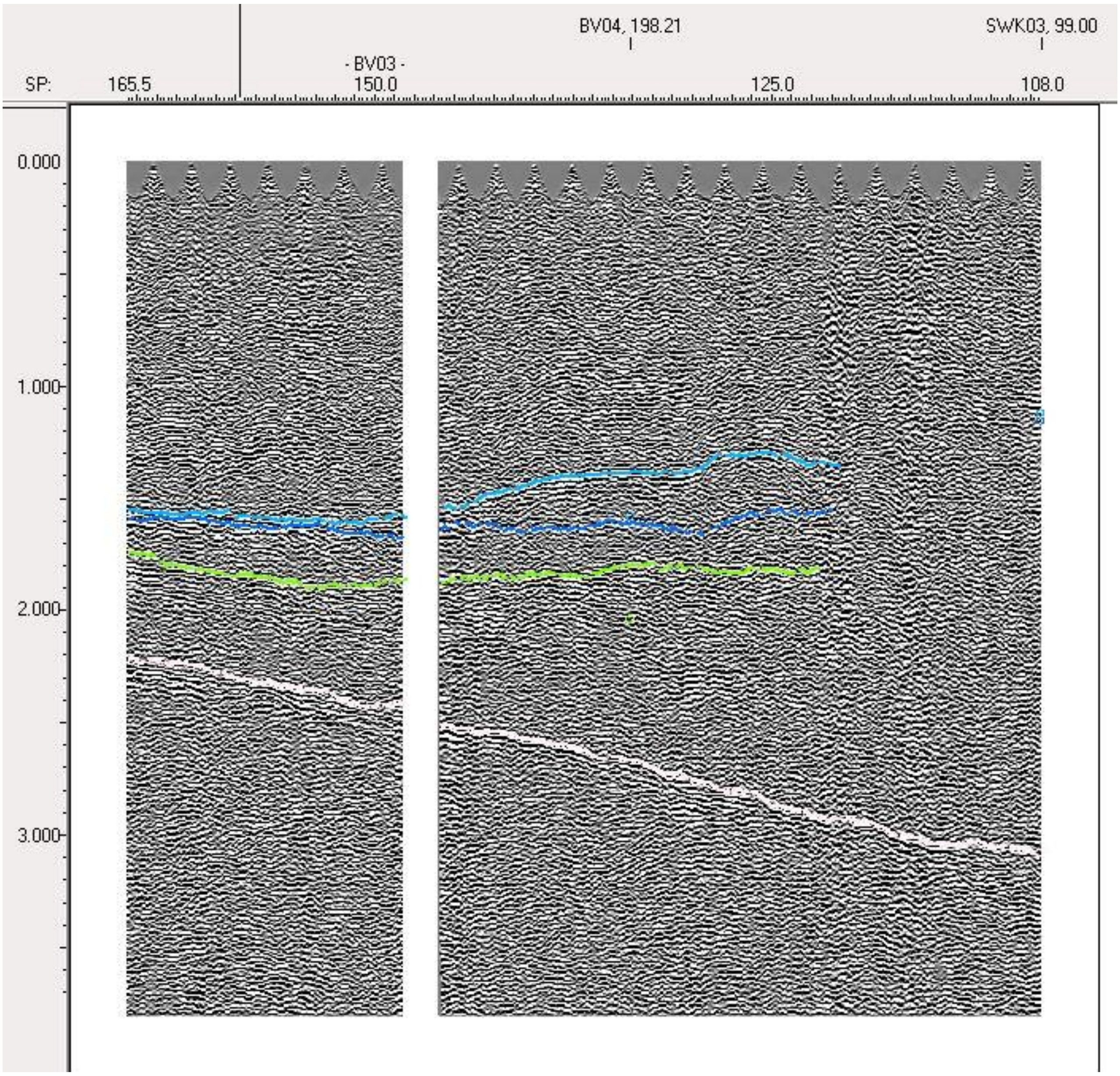


Figure 1.14 Seismic section BV03

The resolution of line BV03 has significantly affected the gridding process (as seen in Figure 1.14). It has been noted that top of the Whitehill has been the most laterally continuous reflector across all the lines examined, but on some of the seismic profiles it was difficult to discern the Whitehill due to the noise in the data which has caused significant error in the gridding process.

The problem occurred due to the fact that where the Whitehill reflector could not be clearly interpreted the computer interpolated during gridding where it estimated the Whitehill to be and this created false data which when gridded caused these anomalies.

Essentially these areas where the data was not very clear (as in BV03) was left uninterrupted and the computer filled in the empty interpretation with its own and cause the creation of these unusually shallowing anomalies.

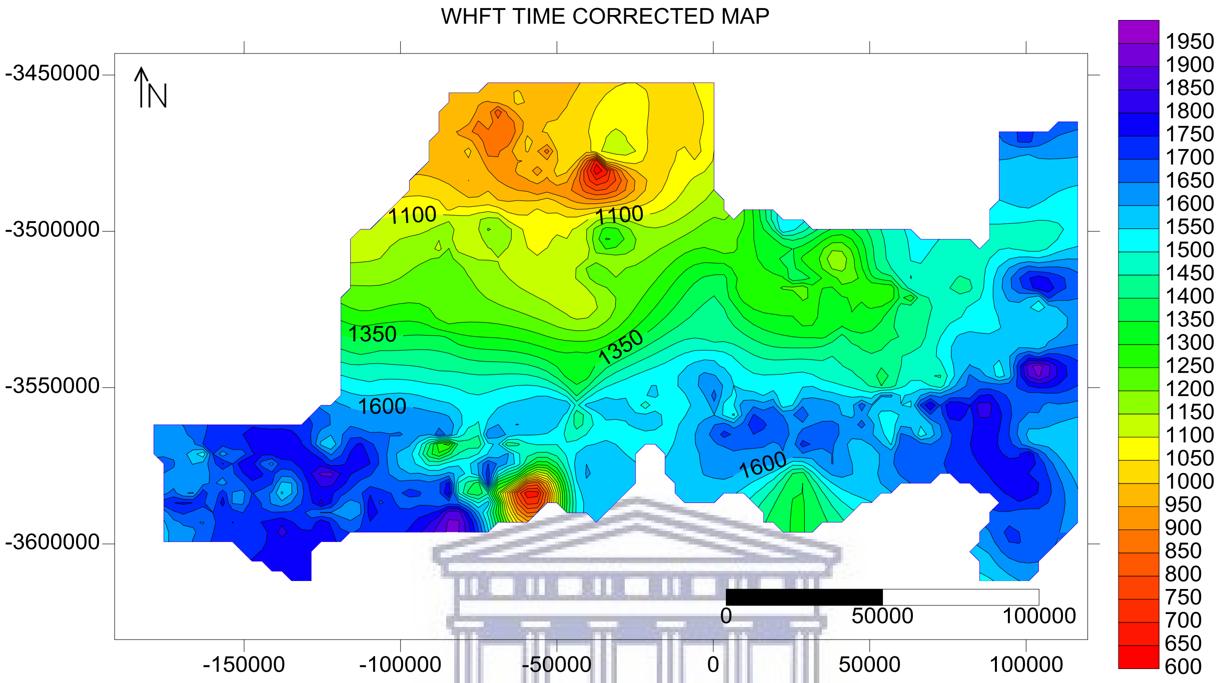


Figure 1.15 Whitehill formation top in time corrected map (based on velocity model created)

The time variation map (see Figure 1.15) has the same character and shape as the depth variation map in Figure 1.13. The time variation maps are very similar to the depth variation maps but they need to be included as the seismic lines are actually in two-way time and need to be converted into depth using velocity data and sonic logs for the seismic lines and well logs. This has been challenging due to the fact that there was limited sonic logs and no velocity data. The time variation maps were also created in Surfer using the natural neighbour algorithm and a cell size of 61X100.

The base of the Whitehill displays the same shape and character of the top of the Whitehill except that the depth ranges slightly from 1400m to 4800m (seen in Figure 1.16). The base also has the anomalous shallowing behaviour in the south intersecting with BV03.The same character is visible in the WHFB as in the WHFT depth variation map.

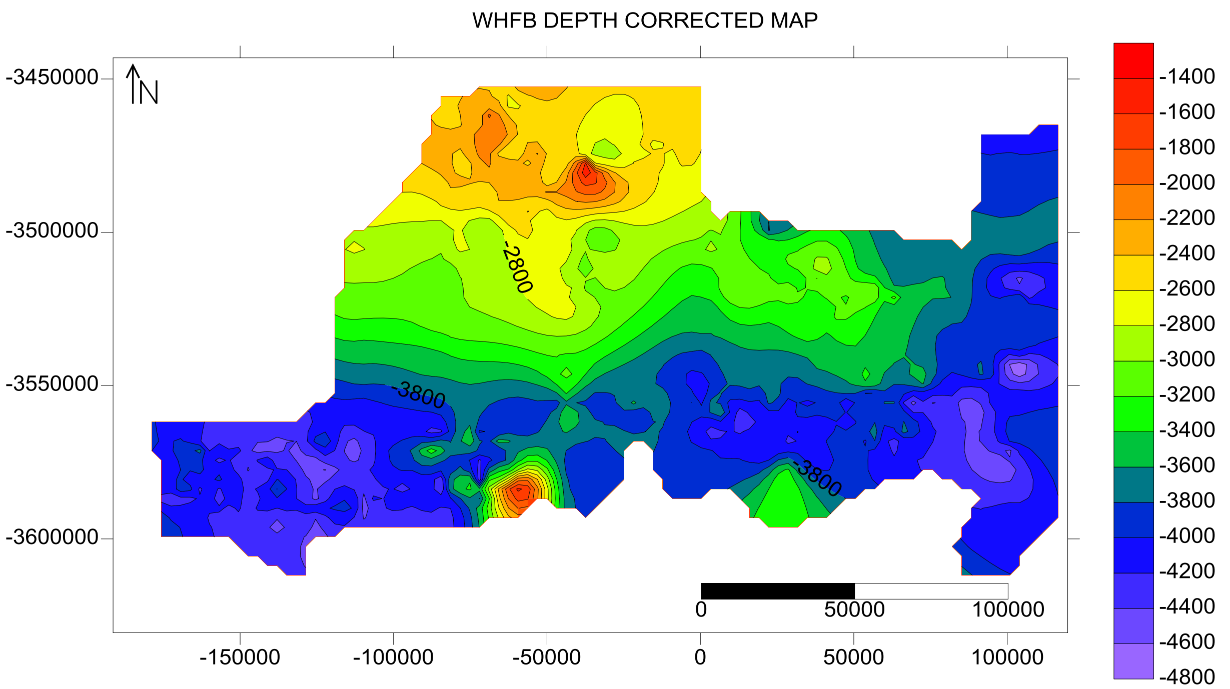


Figure 1.16 Whitehill formation base depth in meters(corrected to seismic datum of 700m)

Although it was much more difficult to discern the base of the Whitehill that the top of the Whitehill due to the quality of the data. Previous studies have attempted to estimate the base of the Whitehill to determine the thickness of the Whitehill but this is not an easy task as the resolution of the data is limited what can be achieved with it.

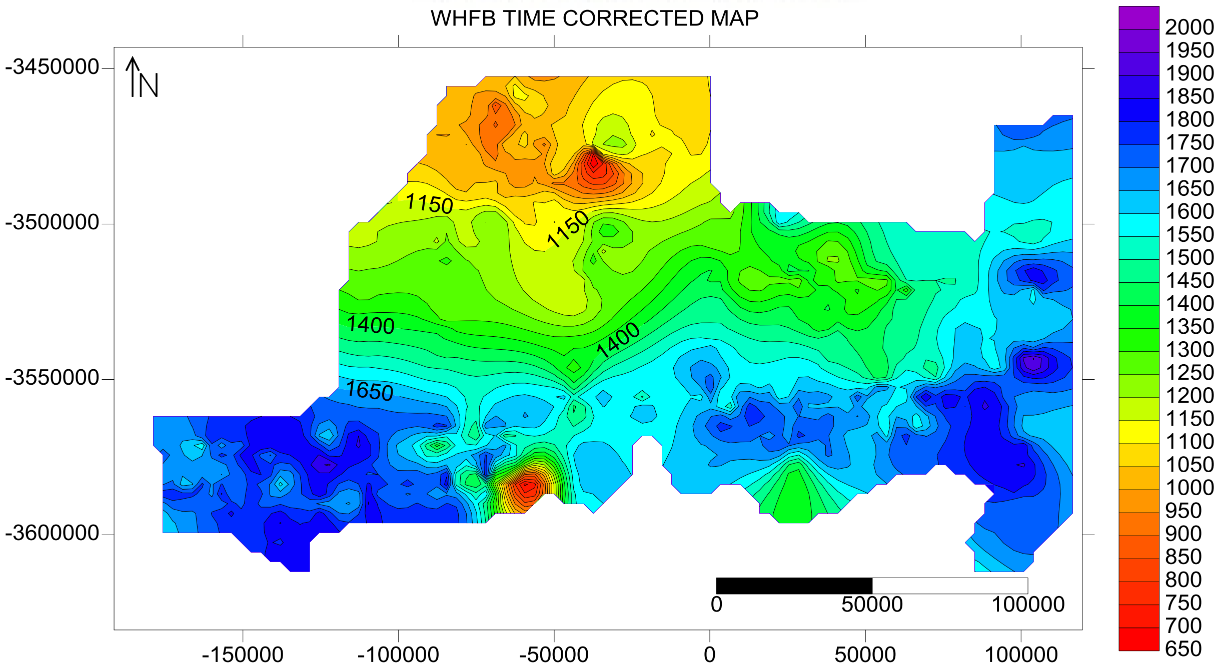


Figure 1.17 Whitehill formation base in time corrected map (based on velocity model)

The time variation map for the Whitehill base is consistent with the depth variation map, however the shape and character of these horizons are better displayed in 3D. This can be seen in Figure 1.18 and Figure 1.19.

5.3 3D SURFACE MAPS

These 3D Surface maps were created in Surfer using the surface function to the depth grid for both the top and base of the Whitehill formation. This created a view which defines the shape of the Whitehill below the surface keeping in mind that a datum of 700m was used to correct the data in Kingdom SMT initially.

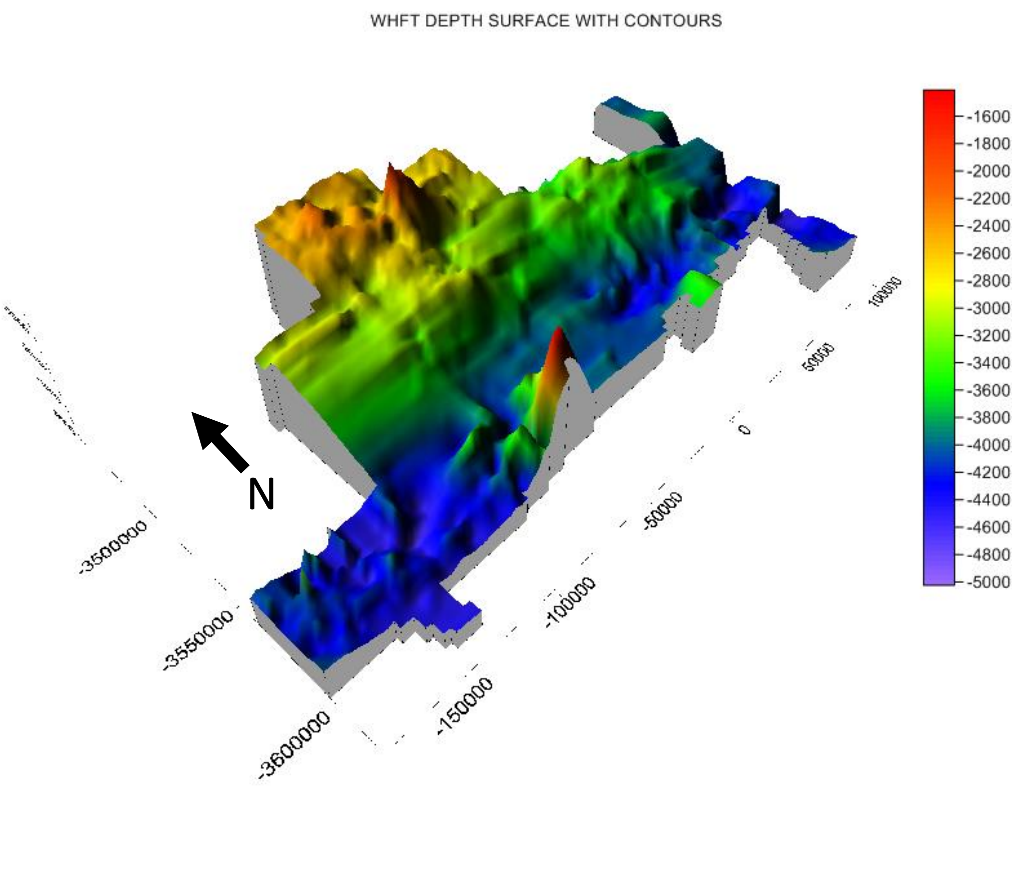


Figure 1.18 3D Surface of the Whitehill Formation top

The anomalous shallowing of the surface viewed in Figure 1.18 and Figure 1.19 and can be attributed to the poor quality of the data as mentioned before. It must also be considered because of the wide spacing between the seismic lines that there would be some error in calculating the gird for depth, amplitude, TWT and even velocity variation. These surfaces where created using the previous contour depth map grids (Nearest Neighbour Method).

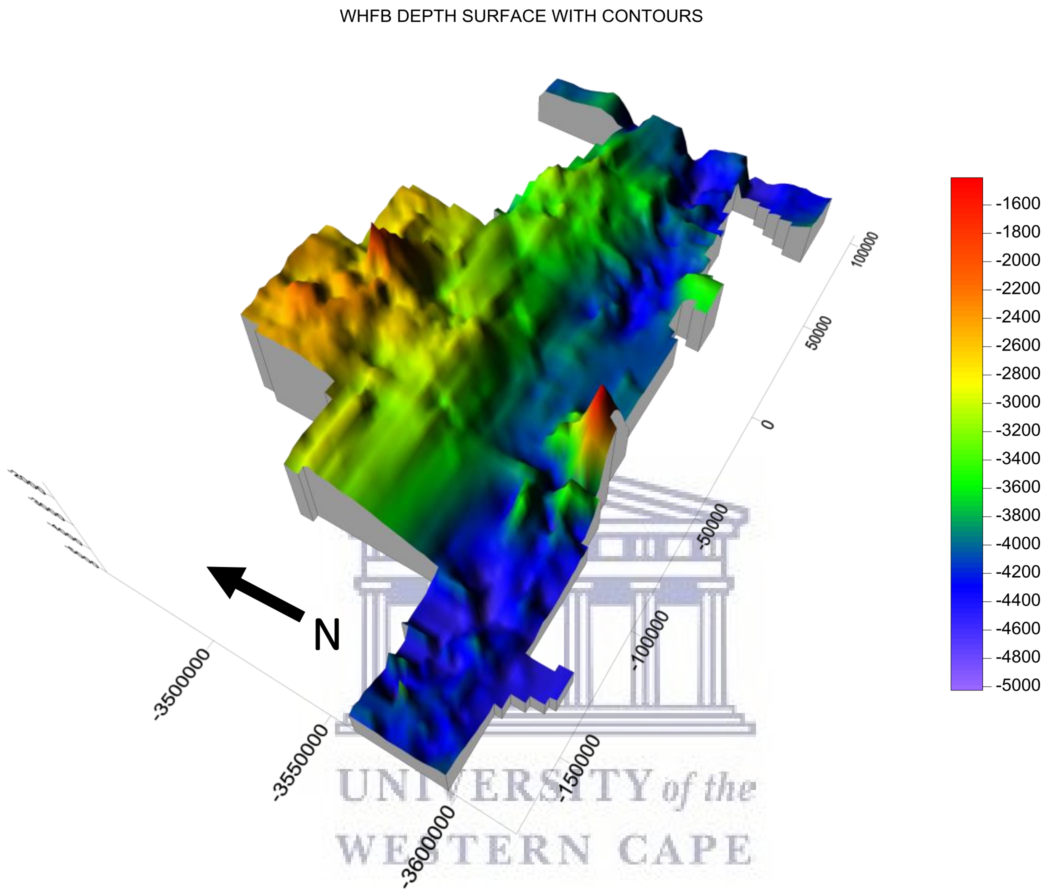


Figure 1.19 3D Slope of the Whitehill formation base

5.4 AMPLITUDE VARIATION MAPS

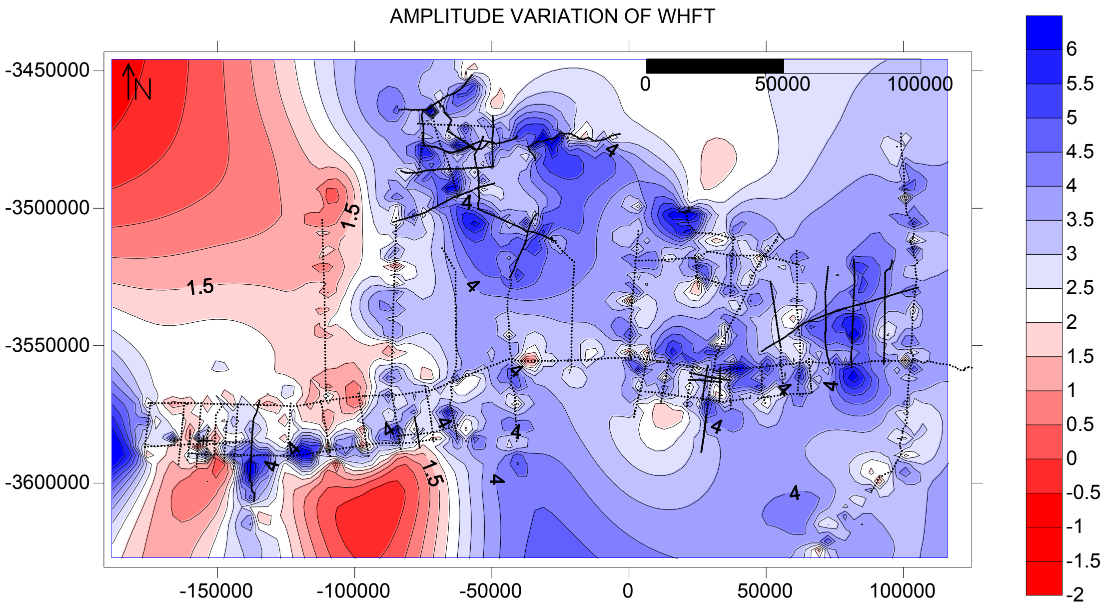


Figure 1.20 Amplitude variation map for Whitehill formation top

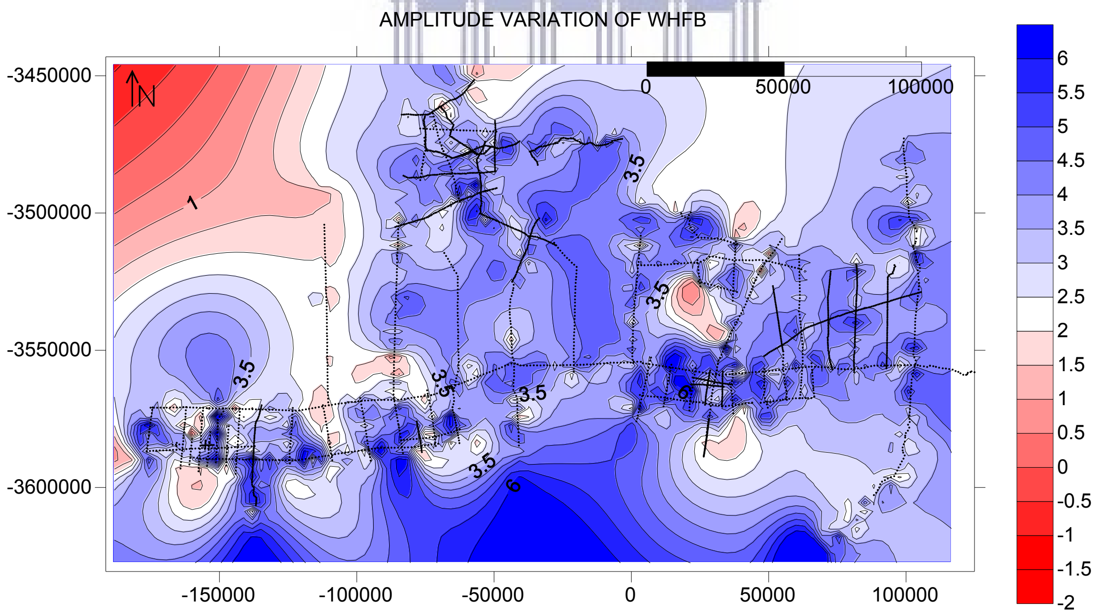


Figure 1.21 Amplitude variation map for Whitehill Formation base

From the literature it is understood that with shale gas the possible gas sites could either be associated with the bright spots (higher values) or the dim spots (lower values). The amplitude variation maps have been gridded using the Nearest Neighbour method in surfer and have a scale which ranges from -1 to 6 for the top of the Whitehill and -1.5 to 6 for the base of the Whitehill.

Along seismic line BV21 which intersects with the Beaufort West study area displays moderately positive amplitude, whereas there considerably high amplitude bright spots is intersecting the majority of the seismic lines in Figure 1.21 for WHFB. The same character is evident in Figure 1.20 for WHFT except for the dim spots seen in the north and south ends of BV21.The dark blue is indicative of a high amplitude value (bright spot) and the red is indicative of a dim spot.

5.5 ISOPACH MAP

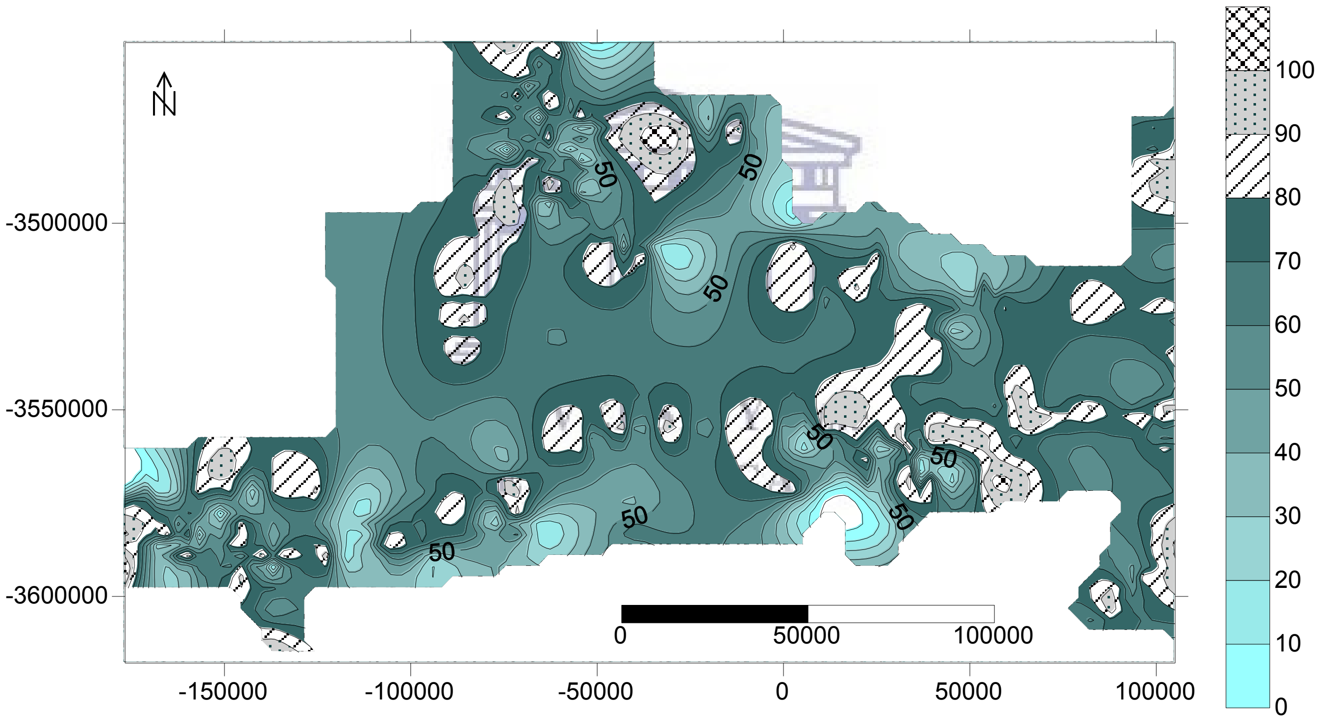


Figure 1.22 Isopach map of the Whitehill created from WHFB-WHFT

The isopach map was created by subtracting depths for WHFB from WHFT which gave the thickness for the Whitehill formation using the minimum curvature gridding method. The calculation of the isopach data was filtered to only grid the data with the corrected values between 0 and 100 m. The thickness of the Whitehill according to studies done by Cole & McLachlan in1994 indicates that the Whitehill does not exceed a thickness of 70 meters. However, for this study it was observed that the Whitehill exibited an average thickness of 183 m which cannot be correct. It should be noted that because of the low quality of the seismic data it was difficult to disearn what the base of the Whitehill was and this resulted in the large amount of error assoaciated with the isopach map.

Figure 1.22 shows the thickness values from 0 to 100 meters but this was only achieved by removing all the values less than 0 and more that 100 meters. This left a data set with 16997 vlaues of an original dataset of 56474 values which means that 69.9% of the data was removed to produce the isopach map in Figure 1.22.

Column1	
Mean	61.38759075
Standard Error	0.19473427
Median	64.3518
Mode	81.51228
Standard Deviation	25.38800199
Sample Variance	644.5506448
Kurtosis	0.631645308
Skewness	0.494514942
Range	99.93456
Minimum	0
Maximum	99.93456
Sum	1043404.88
Count	16997
Confidence Level (95.0%)	0.381699338

Figure 1.23 Statistical Analysis for the Whitehill Isopach dataset

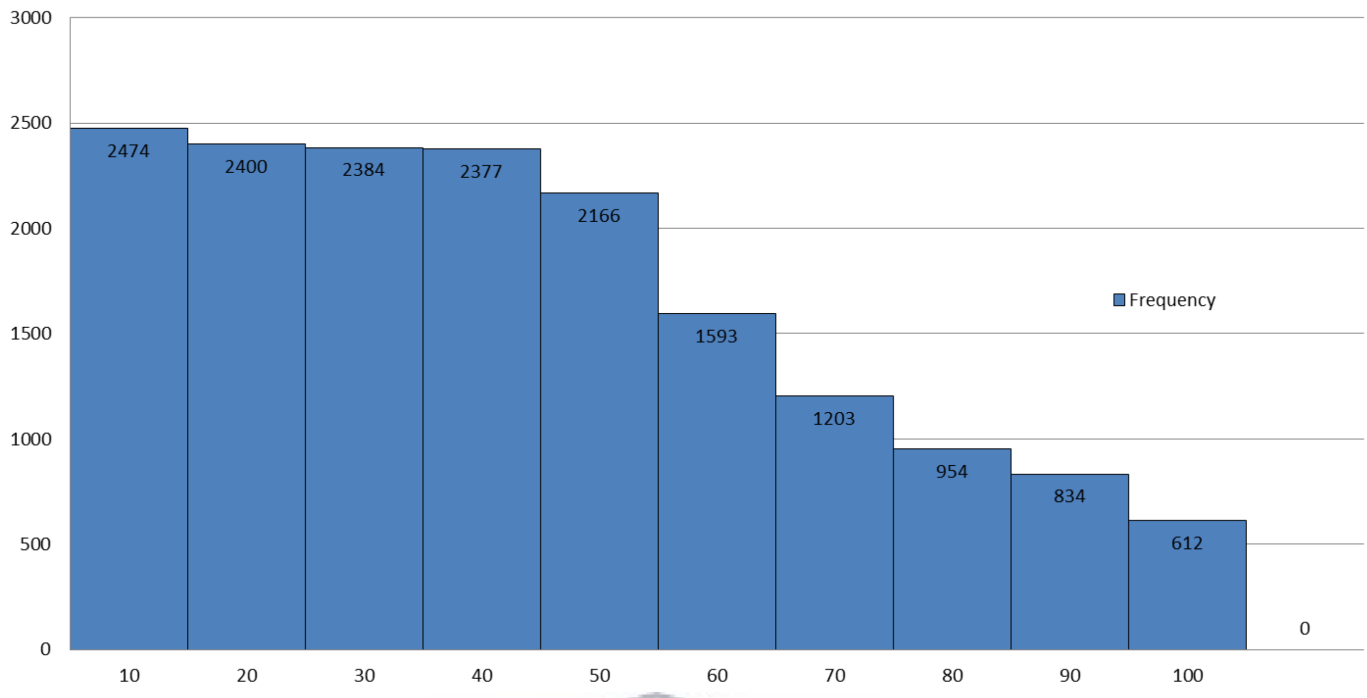


Figure 1.24 Histogram for the Whitehill Formation isopach dataset

According to the histogram and table (see Figure 1.23) above average thickness are 61.38 m and the mode of the dataset is 81.51 m. Based on the fact that the average thickness is in less than 70% and the most common thickness value is 81.51 m there is some value in the refined data set. The areas that have been picked that fall within the realistic values for the Whitehill formation thickness can be considered (<75)and the others which do not fall within the dataset (> 75 m)considered outliers due to the poor quality of the data as well as a lack of proper sonic log and velocity data.

In Figure 1.24, the data is graphically illustrated and that only 20.88% of the data falls within the already reduced dataset. This is proof that there is significant error associated with the WHFB (Whitehill formation Base) data and also the error associated with the velocity model and depth conversion can also be considered.

It is evident that to do a proper Net to Gross estimation of the shale gas potential of the Whitehill and isopach mapping requires better resolution data to produce more conclusive results.

CHAPTER SIX:

6 CONCLUSION

The focus of this research has been to examine key seismic attributes and well information available in the South West Karoo and interpret the Whitehill formation top and base, extract velocity changes as well as amplitude variation. The main focus has been to determine if Horizon Velocity Variation can be used as a direct hydrocarbon indicator.

The time and depth maps for the Whitehill base and top have been gridded and mapped and based on the data dose generally follow the realistic shape of the Whitehill across the South West Karoo. The only problem encountered was due to the isopaching map which did not correlate the documented and expected thickness of the Whitehill across the SW Karoo. This is greatly due to the poor quality of the data and picking the horizon for the base of the Whitehill was considerably difficult. Similar to the time, depth maps and the 3D surface display the shape of the top of the Whitehill with the exception of the anomalies identified in the north and south of an area.

According to the Amplitude Variation maps due to the data being so widely spaced there is considerable error associated with gridding but the data collected along the seismic lines do infer several bright spots and a few dim spots along the seismic lines in the western part of the area namely line BV21 (close to Beaufort West).

The Whitehill has been documented to be a likely shale gas reservoir although the data may not be reliable to conclusively say that it is an economic shale gas reservoir (Cole & McLachlan, 1994) (Geel, et al., 2013). There needs to be more exploration wells drilled as well as logs done in order to better understand amplitude variation of the Whitehill formation.

To conclude it needs to be stated that in order to do a proper seismic attribute analysis of the Whitehill in the SW Karoo there need to be acquisition of not only seismic lines, but well logs with a complete suite of petro physical logs being done as well.

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