



بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

Sudan University of Science & Technology  
College of Petroleum Engineering & Mining



Department of Petroleum Exploration

Experimental study to detect clay minerals using  
core analysis (XRD&SEM)

دراسة تجريبية للكشف عن المعادن الطينية باستخدام تحليل اللباب  
(XRD&SEM)

This dissertation is submitted as partial requirement of B.SC  
degree (Honor) in exploration engineering

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## الآية

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

﴿ اقْرَأْ بِاسْمِ رَبِّكَ الَّذِي خَلَقَ \* خَلَقَ الْإِنْسَانَ مِنْ عَلَقٍ \* اقْرَأْ  
وَرَبُّكَ الْأَكْرَمُ \* الَّذِي عَلَّمَ بِالْقَلَمِ \* عَلَّمَ الْإِنْسَانَ مَا لَمْ يَعْلَمْ ﴾

صدق الله العظيم

## Abstract

This research focuses on the sedimentological and petrographical analyses on Core-1 intervals (447.46m – 456.00m) and Core-2 intervals (515.00m – 545.33m) at X well, Y Basin, Sudan.

The sedimentological investigations such as scanning electron microscope and X-Ray Diffraction analyses were carried out at reservoir beds from the above mentioned two core intervals with total length of 19.63m, apart from the preserved intervals, at X well.

In addition to that, significant quantities of Kaolinite and some amounts of iron oxide as authigenic minerals were detected in most of the investigated reservoir beds. The clay mineral analysis (XRD) revealed that the studied strata are essentially composed of kaolinite with few amounts of chlorite, illite, smectite and mixed layer clay minerals.

The vertical arrangements of the studied two core facies sequences retrieved from X well logs; suggest deposition in both fluvial (braided and meandering) and deltaic distal channels' depositional environments. Moreover, the higher amounts of the kaolinite in the studied core; suggest most probably intensity of chemical weathering and leaching processes under warm humid climate. The increase of the authigenic kaolinite clay minerals and iron oxides minerals in the studied reservoir sand beds contribute towards decrease of the reservoir porosity at the studied well. On the other hand, Partial dissolution of feldspars and mica during the diagenesis produce a fair to good reservoir at some depths of X well.

## ألتجريد

يركز هذا البحث على التحليلات الرسوبية والبتروغرافية على عمق العينه رقم(1)(447.46-456.00متر) وعمق العينه رقم (2)(515.00-545.33متر) بئر X بحوض Y.

حيث تم إجراء الفحوصات لعينات اللباب الصخري بأستخدام جهاز المسح الالكتروني وتحليل حيود الاشعه السينية في الاعماق المذكوره اعلاها والتي يبلغ طولها (19.63متر) في البئر X . حيث تم الكشف عن كميات كبيره من الكاوليين وبعض من أكسيد الحديد كمعادن متأصلة في معظم طبقات المكن التي تم كشفها .وأظهر التحليل المعدني للطين ان طبقات المكن تتكون بصوره اساسيه من الكاولينيت وكميات قليله من (الكوريت,الإيلايت والسميكتايت).

حيث يؤدي وجود المعادن الطينيه الى تقليل مسامية الخزان ومن ناحيه اخرى يؤدي الانحلال الجزئي لمعدني الفلسبار والمايكا الى زيادات المخزون النفطي في بعض مناطق البئر X.

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## Nomenclature

CEC	: Cation Exchange Capacity
QV	: Total Pore Volume
SEM	: Scanning Electron Microscope
XRD	: X-Ray Diffraction
SW	: Water Saturation
SO	: Oil Saturation
SG	: Gas Saturation
IUCR	: International Union of Crystallography



# CHAPTER 1

## Introduction

# Chapter 1

## Introduction

### 1.1 Introduction

Reliable evaluation of hydrocarbon resources encountered in shaly clastic reservoirs of low porosity and low permeability is an important although difficult task.

Log-derived estimates of the volume type and distribution modes of various clay minerals determination of cation exchange capacity (CEC) and  $Q_v$  (CEC per unit of total pore volume) and properly selected water saturation calculation models assist formation evaluation.

Since shaly clastic reservoir rocks require extensive core sampling for CEC and  $Q_v$  analysis which is tedious time consuming and expensive attempts have been made to correlate such CEC and  $Q_v$  data with one specific or a combination of several well logging measurements. The latter include the spontaneous potential gamma ray natural gamma ray spectral data dielectric constant and acoustic density and/or neutron-derived porosity etc.

**Clay Minerals** Clay minerals used as a rock and particle term describe an earthy fine-grained natural material which develops plasticity when mixed with a small amount of water. Such clay minerals significantly affect important reservoir properties such as porosity water saturation and permeability. Clay minerals are composed of small crystalline particles which are classified according to their crystal particles which are classified according to their crystal structure.

Important ones of interest to the petroleum engineer and geologist are kaolinite montmorillonite illite chlorite and mixed layer minerals. They are essentially layered hydrous aluminium silicates which may contain small amounts of alkalies and alkaline earths and have some substitution of aluminium by other cations such as magnesium iron etc.

The most common clay minerals their composition matrix density hydrogen index CEC and distribution of potassium thorium and uranium based on natural gamma ray spectral Numerous experimental data show that the CEC value of clays is directly related to their capacity to absorb and hold water. Clays of the montmorillonite (smectite) group have the greatest capacity to absorb water and also the highest CEC values. Kaolinite and chlorite have very low CEC and their capacity to hold water is also low. Shale can be defined as an earthy fine grained sedimentary rock with a specific laminated character. Based on the analyses of 10,000 shales Yaalon describes the mineral composition of the average shale as follows: clay minerals (predominantly illite) 59%; quartz and chert 20%; feldspar 81%; carbonates 71%; iron oxides 30%; organic materials 1%; others 2%. Generally speaking illite appears to be the

dominant clay mineral in most of the shales investigated. Chlorite mica is frequently present smectite is a common component in Mesozoic and younger shales and kaolinite usually occurs in small amounts only. Therefore a typical shaly clastic reservoir rock and/or a typical shale formation may consist of several components. Hence no universal shale parameter can be used to

Characterize a specific type of argillaceous sediment or rock.

Clay Types and Distributions: In discussions of shaly sands, a distinction is usually made between the terms clay and shale (See discussion in Chapter 10). In this discussion “clay” or “dry clay” will be used to refer to dehydrated clay minerals, and “shale” will be used to refer to hydrated clay materials. The potter Works with wet clay, but you eat off china (dry clay). In some of the literature, the terms are used interchangeably, which can confuse the issue. The effect of shale on the response of standard log -ging tools depends on:

- The distribution of the clay material
- The type of clay material
- The amount of clay material
- The salinity of the formation water
- The water saturation

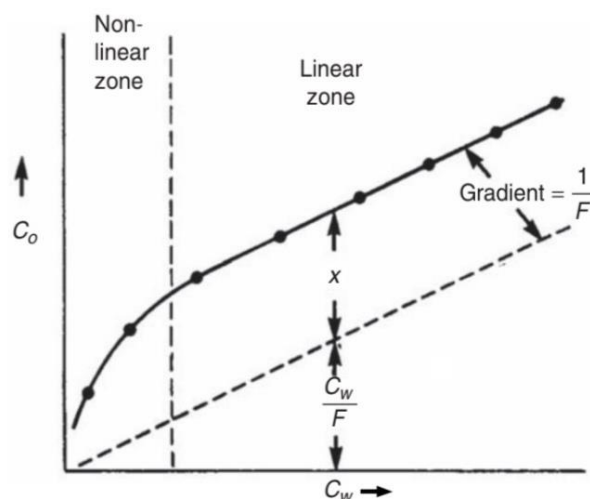


Fig 1.1  $C_w$  Vs  $C_o$  for shaly sand (worthington1985).Reprinted by permission from the SPWLA .

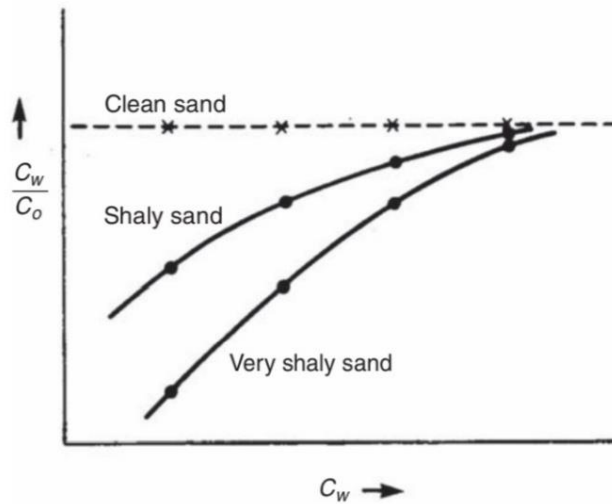


Fig 1.2 CJs as a function of  $C_o$  and shale content (worthington1985).Reprinted by permission from the SPWLA.

Distribution: Fig. 1.3 illustrates three different ways in which clay materials may be

1- Dispersed shale is an inexact term used to describe clay overgrowths on the matrix material (For example, sand grains). These clay particles reduce porosity and permeability within the pore structure of the sandstone.

2-Laminated shale can occur as layers of compacted clay, mudstone, or siltstone and meets this model definition provided that it has zero effective porosity. In a laminated sand/shale sequence, an added complication can be the matter of logging-tool bed resolution.

3-Structural shale is a term used to describe the random replacement of grains of primary matrix Material with fragments of lithified reworked shale.

Clay Types:

There are two ways of defining shales. One is by grain size, and the other is by mineralogical description. For example, the standard definitions by grain size (diameter) are:

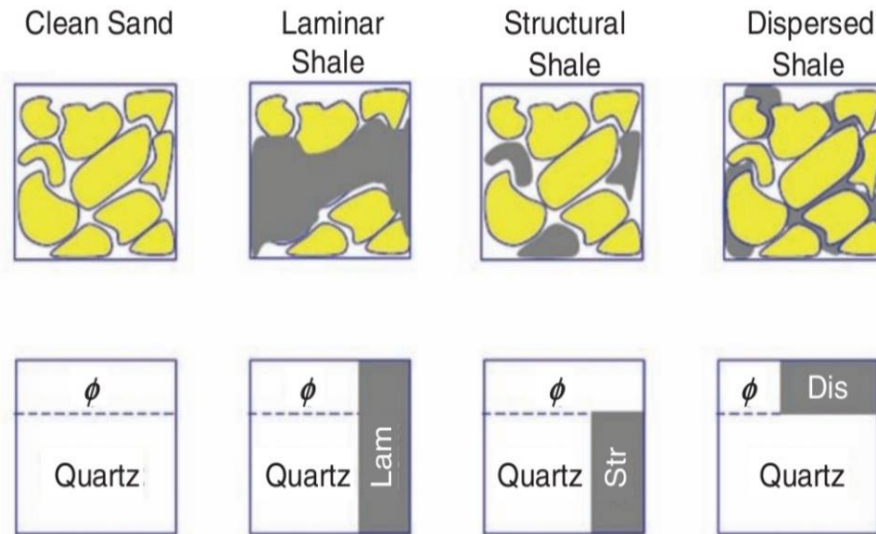


Fig 1.3 Physical models of shale distribution.

- Sand: 0.05 to 2 mm (50 to 2000  $\mu\text{m}$ )
- Silt: 0.004 to 0.05 mm (4 to 50  $\mu\text{m}$ )
- Clay: less than 0.004 mm (less than 4  $\mu\text{m}$ )

Mineralogical analysis defines the common clay minerals as:

- Montmorillonite (smectite)
- Illite
- Kaolinite
- Chlorite

These are various molecular arrangements of aluminosilicates with various quantities of quartz

And feldspar, which can be subclassified further by their origin:

Detrital clays are deposited with the sandstone at the time the sediments are laid down.

Antigenic clays appear as precipitates from solution at a later time.

A schematic of the molecular building blocks and their various arrangements to form clay crystals is shown in Fig. 1.4.

The most important aspect of these minerals is their ability to hold adsorbed water on their grain surfaces. Table 1.1 lists the specific areas of porous formations.

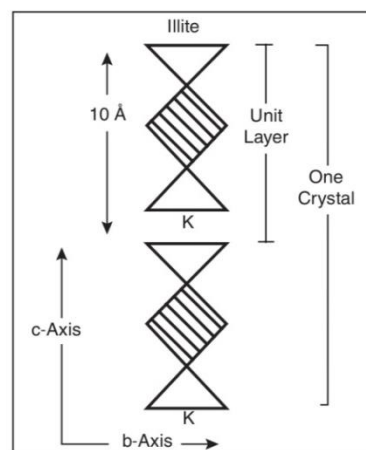
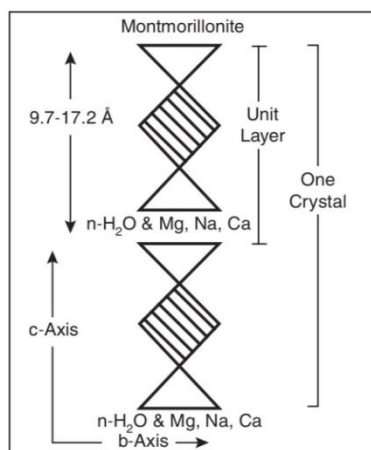
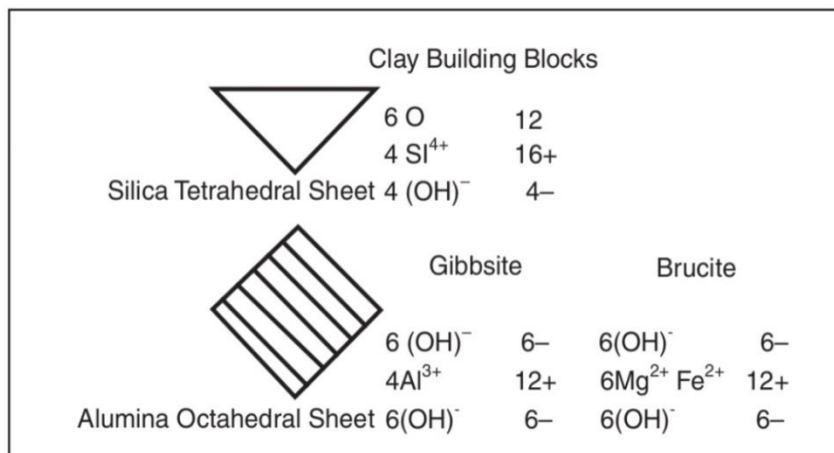
Fig. 1.5 generalizes the relationship between grain size and grain surface area. As grain diameter decreases, so too does pore-throat radius.

As noted in Chapter 6, this decrease in pore-throat radius is accompanied by an increase in capillary pressure and hence an increase in the amount of water that can be imbibed into the system.

When silt- and clay-sized particles are present, micro porosity accounts for a large percentage of total porosity. Under these circumstances, irreducible water saturation can be very high. To provide a visual understanding of where and how the micropore system develops, Fig. 1.6 shows SEM photos of the major clay types.

Crystal surfaces have what are known as exchange sites, where ions can temporarily reside because of the charge imbalance on the external surface of the clay's molecular building blocks. These exchange sites effectively offer an electrical path through the clay by means of surface conductance.

A dry clay is an insulator of course but a wet clay is not. The CEC can be measured to quantify the conductivity of wet clays. It will come as no surprise to find that the larger the specific surface area, the larger is the CEC; or in other words, the clay type per se is not important only its specific surface area. Even quartz sand grains, if sufficiently small, exhibit surface



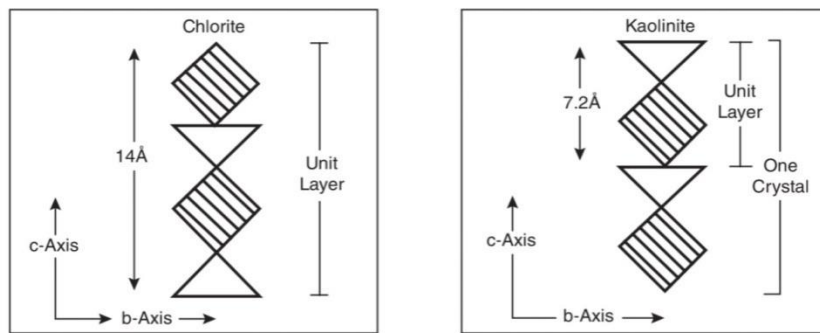


Fig 1.4 Schematic of crystal structure After Moore(1960)

Formation	$\text{m}^2/\text{cm}^3$	acres/ $\text{ft}^3$
Montmorillonite	900	6300
Illite	280	1960
Kaolinite	50	350
Sands (100 grains)	—	0.1 to 0.2

Conductance and can be ascribed a CEC value. Fig. 1.5 shows the relation between CEC and surface area.

Unfortunately, log measurements do not permit direct measurement of either CEC or surface area. Table 1.2 lists the properties of, and log responses to, the common clay minerals. It can be seen that there is no general correlation between the CEC or specific-area numbers and any one clay indicator. Perhaps the best hope for determining clay type from logs is to note that the least electrically active clays have a large neutron-density difference and the most active clays have a small one.



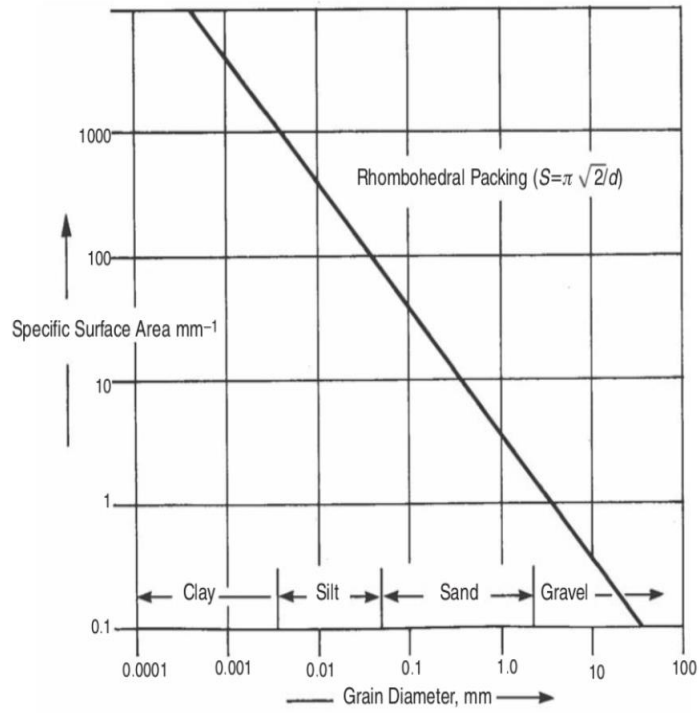


Fig. 1.5—Specific grain surface area as a function of grain diameter for granular formations.

Kaolinite



Chlorite



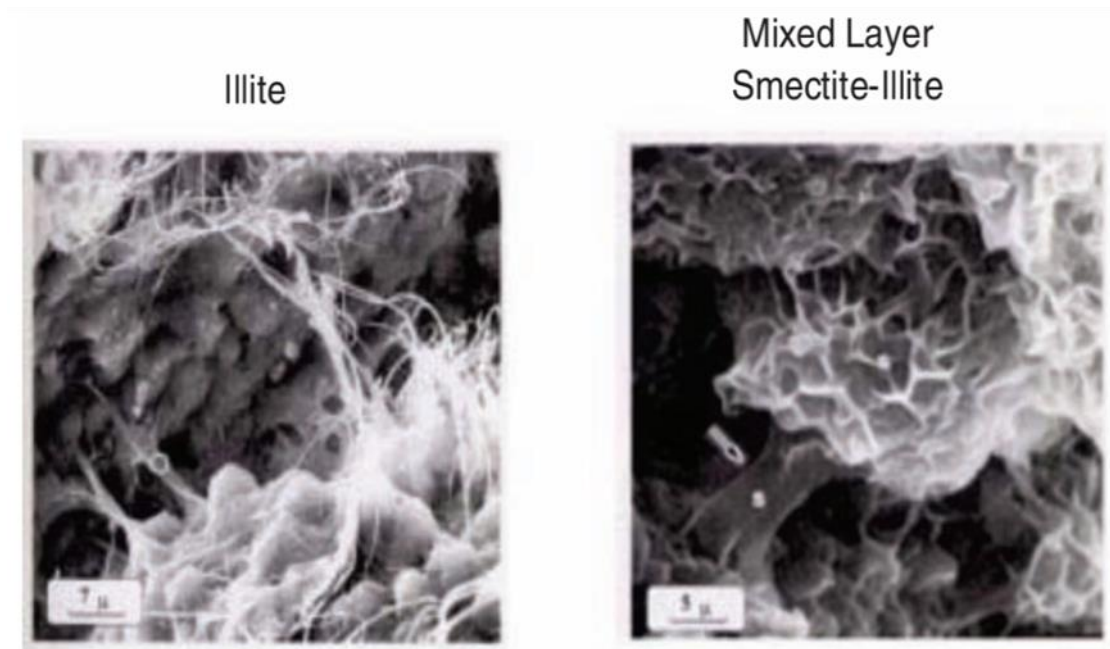


Fig. 1.6—SEM photos of the major clay types and associated microspore structure

## 1.2 Problem Statement:

The clay swelling effects on the reservoir quality, porosity, permeability, flow rate. And also many effect on drilling operations in conventional oil production and in enhanced oil recovery.

## 1.3 Research objectives:

1. The major cause for permeability and porosity reduction due to clay minerals in hydrocarbon reservoirs.
2. Identification and classification of clay minerals
3. Estimation of clay minerals in Core-1 intervals (447.46m – 456.00m) and Core-2 intervals (515.00m – 545.33m) at X well, Y Basin, Sudan.
4. Effective of clay minerals on the reservoir flow rate



# CHAPTER 2

## Background & Literature Review

## Chapter 2

# Background & Literature Review

### 2.1 Background:

#### 2.1.1 X-ray Diffraction (XRD):

Barbara L Dutrow, Louisiana State University, Christine M. Clark, Eastern Michigan University

What is X-ray Diffraction (XRD)?

X-ray diffraction (XRD) is a rapid analytical technique primarily used for phase identification of a crystalline material and can provide information on unit cell dimensions. The analyzed material is finely ground, homogenized, and average bulk composition is determined.

Fundamental Principles of X-ray Diffraction (XRD)

Max von Laue, in 1912, discovered that crystalline substances act as three-dimensional diffraction gratings for X-ray wavelengths similar to the spacing of planes in a crystal lattice.

X-ray diffraction is now a common technique for the study of crystal structures and atomic spacing.

X-ray diffraction is based on constructive interference of monochromatic X-rays and a crystalline sample. These X-rays are generated by a cathode ray tube, filtered to produce monochromatic radiation, collimated to concentrate, and directed toward the sample. The interaction of the incident rays with the sample produces constructive interference (and a diffracted ray) when conditions satisfy Bragg's Law ( $n\lambda=2d \sin \theta$ ). This law relates the wavelength of electromagnetic radiation to the diffraction angle and the lattice spacing in a crystalline sample. These diffracted X-rays are then detected, processed and counted. By scanning the sample through a range of  $2\theta$  angles, all possible diffraction directions of the lattice should be attained due to the random orientation of the powdered material. Conversion of the diffraction peaks to d-spacing allows identification of the mineral because each mineral has a set of unique d-spacings. Typically, this is achieved by comparison of d-spacing's with standard reference patterns.

All diffraction methods are based on generation of X-rays in an X-ray tube. These X-rays are directed at the sample, and the diffracted rays are collected. A key component of all diffraction is the angle between the incident and diffracted rays. Powder and single crystal diffraction vary in instrumentation beyond this.

## **2.1.2 X-ray Diffraction (XRD) Instrumentation - How Does It Work?**

X-ray diffractometers consist of three basic elements:

- 1-X-ray tube
- 2-sample holder
- 3-X-ray detector.

## **2.1.5 Applications:**

X-ray diffraction is most widely used for the identification of unknown crystalline materials (e.g. minerals, inorganic compounds). Determination of unknown solids is critical to studies in geology, environmental science, material science, engineering and biology.

Other applications include:

## **2.1.6 Characterization of crystalline materials:**

- 1- Identification of fine-grained minerals such as clays and mixed layer clays that are difficult to determine optically
- 2-determination of unit cell dimensions
- 3-measurement of sample purity

## **2.1.7 With specialized techniques, XRD can be used to:**

- 1-determine crystal structures using Rietveld refinement
- 2-determine of modal amounts of minerals (quantitative analysis)

## **2.1.8 Characterize thin films samples by:**

- 1-determining lattice mismatch between film and substrate and to inferring stress and strain
- 2-determining dislocation density and quality of the film by rocking curve measurements
- 3- Measuring superlattices in multilayered epitaxial structures
- 4-determining the thickness, roughness and density of the film using glancing incidence X-ray reflectivity measurements
- 5-make textural measurements, such as the orientation of grains, in a polycrystalline sample

## **2.2 Literature:**

The following literature can be used to further explore X-ray Powder Diffraction (XRD)

Bish, DL and Post, JE, editors. 1989. Modern Powder Diffraction. Reviews in Mineralogy, v. 20. Mineralogical Society of America. Cullity, B. D. 1978. Elements of X-ray diffraction. 2nd ed. Addison-Wesley, Reading, Mass.

Klug, H. P., and L. E. Alexander. 1974. X-ray diffraction procedures for polycrystalline and amorphous materials. 2nd ed. Wiley, New York.

Moore, D. M. and R. C. Reynolds, Jr. 1997. X-Ray diffraction and the identification and analysis of clay minerals. 2nd Ed. Oxford University Press, New York.

#### Related Links

For more information about X-ray Powder Diffraction (XRD) follow the links below.

For more information on XRD Methods, visit the USGS website

For additional information on X-ray basics; Materials Research Lab, University of California-Santa Barbara

Rigaku Journal; an on-line journal that describes and demonstrates a wide range of applications using X ray diffraction.

Cambridge University X-ray Tutorial

International Union of Crystallography (IUCr) Teaching Pamphlets

Introduction to X-ray Diffraction--University of California, Santa Barbara

Introduction to Crystallography--from LLNL

X-ray Crystallography Lecture Notes--from Steve Nelson, Tulane University

Reciprocal Net--part of the National Science Digital Library. Use the "Learn About" link to find animations of the structures of common molecules (including minerals), crystallography learning resources (tutorials, databases and software), resources on crystallization, and tutorials on symmetry and point groups.

Teaching Activities and Resources

Teaching activities, labs, and resources pertaining to X-ray Powder Diffraction (XRD).

X-ray techniques lab exercises from the SERC Teaching Mineralogy Collections

Weathering of Igneous, Metamorphic, and Sedimentary Rocks in a Semi-Arid Climate - An Engineering Application of Petrology - This problem develops skills in X-ray diffraction analysis as applied to clay mineralogy, reinforces lecture material on the geochemistry of weathering, and demonstrates the role of petrologic characterization in site engineering.

Teaching Guide to X-ray Diffraction at Cambridge

A Powerpoint presentation on use of XRD in Soil Science (PowerPoint 1.6MB Sep7 07) by Melody Bergeron, Image and Chemical Analysis Laboratory at Montana State University.

Brady, John B., and Boardman, Shelby J., 1995, Introducing Mineralogy Students to X-ray Diffraction Through Optical Diffraction Experiment

# CHAPTER THREE

## Material, Methodology and Data Analysis



## **CHAPTER THREE**

### **Material, Methodology and Data Analysis**

#### **3.1 The materials:**

This report focuses on the sedimentological and petrographical analyses on Core-1 intervals (447.46m – 456.00m) and Core-2 intervals (515.00m – 545.33m) at X well, Y Basin, Sudan.

#### **3.2 Methods:**

##### **3.2.1. Scanning Electron Microscopy (SEM) Analysis:**

Scanning electron microscopy (SEM) analysis was carried out on a total of six (6) chip core samples (cf., Table 3.1). The chip core samples were first cleaned in a cold chloroform to remove hydrocarbon residues, and then fixed on standard aluminum SEM stubs using sputter aluminum tape. The SEM analysis involved a detailed investigation and description for the sample material with a special focus on the pore geometry, composition as well as on the morphology of the main pore-filling authigenic minerals. Results from the SEM analysis are included in Chapter four and the characteristics of each sample are further illustrated by two photomicrographs for each examined sample (SEM Plates: 1 to 6).

##### **3.2.2. X-Ray Diffraction (XRD) Analysis:**

In this study, the clay fraction (<2 microns) as known (CF) method was applied to seven (7- XRD) core samples (cf., Table 3.1). X-ray diffraction analysis was carried out in order to identify and semi-quantitatively deduce the percentages of the different clay minerals present in the studied core intervals. Moore & Reynolds, 1997 gave comprehensive treatment of the theoretical and practical aspects of the XRD technique. However, Tucker (1988) provided a concise summary about the application and interpretation aspects. The results of the XRD analysis are included in Chapter 4 (Table 5 and Figures 5.1 to 5.7).

#### **3.3 Data Analysis:**

This study focuses on Core-1 intervals (447.46m – 456.00m) and Core-2 intervals (515.00m – 545.33m) at X well. Hence, the total length of the core is 19.63m, apart from the preserved intervals. These core intervals are parts of the Cretaceous reservoir strata in the Y Basin. A compendium of sedimentological laboratory techniques of core samples, including their depths, facies type and a list of the performed analyses, are presented in Table 1.

##### **3.3.1 SCANNING ELECTRON MICROSCOPE (SEM) ANALYSIS:**

Since the 1800s, thin section analysis of rocks using a polarizing or petrographic microscope has been a traditional tool of the geologist. Within the petrographic microscope, geologists are able to examine a two-dimensional cross section through a rock, estimate the bulk mineral composition, and make important observations regarding grain fabric and texture. However,



the actual three-dimensional grain relationships and details of the intergranular pore structure were always beyond our reach (Joann, W. 2003).

The use of SEM and EDX systems, geologists are able to look down into the grain pores, identify the clay minerals, and also examine the distribution of these minerals within the pores. Moreover, The advantages of SEM over optical petrography are ease of sample preparation, greater depth of field and high resolution (10x up to 20,000x) as pointed out (Joann, W. 2003).

### 3.3.2 XRD CLAY MINERALS ANALYSIS:

The study of the clay minerals has involved XRD analytical technique. In addition, seven (7) sandstone chip core samples from the studied core intervals have been analysed with the XRD technique (1.3.5). Three clay mineral types were identified from the size fraction less than 2 micron using the procedures of Chamley (1989) as well as Moore and Reynolds (1997).

Table 3.1: Compendium of sedimentological Lab. Techniques of two core intervals at X well, Y Basin, Sudan.

CORE NO.	DEPTH INTERVALS (m)	FACIES TYPE	PERFORMED ANALYSES	
			SEM	XRD (CF)
1	447.46 – 456.00	Sm & Fm	-	-
2	515.00	Sm	1	1
	522.30	Sm	1	1
	524.50	Sm	1	1
	526.70	Sm	1	1
	530.30	Sm	1	1
	540.10	Sm	1	1
	545.00	Sm	-	1
<b>Total Thickness / Analysis</b>			<b>6</b>	<b>7</b>

Abbreviations for performed analyses: SEM: Scanning Electron Microscope Analysis and XRD (CF): X-Ray Diffraction Analysis of the <2 Micron Clay Fraction.



# CHAPTER FOUR

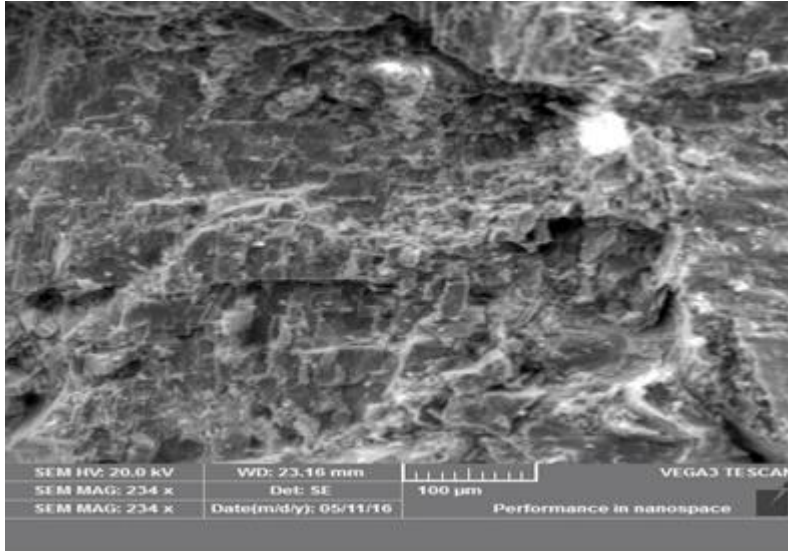
## Results and Discussion

## CHAPTER FOUR Results and Discussion

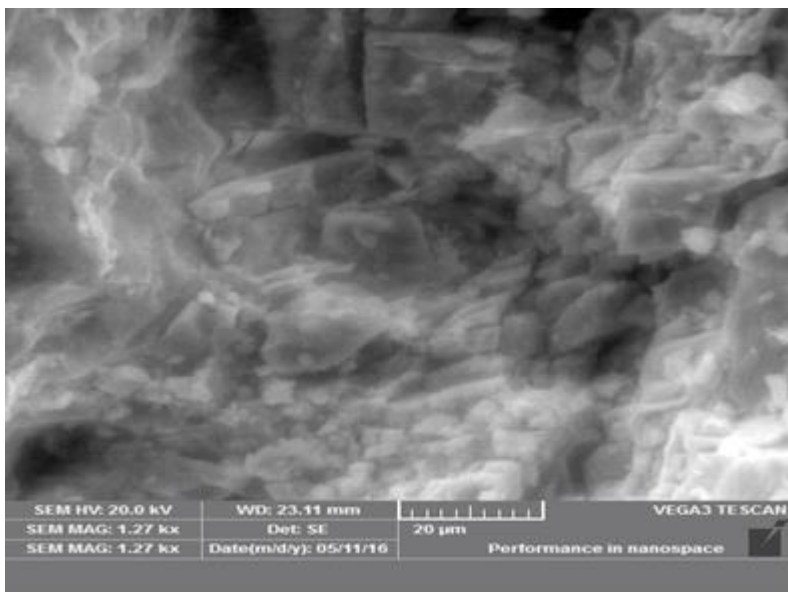
### 4.1 The Results

#### 4.1.1 Scanning Electron Microscopy (SEM) Photomicrographs:

A)



B)



540.10m

PLATE 1

### PLATE 1 (A & B)

#### Scanning Electron Microscopy (SEM) Photomicrographs

WELL: X

Depth: 540.10m

Core: 2

Photo Type: SEM

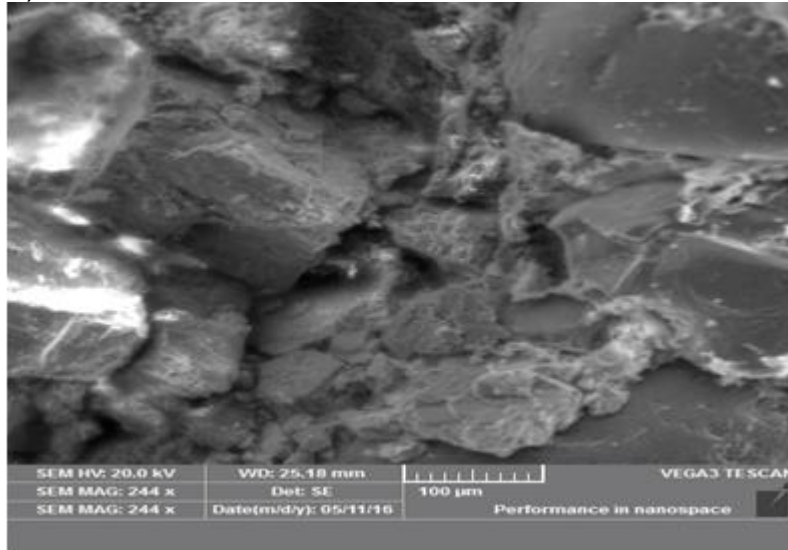
**Photo A - plate 1 SEM:**

Fine-grained clay matrix partly fills pores between detrital quartz and feldspar grains (SEM magnification 234xs).

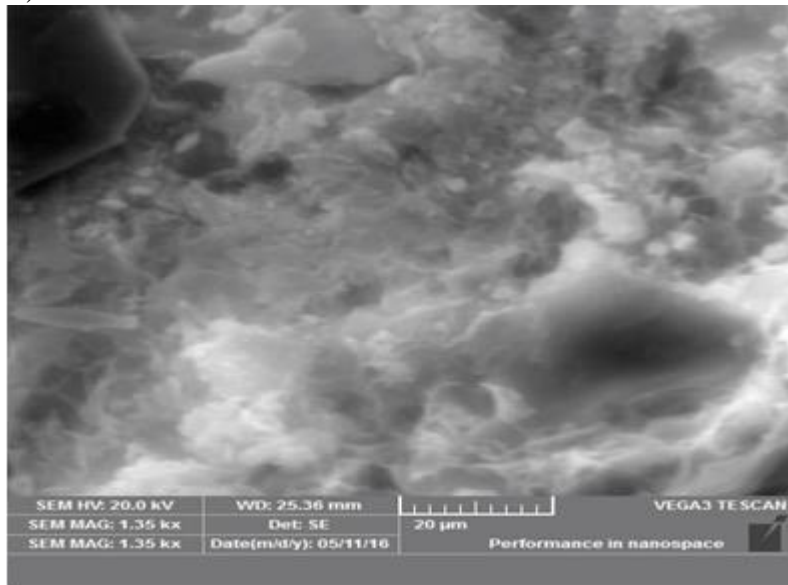
**Photo B-plate 1 SEM:**

Detrital feldspar grains cemented with fine grained detrital Kaolinite clay mineral (SEM magnification 1.27Kx). authigenic kaolinite appears as vermiform crystal habit which arranged face-to-face. Individual crystals range from 1 to 8  $\mu\text{m}$  (SEM magnification 1.27Kx).

A)



B)



530.30m

PLATE 2

**PLATE 2 (A & B)**

**Scanning Electron Microscopy (SEM) Photomicrographs**

**WELL: X**

**Depth: 530.30m**

**Core: 2**

**Photo Type: SEM**

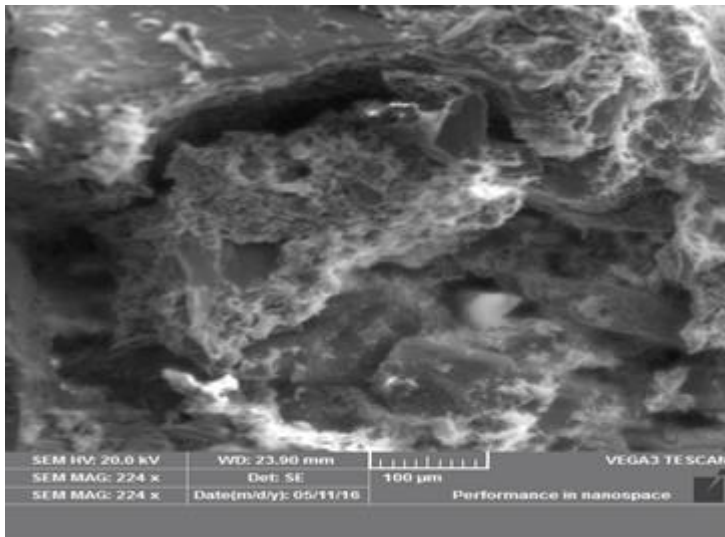
**Photo A-plate 2 SEM:**

Fine-grained clay matrix partly fills pores between detrital quartz and feldspar grains (SEM magnification 244xs).

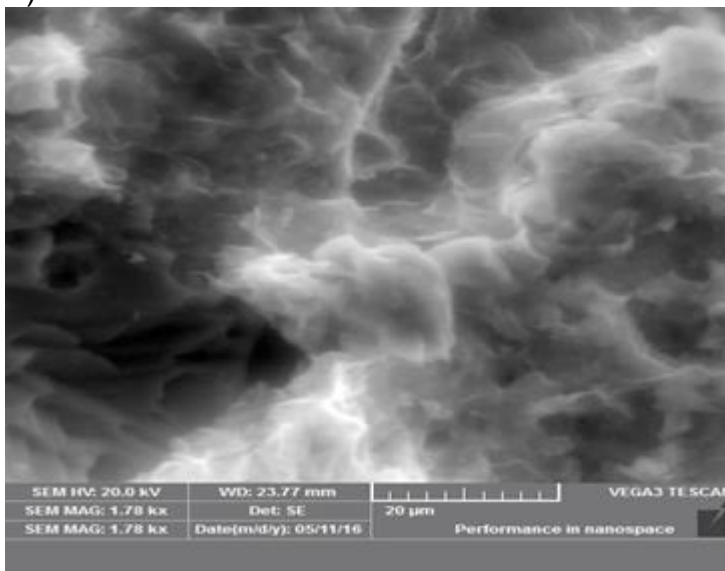
**Photo B-plate 2 SEM:**

Authigenic kaolinite appears as vermiform crystal habit which arranged face-to-face. Individual crystals range from 1 to 10 µm (SEM magnification 1.35Kx). Iron oxides mineral grains with authigenic Kaolinite mineral grains (SEM magnification 1.35kx).

A)



B)



526.70m

PLATE 3

PLATE 3 (A & B)

Scanning Electron Microscopy (SEM) Photomicrographs

WELL: X

Depth: 526.70m

Core: 2

Photo Type: SEM

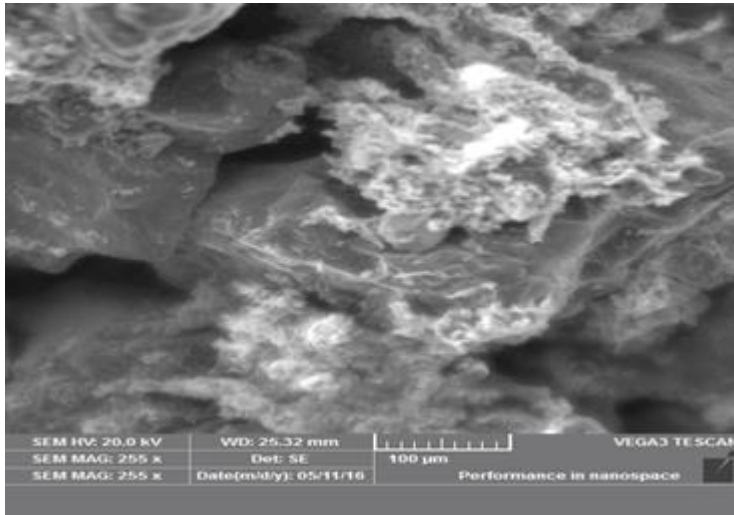
**Photo A -plate 3 SEM:**

Fine-grained clay matrix partly fills pores between detrital quartz and feldspar grains (SEM magnification 224xs).

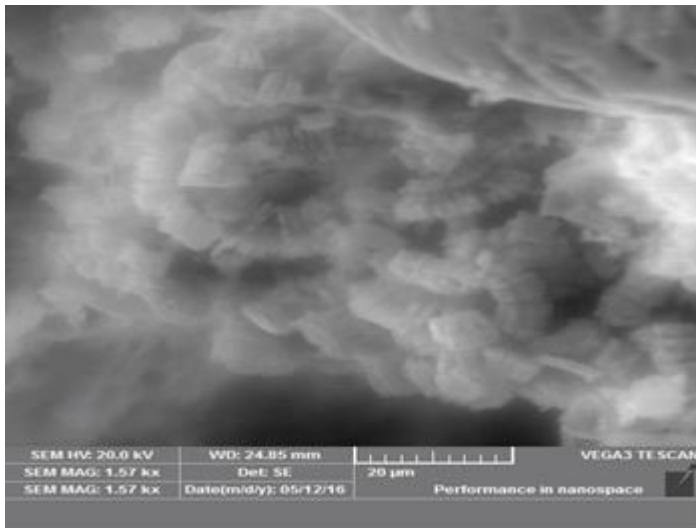
**Photo B-plate 3 SEM:**

Due to diagenetic process of detrital K-feldspar grains into mixed detrital and authigenic kaolinite (SEM magnification 1.78Kx).

A)



B)



524.50m

PLATE 4

PLATE 4 (A & B)

**Scanning Electron Microscopy (SEM) Photomicrographs**

**WELL: X**

**Depth: 524.50m**

**Core: 2**

**Photo Type: SEM**



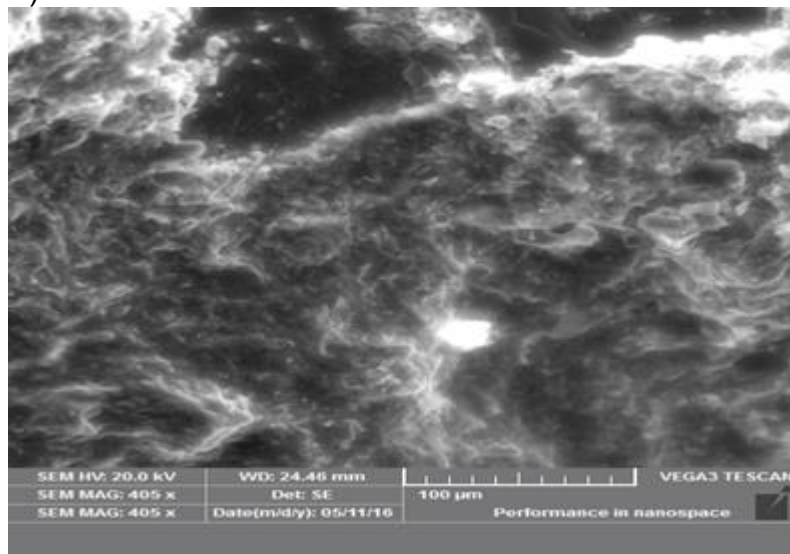
**Photo A-plate 4 SEM:**

Fine-grained clay matrix partly fills pores between detrital quartz and feldspar grains (SEM magnification 255xs).

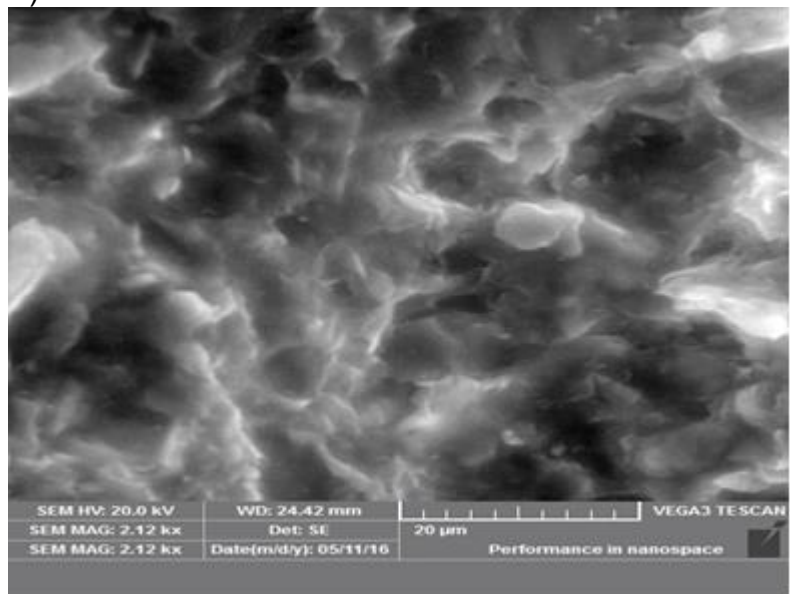
**Photo B-plate 4 SEM:**

Authigenic kaolinite appears as vermiform crystal habit which arranged face-to-face. Individual crystals range from 2 to 12  $\mu\text{m}$  (SEM magnification 1.57Kx).

A)



B)



522.30m

PLATE 5

PLATE 5 (A & B)

**Scanning Electron Microscopy (SEM) Photomicrographs**

**WELL: X**

**Depth: 522.30m**

**Core: 2**

**Photo Type: SEM**

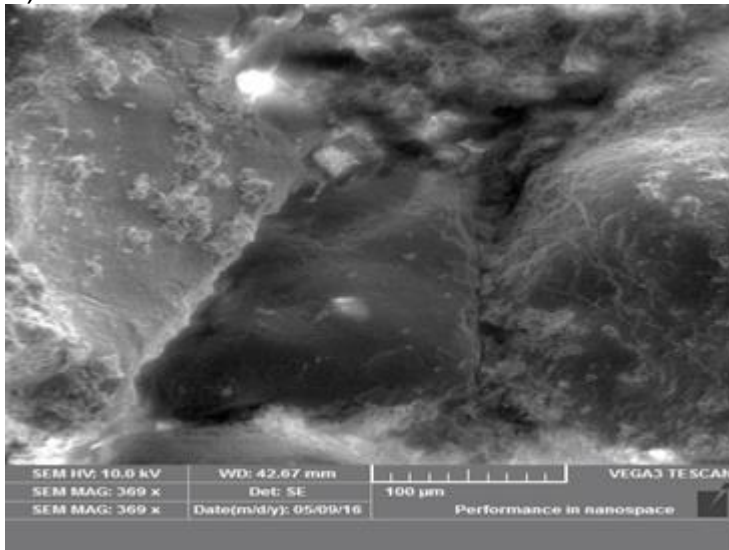
**Photo A-plate 5 SEM:**

Fine-grained clay matrix partly fills pores between detrital quartz and feldspar grains (SEM magnification 405xs).

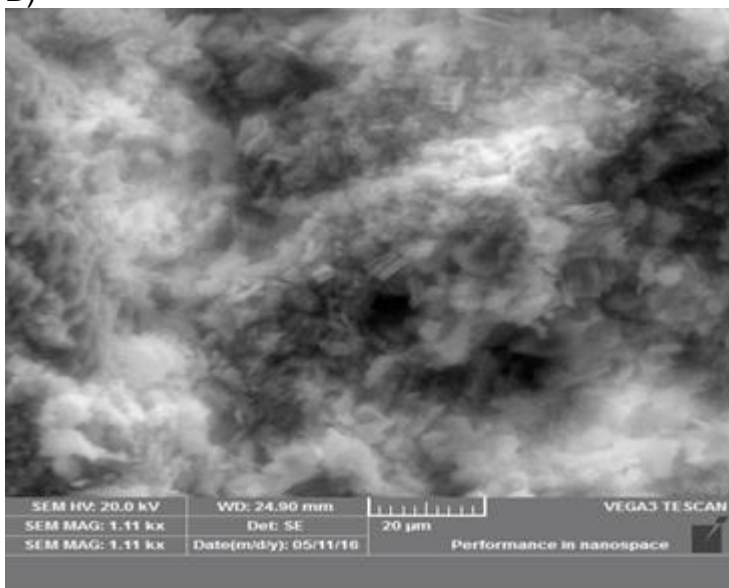
**Photo B-plate 5 SEM:**

Authigenic kaolinite appears as vermiform crystal habit which arranged face-to-face. Individual crystals range from 2 to 10  $\mu\text{m}$  (SEM magnification 2.12Kx).

A)



B)



515.00m

PLATE 6

**PLATE 6 (A & B)**

**Scanning Electron Microscopy (SEM) Photomicrographs**

**WELL: X**

**Depth: 515.00m**

**Core: 2**

**Photo Type: SEM**



**Photo A-plate 6 SEM:**

Fine-grained clay matrix partly fills pores between detrital quartz and feldspar grains (SEM magnification 369xs).

**Photo B-plate 6 SEM:**

Authigenic kaolinite appears as vermiform crystal habit which arranged face-to-face. Individual crystals range from 1 to 8  $\mu\text{m}$  (SEM magnification 1.11Kx).

**4.1.2 XRD results:**

A quantitative estimation of the clay mineral constituents were computed mainly from the ethylene-glycol solvated XRD patterns as suggested by Schwertmann et al. (1993). The results of the XRD analysis were discussed and summarized in Table (4.1).

Table 4.1: Summary of the clay minerals' results from the studied cored intervals at X well.

Core No.	Sample Depth intervals (m)	Clay Minerals %				
		Kaolinite	Smectite	Illite	Chlorite	Smectite/illite
2	515.00	89.11	7.05	2.45	0.88	0.56
	522.30	99.57	0.05	0.24	0.08	0.05
	524.50	99.40	0.22	0.25	0.08	0.06
	526.70	87.93	0.99	8.62	1.47	0.99
	530.30	95.54	0.43	3.39	0.38	0.26
	540.10	99.18	0.10	0.45	0.15	0.10
	545.00	99.51	0.06	0.27	0.09	0.06

## 4.2 Discussion

### 4.2.1 Discussion of (SEM) Analysis:

The SEM sample preparation and analytical techniques were explained in chapter 3. In addition six (6) sandstone chip cored samples after petrographical thin section and XRD analyses have been investigated through the SEM technique. Authigenic iron oxides mineral and detrital clay minerals such as kaolinite and chlorite were identified due to their morphologies. Furthermore, SEM photomicrographs were shown in plates (1 to 6) in order to clarify the diagenetic effects of the clay minerals on the reservoir quality at X well.

### 4.2.2 Discussion of XRD Analysis:

#### 4.2.2.1 Kaolinite:

Kaolinite is identified by its 7.1 Å and 3.58 Å peaks in the dried X-ray diffraction patterns, which are unaffected by the ethylene glycol treatment but are destroyed after heating to 550°C (Chamley 1989; Moore and Reynolds 1997). The clay mineral kaolinite was recorded in all of the investigated samples with variable percentages ranging between 87.93% – 99.57% (Table 4.1).

According to Chamley (1989), kaolinite mainly forms in surficial environments through pedogenetic processes. Also it may be formed in lacustrine environments from the alteration of K-feldspar in acid organic-rich pore waters (Tucker, 1991). Moreover, hydrothermal alteration of aluminosilicates, especially of feldspars may also form kaolinite (Moore & Reynolds, 1997). According to Keller (1956) and Weaver (1989), detrital kaolin minerals require for their formation the efficient removal of the metal cations and presence of H<sup>+</sup> ions. These conditions are favoured by strong leaching in the source area, which implies abundant rainfall, permeable rocks and favourable topography, and hence, evacuation of the Ca, Mg, Na and K ions. Climatic conditions favourable for the formation of kaolinite mineral are essentially tropical and subtropical.

The authigenic kaolinite was formed due to the complete alteration of the K-feldspar in the organic-rich horizons as happened in studied samples at most depths. However, other part of the clay mineral kaolinite in the studied intervals is detrital formed by hydrolytic processes. Furthermore, this detrital presence of the kaolinite has been confirmed by the relatively flattened kaolinite peaks in the XRD plates.

#### 4.2.2.2 Smectite:

The concentrations of this clay mineral in the investigated samples show very low concentrations which range between 0.05% and 7.05% of smectite minerals as indicated in

Table 4.1. The mineral was determined after the glycolation where the d-spacing of its basal reflection (001) expands from 15 Å in the normal pattern to 18 Å in the ethylene-glycol solvated pattern (Chamley 1989; Moore & Reynolds 1997).

According to Weaver (1989), “the climatic and the topographic conditions necessary for the formation of smectite are basically the opposite to those which favour the formation of kaolinite”. Smectite is generally formed in low relief areas where poor drainage prevents the silica and the alkaline earth ions such as K<sup>+</sup>, Na<sup>+</sup>, Ca<sup>+2</sup> and Mg<sup>+2</sup> from being rapidly removed. Moreover, smectite normally develops from the weathering of basic and ultra basic rocks or their metamorphic equivalents in areas of low rainfall, low water flux and low temperature.

#### 4.2.2.3 Illite:

Illite was identified by its basal diffraction at about 10 Å, which is neither affected by ethylene glycol treatment nor by heating. However, some illite clay minerals may show expandability of approximately up to 5 % (Chamley 1989; Moore and Reynolds 1997). Illite occurs as very low amounts in all of the analyzed samples and it vary between 0.27% and 8.62% as shown in table 4.1 According to Moore & Reynolds (1989) and Chamley (1989), illite is considered to have more Si, Mg and H<sub>2</sub>O but less Al-tetrahedral layer and less K-interlayer than muscovite. It is principally formed where the parent rocks are essentially acid igneous or their metamorphic equivalents. Illite is not present in sedimentary rocks derived from basic rock terrain. Rarity of rainfall and hot climate condition favour the detrital formation of illite. However, the diagenetic replacement of muscovite by illite is favoured in clean washed sands but that of feldspar by illite instead of kaolinite appears to be favoured by ion-enriched, less acidic pore waters.

#### 4.2.2.4 Chlorite:

The characterizing basal spacing for the structural unit of the clay mineral chlorite is close to 14 Å. Swelling chlorites or pseudo-chlorites expand like smectite when immersed in water or ethylene glycol, but resist heating, where the d-spacing is kept constant at 14 Å and 7 Å for the reflections (001) and (002) respectively.

The concentration of the chlorite in the examined samples ranges between 0.08% & 1.47% (Table 4.1 Chlorites are considered either as a 2:1 layer group with a hydroxide interlayer, or as a 2:1:1 layer group. Their typical structure shows a regular alternation of negatively charged trioctahedral micaceous layers and of positively charged octahedral sheets. Chlorites

are common constituents of low-grade metamorphic rocks. They are less common in igneous rocks, where they occur as hydrothermal alteration products of ferromagnesian minerals. Moreover, they may be formed authigenically as a direct by-product of the smectite to illite transformation, utilizing iron and magnesium released from smectite, diffused at proximity and reprecipitated together with silicon supplied from smectite or other detrital silicates (Chamley, 1989). Moreover, the high amount of chlorite in some of the studied clay minerals suggested that due to the source rock origin, which is rich in the ferromagnesian mineral.

# CHAPTER FIVE

## Conclusion & Recommendation

## **CHAPTER FIVE**

### **Conclusion & Recommendation**

#### **CONCLUSIONS**

This research focuses on the sedimentological and petrographical analyses on two cored intervals at X well located in Y Basin, Sudan.

The sedimentological analyses such as a scanning electron microscope and X-Ray Diffraction investigations were carried out at reservoir strata from two cored intervals with total length of 19.63m at the study well. The results from the above mentioned analyses were discussed and concluded as follow:

#### **Depositional environments:**

The composition and the internal arrangement of the studied two cored intervals at X well suggest fluvial braided channel bars and few parts of deltaic distal bar depositional environments (core-2). In addition to that, core-1 intervals exclusively indicate fluvial meandering channel depositional environment. Furthermore, (cf., sedimentological core log summaries in Enclosure 1).

#### **Petrographical rock names:**

The petrographical analysis under the plane polarized microscope for the sandstone lithofacies types exist within the investigated cored intervals at the studied well allowed classifying into Subfeldspathic Wacke (3 samples), Feldspathic Arenite (2 samples) and Feldspathic Wacke (2 samples).

#### **Diagenetic processes and reservoir porosity:**

Reservoir porosity of the investigated core samples range from 13.20% to 24.20% and their pore interconnectivity varies from fair-poor to good . These porosity values were affected by several diagenetic processes, which have either resulted in a decrease or in an increase of the reservoir quality. Hence, factors and processes which have reduced or increased the porosity of the studied core samples are summarized as follow:

1-The presences of significant quantities of authigenic Kaolinite and some amounts of iron oxides in the studied reservoir intervals contribute towards decrease of the reservoir porosity of X well.

2-Partial dissolution of feldspars and mica during the diagenesis produce a fair to good reservoirs at some depth intervals of X well.

### **Recommendation**

1-samples must be homogeneous and single phase to identification of clay minerals from (XRD-SEM).

2-We used 2 samples in single well X well but must use many samples in multi wells.

3- Samples must keep at natural well bore conditions.

4- Core lab must take shorter time to obtain good final result.

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# Appendix

