THE SEMLIKI BASIN, UGANDA: ITS SEDIMENTATION HISTORY AND STRATIGRAPHY IN RELATION TO PETROLEUM ACCUMULATION

BY

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DEDICATION

This work is dedicated to my husband, Charles and sons, Charlton and Carlin.

ACKNOWLEDGEMENT

I would like to extend my sincere gratitude to Energy Africa together with the Government of the Republic of Uganda for the sponsorship of this course. I am very grateful for their kind support towards my course from the beginning to the end.

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ABSTRACT

The Semliki Basin is covered by sediments that represent the Middle Miocene to Recent, which are described from outcrop and well data, underlain by possible Jurassic or Permo-Triassic to Early Tertiary sediments, which rest unconformably on Basement, described from seismic data.

Thin-section analysis of selected samples, collected from the field, has shown that sandstones from the Semliki Basin are predominantly composed of quartz, potassium feldspars and plagioclase feldspars with subordinate clay minerals. Accessory minerals, such as micas (biotite and muscovite), heavy minerals, garnet and epidote, are present in minor amounts. This mineralogy indicates that the sediments have a granitic and gneissose origin, related to continental-block provenances.

The X-ray diffraction scans of bulk samples reveal that the mudrocks/claystones are dominated by clay minerals with subordinate quartz, feldspars and calcite. The clay minerals include illite, illite-smectite, kaolinite, montmorillonite, illite-montmorillonite, and mica with mixed layer illite-smectite and illite layers dominating. The clay minerals in the sediments were interpreted to be as a result of weathering of feldspars and volcaniclastic sediments. Authigenic minerals such as anatase and jarosite and secondary precipitates such as calcite and gypsum have also been interpreted as oxidation products of sulphides in the sediments.

The study has allowed a better understanding of the stratigraphic relationship of the different rock units that are exposed on outcrop, those encountered in the wells, plus a section interpreted from seismic data. In general, the depositional environment of the sediments in the Semliki Basin is fluvial-lacustrine/deltaic showing significant variations in gamma-ray character, which reflect the water-level changes and river interactions through the depositional period and the influence of rifting tectonics on sediment deposition through time and space.

The sediments in the Semliki Basin represent a petroleum play for hydrocarbon accumulations, in which the necessary elements of a valid petroleum system were identified. These include excellent or good potential for reservoirs and top seals as well as circumstantial evidence of regionally mature source rocks, possible seals, traps and hydrocarbon-migration pathways.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 LOCATION

The Semliki Basin lies within Petroleum Exploration Licence Block 3 (Figure 1.1) which is in the Albertine Graben, Uganda. The Albertine Graben is part of the western arm of the East African Rift Valley System and runs the whole length of Uganda's western boundary. The Ugandan portion of the Semliki Basin covers the southern part of the Ugandan portion of Lake Albert, plus a landward area to the south of the lake. This includes the eastern part of the floodplain of the Semliki River and Lake Albert, known as the Semliki Flats, as well as the adjacent Toro Plain, a slightly more elevated escarpment area to the east of the flood plain (Figure 1.2). The study area covers the landward part of Block 3, south of Lake Albert.

1.2 PHYSIOGRAPHY

On the eastern flank of the rift, the graben-bounding fault is expressed as a high escarpment, which overlooks the flood plain of the Semliki River. Much of this plain has a flat or very gently undulating surface with savannah vegetation. The Blue Mountains of Zaire, which form the opposite (western) side of the Graben at this point, are more highly elevated than the eastern side. The Rwenzori Mountains are seen to plunge northwards beneath the Semliki Flats, with steep, fault-controlled escarpments on both east and west sides of the north-north-easterly spur. The topography of the Semliki Basin is distinct from the rest of western Uganda largely because of its lower elevation of about 650m above mean sea level compared with about 1650m for the adjoining rift shoulders. In the Semliki Basin, a major fault separates the Toro Plain from the Semliki Flats.

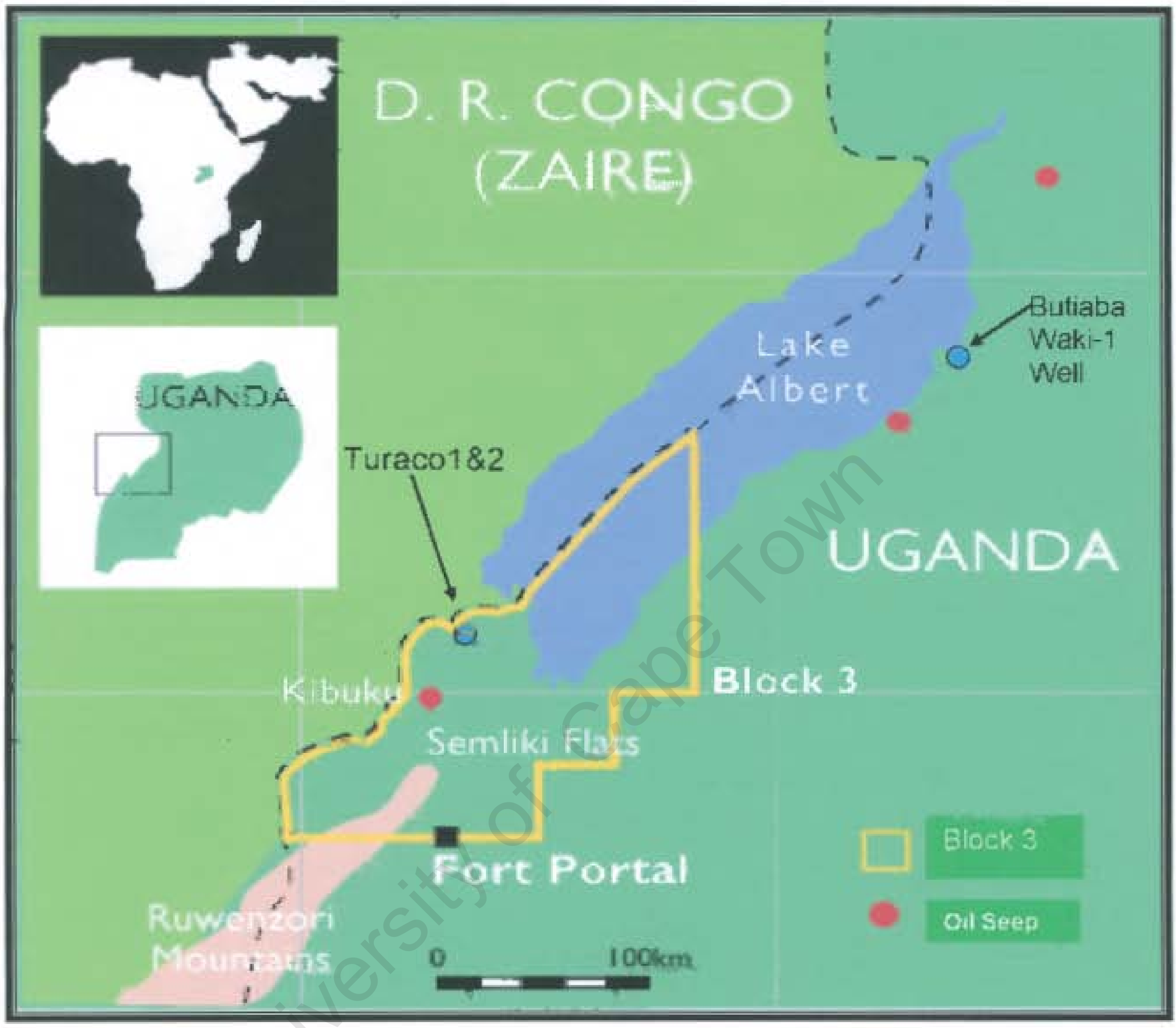


Figure 1.1: Block 3 location, Albert Graben Uganda (Modified after Heritage Oil and Gas Ltd, 2001.)

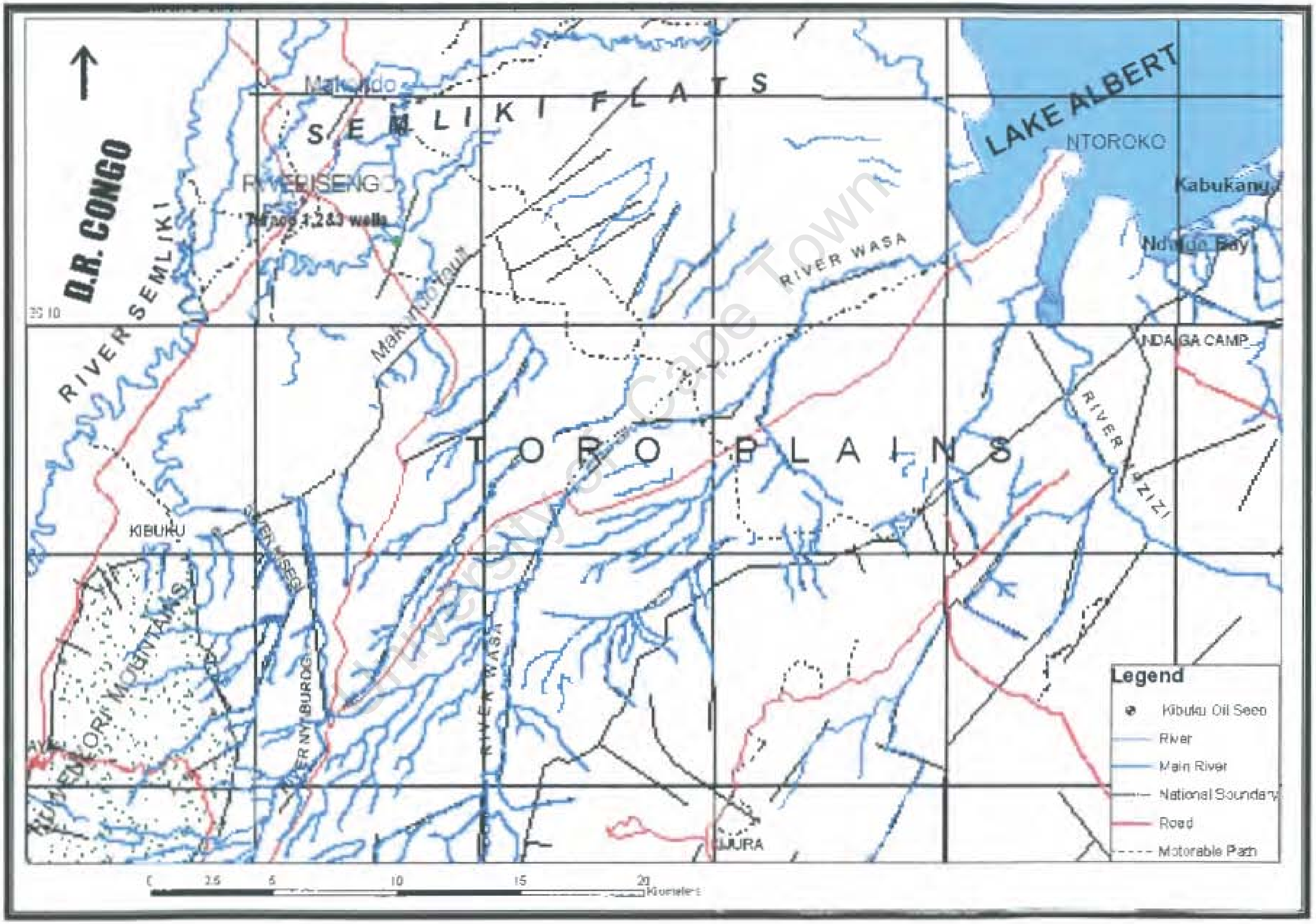


Figure 1.2: Location map of the Semliki Basin, Albert Graben, Uganda (Modified after Petroleum Exploration and Production Department, 2002.)

1.3 CLIMATE

Uganda experiences a typical tropical climate, which is warm and humid. In most parts of the country, including the study area, there are two dry seasons (June to August and December to February) and two wet seasons (March to May and September to November) during the year. According to the Ugandan Meteorological Department, temperatures in general range from 12-30°C with slight variations due to altitude. The area of study is usually hot, around 30°C during the day.

1.4 STUDY MOTIVATION

A number of active oil seeps have been identified along the basin margins, where basement rocks are in contact with a thick sedimentary pile in the Albertine Graben. This has stimulated interest in the hydrocarbon potential of the Albertine Graben for many years. Geological fieldwork has confirmed that there are potential reservoir and top seal/cap rocks present. Geochemical studies have shown the seeps to be actively expelling oil, generated from an early mature lacustrine source-rock of Cretaceous or younger age. The Butiaba-Waki well (Figure 1.1) was drilled in the Albertine Graben to a depth of 1222m and the Turaco-1&2 wells cluster (Figure 1.1) was drilled in the Semliki Basin to a depth of 2870m. The well depths are given, throughout this dissertation, in metres below Kelly Bushing, unless otherwise stated. Kelly Bushing is the convenient level on the drilling rig from which depth measurements are conventionally made. Correlation and integration of the available seismic, well and surface data will be used to understand the stratigraphy and sedimentology of the Semliki Basin and to investigate the petroleum play in the area.

1.5 OBJECTIVES

1.5.1 General objective

The aim of the study is to contribute to the knowledge of the sedimentology and stratigraphy and to evaluate the hydrocarbon potential of the Semliki Basin in the Albertine Graben, Uganda.

1.5.2 Specific objectives

- To establish the sedimentation history of the sediments in the Semliki Basin.
- To determine the depositional environment of the sediments in the Semliki Basin.
- To establish the stratigraphic relationship between the different formations in the Semliki Basin.
- To delineate the structures in the study area.
- To predict the petroleum potential of the study area.

1.6 SCOPE OF WORK

The scope of this work involved field investigations in the Semliki Basin, during which surface geological mapping was carried out. Laboratory analysis of the collected samples, as well as of the cuttings from the existing wells (Turaco 1&2) has been carried out to determine the lithology and the depositional environments. Geophysical (seismic, gravity and magnetics) data interpretation and wireline-log interpretations have also been carried out during this study. Comparison with analogous basins in the East African Rift System and other comparable basins worldwide was also part of this study. Integration and correlation of all the above data helped in understanding the sedimentology as well as petroleum geology of the area.

1.7 WORK PLAN

1.7.1 Desk study

- Study of the geological and topographic maps and aerial photographs and other data to obtain an overview of the geology and geomorphology of the study area.
- Obtaining and studying the relevant literature of the study area.

1.7.2 Reconnaissance survey

- Visiting the study area to identify the appropriate location of sites to be investigated.
- Making traverses of all the located points

1.7.3 Detailed fieldwork

- Outcrop mapping and plotting the location points obtained using the Global Positioning System on the area topographic sheet.
- Sample descriptions (texture, stratigraphic relationships of the layers and thickness measurements).
- Structural mapping (dip and strike determination) and plotting these structures on the topographic map
- Sediment sampling into plastic bags, labelled for each sample number.

1.7.4 Laboratory work

- Digitising the topographic sheets to produce the geological and station maps of the area of study.
- Digitising the stratigraphic columns
- Preparation of thin-sections for petrography
- Petrography
- Grinding of samples for XRD analysis
- XRD Analysis

CHAPTER TWO

2.0 LITERATURE REVIEW

Before actual activities were undertaken, a literature study was carried out in order to plan in detail how the proposed activities should be carried out. This was helpful not only in planning data collection and field-investigation activities, but also in the selection of the most appropriate methods to employ. This literature study provided the following brief summary/review of the work that has been done by previous workers which is relevant to this study.

2.1 REGIONAL GEOLOGY

The Albertine Graben comprises the northern extremity of the western arm of the East African Rift System. It runs for 550km from Rwanda in the south, to the Uganda/Sudan border in the north, straddling the border between Uganda and the Democratic Republic of the Congo (DRC) (Figure 2.1). The Graben contains the Lake George –Edward Basin, in the south (Figure 2.2), bounded on the northwest by the Rwenzori Mountains which rise to over 5000 metres above mean sea level. The Graben is offset to the west and continues beyond the north end of the Rwenzori Mountains in an en echelon trend comprising the Semliki and Lake Albert (Kaiso-Tonya Area) Basins and the Rhino Camp Basin (Figure 2.2).

The Graben is bordered on either side by gneissic-granulitic complexes that in places rise to over 2000m above mean sea level. Major NNE-SSW boundary faults separate the Graben from the basement complexes. The lake level has fluctuated significantly since the Miocene and thick deposits of lacustrine sediments occur considerable distances north and south of the present-day shoreline of Lake Albert. Seismic evidence suggests up to 5-6 kilometres of fill (Heritage Oil and Gas Limited, 2001). The oldest known sediments are dated using fossils from outcrop studies to the Middle Miocene (Pickford and Senut, 1994), though it is possible that some of the Tertiary fill may be as old as Oligocene. There is some regional evidence to suggest that Jurassic or Permo-Triassic (Karoo) deposits could underlie all or parts of the graben.

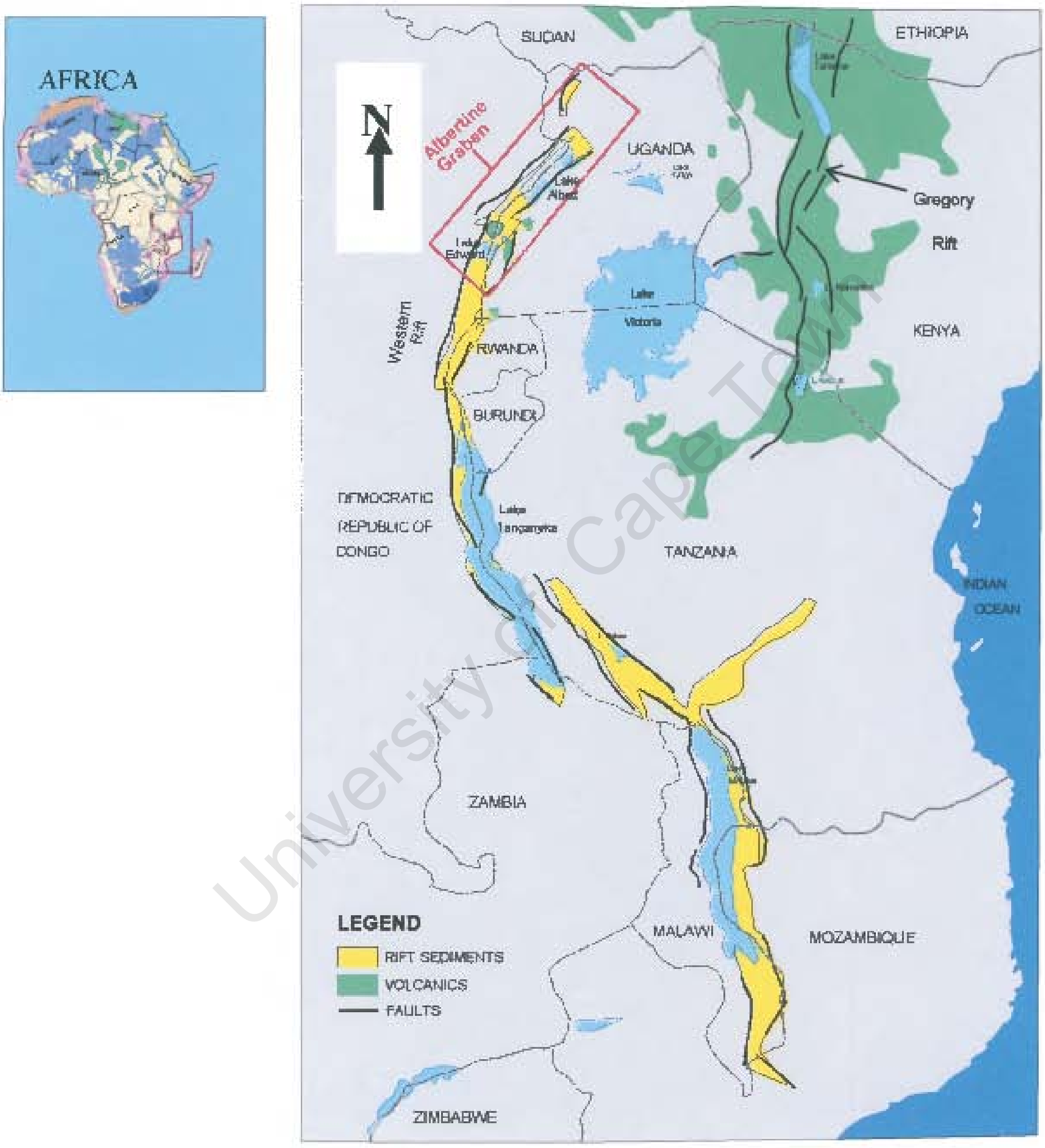


Figure 2.1: Location of the East African Rift System and the Albertine Graben (Petroleum Exploration and Production Department, 2002).

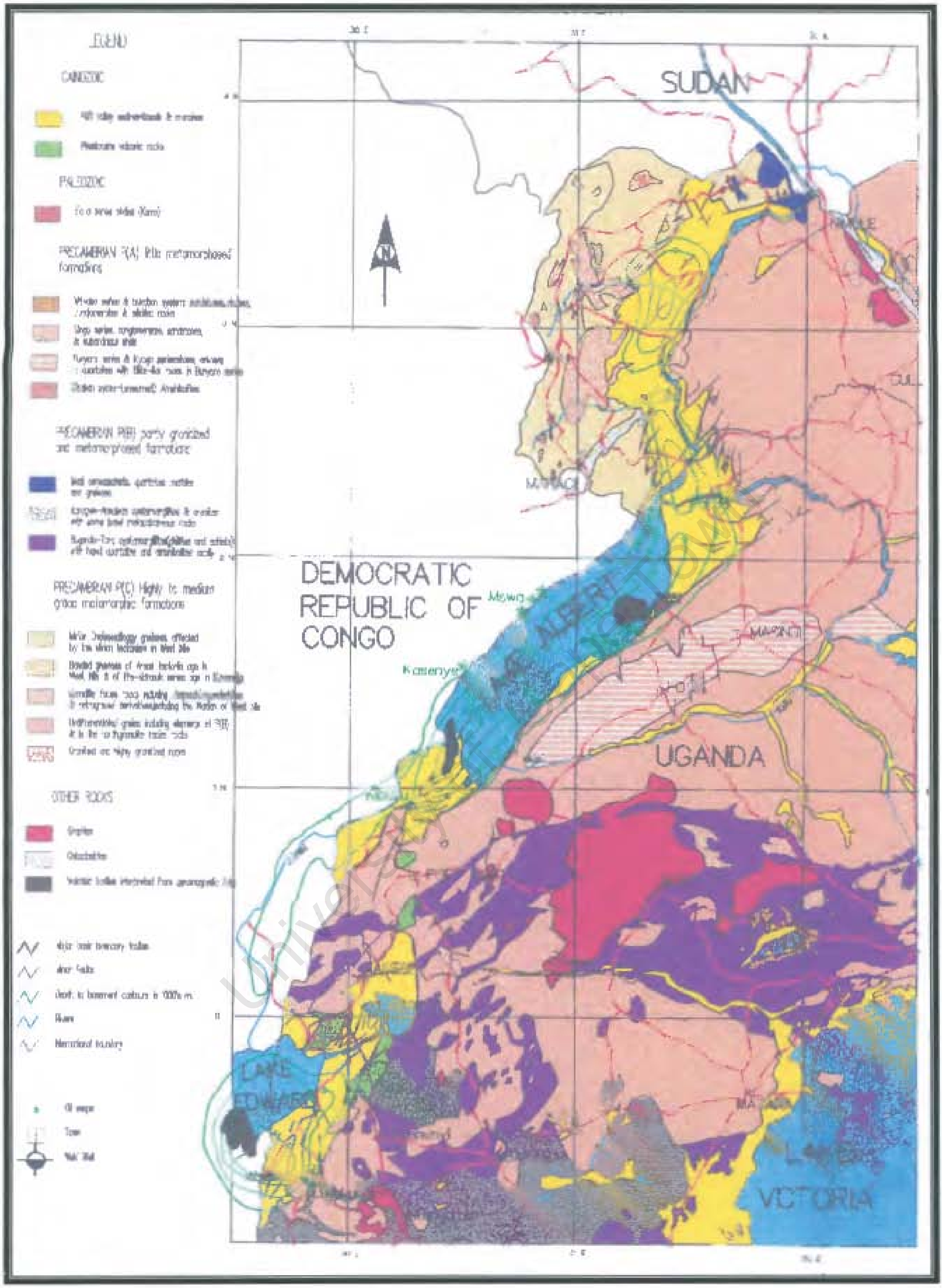


Figure 2.2. Geological map of Western part of Uganda (After Petroleum Exploration and Production Department, 2002).

Rosendahl *et al.*, (1986) noted that seismic data show that most of the East African Rift Grabens are asymmetrical. They are bounded by a major normal fault on one side and a faulted flexure on the other side (Chorowics, 1989). Chorowics (1989) also noted that the main grabens resulted from a long structural evolution which began during the Miocene or Late Oligocene times and continued through to the Holocene. The main grabens are divided into smaller basins separated by transverse structures. These structures, commonly known as the transfer fault zones, generally strike in a NW-SE direction (that is, perpendicular to the main basin structural trend).

Basins in the East African Rift System range in character from deep, narrow and structurally simple like Lake Tanganyika, to broad, shallow and structurally complex such as Lake Baringo (Frostick and Reid, 1990). While volcanism characterizes most of the Kenya Rift and part of the Lake Edward- Lake George Basin, the Semliki, Lake Albert and Rhino Camp Basins are devoid of volcanism (Morley *et al.*, 1999).

Sedimentation in the Albertine Graben appears to be controlled by tectonics, volcanism, climatic changes and patterns of river drainage. The major depositional environments include alluvial fans and fan deltas, fluvial deltaic systems (braided, meandering and floodplain), and lacustrine (Morley *et al.*, 1999).

2.2 TECTONIC SETTING

Initial early rifting commenced with the start of separation of West and East Gondwana (Morley *et al.*, 1999), with gradual break-up of eastern Africa from Lower-Middle Permian times, with marine incursions along the proto-Mozambique Channel and eventual undocking of the Madagascar terrane from the Kenya-Tanzania sector of the African Plate. The East African Rift System has been the classic area of continental rifting since the process was described in Kenya by Gregory (1896, 1921). The East African Rift System is composed of two rift trends called the eastern and western branches (Figure 2.1). The eastern branch, located north and east of Lake Victoria, is a volcanic-rich system that forms the Kenya and Ethiopia Rifts and is believed to have been initiated in the Early Miocene, but evidence exists for earlier Paleogene activity in northern Kenya and Ethiopia (Ebinger *et al.*, 1993, Hendrie *et al.* 1994). The western branch appears to have been initiated later than the eastern branch during the Late Miocene (Ebinger 1989) and exhibits a lesser amount of volcanism. It is composed of a series of extensive deep and shallow lakes: Albert, Edward, Kivu, Tanganyika, Rukwa and Malawi (Morley, 1995).

The two branches of the East African Rift System have undergone different tectonic histories. In general, the western branch can be regarded as a good model for a young continental rift, whereas the eastern branch is representative of a 'failed' mature continental rift system (Morley *et al.*, 1999).

The western branch of the rift contains a string of half-graben basins, which are mostly concealed beneath the major lakes. The basins tend to be characterised by the dominance of large boundary faults, which produce asymmetrical half grabens (Morley *et al.*, 1999). Long rift segments exhibit an alternation in the sense of 'polarity' of the half grabens about every 60-90 km (Rosendahl *et al.*, 1986, Ebinger *et al.*, 1987). These basins are filled predominantly by clastic sediments eroded from Pre-Cambrian basement and Permo-Triassic sedimentary-rock source areas and deposited in fluvio-deltaic and lacustrine environments. On the other hand, the rift basins in the eastern branch are more poorly known. Extensive Miocene- Recent lava flows have concealed much of the older rift history.

The Albertine Graben is a NE-SW trending intracratonic rift basin, turning to an almost N-S trend in the northern part. The graben is highly asymmetrical in some places, but trends NE-SW through most of its length. It trends N-S in the Pakwach and Rhino Camp Basins, to the north of Lake Albert, due to a translation over a pull-apart (transfer) zone. Tectonic forces in the graben are overwhelmingly extensional, although there is evidence of lateral movements occurring together with extension. The presence of a number of peneplains demonstrates the occurrence of vertical movements.

The structural regime of this area is typical of extensional rift basins, that is, the major boundary faults that trend northeast-southwest demarcate the extent of the rift. In this area, two regional faults were mapped; the one that separates the Toro Plain (Figure 1.2) from the Semliki Flats (Figure 1.2) and another that separates the escarpment from the Toro Plain. Faults trending almost E-W occur in the rift between the boundary faults. Morley *et al.* (1990) have described these faults as transfer faults. Transfer zones are structural features that develop between the transfer faults as the rift evolves. This step-faulting down to the Semliki Flats characterises the area, giving a typical half-graben structure in rift settings, which result from the separation of a border fault system in the deepest parts of the basin and the highest rift mountains and or escarpments.

2.3 STRATIGRAPHY

The stratigraphic succession consists of the pre-rift and syn-rift sections. The pre-rift consists of the Proterozoic, which is well exposed on the rift flanks and shoulders of the Albertine Graben. It is composed predominantly of high-grade metamorphosed and igneous rocks of Precambrian age.

The syn-rift section of the Albertine Graben was recorded in the Butiaba Waki-1B well (Figure 1.1), drilled in 1938. The Butiaba Waki-1 well penetrated both Upper and Lower Tertiary and went through the Mesozoic before reaching the Basement. Although the thickest section in the graben is Tertiary to Recent, there are indications of a Mesozoic section (Jurassic or Cretaceous) at the base of the section (Heritage Oil and Gas, 2001). The Lower Tertiary may overlap the crystalline basement in many parts of the graben, but there is a strong possibility that it overlies a Mesozoic section (Karoo) in most parts of the graben (Heritage Oil and Gas, 2001).

2.4 PREVIOUS WORK

Wayland (1925) undertook the first petroleum geology in the area and his findings are documented in the publication "Petroleum in Uganda". He described a series of oil and gas seeps at various locations along the basin margin.

The Butiaba Waki-1 well (Figure 1.1), drilled by the African and European Investment Company in 1938, was drilled in the Albertine Graben. This well was drilled close to the oil seep at Kibiro, on the eastern shore of Lake Albert, to the north of Block 3. The Butiaba Waki-1 well is located at latitude 01° 47' 12" N, longitude 31° 21' 17" E, at an altitude of 664m. The well was drilled through the basin-bounding fault into the basement rocks at 1,222m. It intersected a sequence of interbedded shales, sandstones and conglomerates and proved the presence of both source rocks (described as oil shales) and hydrocarbon shows in the form of oil-stained sandstones. No logs were run and information from the well is limited to mudlog lithology (Figure 2.3) and 'shows' data. Oil 'shows' were encountered while drilling.

Harris *et al.* (1956) further described the presence of the oil seeps in detail. Kibuku oil seep, located at the foothills of the Rwenzori Mountains at the contact of sedimentary basin-fill and underlying basement is one of the major oil seeps in the area of study and the Albertine Graben as a whole.

Harris *et al.* (1956) also noted that escarpments bordering the Albertine Rift, as well as the Rwenzori range, are composed of metamorphic rocks of the Basement Complex. Harris *et al.* (1956) divided the sedimentary rocks into the Kisegi, Kaiso and the Epi-Kaiso beds. They noted that the following sequence of events took place:

- Faulting was initiated during the Late Oligocene-Early Miocene
- There was slow subsidence and deposition of Kisegi Beds during Miocene-Pliocene

- Great tectonic movements during the Late Pliocene-Pleistocene led to depression and tilting of the rift block and Kisegi Beds.

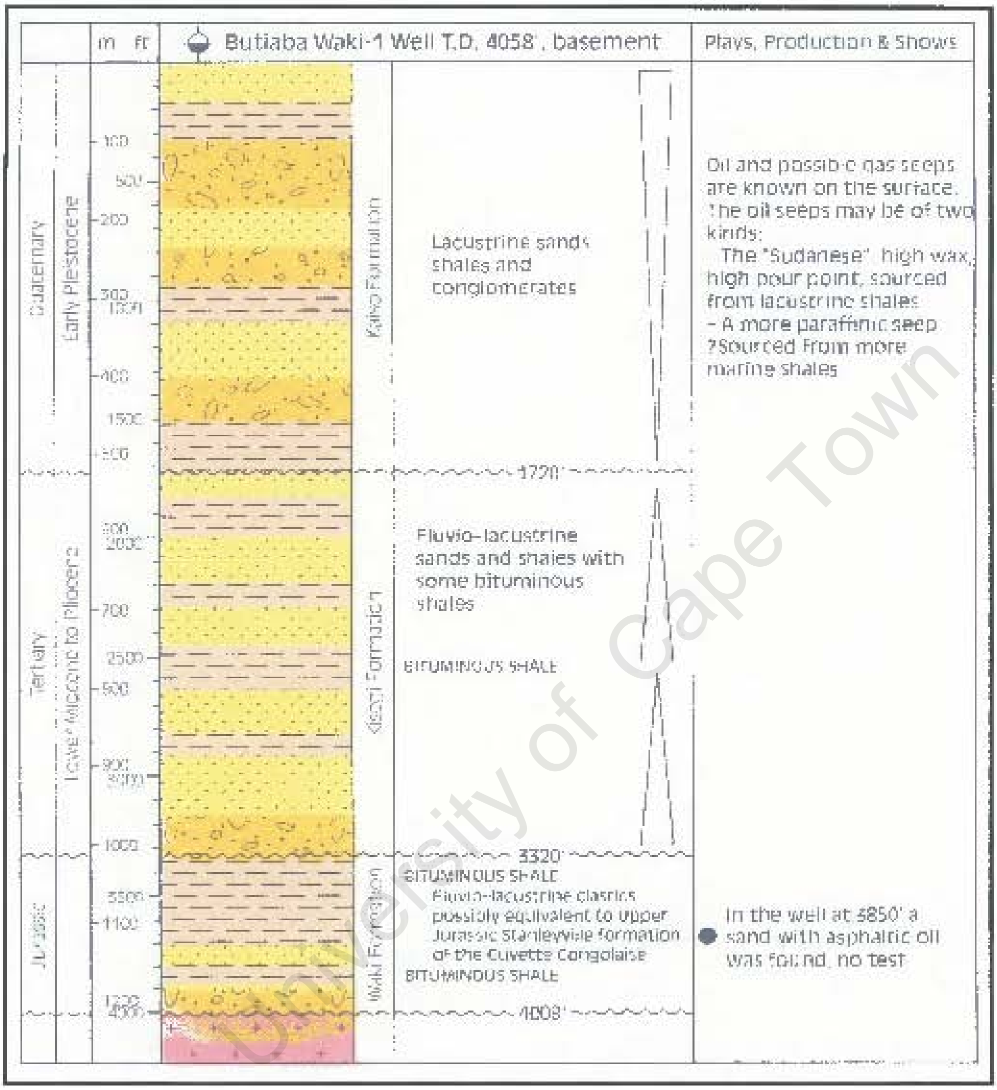


Figure 2.3: Butiaba Waki-1 Well Litholog (Petroleum Exploration and Production Department, 2002).

The area has been mapped by Pickford (1987). He set up a series of formation names, which have been used by all the later workers. The entire graben was subjected to a detailed stratigraphic and palaeontological study by Pickford and Senut (1994), who dated and correlated the outcropping beds using predominantly vertebrate and molluscan faunal assemblages. These suggest that the rocks exposed have an age-range of Middle Miocene to Holocene. Surface geological mapping and radiometric dating by Pickford *et al.* (1994), revealed a stratigraphic section at outcrop that ranges from Middle Miocene (11.5 Ma) to Holocene (Table 2.1). This basic stratigraphic framework for the area has been further refined by the Petroleum Exploration and Production Department (PEPD) of Uganda in various unpublished field reports. One new formation, the Kasande Formation, which was not mapped by the previous workers, was added to the stratigraphic column of the Semliki Basin (Rubondo and Kasande, 1996).

Table 2.1: Summary of Semliki Basin outcrop stratigraphy (After Pickford *et al.*, 1994)

Ma	**Age**	**Formation**
0.0	Late Pleistocene	Rwebisengo
	Early Pleistocene	Middle-Upper Nyabusosi
2.0		
	Late Pliocene	Lower Nyabusosi-Katorogo?
	Early-Middle Pliocene	Katorogo-Nyakabingo
4.0		
	Late Miocene-Early Pliocene	Nyaburogo
6.0	Late Miocene	Oluka
	Late Miocene	Kakara
8.0		
??		?
13.0	Middle Miocene	Kisegi?

The oldest section at outcrop is the Kisegi Formation, a predominantly sandy unit, which is made up primarily of stacked channel-fill sands. The Kisegi Formation has an onlapping relationship with the Basement schists and quartzites of the Rwenzori

Mountains; therefore, the thickness described at outcrop may grossly underestimate the true total thickness of the formation.

Above the Kisegi Formation lies a predominant clay-prone sequence with subordinate sands. These have been subdivided into the Kasande, Kakara, Oluka, Nyaburogo, Nyakabingo and Nyabusosi formations, based on subtle changes in sand:shale ratio, supported by microfossil content.

A series of gravity and magnetic surveys have been undertaken. In the 1980s, a 15,000 line-kilometre aeromagnetic survey was carried out over the entire Albertine Graben in an effort to establish the presence of sedimentary basins as an initial step towards a systematic evaluation of its petroleum potential. The Petroleum Exploration and Production Department has acquired gravity and magnetic profiles in a series of traverses across the basin since 1990. The Bouguer anomaly map for the Semliki Basin was generated from these profiles (Figure 2.4).

The modelling of these data suggests a thickness of sedimentary section varying from 4-6 km in the deeper parts of the basin (Figure 2.5).

Gravity profiles across the Semliki Basin also suggest a major change in sedimentary thickness across an intra-basin fault, which indicates that there may be structures present in the section.

From the Bouguer anomaly map of the Semliki Basin, there is a major variation in the Bouguer values in the immediate vicinity of the rift escarpment. The values rapidly become more negative towards the centre of the rift. The Bouguer anomaly decreases (becomes more negative) towards the centre of the entire basin and the amplitude and rate of decrease indicates the slope of the basin, depth and mass difference. It was noted that the basin extends over large distances, as evidenced by the contour lines that are more or less parallel to the strike of the body towards the centre of the basin.

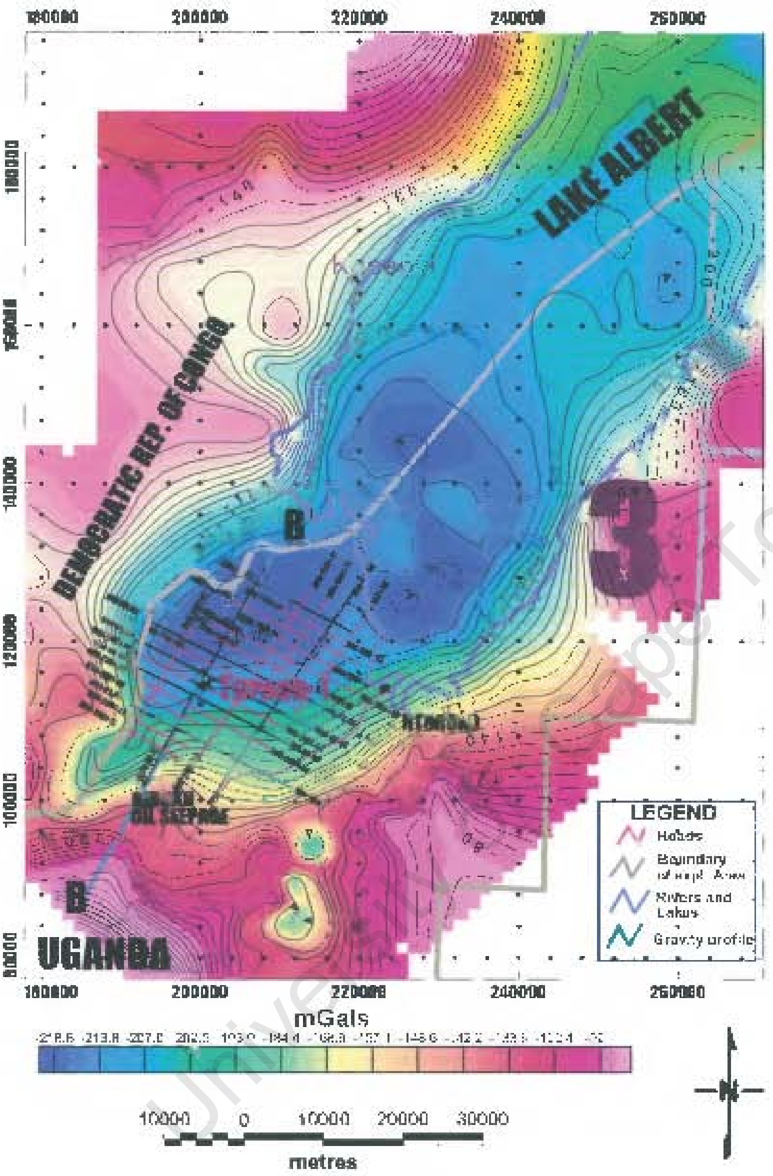


Figure 2.4. The Bouguer anomaly map of the Semliki Basin (After Petroleum Exploration and Production Department, 1994).

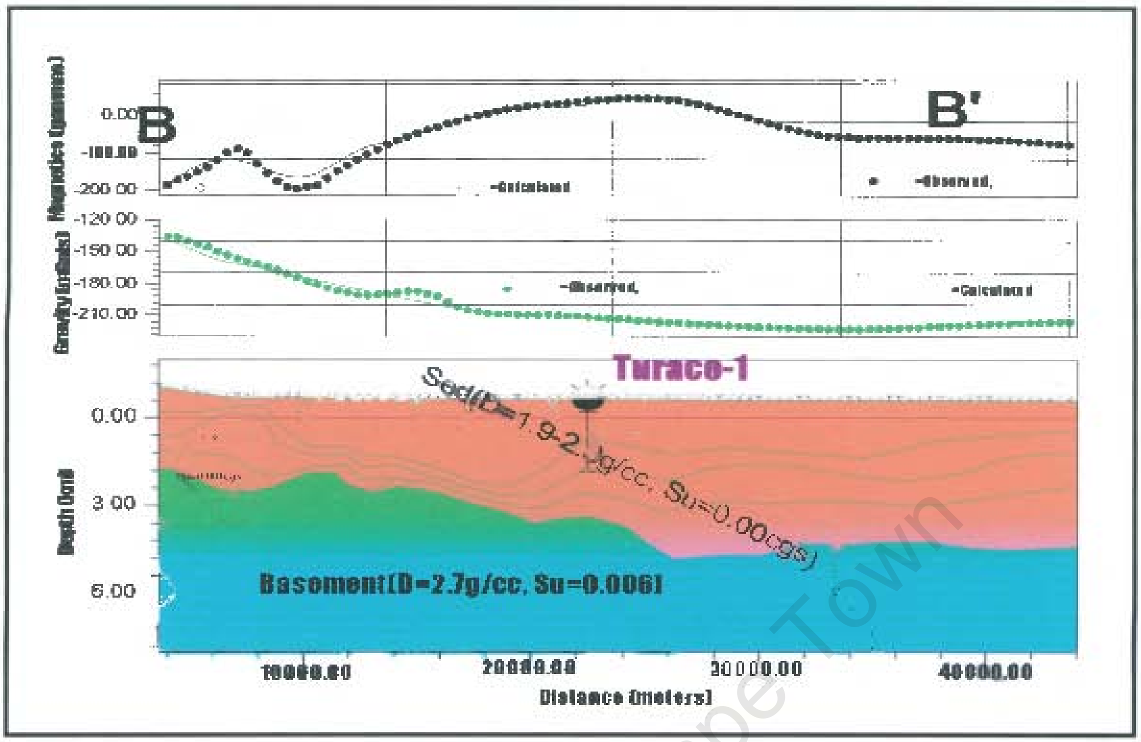


Figure 2.5. Bouguer gravity model along B-B (After Petroleum Exploration and Production Department, 1994).

The first-ever seismic data in Uganda were acquired in the Albertine Graben in 1998 and 2001 by Heritage Oil and Gas Limited (the HOG-98 and HOG-2001surveys). A total of 400 km of data were acquired by IMC Geophysics employing a dynamite source. Figure 2.6 shows the base map of the acquired seismic data.

The major fault in the area, the Makondo Fault (Figure 1.2), is interpreted as the eastern fault of a flower structure. This same fault is described on the earlier gravity profiles bisecting the basin and forming an escarpment at the surface separating the Semliki Flats from the more elevated Toro Plain. The Makondo Fault runs southwards into the Kibuku Fault on the northern flank of the Rwenzori Mountains.

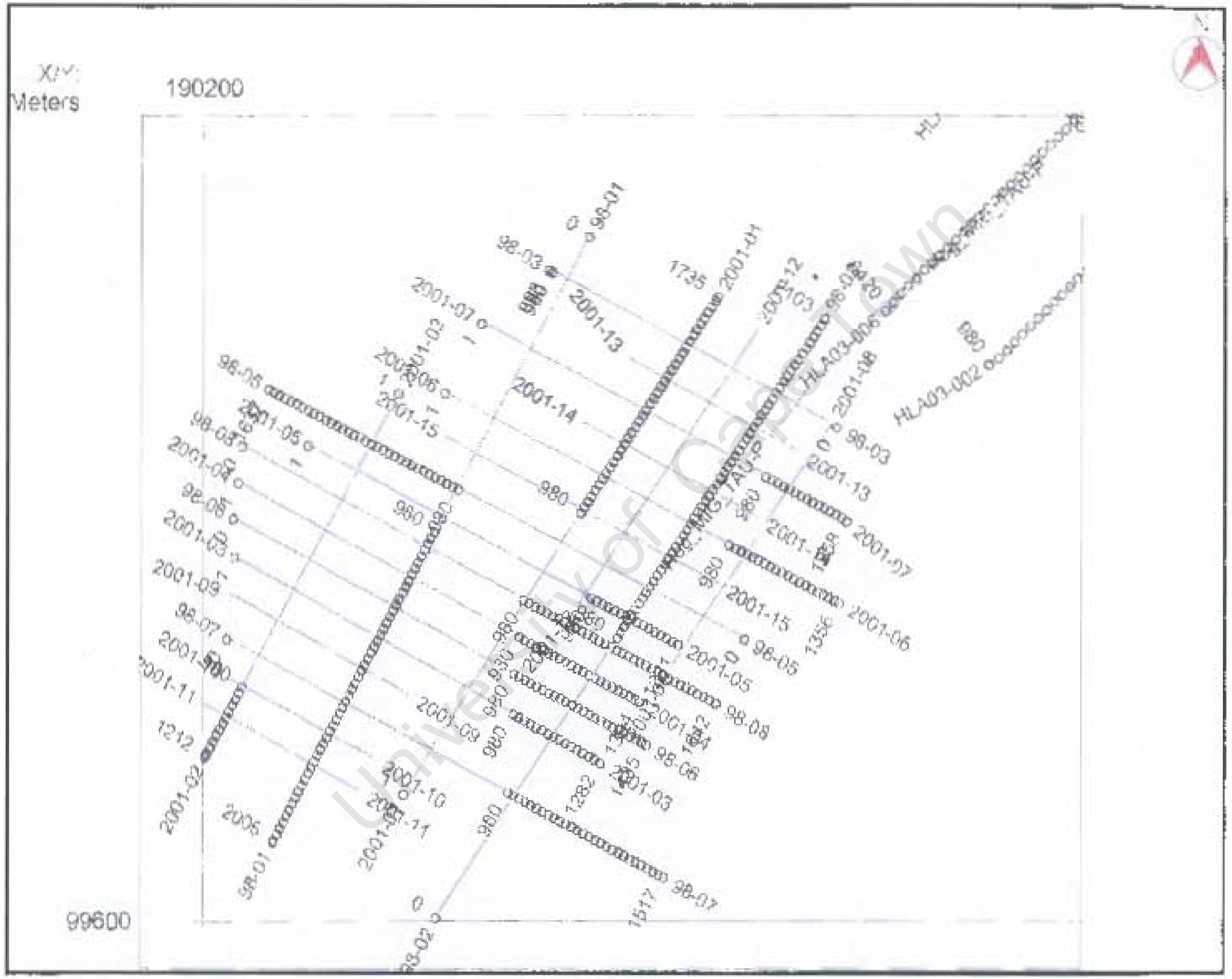


Figure 2.6. Base map of the acquired seismic data from Semliki Basin.

The interpretation of the seismic data by Heritage Oil and Gas Limited led to the location of the drilling sites for the Turaco 1&2 wells (Figure 1.1) in the Semliki Basin in 2002 and 2003, respectively. The exploration wells, Turaco 1 and 2 in the Semliki Basin were drilled in an effort to evaluate the existence of a full petroleum system in the subsurface. The Turaco-1 well was drilled during the period September 2002 to January 2003, to test the hydrocarbon potential of a structure located in Block 3. The Turaco-1 well is located at Latitude 01° 01' 51.3", Longitude 30° 18' 06.0" and UTM E199669, N114061 (Central Meridian-33°). The Turaco-1 well was designed to drill to 2,500m to test for hydrocarbons at a number of levels within a Miocene to Pliocene section, suggested by studies on nearby outcrops to comprise an association of lacustrine mudstones with subordinate lacustrine margin (mainly fluviatile and beach) sandstones.

The Turaco-1 well was drilled to a depth of 2487.7m, but logging was not performed to total depth for technical reasons. The target Kisegi Formation had not, however been reached. Turaco-2, a sidetrack of Turaco-1 from a depth of 1460m, was drilled during 2003 and 2004 to a total depth of 2980m. It intersected the Kisegi Formation at a depth of 2555m. Lithologs and wireline logs have been interpreted and will be presented in Chapter Four.

Heritage Oil and Gas Limited (2002) carried out petrographic and petrophysical studies of selected samples from the Semliki Basin and found that the porosities in sandstones are excellent and, in the clean sands, typically are in the range of 28-36%, though typically in the low 20 per cents in the shalier sands. There is a moderate downhole decline in porosity, related to compaction in the sandstones with depth. The predominant medium to coarse grain size and weakly consolidated nature of the sandstones imply that the permeabilities are good to excellent.

CHAPTER THREE

3.0 METHODOLOGY

3.1 FIELD WORK

The geological mapping of the Semliki Basin was carried out by the writer during the months of June and July 2004. Mapping started with the interpretation of aerial photographs at the Department of Petroleum Exploration and Production, Uganda. All the relevant geological information was transferred onto 1: 50 000 topographic sheets.

While in the field, a Global Positioning System (GPS) was used to determine the location of the sampling points, which were then plotted onto 1: 50,000 topographic maps of the area. The topographic sheets were then digitised to produce a station map and the geological map of the area. On each exposure, rock descriptions such as colour, grain size, texture, stratigraphic relationships of the layers and thickness measurements, dip and strike determination were done and recorded in the field notebook. The thicknesses of the units were measured using a tape measure depending on the scale of the interval. A hand lens was used to estimate grain size, sphericity/roundness of the clasts, sorting and cementation of the samples in the field. A Soil/Rock Colour Chart was used to estimate the colour of the sediment. Observations of sedimentary structures, both primary and secondary, were made to assist in the elucidation of the depositional environment. The angles of dip and strike of the beds and any other structures were measured by the use of a compass. Sedimentary structures were recorded by field sketches and by photography.

Samples were collected from the outcrops and were described in the field macroscopically and later taken to the laboratory for petrographic study and X-ray diffraction, XRD.

3.2 LABORATORY WORK.

3.2.1 Cartography

3.2.1.1 Geology and Station maps

Topographic sheets from the field were digitized on a digitising table to produce the study area's geological and station maps in the cartography section of the Department of Petroleum Exploration and Production, Uganda. Using the ArcGis software, the geological map of the Semliki Basin and the station map of the area mapped were produced.

3.2.1.2 Stratigraphic Profiles

After a detailed study of the lithology, primary structures and fossils in the formations of the Semliki Basin, a special key was devised for their illustration. The stratigraphic profiles were drawn according to the standard method (Johnson, 1987; Selley, 1982). This is a graphic presentation that represents the lithology (grain size and sorting), thickness of the different units, structure and paleontological information (fossils).

The process involved digitising the stratigraphic columns from the field notebook on a digitizing table and then generating the stratigraphic columns (drawn to scale), using ArcGis software. This simplified the comparison between sections.

3.2.2 Petrography

3.2.2.1 Thin-section Analysis

Thin-sections of the selected samples were prepared by the Technical Workshop, Department of Geological Sciences, University of Cape Town. The lithology of the selected samples was examined and described microscopically, using a petrographic microscope. Both crossed polars and plane polarised light were used in order to determine the mineralogy of the samples.

3.2.2.2 X- ray Diffraction (XRD)

X-ray diffraction techniques allow the qualitative and quantitative determination of crystalline solid materials, by measuring the distance between atomic planes in the crystal lattice. X-ray powder diffraction (XRD) is one of the most important techniques for characterising polycrystalline materials. XRD was done on selected sediment samples to gain a qualitative understanding of the mineralogical composition of the samples using the X-ray powder diffractometer. The bulk mineralogy of all samples was analysed, and selected samples were analysed for clay mineralogy.

Samples for bulk mineralogy were prepared for qualitative powder X-ray diffraction (XRD) analysis by grinding 80 g of sample to -300 mesh in a carbon steel mill and then drying overnight at 60°C. A small quantity of powder was top loaded into an aluminium holder and scanned on a Phillips (PW1130/90) X-ray diffractometer, housed in the Department of Geological Sciences at the University of Cape Town (UCT).

Clay-size fractions (<2μm) were separated from the bulk sample by dispersion with a Virtis Virsonic 475 ultra-sonicator using Na_2CO_3 to increase the pH to aid dispersion. The clays were decanted and NaCl added to increase the ionic strength of the suspension and induce flocculation, so increasing the clay concentration (Moore and Reynolds, 1997). After desalination in dialysis tubing, the clay was placed onto a glass slide as a suspension and allowed to dry to obtain preferred orientation. Because many clay minerals have similar d-spacings (i.e. separation between crystal layers), sample treatments were required to aid identification, for example heating or treating with glycerol (Whittig and Allardice, 1986). After the first XRD scan, each slide was treated with glycerol by spraying. Glycerol causes the 14 Å peak of smectite to shift to 18 Å. Random smectite-mica interstratification will result in a shift of the peak to a d-spacing between 10 Å and 18 Å, rather than to exactly 18 Å. Interstratified clays were identified by the change in shape of the curve from convex to concave between 12 Å and 18 Å, rather than from a particular d-spacing.

The Phillips (PW1130/90) X-ray diffractometer, was operated at the following settings;

- Copper Kα X-Ray tube generating monochromatic x-rays of wavelength 1.542 Å
- X-ray generator set at 40 kV and 25 mA
- NaI scintillation counter
- Pre-slit (fixed) 2 mm

Bragg angles between 4° and 75° were scanned for bulk samples resulting in an approximately 30-minute-long scan. The same settings were used for analysis of clay mounts, except that only an angle of 30° was scanned.

Diffractograms of the X-ray intensity pattern against 2θ angle were plotted using in-house softwares GSCAND, and GRAFIT® (Graphicus, Inc.). These were used to identify the dominant minerals in the powdered rock samples. Minerals were identified from the d-spacing and relative peak intensities using the JCPDS PDF-2 DATA BASE RETRIEVAL/DISPLAY SYSTEM (International Centre for Diffraction Data). Crystal d-spacing data and peak intensities for the major peaks were matched against X-ray diffraction data from PCPDS cards to identify mineral species (JCPDS, 1997).

3.3 SEISMIC DATA

Seismic prospecting is based on the study of the propagation times of elastic waves generated at the earth's surface by artificial means (such as explosives) in the subsurface formations (Mitchum, et al., 1977). The geological sections, consisting of different rock formations, therefore, may be viewed as a section composed of elastic layers. The sections show the sedimentary layers of the basin in two or three dimensions and this helps in analysing how the sedimentary layers differ horizontally and/or vertically. Since the seismic velocity is the most significant elastic parameter, the geological section in seismic prospecting is regarded as a section of layers, each with different velocity value.

The seismic results are finally given in sections, in which all the seismic boundaries are in time or depth against seismic recording distances along the ground.

Analysis and interpretation of seismic sections helps in the study and delineation of sediment structures and depositional environments. This is based on the fact that very fine sediments such as claystones and shale are characterised by relatively slow seismic velocities and therefore exhibit continuous and high-amplitude reflections. Sandstones, on the other hand, are characterised by relatively high seismic velocities and by relatively weak and discontinuous reflections. This can help in the prediction of depositional environments in that the fine sediments are normally associated with lacustrine environments and/or floodplains, whereas sandstones are associated with fluvial and/or beach environments.

Seismic reflections represent seismic energy reflected from a particular reflector (such as bedding, unconformities, change in lithology, faults and change in fluid medium) due to a change in acoustic impedance in the subsurface media (Mitchum *et al.*, 1977). Seismic data interpretation in this study was based on the data that were acquired by Heritage Oil and Gas Limited in 1998 and 2001. A total of 400 line-kilometres of two dimensional (2D) seismic data of the Semliki Basin data were acquired. These data have been analysed and interpreted during this study and this has helped in the study of sedimentary facies of the subsurface. Kingdom Suite Software (User Mannual, 2001) has been used in the interpretation of these data.

The first step in seismic interpretation was the calibration and picking of seismic reflections. A number of reflections were picked for these data, based on the stratigraphy of Turaco-1&2 wells and outcrop ties. Other reflections, identified below the Turaco-2 well depth, were selected for mapping purposes. All these reflections were picked, based on seismic attributes. Seismic attributes are any measurements based on seismic data that help one to visualize and to identify structural features and depositional environments (Sheriff, 1991). There are different types of seismic attributes, such as envelope (also called instantaneous amplitude or reflection strength), instantaneous phase and instantaneous frequency (Sheriff, 1991).

- Envelope: An envelope attribute determines the reflection strength of a reflection event. The amplitude of a reflection oscillation generally builds up to the maximum and diminishes towards the end. The presence and clarity of this overall shape (envelope) provides a measure of certainty with which the energy may be classified as reflection energy.

- Instantaneous phase is a quality dependent on reflection strength. It emphasizes the continuity of events and is effective in showing faults, pinchouts, angularities and interference of events with different dip attitudes.

- Frequency is the time derivative of instantaneous phase. It is very sensitive to changes in bed thickness and is thus useful in telling where stratigraphic changes occur. Hydrocarbon accumulations often have low frequencies referred to as low-frequency shadow and this is one of the hydrocarbon indicators.

- Fundamental oscillation: The minimum requirement in identifying the reflected energy pulse is a fundamental oscillation of one or a half cycle of substantially identified frequency over its entire span.

- Continuity. This is related to an analysis of one trace at a time. The consistency of these characters over a number of adjacent traces provides a measure of confidence for identification and correlation of a reflection-energy pulse from one trace to another. The reflections are good, fair or poor according to the certainty with which the energy may be classified as reflection energy and accuracy with which the local dip may be picked.

- Polarity is the sign of the trace whether negative or positive, at the instant where the reflection strength is at a maximum value. The top of a gas reservoir, for example, may give rise to a strong negative reflection coefficient, whereas that from the gas-water contact is expected to be a weak positive reflection coefficient. Polarity figures can thus be used to decipher gas accumulations.

3.3.1 Stratigraphic Interpretation

Stratigraphic interpretation of seismic data was based on the seismic resolution. Seismic sequence mapping is the first step that leads to analysing the seismic attributes, including seismic facies and reflection characteristics (Mitchum *et al.*, 1977).

Unconformities, which are surfaces of erosion or non-deposition, represent gaps in the geologic record. The strata below the unconformities are commonly weathered, thus providing a density/velocity contrast. They were identified on seismic sections because they commonly separate strata (sequences) with different physical properties or attitudes (Mitchum *et al.*, 1977). The mapping of unconformities is thus the key to seismic sequence analysis. Disconformities commonly separate rock units having different dips, at least on a regional scale, and were recognised by interpreting systematic patterns of reflection terminations along them. Unconformities and disconformities are also commonly associated with onlap, downlap, toplap and truncations by the overlying or underlying sequences (Mitchum *et al.*, 1977).

Pinchouts and erosional truncations were identified from the seismic data by analysing the angle between the truncation surface and the surfaces of bedding. When the sequence is thickening, a single reflection splits and passes into two reflections of geological significance. Pinchouts often cause the character of the reflection to change continually in the lateral direction, because of progressive shifts in the phase relation between constituent signals from different lithological boundaries, encompassed by a single seismic wavelength (Nimmagadda, 2002). Lateral discontinuities and pinching out of reflections on a vertical section could represent faults, channel systems or fan deposits.

Stratigraphic features, representing sand lenses, were also identified from the seismic data. Channel and fan features were best recognised by their distinct geometry on horizon slices. The nature of contact, thickness spacing, lateral extent and lateral changes in the sand bodies are dependent on the depositional process (Waters, 1987). All these influence the reflection signature associated with these interfaces. The sandstones in the channels have sharp bases, and merge transitionally upward into mudrocks. So, the sharp base reflections from the base and weak reflections from the top with discontinuous and variable character have been mapped from the seismic data.

3.3.2 Direct Hydrocarbon Indicators (DHIs)

Hydrocarbon accumulations sometimes have an effect on seismic data that can be used to indicate their location. This is based on the identification of an acoustic contrast associated with the presence of hydrocarbons, particularly free gas (Mitchum *et al.*, 1977). The most prominent of these indicators is often a marked increase in amplitude or "a bright spot". The studies of seismic velocity of a porous material upon the fluid contained in the pore spaces have shown that a sand containing gas will have a lower velocity than that same sand saturated with oil or water. The lowering of velocity and density is often so large to produce exceptionally large acoustic impedance contrasts, resulting in high amplitude reflections. This high-amplitude portion of the reflection is referred to as a bright spot (Sheriff, 1991). One of the most diagnostic features of gas is the presence of a strong horizontal reflection, just below another reflection that has the dip associated with the lithological boundaries of the gas trap, in the portion of the section where it occurs (Mitchum *et al.*, 1977). Therefore, a horizontal event is often a product of gas/oil or gas/water interface/contact within the reservoir.

3.4 BOREHOLE DATA

Borehole data help in supplementing, either directly or indirectly, the subsurface geological information (Pirson, 1977). Borehole analysis helps in interpreting the geology of the area of interest, providing detailed vertical information, but only at one location. The borehole geophysical methods used in the evaluation of formations are called well-logging methods (Fons, 1969). Of these well-logging methods, spontaneous potential logging, resistivity logging, neutron logging, density logging and natural gamma logging are very commonly used in formation evaluation. Well logs are a record of one or more physical measurements, as a function of depth in a borehole (Sheriff, 1991). Wireline logs are of special interest in that they provide the only source of data to give accurate information on the depth and the apparent, and even real, thickness of beds and they give a nearly continuous analysis of the formations (Serra and Abbott, 1980). Therefore, the lithology, depositional history of the formations, fluid contacts, composition, texture and sedimentary structures of the different subsurface formations can be inferred from the study of well data (wireline logs, cuttings and cores). Analysis and interpretation of wireline data is very important in the comparison of well and outcrop stratigraphy.

In this study, gamma-ray, caliper, resistivity, neutron porosity, sonic and density logs were studied and interpreted to elucidate the lithology of the subsurface. The interpretation of these logs follows Schlumberger (1972, 1974), Serra and Abbott (1980) and Serra (1984). The analysis of the different log responses in different lithological units has led to the correlation of the surface geology with the subsurface geology.

According to Serra and Abbott (1980) different lithological units give different log responses. For example, tight formations such as shale, limestone or claystone give higher gamma-ray values, whereas loose formations, such as sandstones, give lower gamma-ray values. Gamma-ray emissions are also highest in clay-rich or potassium-rich formations. Table 3.1 below gives an idea of how different logs respond to different lithological units.

Table 3.1. Log responses in terms of lithology

Log	Lithology	Response (value)
Gamma Ray	Shale, claystone, limestone	High
	Sandstone	Low
Sonic	Shale, claystone	Slow velocities
	Sandstone	Fast velocities
Neutron Porosity	Shale, claystone, limestone	Low (Negative separation)
	Sandstone	High (Positive separation)
Density	Shale, claystone, limestone	High
	Sandstone	Low
Resistivity	Shale, claystone	Low
	Sandstone	High

Using the criteria from the table above; sandstones were revealed by the low gamma ray, low density, high porosity and high resistivity responses, whereas claystones/shales were revealed by high gamma ray, high density, low porosity and low resistivity responses. In the analysis and interpretation of well logs for lithology, it is advisable to integrate the responses of a particular lithologic unit to different logging methods, since some log responses may not be reliable (Serra, 1984). For example, density and neutron logs may not be reliable alone, based on the fact that the tool is immersed in drilling mud during measurement and therefore the radioactivity emitted by the tool may be absorbed by the components of drilling mud, rather than the formation at that particular depth.

Density logs deflect to the left in sandstone formations and to the right for shales/claystones and the reverse is true for neutron porosity logs. Because neutron porosity logs respond to hydrogen ions (measure hydrogen index value), the minerals containing hydrogen in their structure can be responsible for the anomalously high apparent porosities. Where two porosity logs cross over and are in agreement, clean sand is indicated.

Gamma-ray and spontaneous potential (SP) logs deflect to the right for shales/claystones and to the left for clean sandstones. The response on a gamma ray log is attributed to the higher concentration of radioactive elements (K, Th and U) in the clay minerals as compared to those in the sandstones. Sandstones have relatively fast velocities, as compared to the claystones and shales.

Caliper logs show values lower than the bit size (deflect to the left) in sandstone formations accompanied by mud cake build up, the same as the bit size for limestones and higher than the bit size (deflect to the right) for claystones/shale.

The results of the interpretation of the different wireline logs for Turaco 1&2 wells are presented in Chapter Four.

CHAPTER FOUR

4.0 PRESENTATION AND INTERPRETATION OF DATA

4.1 INTRODUCTION

The aim of this study is to establish the relationships among the sedimentation history, stratigraphy and petroleum accumulations in the Semliki Basin. In relation to the above, the writer carried out geological mapping of the Semliki Basin during the months of June and July 2004. Results of this study, along with their analysis and interpretation, are presented in this chapter. This includes field descriptions and laboratory analyses (petrography and X-ray diffraction) of the selected samples.

Available geophysical and borehole data were also analysed and interpreted to support the findings of the geological interpretations. These include seismic and borehole data (well cuttings and well logs) from the Turaco 1&2 wells.

4.2 GEOLOGY AND STRATIGRAPHY

All the measured outcrop sections were logged in field notebooks. The best exposures occur in the river valleys, where river incision has cut through the surficial sediments to expose the underlying sediments, and along the shores of Lake Albert. The locations of the different stations were recorded in the field notebooks and then plotted on the area topographic sheets. These sheets were digitised on a digitising table and, with the use of ArcGis Software, the station map (Figure 4.1) and the geological map (Figure 4.2) of the Semliki Basin were generated. The GPS locations of the stations visited are presented in Appendix 1.

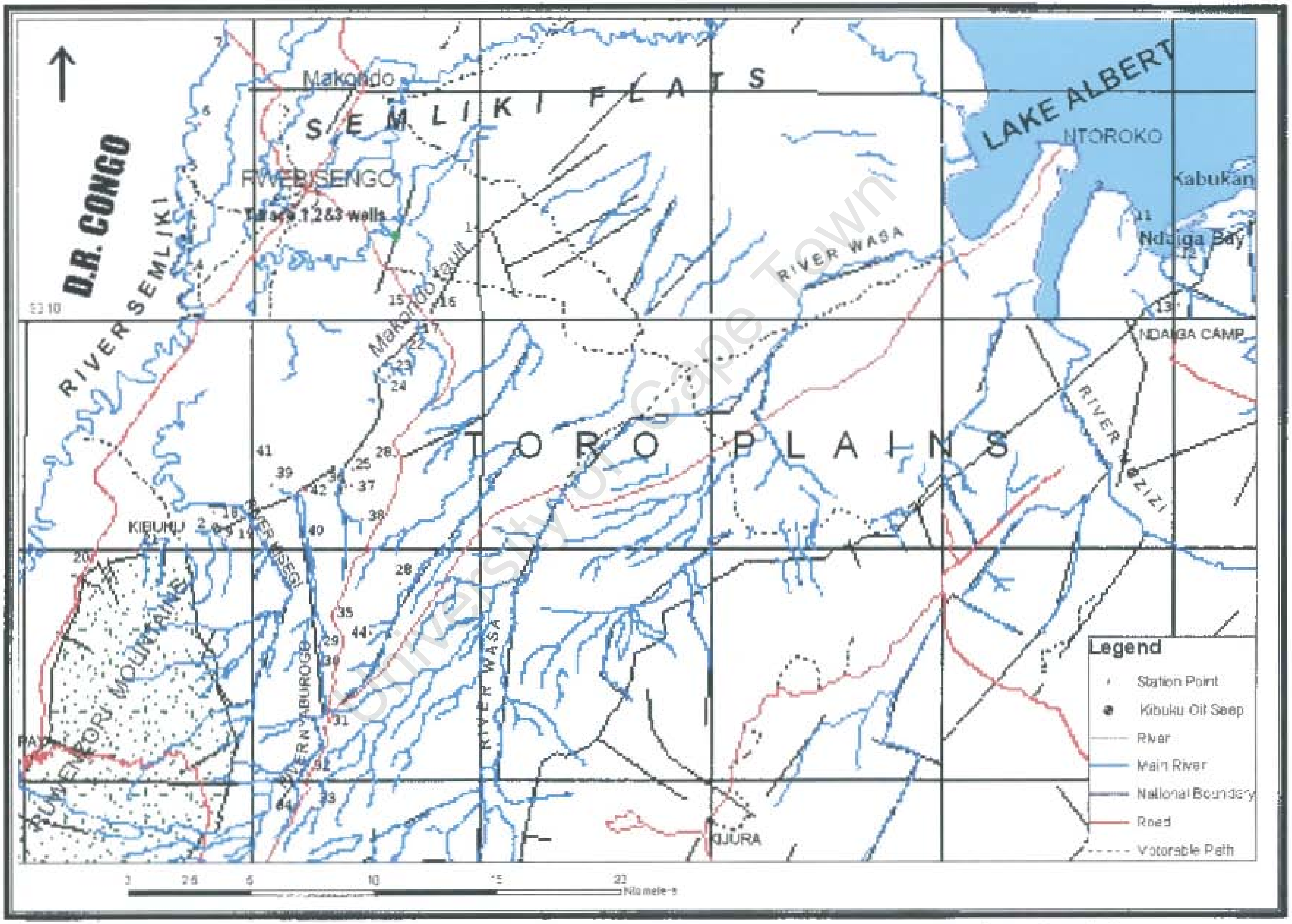


Figure 4.1. The station map of all the station points made during the geological mapping of the Semliki Basin.

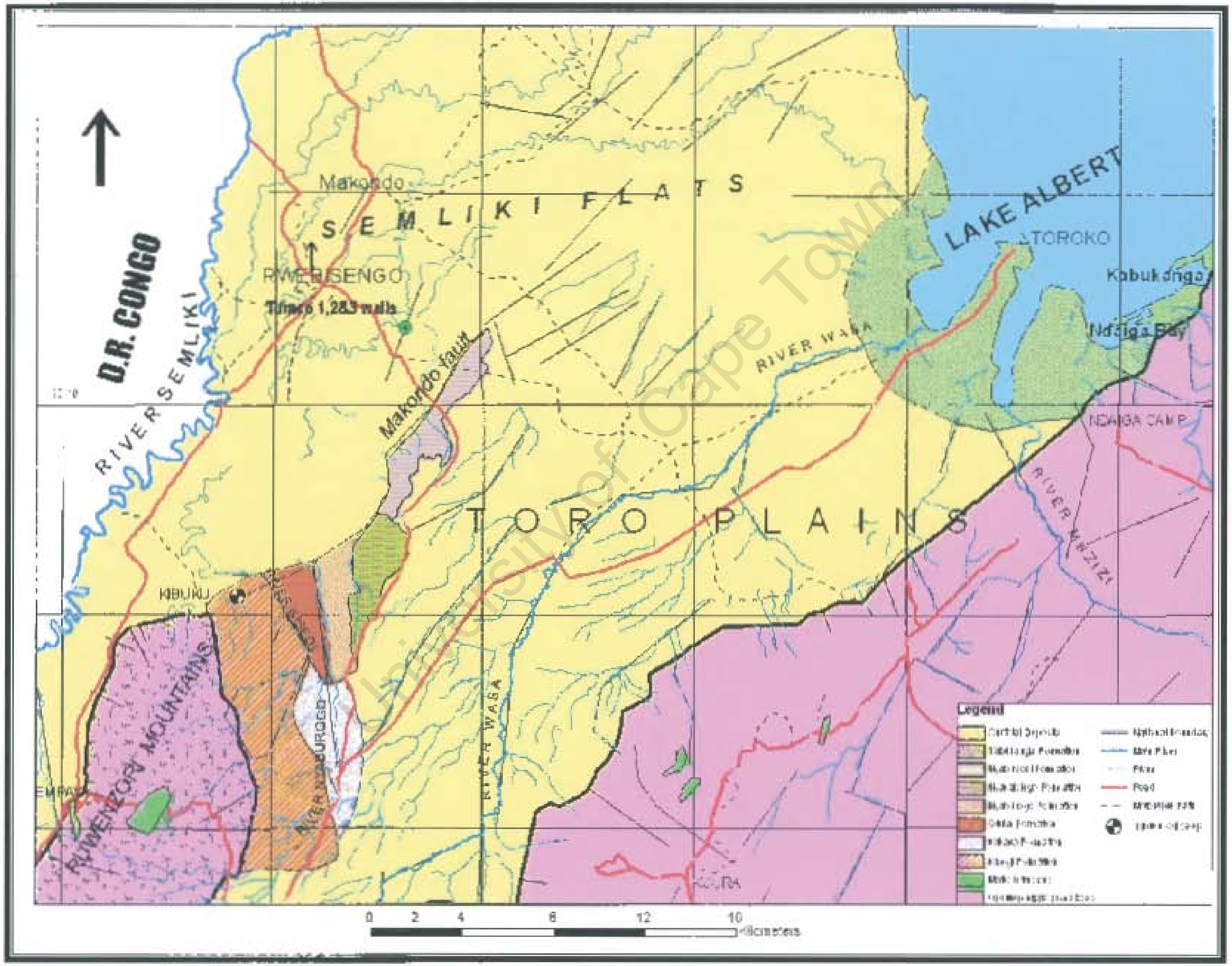


Figure 4.2. Map of the geology of the Semliki Basin

Based on the geometry and degree of consolidation, the sedimentary rocks mapped were divided into seven formations, according to Harris *et al.* (1956). They are in decreasing age, the Kisegi, Kasande, Kakara, Oluka, Nyaburogo, Nyakabingo and Nyabusosi formations. Two other formations, the Kabukanga and Rwamabare formations, mapped during fieldwork, had not been mapped before and could not be associated with any of the already existing formations. The Kasande Formation is not shown on the map owing to its small areal extent. The Kabukanga Formation was added onto the geological map of the Semliki Basin, but the Rwamabare Formation could not be shown on the map due to its limited areal extent. The basement rocks mapped in this area included mostly felsic gneisses.

4.2.1. Kisegi Formation

Sediments of this formation were mapped in the Kaiso Nsolya valley, above the Kibuku oil seepage, on the northern termination of the Rwenzori Mountains and the surrounding hills (Figure 4.2). The sediments are mainly arenaceous and can be traced eastwards to the Kisegi River, where they are faulted against younger Kakara Formation clays and sands and westwards, where it onlaps basement outcrop of the Northern part of the Rwenzori. On the western (proximal) side of the Kisegi Formation, where it onlaps the basement outcrop, it is more conglomeratic, as a result of having incorporated contemporaneous hillwash from the Rwenzori highlands. In outcrop, the Kisegi Formation is seen to onlap, unconformably, the Basement schists and quartzites of the Rwenzori Mountains. Therefore, the thickness described at outcrop may grossly underestimate the true thickness of the section farther into the basin.

At the Kibuku oil seep outcrop, the smell of an aromatic hydrocarbon is immediately apparent and there is obvious widespread oil staining in the lower part of the section and patchy oil staining in the upper part of the section. At this point, the contact between Basement and sedimentary rocks is located, striking N50°W and dipping 60° to the NE. The Basement rocks consist of sub-vertically dipping high-grade meta-quartzite, which is weathered at the surface. The Basement quartzites are mica-rich and are traversed by numerous pinkish white to grey quartz veins.

The basal part of the Kibuku section is a grey-coloured, oil-stained, poorly sorted conglomerate (Plate 4.1) with an obvious unconformable contact with the underlying meta-quartzite. At this point, the outcrop is more conglomeratic as a result of having incorporated contemporaneous hill wash from the Basement. Above the conglomerate is friable yellow, well-sorted, medium to fine-grained sandstone. The section is mainly composed of intercalations of conglomerates and low-angle cross-bedded sands (Figure 4.3). The conglomerate beds range from 600-1200mm thick (thick to very thick beds), with individual pebbles being 10-50mm in diameter (medium pebbles). Textural descriptions are according to Boggs (1995). The sandstone beds are 400-1000mm thick (thick beds). These sediments were probably deposited by fast-moving streams on marginal fault scarps in an alluvial-fan environment.

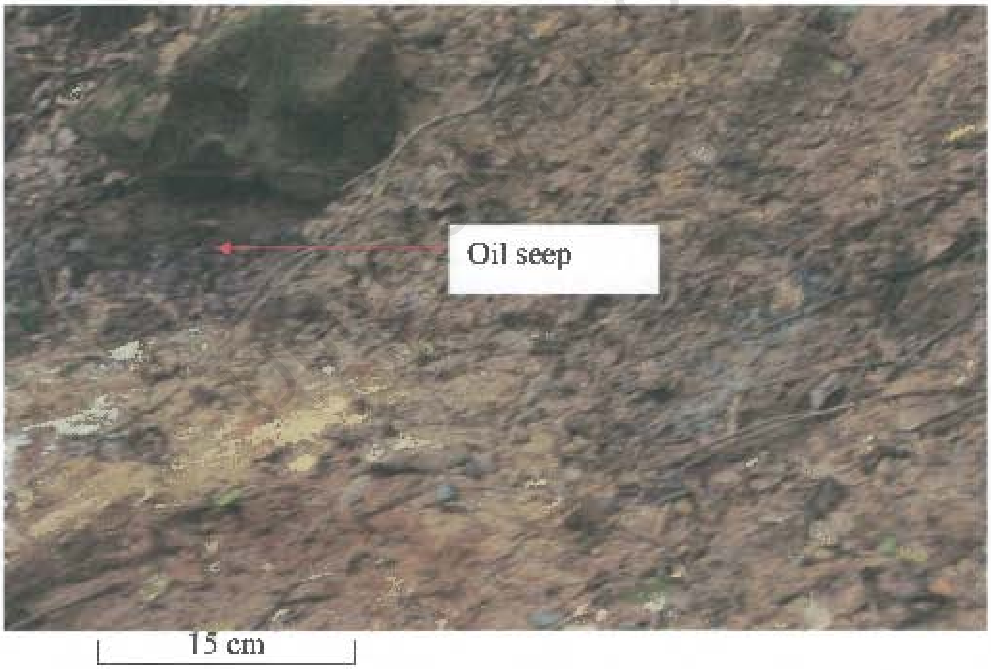


Plate 4.1. The oil-stained conglomeratic unit of the Kisegi Formation, at the Kibuku outcrop in the Kaiso Nsolya river valley, station 1. The photograph was taken from the West.

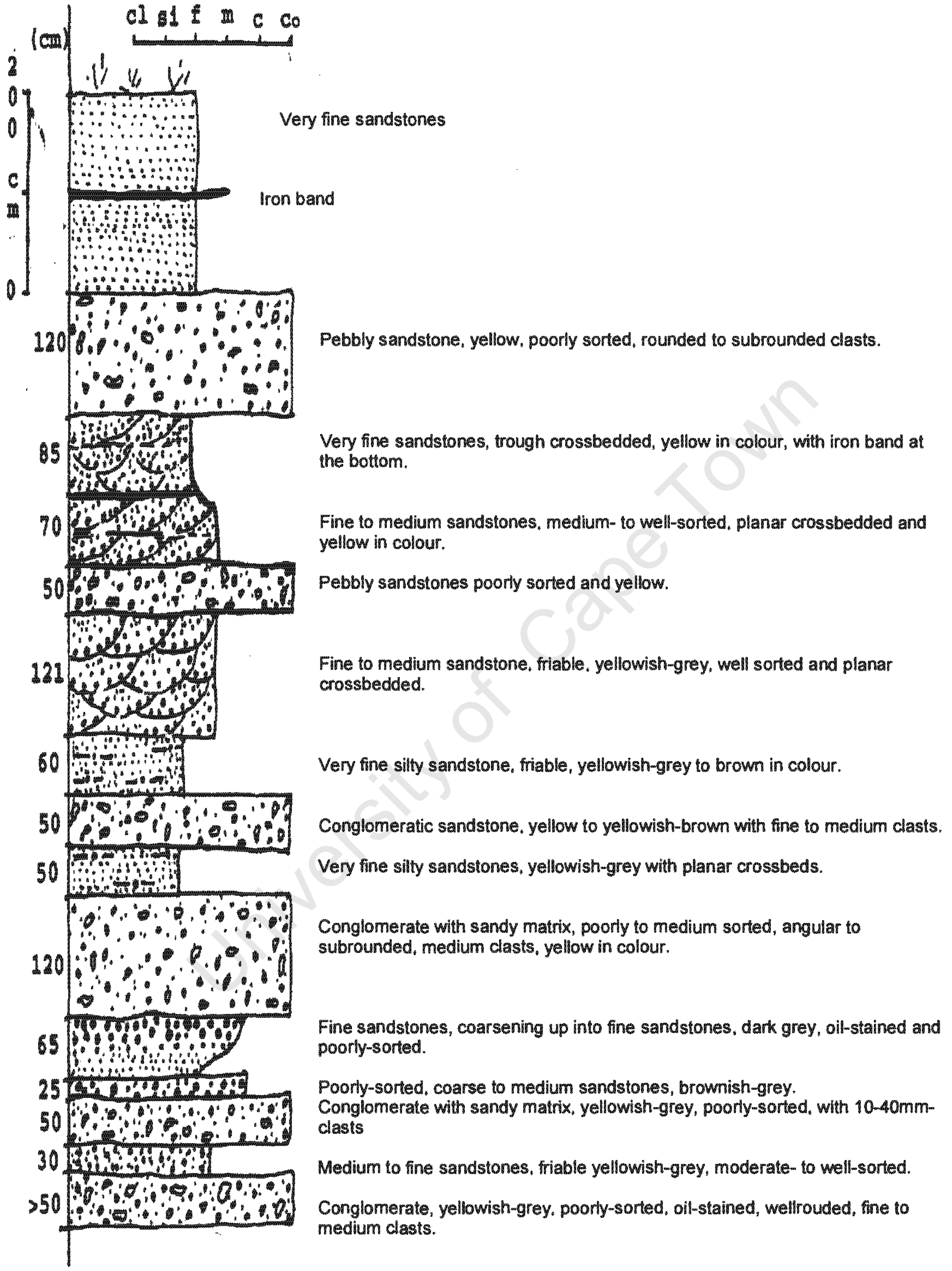


Figure 4.3. Stratigraphic profile of the Kibuku outcrop section, Kisegi Formation, close to the Basement contact on the western side of the Kaiso Nsolya Valley, station 1.

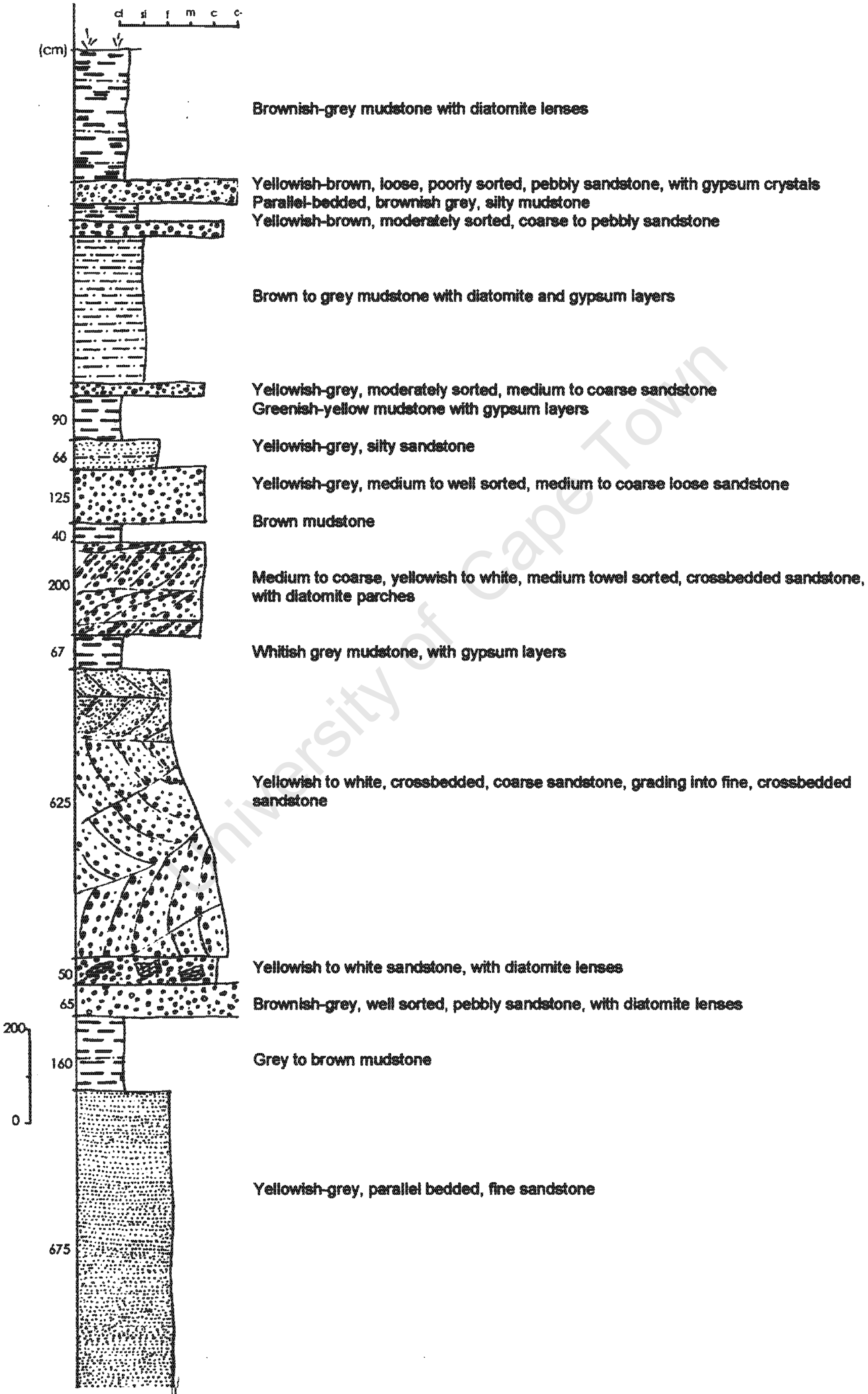
The pebble-conglomerate described at the Kibuku outcrop is a facies that pinches out laterally with a maximum width of a few metres. This section displays a fining-upward sequence that is typical of fluvial environments (Allen, 1970).

Horizontally laminated and bedded, millimetres to centimetres thick layers make up the sandstones of the Kibuku outcrop. Well-exposed trough and planar cross-bedded units of sand occur in the fine-medium grained sandstones within the conglomerates of the Kibuku outcrop. Cross-bedding in the sand units is clear and is seen to be dipping at angles of 10° to 25°. Horizontal laminations and low-angle crossbedding are associated with the conglomerates of the Kibuku outcrop. The planar crossbeds dip at angles of less than 10° in these conglomerates. A 1200mm-thick conglomerate with pebbles and cobbles between 10mm and 70mm in diameter, displays both horizontal and cross bedding.

Examination of further unmeasured sections, farther upstream, shows that the Kisegi Formation onlaps the Basement and that the conglomeratic Kibuku outcrop is merely the proximal part of the Kisegi Formation, where it contains abundant quartzitic clasts that have been derived from hill wash.

The main outcrop of the Kisegi Formation was mapped at Station 9, a few hundred metres upstream from the Kibuku outcrop. The section is mainly arenacous with individual beds in the range of 1000-3000mm in thickness (very thick beds) (Figure 4.4). The sandstones are mostly yellow to yellowish-grey, medium to coarse grained, subround to subangular grains. There is excellent visible porosity, as observed through a hand lens, throughout the exposed sandstones in the outcrop.

The basal part of the outcrop is composed of rapid alternations of yellowish grey sandstones developed in thin lenses with interbeds of well-bedded gypsiferous siltstone and claystone beds. The claystones and siltstones have a grey, green and greenish blue colouration. Flakes of mica are abundant in sediments of this part of the outcrop.


cl
sl
f
m
c
c-
(cm)
Brownish-grey mudstone with diatomite lenses
Yellowish-brown, loose, poorly sorted, pebbly sandstone, with gypsum crystals
Parallel-bedded, brownish grey, silty mudstone
Yellowish-brown, moderately sorted, coarse to pebbly sandstone
Brown to grey mudstone with diatomite and gypsum layers
Yellowish-grey, moderately sorted, medium to coarse sandstone
90
Greenish-yellow mudstone with gypsum layers
66
Yellowish-grey, silty sandstone
125
Yellowish-grey, medium to well sorted, medium to coarse loose sandstone
40
Brown mudstone
200
Medium to coarse, yellowish to white, medium towel sorted, crossbedded sandstone, with diatomite parches
67
Whitish grey mudstone, with gypsum layers
625
Yellowish to white, crossbedded, coarse sandstone, grading into fine, crossbedded sandstone
50
Yellowish to white sandstone, with diatomite lenses
65
Brownish-grey, well sorted, pebbly sandstone, with diatomite lenses
200
160
Grey to brown mudstone
0
675
Yellowish-grey, parallel bedded, fine sandstone

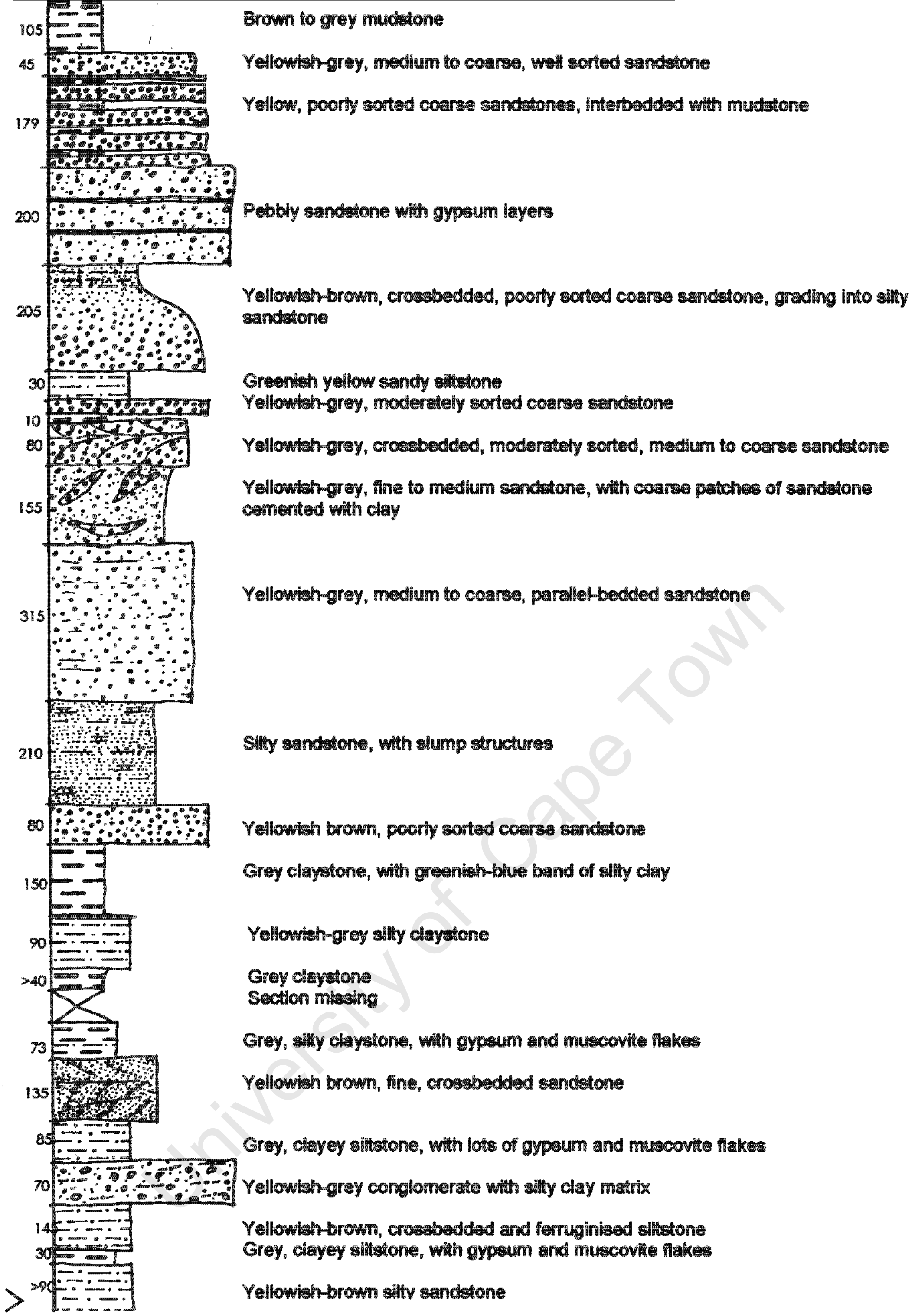


Figure 4.4. Stratigraphic profile of the main Kisegi Formation outcrop section at 192907E/0102008N, station 9.

Some patches of brown staining, observed in this section, are probably the result of local iron enrichment, due to subaerial exposure. The sands are clean, medium to fine grained and well sorted, with subrounded to subangular grains.

The middle part of the Kisegi Formation outcrop is arenaceous. The sandstones are mostly yellow to yellowish grey, with medium to coarse-grained, well sorted with sub-rounded to sub-angular grains. There is excellent visible porosity throughout the sandy part of the outcrop. Graded bedding was observed in this part of the section with some beds grading from conglomeratic bases through to coarse sandstones passing into gypsiferous muds and/or silts.

Thin beds of fine sediments, were found interbedded with the sandstones of the Kisegi Formation. These sediments are dirty white to brown and green in colour. The green colouration is believed to be due to chlorite replacement (Tucker, 2003). These sediments contain glass shards or their pseudomorphs, with crystals of quartz and feldspars, concentrated on the bedding surfaces between the sandstones and these fine sediments. The glass shards or their pseudomorphs, with crystals of quartz and feldspars, impart a sheen that enhanced the original bedding planes. These rocks are interpreted to be of volcanic origin.

At the top of the main Kisegi Formation outcrop, the formation terminates at an angular unconformity (Plate 4.2), overlain by a downlapping argillaceous sequence, the Kasande Formation. Figure 4.5 shows a sketch of the angular unconformity and bedding surfaces of the Kisegi and the Kasande formations. There is some reddening of the upper Kisegi Formation and the top is highly cemented, suggesting that there is a time gap in deposition between the Kisegi and the Kasande formations since the Kasande Formation is less well cemented.

Plate 4.2. The angular unconformity that separates the Kisegi and the Kasande formations at location 192907E/0102008N (hammer at and parallel to the unconformity surface), station 9. Photograph taken from the West.

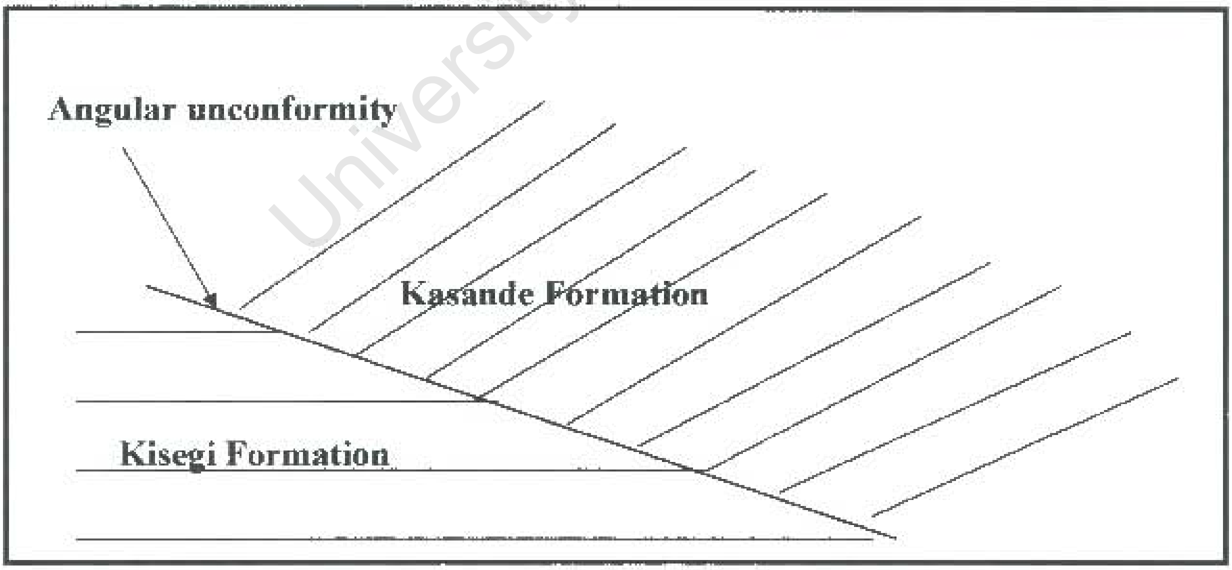


Figure 4.5. Sketch of the angular unconformity that separates the Kisegi and the Kasande formations.

Trough cross-bedded units were observed in the sequence and planar cross-bedding appears to be in the form of large-scale individual cross beds measuring about 1m thick. The readings for the angles of inclination of the cross-strata were made with the use of a Brunton compass with angles varying between 25° and 45°. The sandstones are highly weathered and weakly cemented with ferruginous calcite cement. This intense weathering sometimes obscures the laminations and bedding surfaces.

Plate 4.3. Sedimentary structures as seen in the sediments of the middle part of the Kisegi Formation, station 9. Parallel beds and laminae, interbedded with diatomites (white sediments), laterally pinch out. Photograph taken from the West.

In the Kisegi Formation, planar cross-bedding was used as a palaeocurrent indicator. The palaeocurrent direction is given by the direction of maximum dip, since the direction of inclination of a plane of cross-stratification coincides with the general direction of the palaeocurrent which deposited the sediment. The readings for the angles of inclination of the cross-strata were made with the use of a Brunton compass with angles varying between 30° and 45° for the Kisegi. Since the readings from the beds are almost similar, this indicates a unimodal palaeocurrent pattern from northeast to southwest.

Slumping structures (Plate 4.4) were also encountered in the sediments of the Kisegi Formation. Tucker (2003) describes slump structures as being developed where a sediment mass is internally deformed during downslope movement.

Plate 4.4. Slumping structures as observed in the Kisegi Formation at location 192912E/0101001, station 9. Photograph taken from the Northwest.

According to Dingle and Robson (1985), slumps develop when the thickening of the sediment pile causes the sediments to slump downslope if the sediment pile exceeds carrying capacity. Tucker (2003) further notes that the fold axes are often oriented parallel to the strike of the slope as the slump moves, and the direction of overturning of folds is downslope. The direction of slumping, as measured from the orientation of fold axes and axial planes of the slump folds is 150°, to the southeast. The presence of slumps in the succession of the Kisegi Formation was deduced from the occurrence of undisturbed beds above and below, and a lower contact (the surface upon which the slump took place), which cuts across the bedding (Figure 4.6).

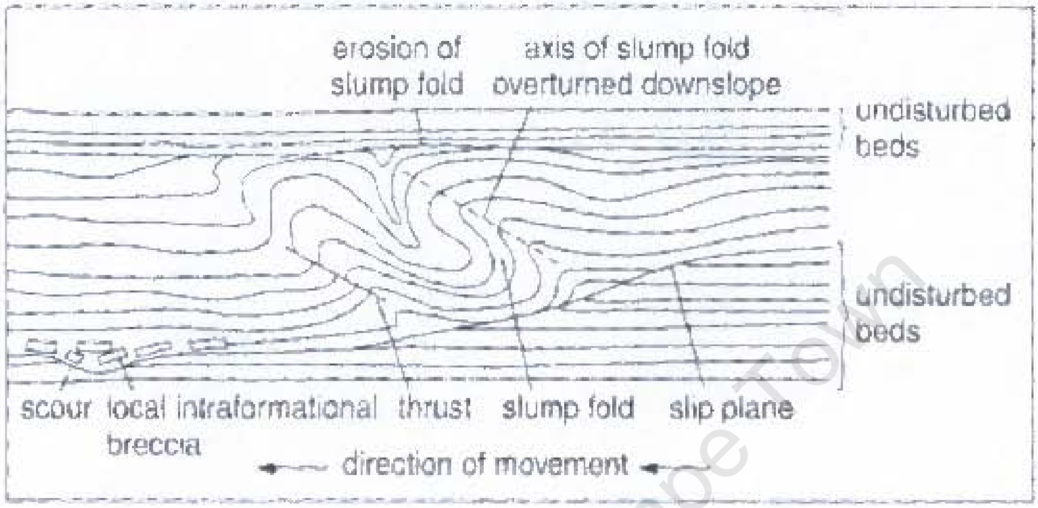


Figure 4.6. Principal features of a slumped bed (After Tucker, 2003).

4.2.2 Kasande Formation

The Kasande Formation lies above the main Kisegi Formation outcrop in the Kaiso Nsolya outcrop, station 9. It has only been recognised at this outcrop, and it has therefore not been shown on the geological map (Figure 4.2). It represents a complete change in deposition from the Kisegi Formation. The formation is highly argillaceous, and is almost entirely made up of reddish brown to yellowish-brown, highly weathered and fractured claystone/mudstone and silty claystone with occasional sandstone stringers. These siltstone and sandstone stringers become more frequent in the upper part of the section. The sandstones are poorly sorted and medium to coarse grained. The fractures in the mudstones are filled with yellow siltstone (Plate 4.5). Gypsum crystals were encountered in the lower section whereas diatomite lenses were encountered in the higher section of this formation.

Plate 4.5. Fractured mudstones of the Kasande Formation, Kaiso Nsolya outcrop, station 10. Photograph taken from the West.

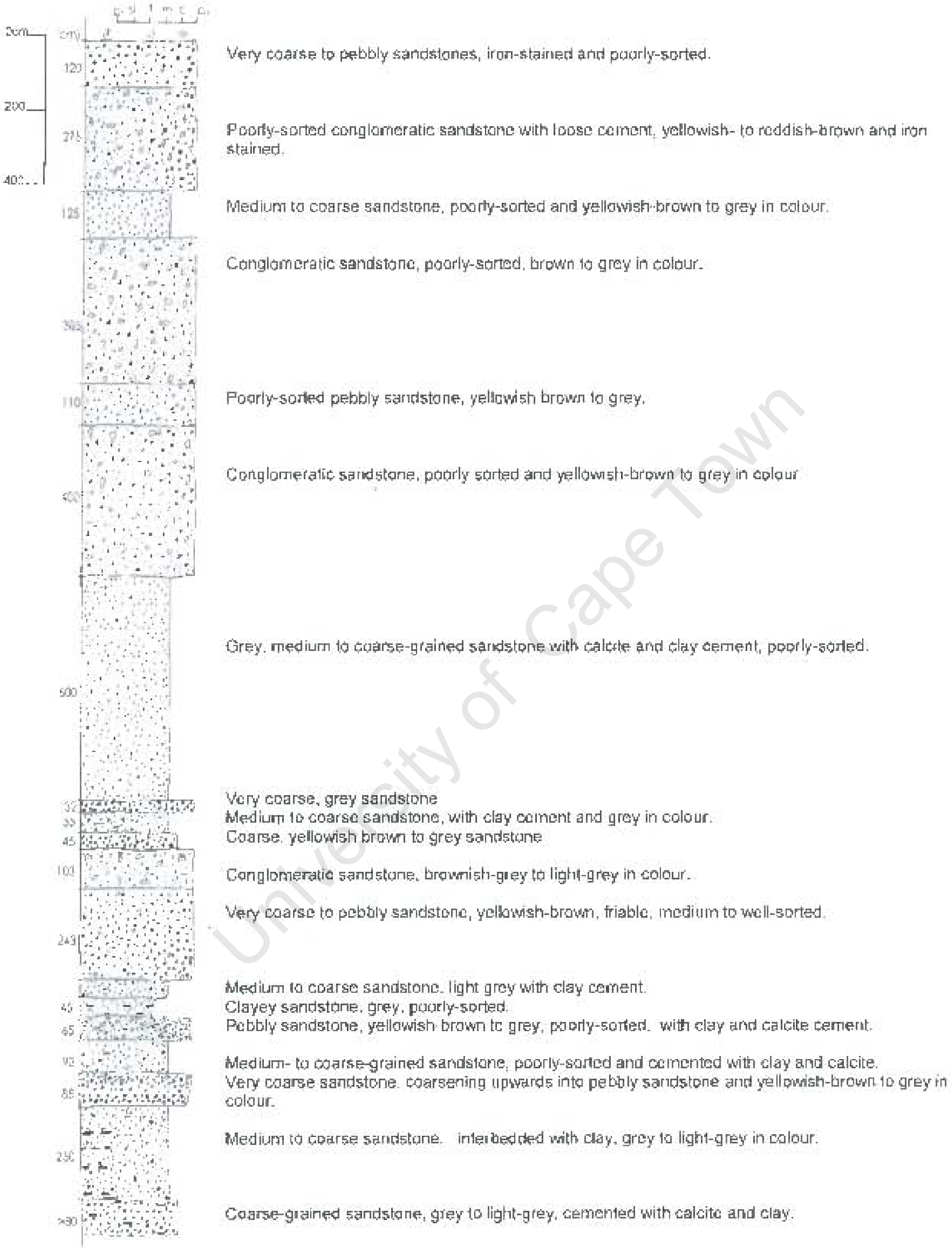
The section is approximately 45m thick and has only minor, laterally inconsistent, ferruginous sandstone stringers in a mudstone/claystone section. The mudstones and claystones are silty and occasionally sandy. The Kasande Formation, in outcrop, appears to consist of weathered mudstones and siltstones, and to have a very low sand content. Some of the sediments are well bedded, showing weakly defined, near-horizontal bedding. The sandstone units in the Kasande Formation are not well defined, as compared to those of the younger formations. The sediments of the upper part of the section are composed of silty to sandy, claystones with poorly sorted sandstone and diatomite lenses. This shows the appearance of being a sedimentologically immature sediment that has been very rapidly deposited in a lake.

4.2.3 Kakara Formation

The outcrops of the Kakara Formation (Figure 4.2) were mapped on the eastern side of the Kisegi River and the Nyaburogo River valleys and it appears to be vertically continuous with the overlying Oluka Formation. The exact nature of the contact with the underlying Kasande and Kisegi formations was not seen in outcrop. The Kakara Formation is an arenaceous to rudaceous unit, but with much clay in the matrix, with well-defined, mainly laterally continuous sandstone layers. Exposures of this formation, found between the Nyaburogo and Kisegi river valleys, are mainly intercalations of unconsolidated, yellowish-brown, poorly sorted, medium to coarse grained sandstones, sand-matrix conglomerates and brown to red pebbly and muddy sandstones. These are interbedded with grey, soft, silty/sandy claystones. Figure 4.7 shows the stratigraphic profile of one of the sections of the Kakara Formation. Most of these sandstones are less than 1.5m thick and appear to be laterally consistent. Some of the sandstones are more cemented than the others. Fining-upward sequences, from coarse to medium sand, towards the top of the sections, were observed in some outcrops of this formation.

The beds show an increasing amount of iron from base to top. These grade from yellowish white through yellowish brown, iron-stained sandstones to brown ferruginous sandstone. The ferruginised sandstones average about 400mm thick with freshwater gastropod fossils in some places.

The sediments of the Kakara Formation display well-preserved, parallel and cross laminations and beds. Horizontally laminated, millimetre to centimetre thick units, are present in the coarse and pebbly sandstone units of this formation. Some of these units are lenticular and pinch out over a short distance. Scattered pebbles occur in the planar crossbedded sandstones, which are overlain by a number of fining-upward cycles and medium to coarse grained pale brown to grey trough crossbedded sandstones. The trough crossbedding is more common in the coarser-grained units, conglomerates, of this sequence. The sandstone beds contain lenses of pebbly sandstone, which are mostly less than a metre thick with sub-angular to angular pebbles of 1-5cm in diameter (Plate 4.6).



Very coarse to pebbly sandstones, iron-stained and poorly-sorted.

Poorly-sorted conglomeratic sandstone with loose cement, yellowish- to reddish-brown and iron stained.

Medium to coarse sandstone, poorly-sorted and yellowish-brown to grey in colour.

Conglomeratic sandstone, poorly-sorted, brown to grey in colour.

Poorly-sorted pebbly sandstone, yellowish brown to grey.

Conglomeratic sandstone, poorly sorted and yellowish-brown to grey in colour

Grey, medium to coarse-grained sandstone with calcite and clay cement, poorly-sorted.

Very coarse, grey sandstone
Medium to coarse sandstone, with clay cement and grey in colour.
Coarse, yellowish brown to grey sandstone

Conglomeratic sandstone, brownish-grey to light-grey in colour.

Very coarse to pebbly sandstone, yellowish-brown, friable, medium to well-sorted.

Medium to coarse sandstone, light grey with clay cement.
Clayey sandstone, grey, poorly-sorted.
Pebbly sandstone, yellowish-brown to grey, poorly-sorted, with clay and calcite cement.

Medium- to coarse-grained sandstone, poorly-sorted and cemented with clay and calcite.
Very coarse sandstone, coarsening upwards into pebbly sandstone and yellowish-brown to grey in colour.

Medium to coarse sandstone, interbedded with clay, grey to light-grey in colour.

Coarse-grained sandstone, grey to light-grey, cemented with calcite and clay.

Figure 4.7. Stratigraphic profile of the Kakara Formation outcrop at 196734E/0097450N, near the Rwebiseno-Ntoroko road junction, station 30.

Plate 4.6. Poorly cemented polymictic conglomerate of the Kakara Formation, near the Rwebisengo-Ntoroko road junction, station 31. The clasts display different colours, implying that their lithology is different. Photograph taken from the East.

4.2.4 Oluka Formation

The sediments of the Oluka Formation were mapped on the ridge between the Nyaburogo and Kisegi Rivers and in the Nyaburogo River valleys (Figure 4.2). They comprise an association of interbedded claystones, shales, siltstones and sandstones, broadly similar to those in the overlying formations (Figure 4.8). In some places the formation contains diatomaceous units, cherts and palaeosols.

The section is highly argillaceous with some thin ferruginous sandstones. The finer lithologies comprise alternations of vari-coloured claystone, light grey to dark grey, soft, with argillaceous siltstone, white to light grey to dark grey claystone.

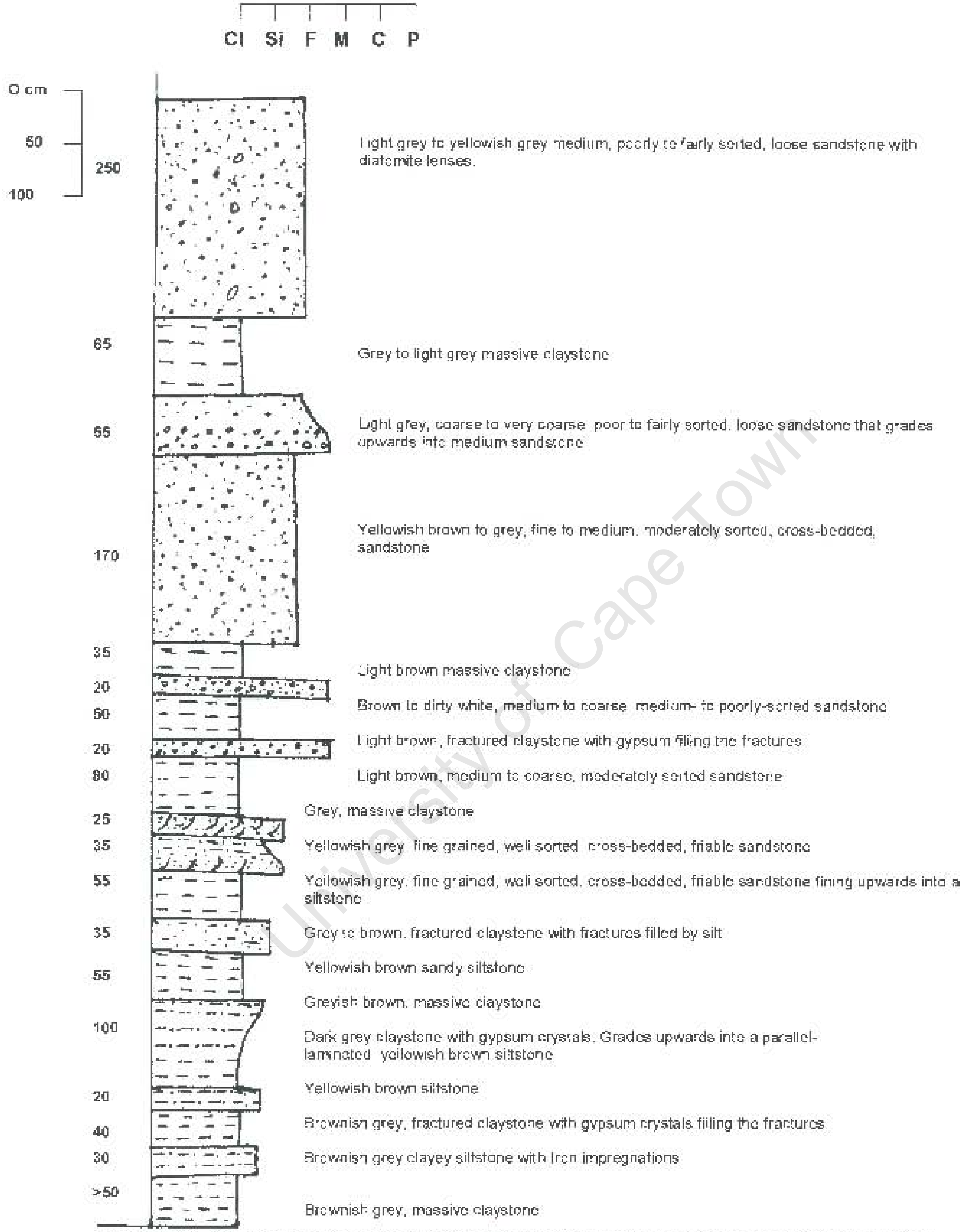


Figure 4.8. Stratigraphic profile of the Oluka Formation outcrop near the top of the ridge on the eastern side of the Kisegi River at 193116E/0102225N, station 1.

The sand grains are mainly medium to coarse-grained sandstones with hardened ferruginous bands in some places, which are orange to reddish brown coloured. The majority of sandstones are very fine to medium grained and moderate to well-sorted. Horizontally laminated and crossbedded sandstone units range between 30cm and 2.5m thick and tend to maintain their thickness laterally. There may be a general fining-upward trend in each of these units. Some thin sandstones and the tops of some thicker sandstone beds show nodular cementation with ferruginous carbonate cement and they are highly bioturbated by plants and other soil-forming processes. Although occasionally cemented, the sandstones are more often loose or friable and show low-angle crossbedding.

Several beds, less than 20cm thick, of white to light grey to white, very low density sediments were encountered towards the top of the Oluka Formation (Plate 4.7). These were interpreted as diatomites. Others were encountered in the Nyaburogo River outcrop together with siliceous spiculites. Most of these beds were encountered in the Nyaburogo River outcrop (Plate 4.8), whereas other single beds and diatomite lenses were encountered in other outcrops of the formation.

Plate 4.7. Small-scale mining of diatomites in the sediments of the Oluka Formation near the top of the ridge on the eastern side of the Kisegi River, station 19. Photograph taken from the North.

Plate 4.8. Spiculite layer in the sediments of Oluka Formation in the Nyaburogo River outcrop, station 29 (spiculite layer above the hammer). Photograph taken from the East.

A chocolate brown bed, approximately 30cm in thickness, of very fine, friable sediments was encountered towards the top of the sections of the Oluka Formation (Plate 4.9). This was interpreted to be a palaeosol, a buried soil or horizons of the geologic past (Catt, 1986; Ratallack, 1990). The sediments were found inter-bedded between very fine sand and very coarse sand at the lower and upper boundaries respectively. The top of the horizon was sharply truncated by an erosional surface, but the boundaries between underlying horizons were gradational. Owing to bioturbation (disruption) by plants and animals, wetting and drying, and other soil-forming processes, palaeosols develop characteristic soil structures at the expense of the original bedding and structures in the parent rock (Ratallack, 1990). A network of irregular planes, breaking up the sediment into angular blocks, was observed at the surfaces of these sediments.

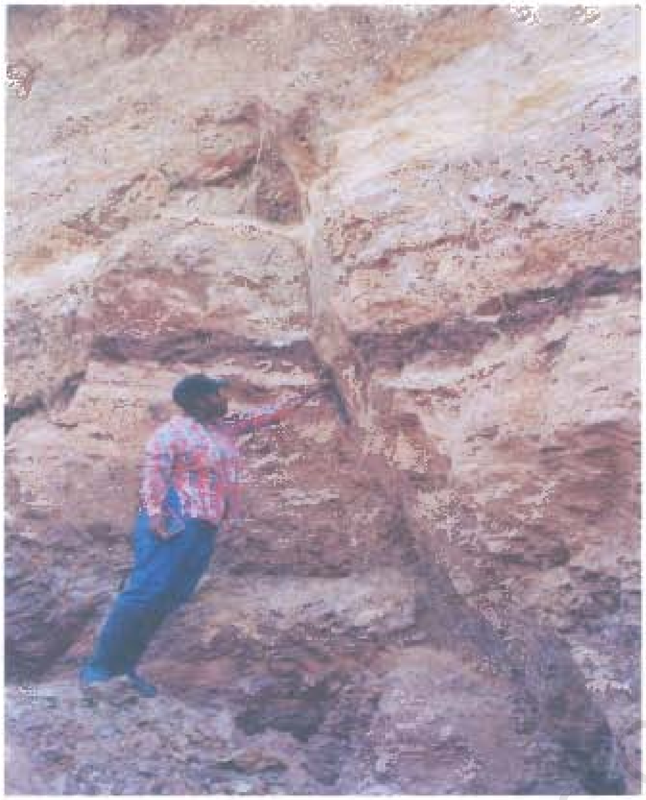


Plate 4.9. Paleosols as observed in the sediments of the Oluka Formation at location 193116E/0102225N (hammer at the base of the palaeosol unit), station 19. Photograph taken from the Northwest.

Gypsum veins extend laterally within the claystones of this area. Gypsum occurs as nodules of crystals, of various sizes that range between 2mm to 100mm in the mudstones/claystones. It is not clear whether the source of gypsum in the fine-grained sediments of this formation is as a result of oxidation of sulphides or as a result of evaporation. When rainfall is high, large amounts of dissolved substances enter the lakes and with no outlets and with a hot and dry climate, evaporation reduces the water volume and increases the salinity to the point where evaporite minerals begin to crystallise (Hardie *et al.*, 1978). Continued evaporation shrinks the volume and the area of closed lakes, eventually disappears leaving a residue of evaporites. On burial to depths greater than several hundred metres all the gypsum is converted to anhydrite. Uplift of anhydrite sequences results in the generation of secondary gypsum, as the anhydrite comes into contact with fresh near-surface groundwater.

4.2.5 Nyaburogo Formation

Sediments of this formation were mapped in the northern end of the Nyaburogo and Nyakabingo valleys and the ridge to the east of the Nyaburogo River (Figure 4.2). The outcrops of this formation tend to be small, apart from those exposed by the river.

The lowest section of the Nyaburogo Formation is mainly arenaceous with a stacked fluvial channel-sandstone sequence, which fines upwards into a more clayey sequence with subordinate sandstone units (Figure 4.9). Many of the thinner units are nodular, bioturbated and cemented with iron and carbonate cement.

Lithologically, the formation is mainly comprised of thick sequences of rusty brown to yellowish brown sandstones and grey to black hard claystones with intercalations of rusty brown, well bedded siltstones, fining upwards through silty clay to clay (Plate 4.10). The muddier part of the section is virtually undistinguishable from the underlying Oluka Formation or the overlying Nyakabigo Formation. The rusty appearance of the siltstones could be a result of oxidation of iron following subaerial exposure.

The sandstones of the Nyaburogo Formation are friable to loose and display prominent parallel-laminated and crossbedded/laminated structures. The planar crosslaminated, fine-grained sandstone is overlain by parallel-laminated, fine-grained, sandstone that grades into a pale brown to yellowish brown sandstone (Plate 4.11). The channel-sandstone unit, at the base of the Nyaburogo Formation, shows lateral accretion surfaces (Plate 4.11) indicating that it was deposited in a meandering river environment (Pettijohn, 1975). Lateral accretion deposits provide evidence of point bar deposition recording periodic additions of sediment into the point bar surface (Leeder, 1982).

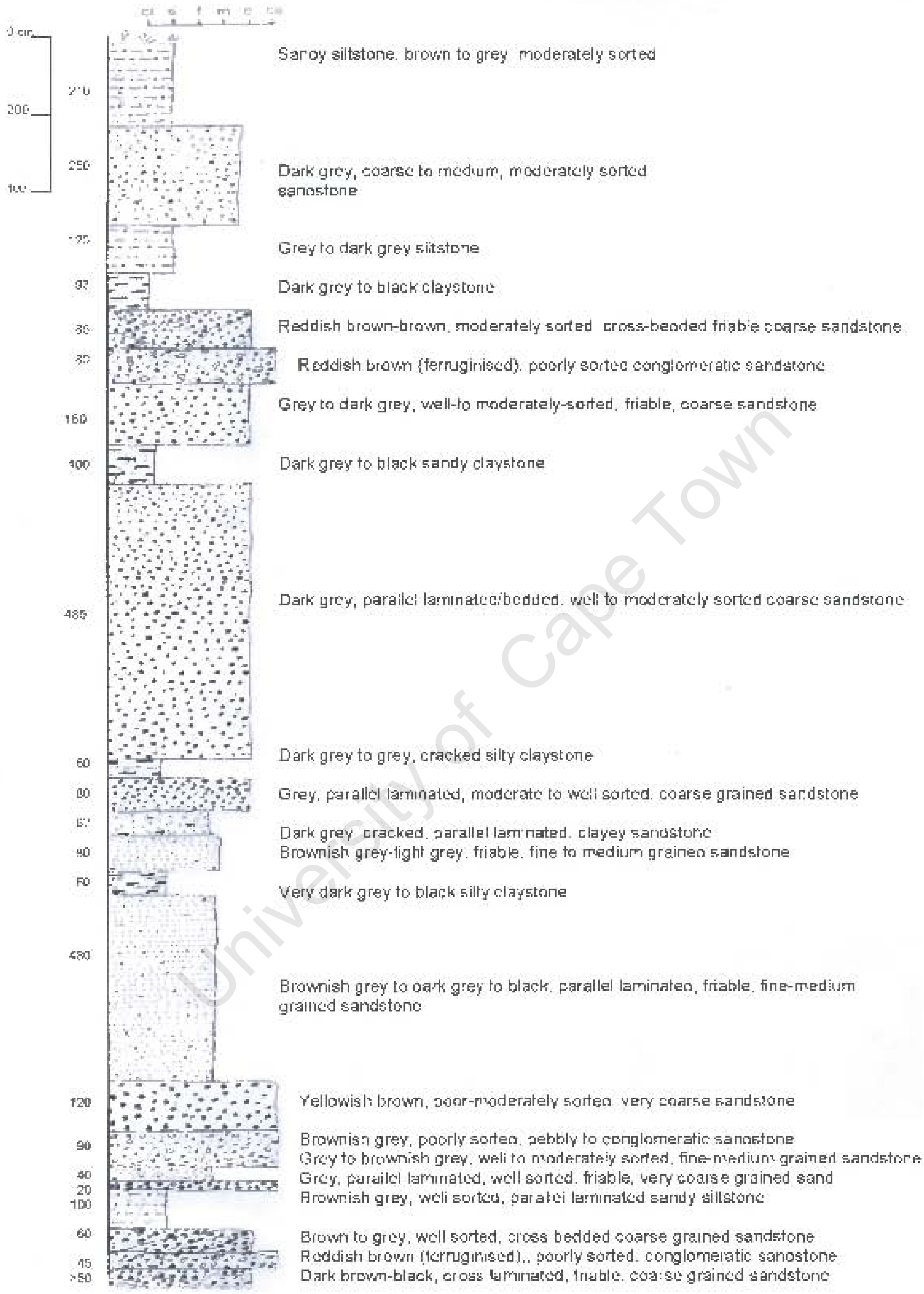


Figure 4.9. **Stratigraphic profile of the Nyaburogo Formation outcrop in the Nyaburogo River at location 196125E/0101908N, station 40.**

Plate 4.10. Nyaburogo Formation outcrop as observed from the Nyaburogo River at location 196125E/0101908N, station 40. Photograph taken from the Northwest.

Plate 4.11. Parallel-laminations and crosslaminations and accretion surfaces, as observed in the loose sandstones of the Nyaburogo Formation in the Nyaburogo River outcrop, station 40. Photograph taken from the Northwest.

In some cases, the parallel-laminated, loose, fine-grained sandstones are overlain by planar crosslaminated, loose, fine-grained sandstones (Plate 4.12). The laminations are seen to pinch out into the overlying sandstones.

Plate 4.12. Parallel and pinched-out laminations as observed in the loose sandstones of the Nyaburogo Formation in the Nyaburogo River outcrop, station 40. Photograph taken from the Northeast.

4.2.6 Nyakabingo Formation

Sediments of the Nyakabingo Formation were mapped in and east of the Nyakabingo River valley (Figure 4.2). Plate 4.13 shows one of the Nyakabingo Formation outcrops observed at a distance. The sediments are poorly exposed (Plate 4.14) and a traverse through the section sometimes requires removal of vegetation in small outcrops. The formation is argillaceous. Poorly exposed outcrops of the Nyakabingo Formation show intercalations of poorly sorted, pebbly and coarse sandstone, iron-stained siltstone and consolidated, greenish grey claystone. In general, the section is clay-rich, with subordinate sandstones that may or may not have ferruginous carbonate cement. In this area, lacustrine oolitic ironstone bands, containing freshwater gastropod fossils were observed.

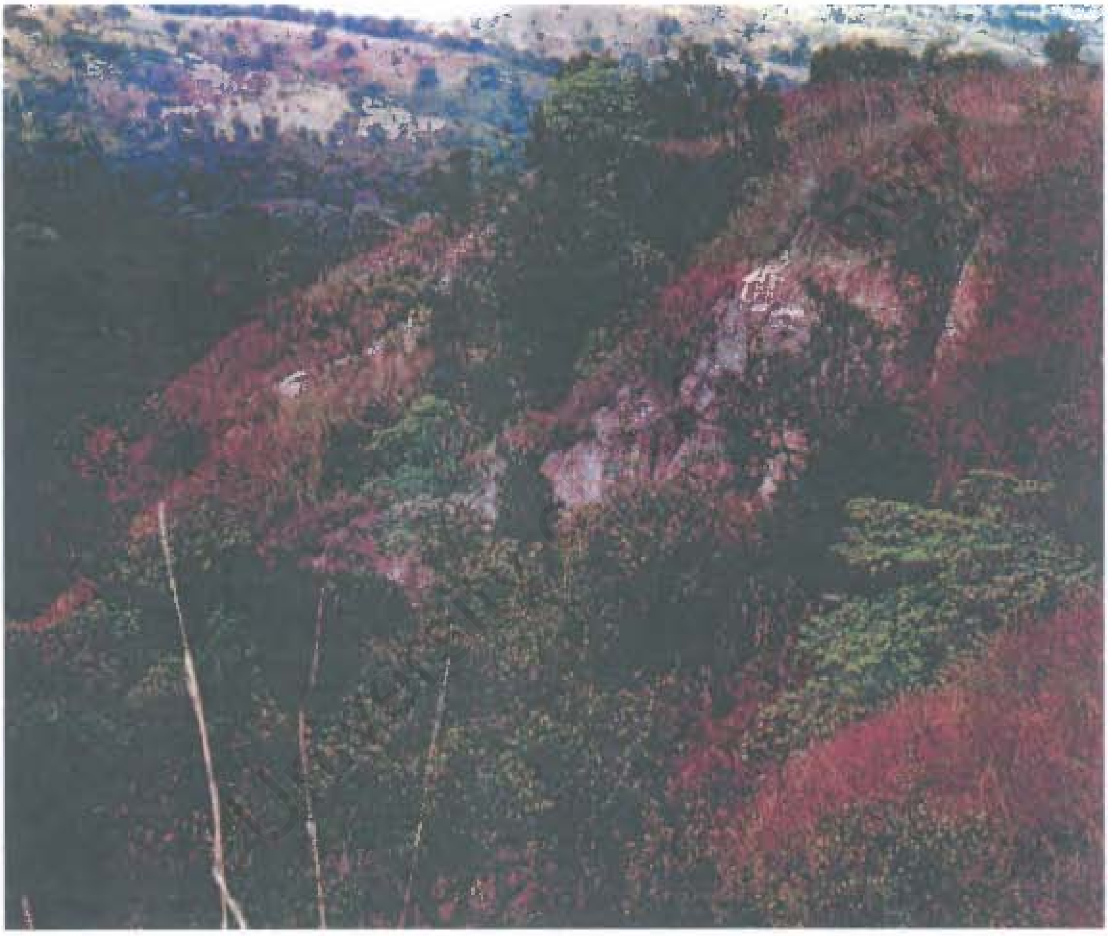


Plate 4.13. Nyakabingo Formation outcrop observed from the Rwebisengo-Karugutu Road, station 28. Photograph taken from the Southeast

Plate 4.14. Poorly exposed outcrop of the Nyakabingo Formation at location 197801E/0104576N, station 25. Photograph taken from the West.

Sedimentary structures are not well preserved in the sediments of the Nyakabingo Formation due to the lack of well-preserved outcrops. Thin, millimetre to centimetre-thick, horizontally laminated laminae and beds are however, characteristic of medium to coarse-grained sandy claystones in most of the profiles.

4.2.7 Nyabusosi Formation

Sediments of this formation were mapped in the northern part of the study area, close to the Semliki Flats and at Nyabusosi near Makondo (Figure 4.2). The sediments of the Nyabusosi Formation are poorly exposed and a traverse through the section sometimes requires removal of vegetation from small outcrops. The formation is highly argillaceous. It consists mostly of intercalations of light grey to light greenish grey claystones and subordinate sands/sandstones. The interbedded sand/sandstones are poorly consolidated to loose, and comprise mainly medium to very coarse grains, and are locally granule-rich or pebbly. Grains are quartzitic, subelongated to subspherical, subangular to subrounded. Plate 4.15 shows a poorly exposed outcrop of the Nyabusosi Formation. The claystones are silty in places with traces of plant fragments and dolomitic freshwater fossil fragments. The consolidated clay contains a black oxide along cleavage planes with lenses of micaceous siltstones in the clay horizons.

Plate 4.15. Outcrops of the Nyabusosi Formation near Makondo, showing the fine-grained sediments (claystones), station 23. Photograph from the East.

Exposures observed at Nyabusosi contain a few fishbone fossils, oyster shells (*Ostrea*) and bivalves (*Atrina* and *Modiolus*) fossils. Unbroken bivalves, with clear ornamentation, deposited parallel to the laminations, are present in the sediments of this formation. These fossils are believed to be associated with the lacustrine environment. Such types of invertebrate organisms live in lakes mostly at water depths less than about 10m in oxygenated waters (Reineck and Singh, 1980). This suggests that either the present Lake Albert was bigger than it is today or that there was an earlier lake covering the location at the time of deposition of these sediments. Diatomite floats, probably washed down the hill from outcrop, were encountered on the surface. Dolomite floats, were also encountered lying on the ground. These respond with a fizzing reaction when dilute hydrochloric acid is added. If these samples, although not *in situ*, are from higher up in the Nyabusosi Formation, they would support the above interpretation of lacustrine environment.

4.2.8 Kabukanga Formation

Sediments of the Kabukanga Formation were mapped on the shores of Lake Albert around Ntoroko, Kabukanga village and Ndaiga Bay (Figure 4.2). These sediments have not been mapped before and therefore the name (Kabukanga) came from the locality of the main outcrops. Most of the sediments of the Kabukanga Formation are poorly exposed apart from where the sediments have been exposed along the shores of the lake (Plate 4.16).

Plate 4.16. Section of the Kabukanga Formation as observed from Lake Albert at location 227989E/0115421N, station 3. Photograph taken from the Southeast.

The Kabukanga Formation comprises an association of inter-bedded claystones and sandstones (Figure 4.10). The claystones comprise alternations of dark grey to grey to light grey to olive grey colours. The lower claystones are intensely fractured (Plate 4.17) and darker in colour, whereas the upper ones are deeply weathered and light in colour.

Plate 4.17. Fractured claystone of the Kabukanga Formation at location 227989E/0115421N, station 3. Photograph taken from the Southeast.

The sandstones are mainly medium to coarse grained with iron bands in most places, which cause these sandstones to range from reddish brown to brown to brownish grey. The sands are in some places loosely cemented with calcite, but are more often loose and/or friable.

In general, the sediments of the Kabukanga Formation are laterally continuous and show a coarsening-upward sequence with the finer sediments at the base of the formation and coarser sediments towards the top of the formation as revealed in the stratigraphic column (Figure 4.10).

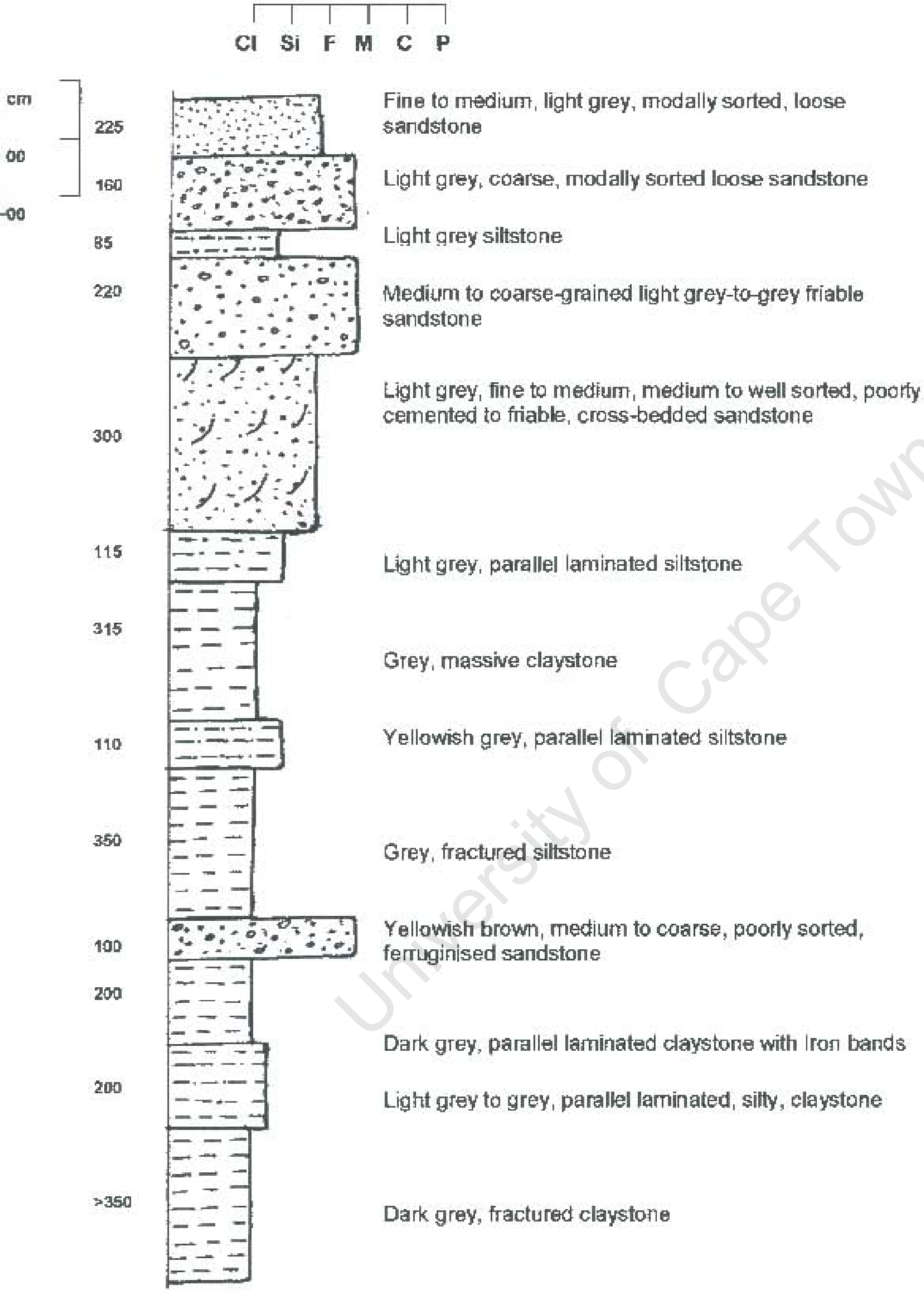


Figure 4.10. Stratigraphic profile of the Kabukanga Formation at location 227989E/0115421N, station 3.

A number of faults were encountered in the sediments of the Kabukanga Formation. Most of these are normal faults with throws ranging between 1m and 4m. These faults are graben-shaped, and strike at 185°, 225° and 245° and 170° and dipping at approximately 65° and 310° (Plates 4.18 and 4.19).

Plate 4.18. Graben faults in the sediments of the Kabukanga Formation at location 227989E/0115421N, station 3. Photograph taken from the Northeast.

The sediments of the Kabukanga Formation are characterised by horizontally laminated/bedded units ranging from millimetres to centimetres thick. These are obvious in the sandstones and a few claystones, where the iron bands fill the bedding surfaces. Crosslaminations are rarely present in the sandstones of this formation. The basal claystone, cropping out beside the lake, is massive, but it has been intensely fractured as seen in Plate 4.17.

Plate 4.19. Normal fault in the sediments of Kabukanga Formation at location 227989E/0115421N, station 3. Photograph taken from the Northeast.

4.2.9 Rwamabare outcrop

The sediments of the Rwamabare section were mapped at Station 20 (Figure 4.1) on the ridge of the Rwamabare Refugee Camp and Army Camp on the northwest corner of the Rwenzori basement outcrop. This outcrop has not been previously described and can be described as an outlier that lies approximately 6km from the main Kibuku and Kisegi outcrops. A number of small, slumped outcrops were seen in the area lying on the northwest corner of the Rwenzori basement outcrop.

The main outcrop was mapped in the bank of a small ephemeral stream and a section, approximately 10m long, was logged (Figure 4.11). The basal section of this outcrop could not be logged and therefore the thickness of the section could not be ascertained with accuracy. Most of the outcrops are scattered around the village, but are too small to be logged. Plate 4.20 shows the lower part of the Rwamabare outcrop.

The section is composed mainly of intercalations of very fine sandstones that grade upwards into siltstones and claystones. The sediments are brown to yellowish brown to yellowish grey in colour. In general, the sediments display fining-upward sequences. The sands and silts are well laminated, laterally continuous and in some places iron-stained and cemented, whereas the clays are fractured (Plate 4.21). The sediments of this outcrop dip at angles between 10° and 25° to the northeast.

Plate 4.20. Lower part of the Rwamabare outcrop mapped on the eastern side of the Army Detachment, in a small ephemeral stream, station 20. The foreground shows aligned, wellrounded pebbles and cobbles, derived as hillwash. Photograph taken from the Northwest.

The sediments of the Rwamabare outcrop could not be associated with any of the already known formations in the Semliki Basin, due to lack of palaeontological, chemostratigraphical or palynological information. However, on the ground of lithology, they possibly belong to the Nyaburogo or Kisegi Formation due to the presence of sandstones of reasonable quantity.

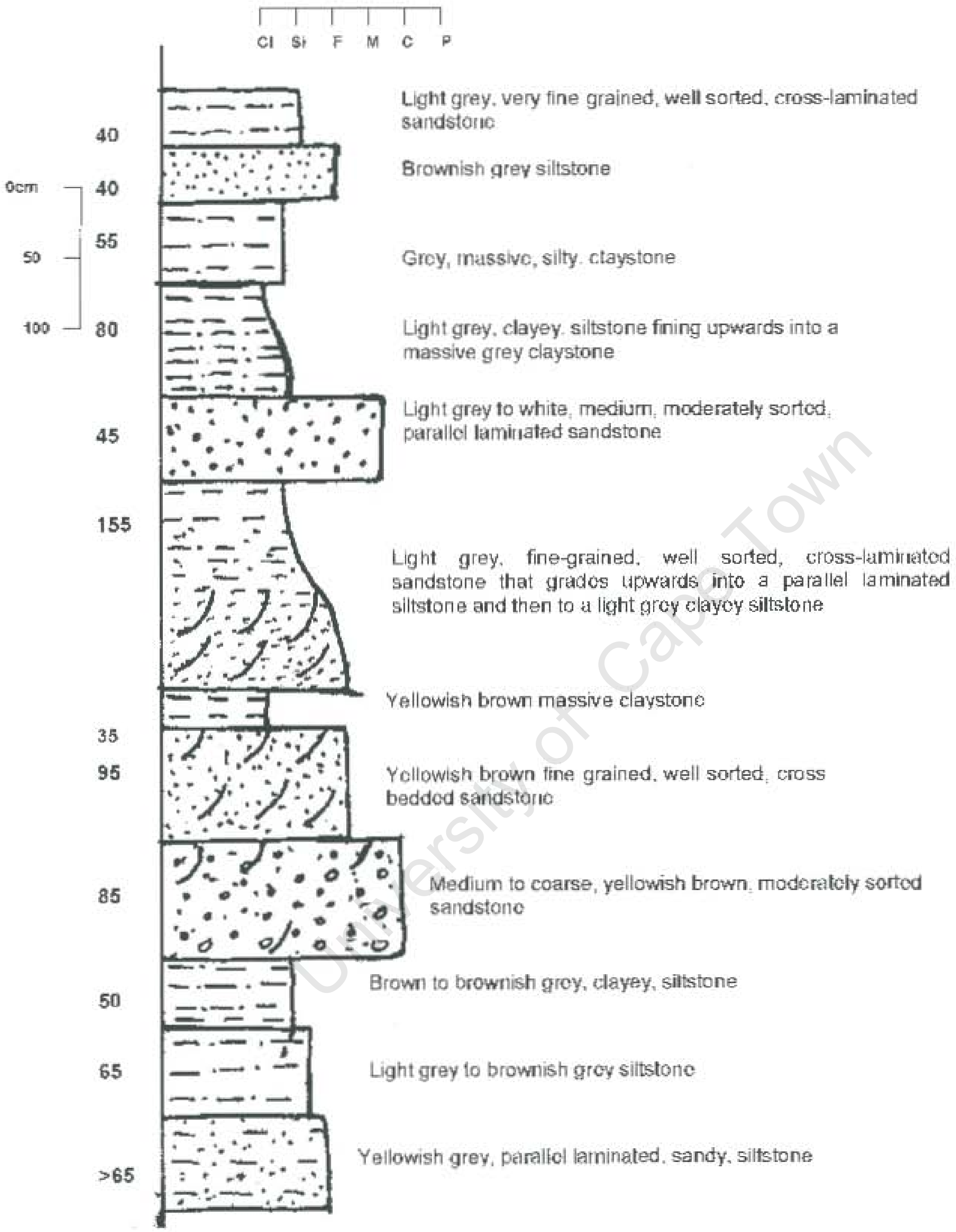


Figure 4.11. Stratigraphic profile of the Rwamabare outcrop at 187099E/0099962N on the eastern side of the Army Camp, in a small ephemeral stream, station 20.

Plate 4.21. Sediments of the Rwamabare outcrop in a small ephemeral stream, west of the Army Camp on the northwest corner of the Rwenzori, station 20. Photograph taken from the Northeast.

4.2.10 Alluvium of the Semliki Flats and Toro Plain

The Semliki Plain and the Toro Alluvium deposits cover much of the area in the Semliki Basin and have been described as surficial deposits in this text (Figure 4.2). The unconsolidated Semliki Flats deposits are composed of mainly mixed sand and clay deposits, whereas the Toro Alluvium is pebbly. These represent the youngest deposits within the basin. The Semliki Plains Alluvium has probably been formed during flooding of the Semliki River, lateral migration of the river meanders and perhaps during periodic highstands of Lake Albert. On the other hand, the Toro Alluvium appears to be related to fluvial wash from the Rwenzori Mountains.

4.3. SAMPLE DESCRIPTIONS

The analysis of rock samples by defining their facies through the mineralogical, textural and structural characteristics of the rocks is very important in the study of sedimentary deposits (Friedman and Sanders, 1978). Mineralogy is a particularly important property for studying the origin of siliciclastic sedimentary rocks, because it provides almost the only available clue to the nature of vanished source areas (Boggs, 1995). The mineralogy of the different formations was determined using field observations, petrographic analysis and x-ray diffraction analysis. Table 4.1 shows the arrangement of analysis methodologies, whereas Table 4.2 shows the field-sample descriptions. The argillaceous sedimentary rocks are too fine-grained to resolve all the mineral constituents under an optical microscope (Adams *et al.*, 1984) and therefore their mineralogy was determined by XRD only.

Table 4.1 Sample listing and analyses.

Sample Name	Formation Name	Analyses
Rwm1	Rwamabare outcrop	XRD, Thin section
Ka2	Kabukanga	XRD
Ka1	Kabukanga	XRD, Thin section
Ny1	Nyabusosi	XRD
Nybr1	Nyaburogo	XRD, Thin section
O3	Oluka	XRD
O2	Oluka	XRD, Thin section
O1	Oluka	XRD, Thin section
KK1	Kakara	XRD, Thin section
K6	Kisegi	XRD, Thin section
K5	Kisegi	XRD, Thin section
K4	Kisegi	XRD
K3	Kisegi	XRD
K2	Kisegi	XRD, Thin section
K1	Kisegi	XRD, Thin section

It is, however, important to note that all the samples analysed for X-ray diffraction and petrography were obtained from surface outcrops and were all chemically weathered to various extents. Therefore, weathering could have modified the original mineralogy of the samples.

4.3.1 Field-sample description

Table 4.2 Field-sample descriptions

Sample	Colour	Grain size	Sorting	Grain shape	Induration	Structure
Rwm1	Yellowish brown	Fine to medium	Well-sorted	Sub-angular to sub-round	Hard	Laminated
Ka2	Grey to Dark grey	Very fine			Very hard	Fractured
Ka1	Very light grey	Very fine			Hard	Layered and intensively weathered
Ny1	Dirty white	Very fine			Very hard	Massive
Nybr1	Light to yellowish grey	Fine to medium	Moderate-well sorted	Sub-angular to sub-round	Hard	Weakly laminated
O3	Chocolate brown	Fine-very fine	Very well sorted		Friable	Massive
O2	Dark grey to greenish grey	Very fine			Very hard	Massive
O1	Yellowish grey	Fine-medium	Moderate	Sub-angular to sub-round	Hard	Weakly laminated
KK1	Greenish grey to yellowish grey	Medium-very coarse	Moderate	Sub-angular to sub-round	Hard	Massive
K6	Yellowish grey	Medium grained	Well sorted	Sub-angular to sub-round	Hard	Parallel lamination
K5	Yellowish grey-reddish brown	Fine-coarse grained	Poorly sorted	Sub-angular to sub-round	Hard	Parallel laminated
K4	Greyish yellow	Fine-medium grained	Medium-well sorted	Sub-angular to rounded	Hard	Massive
K3	Brownish grey	Very fine grained			Very hard	Massive
K2	Greyish yellow	Fine-medium grained	Medium-well sorted	Sub-angular to rounded	Hard	Layered
K1	Greyish yellow	Very fine-fine grained	Well-very well sorted	Sub-angular to sub-round	Hard	Massive

4.3.2 Petrography

Petrography was undertaken on selected sandstone samples. The results of the petrographic analysis are presented below. Very fine-grained samples (claystones and mudstones) were not analysed petrographically since the clay minerals cannot be readily identified using a petrographic microscope. Therefore, their descriptions are not considered here.

4.3.2.1 Kisegi Formation

K1, Kisegi Formation Sandstone

K1 is a medium grained, well-sorted sandstone, predominantly composed of sub-angular to subrounded quartz grains. The quartz grains can be divided into monocrystalline and polycrystalline grains (Plates 4.22A and 4.22B). Rock fragments are abundant and most of the quartz grains in the rock fragments are strained, due to compaction, and have packing angles of approximately 120°, as seen in the rock fragment in the upper and lower field of view of Plate 4.22A. Other common constituents are potassium feldspars and lithic grains altered to clays. Minor components include micas (muscovite and biotite), and heavy (opaque) minerals.

Mineralogy (%)	
Quartz	65
Feldspars	15
Clay minerals	5
Micas	Trace
Rock fragments	15
Opaque minerals	Trace

Kisegi Formation Sandstone

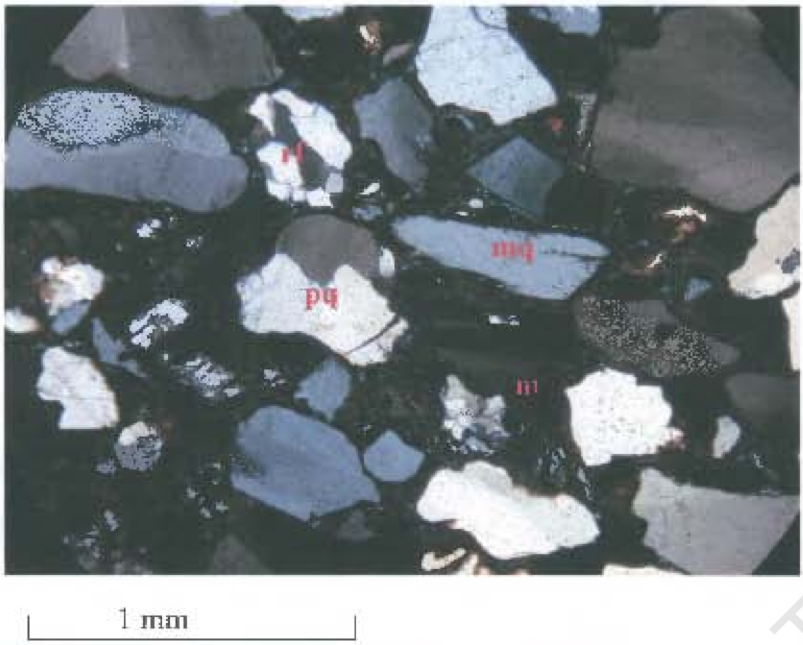


Plate 4.22A. Photomicrograph of sample K1 (station 9), under crossed nicols, showing mono- and polycrystalline quartz grains and rock fragments. mq=monocrystalline quartz, pq= polycrystalline quartz, m=matrix, rf= rock fragment.

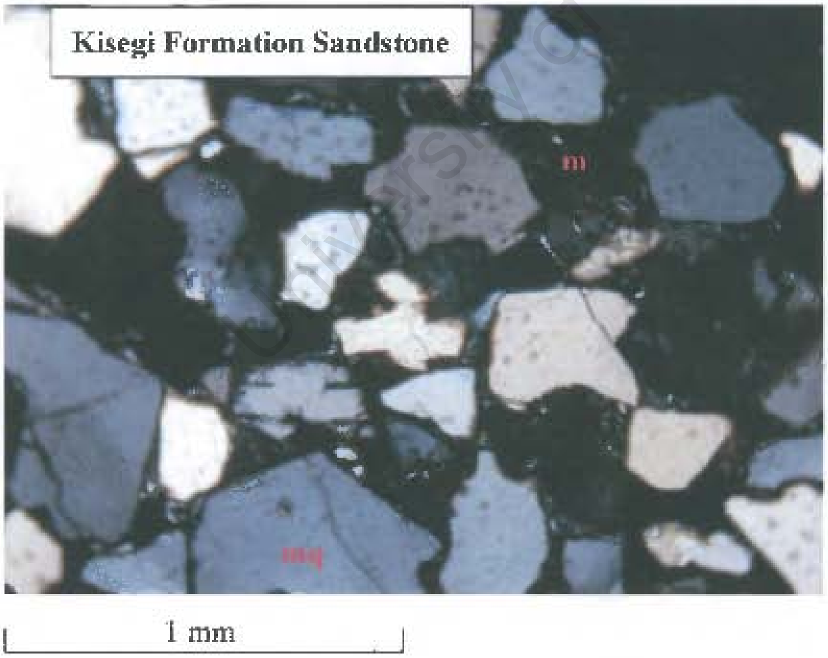


Plate 4.22B. Photomicrograph of sample K1 (station 9), under crossed nicols, showing angular to subrounded quartz grains. mq=monocrystalline quartz, m=matrix.

K2, Kisegi Formation Sandstone

K2 is a medium-grained, moderate to well-sorted sandstone, predominantly composed of subangular to subrounded quartz grains. Plates 4.23A and 4.23B are dominated by angular grains of quartz, which can be divided into monocrystalline and polycrystalline grains. The grains are of a composite nature, with sutured grain boundaries and show undulose extinction (Plate 4.23A). Most of the quartz grains in the rock fragments are strained due to compaction at packing angles of approximately 120°. The grains mainly comprise potassium feldspars and lithic grains altered to clays. The main feldspar grains comprise albite and microcline, as evidenced by twinning (Plate 4.23C). Plate 4.23C shows most of the potassium feldspars altered to clays in a reddish brown matrix. Minor components comprise micas (muscovite and biotite), and heavy, opaque minerals, such as garnet.

Mineralogy (%)	
Quartz	50
Feldspars	15
Clay minerals	20
Micas	Trace
Rock fragments	10
Opaque minerals	Trace

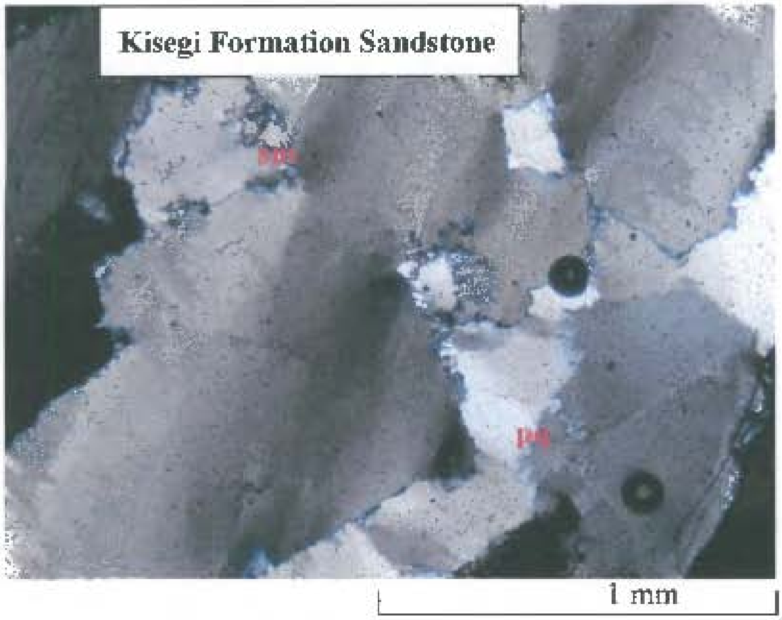


Plate 4.23A. Photomicrograph of sample K2 (station 9), under crossed nicols, showing angular quartz grains with sutured boundaries. sm=sutured margin, pq=polycrystalline quartz.

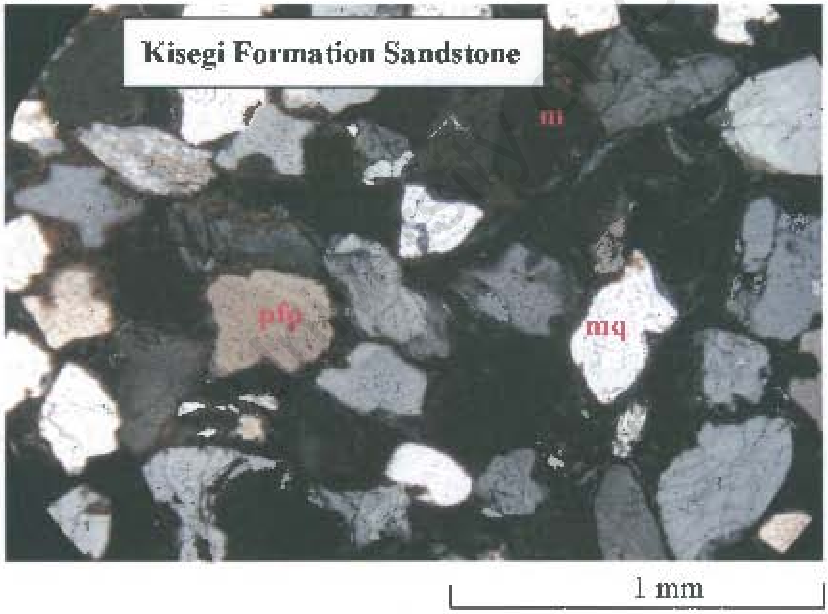


Plate 4.23B. Photomicrograph of sample K2 (station 9), under crossed nicols, showing angular to subrounded mineral grains. mq=monocrystalline quartz, m=matrix, pfp=plagioclase feldspars.

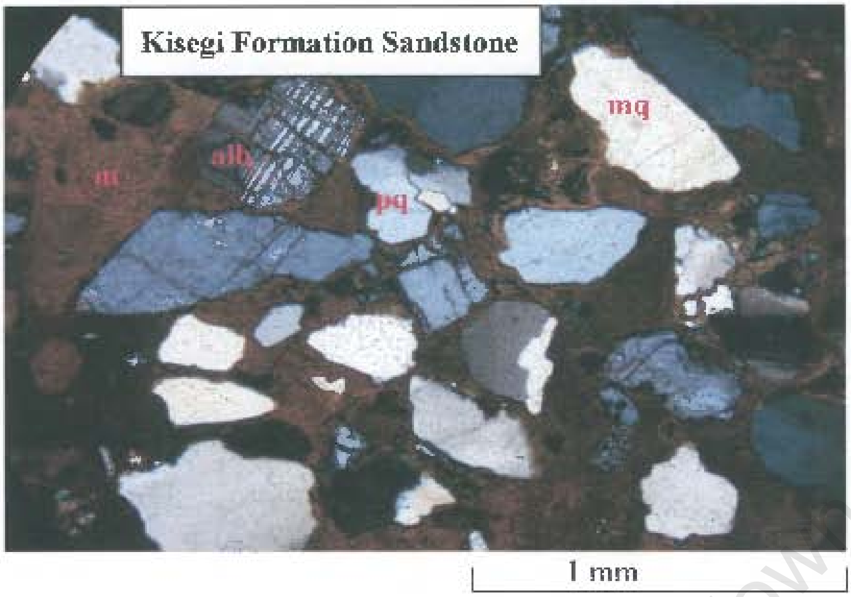


Plate 4.23C. Photomicrograph of sample K2 (station 9), under crossed nicols, showing albite twinning and partial alteration of feldspars to clay minerals. mq=monocrystalline quartz , pq= polycrystalline quartz, m=matrix, alb=albite.

K5, Kisegi Formation Sandstone

K5 is a medium to coarse-grained, poorly sorted sandstone, predominantly composed of subangular to rounded quartz grains (Plate 4.24A). The grains mainly comprise quartz and potassium feldspars. Authigenic components are dominated by clay-grade material, which could be as a result of alteration of lithic grains and feldspars. Rock fragments are abundant and are mainly/exclusively composed of strained quartz grains as evidenced by the wavy extinction of the quartz grains in the fragments. Plate 4.24B shows graded bedding of the quartz grains, whereas Plate 4.24C shows a quartzite fragment (1mm) exclusively composed of strained quartz crystals. Plate 4.24D shows a gneissic grain (2mm) showing parallel alignment of minerals (foliation) with quartz vein cutting across it. These lithic (gneissic) grains are a clear indication of the provenance of these sediments. Micas (muscovite and biotite), and heavy, opaque minerals, such as garnet, comprise the minor components in the sample.

Mineralogy (%)	
Quartz	60
Feldspars	15
Clay minerals	10
Micas	Trace
Rock fragments	15
Opaque minerals	Trace

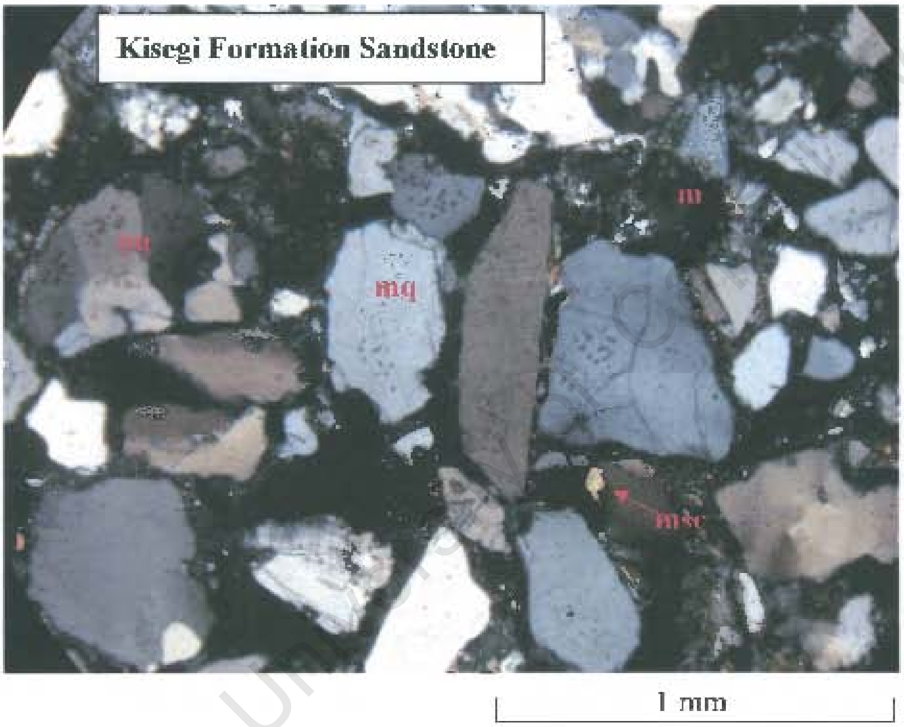


Plate 4.24A. Photomicrograph of sample K5 (station 18), under crossed nicols, showing elongated, angular to subrounded quartz grains. pq=polycrystalline quartz, mq=monocrystalline quartz, msc=muscovite, m=matrix

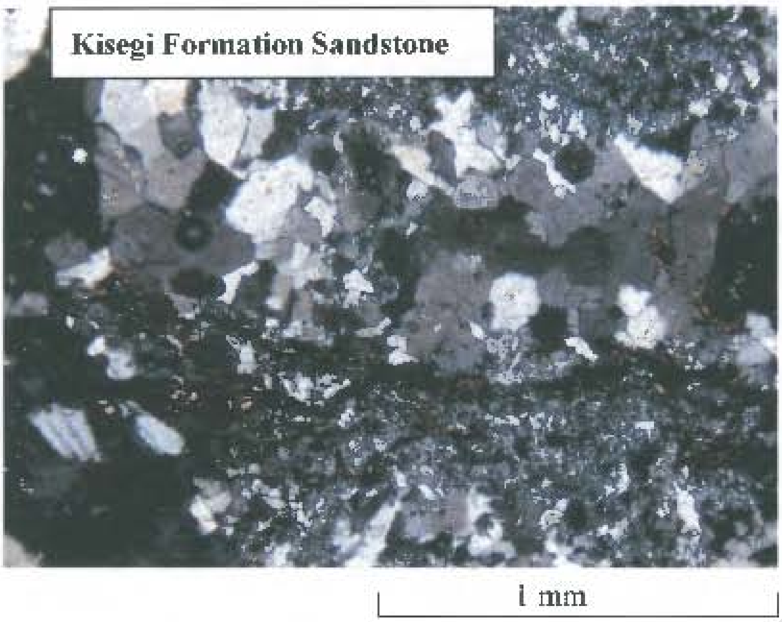


Plate 4.24B. Photomicrograph of sample K5 (station 18), under crossed nicols, showing graded bedding.

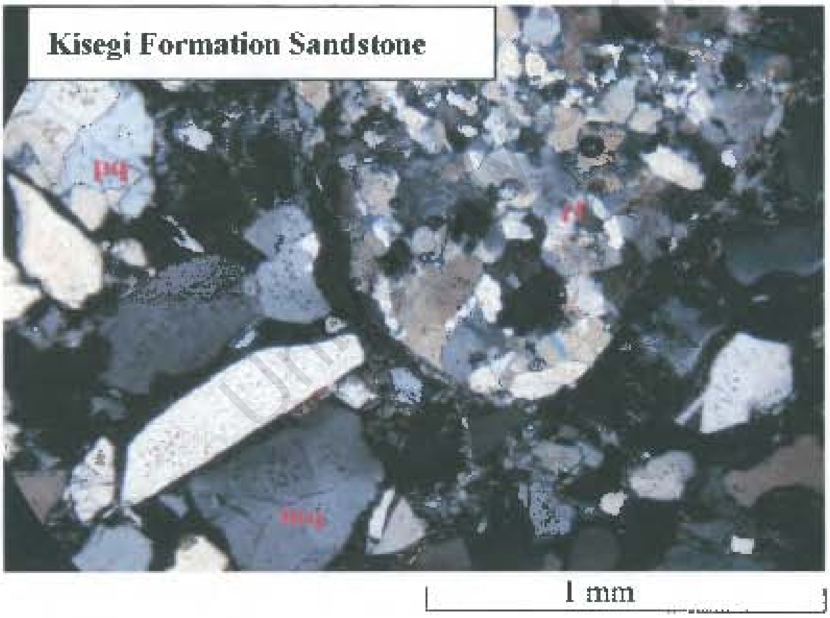


Plate 4.24C. Photomicrograph of sample K5 (station 18), under crossed nicols, showing a quartzite fragment exclusively composed of strained quartz grains. mq=monocrystalline quartz, pq=polycrystalline quartz, rf=rock fragment.

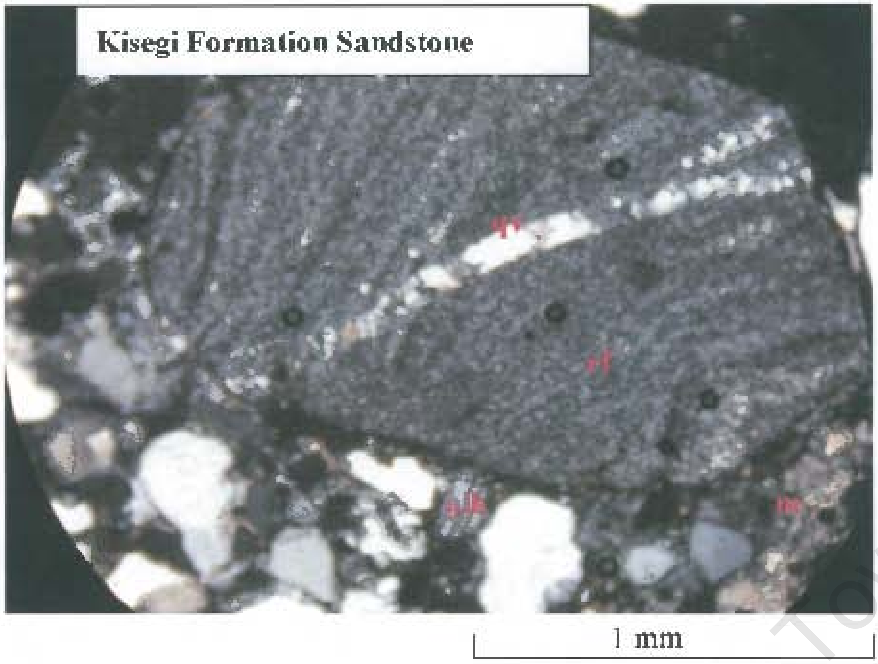


Plate 4.24D. Photomicrograph of sample K5 (station 18), under crossed nicols, showing a 2mm gneiss fragment with parallel alignment of minerals. rf=rock fragment, alb=albite, mq=monocrystalline quartz, m=matrix, qv=quartz vein.

K6, Kisegi Formation Sandstone

K6 is a fine- to medium-grained, poor to moderately sorted sandstone, predominantly composed of subangular to subrounded quartz grains. The grains mainly consist of quartz and potassium feldspars. Plate 4.25A shows that most of the feldspars are almost entirely altered to clays with epidote. The relative abundance of feldspars is indicated in Plate 4.25B, where the albite twinning is clearly visible. Clay minerals are abundant in the sample and are thought to be as a result of alteration of feldspars. Micas (muscovite and biotite), opaque and heavy minerals, such as garnet, are also present in the sample. Plate 4.25C shows muscovite in the upper left part of the field of view. The mineral grains display triple junctions and embayed margins, characteristic of compacted sediments.

Mineralogy (%)	
Quartz	55
Feldspars	13
Clay minerals	15
Micas	2
Rock fragments	15
Opaque minerals	Trace

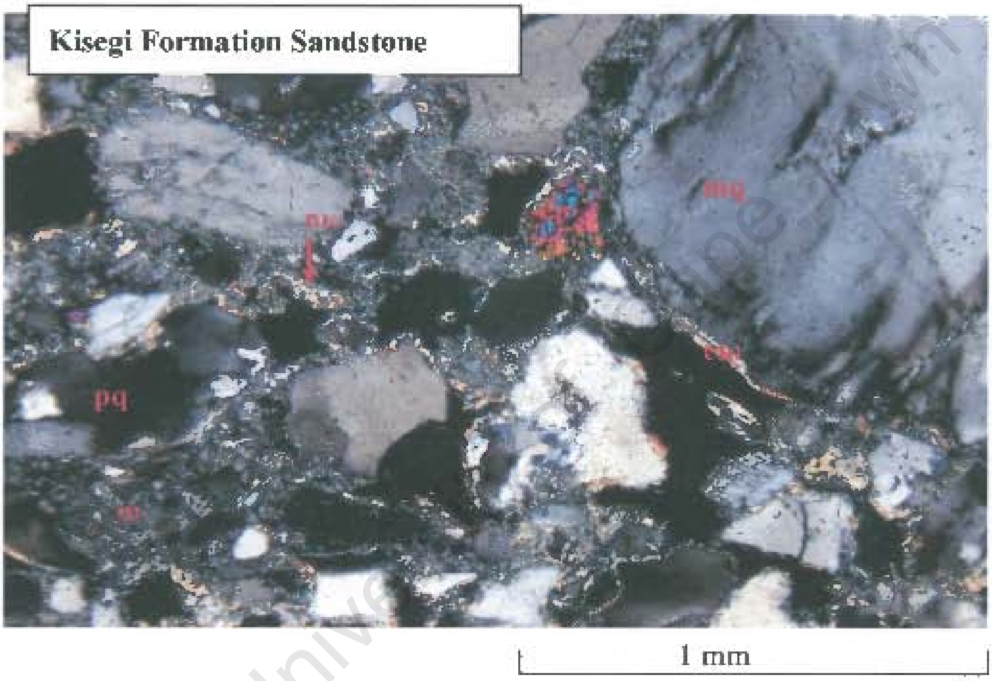


Plate 4.25A. Photomicrograph of sample K6 (station 18), under crossed nicols, showing embayed margins and epidote in the upper field of view and micas. rf=rock fragment, mq=monocrystalline quartz, m=matrix, em=embayed margin, pq=polycrystallime quartz, ep=epidote, mc=mica

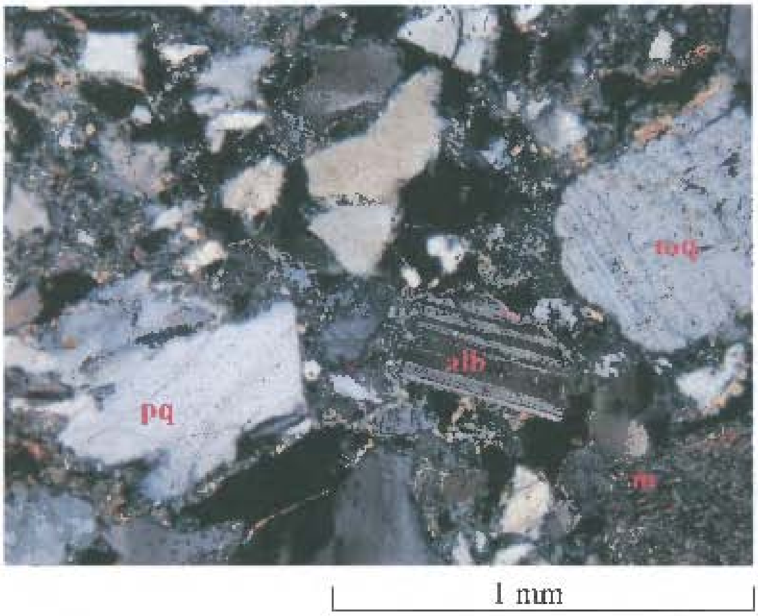

Kisegi Formation Sandstone

Plate 4.25B. Photomicrograph of sample K6 (station 18), under crossed nicols, showing a poorly sorted sandstone with a clay matrix. pq=polycrystallime quartz, mq=polycrystalline quartz, m=matrix, alb=albite.

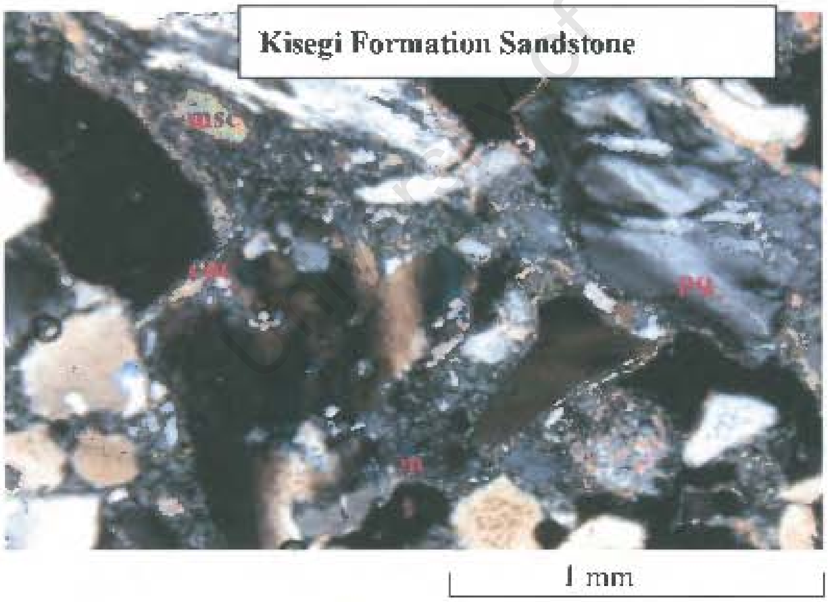


Plate 4.25C. Photomicrograph of sample K6 (station 18), under crossed nicols, showing muscovite in the upper left field of view. pq=polycrystallime quartz, msc=muscovite, m=matrix, em=embayed margin.

4.3.2.2 Kakara Formation

KK1, Kakara Formation Sandstone

KK1 is a medium- to coarse-grained, moderately to poorly-sorted sandstone, predominantly composed of subangular to rounded quartz grains. The grains mainly comprise quartz and potassium feldspars. The relative abundance of feldspars is indicated in Plate 4.26B, where albite twinning is clearly visible. Clay minerals are abundant in the sample and are thought to be from alteration of feldspars (Plates 4.26 A&B). Rock fragments (Basement quartzite) are abundant and are mainly/exclusively composed of strained quartz grains, as evidenced by the wavy extinction of the quartz grains in the fragments. Plate 4.26A shows a rock fragment, composed of quartz that shows packing of the grains at 120°, whereas Plate 4.26C is made from one of the quartzite fragments, showing parallel alignment of minerals (foliation). Micas (muscovite and biotite), other minerals, such as garnet and epidote are also present in the sample.

Mineralogy (%)

Quartz	40
Feldspars	15
Clay minerals	20
Micas	5
Rock fragments	10
Opaque minerals	Trace

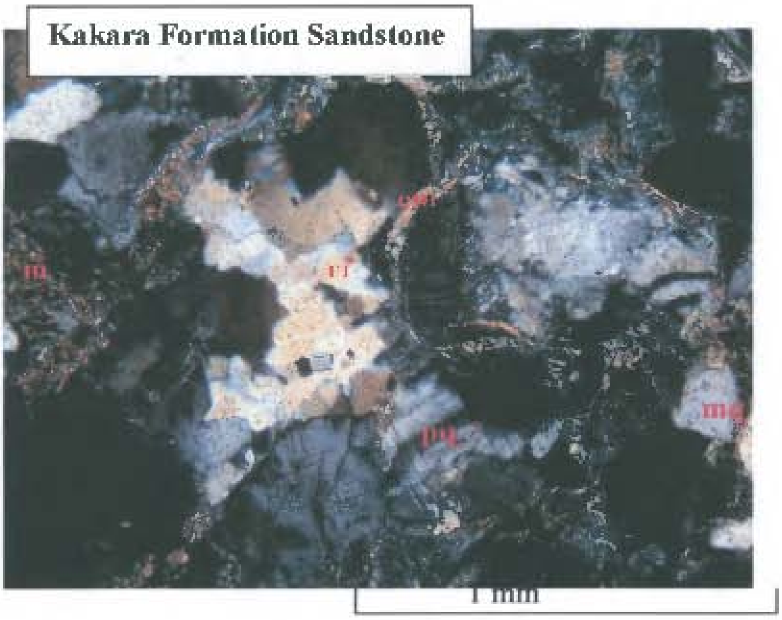


Plate 4.26A. Photomicrograph of sample KK1 (station 30), under crossed nicols, showing a rock fragment, composed of quartz that shows triple junctions. pq=polycrystallime quartz, mq= monocrystallime quartz, rf=rock fragment, m=matrix, em=embayed margin.

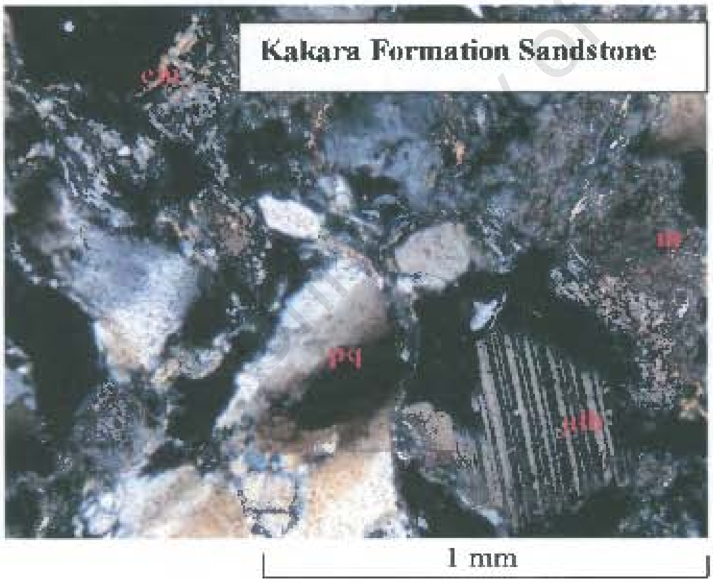


Plate 4.26B. Photomicrograph of sample KK1 (station 30), under crossed nicols, showing a coarse grained sandstone with albite in the lower right corner of the field of view. pq=polycrystallime quartz, alb=albite, m=matrix, em=embayed margin.

Kakara Formation Sandstone

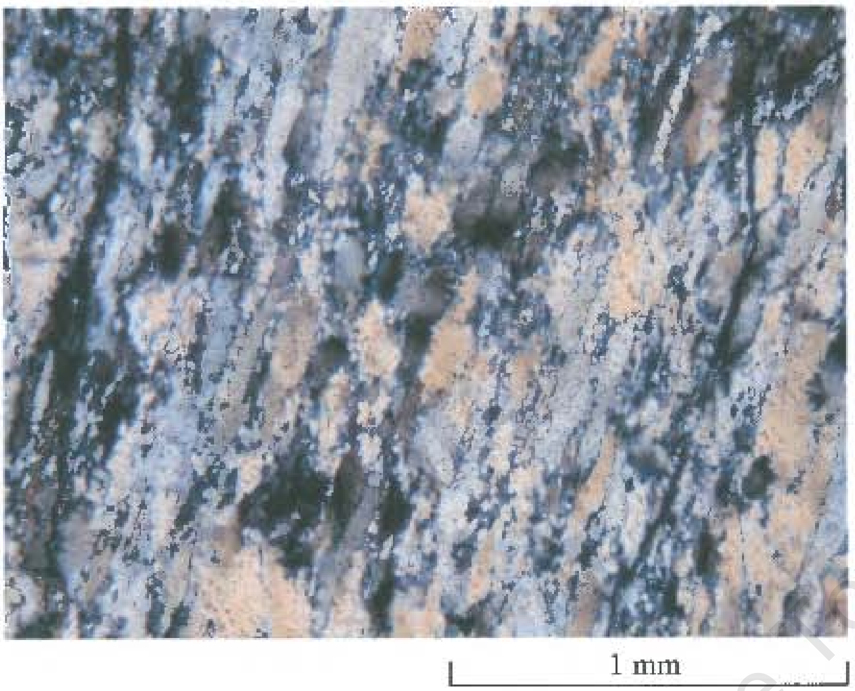


Plate 4.26C. Photomicrograph of sample KK1 (station 30), under crossed nicols, from one of the quartzite fragments showing parallel alignment of minerals (foliation).

4.3.2.3 Oluka Formation

O1, Oluka Formation sandstone

O1 is a medium-grained, moderately to well-sorted, weakly laminated sandstone predominantly composed of subangular to rounded quartz grains. The grains mainly comprise quartz and potassium feldspars. Clay minerals are abundant in the sample and are thought to be from alteration of feldspars. Rock fragments (Basement quartzites) are abundant and are mainly/exclusively composed of strained quartz grains as evidenced by the wavy extinction of the quartz grains in the fragments. Micas (muscovite and biotite), opaque and other minerals, such as garnet and epidote, are also present in the sample.

Mineralogy (%)

Quartz	40
Feldspars	15
Clay minerals	15
Micas	5
Rock fragments	15
Opaque minerals	Trace

Oluka Formation sandstone

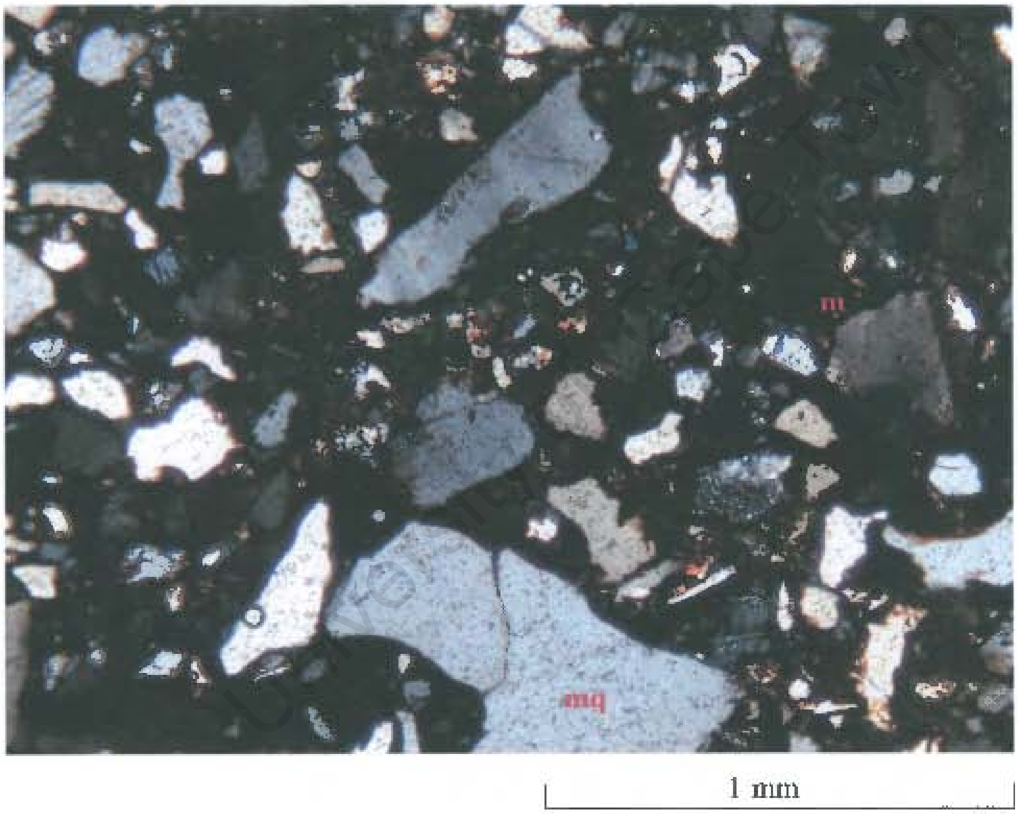


Plate 4.27. Photomicrograph sample of O1 (station 19), under crossed nicols, showing subangular to angular mineral grains.
mq= monocrystallime quartz, m=matrix.

4.3.2.4 Nyaburogo Formation

Nybr 1, Nyaburogo Formation Sandstone

Nybr 1 is a fine to medium grained, moderately to well-sorted sandstone, predominantly composed of subangular to rounded quartz grains (Plate 4.28). The grains mainly comprise quartz and potassium feldspars (albite and microcline). Clay minerals are abundant in the sample and are thought to be as a result of alteration of feldspars. Micas (muscovite and biotite), and heavy and opaque minerals, such as garnet, comprise the minor components in the sample.

Mineralogy (%)	
Quartz	60
Feldspars	15
Clay minerals	15
Micas	Trace
Rock fragments	5
Opaque minerals	Trace

Nyaburogo Formation sandstone

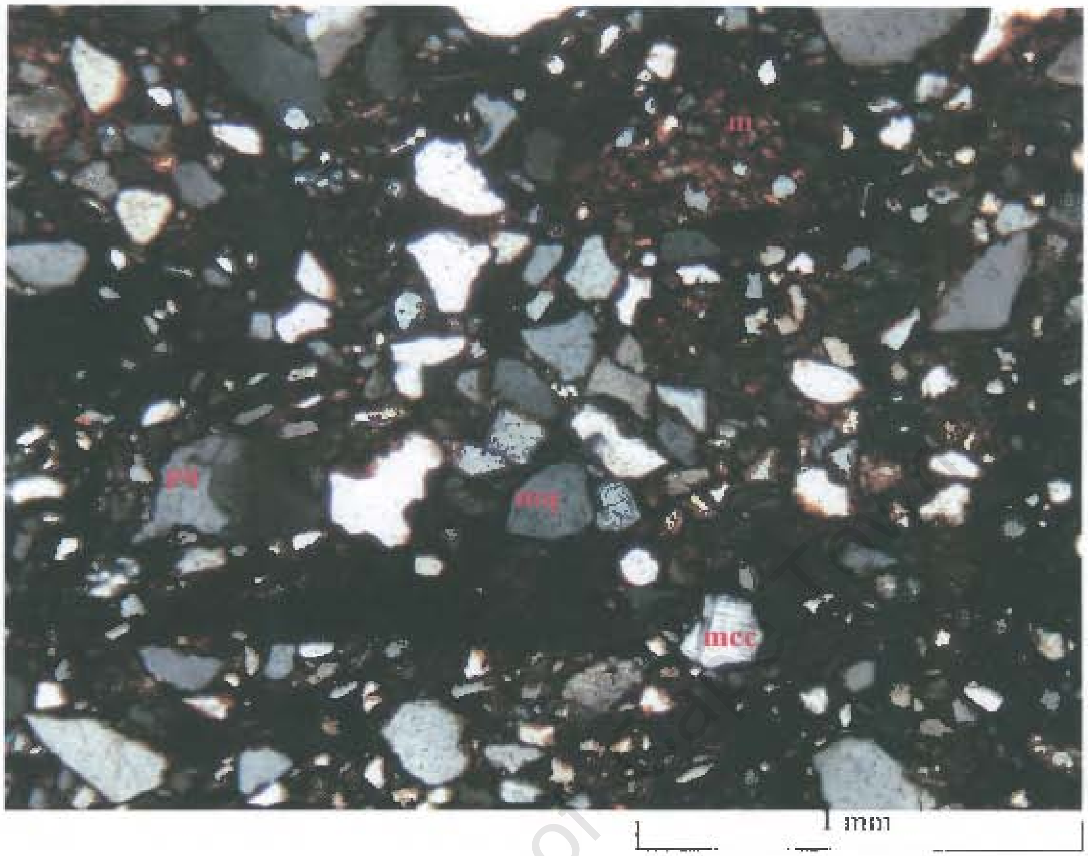


Plate 4.28. Photomicrograph of Nybr 1 (station 40), under crossed nicols, showing fine-grained, medium-sorted sandstone. pq=polycrystallime quartz, mq= monocrystallime quartz, mcc=microcline, m=matrix.

4.3.3 X-RAY DIFFRACTION (XRD)

4.3.3.1 Bulk samples

X-ray diffraction analysis of the samples from the different formations of the Semliki Basin was carried out to identify the mineralogy of the different rocks obtained from the field. The X-ray diffraction scans of bulk samples reveal that the mudrocks/claystones are dominated by clay minerals with subordinate quartz, feldspars and calcite, whereas the sandstones are dominated by quartz, feldspars and calcite. All the X-ray diffraction scans for bulk samples referred to here are presented in Appendix 2. A summary of the bulk mineralogy determined by X-ray diffraction is given in Table 4.3 below. Peaks of secondary precipitates, such as calcite and gypsum, were mostly observed in mudrocks/claystones of the Kisegi, Oluka and Nyabusosi formations. These carbonates and sulphates may have formed as oxidation products of sulphide in the sediments or as evaporites (calcite first, then gypsum as salinity increases).

The X-ray diffraction analyses show that all samples contain clay minerals. XRD difractograms demonstrated that the principal clay mineral present was kaolinite. These clay minerals are recognised in thin-sections as grain coatings (necking between grains), suggesting that they may not be associated with burial diagenesis, but that they are more likely to be the result of eluviation/weathering in the shallow vadose zone. The clay minerals include illite, illite-smectite, kaolinite, montimorillonite, illite-montimorillonite, and mica. In the Kisegi samples K4 and K2, lithic grains, altered to clay minerals, are present. These could not be identified in thin-section, but X-ray diffraction analysis shows that they are clay minerals and chlorite.

Authigenic minerals such as anatase and jarosite were also recognised in X-ray diffraction. Jarosite was present in Kisegi samples K1 and K5, whereas anatase was present in Kabukanga and Kisegi Formation samples Ka1, K5, K4 and K1.

Oxides of iron (haematite and magnetite) were detected in samples from Kisegi (K5) and Oluka (O2 and O3) formations.

4.3.3.2 Clay-size samples

The analysis of the <2μm clay size fraction indicates that the mineralogy from all the samples is dominated by the mixed layer illite-montimorillonite and illite layers in the structure. The clay mineralogy is summarised in Table 4.4. All samples contain kaolinite and illite and most contain montimorillonite. XRD scans for the clay-size samples are presented in Appendix 2.

Table 4.3. Mineralogy of the bulk samples

Sample Name	Formation Name	Mineralogy
Rwm1	Rwamabare	Quartz, Albite, Illite, Magnesium Calcite, muscovite.
Ka2	Kabukanga	Quartz, Gypsum, Calcium, Magnesium, Illite-Montmorillonite, Anatase, Manganese Oxide, Jarosite, Muscovite, Magnetite, Haematite, Manganese
Ka1	Kabukanga	Quartz, Calcium, Magnesium, Gypsum, Illite-Montmorillonite, Kaolinite, Smectite-Kaolinite, Anatase, Manganese Oxide.
Ny1	Nyabusosi	Calcite, Dolomite, Manganocalcite, Magnesium calcite
Nybr1	Nyaburogo	Quartz, Potassium feldspars, Calcite, Illite, Kaolinite, Montmorillonite.
O3	Oluka	Quartz, Magnetite, mangano-calcite, Gypsum, Illite-Montmorillonite, Kaolinite, Copper Nickel, Calcite
O2	Oluka	Quartz, Magnetite, Magnesoferite, Gypsum, Illite, Montmorillonite, Kaolinite, Copper Nickel, Zinc
O1	Oluka	Quartz, Cobaltite, Olivine, Gypsum, Anhydrite, Calcium sulphate hydrate, Illite, Potassium feldspars, muscovite, Kaolinite.
KK1	Kakara	Quartz, Illite, Kaolinite-Montmorillonite, Rectorite
K6	Kisegi	Quartz, Albite, Illite-Montmorillonite, Rectonite, Potassium feldspars, Plagioclase, Illite, Haematite, Montmorillonite
K5	Kisegi	Quartz, Gypsum, Illite, Albite, Jarosite, Anatase, Magnetite, Smectite-Kaolinite.
K4	Kisegi	Quartz, Gypsum, Albite, Anatase
K3	Kisegi	Quartz, Albite, Illite, Illite-Montmorillonite Smectite-Kaolinite, Kaolinite
K2	Kisegi	Quartz, Gypsum, Mangano-calcite, Albite, Calcite, Chlorite.
K1	Kisegi	Quartz, Anatase, Jarosite, Illite, Potassium feldspars

Table 4.4. Mineralogy of clay-size samples

Sample Name	Formation Name	Mineralogy
Rwm1	Rwamabare	Kaolinite, Illite, Mica,
Ka2	Kabukanga	Kaolinite, Illite-Montmorillonite, Illite, mica
Ka1	Kabukanga	Illite-Montmorillonite, Illite-smectite, Kaolinite, Smectite-Kaolinite, mica
Ny1	Nyabusosi	Kaolinite, Calcite, interstratified smectite-mica
Nybr1	Nyaburogo	Illite, Kaolinite, Illite-smectite, Chlorite.
O2	Oluka	Illite, Montmorillonite, Kaolinite, gypsum, mica
KK1	Kakara	Illite-Montmorillonite, Illite, kaolinite,
K6	Kisegi	Kaolinite, Illite-Montmorillonite, Illite, Montimorillonite,
K5	Kisegi	Kaolinite, Illite, Smectite-Kaolinite, Chlorite.

4.4. SEISMIC DATA

4.4.1 Introduction

Seismic reflections represent seismic energy reflected from a particular reflector (such as bedding, unconformities, change in lithology, faults and change in fluid medium), due to a change in acoustic impedance in the subsurface media (Mitchum *et al.*, 1977). Seismic data interpretation was based on data acquired by Heritage Oil and Gas Limited in 1998 and 2001 (Figure 4.12). A total of 400 line-kilometres of two-dimensional (2D) seismic data of the Semliki Basin were acquired. The data have been analysed and interpreted during this study and this has helped in the study of sedimentary facies of the subsurface.

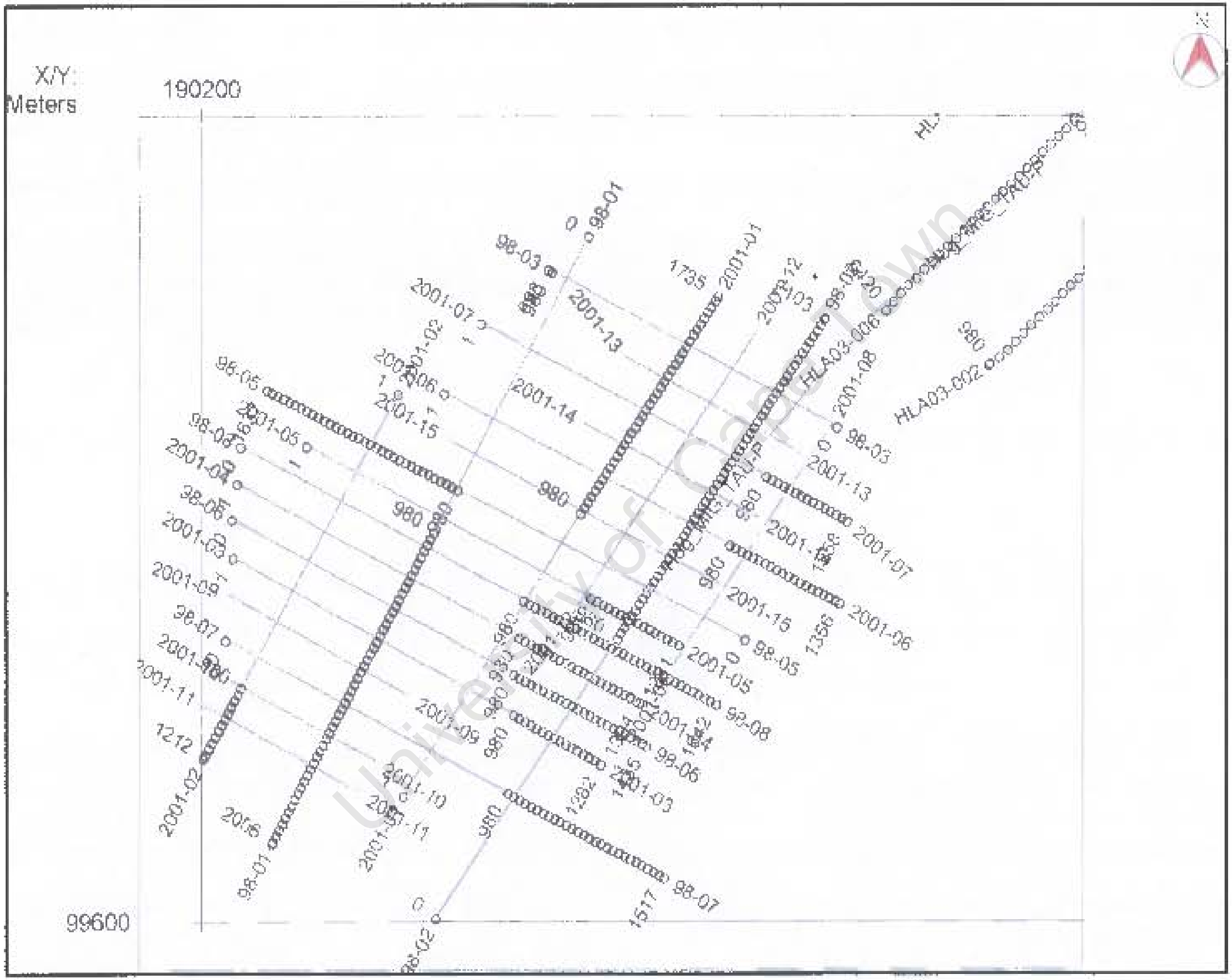


Figure 4.12. Base map of the acquired seismic data from Semliki Basin.

High frequency reflections provide excellent structural resolution in a complex setting in the upper parts of the sections. There is excellent reflection continuity throughout the Miocene section. The reflection continuity is, however, strongly affected by the complex normal faulting within the basin. The basin fill occupies the greater part of most lines and comprises a reflective sequence up to approximately 4.5 seconds thick. This basin fill is typically highly reflective and many of the reflections exhibit good lateral continuity. All of the interpreted seismic sections are presented in Appendix 3. The vertical scale of all seismic sections is seconds two-way-time.

4.4.2 Reflection identification

A strong (high amplitude) reflection is seen across the whole survey (Figure 4.13) and is regarded as top of basement. Below this reflection, the data quality deteriorates and the reflections are difficult to interpret. The Red Reflection has thus been assigned to the top of basement and is clearly seen across the whole survey as a strong reflection. The Top Basement event represents the highest amplitude encountered and appears as a major geological boundary. Apparent thrust faulting as well as normal faulting has cut this event and this faulting has sometimes resulted in significant displacement of the Red Reflection.

The Gold Reflection (Figure 4.14) has been assigned to the base of the Tertiary basin fill. Turaco-1&2 wells did not reach this depth, but, based on the reflection character above it (clear and continuous), it represents the basin fill. This reflection was interpreted to be near the base of the Miocene (Heritage Oil and Gas Limited, 2001). Below this reflection, data quality is poor and only a few continuous reflections can be picked. This section lies above the Basement. Karoo beds have been found on top of the Basement in other adjacent basins in the western rift area. Therefore, this section has been interpreted to be of Karoo age. These sediments onlap the basement and are likely to have formed under continental conditions. Possible Jurassic age rocks were intersected in the Butiaba Waki-

1 well, drilled on the margins of the Albertine Graben and their presence here is quite likely.

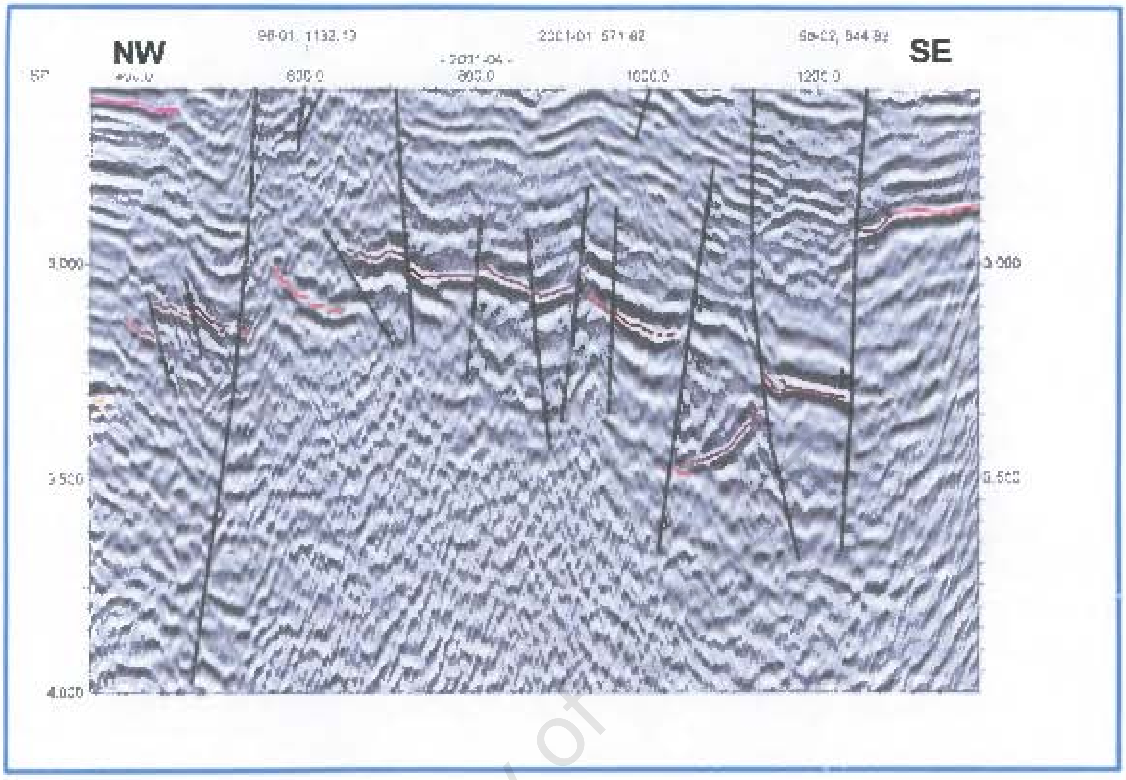


Figure 4.13. A section of Seismic Line HOG 2001-04 showing the Top Basement (Red Reflector) cut by faults.

The Magenta Reflection (Figure 4.14) has been assigned to the base of Kisegi Formation. This formation was encountered in Turaco-2. The Magenta Reflection is a high-amplitude doublet event and is continuous across the survey. This sharp seismic boundary may be an indication that the area was subjected to intense erosion and peneplanisation in the Post-Karoo period. It is possible that the area became uplifted and subjected to erosion throughout the period from Triassic to Early Tertiary. In the Kenyan Rift, Early Tertiary sediments lie above Karoo sediments, and below Middle Miocene to Recent deposits. By analogy, it is reasonable to assume that the sequence overlying the

Karoo in the Albertine Graben, which appears broadly similar on seismic profiles to that in the Kenyan Rift, is also of Early Tertiary age. These sediments are thought most likely to be predominantly siliciclastic. They are associated with continuous reflectors, which are more typical of the seismic character associated with lacustrine settings, rather than fluvial settings. These sequences appear to onlap the Basement highs. A series of reverse and thrust faults were developed within the survey area, which cut the Basement, Karoo and Early Tertiary sections, but are terminated by an unconformity. The Basement was thrust upwards, possibly causing erosion of the thrust sediments, forming a marked angular unconformity. The Basement was juxtaposed against the sediments and then the Early Tertiary sediments were deposited basinward. Delta sequences are seen to prograde and retrograde with channel incisions into the deltas.

The Blue Reflection (Figure 4.14) is assigned to the Top Kisegi/Base Kasande Formation. Most of the other reflections above the Kisegi Formation are cyclic and therefore repeated reflections were picked. These correspond to the Oluka, Nyaburogo, Nyakabingo/Nyabusosi formations. These reflections correspond to high-amplitude events in the most faulted part of the sections, possibly representing a strike-slip fault-induced flower structure. Most of the sediments above the Magenta Reflection were interpreted to have been deposited in a fluvio-deltaic/lacustrine environment, based on the reflection character. Figure 4.14 shows the interpreted seismic section of line HOG-98-01 illustrating different structures and sequences.

Seismic lines 98-08, 2001-04, 98-06, 2001-03, 2001-09 and 98-07 are lines where the seismic-reflection packages are seen to emerge at the surface. These lines are seen to pass through the outcrops that have been mapped by Pickford *et al* (1994) and are of Mid Miocene to Recent age (Figure 4.15). Figure 4.16 shows the interpreted section of line HOG 2001-04, illustrating the correlation of seismic data with surface outcrops of the Semliki Basin.

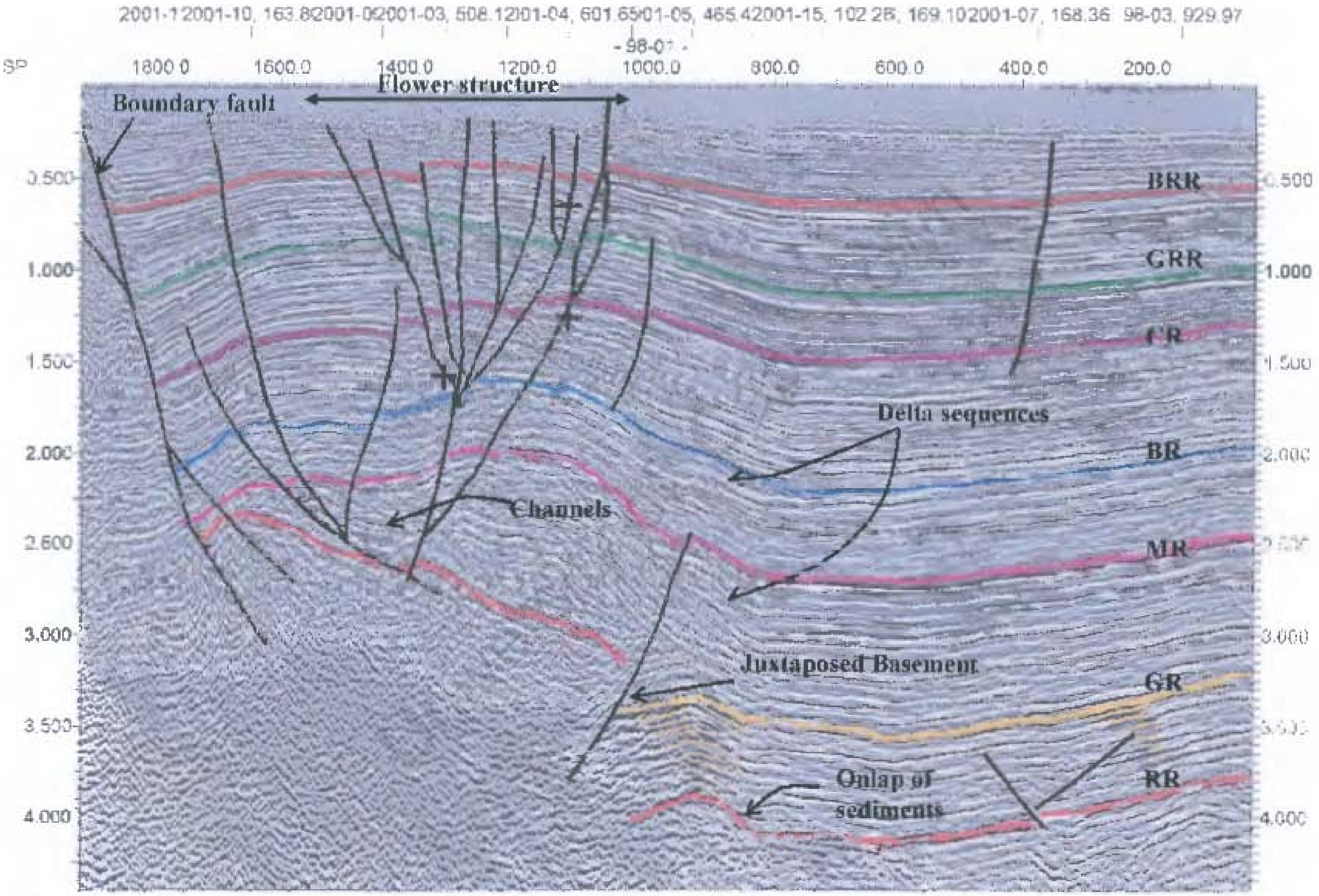


Figure 4.14. Interpreted section of line HOG-98-01 showing the different horizons and the depositional history of the Semliki Basin. RR=Red Reflection, GR=Gold Reflection, MR=Magenta Reflection, BR=Blue Reflection, CR=Cyan Reflection, GRR=Green Reflection, BRR=Brown Reflection.

4.4.3 Structural interpretation

A seismic interpretation of line HOG-98-01 shows a basin that has undergone both rifting and thrust tectonics. Based on the seismic reconstruction of the area, thrusting predates the major rifting phase though it may seem likely that there could have been another thrust episode after rifting. This is indicated by the folding of the strata against the main fault as seen on seismic line HOG 98-01 (Figure 4.14). This faulting may have been oblique to this line, since there is no expression of the thrust fault on this line controlling the folding of the later sediments.

Lines HOG 2001-01 and HOG 98-01 display westward-thickening reflection packages (Figure 4.16). It is possible that the faults within the flower structure have been constantly active throughout deposition and are likely to have cut to the surface throughout the depositional period. Thickening on one side of the fault implies that faulting was syn-depositional. Thickness changes across the faults imply lateral movement on the faults, other than normal faulting. For example, the Kisegi to Nyabusosi unit is thicker on the upthrown side of the fault that it is on the downthrown side (Figure 4.16). These thickness differences are more typical of juxtaposition of the section developed near the basin depocentre being juxtaposed against a thinner, more marginally deposited section.

4.4.4 Stratigraphic interpretation

Pinchouts and erosional truncations are very important in seismic stratigraphic interpretation, since they are normally associated with major lithological boundaries such as unconformities. Pinchouts and truncations are also associated with depositional indicators, such as sand lenses and channel and fan features. Lateral discontinuities and pinching-out of reflections on a vertical section could be associated with faults, channel systems or fan deposits.

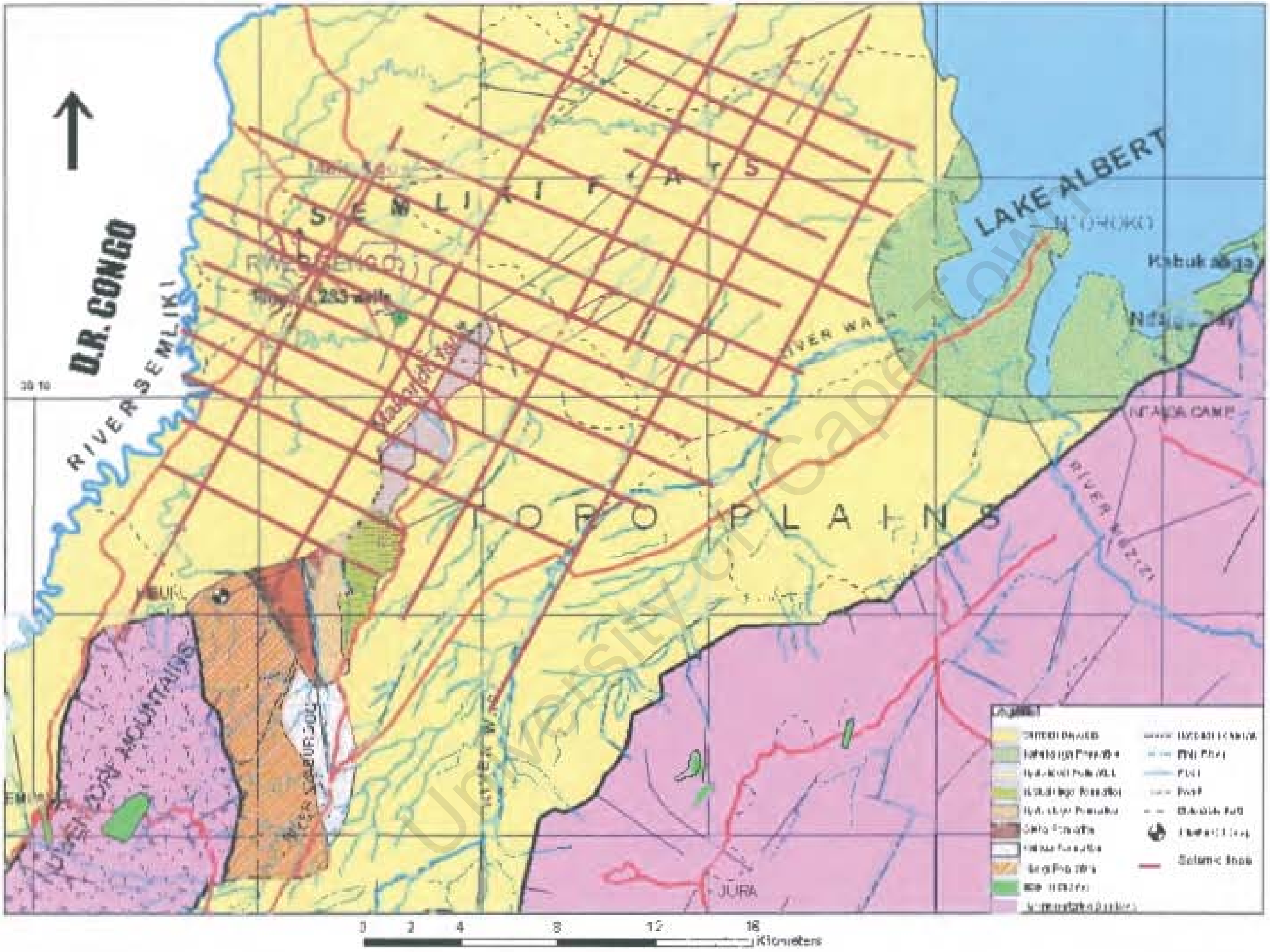


Figure 4.15. Seismic base map superimposed onto the Geology of the Semliki Basin.

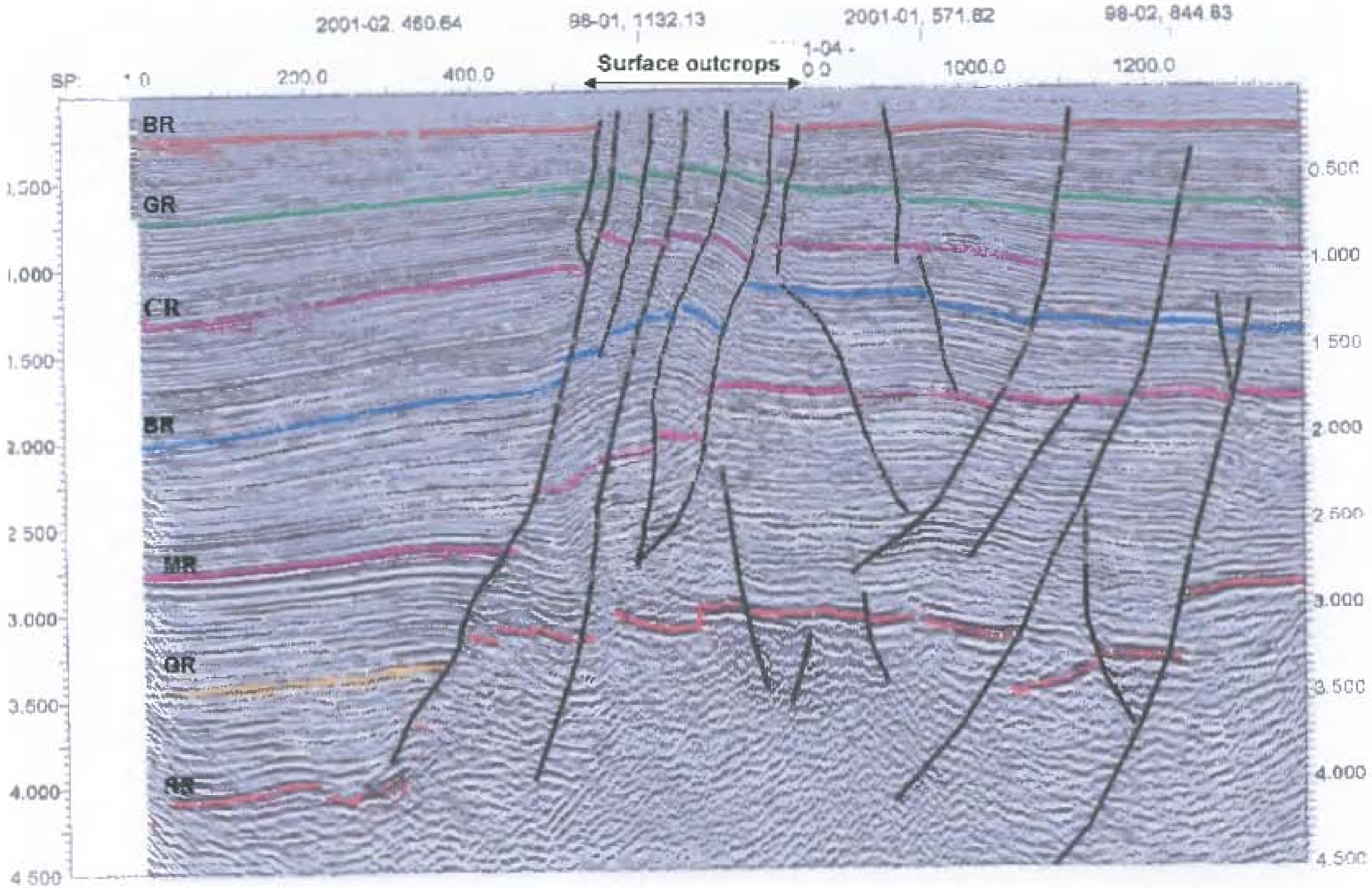


Figure 4.16. Interpreted section of line HOG-2001-04 illustrating the correlation to the surface outcrops. RR=Red Reflection, GR=Gold Reflection, MR=Magenta Reflection, BR=Blue Reflection, CR=Cyan Reflection, GRR=Green Reflection, BRR=Brown Reflection

Pinchouts and erosional truncations were identified from the seismic data by analysing the angle between the truncation surface and the surfaces of bedding. For example, Figures 4.17A-B show reflections on line HOG-2001-03 pinching out laterally, which could form important traps.

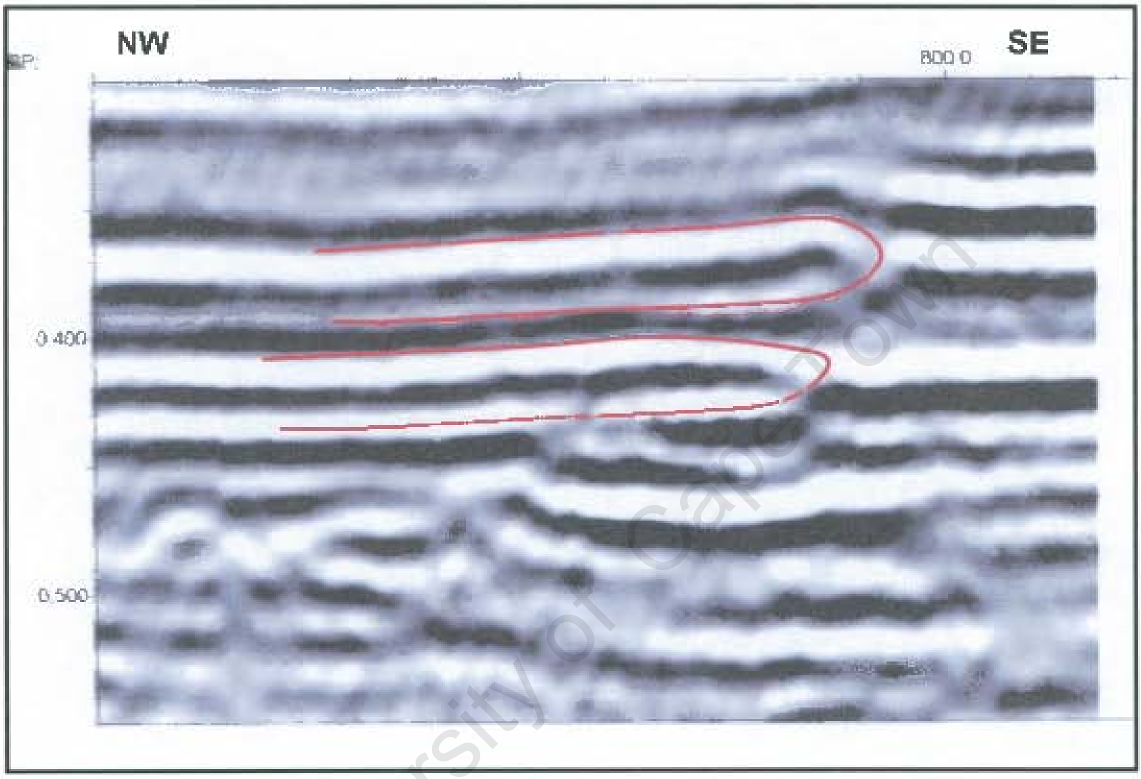


Figure 4.17A. Pinchouts associated with faults, mapped on line HOG-2001-03.

Stratigraphic features, representing sand lenses, have also been identified from the seismic data. The attributes slices presented in figures 4.18A and 4.18B illustrate a distinct trend of high amplitudes on various lines that have been associated with channels.

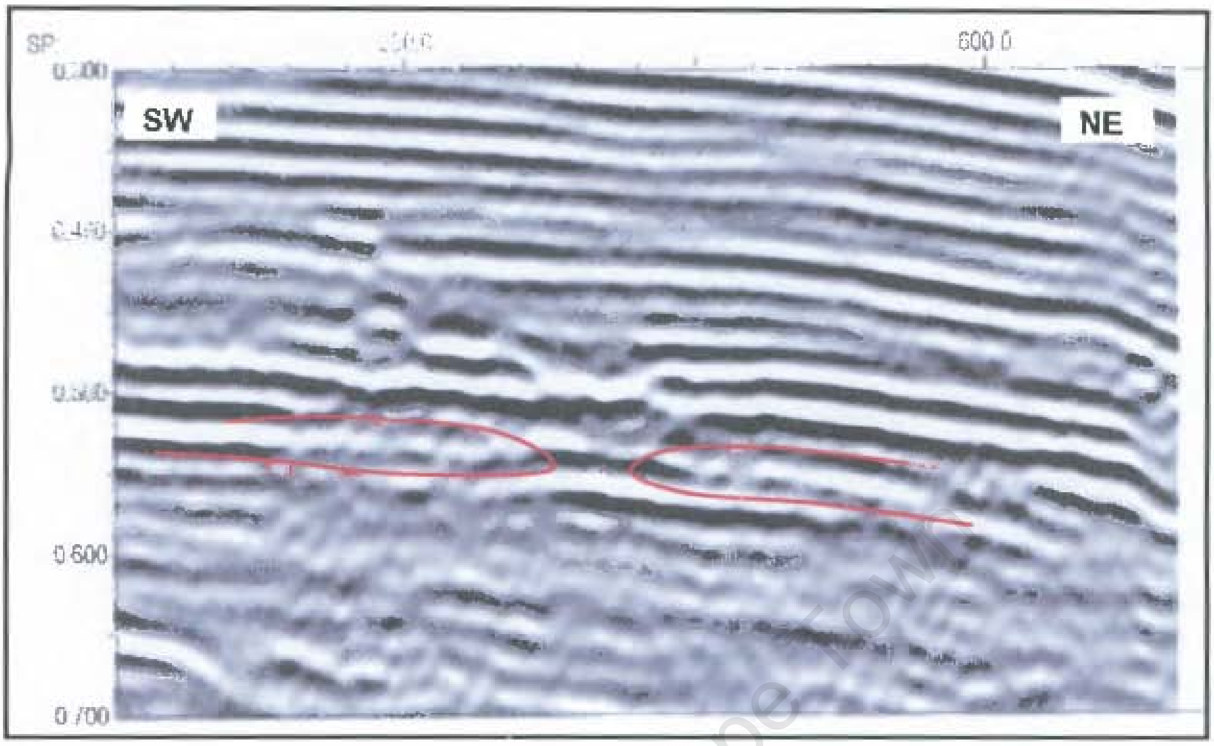


Figure 4.17B. Pinchouts mapped on seismic line HOG-2001-01

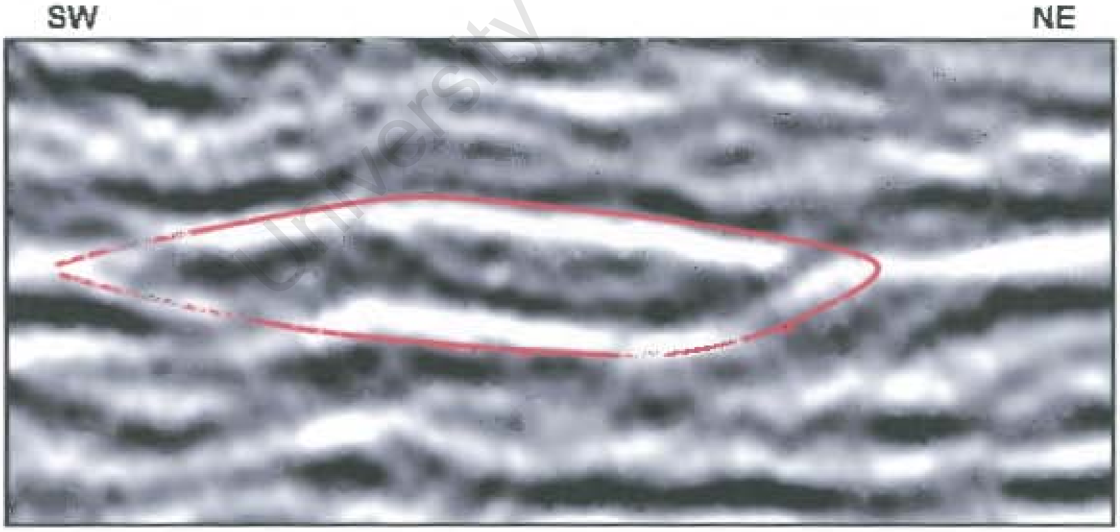


Figure 4.18A. Channel features mapped on line HOG-2001-01

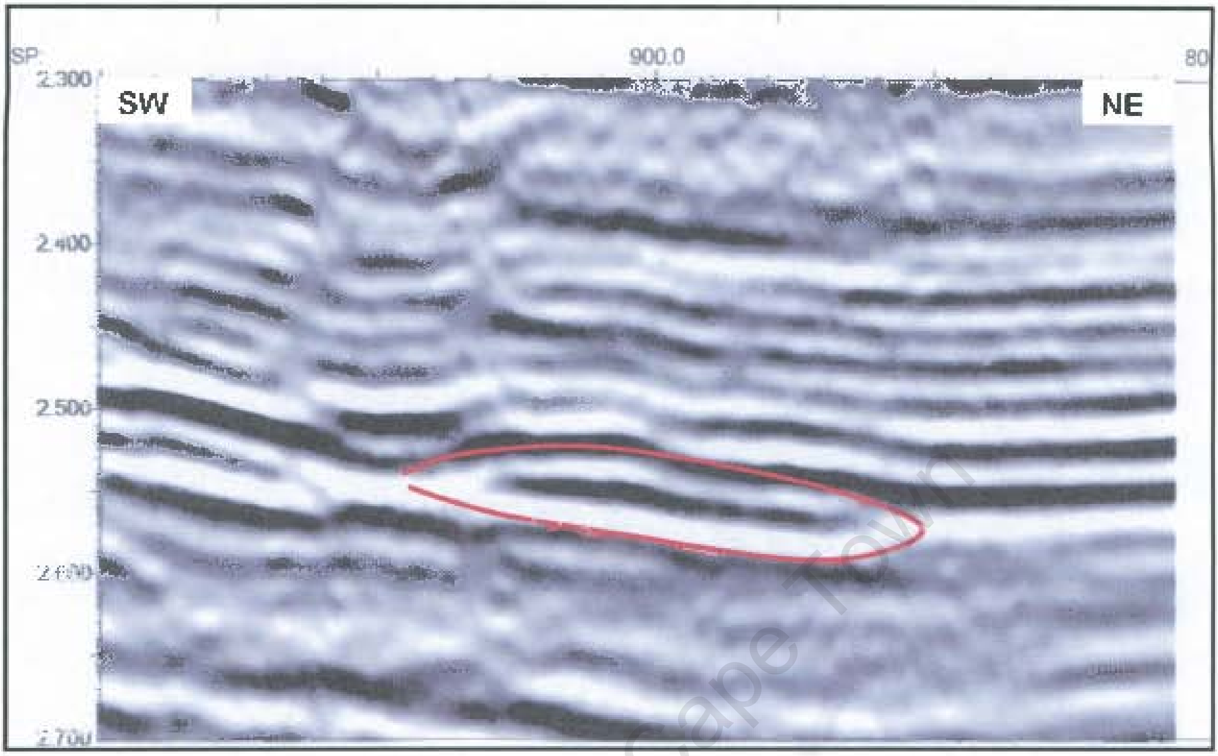


Figure 4.18B. Channel features mapped from seismic line HOG-2001-02.

4.4.5. Direct hydrocarbon indicators (DHIs)

Seismic-attribute analysis for hydrocarbon indicators was performed on the seismic data. Different types of seismic attributes were applied in order to analyse for any direct hydrocarbon indicators that may be present from seismic data. Numerous events, interpreted as direct hydrocarbon indicators (DHIs), were mapped from seismic sections. These are seen as flat spots, high-amplitude spots (bright spots), dim spots or polarity reversals. They were interpreted to be associated with the hydrocarbon- water contacts.

Seismic-amplitude anomalies, shown in Figures 4.19A and 4.19B, show bright and flat spots, indicating the presence of hydrocarbons in the Semliki Basin sandstones. Line 98-

01 (approximately 2.0 seconds and 1180m shot point) shows a high-amplitude (bright) spot that stands out from the rest (Figure 4.19A).

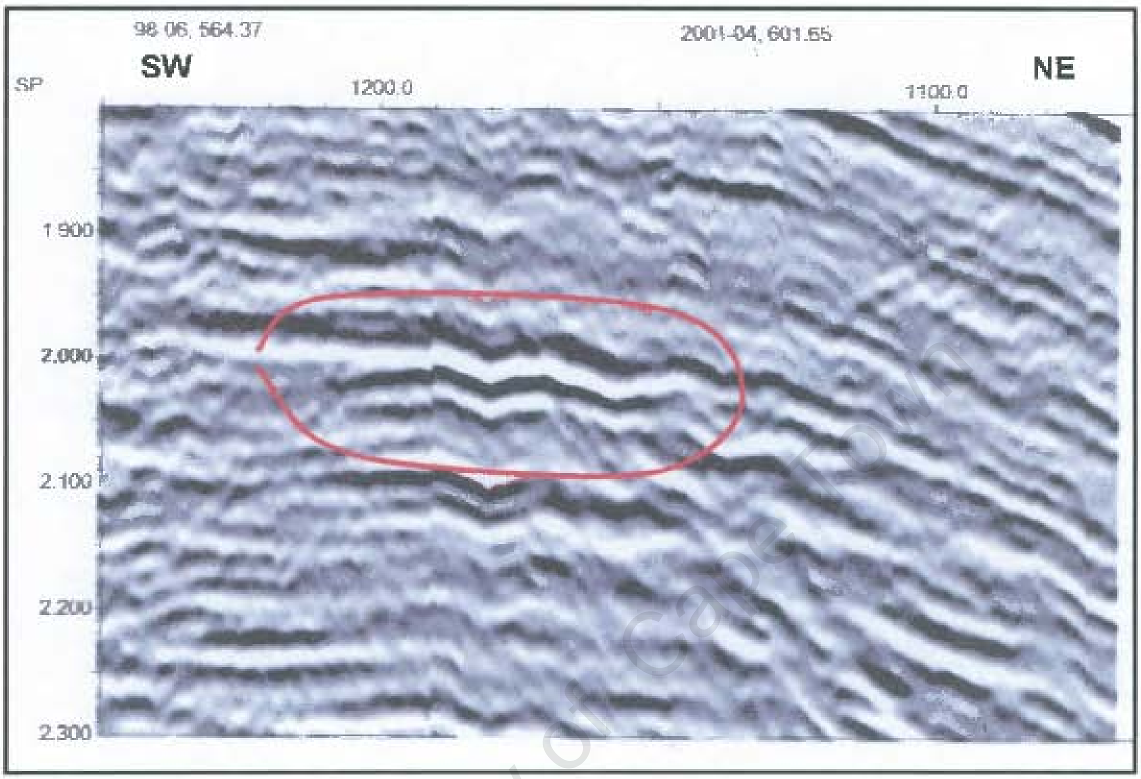


Figure 4.19A. A high amplitude reflection on line HOG-98-01

Another bright and flat spot was mapped on line 2001-04 (approximately 2.0 seconds and 600m shot point) tilted towards the west (Figure 4.19B). These were interpreted as a response to cementation along an old hydrocarbon-water contact, which was later tilted to the west. The Kisegi Formation was mapped above this level and it is believed that there are hydrocarbons associated with the structure, since Kisegi Formation sandstones have been cited as potential reservoirs.

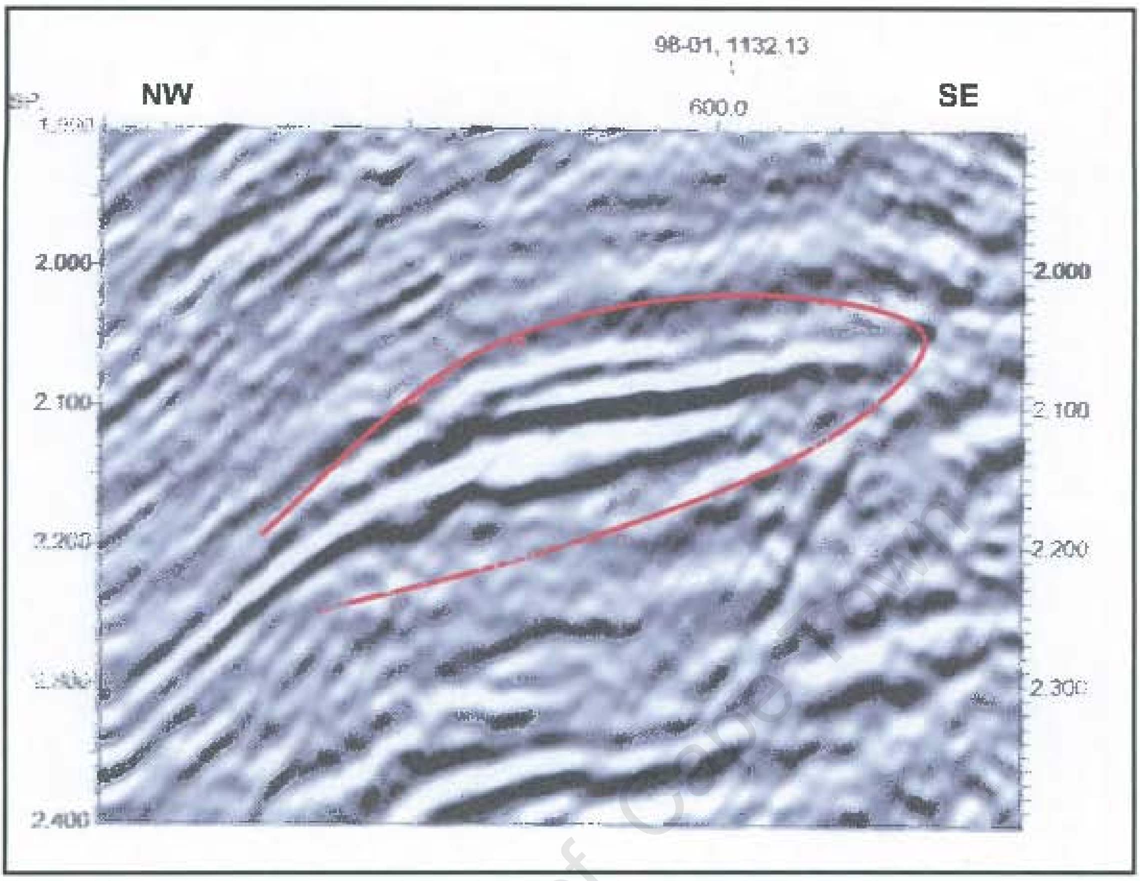


Figure 4.19B. A high-amplitude/bright spot on line HOG-2001-04 tilted to the west.

4.5 BOREHOLE DATA

The reference/well cuttings from Turaco 1 and 2 were taken at depth intervals of 5m. Heritage Oil and Gas Limited described these both on site and in the laboratory and lithologs were compliled. Wireline logs were also run in both Turaco-1&2 wells and these include gamma-ray, caliper, resistivity, neutron porosity, density, sonic and temperature logs. Based on these well-cuttings descriptions and wireline-log responses, the stratigraphy of the Semliki Basin was interpreted. Lithologs and wireline logs have been analysed and interpreted together during this study and the findings are presented below. Outcrop and well data in this study were correlated, mainly based on lithological grounds, by comparing the observations made from outcrop and those from the well cuttings from both Turaco 1&2 wells. The observations made from surface geological mapping were also compared with those from wireline-log interpretations.

4.5.1 Stratigraphy from wireline logs and well cuttings

Evaluation and analysis of the mudlogs and the well log for Turaco-1&2 wells shows that the wells penetrated a sequence of claystones interbedded with sands/sandstones. Litholog evaluations for Turaco 1 and 2 wells showed variations in sand and shale percentages and sequences down the wells. Composite well logs for Turaco 1&2 wells are presented in Appendix 4.

Based on the analysis of litholog and wireline logs for Turaco 1&2 wells, the formations encountered at depth during the drilling operations were correlated with those mapped at the surface during fieldwork. The sand/shale association here may reflect interaction of sandy fluvio-deltaic and muddy lacustrine systems. Where the clastics are finer, they may represent a distal end of deltaic or moderately deep lacustrine environments. Where they are coarse, they may represent a more proximal fluvial influence or deltaic progradational packages.

4.5.1.1 Kisegi Formation: 2555m to 2962.5m

The Kisegi Formation is comprised of intercalations of sandstone and claystone. This interval comprises 1-8m interbeds of sandstones and claystones, the latter forming about 70% of the interval. The thickest sandstone layer was encountered between 2798m and 2817m. The low gamma ray log response at this depth shows that this is a clean sandstone. The density and neutron porosity logs show a good negative separation and the resistivity is high, the sonic velocities are slow and a combination of all these leads to the conclusion that it is a sandstone of good reservoir quality, but that it does not contain hydrocarbons, because of low resistivity. The intervals 2788-2798m, 2819-2831m may represent impure coals.

The sandstone grains in the Kisegi Formation are transparent to translucent, very fine to coarse-grained, poorly sorted, angular to subrounded, subspherical, loose, quartz and feldspars, with moderate to good visual porosity. The claystones are similar to those of the overlying Kasande Formation.

4.5.1.2 Kasande Formation: 2437.5 to 2555m

The Kasande Formation is the argillaceous (mudstone-dominant) interval from 2437.5 to 2555m. It comprises an association of differing claystone types. These are variably pale to medium dark grey, pale to medium green/blue grey yellow brown or dark reddish brown, generally firm to moderately hard, blocky to sub-blocky, splintery in places, locally waxy, non-calcareous.

4.5.1.3 Kakara Formation: 1881m to 2437.5m

The Kakara Formation directly overlies the Kasande Formation. It consists of interbedded claystones and sandstones with the latter being about one third of the sequence and forming beds of 1-10m thick. Claystone units range between 0.2-30m thick, whereas the sandstones are mainly thin (0.1-0.2m) with few layers up to thickness of 10m.

The claystones are varicoloured, including pale blue/green grey, dark grey, brown grey, black to dark brown, pale to medium grey, common dark grey, locally orange or reddish brown. They are variably soft to hard and typically have a blocky to irregular fracture, splintery in places. The claystones are locally silty/sandy and carbonaceous material is recorded in places.

The interbedded sand/sandstones are poorly consolidated to unconsolidated, mainly fine to medium grained (very fine to coarse sand in places), moderately to well sorted and composed of mainly angular to subangular quartzitic grains.

4.5.1.4 Oluka Formation: 1502m to 1881m

From the Turaco-2 composite log, the sediments of the Oluka Formation were encountered at depths between 1502-1782m. They are clay prone with claystone units ranging between 0.2-30m thick. The Oluka Formation comprises an association of interbedded claystones, shales, siltstones and sandstones broadly similar to those in the overlying formations. The sandstones are thin with a few layers up to 10m thick apart from a 15m bed occurring from 1629-1644m. Compared to the overlying formations, Oluka Formation is more argillaceous and shows a predominance of fining-upward cycles as evidenced on the gamma ray and sonic logs.

Claystones are vari-coloured, light grey to olive grey, soft, silty, locally they grade to argillaceous siltstone, white to light grey/grey, argillaceous, and soft. Shales are also common and are grey to dark grey, firm and weakly to moderately fissile. The thicker sandstone beds are mainly medium to coarse-grained, though the majority of sandstones are very fine to medium grained and moderate to well-sorted.

4.5.1.5 Nyaburogo Formation: 1049m to 1502m

From the wireline logs, the sediments of the Nyaburogo Formation are more arenaceous than the overlying Nyakabingo and the underlying Oluka formations, although they are generally argillaceous. They were encountered at a depth between 1049 and 1502m. The formation comprises interbedded sands and claystones with bed thicknesses of typically 0.2-15m. These sediments display depositional cyclicity in which coarsening-upward cycles predominate.

The sand grains are quartzose, typically colourless and, translucent, very fine to very coarse, angular to subangular, rarely subrounded, elongate to sub-spherical, poorly sorted with inferred good visual porosity. The claystones are light to dark grey to black, locally speckled, firm, blocky to irregular, subfissile to splintery, earthy to smooth, locally silty, slightly calcareous in places, micromicaceous, locally with carbonaceous specks/rare laminations and non-swelling.

4.5.1.6 Nyabusosi-Nyakabingo Formations: 200-1049m

The sediments of the Nyakabingo and Nyabusosi formations could not be separated on the well logs of the Turaco-1 Well. These formations comprise an association of claystones interbedded with subordinate sands/sandstones. The shalier interval from 847-1049m, however, might comprise the Nyakabingo Formation. The thickness of individual claystone units varies between 0.5-40m whereas the sandstones range between 0.1-10m thick. These sediments show a predominance of coarsening-upward cycles, which are commonly, though not invariably, overlain by fining-upward cycles. These small-scale cycles are typically 5-10m thick. The coarsening-upward cycles are interpreted from the gamma-ray-log response.

The claystones are light grey to light greenish grey, soft, locally silty, in places with traces of plant fragments/carbonaceous debris, mica and sideritic/dolomitic fossil (gastropod?) fragments. The interbedded sand/sandstones are poorly consolidated to loose, and comprise mainly medium to very coarse grains, and are locally granular to pebbly. Grains are quartzose, clear to milky and are sub-elongated to sub-spherical in shape, sub-angular to sub-rounded. Better-sorted fine to medium sands are present in places.

4.5.1.7 Surface Alluvium: 0-200m

The surface alluvium was encountered at depth between 0-200m. The sediments are mainly composed of intercalations of loose to semi-consolidated sands and thin layers of silts (<0.5m) and thin (<0.5m) layers of clay. These represent the youngest deposits within the basin. The sands contribute the biggest percentage and their individual bed thickness ranges between 0.2-20m.

The sediments are almost entirely loose sand, quartzitic, yellow to white, medium to very coarse grained. The grains are sub elongated to sub spherical, sub angular to sub rounded, poorly sorted with minor muscovite, green glauconite(?) and traces of soft to moderately hard lignitic material.

4.5.2 Cyclicity from wireline logs

The wireline logs and lithological sequences from the well suggest strongly cyclic depositional patterns. The gamma-ray patterns indicate the coarsening-upward and fining-upward cycles. These variations in gamma-ray character may reflect water-level changes and river/lake interactions through the depositional period and the influence of rifting tectonics on sediment deposition through time. Cyclicity is important, because during a lacustrine transgression, fine sediments are deposited and during a lacustrine regression, coarse sediments are deposited.

At the small scale, the logs show a predominance of coarsening-upward (regressive) cycles, which are commonly, though not invariably, overlain by fining-upward (transgressive) cycles (Downie, 2003). These small-scale cycles are typically from 5-10m thick. For example, the interval between 1150-1900m shows individual regressive units of 5-10m are overlain by transgressive units (Figure 4.20). At an intermediate scale, the small cycles stack to form overall regressive (coarsening-upward) and transgressive (fining-upward) cycles. These cycles are typically of the order of magnitude of about 100-150m

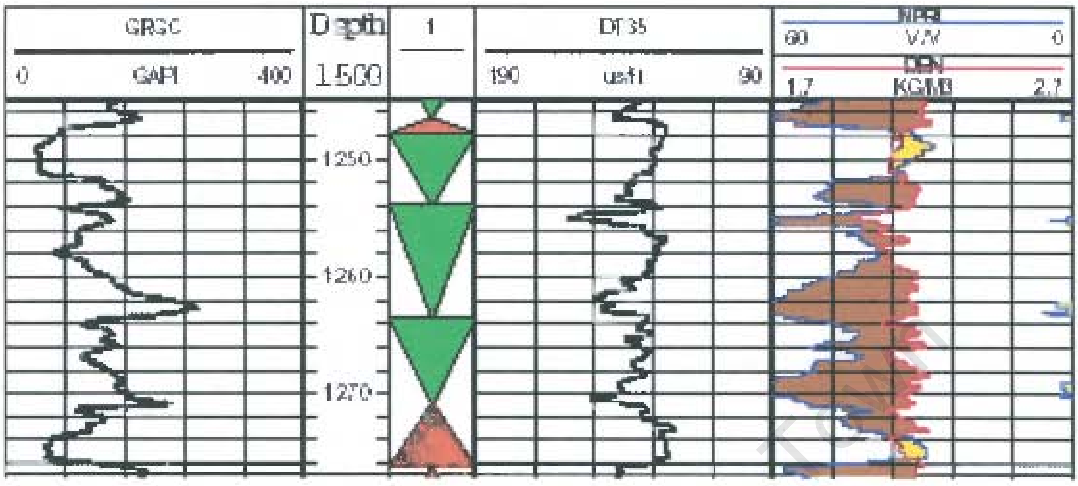


Figure 4.20. Small-scale cyclicity from Turaco-1 well logs (Adapted from Downie, 2003). GR= gamma-ray log, DT=sonic log, NP=neutron porosity log, DEN=density log.

The analysis of the wireline logs and lithilogs from Turaco-1&2 indicates the coarsening-upward and fining-upward cycles (Heritage Oil and Gas Limited, 2002). These are interpreted as being from 200-1049m and from 1049-1883m. Stacking of cycles at an intermediate scale form overall coarsening-upward and upward-fining cycles (Figure 4.21).

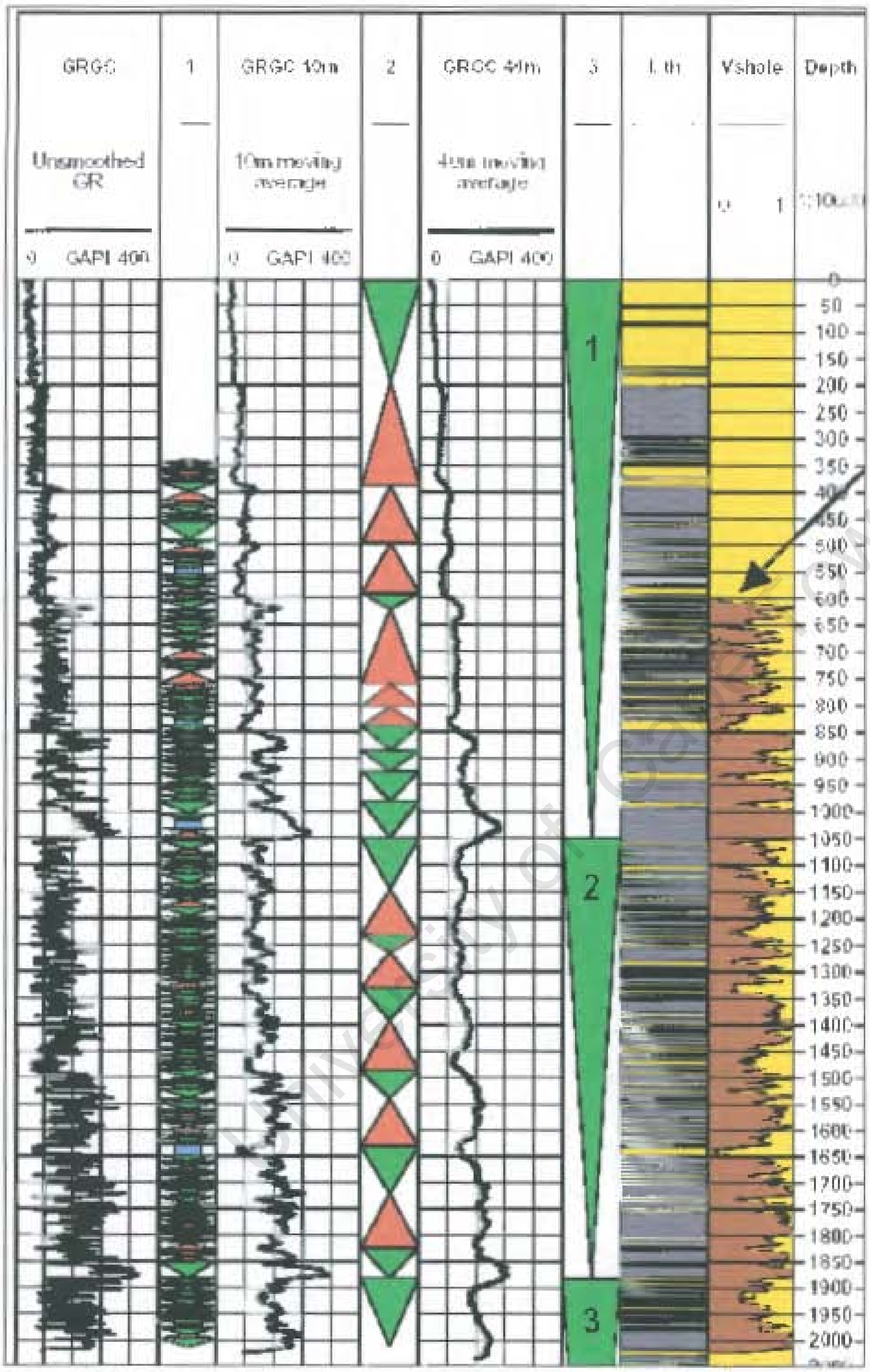


Figure 4.21. Coarsening-upward and fining-upward cycles from gamma-ray-log analysis (Adapted from Downie, 2003). Vshale represents the fractional volume of claystone.

CHAPTER FIVE

5.0 DISCUSSION

5.1 INTRODUCTION

The main aim of this study was to establish the relationship among the sedimentology, stratigraphy and the hydrocarbon potential in the Semliki Basin. Sedimentology deals with the scientific study of the classification, origin and interpretation of sediments and sedimentary rocks (Boggs, 1995). It is concerned with physical (textures, structures and mineralogy), chemical and biologic (fossils) properties of sedimentary rocks and the processes by which these properties are generated. On the other hand, stratigraphy deals with the science of rock strata (Boggs, 1995). It is concerned with the age relationships of strata, succession of beds, correlation of strata, stratigraphic order and chronologic arrangement of beds in the geologic column.

Data have been analysed, interpreted and integrated in order to establish the sedimentation history and the stratigraphic relationships among the different formations in the basin, to determine the depositional environment and to evaluate their petroleum potential. These data include surface geological mapping and subsurface (seismic, wireline and well cuttings) data.

5.2 SEDIMENTARY ENVIRONMENTS

A depositional environment is a geographically restricted part of the earth's surface, which can be distinguished from its adjacent areas by the complex of physical, chemical, and biological conditions, influences or forces under which a sediment accumulates (Krumbein & Sloss, 1963; Selley, 1970, 1978; Reineck & Singh, 1980; Blatt *et al.*, 1980; Selley, 1982). Facies can be related to present-day depositional environments in order to construct a depositional model for the ancient rocks (Selley, 1982).

The depositional framework of the Semliki Basin is dominated by clastic sediments in which lacustrine and fluvial environments are most commonly observed. This is in agreement with the general sedimentary environments in the East African Rifts (Morley *et al.*, 1999). Fluvial/lacustrine systems are characterized by diverse lithologies, which include conglomerates through sandstones to mudstones, cherts, oil shales and coals (Selley, 1990). The distribution, orientation and internal geometry of fluvial/deltaic deposits is controlled by a number of factors including climate, water discharge, sediment load, rivermouth processes, waves, tides, currents, winds, shelf width and slope and the tectonics and geometry of the receiving basin (Selley, 1978).

Lacustrine sediments are widespread in the Semliki Basin. They are dominated by claystones, siltstones, and interbedded sandstones. The lacustrine interpretation is commonly confirmed by the presence of invertebrate fossils, such as the freshwater bivalves, and distinctively lacustrine sediments such as evaporites and diatomite. Sandstones within the claystones may represent lake shoreline sands, deltas, offshore bars or turbidites (Magnavita and da Silva, 1995). Fluvial deposits vary in thickness, and form laterally consistent, fine- to very coarse-grained, channelized sandstones. Sedimentary facies associated with steep faulted margins (e.g., Magnavita and da Silva, 1995) are rare in the Semliki Basin, since they tend to be confined to narrow strips along faults.

From the Gamma-Ray Log Facies analysis, the stratigraphy of the Semliki Basin reveals predominantly progradational packages that are typical of fluvial-lacustrine type of basins. This facies association tends to be composed dominantly of marlstone, argillaceous coquina, bioclastic grainstone sandstones, carbonaceous mudstones and coals (Geirlowski-Kordesch and Kelts, 2000). Facies associations in such environments reflect changes in water level through climatic and tectonic events (Allen, 1970). Shallowing-up sequences are common and are normally capped by exposure (pedogenic/palaeosol) horizons. These facies are difficult to interpret with limited surface exposures, making stratigraphic reconstruction difficult. This is further hampered in areas of syndepositional tectonics.

In general, the sedimentary environments of the Semliki area, in the vicinity of the Turaco prospect, are fluvial-lacustrine, showing significant variations in gamma ray character that reflect water-level changes and river-lake interactions throughout the depositional period and the influence of rifting tectonics on sediment deposition through time.

Sedimentologically, the depositional environments of the sediments in the Semliki Basin were analysed for each individual formation. Numerous sub-environments were recognised from profiles of the individual formations of the Semliki Basin. Sedimentary rocks found in outcrop and in wells are either dominantly fluvial sandstones or alternating claystones and sandstones (lacustrine deposits). Other types of continental deposits such as carbonates and volcaniclastic sediments are rare. Various facies were identified from their geometry, lithology, sedimentary structures and fossil content.

5.2.1 Kisegi Formation

At the Kibuku outcrop, the section fines upwards from conglomerates, through coarse and fine sandstones to siltstones. The poorly sorted, angular conglomerates at the bottom of the section are interpreted as having been deposited rapidly with no reworking by currents. The clean sands and the sand matrix of the conglomerates are interpreted to have been deposited in fluvial channels, which may have been braided. They could have been deposited a distance away from the sediment source, but owing to the quartzitic nature of the adjacent Basement, the sand may not be a mature sediment and may be locally sourced. The overall fining- upward character is typical of deposition in a fluvial environment. The conglomeratic facies are also interpreted as talus slope deposits associated with steep faulted margins along the Kibuku Fault.

The basal part of the Kisegi outcrop is composed of rapid alternations of yellowish grey sands developed in thin lenses with interbeds of well bedded gypsiferous silt and clay beds. The sands are clean, medium to fine grained and well sorted, with subrounded to subangular grains. These are interpreted to have been deposited in an inter-channel setting with occasional minor flood events or with small ephemeral streams crossing an inter-channel plain. Overbank flooding takes place leading to the deposition of fine silts and mud on the bank or near the stream edge (Allen, 1970). Patches of brown staining, observed in this section, are probably the result of local iron enrichment due to subaerial exposure.

The highly arenaceous part of the Kisegi Formation is composed of yellowish grey, medium to coarse-grained, well-sorted sand units with subrounded to subangular grains. Graded bedding was observed in this part of the section with some beds grading from conglomeratic bases through to coarse sands passing into gypsiferous muds and/or silts. According to Allen (1970), meander migration leads to deposition of coarse lag deposits that become overlain by sandy fining-upward point-bar deposits, which themselves are overlain by silty and muddy overbank deposits, producing an overall fining-upward succession. Therefore, this section was interpreted to have been deposited as large-scale channel fills or as a sequence of stacked channels.

5.2.2 Kasande Formation

The Kasande Formation is mainly argillaceous with only minor, laterally inconsistent, poorly sorted ferruginous sandstone stringers in a mudstone/claystone section. This section is interpreted to have been laid down in a lacustrine environment possibly during a lake highstand. The thin sandstone stringers may have resulted from short-lived, increased sediment input, possibly caused by either storm runoff or by localised deltas. The upper part of the section, composed of silty to sandy claystones with poorly sorted sandstone and diatomite lenses, gives the appearance of being a sedimentologically immature sediment that has been very rapidly deposited in a lake. Deposition of diatomites is an indication of a sediment-starved, higher-latitude lake environment (Tucker, 2003). Therefore, the existence of diatomites in the sediments of the Kasande

Formation is an indication of less clastic input. The existence of gypsum signifies semi-arid conditions resulting in high rates of evaporation and therefore precipitation of evaporites. The red colouration may well result from intense tropical weathering.

5.2.3 Kakara Formation

The Kakara Formation is made up of an alternation of predominant silty, clayey sandstones that show fining-upward sequences from coarse to medium grain size. The section is mainly composed of intercalations of crudely bedded gravels with minor sand, silt or clays. These are interpreted as deposits of waning floods and overbank deposits in a braided stream. Intercalations of very fine sands, silts and mud encountered in this Formation are interpreted as being longitudinal bars and channel-lag deposits. The bulk of the Kakara Formation section is therefore interpreted to have been deposited in a fluvial setting, where the laterally continuous sands represent either deltaic distributary mouth bars or lacustrine turbidites. Because of the dynamic nature of fluvial systems, the deposits are highly variable, depending on the size of the bedload grains, sediments transported, depth of stream channel, and the amount and variability of the stream discharge (Boggs, 1995). Therefore, streams are constantly shifting position as they migrate laterally, leaving sheet-like or wedge-shaped deposits of the channel and bar complexes. Lateral migration combined with aggradations lead to deposition of sheet sandstones or conglomerates with thin, non-persistent shales enclosed within coarser sediments (Boggs, 1995).

The section is, therefore, interpreted to have been deposited as an alluvial-fan deposit, perhaps close to the break in slope at the edge of an alluvial plain. The internal bedding structures are obvious, but it is likely that much of the sediment may have been transported in braided, ephemeral streams. The fining-upward sequences of variable scale reflect deposition in braided rivers with mixed bedloads of sand and gravel, where deposition may occur at different level within the channels or where channel aggradation is followed by channel shifting (Boggs, 1995). The laterally inconsistent sands may represent a low-sinuosity distributary channel-fill developed close to the lake-margin or fluvial deposition in the distal alluvial plain. The argillaceous sediments are interpreted to have been deposited in a lacustrine setting, whereas the laterally continuous sands represent either mouthbars or more probably lacustrine turbidites.

5.2.4 Oluka Formation

The Oluka Formation is highly argillaceous, but with some uncemented sandstone units towards the top of the section that show low-angle crossbedding. The deposition of clays is interpreted to have occurred during low-energy episodes, whereas the coarser clastics were deposited during high-energy episodes.

The environment of deposition of clays is interpreted as predominantly lacustrine, the thin sand horizons being developed at periods of low run-off at times of ephemeral, lake lowstand margin. The laterally consistent sands are interpreted to be fluvial deposits or mouth bar sands developed into a lake environment. The presumed tuff is interpreted to be of volcanic origin.

Several beds of white to light grey, low-density sediments, identified as siliceous spiculites/bedded cherts, diatomite lenses and gypsum veins and crystals were encountered in the sediments of the Oluka Formation. Their presence in the sediments indicates deposition in a shallow evaporating lacustrine environment. Diatomites are formed by diatoms, unicellular organisms that occur in great abundance in lakes (Tucker, 1991). Eugster (1969) describes chert being formed as silica is leached from volcanic rocks and rock fragments by water of low pH and being precipitated as it enters very alkaline sodium carbonate-rich lake waters. Evaporation and decrease in pH cause the silica to be precipitated as magadiite, a metastable hydrated sodium silicate that is converted to chert in a relatively short time. For example, detrital quartz and clay minerals, partially dissolved at high pH values (greater than 9) causes the waters to become supersaturated with respect to amorphous silica. Evaporation and decrease in pH cause the silica to be precipitated as a gel of cristobalite, which would give rise to chert on maturation (Peterson & von der Borch, 1965). The presence of bedded cherts, diatomites and gypsum in the sediments indicate deposition in a shallow lacustrine environment with desiccation. Hiatuses during these episodes could have caused exposure and high evaporation leading to cracking of the clay and deposition of calcite and gypsum. The presence of palaeosols in the sequence provides diagnostic evidence that the rocks were exposed to the atmosphere (Reinhardt and Sigleo, 1988).

5.2.5 Nyaburogo Formation

The Nyaburogo Formation consists of a lower mainly arenaceous sequence with stacked fluvial channel-sandstone sequences, but this fines upwards into a more clayey sequence with subordinate channel-fill sandstones. This fining-upward sequence confirms the fluvial environment of deposition (Boggs, 1995). The sandstone units are fine grained and display prominent parallel and crossbedding structures. The channel-fill sandstone at the base of the Nyaburogo Formation displays lateral and vertical accretion surfaces indicating possible deposition in a meandering river environment (Leeder, 1982). The conglomeratic lags at the bases of individual sand units in the upper part of the section also suggest a fluvial (meandering river) origin (Magoon and Dow, 1994). There is some evidence of lateral thinning of the sandstone units and this supports the idea that the sediments were deposited in a fluvial environment. Some of the thinner sandstone units have highly cemented tops that include iron-rich carbonate nodules. These cemented layers are interpreted to be lake-margin facies, formed at times of low sediment input and lake lowstand.

5.2.6 Nyakabingo and Nyabusosi Formations

The sediments of the Nyakabingo and Nyabusosi formations are highly argillaceous. They consist mostly of intercalations of light grey to light greenish grey clay and subordinate sands. This interval represents an alternation of low-energy lake-centre and high-energy lake-margin conditions. Most of the exposures observed contain fossils such as fishbones, oyster shells (*Ostrea*) and bivalves (*Atrina* and *Modiolus*). These types of invertebrates live in lakes, mostly at water depths of less than about 10m (Reineck and Singh, 1980). Therefore, these fossils are believed to be associated with a shallow lacustrine environment. The gastropod fossils are indicative of freshwater (lacustrine) environment of deposition, where there was considerable lake-level fluctuation. The high concentration of the fossils suggests there could have been flooding in this area or death if the lake became too saline. Therefore, this area was interpreted as lacustrine or flood plain and/or lagoonal. This suggests that either the present Lake Albert was bigger than it is today or that there was a lake covering the location at the time of deposition of these sediments. Iron staining is indicative of oxidation, following subaerial exposure, perhaps after retreat of the lake during lake lowstands.

5.2.7 Kabukanga Formation

The Kabukanga Formation comprises an association of interbedded claystones and sandstones. The sediments of the Kabukanga Formation are laterally continuous and show a coarsening-upward profile with the finer sediments at the base of the formation and coarser sediments towards the top of the formation. The deposition of clays is interpreted to have occurred during low-energy episodes, whereas the coarser clastics were deposited during high-energy episodes (Boggs, 1995).

Lake level and sediment supply are directly linked in lake systems (Bohacs *et al.*, 2000). The lake level rises when river discharge is high and falls when the river discharge drops.

The strength of this linkage varies with lake-basin type with the strongest in closed hydrology and the weakest in open hydrology systems (Bohacs *et al.*, 2000). Lake shorelines can move basin-ward by progradation or by simple retreat of waters. Progradation leaves distinct sediment packages while simple lake withdrawal hardly leaves traces apart from the desiccation features in/on previously deposited strata (Carroll and Bohacs, 2001).

The nature and existence of a lake is also controlled by the relative rates of accommodation change and sediment supply including water (Carroll, 1998). The type of lake system is controlled by how much accommodation space is filled by sediments and water over a period of time and span. The climate, sediments and water, and tectonics or inherited topography will exert co-equal control on the nature and distribution of lacustrine depositional system tracts and their source, reservoir and seal lithofacies (Carroll, 1998).

Boggs (1995) describes the shallowing and coarsening-upward profiles in lake facies as being generated by the process in which coarser, nearshore sediments gradually encroach on the finer, deep-lacustrine sediments, which are in turn covered with fluvial sediments. Since lakes are believed to be a closed system with respect to sediment transport, lake basins eventually fill with sediments, and most are converted into fluvial plains as they are overrun by fluvial systems. As the lake levels rise and fall, the shoreline facies extend landward or prograde into the lake forming cyclic packages that coarsen upwards (Magoon and Dow, 1994).

The sediments of this formation are, therefore, interpreted to have been deposited in lacustrine delta fill and flood plain environments such as swamps and marshes. The sandstones are interpreted to be mouth bar or shoreline sequences.

5.2.8 Rwamabare Outcrop

The sediments of the Rwamabare section are composed mainly of intercalations of well-laminated, laterally continuous, very fine grained sandstones that grade upwards into silt and clay. In general, the sediments display a fining-upward profile. The sandstones are interpreted to be fluvial deposits, particularly channel-fill sandstone deposits, whereas the clays are interpreted as floodplain deposits or lake deposits. The overlying argillaceous section, with thin sand stringers near the top, are interpreted as having been deposited in an inter-channel setting with occasional minor flood events. The laterally continuous sandstone stringers may on the other hand represent lacustrine deposits with occasional input of sediments.

5.2.9 Semliki Plains and Toro Alluvium

These sediments are the youngest deposits in the Semliki Basin. The sand and clay deposits of the Semliki Plains are believed to be the product of flooding of the Semliki River and lateral migration of the river meanders during periodic highstands of Lake Albert. On the other hand, the pebbly, Toro Alluvium appears to be related to fluvial wash from the Rwenzori Mountains.

5.3 MINERALOGY

Mineralogy of rocks is a very important property for studying the origin of siliciclastic sedimentary rocks, because it provides almost the only available clue to the nature of vanished source areas (Boggs, 1995). The study of mineralogy is also very important in understanding the tectonic setting of the source areas and associated depositional sites. Petrography and XRD data were used to characterise the likely provenance for the sediments in the Semliki Basin.

5.3.1 Petrography.

The sandstone samples of the Semliki Basin are predominantly composed of quartz, potassium feldspars and plagioclase feldspars. The quartz grains are angular to subrounded, are polycrystalline and monocrystalline and exhibit both uniform and undulose extinction. The feldspars are mainly albite and microcline as evidenced by parallel and cross-hatch twinning, respectively. In most of the samples, feldspars have been fully or partly altered to clay minerals. Clay minerals are recognised in thin sections as grain coatings (necking between grains), suggesting that they may not be associated with burial diagenesis, but are more likely to be the result of eluviation/weathering in the shallow vadose zone. The common accessory minerals present are micas in which biotite and muscovite predominate. Other minerals, such as epidote and garnet, are present in minor amounts.

The sandstones of the Kisegi, Nyaburogo and Kakara Formations are moderately mature to mature subarkoses and sublitharenites, grain sizes range from fine to coarse, moderate to well-sorted and the grains are angular to subrounded.

Rock fragments of ancient source rocks (provenance) that have not yet disintegrated to yield individual mineral grains (Blatt *et al.*, 1980) were also observed in all the sandstone samples. These are mainly of quartzitic, granitic and gneissose origin and some of the quartz shows wavy extinction and packing of the grains at an angle of about 120°. Kisegi (K5) and Kakara (KK1) sandstones show gneissic grains showing parallel alignment of minerals (foliation), typical of gneissic rocks. .

The presence of potassium feldspars, for example, suggests derivation from an alkali igneous or metamorphic (granitic-gneissose) origin. Micas (biotite and muscovite) also suggest derivation particularly from metamorphic source rocks and plutonic igneous rocks. The shape of the quartz grains, subangular to rounded, moderate to well-sorted and medium to coarse grain size of the Kisegi Formation sandstones, suggests that these sediments have either been transported for significantly long distances or remained for long residence times within the fluvial systems.

Volcaniclastic sediments composed of material of volcanic origin were encountered in the Kisegi succession (sample K2). The presence of glass shards (enveloped by lamina) in outcrop confirms the volcanic origin. These are mainly badly weathered and some appear in a shade of dirty white to pink and some places green. The green colour may be as a result of chlorite replacement (Tucker, 2003). Most of these very fine sediments have undergone diagenetic alteration, leading to the generation of clay minerals (Adams *et al.*, 1984). This is further confirmed by the presence of smectite in the clay mineralogy (from XRD) that is believed to be as a result of weathering of volcanic glass.

5.3.2 X-ray Diffraction

The X-ray diffraction scans of bulk samples reveal that the mudrocks/claystones are dominated by clay minerals with subordinate quartz, feldspars and calcite, whereas the sandstones are dominated by quartz, feldspars and calcite. Minerals of granitic origin, such as quartz, potassium feldspars and plagioclase, mainly detected in sandstone samples, suggest derivation from a granitic-gneissose basement. The clay minerals include illite, illite-smectite, kaolinite, montmorillonite, illite-montmorillonite, and mica. The analysis of <2μm clay-size fraction indicates that the mineralogy from all the samples is dominated by the mixed layer illite-montmorillonite and illite layers in the structure. All samples contain kaolinite and illite and most contain montmorillonite.

Clays commonly originate as weathering products of feldspars and volcaniclastic sediments, but may also be detrital. It is not clear whether any clays are forming *in situ* or if all are detrital. The origin of clay minerals may not be specific, but some is believed to be as an alteration product of feldspars and volcaniclastic sediments. Volcaniclastic sediments may be altered to clay minerals and zeolites, such as smectite, kaolinite and montmorillonite upon weathering and diagenesis. Tuffs may be replaced by silica or calcite, silica released on alteration of glass to clays and zeolites can precipitate as chert by replacement and as cement (Tucker, 1991). The dominance of kaolinite and illite and montmorillonite in the XRD samples may be a result of hydrolysis of feldspars. The presence of smectite and montmorillonite in the clay fraction is an indication of alteration of volcanic glass to smectite.

Peaks of secondary precipitates, such as calcite and gypsum, were mostly observed in mudrocks/claystones of the Kisegi, Oluka and Nyabusosi formations. Their existence in the sediments signifies semi-arid conditions resulting in high rates of evaporation and therefore precipitation of evaporites.

Authigenic minerals, such as anatase and jarosite, were also recognised in X-ray diffraction of bulk samples. Jarosite was present in Kisegi samples K1 and K5, whereas anatase was present in Kabukanga (Ka1) and Kisegi Formation (K5, K4 and K1) samples. Jarosite ($KFe^{3+}_3(SO_4)_2(OH)_6$) is a secondary mineral that is formed through weathering in arid conditions, whereas anatase is a low-temperature polymorph of titanium oxide (TiO2) that is found as an alteration product of titanium-bearing minerals.

The mineralogy of the sand samples from the formations of the Semliki Basin is consistent with derivation from a granitic-gneissose basement. This is suggested by the quartzo-feldspathic composition and presence of minerals such as micas and garnet. Lithic grains that are now altered to clays may be attributed to a volcanic origin.

In relation to tectonic setting and depositional sites of the source areas, the mineralogy of the analysed sediments consists of quartzose sand, feldspars and metamorphic or sedimentary fragments. According to Dickison and Suczek (1979), such a suite of minerals is derived from plutonic igneous, metamorphic, sedimentary and sometimes volcanic rocks that are found in continental-block provenances.

5.4 SEISMIC DATA

The study and interpretation of seismic data was very important in understanding the stratigraphy and the depositional environments of the Semliki Basin. Interpretation of seismic data confirms the presence in the Semliki Basin of a thick succession of post-rift sediments that represent the Middle Miocene to Recent section described in outcrop. These sediments are thought to have been deposited as a result of formation of the main rift shoulders and increased/rapid subsidence of the rift. They are predominantly continental clastic, associated with reflections that are typical of the seismic character associated with fluvial-deltaic and lacustrine settings. A major rift-transfer zone was developed over the survey area with a well-developed flower structure rooted into the major normal fault (Figure 4.14). This fault forms the main 'stem' of the flower structure mapped in the central part of the survey. It is also possible that the faults within the flower structure have been constantly active throughout deposition and are likely to have cut to the surface throughout the depositional period. Possible compressional tectonics have led to the folding of the faulted sediments, mainly against the major fault.

Below this Tertiary rift is an earlier, possibly Early Tertiary section, separated by a sharp angular unconformity. This is an indication that the area was subjected to intense erosion and peneplanation in the Post-Karoo (Post-Triassic) period. It is possible that the area became uplifted and subjected to erosion throughout the Triassic to Early Tertiary period. These sequences appear to onlap the crystalline basement highs with variable seismic character. This is most obvious on line HOG-98-01 above the main thrust and where the Early Tertiary section is truncated over the crystalline basement high (Figure 4.12). These sediments are thought most likely to be predominantly siliciclastic. They are associated with rather continuous reflectors, which are more typical of the seismic character associated with lacustrine settings, rather than fluvial settings. In the Kenyan rift, Early Tertiary sediments lie above Karoo sediments, and below Middle Miocene to Recent deposits (Morley, 1995). By analogy, it is reasonable to assume that the sequence overlying the Karoo in the Albertine Graben, which appears broadly similar on the seismic profiles to that in the Kenyan Rift, is of Early Tertiary age. A series of reverse and thrust faults cut the Basement, Karoo and Early Tertiary, but are terminated by the unconformity marked by the Magenta Reflection. The Basement was thrust upwards, possibly causing erosion of the thrust sediments that formed a marked angular unconformity. The Basement was juxtaposed against the sediments and the Early Tertiary sediments were deposited basinward. Delta sequences are seen to prograde and retrograde in this section with channel incisions into the deltas.

Sediments interpreted to be of Karoo age were mapped below the Early Tertiary basin fill. This section onlaps the basement. These sediments formed under continental conditions and were filled with fluvial sediments. Since possible Jurassic age rocks were intercepted in the Butiaba Waki-1 well drilled on the margins of Albertine Graben, their presence here is quite likely. Although the Karoo sediments are not developed at the outcrop in the Semliki Basin, they are seen in the outcrop on the shores of Lake Victoria, farther southeast, and further to the south in the western arm of the East African Rift. Karoo sediments are developed in a rift setting on the west side of Lake Tanganyika. By analogy with the sediments developed in the Lake Tanganyika area, any sediments developed in a Karoo Basin in the Albertine Graben are likely to be predominantly siliciclastic continental deposits.

The Early Tertiary and older section is cut by a series of predominantly reversed faults testifying to a pre-rift compressional phase. These faults do not penetrate into the rift section, but act as the sites of propagation for the stems of north-northeast trending flower structures, which are prominent on dip-oriented sections. The presence of flower structures, which have been active throughout Late Tertiary rifting to the present day, confirms that the area lies at the site of a lateral transfer zone that offsets the rift.

5.5 DEPOSITIONAL HISTORY OF THE SEMLIKI BASIN

The depositional history and/or stratigraphic succession of the Semliki Basin were described with the aid of the various facies, beginning with the oldest and ending with the youngest. This is based on data from wells (wireline logs and lithologs), outcrops and seismic profiles.

The sequence of description highlights the nature of the sedimentary record in the Semliki Basin. Its stratigraphic record demonstrates that sediments of the Permo-Triassic Karoo Supergroup lie at the base, progressively overlain by Tertiary fluvial-lacustrine and deltaic deposits towards the top.

Stratigraphic interpretation of the seismic data from Semliki Basin has led to the reconstruction of the depositional history of the Basin. An interpretation of seismic lines HOG 98-01 and HOG 98-05 shows deltaic sequences occasionally cut by fluvial channel sequences, also affected by rift and thrust tectonics. Figure 4.14 (Chapter 4) shows the interpretation of line HOG-98-01 for depositional history of the Semliki Basin.

The Basement rocks crop out over much of Uganda, these are predominantly high-grade metamorphic and igneous rocks of Pre-Cambrian age. Extension during the Carboniferous led to the development of a series of predominantly north or northeast trending grabens. These formed under continental conditions and were filled with fluvial and alluvial sediments (possibly of the Karoo Supergroup).

A sharp boundary was mapped at the base of the Early Tertiary sediments. The Basement was thrust upwards, possibly causing erosion of the thrust sediments that formed a marked angular unconformity. The Basement was juxtaposed against the sediments and then the Early Tertiary sediments were deposited basinward. These sediments are suggested to be predominantly siliciclastic, associated with rather continuous reflectors that are more typical of the seismic character associated with lacustrine settings rather than fluvial settings. These sequences onlap the Pre-Cambrian Basement highs. Delta sequences are seen to prograde and retrograde in this section with channel incisions into the deltas.

Formation of the main rift shoulders and rapid/increased subsidence of the rift caused extremely rapid sedimentation/deposition of the later stratal packages. These filled the graben with continental and lacustrine sediments, possibly in a more tectonically relaxed environment. In common with rift basins, the area in the vicinity of the transfer zone, receives a much higher proportion of coarse siliciclastic sediments. Sands are funnelled into the basin along fault valleys at times of greater seismic activity. At times of lower seismic activity, or in periods of greater subsidence, away from the transfer zone, lacustrine conditions would be more widespread.

From well and outcrop data, the stratigraphic record reveals fluvial sediments of the Kisegi Formation at the base, progressively overlain by fluvial-lacustrine deposits at the top. Block diagrams have been used, in this case, to demonstrate the depositional sequences of the basin. Interpretation of wireline logs indicates that the base of Turaco 2 well is dominated by fluvial channel-fill sequences that display classic fining-upward sequences. These fining-upward cycles were interpreted from gamma ray and sonic logs. Block 1 (Figure 5.1) represents a reconstruction of the depositional environment during this time. The sediments of the Kisegi Formation have been attributed to this kind of environment in which the sequences display fining-upward sequences with conglomeratic lags at their bases, as observed from outcrop. This was mainly observed at the base and in the middle parts of the formation.

This was followed by a period of flooding in the fluvial plain with distributary channel, crevasse splay, and overbank facies deposited (Block 2, Figure 5.2). This led to the deposition of fine silts and clays on the bank near the stream edge. Such sequences have been encountered within the Kisegi Formation, where sands are developed in thin lenses with interbeds of well-bedded gypsiferous silt and clay beds.

Block I

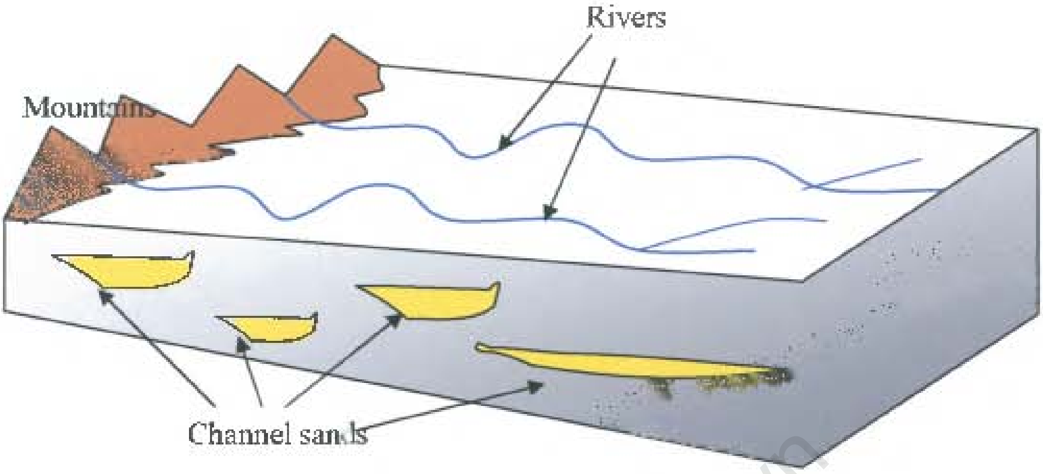


Figure 5.1. Block diagram illustrating the meandering rivers and the related sediments of the Kisegi Formation.

Block 2

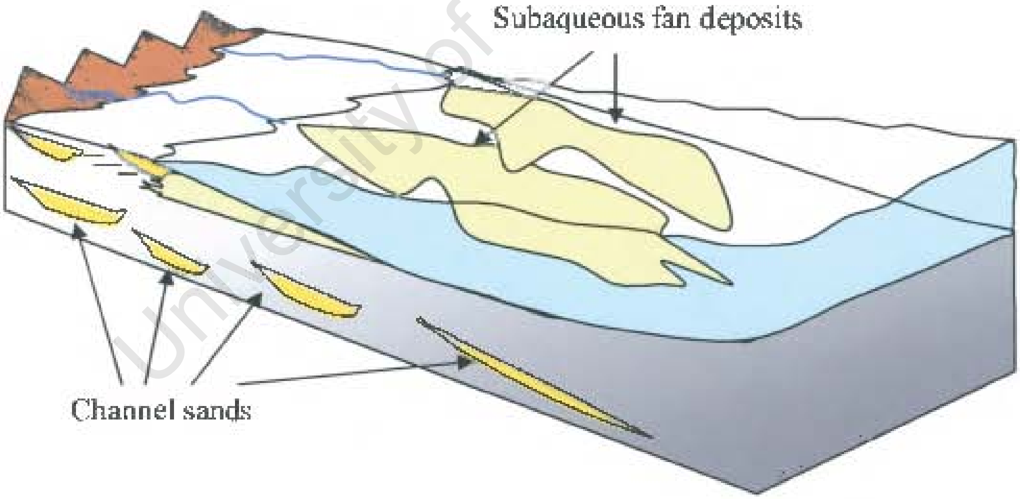


Figure 5.2. Block diagram illustrating the flooding of meandering rivers and the related sediments of the Kisegi Formation.

During or towards the end of this phase, there could have been possible faulting or possible fault reactivation, causing generation of a slope, which led to basinward progradation of more siliciclastic sediments and, further on, generation of a shallow lacustrine system. This movement along the fault continued slowly and generated a deep lacustrine system until such a point when the slope was steep enough to generate gravity flow deposits (Block 3, Figure 5.3).

Block 3

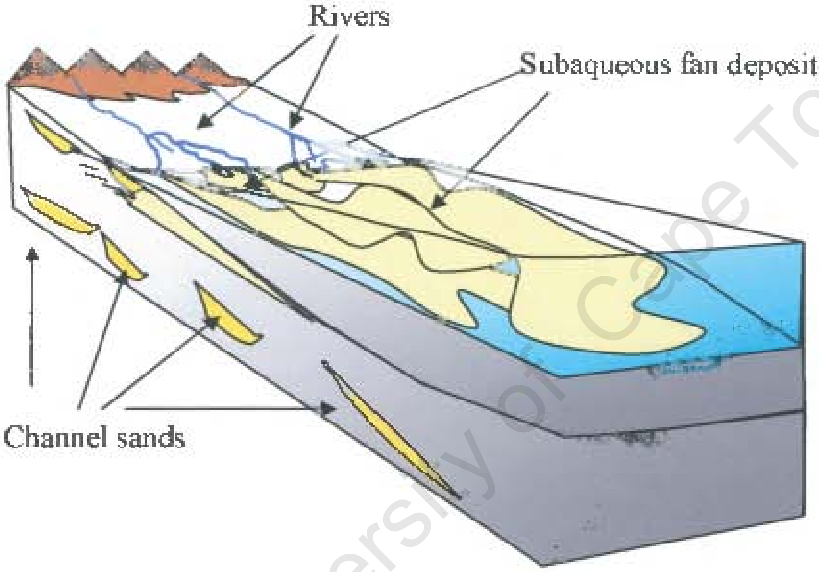


Figure 5.3. Block diagram illustrating depositional enviroment of the sediments in the Semliki Basin.

The next phase of deposition represents a rather stable fluvial lacustrine/delta environment with variations in the energy of both the fluvial and lacustrine systems. This is shown by the progradational, aggradational and retrogradational gamma-ray signatures and corresponds to the younger formations from the Kasande Formation up to the Nyabusosi Formation. These progradational packages occur as several parasequence sets and are marked by flooding surfaces at the top of each of the parasequences. However, where the trends are distorted, the surfaces occur as erosive and may represent sequence boundaries or localized erosional surfaces. To differentiate the two erosional surfaces would require more landward review of the stratigraphy to verifiy lateral extent of these surfaces. One distinct surface is the one that represents the contact between the Kisegi sandstone and the Kasande mudstone formation. This contact is not gradational and since it is an abrupt change from sandstones to mudstones, it may represent a regional hiatus or the most landward migration of a condensed section, the top of which would then be a likely maximum flooding surface.

Block 3 (Figure 5.3) therefore, represents the depositional environment of all the younger formations in the basin. The sediments of the Kasande Formation are composed of muddy sequences with only thin and isolated sandstone units, typical of a lacustrine environment. The Kakara Formation along with the overlying Oluka, Nyaburogo, Nyakabingo, Nyabusosi and Kabukanga formations, are made up of predominantly lacustrine mudstones/claystones and subordinate lake-margin sandstones and turbidites.

The uplift of the Rwenzori block, in very recent times, is likely to have hampered the continuation of the depositional pattern, thus leading to the deposition of the more proximal, coarse siliciclastic material. This is borne out by the younger sediments in outcrop, which consist almost exclusively of coarser-grained siliciclastic sediments.

5.6 STRATIGRAPHIC DIVISION OF THE SEMLIKI BASIN.

The stratigraphy of the Semliki Basin has been divided into a number of formations. In relation to the age relationships of strata and succession of beds, Pickford *et al.* (1987 and 1994) divided the sedimentary rocks of the Semliki Formation into seven formations. These were based on the geometry and degree of consolidation, fossil content and radiometric dating of surface outcrops. The seven formations are in decreasing age, the Kisegi, Kasande, Kakara, Oluka, Nyaburogo, Nyakabingo and Nyabusosi formations. Two other formations, the Kabukanga and Rwamabare formations, mapped during fieldwork, had not been mapped before and could not be associated with any of the already existing formations without palaeontological or chemostratigraphic definition.

During this study, data (surface geological mapping, seismic, wireline and well cuttings) have been analysed, interpreted and integrated. The following observations were made in relation to the startigraphy of the Semliki Basin.

Reflections were picked from seismic data based on seismic attributes. The Red Reflection was assigned to the top of basement and is clearly seen across the whole survey as a strong reflection. The Gold Reflection was assigned to the base of the Tertiary basin fill. The Magenta Reflection, which is a high-amplitude doublet event, continuous across the survey, was assigned to the base of Kisegi Formation. The Blue Reflection was assigned to the Top Kisegi/Base Kasande Formation. Most of the other reflections above the Kisegi Formation are cyclic and therefore repeated reflections were picked. These reflections correspond to high-amplitude events in the most faulted part of the sections, possibly representing a strike-slip fault-induced flower structure. Most of the sediments above the Magenta Reflection were interpreted to have been deposited in a fluvio-deltaic/lacustrine environment, based on the reflection character.

Stratigraphic interpretation of wireline logs reveals a rather stable fluvial lacustrine delta environment with variations in the energy of both the fluvial and lacustrine systems. This is shown by the progradational, aggradational and retrogradational gamma ray signatures. Apart from one distinct surface recognised at the contact between the Kisegi and the Kasande formation, other flooding surfaces at the top of each of the parasequences are distorted. They occur as erosive and may represent sequence boundaries or localized erosional surfaces. The Kakara Formation along with the overlying Oluka, Nyaburogo, Nyakabingo, Nyabusosi and Kabukanga formations, are made up of predominantly lacustrine mudstones/claystones and subordinate lake-margin sandstones and turbidites.

In the view of the writer, therefore, the stratigraphy of the Semliki Basin is over divided. The younger formations (Kakara to Nyabusosi) can be regarded as a single sedimentary unit, in which there is some evidence for cyclicity, from fluvial sands at the bases of the sequences, through lake-margin and ephemeral lake sandstones, silts and clays, to 'permanent' lake conditions dominated by clays. Although these formations have been separated, they span a period of only five million years and would be regarded as a single formation.

5.7 PETROLEUM POTENTIAL

In petroleum exploration, an essential objective is the evaluation of the hydrocarbon potential of a basin (Link, 1982). This requires the determination of the quality, thickness and lateral extent (volume) of the different facies that represent the source rocks in which hydrocarbons will be generated, reservoir rocks in which hydrocarbons will accumulate by migration from the source rocks, and cap rocks which will constitute impermeable traps avoiding/precluding any migration of the hydrocarbon from the reservoirs.

The elements for a successful hydrocarbon play are present in the Semliki Basin. This is based on the analysis, interpretation and integration of all the surface geological mapping data, petrographic data, seismic data and well data. Three basic elements of hydrocarbon plays: source, reservoir and seal were examined in relation to the nature of the basin fill.

Geophysical data interpretation suggests a thickness of sedimentary section varying from 4-6km in the deeper parts of the section. Surface geological mapping has revealed a Tertiary section of Middle Miocene to Recent in the Semliki Basin. This stratigraphy has been supported by the results from interpretation of seismic data and well logs.

5.7.1 Source Rocks

Active oil seeps have been identified along the basin margins, where Basement rocks are in contact with a thick sedimentary pile in the Albertine Graben. The Kibuku seep demonstrates that oil is being generated in this part of the Semliki Basin and in the absence of any mapped volcanic rocks in the area suggests a regionally mature source rock, rather than oil derived from local heating. Work by Morgan (1983) has shown that although heatflows are generally low in the East African Rifts (30mW/m^2), that these increase in the areas where the rifts are offset by transfer zones. In these positions, the heatflow may increase to more than 100mW/m^2. If this type of heatflow is present in the Albertine Graben transfer zone, it is possible that much of the shale-prone Miocene section in the area may be mature and capable of expelling oil.

From surface geological mapping and well-log interpretation there are clearly potential source rocks in the Semliki Basin. It was found out that most of the formations are argillaceous, apart from the Kisegi Formation. Potential source rocks were interpreted at several levels in the Turaco wells, particularly in the Oluka and Kasande formations (Turaco 1&2 composite logs-Appendix 4). Some of these may be mature downdip. If this is true, it is possible that during diagenesis, because of compaction, the oil would be squeezed into the underlying reservoir. The Kasande Formation in outcrop appears to be weathered lake-highstand claystones and siltstones, having a very low sand content. This formation mapped directly on top of the Kisegi Formation comprises more than 30m of claystone in outcrop. This, in particular may be a viable source for the underlying Kisegi sands, where it is mature downdip of the Turaco area.

The Butiaba Waki-1 Well penetrated more than 200m of shale, described as bituminous and reported to have a total organic carbon content of 6%, interbedded with sands stained with asphaltic oil. This shale underlies substantial sand thought to be equivalent to the Kisegi Formation (African and European Investment Company, 1938). Although the age of this shale is unknown, it has been correlated with the Late Jurassic Stanleyville Formation of the Cuvette Central in the Democratic Republic of Congo. However, geochemical studies, carried out by Hall (1998) on samples from the oil seeps point to a fluvio-lacustrine origin, which tends to support the Tertiary age for this section, as the Jurassic age would be expected to have marine affinities. This shale may well be responsible for sourcing the oil at the Kibiro seep. If this shale is present basin-wide, then it may also be responsible for sourcing the oil at the Kibuku seep in the Semliki Basin.

5.7.2 Reservoir Rocks

Potential reservoir rocks were encountered in the syn-rift phase in the Semliki Basin. These sandstones consist of medium-to coarse-grained siliciclastics of the Kisegi, Nyaburogo and Kakara Formations. Petrographic and petrophysical studies from selected samples from the Semliki Basin found that the porosities in sandstones are excellent and, in the clean sands, are typically in the range of 28-36%, though typically in the low 20 percents in the shalier sands (Heritage Oil and Gas Limited, 2002). They are Basement-derived, based on their detrital mineralogy from petrographic studies.

The Kisegi Formation sandstone, which crops out in the Kaiso Nsolya River Valley, has been estimated to be over 200m thick. Petrographically, the sands are quartzo-feldspathic and are moderately mature in respect of their textural and chemical characteristics. The sandstones are mainly composed of quartz and smaller percentages of feldspars and therefore, the permeability may not be greatly affected by diagenetic breakdown of feldspars. Analyses have shown high helium porosities from 36.2-39% and excellent permeablility (Heritage Oil and Gas Limited, 2002). These sandstones were encountered in the subsurface in the borehole (Turaco-2) at a depth of 2555-2962m and they seem to retain good reservoir characteristics. A few sandstone samples of the Kisegi Formation contain volcanic-derived materials and clay minerals, which may lead to reduced porosity upon diagenetic alteration. This may, downgrade the reservoir quality.

The sandstones of the Nyaburogo and Kakara formations show similar detrital mineralogy and textural characteristics as those of the Kisegi Formation. Analyses have shown helium porosities of 35.7% and 33.0% for Nyaburogo and Kakara sandstones, respectively (Heritage Oil and Gas Limited, 2002).

The detrital mineralogy of these sandstones is consistent with derivation from a granitic/gneissose basement, or a high-grade metamorphic sedimentary source, owing to the predominance of quartz mineralogy and presence of rock fragments that are typical of a granitic or gneissose origin. The moderate textural and chemical maturity suggests either significant distances of transport within fluvial systems for the sand to have been winnowed, such that it is a clean and well sorted. The relatively high quartz content and only moderate content of feldspars and lithics implies the likelihood of good reservoir quality.

5.7.3 Traps and Seals

Seals to the reservoir rocks impact the hydrocarbon prospectivity of any sedimentary basin (Morley *et al.*, 1999). A thicker and more laterally consistent seal is required. As is typical of rift basins, the Semliki Basin has relatively rapid facies changes, common in fluvial, deltaic and lacustrine sediments, which provide the potential for stratigraphic traps. Sandstones interbedded with impermeable lacustrine sediments (claystones) and sandstones overlain by fine-grained lacustrine sequences are present.

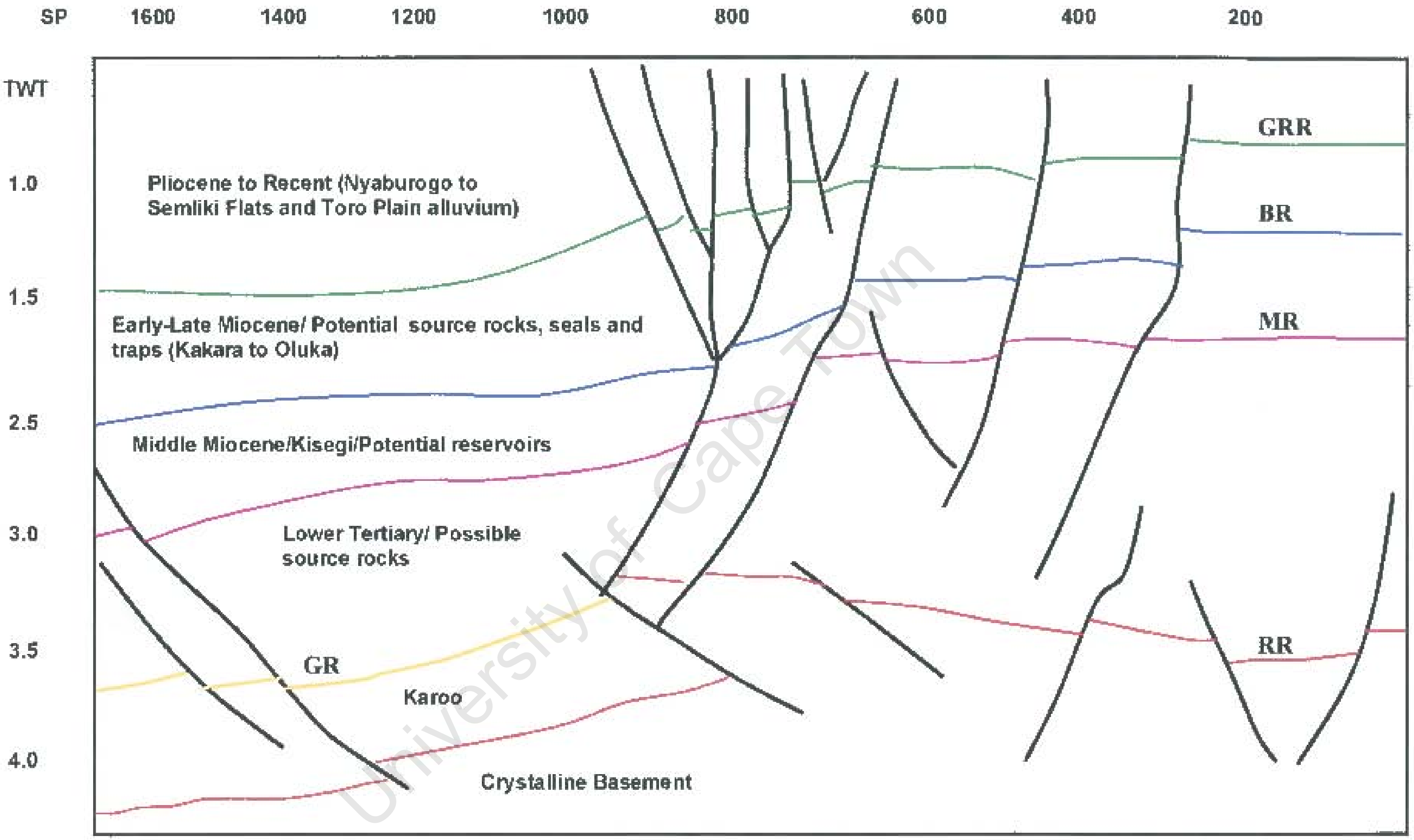
Sedimentary sequences mapped in outcrop show strong cyclicity of depositional patterns that represent coarsening-upward (regressive) and fining-upward (transgressive) cycles of deposition. Cyclicity is important, because during transgression, fine sediments are deposited and these, when interbedded with coarser material, could provide good seals and traps at depth. Relatively rapid facies changes common in alluvial fan, deltaic and lacustrine sediments provide the potential for stratigraphic traps with or without structural traps. Unconformities mapped at both outcrop and in seismic data in the sedimentary sections of the Semliki Basin also provide for stratigraphic, or combined strati-structural traps. Since most of the formations in the Semliki Basin are clay prone, these could be potential top seals for the proposed reservoirs. The Kasande Formation mapped directly on top of the Kisegi Formation comprises a more than 30m thick claystone and could be a potential regional seal.

Different structures have been delineated from seismic-data interpretation. These could act as good traps to the hydrocarbons. These include tilted fault blocks, horsts, hanging-wall anticlines and inversion features associated with faults. For example, when a fault juxtaposes a permeable reservoir against an up-dip impermeable layer, a lateral seal and trap may be provided for the reservoir. In a sedimentary section, composed of alternating layers of reservoirs and seals, the probability that a reservoir is trapped across a fault by a sealing layer depends on the relative proportions of reservoir to seal within a fault-affected section. More sub-parallel faults increase the probability of lateral sealing of the reservoir.

5.7.4 Migration pathways

Surface geological mapping and seismic data interpretation have led to identification of hydrocarbon migration pathways in the Semliki Basin. Steep-dipping structures, fault systems associated with multiple and jointed faults and unconformities have been identified from seismic data. Seismic lines HOG-98-01 and HOG 2001-01 (Figures 4.12 and 4.14) display such fault systems. These may be responsible for oil migration from the kitchen areas towards the structurally up-dip areas. Lateral and vertically trending steep fault systems may act as hydrocarbon migration pathways. All these have been identified from the data.

All in all, the study has shown that the sediments in the Semliki Basin have potential for hydrocarbon accumulations. Through fieldwork it was possible to see that there is excellent potential for reservoirs, regional top seals and circumstantial evidence for regionally mature source rocks. Interpretation of seismic data has led to identification of possible seals, traps and hydrocarbon migration pathways. Faults and unconformities, mapped in the upper sections may act as traps and migration pathways. A schematic cross-section of the Semliki Basin representing all the potential hydrocarbon plays is thus presented in Figure 5.4. This was based on the integration of surface geology, well data and seismic data on seismic line HOG-98-05.



Sp= shot point, TWT= Two-way time, RR=Red Reflector, GR=Gold Reflector, MR=Magenta Reflector, BR=Blue Reflector, GRR=Green Reflector.

Figure 5.4. Schematic cross-section of the Semliki Basin based on seismic line 98-05.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The study has allowed a better understanding of the stratigraphic relationship of the different rock units that are exposed on outcrop, encountered in the wells and interpreted from reflection seismic data only. Therefore, the stratigraphy of the Semliki Basin has been described, based on lithological data from surface outcrop, seismic and well data.

Seven formations have been described, based on outcrop and well data, and these have been tied with seismic data. Surface outcrops are comprised of Middle Miocene to Recent section and these were also mapped on seismic data. The sediments dated from outcrop studies are Middle Miocene to Recent, although it is possible that some of the sediments as old as Jurassic or Permo-Triassic may be present in the basin. This is inferred from interpretation and analysis of seismic data and extrapolation from other basins in the rift. .

Well and outcrop data record that siliciclastic sedimentation is dominant in the Semliki Basin, although minor carbonates and volcaniclastic sediments are present. The Middle Miocene to Recent section of the Semliki Basin is dominated by sandy fluvio-deltaic deposits and /or lacustrine deposits. The sediments of the area comprise a sandy lower sequence of the Kisegi Formation, which is overlain by a primarily muddy sequence with only thin and isolated sand units. These have been separated, mainly by previous workers, into a series of formations namely; Kasande, Kakara, Oluka, Nyaburogo, Nyakabingo, and Nyabusosi formations, based on minor changes in lithology and fossil content. One new formation, Kabukanga, and one outcrop, Rwamabare (which almost certainly belongs to one of these units) could not be reliably attributed to any of the formations above without palaeontological or chemostratigraphic definition. The Kakara Formation, along with the overlying Oluka, Nyaburogo, Nyakabingo, Nyabusosi and

Kabukanga formations, are all similarly made up of predominantly lacustrine claystones and subordinate lake-margin sandstones. However, these formations can be regarded as a single sedimentary unit in which there is some evidence for cyclicity, from fluvial sandstones at the bases of the sequences, through lake-margin and ephemeral lake sandstones, silts and clays, to 'permanent' lake conditions dominated by clays. Although these formations have been separated, they span a period of only five million years and would normally be regarded as a single formation.

Petrographic analysis of the selected samples collected from the field has shown that sandstone samples from the Semliki Basin are predominantly composed of quartz, potassium feldspars and plagioclases with subordinate clay minerals. Accessory minerals such as micas (biotite and muscovite), minerals such as epidote and garnet are present in minor amounts. The analysis and integration of all these parameters indicate that the sediments have a granitic and gneissose origin related to continental-block provenances.

The X-ray diffraction scans of bulk samples reveal that the mudrocks/claystones are dominated by clay minerals with subordinate quartz, feldspars and calcite. The clay minerals include illite, illite-smectite, kaolinite, montmorillonite, illite-montmorillonite, and mica with mixed layer illite-smectite and illite layers dominating. Although some of the clay may be detrital, evidence of chemical weathering (alteration) is apparent. The abundance of smectite and montimorillonite in the clay-fraction is an indication of alteration of volcanic glass to smectite. Authigenic minerals such as anatase and jarosite recognised in X-ray diffraction of bulk sample are indicators of weathering and oxidation in arid conditions. Secondary precipitates such as calcite and gypsum have also been interpreted to have formed under semi-arid conditions resulting in high rates of evaporation and therefore precipitation of evaporites.

Seismic data from the Semliki Basin revealed a half-graben basin involving the Jurassic or Permo-Triassic to Recent sequences. Reflection character enabled some predictions about sedimentary environments, stratigraphy and lithology to be made from seismic data. In particular, lacustrine sedimentary rocks are characterised by relatively slow seismic velocities, and continuous high-amplitude reflections. On the other hand, fluvio-deltaic sediments tend to have relatively fast velocities, and discontinuous, weak reflections.

In general, the depositional environment of the sediments in the Semliki Basin is fluvial-lacustrine/deltaic showing significant variations in gamma-ray character that reflect the water-level changes and river interactions through the depositional period and the influence of rifting tectonics on sediment deposition through time and space.

The study has shown that the sediments in the Semliki Basin have potential for hydrocarbon accumulations. It was possible to recognize many of the necessary elements to make up a hydrocarbon province. Through fieldwork it was possible to see that there is excellent potential for reservoirs, regional top seals and circumstantial evidence for regionally mature source rocks. Interpretation of seismic data has led to identification of possible seals, traps and hydrocarbon migration pathways. The Semliki Basin is therefore believed to have good potential to be a significant hydrocarbon province, since all the necessary elements of a valid petroleum system are present in the basin.

6.2 RECOMMENDATIONS

Based on the data that were interpreted and analysed in this study, a number of problems/difficulties were experienced. Most of these were as a result of insufficient data available from the study area. These include the following:

Lack of detailed surface geological mapping data of the entire basin that includes detailed palaeontological and chemostratigraphic analysis to better divide the formations in the basin based on fossil content, lithology and age.

Lack of enough wells to help in the correlation of well stratigraphy. Only Turaco 1&2 wells, which are more or less one well, are available in the Semliki Basin. The stratigraphy of these two wells could not be correlated since the Turaco 2 well is a sidetrack of the Turaco1 well. The few variations in the lithological patterns of these wells may be due to deviations in the angle of drilling and missing out of laterally inextensive sequences among others. This hampered the confidence with which outcrop and well data were correlated.

Lack of three-dimensional (3D) seismic data from the basin. This is very important, because it helps to visualise the picture of the basin better and to carry out interpretations based on good-quality data.

In relation to the above, a few recommendations have been suggested for further research in the Semliki Basin.

- Acquisition and interpretation of three-dimensional (3D) seismic data from the basin is required to help visualise better the structure and depositional setting of the basin.

- There is a need for the detailed surface geological mapping of the entire basin that will include detailed palaeontological and chemostratigraphic analysis to better characterise the sediments in the basin.

- More wells in the Semliki Basin and/or the Albertine Graben are required in order to help in the correlation of outcrop, well and seismic data with greater degree of confidence.

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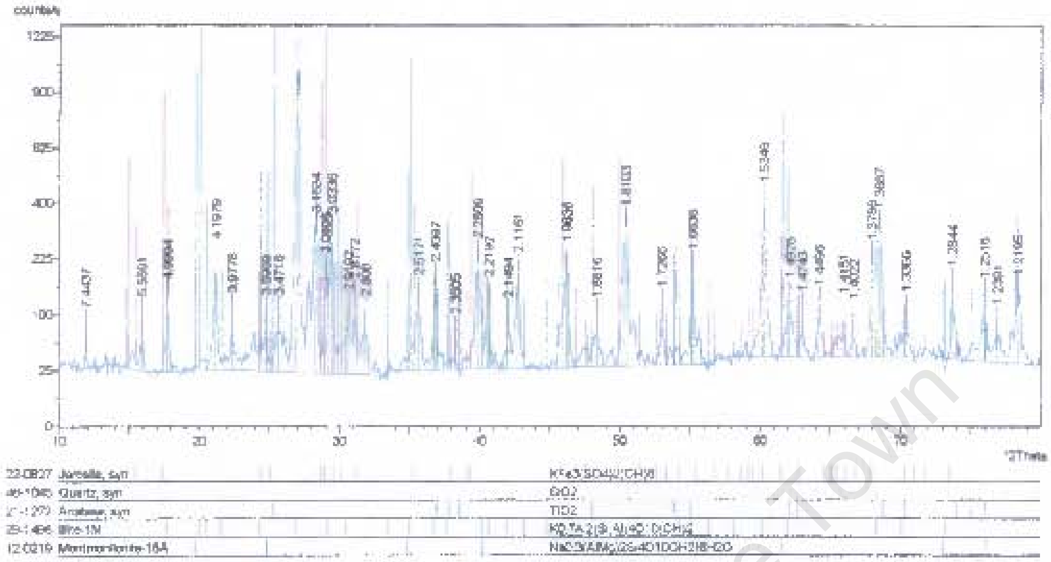
APPENDICES

APPENDIX 1: GPS locations of the station points

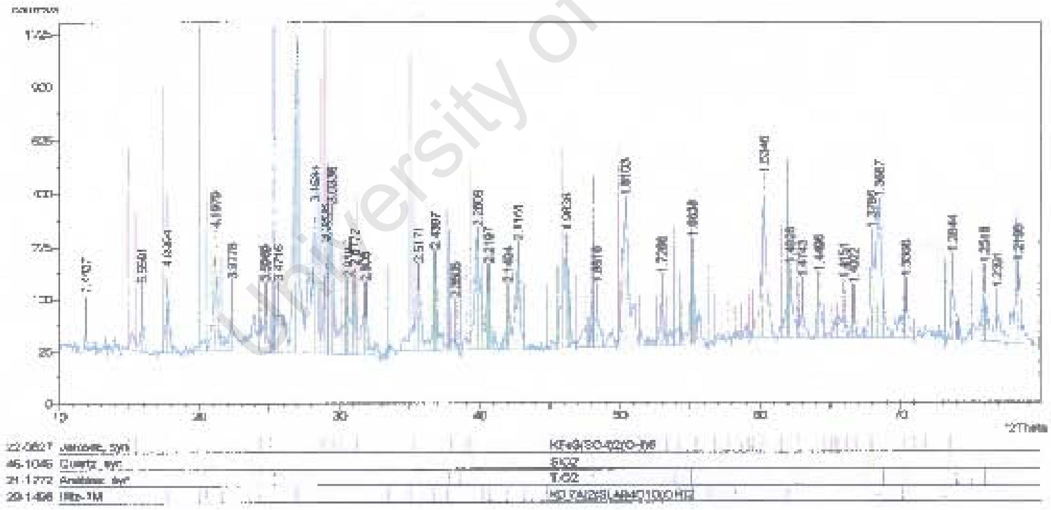
Station No	Latitude (Easting)	Longitude (Northing)	Altitude (m amsl)
1	192685	0101 942	574
2	192357	0101761	568
3	227989	0115421	605
4	191703	0112685	630
5	191387	0116465	636
6	191945	0118586	626
7	193041	0121476	623
8	193952	0125060	604
9	192907	0102008	594
10	192841	0101919	1202
11	230105	0114769	612
12	231274	0113202	619
13	231424	0111056	934
14	203484	0113417	707
15	200396	0111596	619
16	201699	0111432	641
17	201247	0110139	669
18	193116	0102225	737
19	193182	0101851	790
20	187099	0099962	681
21	189234	0001273	623
22	200707	0109355	760
23	200516	0108631	692
24	200267	0108444	653

25	197801	0103621	825
26	199675	0104576	662
27	197249	0098754	797
28	199712	0000098	912
29	196734	0097450	800
30	196803	0096745	831
31	197088	0094454	789
32	196232	0092627	864
33	196245	0091137	1027
34	195494	0090660	924
35	197243	0098895	856
36	198512	0103580	824
37	198079	0104404	710
38	197521	0102520	765
39	194658	0104138	724
40	196125	0101908	629
41	193940	0105418	697
42	196278	0103697	754
43	195797	0115857	648

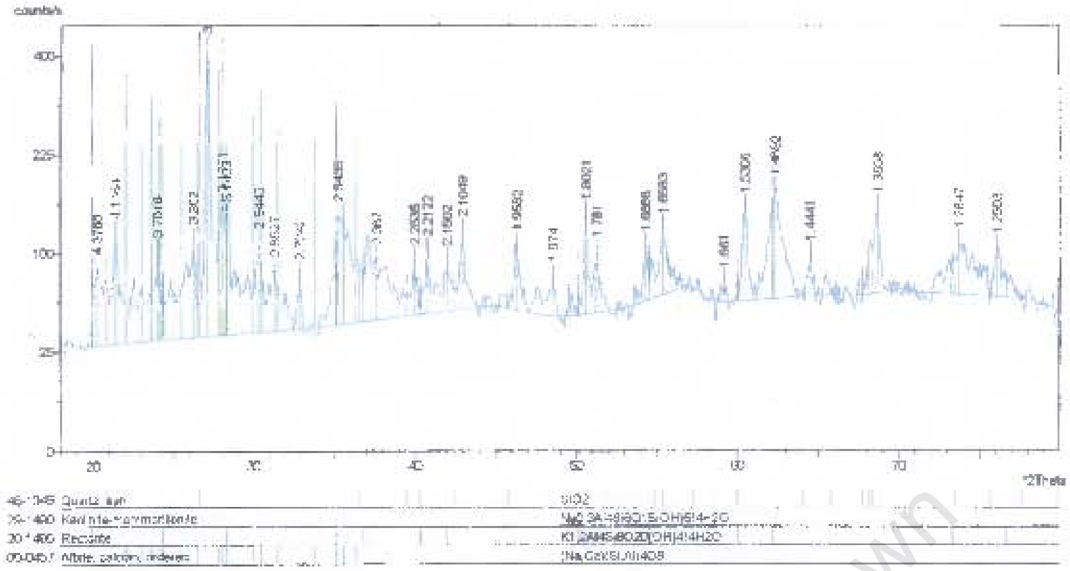
APPENDIX 2: XRD profiles



XRD profile of sample K1



XRD profile of sample K2



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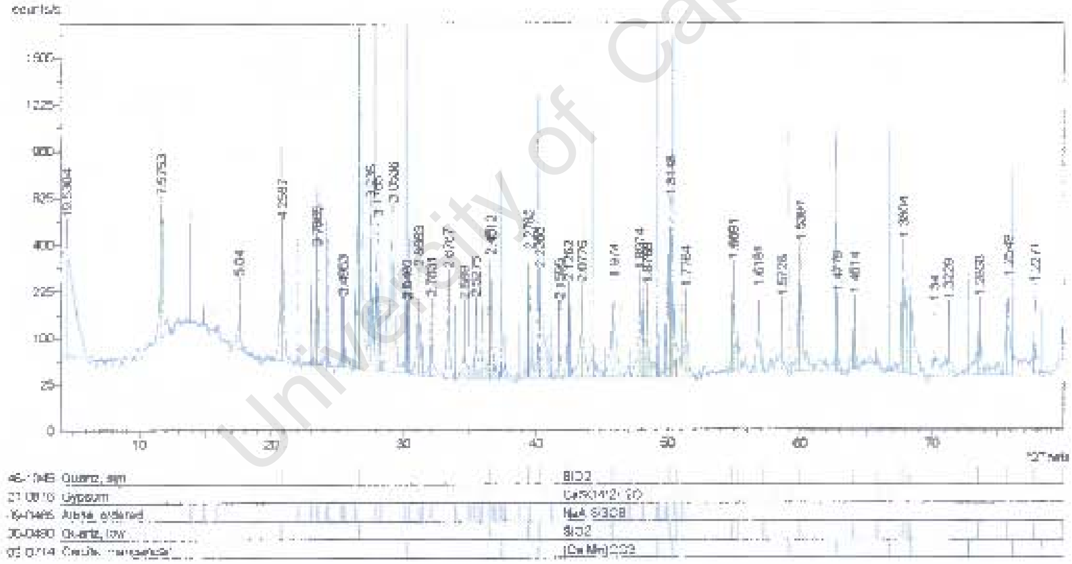
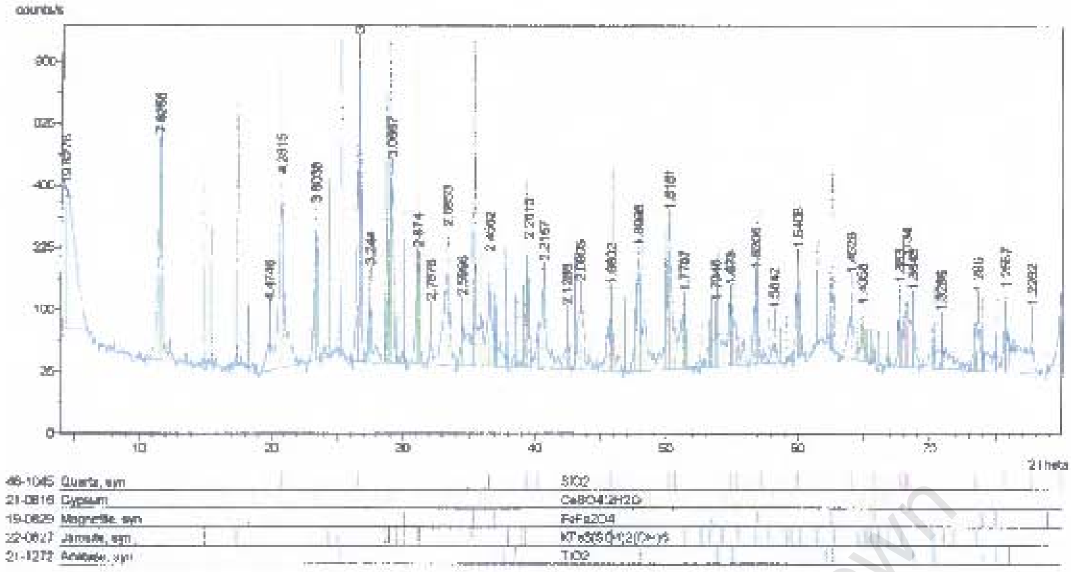


XRD profile of sample K4



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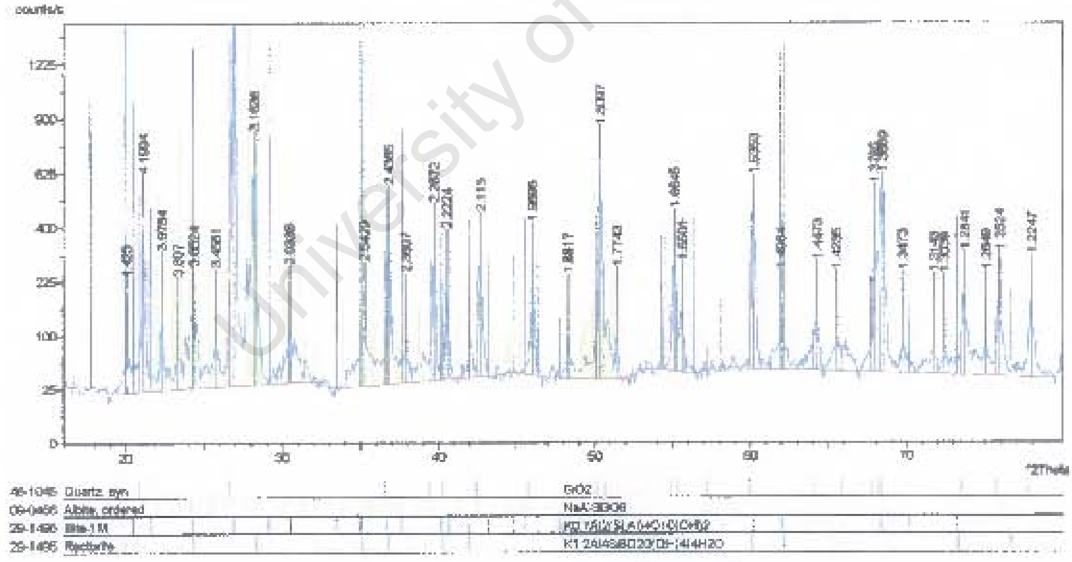
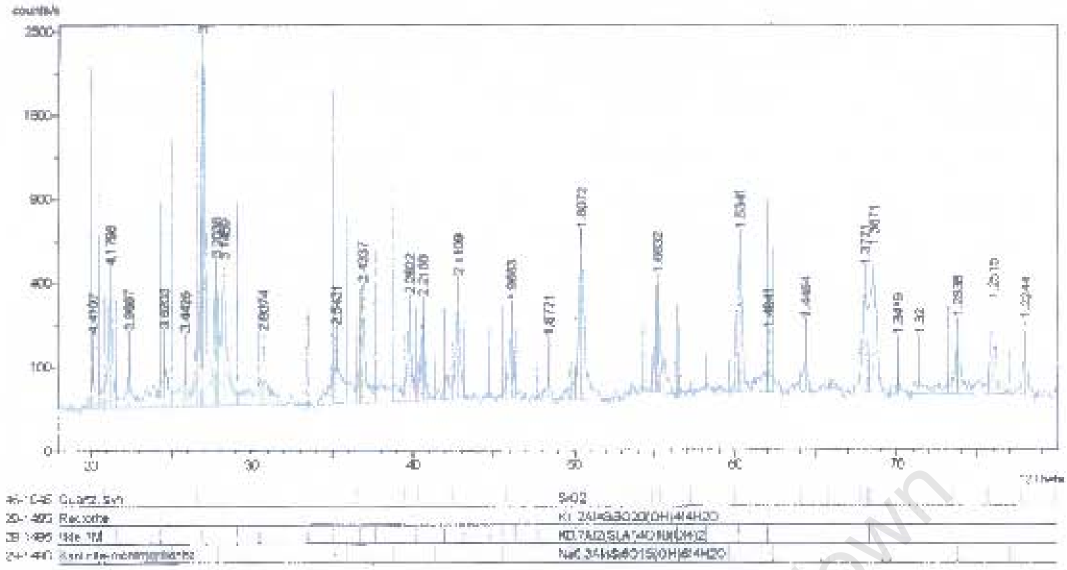
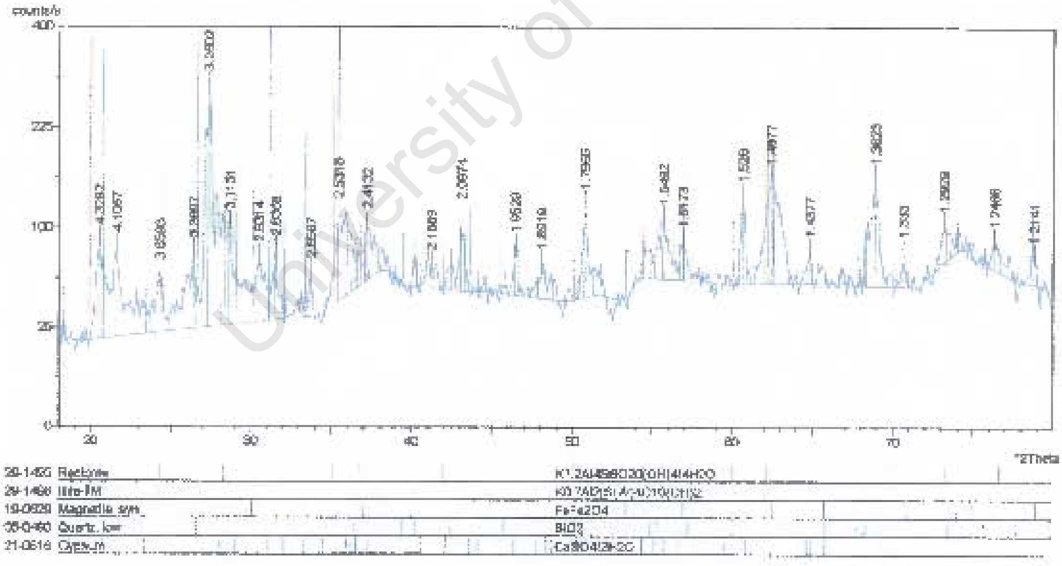


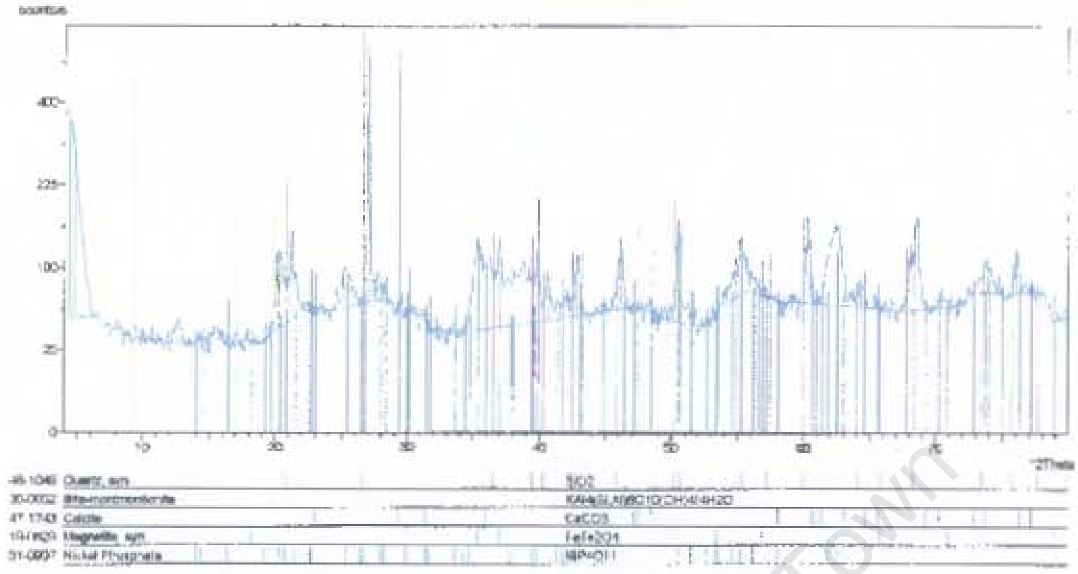
XRD profile of sample K6



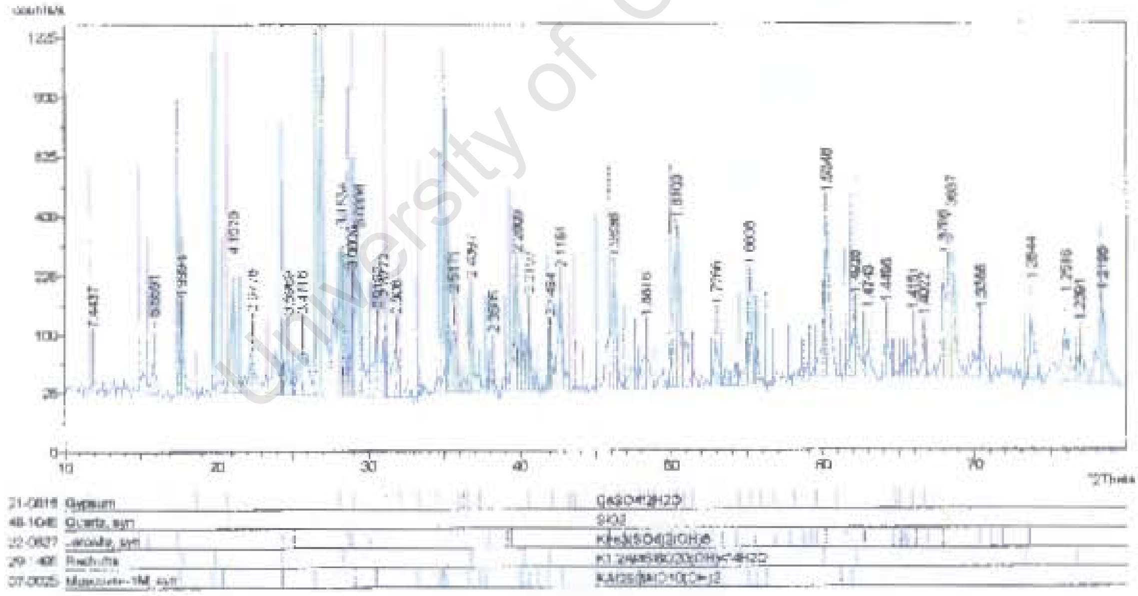
XRD profile of sample KK1



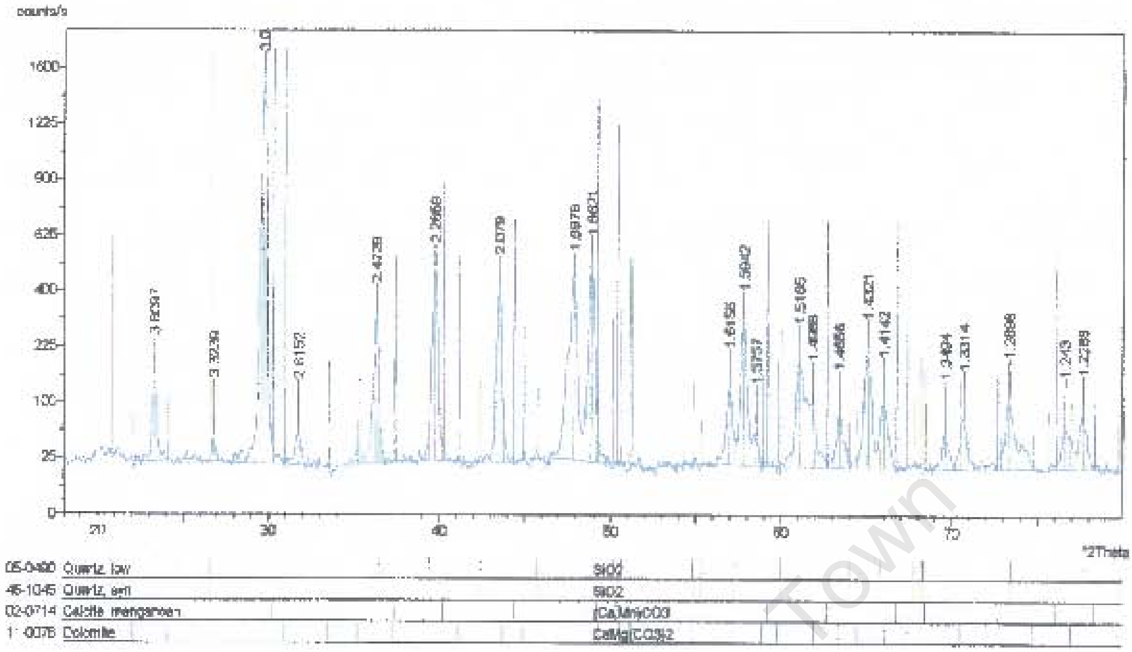
XRD profile of sample O2



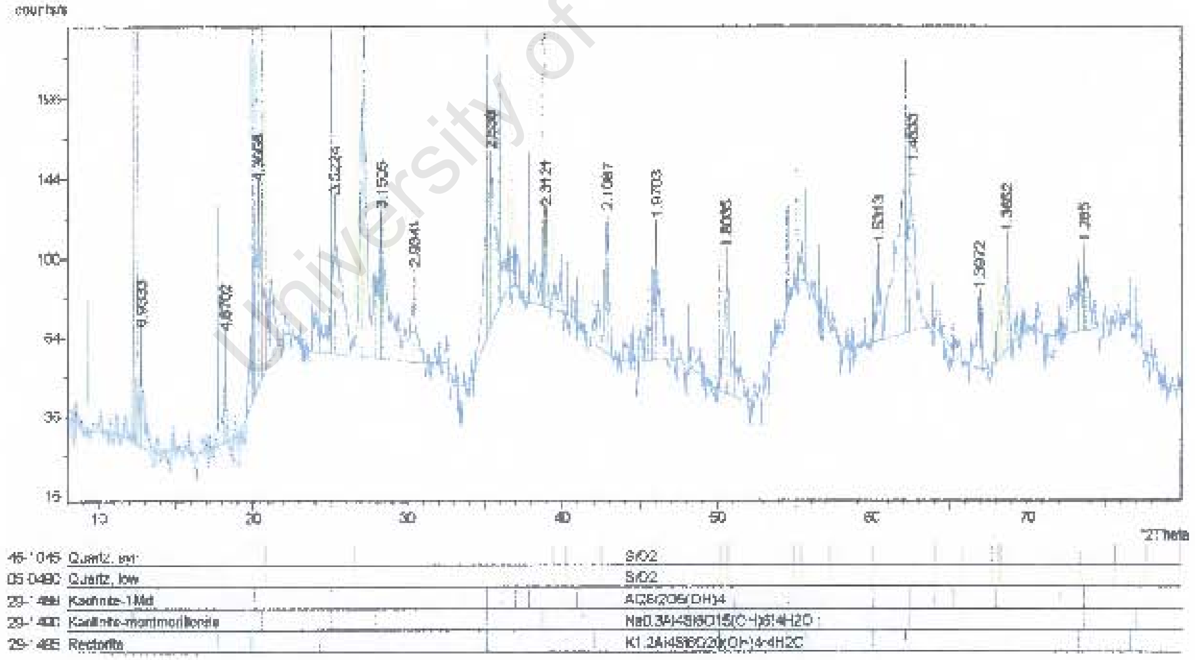
XRD profile of sample O3



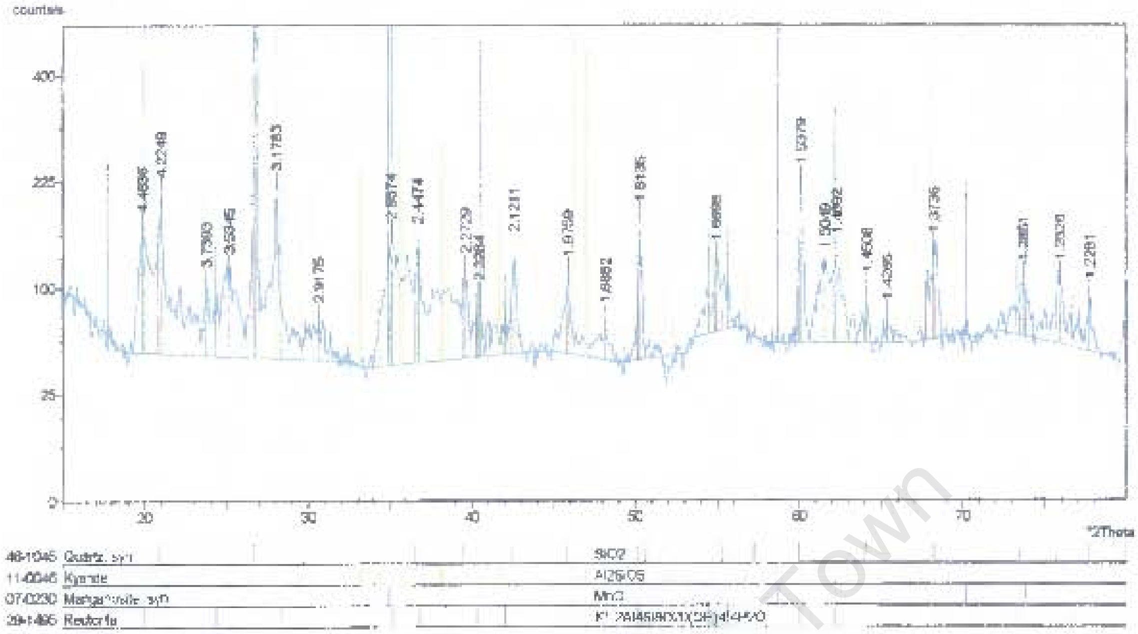
XRD profile of sample Nybr 1



XRD profile of sample Ny1



XRD profile of sample Ka1



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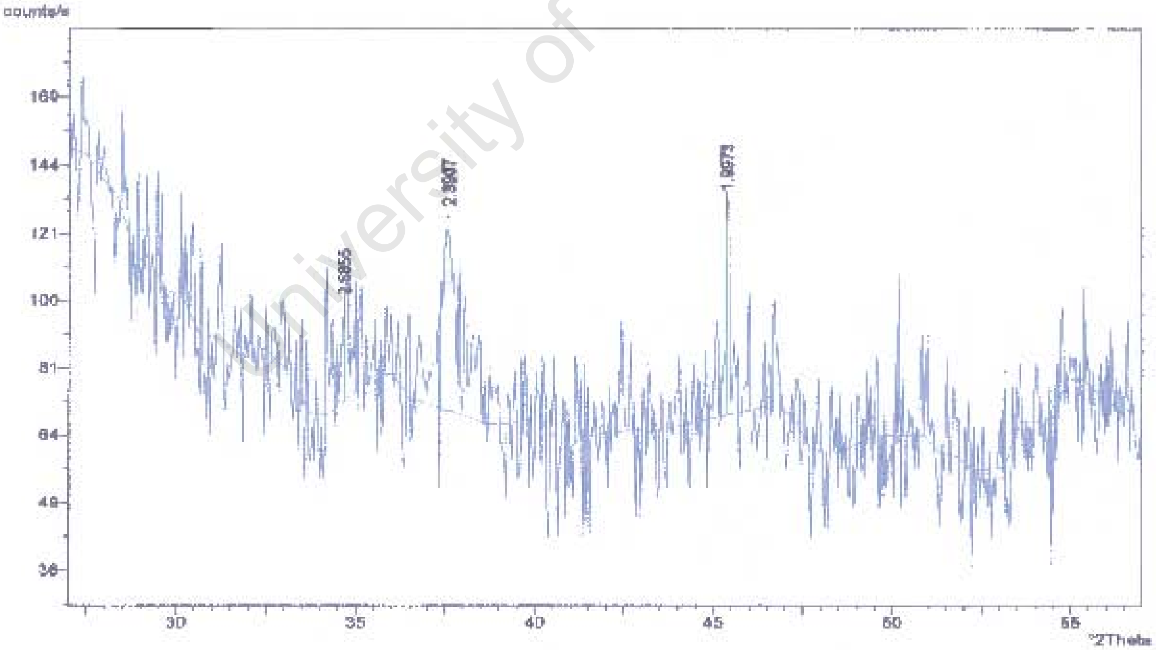
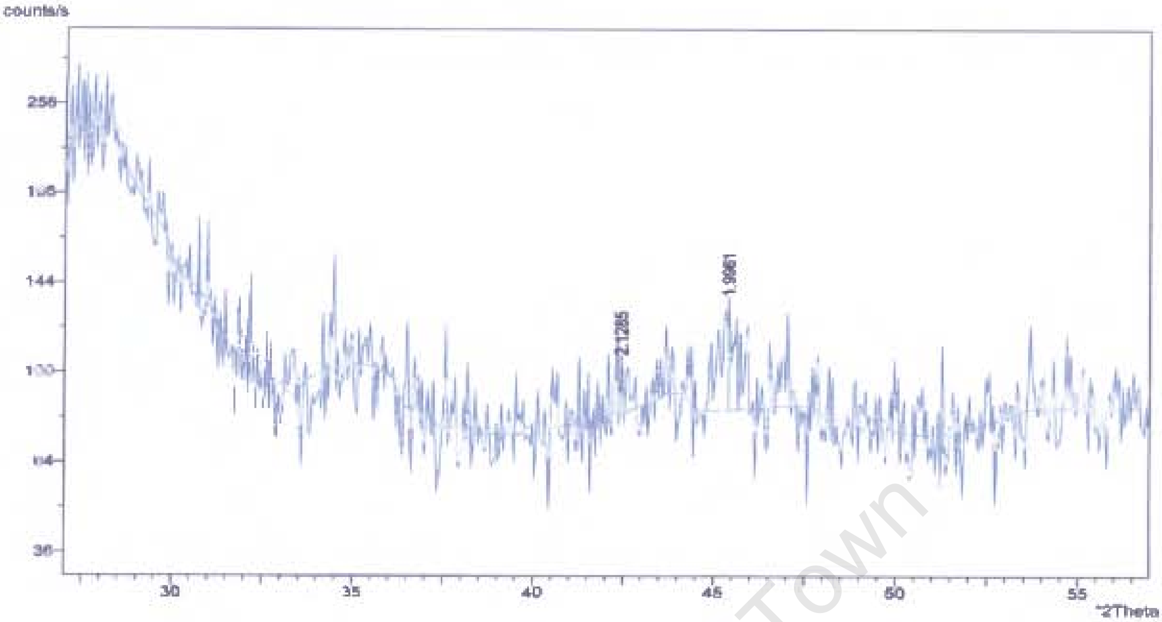


XRD profile for the <2μ size of sample K2



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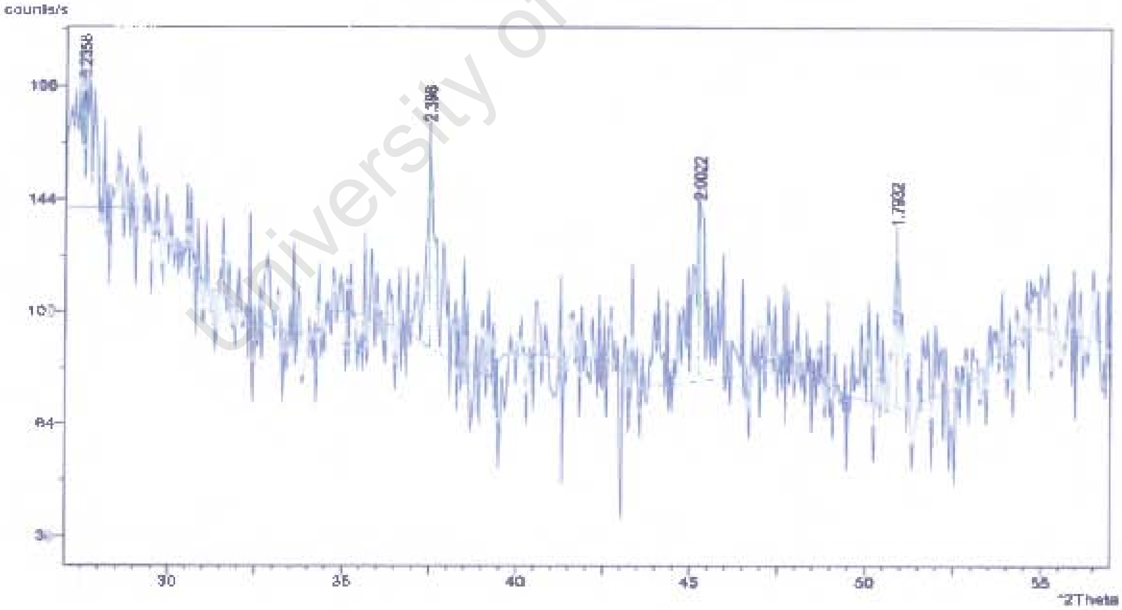
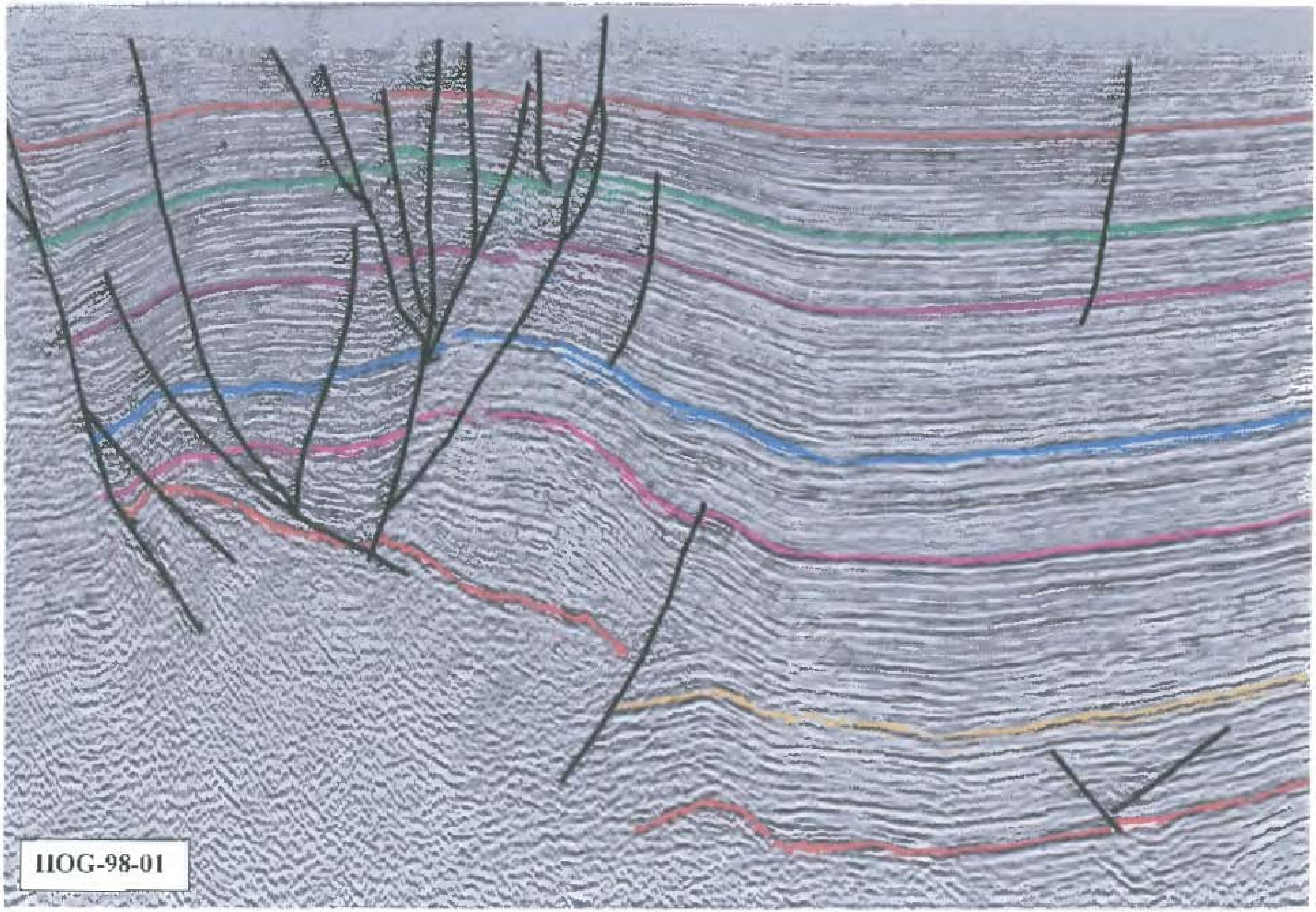


XRD profile for the <2μ size of sample Ka2

APPENDIX 3: Interpreted seismic sections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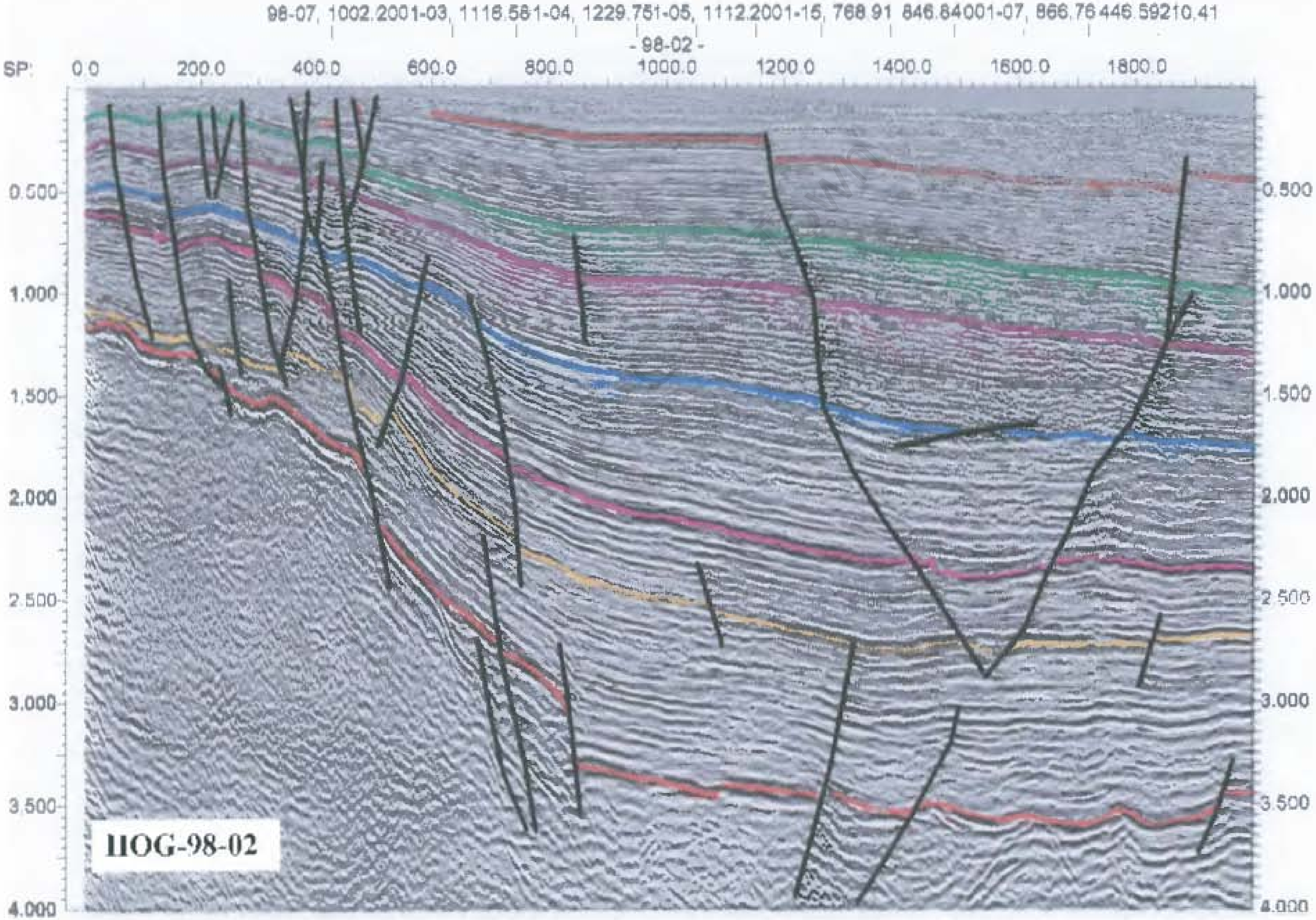
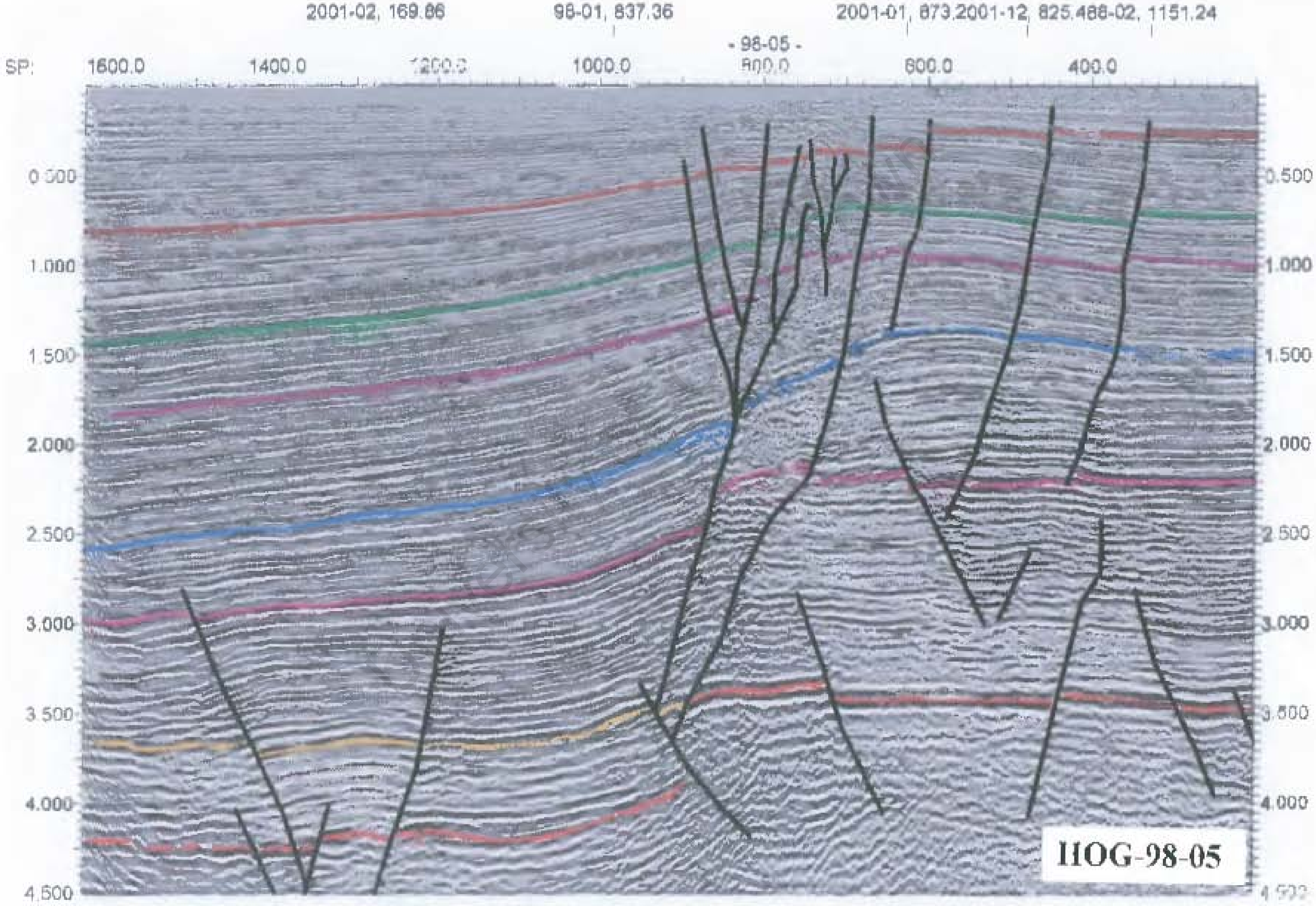

98-07, 1002.2001-03, 1116.581-04, 1229.751-05, 1112.2001-15, 768.91 846.84001-07, 866.76 446.59210.41
- 98-02 -
SP:
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
1800.0
0.500
1.000
1.500
2.000
2.500
3.000
3.500
4.000
IIOG-98-02


2001-02, 169.86
98-01, 837.36
2001-01, 873.2001-12, 825.488-02, 1151.24
- 98-05 -
SP:
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
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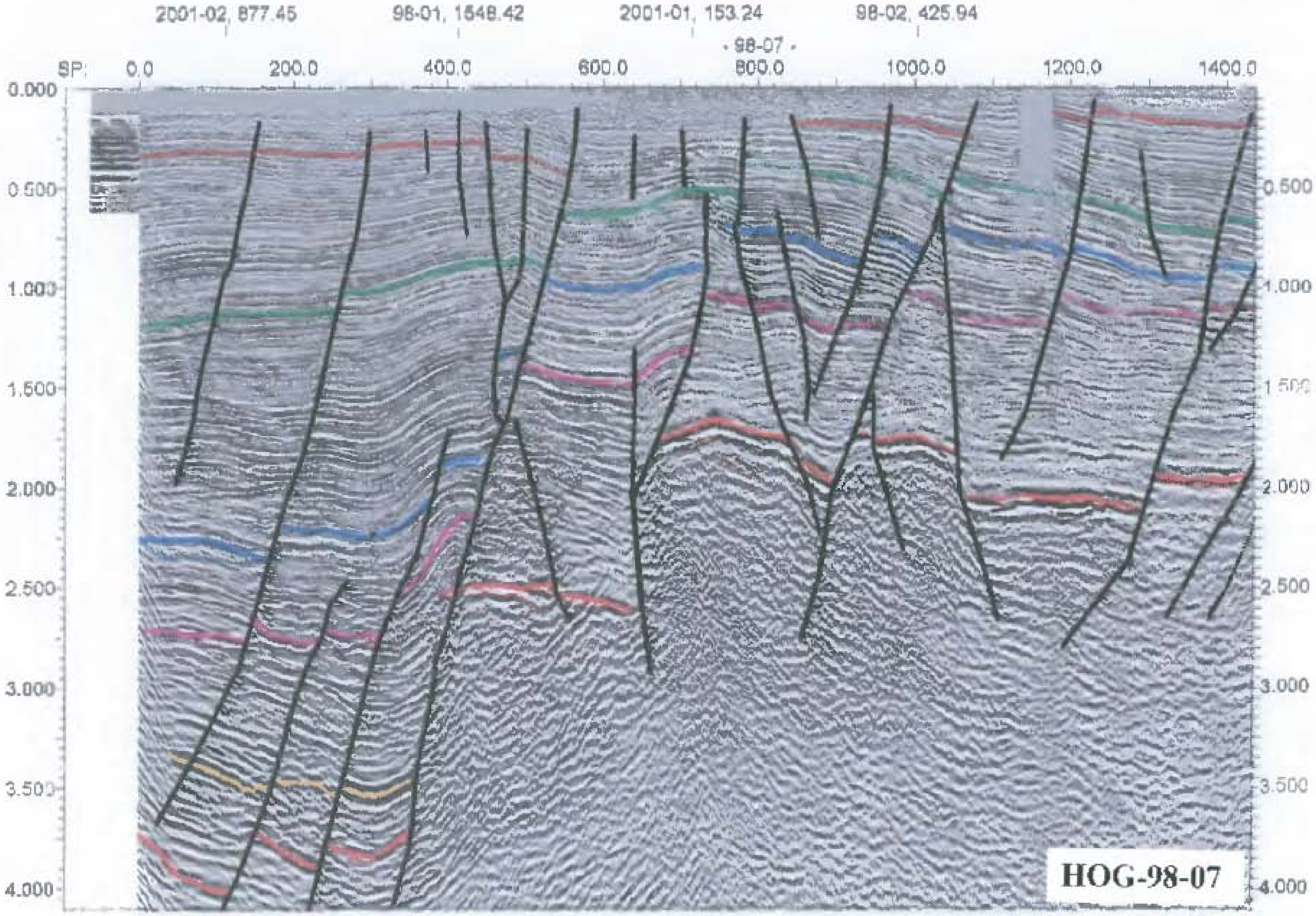
1.000
1.500
2.000
2.500
3.000
3.500
4.000
4.500
HOG-98-05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98-01, 1548.42
2001-01, 153.24
98-02, 425.94
98-07
SP:
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
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0.500
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1.500
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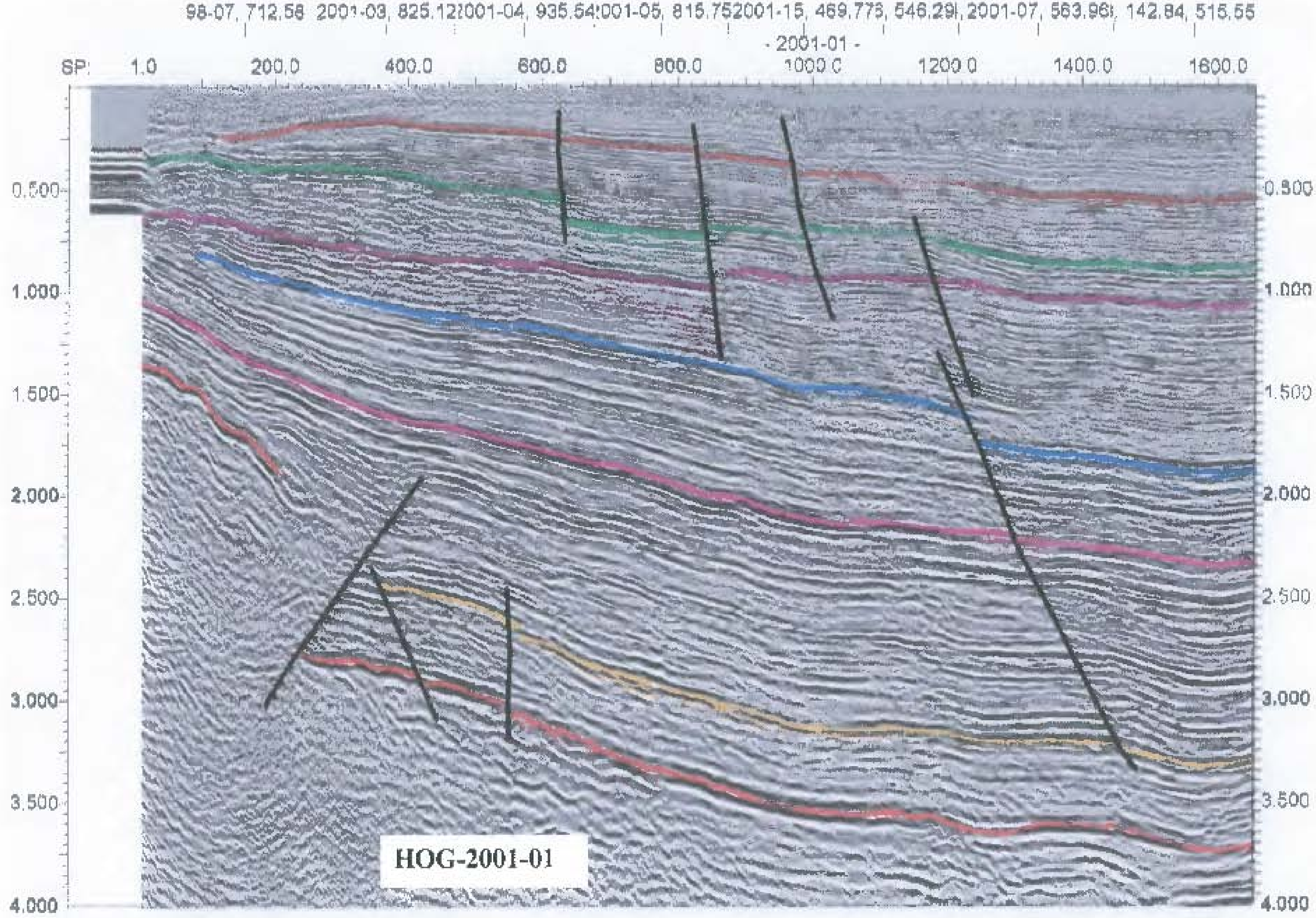
2.500
3.000
3.500
4.000
HOG-98-07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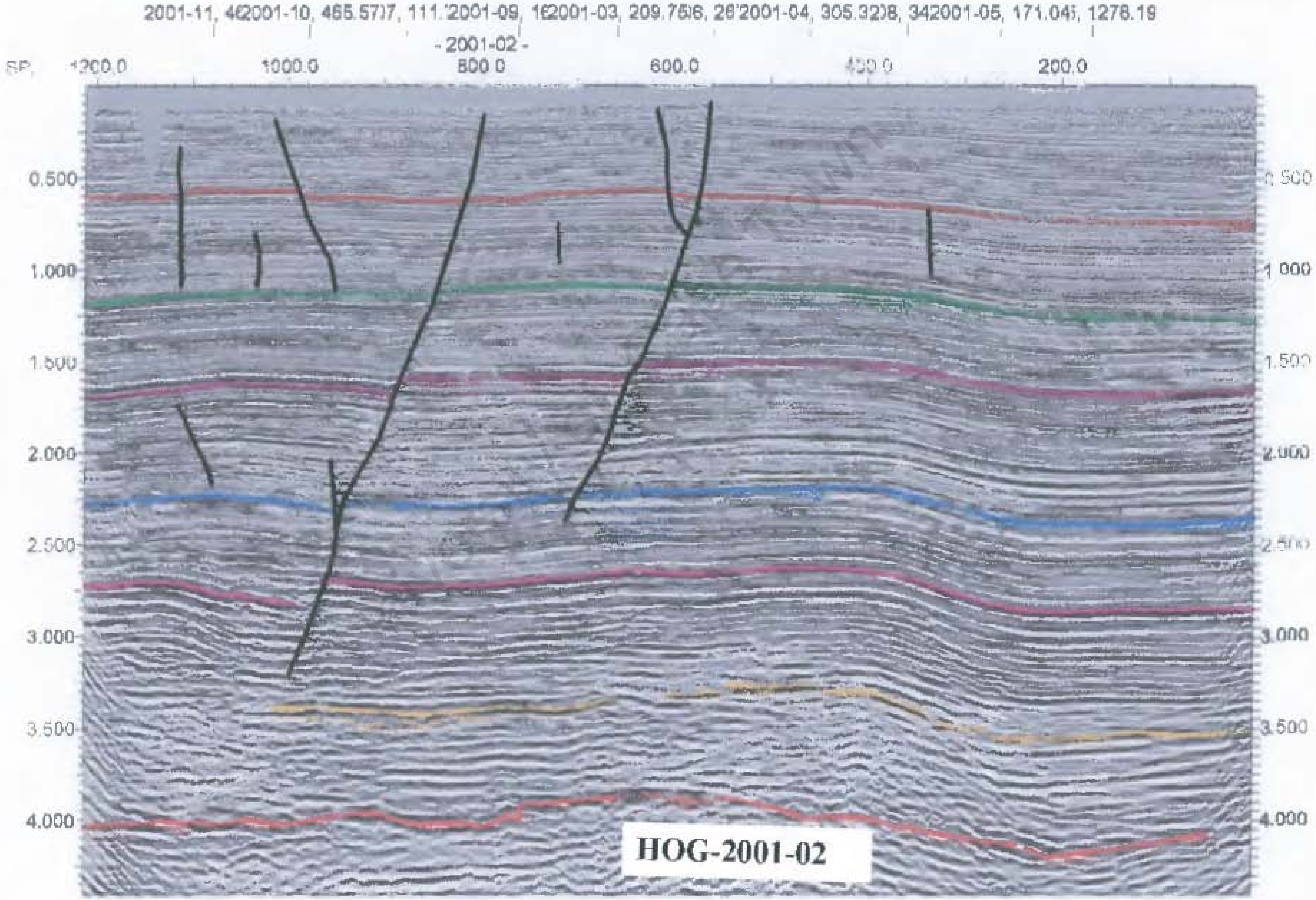
2001-03, 825.12
2001-04, 935.54
2001-05, 815.75
2001-15, 469.77
546.29
2001-07, 563.96
142.84, 515.55
- 2001-01 -
SP: 1.0
200.0
400.0
600.0
800.0
1000.0
1200.0
1400.0
1600.0
0.500
1.000
1.500
2.000
2.500
3.000
3.500
4.000
HOG-2001-01


2001-11, 4€2001-10, 465.57)7, 111.'2001-09, 1€2001-03, 209.75l6, 26'2001-04, 305.32)8, 342001-05, 171.04l, 1278.19
- 2001-02 -
SP, 1200.0
1000.0
800.0
600.0
400.0
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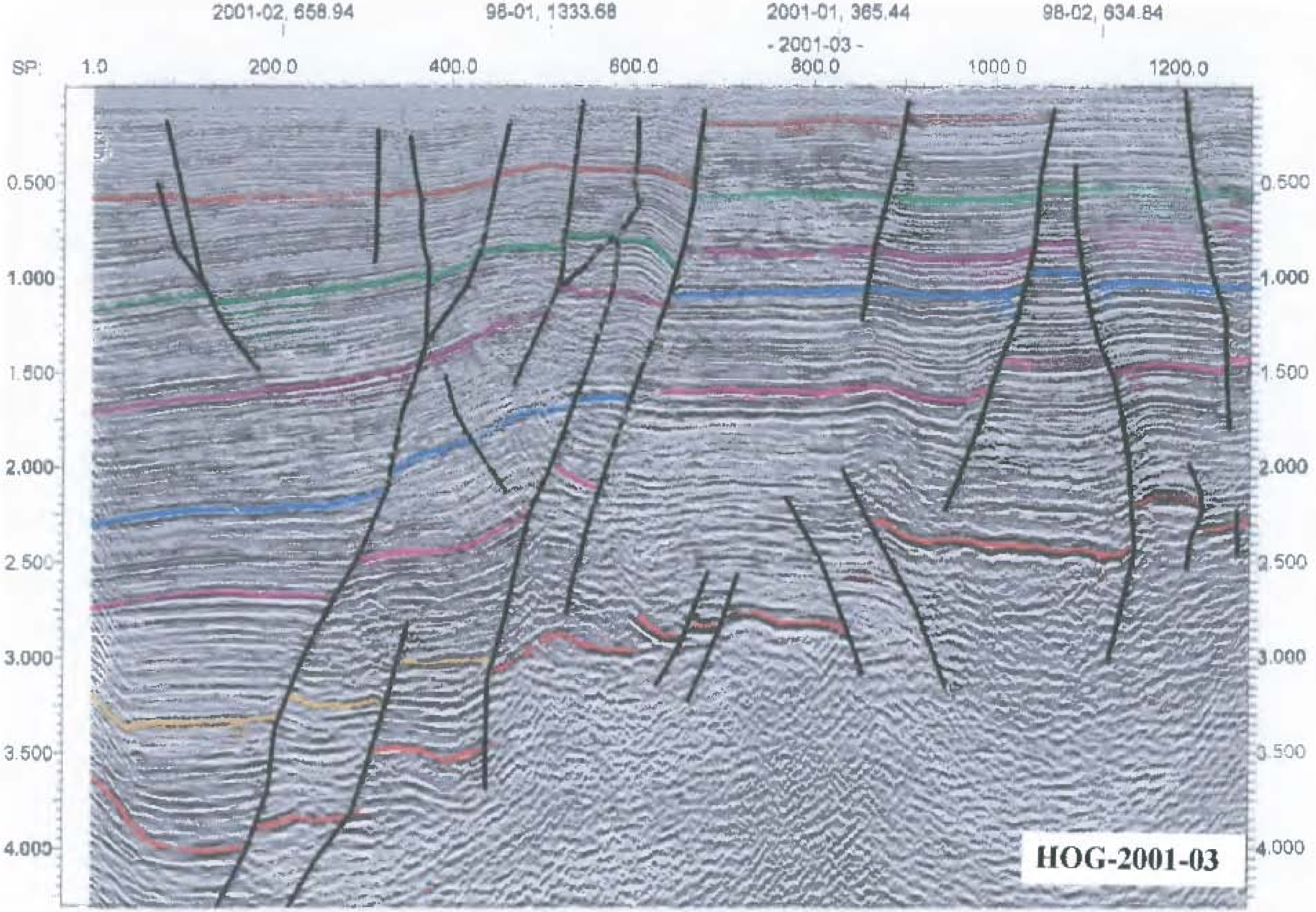
1.000
1.500
2.000
2.500
3.000
3.500
4.000
HOG-2001-02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98-01, 1333.68
2001-01, 365.44
- 2001-03 -
98-02, 634.84
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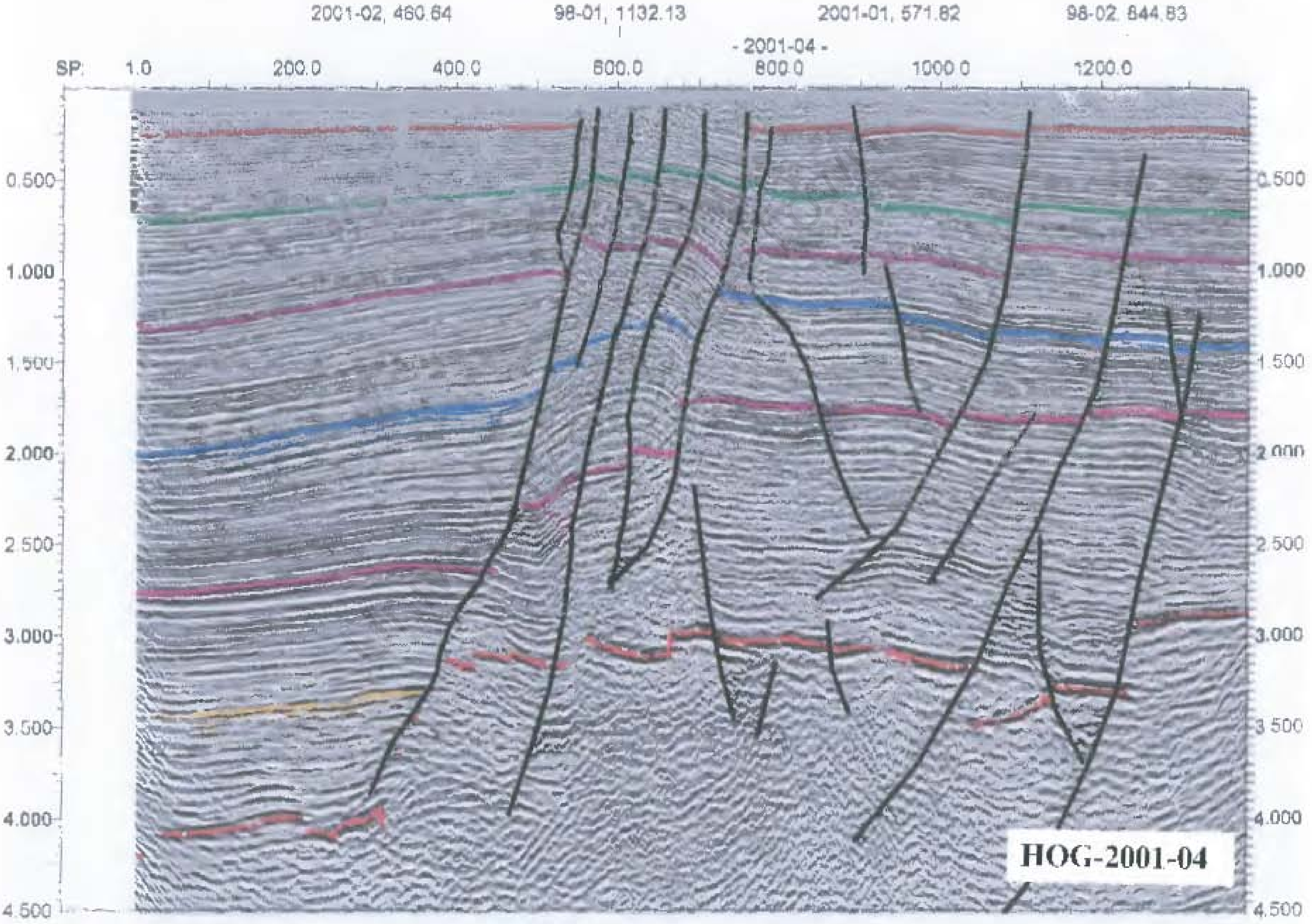
3.000
3.500
4.000
HOG-2001-03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98-01, 1132.13
2001-01, 571.82
98-02, 844.83
- 2001-04 -
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400.0
600.0
800.0
1000.0
1200.0
0.500
1.000
1.500
2.000
2.500
3.000
3.500
4.000
4.500
HOG-2001-04

APPENDIX 4: Composite well logs for Turaco 1&2

HERITAGE

ENCLOSURE 2

TURACO # 1

COMPOSITE WELL LOG

SCALE: 1:500

LOCATION	
COUNTRY:	UGANDA
AREA:	ALBERT GRABEN
LICENCE:	BLOCK 3
CO-ORDINATES	
LATITUDE:	1° 01' 41.2 (WGS84)
LONGITUDE:	30° 18' 08.4"
U.T.M. X:	199,754 (WGS84)
U.T.M. Y:	113,763

WELL CLASSIFICATION: Oil & gas shows

COMPLETION STATUS: Suspended

RIG ON LOCATION:	17/07/02
WELL SPUDDED:	17/08/02
SUSPENDED:	27/01/03
RE-ENTERED:	
T.D. REACHED:	08/12/02
WELL COMPLETED:	
RIG RELEASED:	31/01/03

R.T. ELEVATION:	639m
WATER DEPTH:	N/A
GROUND ELEVATION:	633m

TOTAL DEPTH

DRILLER: Not logged to TD

LOGGER: 2487.7m

FORMATION AT T.D.: Kasande?

RIG NAME:	SD-3000
CONTRACTORS	
DRILLING:	Eagle Drill
LOGGING:	Reeves Wireline
MUDLOGGING:	Dafora Mudlogging
LWD:	N/A
BIOSTRATIGRAPHY:	

WELLSITE GEOLOGISTS	COMPANY
Bob Downie	Heritage Oil & Gas
Paul Burden	Energy Africa
Nigel Castle	Stag Geological Services

LOG COMPILED BY	
Nigel Castle	Bob Downie

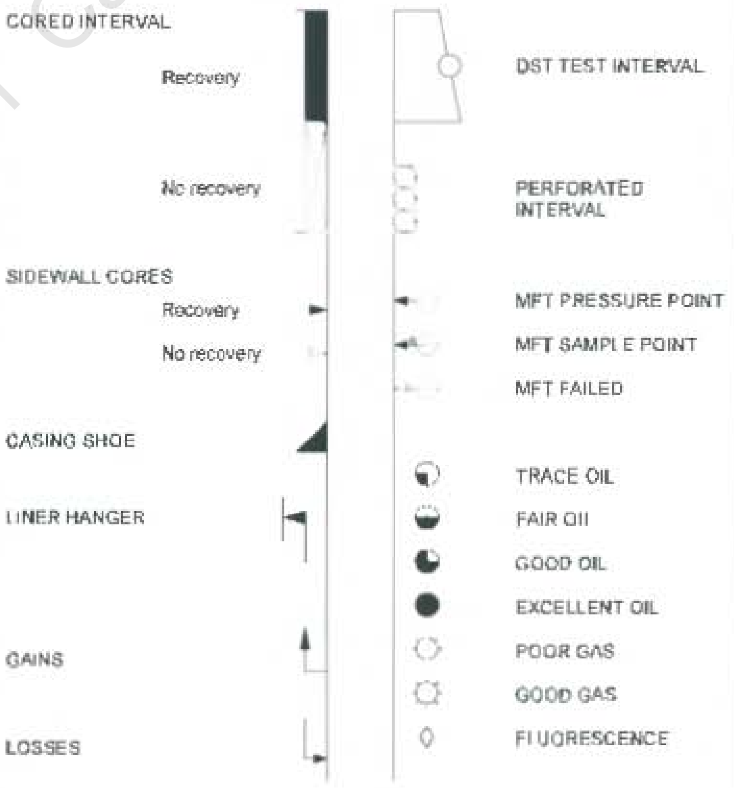
LITHOLOGY

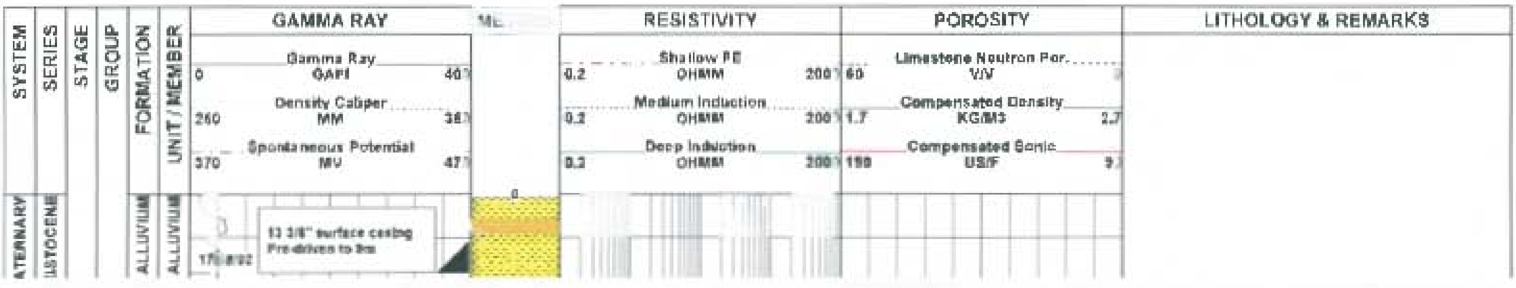
Conglomerate or Breccia	🟧
Sand or Sandstone	🟨
Sandstone Argillaceous	🟧
Silt or Siltstone	🟫
Mudstone, Clay or Shale	🟫
Limestone	🟦
Limestone Argillaceous	🟦
Dolomite	🟦
Chert or Flint	▨
Coal or Lignite	⬛
Halite	▦
Potassium K Salt	▩
Anhydrite or Gypsum	🟪
Tuff	🟪
Volcanic Igneous	🟪
Intrusive Igneous	🟥
Undifferentiated Igneous	🟥

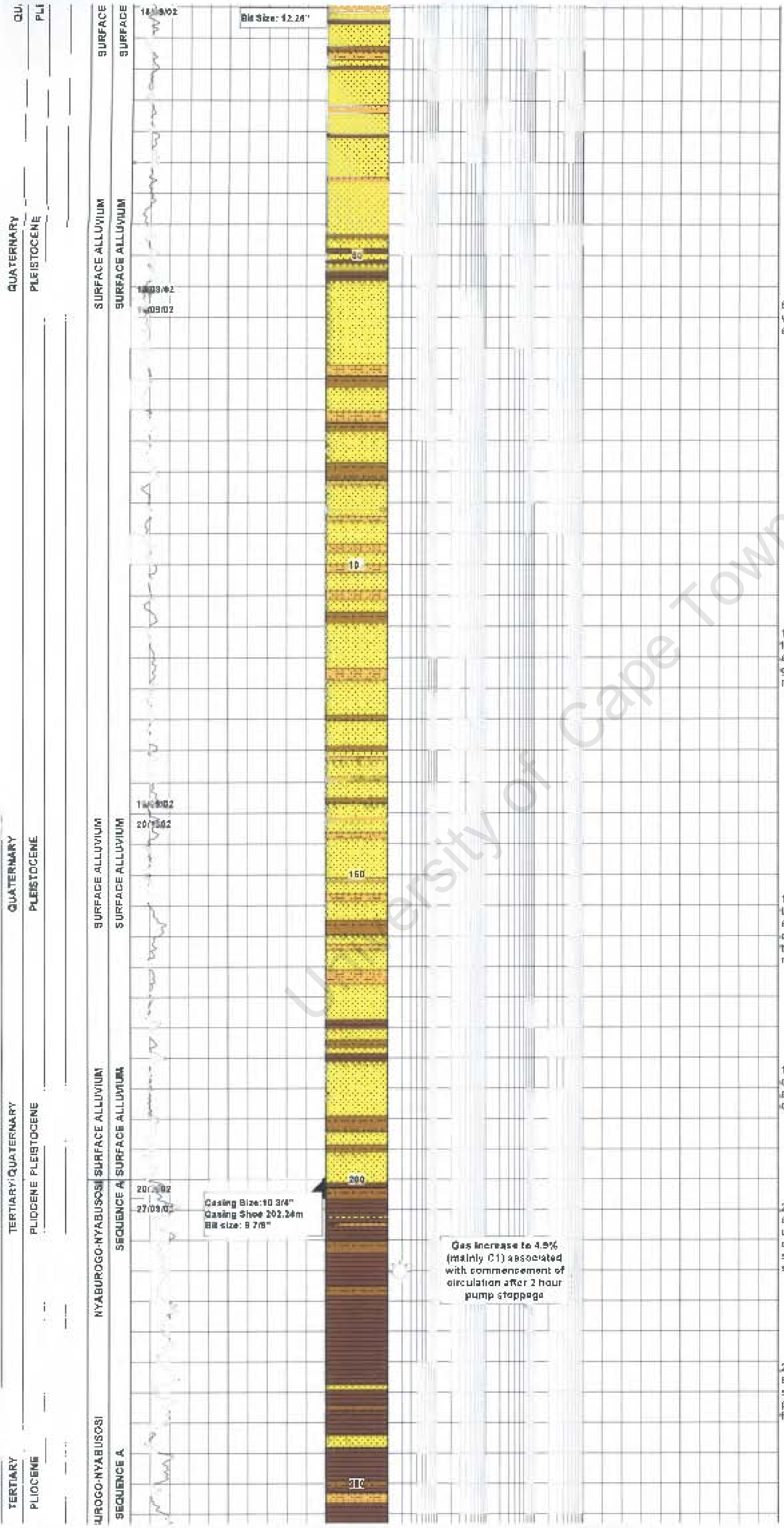
QUALIFIERS / ACCESSORIES

- Sandy
- Silty
- Argillaceous
- Calcareous
- Dolomitic
- Carbonaceous
- Bituminous
- Mica
- Kaolin
- Glauconite
- Anhydrite/Gypsum
- Polyhalite
- Calcite
- Siliceous
- Ferruginous
- Pyrite
- Tuffaceous
- Macrofossil
- Microfossil
- Plant remains
- Bioturbation
- Oolith
- Oncolith
- Peloid
- Coral
- Bone

DRILLING AND EVALUATION LEGEND







67 - 110m: Sand quartzitic, yellow to white, medium to very coarse grained, sub elongated to sub sperical, sub angular to sub rounded poorly sorted, minor muscovite

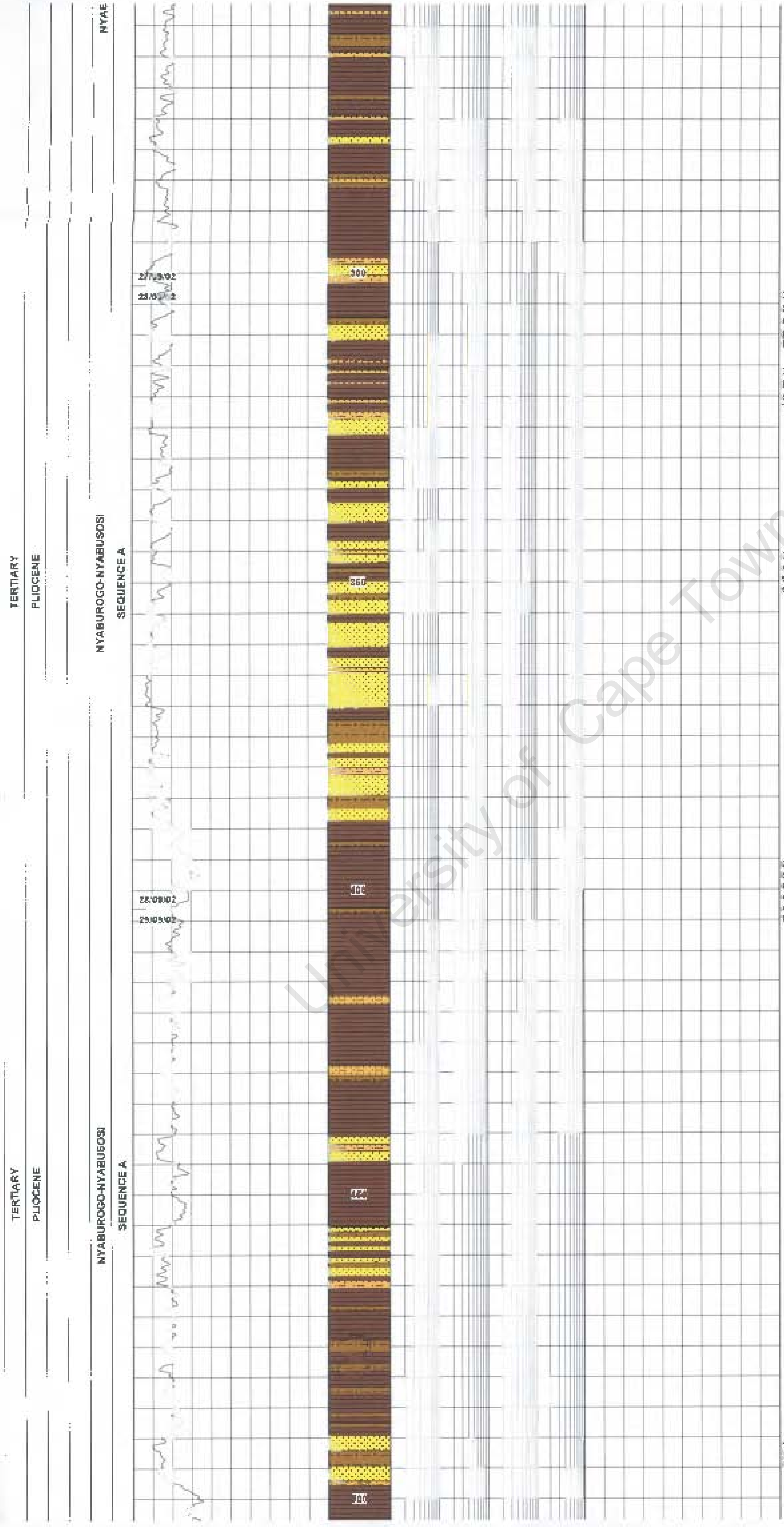
110 - 150m: Sand quartzitic, white to yellow, medium to coarse grained, sub elongated to sub spherical, sub angular to sub rounded, poorly sorted, muscovite, green glauconite(?) and traces of carbonised plant material, soft to moderately hard (< 5% in the samples)

150 - 161m: Sand quartzitic, white to yellow, medium to coarse grained, sub elongated to sub spherical, sub angular to sub rounded, poorly sorted, interbedded with clay gray to brown, silty plastic to soft non fissile and traces of carbonised plant fragments, black, soft to moderately hard.

161 - 200m: Sand quartzitic, white to yellow, medium to coarse grained, sub elongated to sub spherical, sub angular to sub rounded, poorly sorted, associated with clay gray to brown, silty, plastic to soft interbedded with

200 - 230m: Silty-clay, gray to light gray, plastic to soft and silty-clay green, mica, soft. Traces of black to brown carbonised plant material with minor sand quartzitic, clear, medium to coarse, sub elongated to sub spherical, sub angular to sub rounded, moderately sorted

230 – 302.6m: Silty-clay, gray to light gray and green, soft interbedded with very thin sand, medium to coarse sub elongated to sub spherical, angular to sub angular, poorly sorted. Traces of mica, carbonised plant fragments and calcareous fossils.



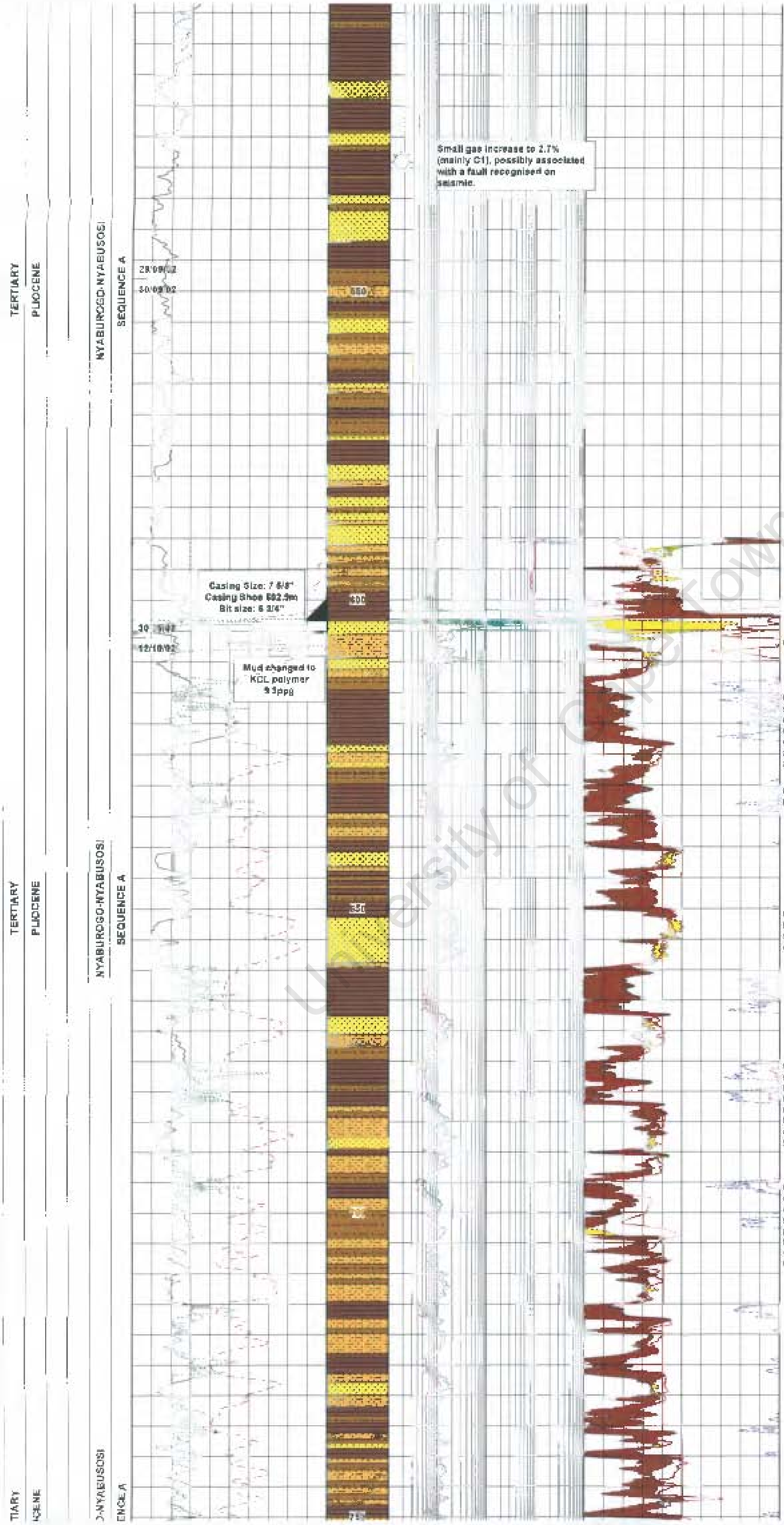
302.6 - 315m: Silty-clay, gray to light gray and green, soft interbedded with very thin sand, medium to coarse sub elongated to sub spherical, angular to sub angular, poorly sorted. Traces of mica, carbonised plant fragments and fossils.

315 – 345m: Silty clay light grey to grey, soft, with interbeds of sand, medium to coarse, sub elongated to sub spherical, angular to sub angular, poorly sorted. Traces of mica, carbonised plant fragments and silt

345-389m: Mainly loose sand, medium to coarse, sub elongated to sub spherical, angular to sub angular, poorly sorted. Subordinate silty clay, light grey to light greenish grey, soft. Traces of carbonised plant fragments and micas.

389-450m: Silty clay, predominantly light greenish gray, soft, similar to above. With variable proportions of subordinate quartzitic sand, fine to coarse, poorly sorted, grains sub elongated to sub spherical, angular to sub angular. Minor amounts of mica (c.a. 0.5%) carbonised plant fragments and fossils.

450-500m: As above though with persistent traces of yellow-brown siderite/ferroan dolomite, as small (mm) nodules(?) and as replacement of fossil gastropods(?).



Small gas increase to 2.7% (mainly C1), possibly associated with a fault recognised on seismic.

Casing Size: 7 5/8"
Casing Shoe 602.5m
Bit size: 8 3/4"

Mud changed to KCL polymer 9.5ppg

Change to 6 ¾", type DS PDC bit

600-650m: Silty claystone, predominantly light greenish gray, soft, similar to above, locally with dark grey, firm, less silty claystone. Minor proportions (0-20%) of subordinate quartzitic sand, mainly fine to medium, poorly sorted, grains sub elongated to sub spherical, angular to sub angular. Minor amounts of carbonised plant fragments and traces of siderite and mica.

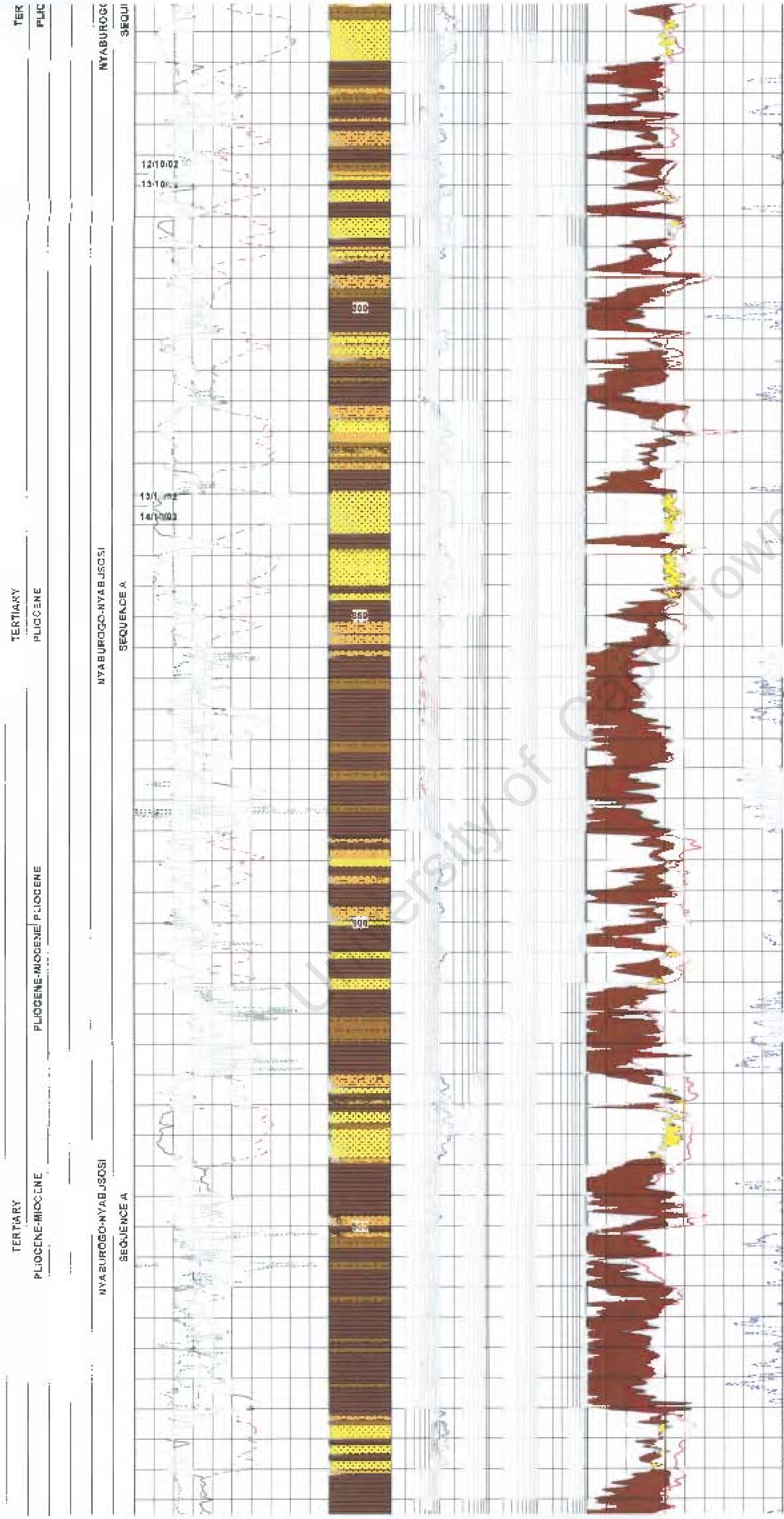
630-650m: Problems with shakers, lithology determined from spot samples only

650-660m: Mainly loose, clear quartzitic sand, largely medium to coarse, moderately sorted, grains sub elongated to sub spherical, sub angular to sub rounded. Associated with claystone A/A

660-695m: Silty claystone, predominantly light greenish gray, soft, similar to above, locally alternating with dark grey, firm, less silty claystone/shale (c.a. 60% from 670-675m). Interbedded with sand: clear, quartzitic, mainly fine to medium, moderately to mod. well sorted, grains sub elongated to sub spherical, sub angular to sub rounded. Minor amounts of carbonised plant fragments and traces of siderite and glauconite(?).

695-750m: Interbedded, claystone, shale and sandstone. The claystone is light greenish gray and soft, and is intercalated with dark grey, firm shale. The sands are clear, quartzitic sand, mainly fine to medium, very coarse to Pebbly (8mm) in places, moderately to mod. well sorted, grains sub elongated to sub spherical, sub angular to sub rounded. Minor amounts of carbonised plant fragments and fossil fragments, the latter more abundant than above.

Note: Breakdown of shakers from 756m to 1328m. Depths of samples hence uncertain.



752-760m: Sand, medium to very coarse, quartzitic, moderately sorted. Collected after a pause in circulation: may not be in situ

760-830m: Claystone/shale, soft to firm, comprising intercalated dark grey and light/greenish grey lithologies. The dark grey lithology predominates, though with intervals of mainly lighter claystone in places. Interbeds of clear to milky, quartzitic sand, mainly medium to coarse, moderately to mod. well sorted, grains sub elongated to sub spherical, sub angular to sub rounded. Minor amounts of carbonised plant fragments and fossil fragments

Shale shaker non-operational

830-846m: Sand, medium to very coarse. Quartzitic moderately sorted, grains subangular to subrounded, sub elongated to sub spherical. A well sorted medium sand was caught in a spot sample at 835m. Associated with light greenish grey soft claystone.

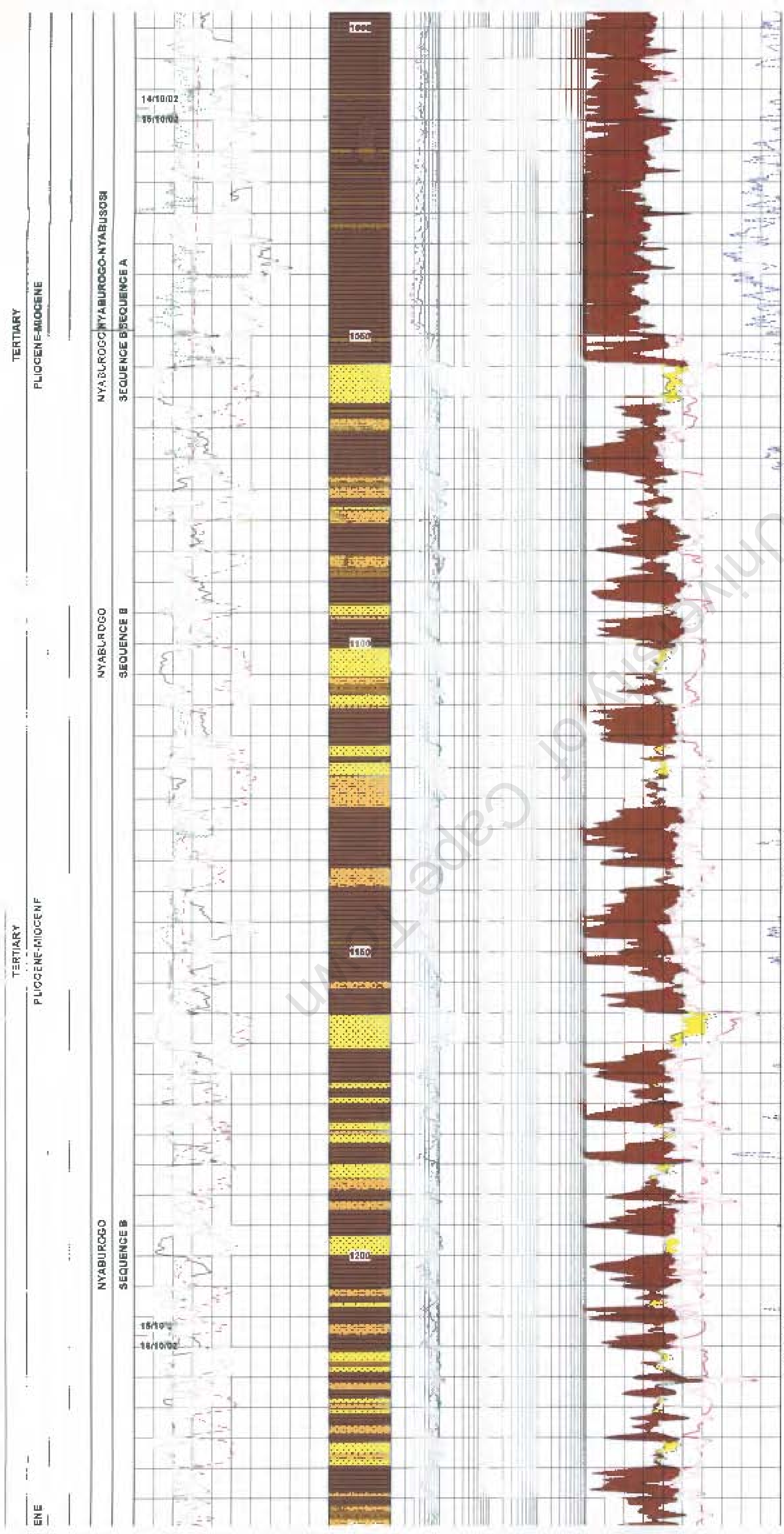
846-886m: Claystone, soft, light greenish grey. A/A. Minor subordinate amounts of dark grey firm shale. Minor interbeds of argillaceous sands. Minor amounts of carbonised plant fragments and fossil fragments.

886-925m: Claystone, soft, light greenish grey (lighter than above), silty in places, with subordinate amounts of dark grey soft-firm shale. Interbedded with clear, quartzitic sand, medium to very coarse, moderately to mod. well sorted grains sub elongated to sub spherical, sub angular to sub rounded. Minor amounts of carbonised plant fragments.

Shale shaker non-operational

925-939m: Sand, mainly coarse to very coarse with granules and small pebbles (10mm), quartzitic, glassy to milky moderately poorly sorted, grains subangular to subrounded

939-1000m: Claystone, soft, mainly light grey, though commonly grey, grading to dark grey firm shale in places. The proportions of the colours vary from sample to sample. With minor interbeds of clear, quartzitic sand, medium to very coarse, typically moderately sorted, grains sub angular to sub rounded. Minor amounts of carbonised plant fragments



Shale shaker
non-operational

1055-1061m: Sand, mainly medium to coarse, moderately sorted, quartzitic, glassy to milky, rare red/orange grains, grains subangular to subrounded. Associated with claystone/shale A/A

1061-1101m: Claystone, soft , mainly light grey, though commonly grey, grading to dark grey firm shale in places. The proportions of the lithologies vary from sample to sample. With minor interbeds of clear to milky, quartzitic sand, medium to very coarse, typically moderately sorted, grains sub angular to sub rounded. Well sorted calcite cemented VF sandstone present in cuttings from 1075m (spot sample) Minor amounts of carbonised plant fragments.

1101-1126m: Sand, medium to very coarse, quartzitic, glassy to milky, moderately poorly sorted, grains subangular to subrounded. Associated with claystone/shale A/A.

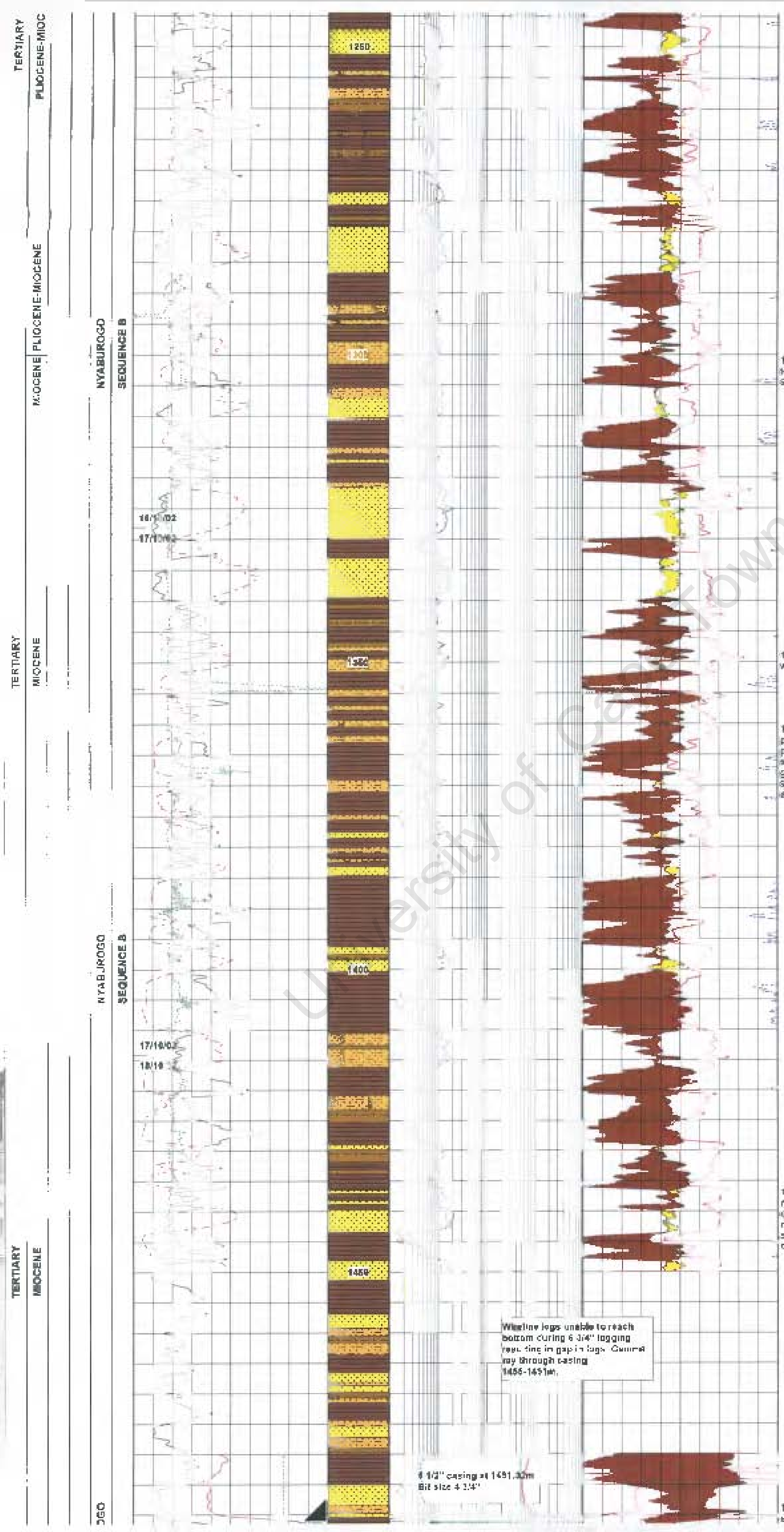
Shale shaker
non-operational

1126-1180m. Claystone, soft , mainly light grey, though commonly grey, grading to dark grey firm shale in places. The proportions of the lithologies vary from sample to sample. Interbeds with minor clear to milky, quartzitic sand, medium to very coarse, typically moderately sorted, grains sub angular to sub rounded

1180-1200m. Sand, medium to very coarse to granule grade, pebbly in places, pebbles fractured during drilling. The grains are mainly quartzitic, glassy to milky, moderately poorly sorted, subangular to subrounded. Some pink feldspar grains. Associated with claystone/shale A/A and minor amounts of grey VF sandstone/siltstone, grey, well sorted, argillaceous matrix, firm, non-calcareous.

1200-1279m: Sand, medium to very coarse, quartzitic, glassy to milky, moderately to poorly sorted, grains subangular to subrounded. Some pink feldspar grains. Associated with claystone/shale, soft to firm, grey to dark grey, and with grey VF sandstone, well sorted with calcareous and argillaceous matrix. Minor amounts of carbonised plant fragments.

Shale shaker
non-operational



Wireline logs unable to reach bottom during 6 3/4" logging resulting in gap in logs. Gamma ray through casing 1486-1491m.

6 1/2" casing at 1491.30m
Bit size 4 3/4"

1279-1340m: Sand, medium to very coarse, quartzitic, glassy to milky, moderately poorly sorted, grains subangular to subrounded. Associated with claystone/shale A/A.

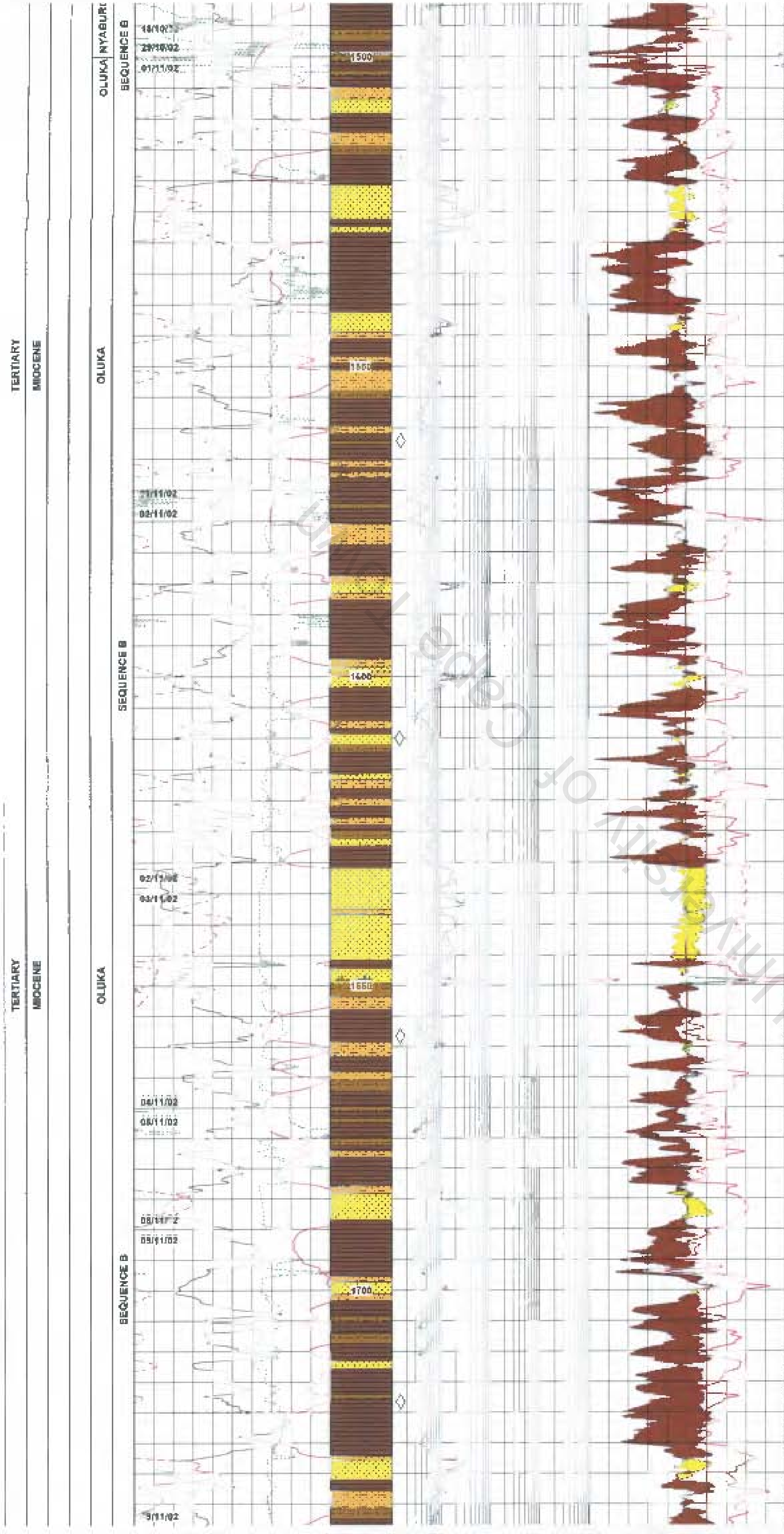
Shale shaker operational from 1326m

1348m: Very slow drilling, (13min/m). Spot sample shows white, soft-plastic, highly calcareous clay (lime mud?)

1340-1436m: Shale, variably light grey to black, though predominantly dark grey/black and carbonaceous (oil shale?) particularly in a spot sample from 1375m. Soft to firm with a splintery fracture . Under UV it shows no fluorescence, though gives a weak pale yellow cut with solvent. The associated sands exhibit very minimal fluorescence which may be associated with shale fragments

1436-1490m: Sand, fine to very coarse, locally with granules, mod. poor sort, grains angular to subrounded, grains quartzitic, clear to milky. Associated with claystone/shale, mainly light grey to grey, locally dark grey/black or greenish, soft, silty. Weak cut and fluorescence in the claystones/shales.

1490-1497m: Claystone/shale, mainly dark grey, soft with splintery fracture, though colours ranging from light grey to



greenish grey. Weak cut and fluorescence. Associated with sand, mainly fine to medium grained, moderately to well sorted, quartzitic.

1500m: Chert, dark grey, glassy, excellent conchoidal fracture, extremely hard. Fragments recovered in PDC bit.

1500-1520m: Alternations of claystone/shale ranging from dark grey with a splintery fracture, though to light grey, silty, soft. Associated with silt/sandstone, very fine grained with a white argillaceous matrix. Loose sand very fine-medium grained, VG sort. Weak cut and fluorescence associated with the claystone/shale.

1520-1529m: Predominantly very fine to fine grained, well sorted sand, grains subangular to subrounded, quartzitic. Associated with claystone/shale and minor amounts of very fine argil. sandstone A/A.

Leak off test at 1491.3m, 14.4ppg EMW

1529-1631m: Claystone/shale, mainly dark grey to black, though colours ranging from light to greenish grey where silty. Generally firm, soft where lighter grey. Traces of plant cuticle in places. Associated with subordinate very fine sandstone intergradational with siltstone, light greenish grey to light grey/white, with argillaceous matrix. Traces of medium to coarse sand in places. Weak to moderate cut and fluorescence in the mudstones.

1628-1660m: Sand, medium to very coarse, quartzitic, glassy, moderately to moderately well sorted, grains subangular to subrounded. Calcareous(?) at interval base.

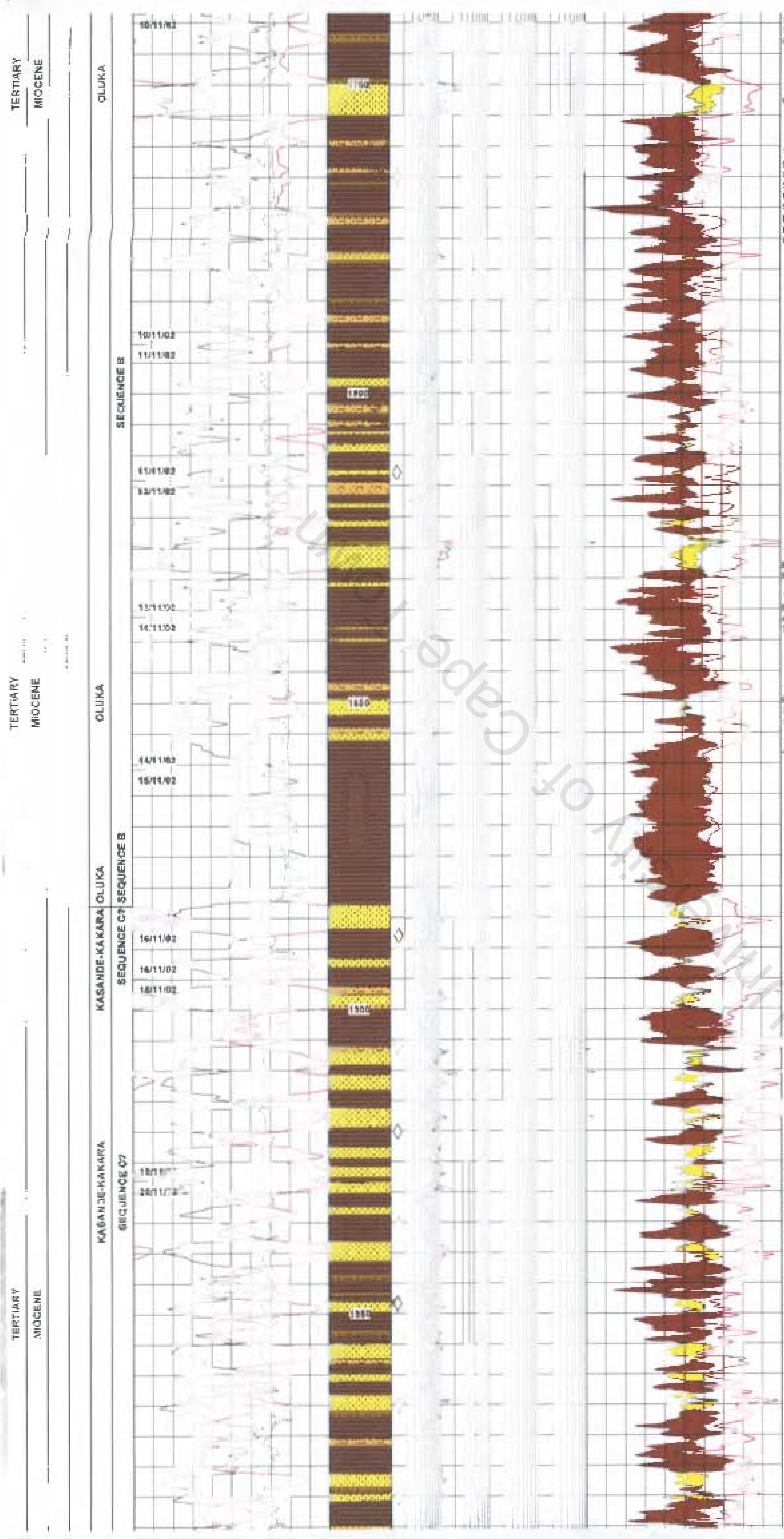
1660-1702m: Alternations of claystone/shale ranging from dark grey shales with a blocky/splintery fracture, though to light or greenish grey, silty, soft claystones. These locally grade to argillaceous siltstones and VF argillaceous sandstones. Medium to coarse quartzitic sand in places. Moderate streaming cut and fluorescence in the claystone/shale.

1670m RIH 4 3/4" PDC, type Huddy bit

1680m 4 3/4" PDC bit failed to make progress. RIH Security 4 3/4" bit, type XS 126

1702-1750m: Alternations of vari-coloured claystone, light grey to olive grey, soft, silty, locally intergradational with argillaceous siltstone, white to light grey/grey, argillaceous, soft. Common shale, grey to dark grey, firm, weakly to moderately fissile. Subordinate amounts of sand and sandstone, mainly very fine to fine, medium to coarse in places, moderately sorted. Soft powdery white material is present in some samples. Traces of a brown carbonate (ferroan dolomite?) and traces of reddish orange clay(?) are present in places.

Angular fragments and splinters of quartz(?) are present in the interval 1702-1750m. These are very hard, very clear and in places have dark inclusions. They appear to have cleavage planes along which the grains have fractured, though these 'cleavages' are believed to comprise fracture planes of



possible tectonic origin, or resulting from the drilling process. It is uncertain whether the quartz(?) is of detrital or authigenic origin

1750-1755m: Sand, very fine to medium grained, moderately well sorted, grains quartzitic, angular to subrounded.

1755-1825m: A succession of vari-coloured claystone, light grey to olive grey, soft, silty, locally intergradational with argillaceous siltstone, white to light grey/grey, argillaceous, soft. Common shale, grey to dark grey, firm, weakly to moderately fissile. Subordinate amounts of sand and sandstone, mainly very fine to fine, medium to coarse in places. Moderately sorted. Calcite cemented in places. Soft powdery white material (rock flour?) is present in some samples

1814.9m RIH PDC 4 3/4", type HUDDY, sr. [illegible], nozzle 4x 14

1825-1828m: Sand, loose, very fine to medium, some coarse grains at interval base, moderately to well sorted, quartzitic grains, angular to subangular.

1828-1847m: Claystone, alternations of olive grey and greenish grey bands, silty in places locally grading to argillaceous siltstone, soft. Minor amounts of shale, dark grey, firm, weakly fissile

1847-1856m: Siltstone, light greenish grey to greenish grey, soft, lightly argillaceous with some very fine sand grains. Interbedded with claystone, light greenish grey soft, and minor amounts of shale, dark grey, firm.

1856-1870m: Claystone, light olive grey, soft, locally silty. Traces of siltstone, light grey, argillaceous, soft.

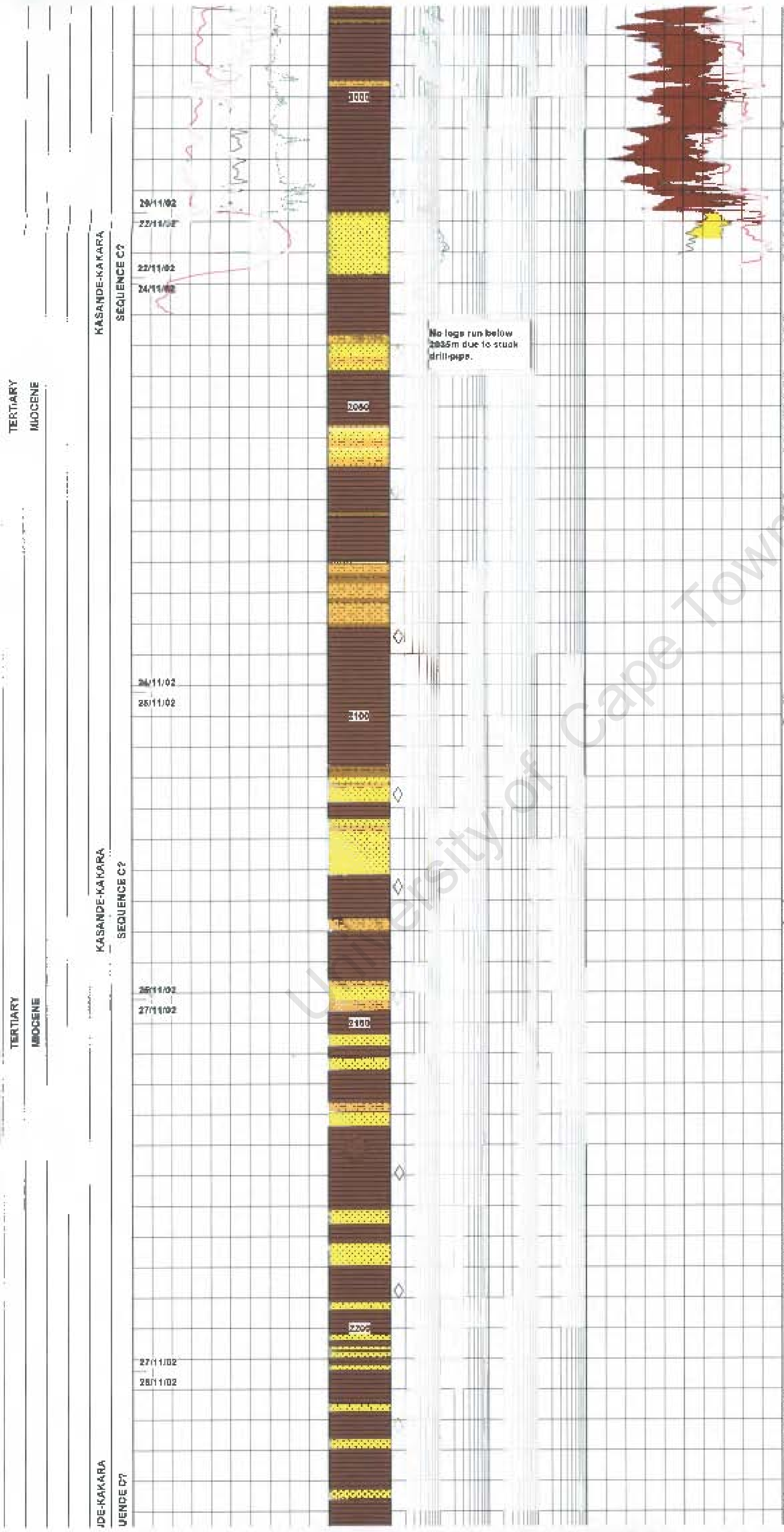
1870-1882m: Claystone, light greenish grey, soft

1885m 4 3/4" PDC bit failed to make progress. RIH Security 4 3/4" bit, type XG 12S

1900-1911m: Shale, dark grey to black, fissile, carbonaceous, no direct fluorescence, faint white to pale yellow cut and crush cut

[illegible]-1981m: Thin interbeds of claystone, shale and sandstone. The claystone is light gray to medium gray, soft to firm, silty, non calcareous, slightly carbonaceous, white cut and strong white crush cut, grades to siltstone. Shale: dark grey to black, fissile, carbonaceous. Sandstone: white to off-white, poorly sorted, fine angular grains, soft, white clay matrix, possibly kaolin or illite, calcareous, grades to siltstone in places, dull yel mineral fluorescence from calcite or marl in places. Quartz Sand, clear to milky white, medium to coarse, ang

1981-2016 m: Claystone: light grey to brownish gray to greenish gray in places, soft to firm, carbonaceous,



micro-micaceous, non calcareous. Shale: trace only dark gray to black, green in places, fissile, carbonaceous. Dolomite: trace only, brown, moderately hard micro-crystalline.

Claystone : as above light greenish gray, sticky

Dol: brown, trace only, moderately hard, microcrystalline

2019m DBS XS12S 437-X. POOH due to high torque, RIH Security 4 3/4" PDC bit, Huddy "Bull Nose"

2018-2029m: Quartz Sand; clear to milky white, coarse to very coarse, ang, white calcareous matrix, no direct fluorescence, pale yellow cut and crush cut possibly contamination. Sandstone: off-white to white, poorly sorted, very fine to medium grained, angular grains, soft, white calcareous matrix, calcite cement gives dull yel mineral fluorescence in places

2029m Huddy PDC. POOH due to slow ROP, RIH 43/4" DBS XS12S 437-X

2029-2038m: Claystone: medium light gray to greenish gray, firm to moderately hard, slightly calcareous, slightly carbonaceous, sub-fissile-fiss where it grades to shale

2038-2044m, 2053-2060m, 2076-2085m, 2110-2126m: Sandstone/Quartz Sand: offwhite to light gray, medium to dark gray where carbonaceous, very fine to very coarse, poorly sorted, angular grains, very argillaceous white clay matrix (kaolinitic?) with darker carbonaceous patches, calcareous in places, grades to both white siltstone and claystone in places, fast bright white to pale yellowish cut and crush cut.

2060-2076m: Claystone: medium light gray, soft-firm in places, non calcareous, slightly carbonaceous, very sticky silty, sandy in places, slow pale yellow cut and crush cut

2085-2110m: Claystone, medium brownish gray, soft, non-calcareous, slightly carbonaceous, very sticky, silty, sandy in places, weak slow pale yellow cut and crush cut.

2126-2167m: Claystone: white to light brownish gray, soft, non-calcareous to slightly calcareous, slightly carbonaceous, very sticky, silty, sandy in places. Sandstone/Quartz sand: clear to light gray to off-white, very fine to coarse, soft to firm where cemented, poorly to fairly well sorted, angular, calcareous cement in places, very argillaceous, white matrix, cemented where white otherwise unconsolidated, silty, slightly carbonaceous grades to siltstone and white claystone in places, no direct fluorescence, weak slow pale yellow cut and crush cut. Shale: trace only, dark gray to black, fissile, carbonaceous.

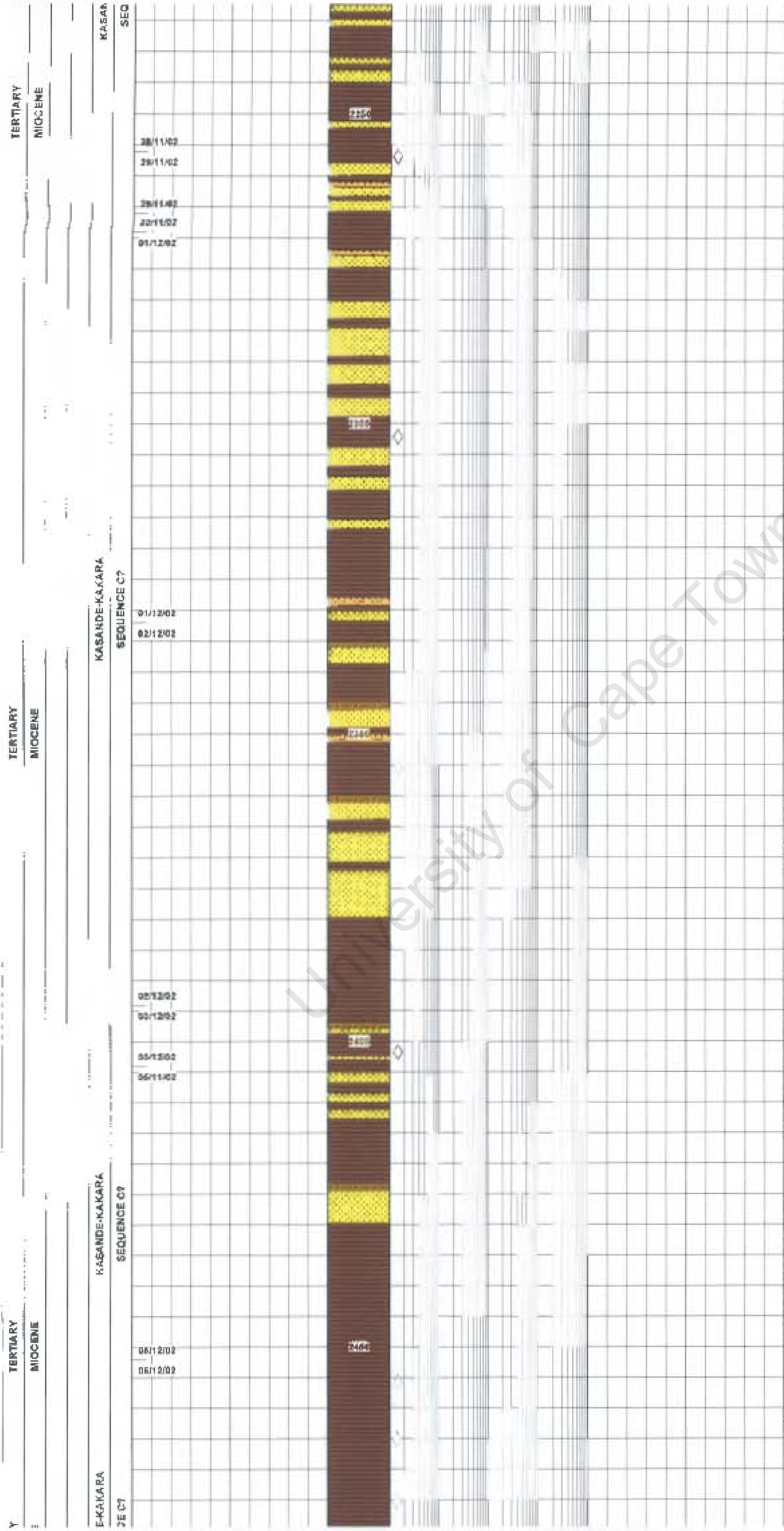
2146.3m: DBS XS12S 437-X. POOH due to high torque, RIH DBS 4 3/4" DBS XS12S 437-X

2167-2180m: Claystone, varicoloured, mainly olive grey though pale brown, light grey to greenish grey or white in places. Soft, non-calcareous, sticky. Traces of siltstone and argillaceous sandstone in places.

2180-2213m: Claystone, white (kaolinitic?) to light olive gray, ranging to light grey, dusky brown or dusky green in places. Soft, non-calcareous to slightly calcareous, very sticky, silty, sandy in places. Interbedded with quartz sand: clear, very fine to coarse, poorly to fairly well sorted, angular (grains fractured). Minor amounts of sandstone locally with calcareous cement or with white clay matrix. Shale: trace only, dark gray to black, fissile, carbonaceous. No direct fluorescence, weak slow pale yellow cut and crush cut.

2213-2227m: Claystone, predominantly white to light grey (kaolinitic?) locally mottled, soft, silty in places, associated with subordinate claystone, light greenish grey and olive grey, soft, sticky. Minor loose sand: fine to coarse, moderately well sorted, grains angular (fractured) to subrounded, quartzitic. Traces of shale, dark grey, fissile, splintery (caved?)

2227-2242m: Claystone, predominantly light olive to olive grey, soft, sticky. Minor white to light grey claystone A/A interbedded with sand, very fine to fine grained, (medium to



coarse in places), well sorted, grains angular to subrounded. No direct fluorescence, weak to negligible cut and fluorescence.

2242-2258m: Claystone, varicoloured, mainly white (kaolinitic?) or light olive to olive grey, soft, silty in places, sticky. Subordinate light greenish grey and light grey claystones. Locally interbedded with sand, predominantly fine to medium grained, coarse in places, generally moderately well sorted, grains mainly angular to subangular.

2258-2266m: Sand, very fine to medium grained, some coarse grains, moderately well sorted, quartzitic grains mainly angular to subangular. Associated with claystone, mainly white (kaolinitic?), soft, silty, locally light greenish grey to light olive grey, soft. Weakly calc. in places. Traces of shale, dark grey-black, splintery (caved?).

2266-2280m: Claystone, mainly light to medium grey or white (kaolinitic?); olive grey, dusky green or dusky brown in places. Interbedded with sand, fine to medium grained, moderately well sorted. Minor VF sandstone. No direct fluorescence, weak to negligible cut and fluorescence.

2280-2299m: Sand, loose, mainly fine to medium, up to coarse grained, moderately well sorted, quartzitic grains, angular (fractured?) to subrounded. Interbedded with claystone, varicoloured: white (kaolinitic), light greenish grey, light grey and light olive grey, generally soft, silty in places. Weakly calc. in places. Traces of shale, dark grey-black, splintery (caved?).

2299-2360m: Complex association of sands and claystones. The claystones are predominantly pale in colour and include the following varieties: *Light olive to olive grey, soft, sticky, slightly calc i.p.; *Light grey to light greenish grey, soft, traces of carbonaceous material; *White (kaolinitic?), soft, silty, locally intergradational with argillaceous siltstone, white to light grey, soft. Trace to minor amounts of shale (caved?), dark grey, firm, fissile are present in most samples. The sands are mainly fine to medium grained with some coarse grains, moderately well to well sorted, with angular to subrounded quartzitic grains. Minor amounts of argillaceous and/or calcareous sandstone present in places.

No direct fluorescence, weak cut and fluorescence in places, mainly in the olive grey claystones.

2360-2380m: Sand, loose, mainly fine to medium grained, ranging from very fine to coarse. Generally moderately well sorted, quartzitic grains angular (fractured?) to subrounded. Associated with abundant (5-30%) white (kaolinitic?) claystone, possibly as a matrix to the sand grains. This claystone is typically silty and is intergradational with light grey-white argillaceous siltstone. Also with claystone, light greenish and light olive grey.

2380-2386m: Claystone, light olive grey and light greenish grey, soft.

2386-2387m: Shale, dark grey, firm, weakly to moderately fissile. Associated with subordinate claystone, light olive grey, soft, sticky.

2387-2403m: Claystone, light greenish grey, light olive grey and white, soft, sticky in places. Associated with sand, mainly fine to medium grained, moderately well sorted, grains angular to subrounded.

2403.6m RIH Bit #13 43/4" DBS XS125 437 X

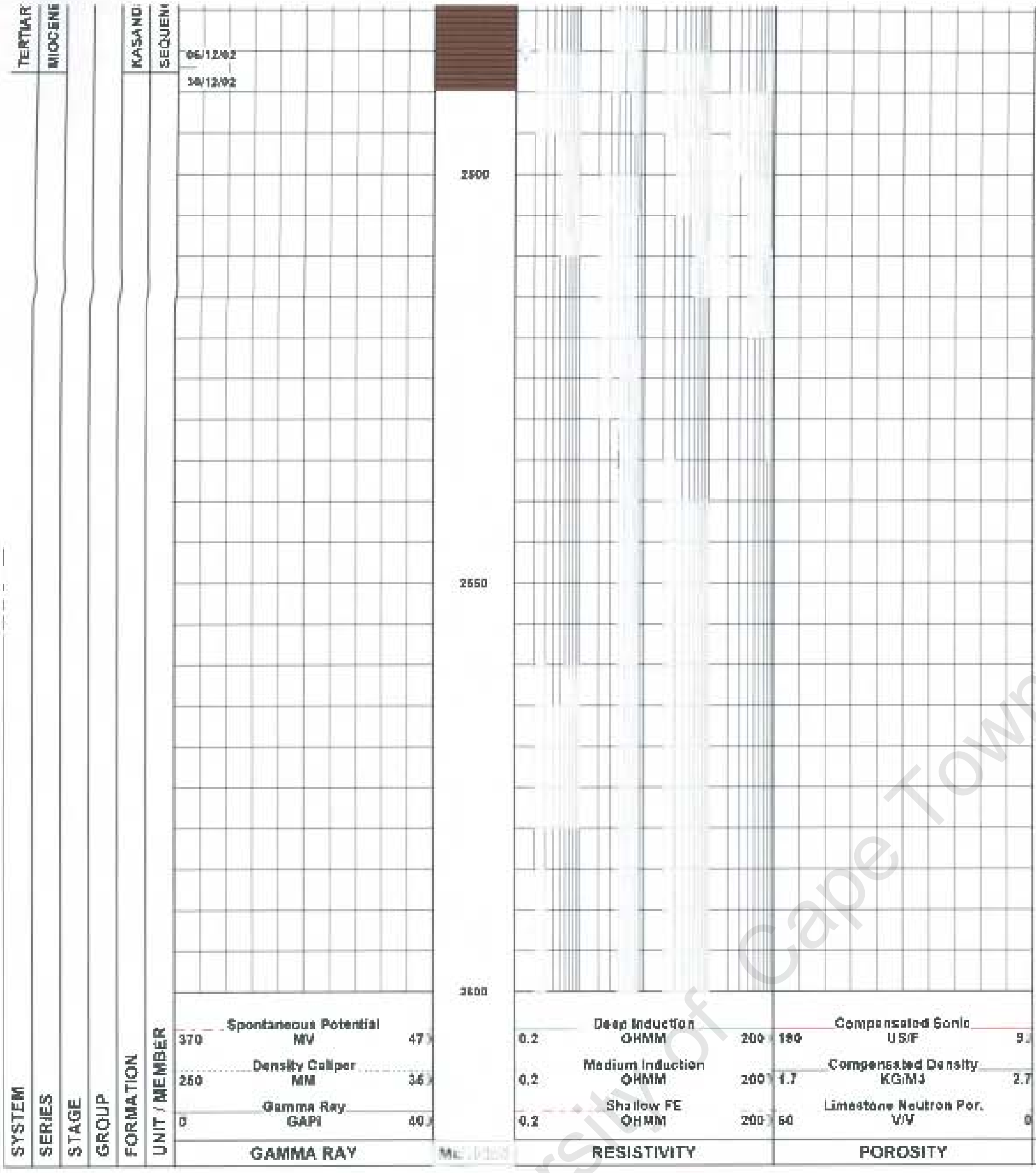
2404-2425m: Claystone, mainly light olive grey A/A or white (kaolinitic?) A/A, minor amounts of light greenish grey or light green claystone. Associated with sand, mostly fine to medium grained, moderately well sorted, grains angular to subrounded.

2425-2430m: Sand, fine to coarse grained, moderately sorted, composed of angular (fractured?) to subangular quartzitic grains.

2430-2462m: An association of shale, dark grey, to greenish grey, firm to hard, and claystone, light greenish grey to greenish grey and light olive grey, soft. The shale is most abundant at the interval top (locally 90% sample), declining downwards. The claystone is light greenish grey at the interval top, grading to light olive grey at the interval base. No direct fluorescence, weak to negligible cut and fluorescence in places, mainly in the olive grey claystones. No cut and fluorescence associated with the dark grey shales.

2462-2467m: Claystone, light olive grey to olive grey, soft, associated with shale, dark grey to dark greenish grey, firm to hard, commonly as elongate 'splinters' or fragments.

A very weak dull orange fluorescence was observed in the samples: 2465-2470m, 2483m & 2487m. No fluorescence could be seen in the intervening samples. All tested samples



LITHOLOGY & REMARKS

In the interval 2462-2487m showed moderate to good cut and yellow fluorescence.

2487.7m RIH Bit #14 Huddy PDC combined corehead/drillbit. Drilling assembly became stuck on 9th Dec 2002 with the bit at 2450m while RIH with coring assembly.
No core was cut.

Extensive fishing operations were carried out between 9th Dec 2002 and 23rd Jan 2003 during which the fish was recovered to 2032m. The exposed hole section was logged with wireline and the hole suspended on xxxxth Jan 2003

Wireline logs run during operations to free stuck pipe
Run 2a 20th Dec 2002 VSP (run inside drill pipe) Logged interval: 2487m - 290m and checkshots to 50m.
Run 2b 22nd Dec 2002 MAI/MFE-MSS-MPD-MDN-VCG (Array induction-Sonic-Neutron/density run without sources-GR)Logged interval: (from top of backed off fish at 1730m - 1491.3m)
Run 2c 23rd Dec 2002 MPD-MDN-MCG (Density - Neutron - GR) Logged interval: 1730m - 1451.3m GR logged through casing to surface (to provide a new reference log for depth control)

Wireline logs run prior to suspending well.
The well was logged after fishing operations were abandoned on 25th Jan 2003. Top fish was at 2032.6m
Run 3A 26th Jan 2003 MAI/MFE-MSS-MPD-MDN-MCG (Array induction-Sonic-Neutron/density-GR-SP)
Logged interval: (from top of backed off fish at 2032m 1491.3m)

HERITAGE

ENCLOSURE 2

TURACO-2

COMPOSITE WELL LOG

SCALE: 1: 500

LOCATION

COUNTRY:	*UGANDA*
AREA:	ALBERT GRABEN
LICENCE:	BLOCK 3

CO-ORDINATES

LATITUDE:	01° 01' 41.2" N (WGS84)
LONGITUDE:	30° 18' 08.4" E
U.T.M. X:	189754m E (WGS84)
U.T.M. Y:	113783m N

WELL CLASSIFICATION: EXPLORATION

COMPLETION STATUS: P&A untested hydrocarbon well

RIG ON LOCATION:	
WELL SPUDDED:	03 Sept 03
SUSPENDED:	
RE-ENTERED:	
T.D. REACHED:	08/02/04
WELL COMPLETED:	15/06/04
RIG RELEASED:	

R.T. ELEVATION:	7.2m	AGL
WATER DEPTH:		
GROUND ELEVATION:	633.0m	AMSL

TOTAL DEPTH

DRILLER:	2962.5m	MDBRT	2949.0m	TVDBRT
LOGGER:	2921.3m	MDBRT	2908.1m	TVDBRT

FORMATION AT T.D.: Kisegi

RIG NAME:	EAGLE DRILL
CONTRACTORS	
DRILLING:	EAGLE DRILL
LOGGING:	REEVES
MUDLOGGING:	DAFORA
LWD:	N/A
BIOSTRATIGRAPHY:	N/A
WELLSITE GEOLOGISTS	COMPANY
GRAHAM STAPLES	SWIFTDALE
BILL PETTIT	SWIFTDALE
LOG COMPILED BY	
BILL PETTIT	SWIFTDALE

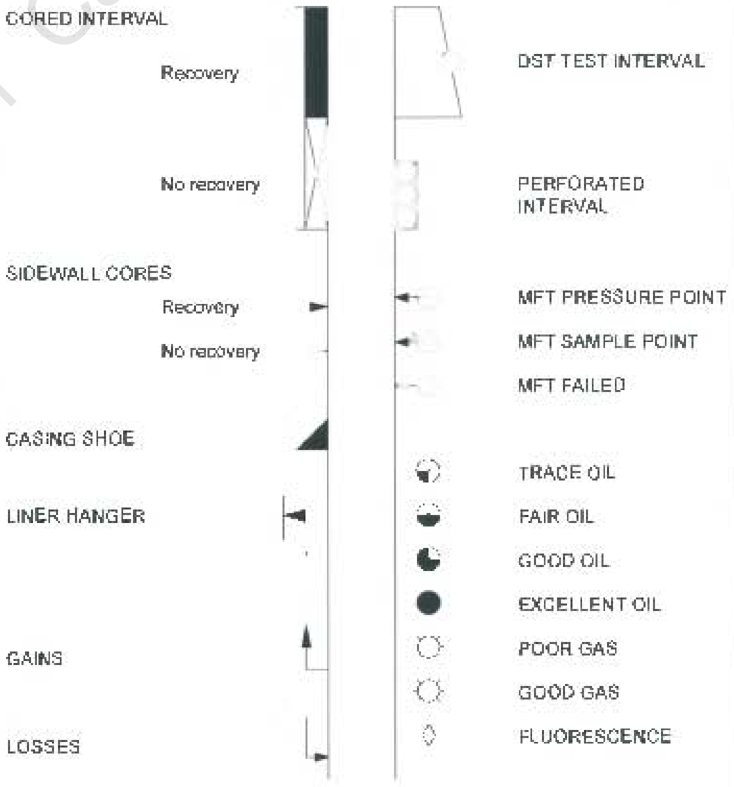
LITHOLOGY

		Chert or Flint	▨
Conglomerate or Breccia	▨	Coal or Lignite	■
Sand or Sandstone	▨	Halite	▨
Sandstone Argillaceous	▨	Potassium K Salt	▨
Silt or Siltstone	▨	Anhydrite or Gypsum	▨
Mudstone, Clay or Shale	▨	Tuff	▨
Limestone	▨	Volcanic Igneous	▨
Limestone Argillaceous	▨	Intrusive Igneous	▨
Dolomite	▨	Undifferentiated Igneous	▨

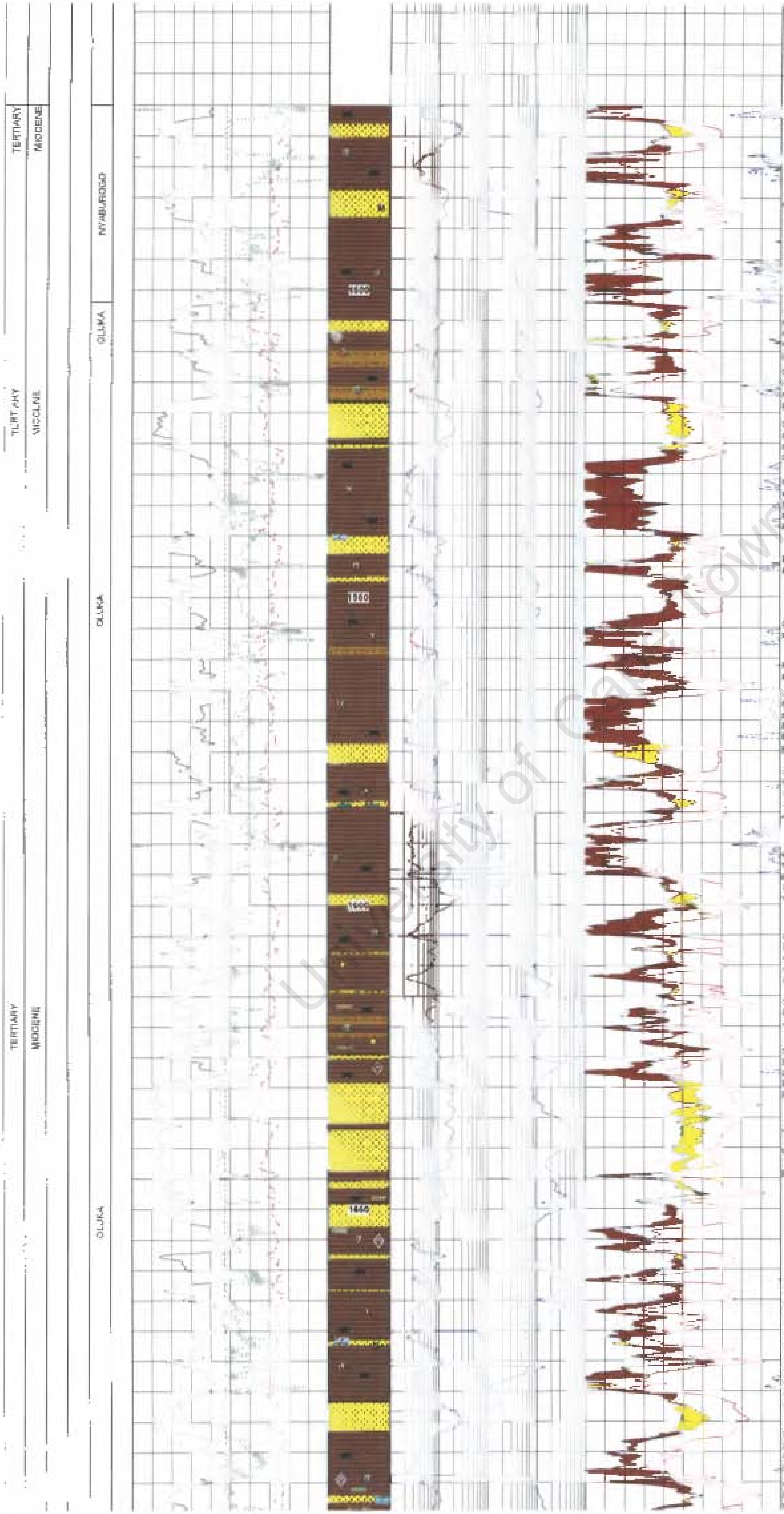
QUALIFIERS / ACCESSORIES

Sandy	...	Siliceous	
Silty		Ferruginous	
Argillaceous		Pyrite	
Calcareous		Tuffaceous	
Dolomitic		Macrofossil	
Carbonaceous		Microfossil	
Bituminous		Plant remains	
Mica	M	Bioturbation	
Kaolin	K	Oolith	
Glauconite	G	Oncolith	
Anhydrite/Gypsum		Pelcid	
Polyhalite		Coral	●
Calcite		Bone	

DRILLING AND EVALUATION LEGEND



SYSTEM	SERIES	STAGE	GROUP	FORMATION	UNIT / MEMBER	GAMMA RAY	METRES	RESISTIVITY	POROSITY	LITHOLOGY & REMARKS
						0 Gamma Ray GAPI 400 0 Caliper ins 10 0 BIT ins 10 0 SPCG 150	1450	0.001 TOTAL GAS % 10 0.2 Shallow Induction OHMM 2000 0.2 Medium Induction OHMM 2000 0.2 Deep Induction OHMM 2000	60 Limestone Neutron Porosity V/V 0 1.7 Compensated Density KG/M3 2.7 180 Compensated Sonic US/F 80	Turaco-2 spudded with re-entry of Turaco-1 at



14:00hrs 03/10/03. Drill out cement plugs and attempt to set whipstock at 1950m. Poor hole condition dictated plugging back inside 9 1/2" casing. Set whipstock at 1471m. Cut window from 1466m to 1470m.

SAND: loose quartz, colourless, translucent, rare milky, smoky, very rare pale pink, pale green; very fine to very coarse, predominantly fine to coarse, angular to subangular, rare subround, elongate to subspherical, poorly sorted, inferred good porosity.

CLAYSTONE: pale to medium grey, locally speckled, firm, blocky to irregular, subfissile to splintery, earthy to smooth, locally silty, slightly calcareous, becoming non calcareous, micromicaceous, locally carbonaceous specks/ rare laminations, nonswelling.

SAND: (1510m) loose quartz, colourless, translucent, occasionally yellowish/smoky, very fine to fine grain, occasionally medium to coarse grain, angular to subangular, elongate to subspherical, moderately sorted, inferred good porosity.

SILTSTONE: pale grey, speckled, friable to firm, blocky to amorphous to irregular, argillaceous, grading claystone, micromicaceous, locally carbonaceous specks/laminations, plant debris.

SAND: loose quartz, colourless, translucent, rare smoky, medium to coarse, occasionally very fine to fine, rare very coarse, angular to subangular, elongate to subspherical, well sorted, inferred good porosity.

CLAYSTONE: medium grey to medium dark grey, firm to moderately hard, blocky to irregular to platy to splintery, fissile, smooth, occasionally earthy, rare silty, non-calcareous, micromicaceous, common carbonaceous specks/laminations, nonswelling. Becoming locally medium to dark green grey.

DOLOMITE: (tr) beige, mottled, very hard, blocky, microcrystalline, sandy.

SILTSTONE: pale grey, speckled, firm, crumbly, blocky, sandy (very fine grain), carbonaceous, micaceous.

CLAYSTONE 2: very pale green grey, slightly speckled/ mottled, crumbly, blocky to irregular.

SANDSTONE 1: white, translucent, moderately hard; quartz, fine to medium grain, angular to subangular, elongate to subspherical, well sorted, strong calcareous cement, rare lithoclasts/mica. Some rock flouring. SANDSTONE 2: pale brown, speckled, soft, amorphous, quartz, very fine grain grading to siltstone.

SAND: loose quartz, colourless, translucent, rare smoky; very fine to medium, commonly coarse, angular to subangular, rare round, elongate to subspherical, moderately sorted, inferred good porosity.
Abundant very fine/fine sand from de-sander.

CLAYSTONE 2: medium to dark green grey, locally mottled, firm to hard, blocky to irregular to platy to splintery, fissile, smooth, occasionally waxy, micromicaceous, locally carbonaceous specks/laminations, nonswelling. Occasionally very pale green grey; as above.

CLAYSTONE: pale to medium dark grey, firm, blocky to irregular to platy to splintery, subfissile, smooth, locally earthy/silty, noncalcareous, micromicaceous, locally carbonaceous specks/laminations, trace disseminated pyrite, nonswelling.

SILTSTONE: pale grey to beige, speckled, firm, crumbly, blocky, sandy (very fine grain), micaceous, carbonaceous, coarse plant debris.

SANDSTONE 1: loose, white, locally speckled, firm to friable, quartz, colourless, translucent, very fine to fine grain, angular to subangular, subspherical, moderately sorted, locally silty grading siltstone, micaceous, occasional lithoclasts.

SAND: loose quartz, colourless, translucent, very rare smoky, pink, milky; fine to very coarse, angular to subangular, elongate to subspherical, moderately sorted, inferred good porosity. No shows. De-sander abundant very fine to medium grain sand.

At 1667m: very dull yellow patchy fluorescence from sand grains. Fast diffuse milky cut.

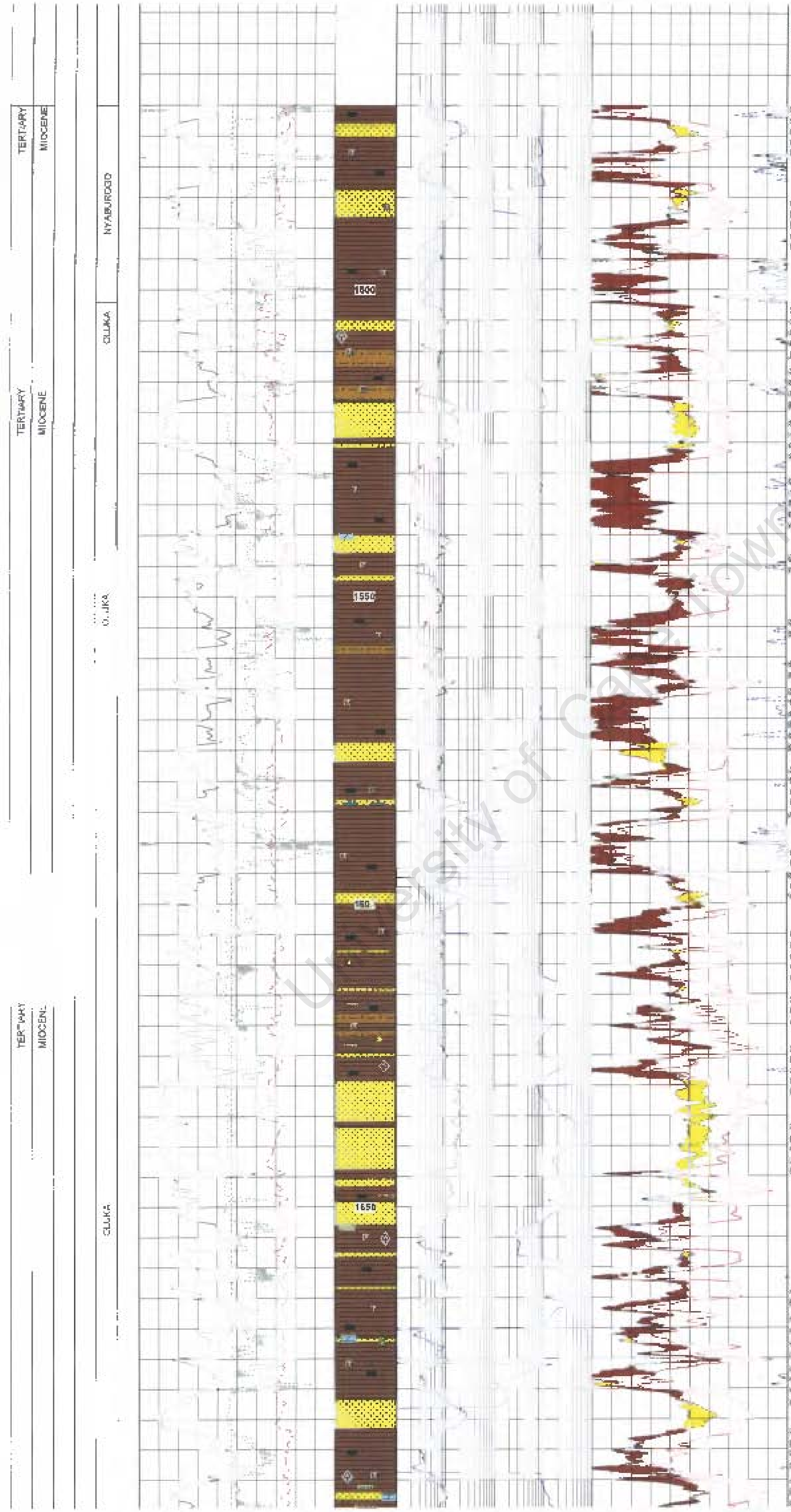
CLAYSTONE 3: pale brown/grey, homogeneous, very soft, amorphous.

CLAYSTONE 4: very pale grey, off-white, beige, locally mottled, soft to firm, friable, irregular to splintery, silty.

SANDSTONE: very speckled, quartz, colourless, translucent, very fine to fine grain, angular to subangular, subspherical, well sorted, moderate siliceous cement, abundant green mineral/lithoclasts, glauconite/chlorite?

SAND: loose, quartz, colourless, translucent, occasional pale pink, yellow, smoky, fine to medium, rare coarse grain, angular to subangular, elongate to subspherical, well sorted, good inferred porosity.

CLAYSTONE: pale to dark grey, firm, subfissile, blocky to irregular to splintery, smooth to earthy, locally silty grading siltstone, micromicaceous, locally carbonaceous



14:00hrs 03/10/03. Drill out cement plugs and attempt to set whipstock at 1960m. Poor hole condition dictated plugging back inside 5 1/2" casing. Set whipstock at 1471m. Cut window from 1468m to 1470m.

SAND: loose quartz, colourless, translucent, rare milky, smoky, very rare pale pink, pale green; very fine to very coarse, predominantly fine to coarse, angular to subangular, rare subround, elongate to subspherical, poorly sorted. Inferred good porosity.

CLAYSTONE: pale to Medium grey, locally speckled, firm, blocky to irregular, subfissile to splintery, earthy to smooth, locally silty, slightly calcareous, becoming non calcareous micromicaceous, locally carbonaceous specks/ rare laminations, nonswelling

SAND: (1610m) loose quartz, colourless, translucent, occasionally yellow/smoky; very fine to fine grain, occasionally medium to coarse grain, angular to subangular elongate to subspherical, moderately sorted, inferred good porosity.

SILTSTONE: pale grey, speckled, friable to firm, blocky to amorphous to irregular, argillaceous, grading claystone micromicaceous, locally carbonaceous specks/laminations, plant debris.

SAND: loose quartz, colourless, translucent, rare smoky; medium to coarse, occasionally very fine to fine, rare very coarse, angular to subangular, elongate to subspherical, well sorted, inferred good porosity

CLAYSTONE: medium grey to medium dark grey, firm to moderately hard, blocky to irregular to platy to splintery, fissile, smooth, occasionally earthy, rare silty, noncalcareous, micromicaceous, common carbonaceous specks/laminations, nonswelling. Becoming locally medium to dark green grey.

DOLOMITE: (?) beige, mottled, very hard, blocky, microcrystalline, sandy.

SILTSTONE: pale grey, speckled, firm, crumbly, blocky, sandy (very fine grain) carbonaceous, micaceous.

CLAYSTONE 2: very pale green grey, slightly speckled/ mottled, crumbly, blocky to irregular.

SANDSTONE 1: white, translucent, moderately hard, quartz fine to medium grain, angular to subangular, elongate to subspherical, well sorted, strong calcareous cement, rare lithoclasts/mica. Some rock flouring. SANDSTONE 2: pale brown, speckled, soft, amorphous, quartz, very fine grain grading to siltstone.

SAND: loose quartz, colourless, translucent, rare smoky; very fine to medium, commonly coarse, angular to subangular, rare round, elongate to subspherical, moderately sorted, inferred good porosity.
Abundant very fine/fine sand from de-sander

CLAYSTONE 2: medium to dark green grey, locally mottled, firm to hard, blocky to irregular to platy to splintery, fissile, smooth, occasionally waxy, micromicaceous, locally carbonaceous specks/laminations, nonswelling. Occasionally very pale green grey: as above.

CLAYSTONE: pale to medium dark grey, firm, blocky to irregular to platy to splintery, subfissile, smooth, locally earthy/silty, noncalcareous, micromicaceous, locally carbonaceous specks/laminations, trace disseminated pyrite, nonswelling.

SILTSTONE: pale grey to beige, speckled, firm, crumbly, blocky, sandy (very fine grain), micaceous, carbonaceous, coarse plant debris.

SANDSTONE 1: cream, white, locally speckled, firm to friable; quartz, colourless, translucent, very fine to fine grain, angular to subangular, subspherical, moderately sorted, locally silty grading siltstone, micaceous, occasional lithoclasts.

SAND: loose quartz, colourless, translucent, very rare smoky, pink, milky, fine to very coarse, angular to subangular, elongate to subspherical, moderately sorted, inferred good porosity. No shows. De-sander abundant very fine to medium grain sand

At 1667m: very dull yellow patchy fluorescence from sand grains. Fast diffuse milky cut

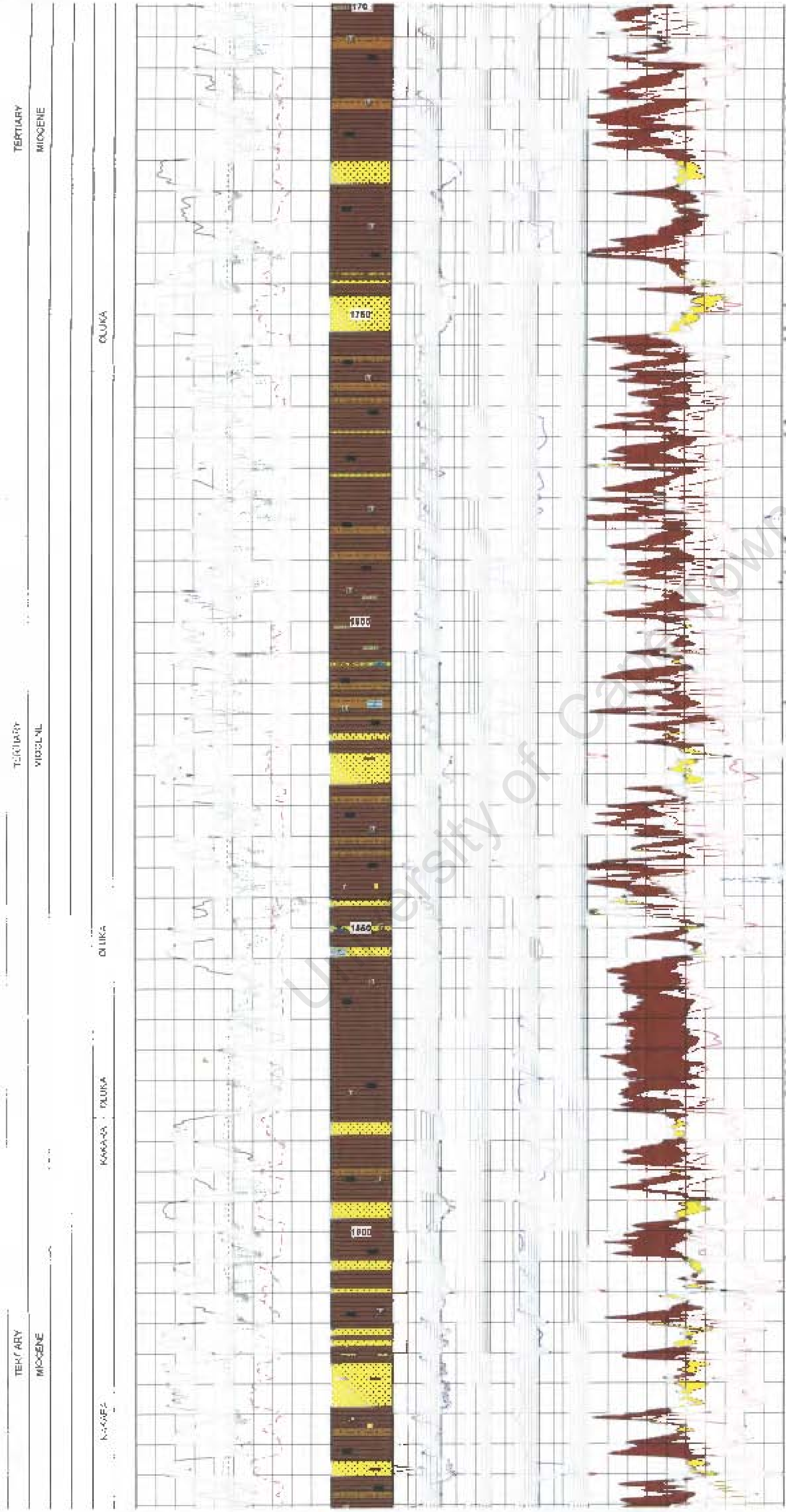
CLAYSTONE 3: pale brown/grey, homogeneous, very soft, amorphous.

CLAYSTONE 4: very pale grey, off-white, beige, locally mottled, soft to firm, friable, irregular to splintery, silty

SANDSTONE: very speckled, quartz, colourless, translucent, very fine to fine grain, angular to subangular, subspherical, well sorted, moderate siliceous cement, abundant green mineral/lithoclasts, glauconite/chlorite?

SAND: loose, quartz, colourless, translucent, occasional pale pink, yellow, smoky, fine to medium, rare coarse grain, angular to subangular, elongate to subspherical, well sorted, good inferred porosity.

CLAYSTONE: pale to dark grey, firm, subfissile, blocky to irregular to splintery, smooth to earthy, locally silty grading siltstone, micromicaceous, locally carbonaceous



specks/laminations, plant fragments

SAND: as above: fine to coarse grain, rare very coarse. Occasional clasts DOLOMITE: pale brown, subrounded, reworked?

SILTSTONE: pale grey to pale brown, tan, locally speckled, very soft, amorphous, (1720 to 1726m grading to plastic claystone), locally sandy, micaceous, carbonaceous specks/laminations.

SANDSTONE: off white, pale to medium grey, speckled, firm, friable, quartz, very fine to fine grain, angular to subangular, subspherical, moderately sorted, very common mica, silty grading siltstone, common as rock flour.

Bulk sample: <5% very dull yellow fluorescence, medium diffuse white cut, no residue. Mostly attributed to siltstone. Fine to coarse grain sands flushed?

SAND: loose, quartz, colourless, translucent, rare pale pink, yellow, orange, smoky, predominantly fine to medium, with locally coarse, very coarse grains, angular to subangular, elongate to subspherical, moderately to well sorted, rare dolomite lithoclasts, inferred good porosity.

CLAYSTONE 2: pale brown, locally mottled, very soft, amorphous, locally silty.

CLAYSTONE: medium to dark grey, locally speckled, firm, subfissile, blocky to irregular to splintery, smooth to earthy, locally silty grading siltstone, microcmicaceous, locally carbonaceous specks/laminations, plant fragments

SILTSTONE: pale to medium dark grey, brown grey, very speckled, soft to firm, blocky to irregular, locally argillaceous/sandy, grading claystone/sandstone, micaceous, variably carbonaceous. Trace dull yellow fluorescence, moderate diffuse white cut, no residue.

SAND: loose, quartz, colourless, translucent, occasional pale pink, yellow, orange, smoky, varying very fine to very coarse grain, predominantly fine to medium, angular to subangular, elongate to subspherical, well to moderately sorted, good inferred porosity. Locally pale brown dolomite clasts

CLAYSTONE: medium to dark grey, becoming increasingly paler grey, and pale blue/green grey, firm, subfissile to fissile, blocky to irregular to splintery to platy, smooth to earthy, locally silty grading siltstone, microcmicaceous, locally carbonaceous specks/laminations, rare disseminated pyrite.

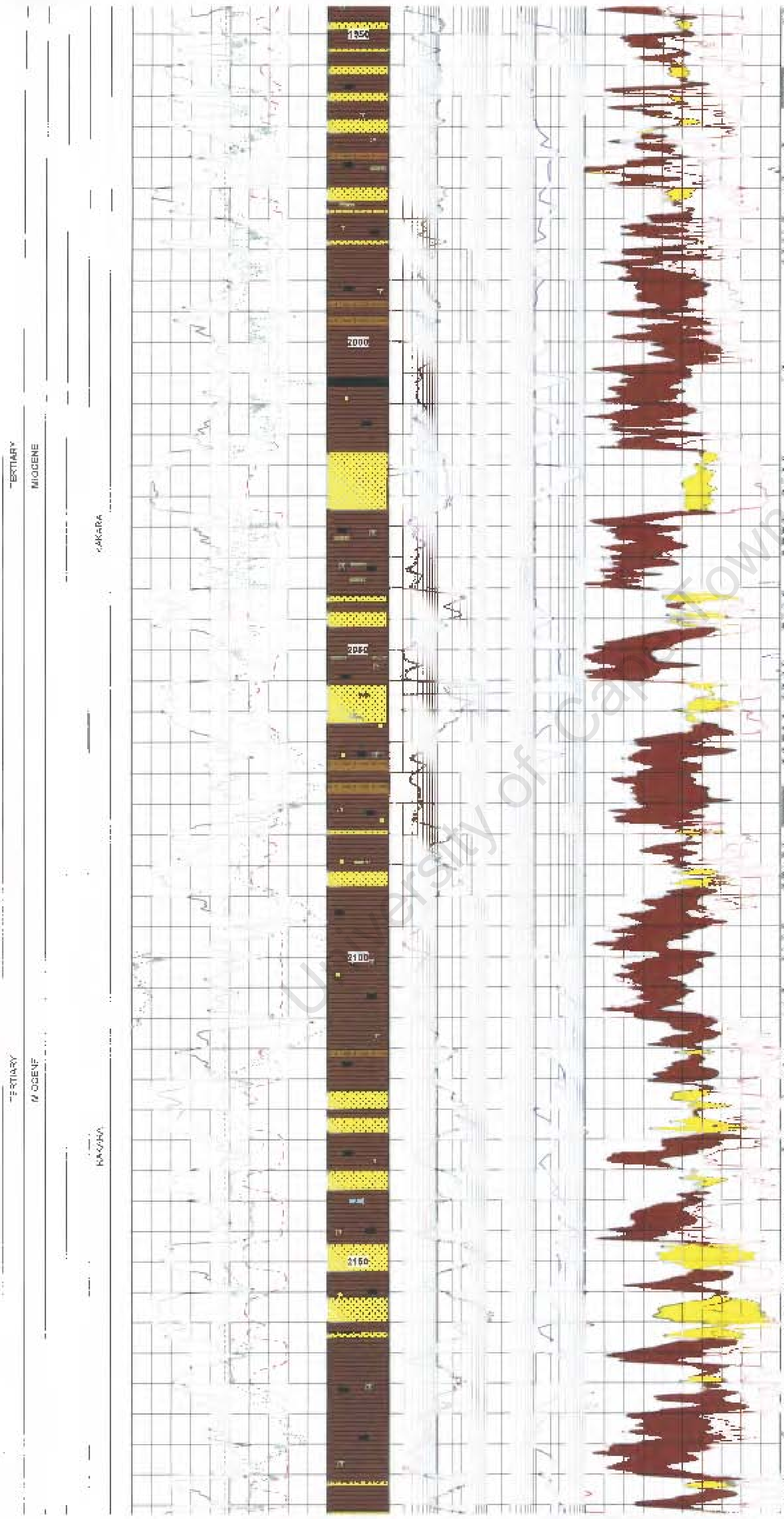
SANDSTONE: off white, very pale green grey, pale brown, locally speckled, friable to firm, quartz, very fine to fine grain, angular to subangular, elongate to spherical, well sorted, locally moderate calcareous cement, rare lithoclasts, mica, very rare glauconite, moderate visible porosity.

CLAYSTONE: predominantly pale grey and pale blue/green grey, plus medium to dark grey, brown grey, firm, subfissile to fissile, blocky to irregular to splintery to platy, smooth, locally earthy silty grading siltstone, locally microcmicaceous, locally carbonaceous specks/laminations. At 1885m rare dark brown grey claystone, no direct fluorescence, exhibiting fast blooming, bright white/yellow cut fluorescence with a white residual fluorescence

SAND: loose, quartz, colourless, translucent, rare pale pink, yellow, predominantly fine to coarse, rare very coarse, angular to round, elongate to spherical, well sorted, good inferred porosity.

SANDSTONE: off white, pale to medium grey, blocky, friable, quartz, colourless, very fine to fine grain, angular, subspherical, well sorted, silty, locally weak calcareous cement, moderate visible porosity

SANDY CLAYSTONE: Trace, pale green, speckled, friable



irregular, with floating sand grains; quartz, colourless, very fine to fine grain, angular, subspherical

Bulk sample periodically exhibiting very slow to fast blooming, bright white/yellow cut fluoresence with a white/yellow residual fluoresence. No direct fluoresence

CLAYSTONE: predominantly pale to medium grey, locally pale blue/green grey, dark grey, brown grey, firm, subfissile, blocky to irregular, rare splintery to platy, smooth, locally earthy, micromicaceous, locally carbonaceous specks/laminations, rare pyrite.

CLAYSTONE 2: black, dark brown, firm, fissile, flakey to splintery to platy to blocky very organic rich. No direct fluorescence, locally exhibiting very slow diffuse, pale white/yellow cut fluorescence, very pale yellow residual fluorescence.

COAL: black, glassy, brittle, fissile, platy to blocky to splintery.

SANDSTONE: medium grey, speckled, friable, quartz colourless, very fine grained, angular, elongate to subspherical, well sorted, silty, common lithoclasts, glauconite?; moderate visible porosity.

CLAYSTONE: pale to medium dark grey, locally pale blue/green grey, dark grey, brown grey, firm, subfissile, blocky to irregular, rare splintery to platy, smooth, locally earthy/silty micromicaceous, locally carbonaceous specks

SAND: loose, quartz, colourless, translucent, pale yellow, smoky, very fine to fine, rare medium/coarse, angular to rounded, elongate to spherical, well sorted, occasional lithoclasts, pyrite, good inferred porosity.

SILTSTONE: pale to medium grey, grey brown, speckled, friable to firm blocky to irregular, argillaceous, locally sandy, grading to very fine sandstone, micromicaceous, carbonaceous specks/laminations.

CLAYSTONE: predominantly pale to medium grey, common dark grey, brown grey, firm (paler softer), subfissile, blocky to irregular, rare splintery to platy, smooth, common earthy grading to siltstone, micromicaceous, occasional carbonaceous specks/laminations, pyrite

BULK SAMPLE: very slow, diffuse, white, cut fluorescence and faint, white, residual fluorescence. No fluorescence or cut from sandstone cuttings.

SAND: loose, quartz, colourless, translucent, very fine to medium, occasional coarse, very coarse, angular, elongate to spherical, moderately to well sorted, good inferred porosity. Finer occasionally as poorly consolidated sandstone locally with moderate calcareous or siliceous cement

SANDSTONE: white, off white, pale grey, friable, irregular, quartz, colouness, translucent, very fine, angular, elongate to subspherical, well sorted, poorly consolidated, rare carbonaceous laminations, good visible porosity. No show.

CLAYSTONE 2: pale to medium dark green/blue grey, firm, subfissile to fissile, blocky to irregular to platy to splintery, smooth, locally slightly waxy, locally micaceous. Locally mottled very irregular with very fine sand inclusions.

SAND: loose, quartz, predominantly smoky, pale orange/brown, plus colourless, translucent, milky, very fine to fine, angular to rounded (smoky/orange grains more round), elongate to spherical, well sorted, occasional pyrite coated grains, good inferred porosity.

SAND: loose, quartz, colourlesss, translucent, very fine to coarse, predominantly medium, angular to rounded, elongate to spherical, moderately well sorted, good inferred porosity.

DOLOMITE: 0.5mm thick lamination: pale brown, hard, brittle platy, microcrystalline.

CLAYSTONE 3: pale to medium brown, orange brown, very soft, amorphous, locally slightly silty.

CLAYSTONE 4: pale to medium brown, medium to dark red brown, firm, locally brittle, subfissile, irregular to splintery, earthy, micaceous

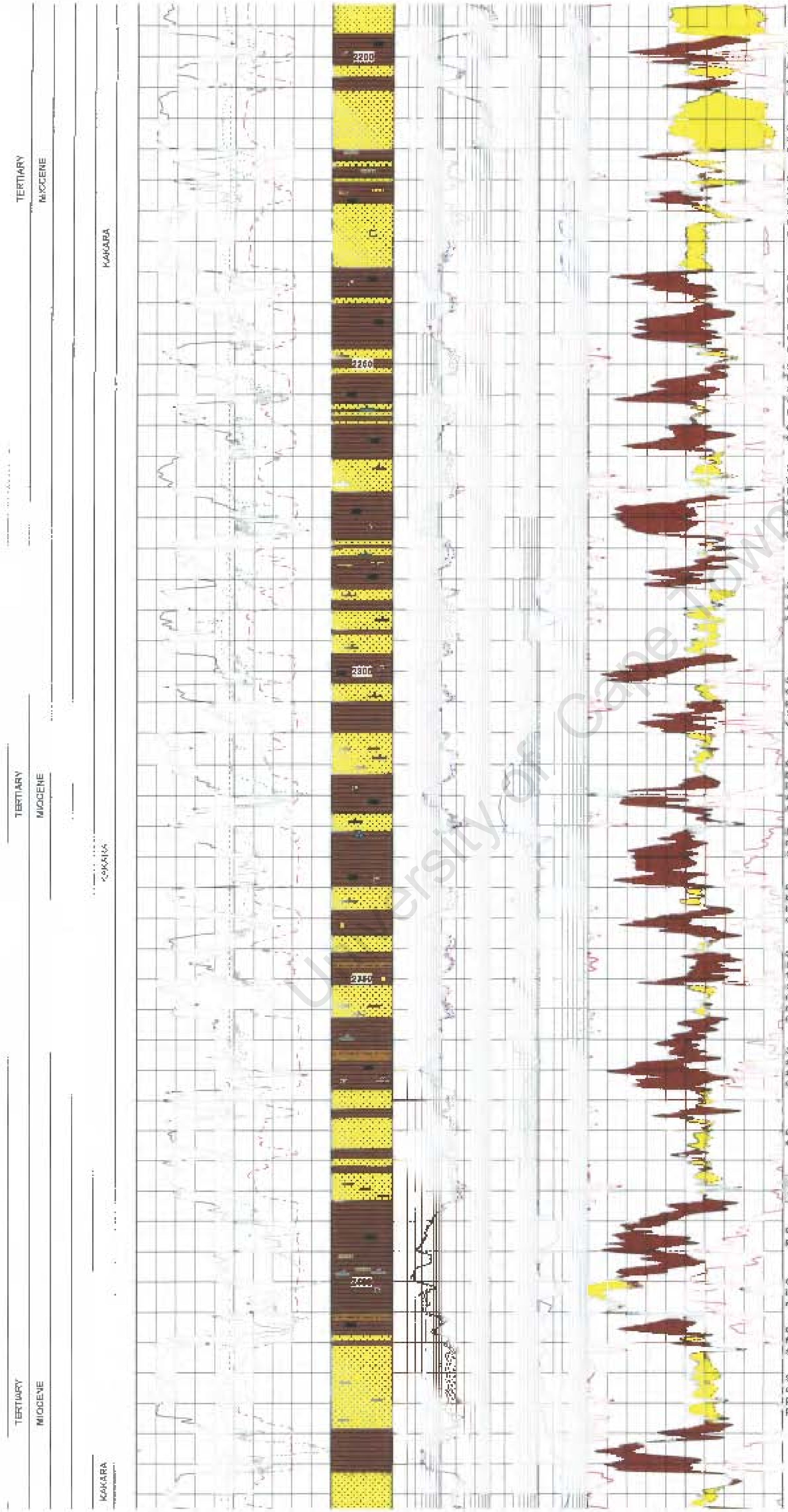
CLAYSTONE 3: very pale brown grey, off white, very soft amorphous, silty, grading siltstone.

SAND: loose, quartz, colourless, translucent, fine to very coarse, predominantly medium, angular to subrounded, elongate to spherical, well sorted, good inferred porosity

CLAYSTONE 2: pale to medium dark green/blue grey, firm, brittle, fissile, very splintery, smooth.

CLAYSTONES: varicoloured, all more homogeneous, fissile, platy to splintery, smooth.

SANDSTONE: off white, white, firm, blocky to irregular, quartz, colourless, translucent, very fine to fine, angular, subspherical, well sorted, moderate siliceous cement, poor to moderate visible porosity.



SAND: loose, quartz, colourless, translucent, fine to coarse rare very coarse, predominantly medium, fining upwards, angular to subrounded, elongate to spherical, well sorted, common brown grey argillaceous lithics, good inferred porosity.

CLAYSTONE 3: pale to medium red grey, firm, brittle subfissile, irregular to platy to splintery, smooth, micaceous.

SILTSTONE: pale brown, cream, slightly speckled, soft, amorphous, argillaceous, sandy, micaceous, locally carbonaceous. Rare sharp contact with sandstone.

SAND: loose, quartz, colourless, translucent, occasionally yellow, orange, smoky pink, fine to very coarse, variable predominance of finer and coarser grains, angular to subangular, rare subrounded, elongate to subspherical, poor to well sorted, locally lithic fragments (fine to very coarse), rare pyrite, good inferred porosity.

CLAYSTONE 1: pale to dark grey, firm, subfissile to fissile, blocky to irregular, splintery to platy, smooth to earthy, micromicaceous, locally dark grey/black carbonaceous.

CLAYSTONE 2: pale green/blue grey, rare olive green, firm, subfissile to fissile, irregular to platy to splintery, smooth to earthy, rare waxy, locally silty/sandy.

SANDSTONE: white, hard to friable, quartz, colourless, translucent, very fine to fine, locally very fine to very coarse, angular to subangular, elongate to subspherical, poorly to well sorted, moderate to strong calcite cement, rare lithics, poor to moderate visible porosity.

CLAYSTONE 3: medium yellow/brown, firm, crumbly, irregular to blocky, earthy, silty grading siltstone, micaceous.

SAND: loose, quartz, colourless, translucent, occasionally yellow, orange, smoky pink, fine to very coarse, variable predominance of finer and coarser grains, angular to subangular, rare round, elongate to subspherical, poor to well sorted, locally lithic fragments (fine to very coarse), rare pyrite, good inferred porosity. Rare very coarse and fine grains with strong calcite cement.

SILTSTONE: pale grey, slightly brown grey, slightly speckled soft and amorphous, occasional firm, blocky to irregular, argillaceous grading claystone, sandy grading to very fine sandstone, micaceous.

SAND: loose, quartz, colourless, translucent, occasional pink, orange, smoky, yellow, fine to very coarse, variable predominance of finer and coarser grains, angular to subangular, rare rounded, elongate to subspherical, poorly to well sorted, good inferred porosity.

CLAYSTONE 2: pale green/blue grey, firm, subfissile, blocky to irregular to platy to splintery, smooth to earthy, locally silty, locally micaceous, locally mottled, sandy grading argillaceous sandstone, clay matrix supported very fine to medium quartz grains.

NODULES: Pale brown spherical (<0.25mm diam) in clay matrix. White homogenous calcareous core with a siliceous/sideritic? outer layer. Organic origin pellet or eggs?.

CLAYSTONE 1: pale to medium dark grey, firm, subfissile, blocky to irregular, splintery to platy, smooth, locally earthy, locally silty, grading siltstone, variably micromicaceous, rare carbonaceous, rare disseminated pyrite.

SANDSTONE: white, off white, pale green/blue grey, pale brown, hard to friable, quartz, colourless, translucent, very fine to fine, locally very fine to very coarse, angular to subangular, elongate to subspherical, poorly to well sorted, moderate to strong calcite cement, locally argillaceous/silty matrix, occasionally matrix supported, rare lithics, poor to moderate visible porosity.

SILTSTONE: pale to medium grey, off white, cream, speckled, firm, irregular, argillaceous, sandy grading very fine sandstone, micaceous, locally carbonaceous, locally dolomitic.

CLAYSTONE 3: pale brown, soft, amorphous, slightly plastic earthy, slightly silty, locally dolomitic.

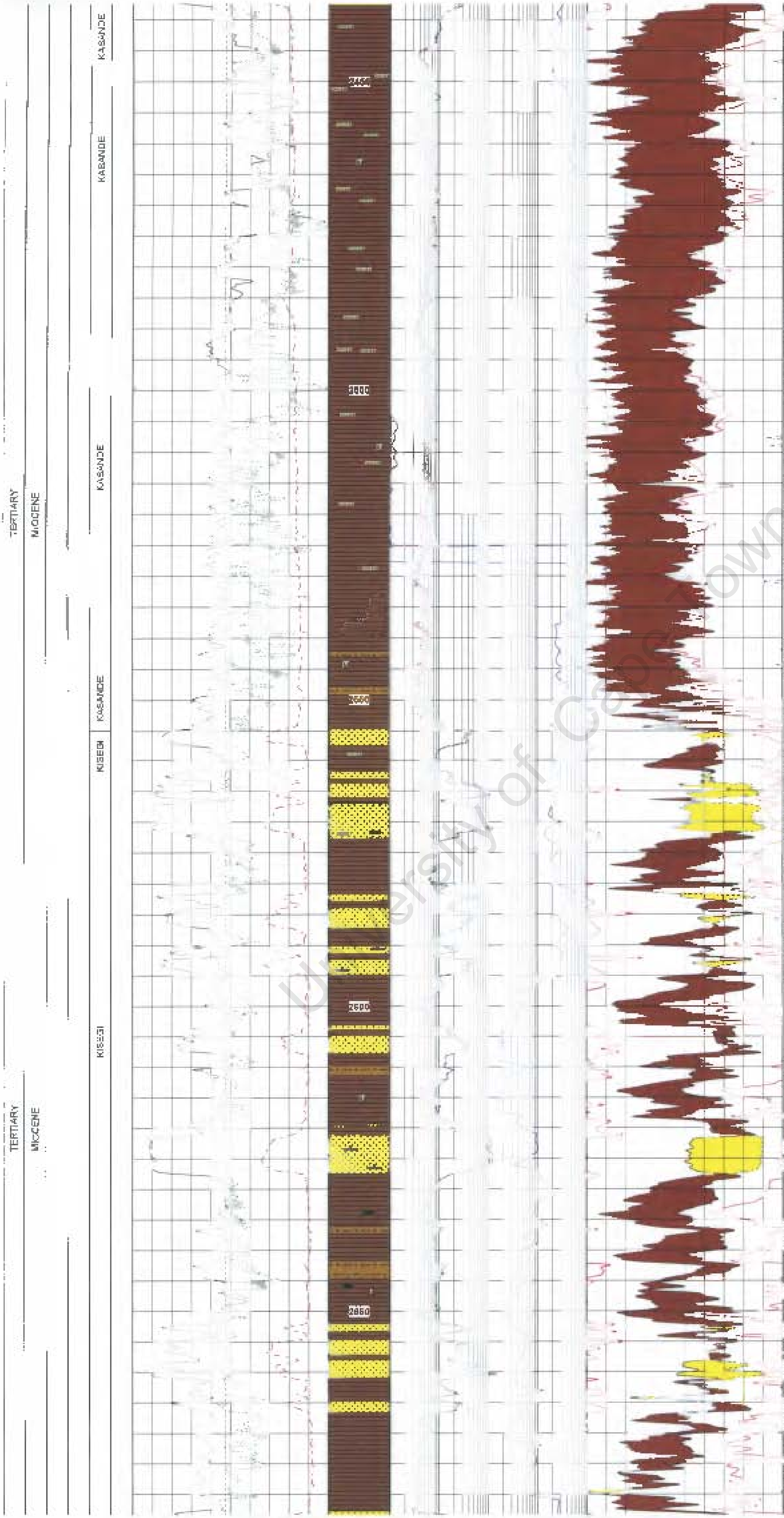
Bulk sample periodic very slow diffuse pale yellow fluorescence; faint pale yellow residual fluorescence

CLAYSTONE 3: (2382m) orange brown, firm, very brittle, platy, smooth, iron rich

CLAYSTONE 4: medium to dark red brown, firm, blocky to irregular, earthy, silty, micaceous. Rare pale brown, moderately hard, smooth, blocky, dolomitic.

CLAYSTONE 2: pale, occasionally medium green/blue grey, firm, subfissile, platy to splintery, locally blocky to irregular, smooth, locally mottled, irregular, sandy.

SAND: loose, quartz, colourless, translucent, very fine to very coarse, angular to subangular, elongate to subspherical, poorly sorted, occasional pale brown lithics, good inferred porosity.



CLAYSTONE: pale to medium dark grey, firm to moderately hard, locally soft, blocky to subblocky, locally splintery, smooth, waxy, very occasionally micromicaceous, non calcareous.

CLAYSTONE 2: pale to medium green/blue grey, firm, subfissile, platy to splintery, locally blocky to irregular, smooth, non calcareous.

CLAYSTONE 4: dark reddish brown, occasionally medium red brown, firm to moderately hard, blocky to subblocky, splintery, smooth, waxy, non calcareous.

CLAYSTONE 3: yellow brown, firm to moderately hard, crumbly break, earthy, occasionally subfissile, non calcareous, locally microlaminated, very slightly hygroscopic in parts, slightly silty.

Bulk sample periodic, very slow, diffuse, pale yellow fluorescence, faint pale yellow residual fluorescence.

TRACE SILTSTONE: pale brown, firm, friable, crumbly break, earthy, non calcareous.

CLAYSTONE: pale to medium dark grey, dark brownish grey, firm to moderately hard, blocky to subblocky, smooth, slightly waxy, non calcareous.

CLAYSTONE 2: pale to medium green/blue grey, firm to moderately hard, blocky to subblocky, locally crumbly, smooth, non calcareous.

SAND: transparent to translucent, white, orange, very fine, well sorted, angular to subrounded, subspherical, loose, quartz, moderate inferred porosity, no direct fluorescence, weak, slow, dull yellow cut.

SILTSTONE: light brownish grey, very soft, crumbly to locally subfissile break, non calcareous, slightly carbonaceous, locally grading to very fine Sandstone.

CLAYSTONE: pale to medium dark grey, occasionally brownish grey, firm to moderately hard, subfissile, blocky to subblocky, smooth, locally occasionally micromicaceous, non calcareous.

CLAYSTONE 2: pale to medium green/blue grey, soft to firm, predominantly crumbly to occasionally subblocky, locally waxy, non calcareous, locally grading to Siltstone.

SAND: transparent to translucent, very fine to coarse, predominantly very fine to fine, moderately sorted, angular to subrounded, subspherical, loose, quartz, moderate to good inferred porosity.

SANDSTONE: white to off white, transparent to translucent, very fine to fine, well sorted, angular to subrounded, subspherical, friable to firm, quartz, weak silica cement, moderate visible porosity, oil stained, moderate uniform white fluorescence, moderate instant white cut.

CLAYSTONE: pale to medium dark grey, occasionally medium brownish grey, pale grey, firm to moderately hard, blocky to subblocky, non calcareous, smooth.

SANDSTONE: white to off white, transparent to translucent, very fine to fine, well sorted, angular to subrounded, subspherical, friable to firm, locally moderately hard, quartz, moderately cemented with silica and calcite, moderate visible porosity, dull yellow fluorescence, no cut, dull yellow crush cut.

SILTSTONE: pale brown to occasional reddish brown, pale grey, firm to moderately hard, crumbly break, local carbonaceous specks and partings, non calcareous.

SANDSTONE: white to off white, mottled grey, transparent to translucent, very fine to fine, well sorted, angular to subrounded, subspherical, friable to firm, weak silica cement, locally moderately hard, moderate silica and calcite cement, quartz, moderate visible porosity, no direct fluorescence, weak slow cut, dull yellow crush cut.

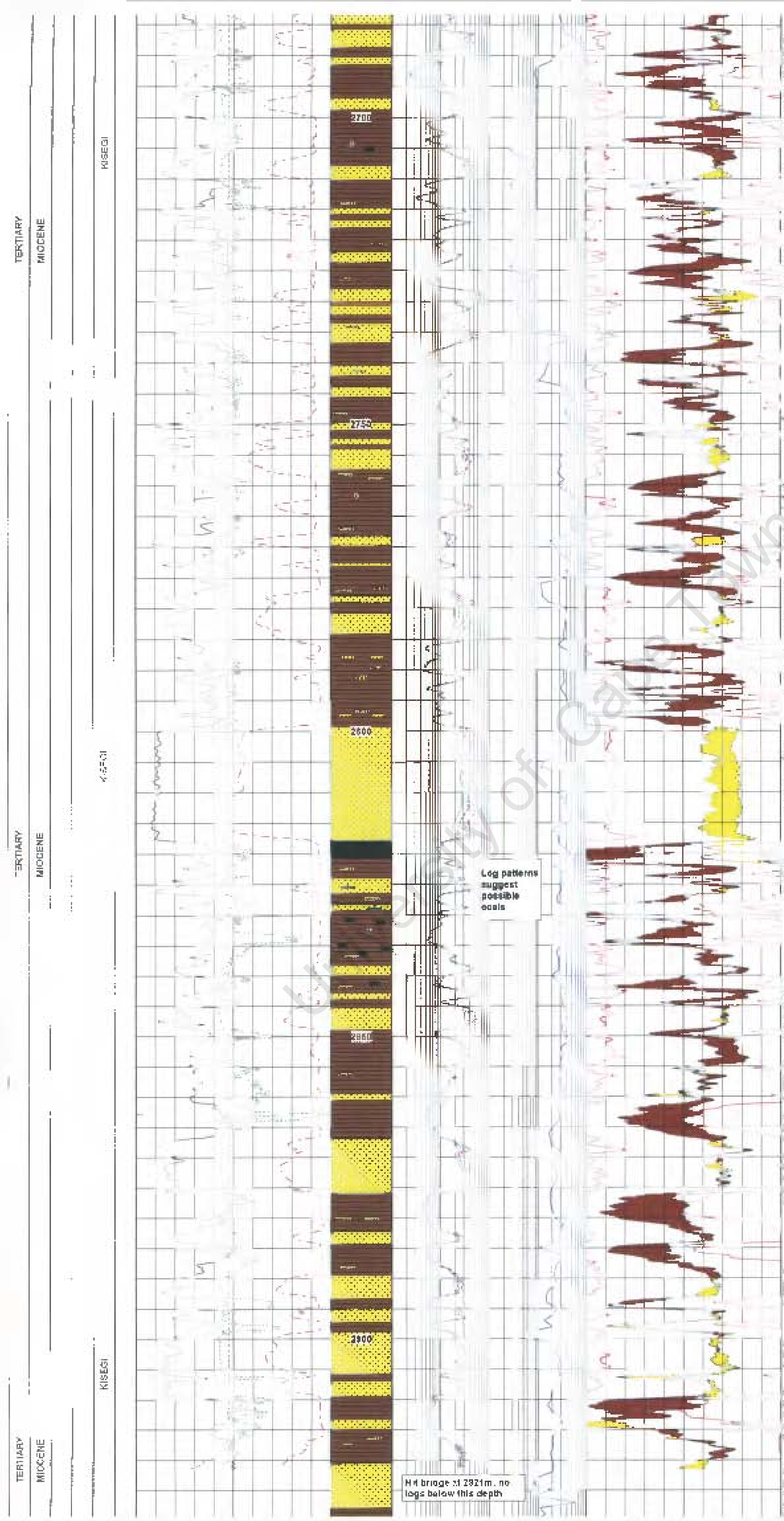
CLAYSTONE: pale to medium dark grey, occasionally brownish grey, firm to moderately hard, subfissile, blocky to subblocky, smooth, locally micromicaceous, non calcareous, locally disseminated pyrite.

CLAYSTONE 2: pale to medium green/blue grey, soft to firm, predominantly crumbly to occasionally subblocky, locally waxy, non calcareous, locally grading to Siltstone.

SANDSTONE: white to off white, transparent to translucent, very fine to fine, well sorted, angular to subrounded, subspherical, friable to firm, weak silica cement, quartz, moderate visible porosity, no direct fluorescence, no cut, dull yellow crush cut.

SAND: transparent to translucent, very fine to coarse, poorly sorted, angular to subrounded, subspherical, loose, quartz, moderate to good inferred porosity.

CLAYSTONE: pale to medium dark grey, occasionally brownish grey, firm to moderately hard, subfissile, blocky to subblocky, smooth, locally micromicaceous, non calcareous, occasionally microcarbonaceous, locally grading to Siltstone.



Log patterns suggest possible coals

Hit bridge at 2921m, no logs below this depth

CLAYSTONE 2: pale to medium green/blue grey, soft to firm, predominantly crumbly to occasionally subblocky, locally waxy, non calcareous, occasional carbonaceous specks or partings, locally grading to Siltstone.

SANDSTONE: white to off white, transparent to translucent, very fine to fine, occasionally medium, moderately sorted, angular to subrounded, subspherical, friable to firm, weak silica cement, quartz, moderate visible porosity, no direct fluorescence, no cut, dull yellow crush cut.

SAND: transparent to translucent, very fine to coarse, poorly sorted, angular to subrounded, subspherical, loose, quartz, moderate to good inferred porosity.

SILTSTONE: pale brown grey, very soft to soft, crumbly break, non calcareous, locally carbonaceous specks or partings.

CLAYSTONE: pale to medium dark grey, occasionally brownish grey, firm to moderately hard, subfissile, blocky to subblocky, smooth, locally micromicaceous, non calcareous, occasionally micro carbonaceous, locally grading to Siltstone.

SAND: transparent to translucent, predominantly fine to locally medium, well sorted, subangular to rounded, spherical, loose, quartz, good inferred porosity, no shows.

CLAYSTONE: pale to medium dark grey, medium brownish grey, firm to moderately hard, non calcareous, smooth, locally slightly silty, locally pyritic.

SILTSTONE: medium grey to pale grey, firm, crumbly break, non calcareous, carbonaceous specks.

SAND: transparent to translucent, fine, very well sorted, subangular to rounded, spherical, loose, quartz, locally trace calcite, good inferred porosity; 2782m to 2785m: uniform moderate yellow fluorescence, moderate fast blooming cut, no oil residue.

CLAYSTONE: pale to medium dark grey, medium brownish grey, below 2790m becoming increasingly dark brown grey, dark grey, firm to moderately hard, blocky to subblocky, platy, non calcareous, smooth, increasingly carbonaceous.

SHALE: black, firm, brittle, fissile, vitreous lustre.

SANDSTONE: white to off white, pale brown grey, transparent to translucent, locally pale green, very fine to fine, occasionally medium, moderately sorted, angular to subrounded, subspherical, friable to moderately hard, good calcite cement, locally clay cemented, quartz, local black carbonaceous laminae, poor visible porosity, no shows.

CLAYSTONE: medium to dark brown grey, medium grey, firm to moderately hard, blocky to subblocky, smooth, non calcareous.

SAND: transparent to translucent, predominantly fine to occasionally medium, angular to subrounded, subspherical to spherical, loose, quartz, very occasionally consolidated, moderately cemented with calcite, moderate to good porosity, no shows.

CLAYSTONE 2: pale green to pale green grey, locally grading pale yellow brown, very occasionally mottled dark red brown, firm to moderately hard, crumbly to subblocky, smooth, locally waxy, non calcareous.

CLAYSTONE 4: dark red brown, purple, firm to moderately hard, crumbly to subblocky, smooth, locally waxy, locally earthy, non calcareous.

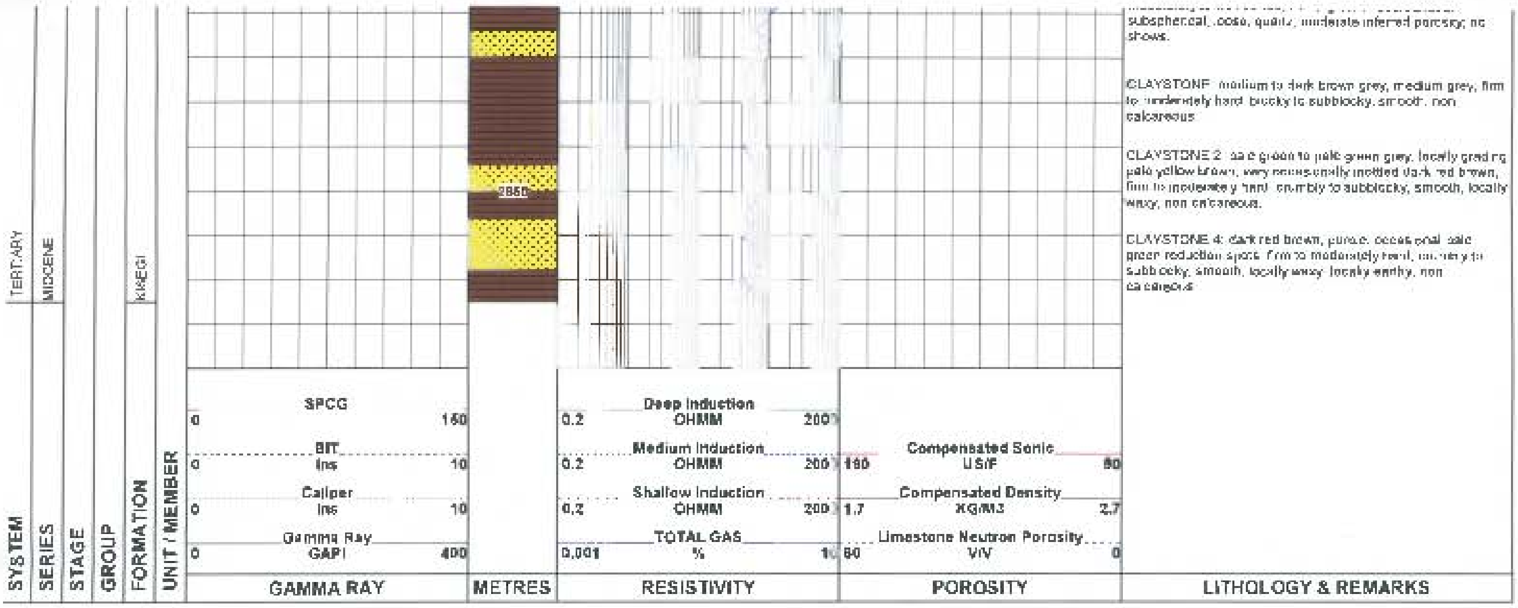
SAND: transparent to translucent, very fine to predominantly fine, occasionally medium, moderately sorted, subangular to subrounded, spherical, loose, quartz, local calcite cement, good inferred porosity, no direct fluorescence, slow, dull yellow cut.

CLAYSTONE 2: pale green to pale green grey, locally grading pale yellow brown, very occasionally mottled dark red brown, firm to moderately hard, crumbly to subblocky, smooth, locally waxy, non calcareous.

CLAYSTONE 4: dark red brown, purple, firm to moderately hard, crumbly to subblocky, smooth, locally waxy, locally earthy, non calcareous.

SAND: transparent to translucent, very fine to predominantly fine, occasionally medium, moderately sorted, subangular to subrounded, spherical, loose, quartz, local calcite cement, good inferred porosity, no direct fluorescence, slow, dull yellow cut.

SAND: bimodal: transparent to translucent, very fine to predominantly fine, moderately sorted, subangular to subrounded, spherical, loose, quartz, local calcite cement, good inferred porosity; also medium to predominantly coarse, moderately to well sorted, subangular to subrounded



subspherical, loose, quartz, moderate inferred porosity, no shows.

CLAYSTONE: medium to dark brown grey, medium grey, firm to moderately hard, blocky to subblocky, smooth, non calcareous

CLAYSTONE 2: pale green to pale green grey, locally grading pale yellow brown, very occasionally mottled dark red brown, firm to moderately hard, crumbly to subblocky, smooth, locally waxy, non calcareous.

CLAYSTONE 4: dark red brown, purple, occasional pale green reduction spots, firm to moderately hard, crumbly to subblocky, smooth, locally waxy, locally earthy, non calcareous