CHARLES UNIVERSITY, FACULTY OF SCIENCE
Institute of Hydrogeology, Engineering Geology and Applied Geophysics

Geological and Petrophysical Characterization of Hawaz Sandstones Reservoir in 'H' Oil Field, Murzuq Basin, SW Libya

BY

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Prague, Ceske Republic
2008

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DECLARATION

I declare that all the results, which are used and published in this thesis, have been obtained by my own experimental work and that all the ideas taken from works of other, are properly referred in the text and the literature survey.

Prague, 2008

Yousef M. A. Sherif

……………………..

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Corporation.
Yousef M. Sherif

TABLE OF CONTENT:

CHAPTER ONE

Geologic setting of Libya and Murzuq Basin SW Libya

1-1 **Introduction** ... 2
1-2 **Objectives** ... 2
1-3 **Geologic setting of Libya** ... 5
1-3-1 Ghadames Basin ... 5
1-3-2 Murzuq Basin ... 5
1-3-3 Kufra Basin ... 6
1-3-4 Sirte Basin ... 9
1-3-5 Cyrenaica platform ... 9
1-4 **Tectonic Elements of Libya** ... 10

CHAPTER TWO

General Stratigraphy and Sedimentology of Murzuq Basin, SW Libya

2 **Stratigraphy and Sedimentology** ... 12
2-1 **Introduction** ... 12
2-2 **Infra-Cambrian** - Mourizidie Fm ... 13
2-3 **Cambro-Ordovician** ... 16
2-3-2 Upper Cambrian (Hasawnah Fm ... 16
2-3-2 Upper Cambrian (Achebyat Fm) ... 17
2-4 **Ordovician** ... 18
2-4-1 Lower to Middle Ordovician (Hawaz Fm) ... 18
2-4-2 Upper Ordovician (Mclez Chograne and Memouniat Fm) ... 21
2-5 **Silurian** ... 25
2-5-1 Lower Silurian Tanezzuft Formation: ... 25
2-5-2 Upper Silurian (Akakus Fm) ... 25
2-6 **Devonian** (Tadrart Fm & Awaynat Wanin Fm) ... 28
2-7 **Carboniferous** (Marar, Assedjefar & Dembaba Fm) ... 28
2-8 **Mesozoic and Quaternary strata**: ... 29

CHAPTER THREE

Lithology and Petrography of Hawaz Rocks

3-1 **Introduction** ... 32
3-2 **Methodology** ... 32
3-3 **Quartz** ... 33
3-4 **Feldspar** ... 37
3-5 **Mica** ... 38
3-6 **Rock fragments** ... 39

3-7 **Bitumen** 41
3-8 **Matrix and Quartz cement** 41
3-9 **Clay minerals** 42
3-10 **Pyrites** 44
3-11 **Porosity** 45
3-11-1 Primary Porosity 46
3-11-2 Secondary Porosity 46
3-12 **Stylolites** 47
3-13 **Diagenesis** 47

CHAPTER FOUR
Facies description and depositional environments

Sedimentary facies
4-1 **Introduction** 52
4-2 **Purpose of Study** 52
4-3 **Material and Methods** 52
4-4 **Sedimentology Observations** 53
4-5 **Reservoir Characterization** 53
4-6 **Facies description and depositional environments** 54
4-6-1 Facies one 54
4-6-2 Facies two 54
4-6-3 Facies three 55
4-6-4 Facies four 56
4-6-5 Facies five 59
4-7 **Sedimentary environments** 60
4-8 **Summary and conclusion** 61

CHAPTER FIVE
X-Ray Diffraction and Elemental Analyses

5-1 **Introduction** 74
5-2 **Methodology and object of study** 74
5-2-1 Sample Preparation 75
5-2-2 Analytical Procedures 75
5-2-3 Main behavior of d Spacing for clay minerals 76
5-3 **Identification and Estimation of Abundance of Clay** 76
5-3-1 Kaolinite Group 76
5-3-2 Illite: (or the clay-mica) 77
5-3-3 Montmorillonite Group 78
5-4 **Distinguishing Clay Minerals** 78
5-5 **Elemental analyses of clay mineral** 78
5-5 **Bulk (whole rock) analysis by XRD (X-ray diffraction)** 81
5-6 **Scanning Electron Microscopies** 82
5-7 **Discussion and summary** 82

CHAPTER SIX

Petrophysical Evaluation

6-1- **Introduction** 99
6-2- **Objectives** 99
6-3- **Methodology and available material** 100
6-4 **Main log Suite used in study** 100
6-4-1 Gamma-ray logs (API) 100
6-4-2 Spontaneous potential SP (MV) 101
6-4-3 Neutron logs 101
6-4-4 Density logs: FDC (formation density compensated) logs 102
6-4-5 Sonic (Acoustic) logs: BHC (borehole compensated) logs 102
6- 4-6 Resistivity logs 102
6-4-7 The porosity logs 103
6-5 **Data Correlation** 103
6-5-1 Log correlation 103
6-5-2 Comparison of log and core data 103
6-6 **Evaluation of petrophysical reservoir quality** 104
6-6-1 Determination of shaliness 105
6-6-2 Evaluation of porosity 117
6-6-2-1 Log Determination of Porosity 117
6-6-2-2 Determination of Porosity in thin section 117
6-6-2-3 Determination of porosity at laboratory measurements 118
6-7 **Permeability at Laboratory measurements** 118
6-8 **Petrophysical parameter relationships** 121
6-8-1 Porosity and shale volume (Vsh) 121
6-8-2 Porosity-permeability relationships 121
6-9 **Generalized stratigraphic sequence analysis** 123
6-10 **Summary and Conclusions** 123

CHAPTER SEVEN

Summary and Conclusions

Summary and Conclusions 132

Bibliography 137
Appendix "A" 145
Appendix "B" 158

List of Tables

Chapter four

Table (4-1) Criteria for facies discrimination on logs 59
Table (4-2) Average Petrophysical parameters for the facies in the Hawaz Fm 60
Table (4-3) Average values from log analysis of selected wells in the 'H' Field 60

Chapter five

Table (5-1) The *d* spacing for main clay mineral at existing conditions 76
Table (5-2) Clay Fraction results (weight percent) 79
Table (5-3) Results of elemental analyses of clay mineral (weight percent) in well H27-NC115 at fixed temperatures 105°C. 79
Table (5-4) Results of elemental analyses of clay mineral (weight percent) in well H5-C115 at fixed temperatures 105°C. 80

Chapter six

Table (6-1) Average result for the Hawaz Fm in the "H" Field........ 103
Table (6-2) The main parameter used in calculation of Vsh with program system GDB4........ 105
Table (6-3) The average of Vsh at different facies in Hawaz Fm at selected wells. 105
Table (6-4) The summary analysis for main well in the H Field at Hawaz Fm 122
Table (6-5) The summary of facies analysis (all values in percentage %) 122

LIST OF FIGURES

Chapter one

Figure 1-1 General Tectonic Framework of Libya........ 3
Figure 1-2 Geologic map of Libya, and adjacent areas 4
Figure 1-3 Map of major structural elements in Libya and adjacent areas 7
Figure 1-4 Map Location of Murzuq Basin and study area. 8
Figure 1-5 The main structures of Murzuq Basin........ 8

Chapter two

Figure 2-1 General Stratigraphic Column in NC115 Murzuq Basin........ 14
Figure 2-2 Generalize Lithology in "H" Oil Field Murzuq Basin, Libya........ 15
Figure 2-3 Main facies characteristic of Hasawnah Fm and Mourizidie Fm 19
Figure 2-4 Hawaz formation type section 20
Figure 2-5 Lower Part of Memouniat Fm in western side of “H” field 22
Figure 2-6 Main Lithology of Cambrian-Ordovician in the “H” field 24
Figure 2-7 The main lithology of Silurian (Tanezzuft and Akakus Fm)........ 26
Figure 2-8 Tanezzuft basil radioactive zone distribution in western Libya 27
Figure 2-9 General Stratigraphic Column in 'H' Oil Field, Murzuq Basin........ 30

Chapter three

Figure 3-1 Thin section under cross polarizer of H27-NC115 34
Figure 3-2 Thin section of H5-NC115 at depth 1473(-970) m........ 35
Figure 3-3 Thin section of Sandstone (with mica) 40
Figure 3-4 Quartzitic sandstone in H5-NC115 crosse polarizer........ 43
Figure 3-5 Photographic of slabbed core showing stylolitized future 49
Figure 3-6 Showing GR log, average porosity, main lithology and the main petrographic thin section in each facies of Hawaz Fm 50

Chapter four

Figure 4-1 General lithology & particular facies in the 'H' Oil Field, Murzuq Basin. 57
Figure 4-2 The facies distribution in the H5-NC115 58
Figure 4-3 Show burrows and surrounding sediment sandstones 55
Figure 4-4 Photographs of slabbed core illustrate interlaminated sandstone and shale with high pressure flood deformation internal structures of upper facies tow 63
Figure 4-5 Thin parallel laminated shale and sandstones (blue arrow), with some vertical burring (small green arrow). In addition a cross-bedding (below red line) with minor low angle and very thin stylolites 64

Figure 4-6 Fine grained sandstones with highly stylolitized future with muddy material .. 65

Figure 4-7 Photographic of slabbed core illustrated the massive sandstones facies character, massive beds type is present with facies tow and three 66

Figure 4-8 Photographic of slabbed core illustrated vertical burrows retch more than 50cm long and more than 5 mm wide, with occasional bioturbation fetcher 67

Figure 4-9 Slabbed core showing horizontal silty shale sandstones interbedded 68

Figure 4-10 Slabbed core showing tow types of burrowing present in the formation: (A) Illustrated vertical burrows at average 15-20 cm long and a few millimeters wide, (B) High intensity of bioturbation, and burrowing activity at siltstones shale interbedded facies type 69

Figure 4-11 showing visibly secondary porosity by dissolved original material, and development of the pore network (Well H5-NC115) 70

Figure 4-12 Showing General lithology, cores in the well H27-NC115 and the log GR respond 69

Figure 4-13 shows the facies and porosity distribution in upper part Hawaz Fm (H27-NC115) 71

Chapter five

Figure 5-1 Graphic presentation of elemental analyses of clay mineral (weight percent) in well H27-NC115 80
Figure 5-1a Graphical presentation of elemental analyses of clay mineral (weight percent) in well H5-NC115 at fixed temperatures 105°C 81
Figure 5-2 XRD for sample at depth 1471 (-968) m, H5-NC115 84
Figure 5-3 XRD for sample at depth 1406 (-903) m, H5-NC115 85
Figure 5-4 XRD for sample at depth 1493 (-995.7) m, H27-NC115 86
Figure 5-5 XRD for sample at depth 1470.6 (-967.8) m, H5-NC115 87
Figure 5-6 XRD for sample H5-NC115 at depth 1489.2(-986.4) m 87
Figure 5-7 XRD for sample H5-NC115 at depth 1506.3 (-1003.5) m 88
Figure 5-8 XRD for sample H5-NC115 at depth 1524.5 (-1021.8) m 88
Figure 5-9 XRD for sample H27-NC115 at depth 1492.8 (-995.5) m 89
Figure 5-10 XRD for sample H27-NC115 at depth 1494.1(-996.8) m 89
Figure 5-11 XRD for sample H27-NC115 at depth 1505.1(-1007.7) m 90
Figure 5-12 XRD for sample H27-NC115 at depth 1517.2(-1020) m. 90
Figure 5-13 XRD of H27-NC115 at depth 1526.4(-1029.1) m 91
Figure 5-14 XRD of H27-NC115 at depth 1581.2(-1089) m 91
Figure 5-15 XRD of H5-NC115 at depth 1469.7(-966.9) m 92
Figure 5-16 XRD of H5-NC115 at depth 1473(-970.2) m. 92
Figure 5-17 XRD of H5-NC115 at depth 1477(-974.2) m. 93
Figure 5-18 XRD of H5-NC115 at depth 1485.5(-982.7) m 93
Figure 5-19 XRD of H5-NC115 at depth 1523.3(-1020.5) m 94
Figure 5-20 XRD of H27-NC115 at depth 1499.5(-1002.2) m 94
Figure 5-21 SEM at depth 1494 (-997) m, well H27-NC115........ 95
Figure 5-22 SEM at depth 1505 (-1008) m, well H27-NC115........ 95
Figure5-23 SEM at depth 1506(1003) m, well H5-NC115 96
Figure 5-24 SEM at depth 1517 (-1020) m, well H27-NC115........ 96
Figure 5-25 SEM at depth 1525 (-1027) m, well H27-NC115........ 97

Chapter Six

Figure 6-1 General lithology and particular facies in the 'H' Oil Field 107
Figure 6-2 Distribution of petrophysical parameter in the Hawaz Fm (H27-NC1115) 108
Figure 6-3 The facies distribution and oil water contact at well H5-NC115 109
Figure 6-4 Spontaneous potential and Gamma-ray logs quality of the Hawaz Fm........ 110
Figure 6-5 X-section S-N with main porosity distribution in different facies 111
Figure 6-6 Structural X-Section (C-C') in the "H" Oil field........ 112
Figure 6-7 Structural X-section (B-B') in the "H" Oil Field W-E 113
Figure 6-8 Seismic cross-section (N to S) through the field 114
Figure 6-9 Seismic cross-section (E-W) through the field 115
Figure 6-10 Structure map of Hawaz Fm (at top Hawaz Fm), and direction of X-sections 116
Figure 6-11 Relation between core and logs porosity & permeability in H27-NC115 119
Figure 6-11a Relation between core and logs porosity in H27-NC115 120

Figure 6-12 Relationship between porosity and Vsh (H27-NC115) 125
Figure 6-13 Relationship between porosity and Vsh (H5-NC115) 126
Figure 6-14 Relationship between porosity and Vsh (H1-NC115) 127
Figure 6-15 Relationship between porosity and Permeability in each facies (H27-NC115) 128
Figure 6-15a) Porosity and permeability relationship (H27-NC115)................................ 129
Figure 6-16 Distribution of the permeability within facies (H27-NC115). 130

ABSTRACT

There are several basins with oil productive formations on the North African Platform. The Murzuq basin is one of them; it is situated in the south-west part of Libya and the northern portions of Niger, representing an intracratonic sag basin. It was initiated during the Palaeozoic Pan-African orogine. The deposition of the basin started with basal barren conglomerates of Hassaouna Formation unconformably overlying the Precambrian basement and being unconformably overlained by productive Hawaz Formation. The top of the Hawaz Formation is strictly demarcated by radioactive shales (lower Silurian Tanezzuft shales). The contact between top of the sedimental cycle of upper fluvial delta to shallow marine sea deposits and Silurian marine pelagic sediments documents an important palaeoclimatic change in sedimentary environment owing to Caledonian Unconformity. Silurian pelagic marine sediments represent an extensive marine flooding in all North-African Platform area. This flooding event of sea level rise was caused by melting and dissolving of the glacial material on the surrounding mountainous area during Caledonian unconformity, while this mountainous area transformed in peneplane.

The present study is based on slabbed cores, core samples, and thin section; photographic of cores, conventional core analysis and well log data of the Hawaz siliciclastic sediment. The average covers thickness is about 130-170m from the total formation thickness. All data are analyzed in terms to focus on the main petrology, lithology of sedimentary facies, clay mineral associated, and the main petrophysical property of the reservoir rocks sequences which related to hydrocarbon potential.

The Hawaz Sandstone Formation shallow marine deposition facies is one of the most important oil-bearing formations in the Murzuq Basin, The Hawaz reservoir occurs within the upper levels of the Lower Paleozoic Group (Lower to middle Ordovician Llanvirnian /Llandeilian time); which occurs directly underlies the lowermost Silurian Tanezzuft shales; attaining thicknesses over (120-150 m) in average.

The Hawaz Formation in the 'H' oil field consists of thin to thick bedded very fine to medium grained quartzitic sandstone, slightly crossbedded and interbedded with feldspar, silty micaceous, and gray to dark gray shale beds. Generally the clastic sediments of the Hawaz Formation is characterize with ranging from weakly calcareous shales (argillaceous) to relatively pure non-fossil very fine to medium grained sandstones; and shows coarsening upward trend. Five facies has been interpreted based on the sandstone/clay ratio, grain size, wireline log response, dominated structure, and petrophysical character for each facies.

The sandstones are typically quartz arenites with other minor rock fragments in trace amounts. The x-ray diffraction results pointed out the essential clay minerals are kaolinite and Illite, In addition, mica, montmorillonite muscovite are important components. Feldspars are present, but due to aggressive dissolution is alteration to clays by weathering and digenesis process. Cementation and grain replacement also occur. The initial matrix is authigenic

clays followed by quartz overgrowth and silica spray cement. Evaluation of reservoir quality has led to recognition of five facies ranging between poor to good porosity (2 to18 %); ranging between negligible to very good permeability (0.01 to >900 mD); and ranging between shale volume (10 to 80%). Primary porosity was controlled by depositional environment with shale content with sandstone facies displaying greater porosities and permeabilities than the more mud-rich facies deposits. Decrease in primary porosity and permeability was affected by cementation process, calcite and authigenic clays precipitation. Mostly of observed porosity in thin section is secondary, developed by dissolution process which contributed to enhanced of the effective porosity. Facies no. three represent the best reservoir potential of hydrocarbon occurrences, in terms of hydrocarbon prospectively.

CHAPTER ONE

Geologic setting of Libya and Murzuq Basin SW Libya

1-1 Introduction

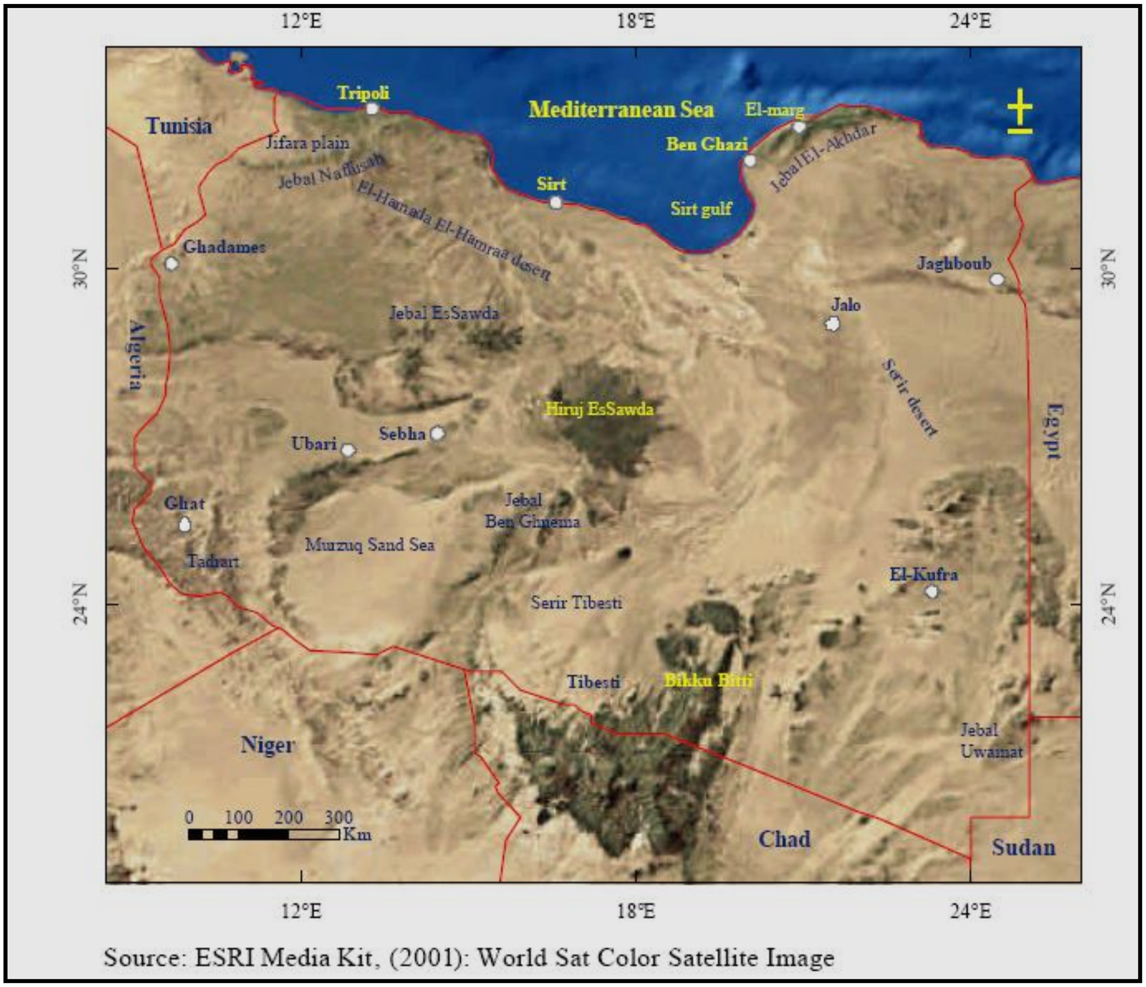
Libya is located on the northern coast of North Africa with approximately 1,700 kilometers of Mediterranean coastline; and about 1,528 kilometers in an east-west direction, and as much as 1,450 kilometers from north to south, with an area of 1,887.105 Km^2 (fig. 1-1).

Geology exploration, starting about 1800, gave the modern world a few glimpses of the country. Many Italian geologists, French geologists, United States Geological Survey and Industrial Research Center are published reports on their studies in the country; in addition to cooperation with the Exploration Society of Libya, National Oil Corporation and the several oil companies operating in the country.

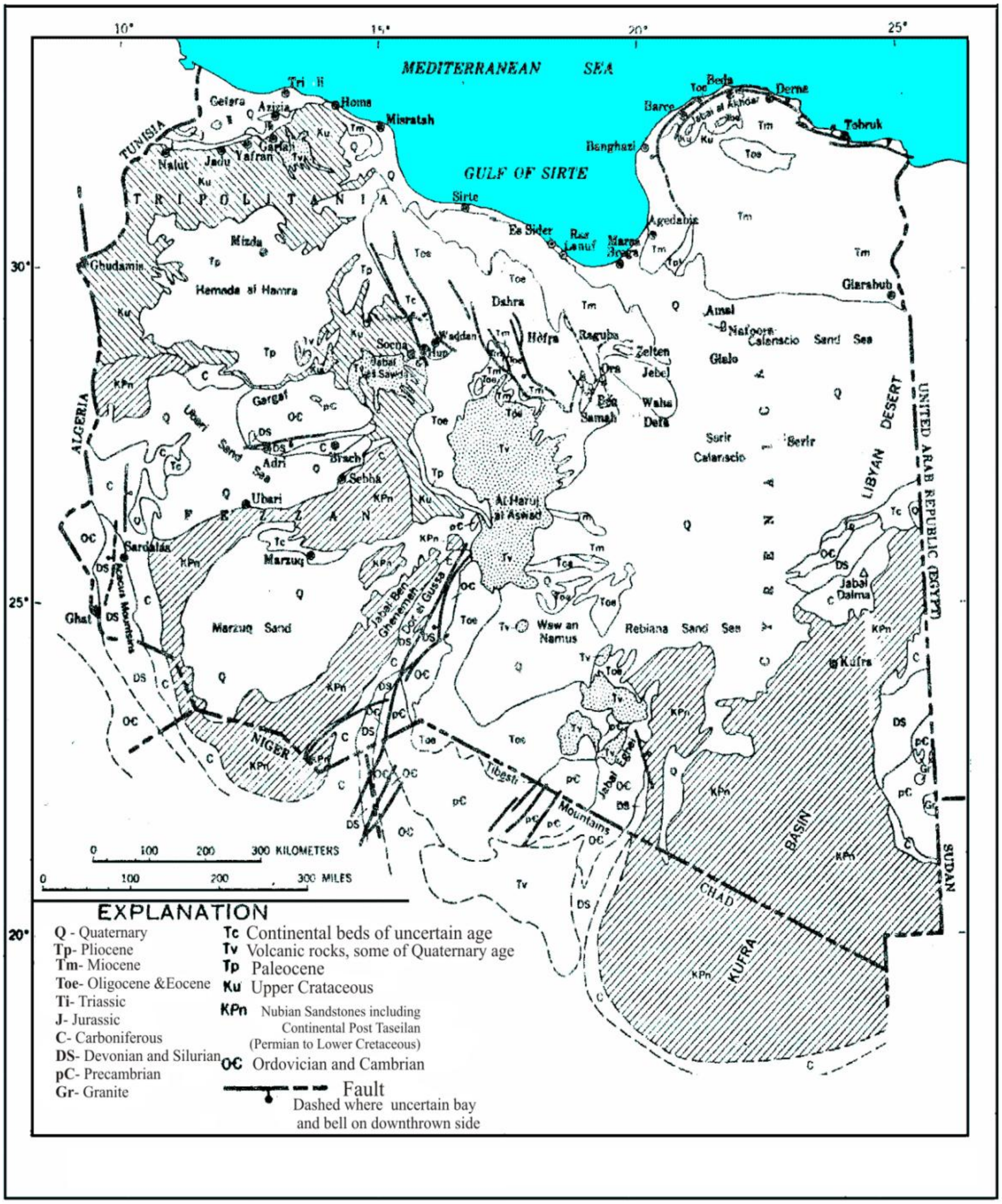
1-2 Objectives:

The objective of this study is a detailed sequence Stratigraphy; petrography Sedimentology with infancies on the petrophysical analysis of the Hawaz Reservoir in the H-115 oil field (El Sharara Field) Murzuq Basin. However, the original environment deposition, facieses pattern and digenetic history has been reconstruction. The general objectives of the study are:

1. Classify the reservoir rocks petrographic characteristics accord to texture, mineral composition and diagenesis property.
2. Understanding of the relation of rock fabric to petrophysical quality (porosity and permeability);
3. Evaluate reservoir rocks in terms of reservoir quality and ;
4. Reconstruct the physical and chemical conditions prevailed during the Hawaz Formation reservoir sedimentation.
5. To provide a detailed sedimentary facies through the reservoir formation.
6. Combining sedimentological and wireline log data in order to derive depositional environmental characteristics.



(Fig.1-1) General Tectonic Framework of Libya



(Fig. 1-2) Geologic map of Libya and adjacent area on south, simplified form Conant and Goudarzi (1964).

1-3 Geologic Setting of Libya:-

Libya is located on the northern coast of Africa and on the southern coast of the Mediterranean Sea with a coastline which extends over 1,800 kilometres from Tunisia in the west to the Egyptian border on the east, and the country extends southwards for more over than 1,500 Km through the Sahara desert. This is situated on the northern part of the Mediterranean foreland of the African Shield representative portion of the 1000 km wide belt of sedimentary rocks which fringe the various exposed basement massifs of Central Africa and extends from the Atlantic to the Red Sea and eastward into Arabia. The southern limits of the Palo-Mediterranean, or Tethys Sea, extended over various portions of this foreland during Cretaceous and Tertiary time. In comparison with the area to the west (the uplifted, folded and, in places, thrusted, Saharan Atlas Mountains of Morocco and Algeria) the tectonic pattern in Libya is relatively simple and the stable foreland to this area. In view of the various oscillations and differential movements, which occurred on the different blocks of which, it is composed. The tectonic units of Libya and the Sahara Epeirogenic down warping, tilting and block faulting differentially depressed the Libyan part of this foreland allowing repeated transgressions of the Tethyan Sea upon its borders. From the tectonic map of Libya (fig.1-1), showing that Libya has five major structural entities, which may be briefly discussed (fig.1-1):

1-3-1 Ghadames Basin:

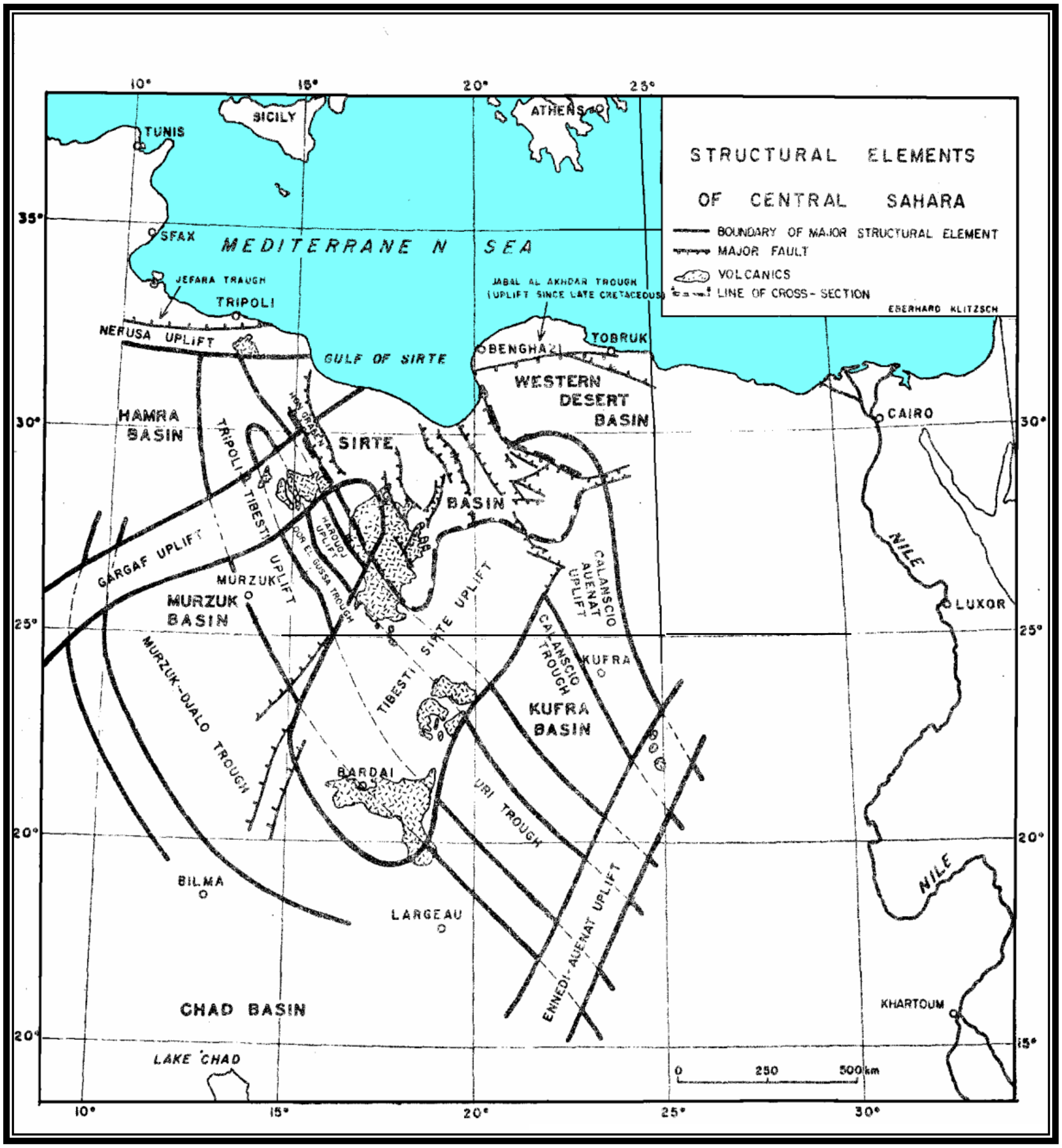
Ghadames Basin covered the northwestern part of Libya (also referred as Hamadah Al Hamra Basin), spread over an area of about 200,000 Km^2. It is a large intracratonic basin on the North African Platform, with NE-SW lineaments and extends over three countries: northwestern Libya, southern Tunisia and east-central Algeria; The Ghadames Basin widens and deepens in the south west to form the Fort Polignac basin of SE Algeria, separated from it by the north-south running Tihamboka Edgele basement high. The Ghadames basin is bound on the west, by die Massaoud High and Amguid El Biod Uplift in Algeria, on the north by the Jefrea Nafusah and Dahar Uplift in Tunisia, , and to the south by the Hoggar Massif in Algeria and Qargaf basement arches in Libya. To the east, the basin wedges out beneath the western part of the Sirte Basin. The basin formed during early Palaeozoic time, and filled predominantly with Paleozoic elastics. This platform has undergone a complex and polyphase history. This is effect on the basin by productive of a series of fault and bounded structural highs surrounding a central depression (fig.1-2). On the Qarqaf arch, a small part of the Palaeozoic succession is exposed, over that the strata thin, but appear to thicken northwards towards the centre of the basin, as suggested by the data obtained from the exploratory oil wells.

1-3-2 Murzuq Basin:

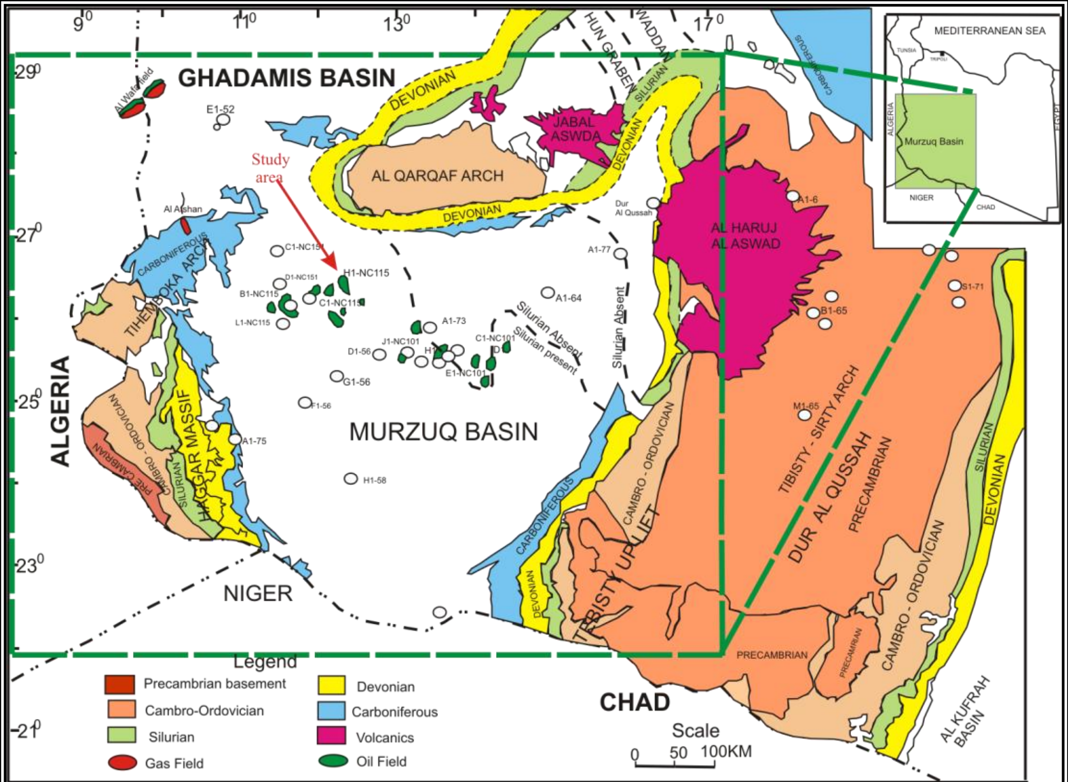
The second is the Murzuq Basin. Its an extensive intracratonic interior sag basin, which covers the southwestern part of Libya and part of northern Niger where it is known as a Djado Basin (Fig.1-2); but the major part lies in Libya, covers an area nearly of about 350,000 km^2 in a broadly triangular shape with a southwards directed apex. The basin as illustrated in (Fig. 1-4 & 1-5) is bounded by uplifted massifs includes the Hugger Massif to the Southwest; whereas the southern boundary is marked by the Tibisti Massif region in Niger and parts of Chad; which together with the basement high and Jabal Bin Ghanimah Massif extending towards Jabal Al Haruj Al Aswad marks its eastern limit. In addition, the Al Qargaf Arch to the North and the Tihamboka Arch to the West. The Tihamboka basement high separated the basin from the adjoining fort Polignac basin, which acts as a saddle between the two basins, over which the Palaeozoic strata thin considerably. The Murzuq basin initiated during the Palaeozoic time. Than separated from the Illizi basin (which lies mostly within Algeria) by the N-S trending Tihamboka Arch. The style of the underlying Pan African structure was control the basin extent and reactivated lower Palaeozoic structural trends. Hercynian tectonic events overprinted these forming a second fundamental control on basin form. The fault patterns seen at the present day surface show the effects of several tectonic episodes during the Cretaceous (Khoja, et al., 1980). The basin filled with Palaeozoic sediments attains a thickness of around 4000 m in the deepest parts of the basin. However, the generally dip towards the centre of the basin at low angles, varying from 1 to 5 degrees, and form prominent escarpments of Jabal Akakus, Jabal Tadrart in the south west and Jabal Bin Ghanimah in the east. Continental Mesozoic-Cenozoic sediment and the sandstones of Idhan Murzuq cover the Palaeozoic strata of Murzuq Basin. The marine transgression that covered the northern Libya during the Upper Cretaceous-Tertiary period did not reach Murzuq basin. Structurally the basin is complicated by several large N-S fault zones, which probably represent the Pan-African lineaments, which where periodically reactivated as strike slip fault, particularly during the Caledonian and Hercynian orogenies (Auguries 2004).

1-3-3 Kufra Basin:

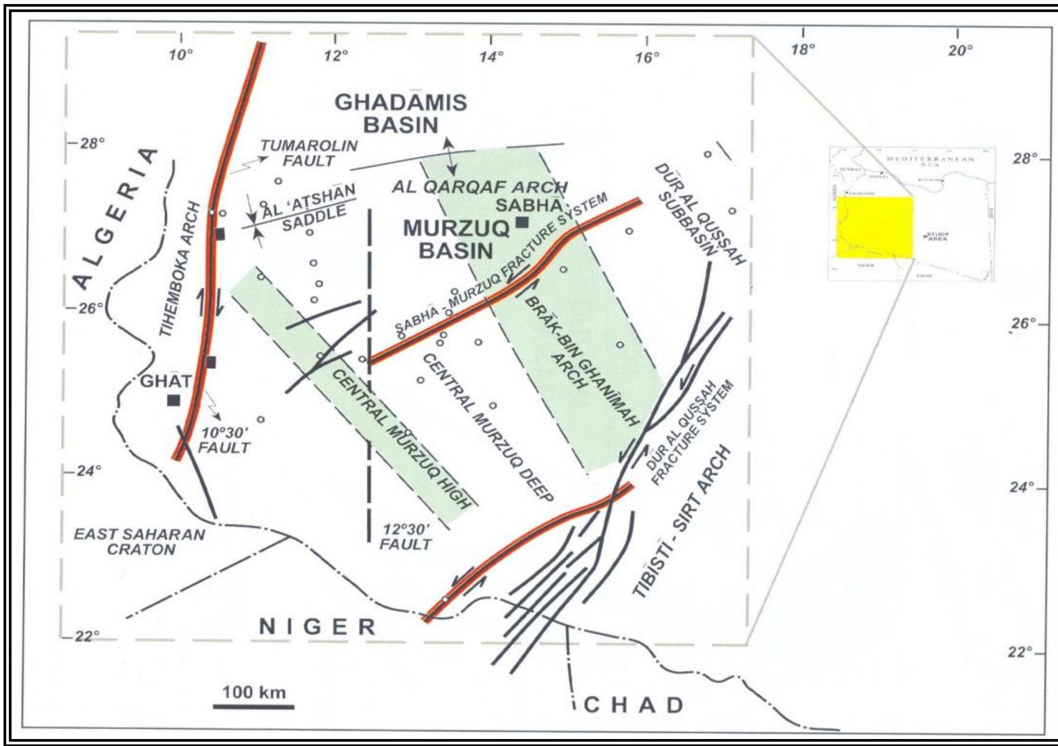
The third is a Kufra Basin in the southeastern part of the country, which is an intracratonic basin, originally developed within the Paleozoic margin of northern Africa. It has the form of a shallow syncline orientated NE-SW. The basin western limit is marked by the Tibisti–Haruj basement high, the eastern limit by Jabal Awaynat massif, whereas the northern marked by the Calanscio basement high, and the southern limit is marked by the basement exposures of the Borkou Ennedi region in Chad. The Kufra Basin forms an elongate depression oriented northeast southwest, with an aerial extent of about 400,000 km^2. The Basin began to the Early Paleozoic by marine transgression during the Lower Silurian and Upper Carboniferous, which intercalated the far-reaching continental sedimentation. The basin fill attains a maximum thickness of 3,500 m and comprises a sequence of Paleozoic sediments unconformably overlain by Mesozoic strata and has remained land since the end of Paleozoic times. The center of the basin is sands covered and except for a few small isolated hills of Cretaceous Nubian sandstone, outcrops are limited to the southeast and southwest of the Kufra oasis. The base of the Paleozoic succession exposed only in the north, southeast and southwest where it rests unconformable on Precambrian basement. The Kufra basin is a relatively shallow Palaeozoic basin with the maximum thickness of around 2,000 meters of Palaeozoic sediment in some of the deeper parts of the basin. The Palaeozoic sediments are gradually thin towards the southern and eastern continuation of Kufra basin, and gradually pinch out in the east towards the Nubian massif.



(Fig. 1-3) Map showing major structural elements in Libya and adjacent



(Fig. 1-4) Map Location of Murzuq Basin and study area.



(Fig. 1-5)The main structures of Murzuq Basin

1-3-4 Sirte Basin:

The Sirte Basin is located in the North part of country (fig.1-2). The Sirte basin, extending roughly NW–SE, formed in Cenomanian time. It characterized by step-like fault blocks, downthrown most strongly toward the east. Initial transgression upon its exposed basement filled the basin with terrigenous sediments. As subsidence continued, shales and carbonates deposited throughout the remainder of the Cretaceous and Tertiary. The maximum subsidence of this basin may have occurred during the lower and middle Eocene. However, the basin accumulated sediments in Lower Cretaceous and Tertiary time. Terrigenous elastics filled the basin during initial transgression. As subsidence continued, shales and carbonates deposited through the Cretaceous and Tertiary. Infect, the Sirte Basin is a late Mesozoic to Cenozoic extensional basin that was initiated in the late Jurassic. The Sirte Basin formed by large-scale subsidence and block faulting that started during the late Cretaceous (Conant and Goudarzi, 1967). The Sirte Basin generally remained a positive element until near the end of the Cretaceous, at which time movements and deformation took place in western Libya (GOUDARZI, 1980). However, the initiation of the Sirte Basin has been interpreted as early as the Jurassic and early Cretaceous times. The centre of the basin was mainly infilled with shales while carbonate sediments generally deposited around the margins. Gillespie and Sanford (1967), state that the sediments are mainly carbonates and shales while evaporates are locally developed and sandstones occur at near the top and bottom of the succession. The Sirte basin generally can be divided into three structural blocks as follows: Jofra block, Dahra-Zelten block and Augila Block.

1-3-5 Cyrenaica platform:

The last is the Cyrenaica platform, which is structurally higher than other basin. The Cyrenaica Platform is part of the Western Desert Basin. The basin is located at northeastern part of Libya and northwestern part of Egypt. The limits of this basin are not well delineated, nevertheless the data available from exploratory oil wells indicates that it had a very wide expanse, covering nearly whole of the Cyrenaica and major part of the Western Desert of Egypt, and had linked with the Kufra basin along the Calanscio basement high. It has been interpreted from the borehole data that about 2,000 to 2,500 meters thick marine to sub-continental sediments were deposited in this basin from Cambrian to Carboniferous period. The Palaeozoic sediments deposited in this basin underlie the Jurassic to Lower Cretaceous continental and upper Cretaceous to Tertiary marine sediments. Jabal Al Akhdar lies NW of the platform and represents an inverted sub-basin in which Cretaceous to Palaeocene muds accumulated prior to Syrian Arc-aged tectonism.

1-4 Tectonic Elements of Libya:

Many authors (e.g. Conant and Goudarzi (1964), Klitzsch (1971), et al have described the tectonic elements. The major diastrophic disturbances include the Caledonian, Hercynian, and disturbances during Cretaceous, middle Tertiary (Oligocene through Miocene) and Holocene time. These events caused uplifts, subsidence, tilting, faulting and intrusions. However, the effects of these diastrophic events were generally broad, and compressional folds are very few (Goudarzi, 1980).

East-west and north-south trending faults are present, but the two major fault systems trend parallel; which consolidated most parts of North Africa during the Precambrian orogenies. Since the Cambrian, the structural development was controlled by block faulting which resulted from epeirogenesis movement. Differential subsidence in early 1aleozoic time formed systems of troughs and uplifts. The geologic map of Libya (fig.1-3) shows two sets of faults cutting through the mid-section of the country. The northern set probably influences the shape of the Gulf of Sirte. Near the intersection of tie two trends is the largest outpouring of lava in Libya.

These two fault trends are approximately parallel with the well-known great rift system in the Gulf of Suez and East African areas, and hence, might have originated as s result of drifting of the African continent.

Volcanic outpourings, chiefly of basalt, probably started in Oligocene time, and some flows are of recent age. The activity was probably concurrent with movements along deep-seated fractures perhaps related to the Alpine orogeny (Conant and Goudarzi, 1967). Several authors have studied the tectonic history of the Murzuq Basin throw Palaeozoic outcrops or in subsurface studies, as (Klitzsch 1969, Echikh and Suleiman 1984, Banerjee 1980, Echikh and Sola 1998, Glover, et al. 1998, and others) The Murzuq Basin was subjected to three major periods of structural development (Echikh, 1969).

First stage started in Precambrian time with folding and consolidation.

Stage began in the Cambrian time with the formation of northwest to north-northwest striking horsts, which became (in Silurian and Devonian time) the core of uplifts separated by troughs (Adamson et al, 1999). The structural relief of early Palaeozoic time was the result of a northeast – southwest tension (Echikh and Sola, 1998).

The last stage initiated during late Mesozoic time by the formation of the northeast trending uplifts and troughs (Glover, et al., 1998). During Jurassic time or within the Jurassic-Cretaceous transgression, block faulting occurred along the edge of some uplifts.

CHAPTER TWO

General Stratigraphy and Sedimentology of Murzuq Basin, SW Libya

Stratigraphy and Sedimentology

2-1 Introduction

The age, general lithology, and approximate formation thickness of the major stratigraphic units within the study area (“H” Oil Field concoction NC115) presented in Figures 2-1 & 2-2. The Cambro-Ordovician sediments and overlying Silurian Formations are the main focus of this investigation. Emphasis placed in this chapter on the Paleozoic stratigraphy of the Murzuq Basin since it is within the Paleozoic strata that hydrocarbons have been generated and trapped.

A brief description of the lithostratigraphic units with a sedimentological interpretation presented here and illustrated at (Fig.2-1 & 2-2). The Lower Paleozoic reference section, presented in upper Figure, has been samurais the main features in the study area. Paleozoic and Mesozoic sedimentary strata well represented in the Murzuq Basin, whilst Tertiary and Quaternary sediments are only locally present.

Many authors have been studied the Cambro-Ordovician sediments of southwest Libya in the Qarqaf region, (where the type sections are located). As (Burollet 1960; Massa & Collomb 1960; Collomb 1962), on the east flank of the Murzuq Basin Tibisti Massif where Jacque (1962) and Klitzsch (1963 & 1966) made detailed studies, and on the west flank of the basin, on the Libya-Algeria border. Burollet1960 and Maghrabi & Cheshitev (1977) studies Devonian section. In addition, the basin was under attention in subsurface by oil company to emphasis the main characters of the basin with published by Mamgain (1980), Bellini and Massa (1980), Vos (1981), Abugares and Ramaekers (1993), and Carr (2002) & (2003), among others.

The stratigraphic scheme established by many authors has slightly modified to incorporate additional information from the subsurface of present field. (Figure.2-1 & 2-2) presents schematically the stratigraphy and petroleum geology of the Paleozoic succession.

The Infracambrian marked by a major ice age, or series of ice ages (Harland & Rudwick 1964). Infracambrian sediments (Mourizidie Formation) are interpreted to be glacio-marine and their widespread global occurrence suggests very extensive glaciation. While in the Paleozoic two thick blanket sandstones are present; the first represents fluvial/shallow-marine, Nubian-type sandstones of Cambro-Ordovician age, and the second is Upper Silurian to Lower Devonian.

The stratigraphic column ranges from the Precambrian to the Quaternary.

The Palaeozoic deposits informally placed in two groups:

- The Lower Palaeozoic group (Cambrian-Silurian) with the Hasawnah, Hawaz, Melaz Shuqran, Mamuniyat, Tanezzuft Akakus Formations; The deposition of these strata started with a basal conglomerate of the Hasawnah Formation unconformably overlying Precambrian basement and unconformably overlain by the Aouinet Ouenine Formation.
- Second the Upper Palaeozoic group (Devonian-Carboniferous) with

the ‘Basal Devonian sandstone’ Aouinet Ouenine, Marar, Assed Jefar and Dembaba Formations. (Fig. 2-1)

The Murzuq basin initiated during the Palaeozoic (Pan-African orogine). It is separated from the Illizi basin (which lies mostly within Algeria) by the N-S trending Tihamboka Arch and from Ghadames basin by Al Qargaf Arch. Pierobon (1991), said that the Cambro-Ordovician System of Libya was first defined in the area of Al Qarqaf Arch and is widespread over large portions of the North African platform.

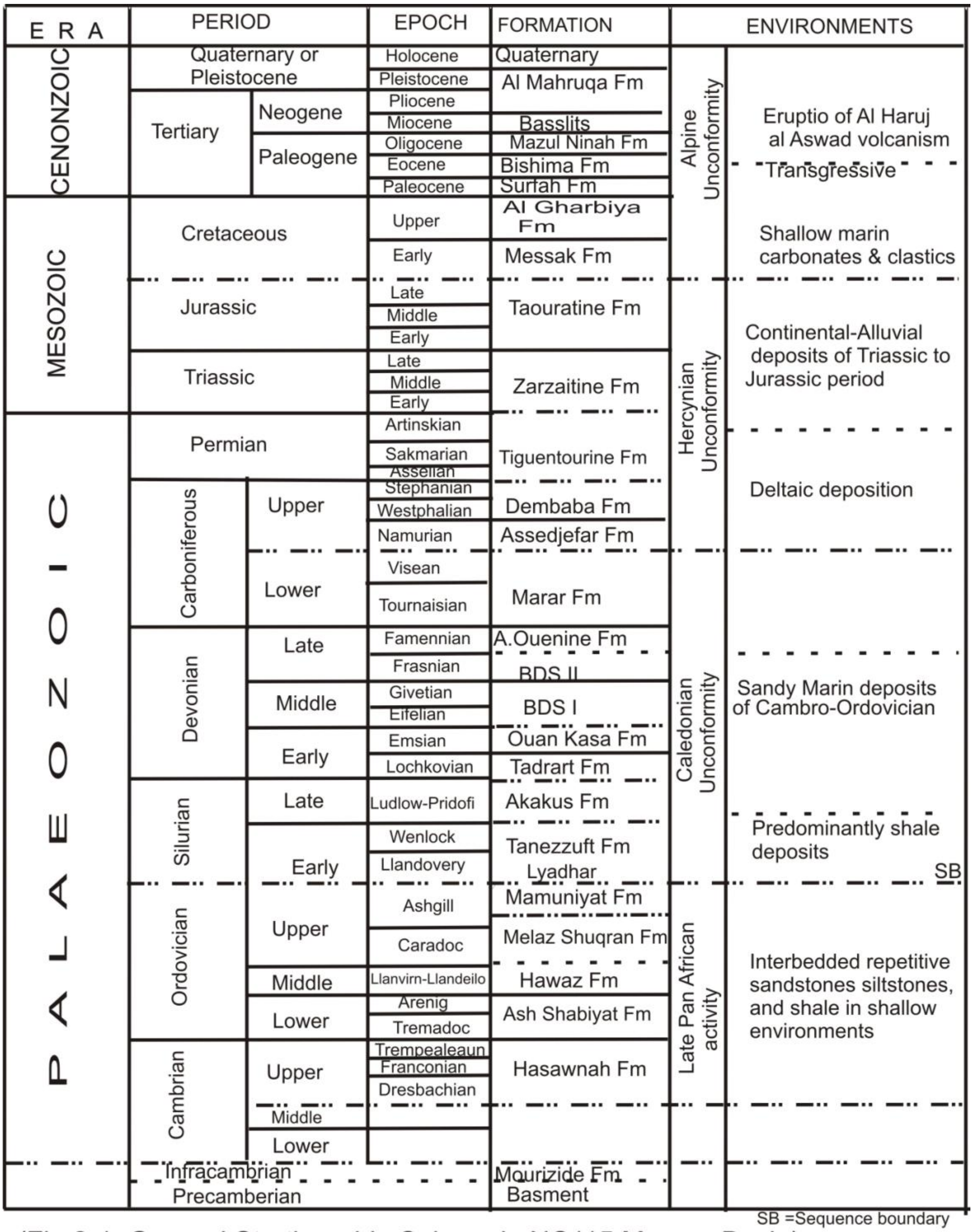
The Murzuq Basin has main unconformities in the succession from Pre-Cambrian to Quaternary as the Caledonian, which included the Lower Silurian Tanezzuft Formation up to Upper Devonian basal sands of the Aouinet Ouenine Formation. Than the Hercynian Event between the Upper Carboniferous Dembaba formation up to the Triassic Zarzaitine Formation, and upper unconformity of the Alpine event between the Jurassic Taouratine Formation up to the Quaternary cover. Minor sedimentation breaks and unconformities occur at other horizons including unconformity between the Hawaz and the Mamuniyat Formations; the Middle-Upper Ordovician; Ordovician- Silurian (Tectonic unconformity); Devonian-Carboniferous (Acadian unconformity), and Triassic-Jurassic boundaries. These are not always consistently present across the entire basin (Fig. 2-1 and 2-2).

The Cambro-Ordovician succession has been divided from fluvial to marine and glacial into four formations: the basal Hasawnah Formation; the Hawaz Formation; the Melez Chograne Formation; the Hawaz and Memouniat Formations. The argillaceous Melez Chograne and Memouniat Formations are very variable thickness and are not always present in the field. Although the Melez Chograne is sometimes considered as a facies change in the Memouniat Formation.

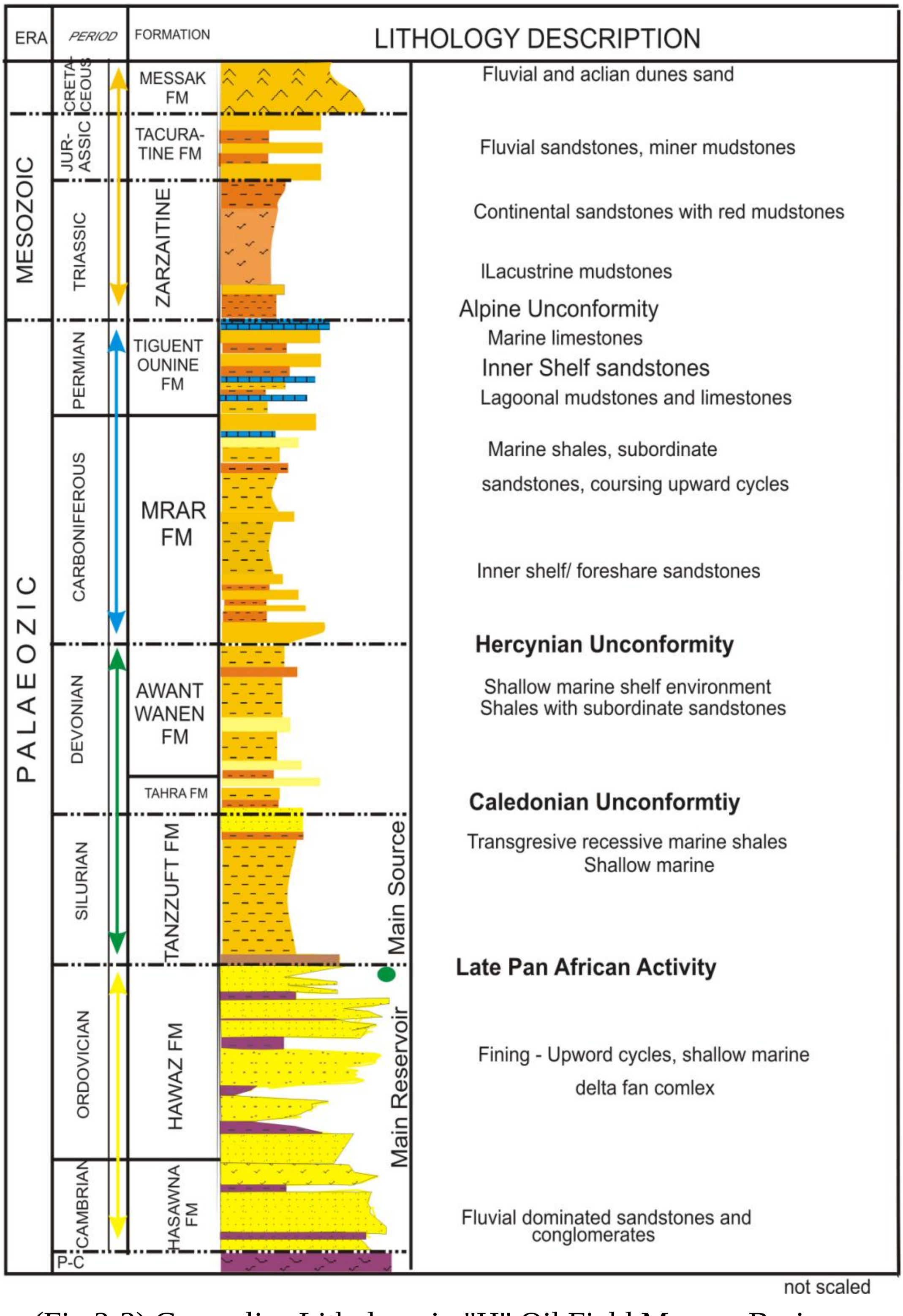
The stratigraphic schemes established by many authors have been slightly modified to incorporate additional information from the subsurface of present field. The Lower Cambro-Ordovician rock sequence in southwest Libya consists of the following rock units (Fig. 2-1):-

2-2 Infra Cambrian - Mourizidie Formation:-

The Mourizidie Formation represents the oldest sedimentary rocks in the basin. The Infracambrian was marked by a major first ice age, or series of ice ages (Harland & Rudwick 1964). Infracambrian sediments (Mourizidie Formation) are interpreted to be glacis-marine and their widespread global occurrence suggests very extensive glaciation (Scott Pickford plc, 1992). A period of tilting and pediplanation followed, after which the Hasawnah Formation, of Cambrian age was deposited. The Hasawnah Formation is underlain, unconformably, by a succession of cross-bedded, fine-grained micaceous sandstones which lie on metamorphic basement. Jacque (1962) defined this succession as the Mourizidie Formation; Burollet and Byramjee (1969) described the main sedimentology and petrography of the formation in western Libya. Bellini and Massa (1980) believed that the Mourizidie Formation to have been laid down in a glacial environment on the evidence of the presence of large blocks of schist; which lie in a sandstone matrix. (Desio 1942. 1943 and Burollet et al, 1963) divided the basement rocks along the



(Fig.2-1 General Stratigraphic Column in NC115 Murzuq Basin)



(Fig.2-2) Generalize Lithology in "H" Oil Field Murzuq Basin, basinal margins into two main groups, the high-grade metamorphic series and the semi-metamorphic series, which includes the Mourizidie Formation.

The formation has been rarely penetrated and cored in the sub-surface in SW Libya. However, only in few subsurface wells at the block NC115 (A1-, B31-, D1-, & H27-NC115), Aziz (2000), identified of the Mourizidie Formation with the general consists of fine-grained siderite-cemented feldspathic sandstone with occasional faint lamination. Petrographic characteristics include very fine to medium grained, poorly sorted subrounded to sub angular, mainly monocrystalline quartz. Polycrystalline quartz is a minor detrital component; orthoclase feldspar is common, while plagioclase and microcline feldspar, muscovite mica and lithic grains are rare. The main diagenetic features are quartz overgrowth, an abundant pseudo matrix of authigenic clay, an ortho-matrix of recrystallized detrital clay, sideritic and dolomitic cement and pyrite. The Formation is thin in thickness at the field area and was penetrated as little as 30 m of the unit.

Hallett (2002), summarize that the Mourizidie Formation was penetrated in the northern Murzuq Basin, where it is 45m thick, these deposits represent local erosion of Precambrian topography prior to the Cambrian marine incursion. However, in several areas in southern Libya un-fossiliferous continental sandstones are present between metamorphosed basement and the conglomerate, which taken to mark, base of the Cambrian strata include Mourizidie Formation. Bellini and Massa (1980) believed the Mourizidie Formation to have been laid down in a glacial environment on the evidence of the presence of large blocks of schist, which lie in a sandstones matrix.

2-3 Cambro-Ordovician**:**

2-3-1 Upper Cambrian (Hasawnah Formation):

Mass and Collomb (1960) name the Cambrian Hasawnah Formation after Jabal Hasawnah region in central Qarqaf was first introduced. It consists of a brown to yellowish brown massive medium to coarse grained highly crossbedded silicified sandstone with abundant conglomeratic lenses, kaolinitic cement and interbedded; minor micaceous beds are the characteristic feature of the formation. (Banerjee 1980) described the succession as typically developed as medium to coarse-grained, cross-bedded sandstone with conglomeratic interbeds. However, Silica and kaolinite are the main cementing agents.

The Hasawnah Formation is an extremely widespread and litho-logically uniform deposit overlying eroded and folded basement and extending over large areas of Libya (Hallett, 2002).

At the base lies a conglomerate, approximately 10 m thick, with feldspars and pebbles of Precambrian basement in a ferruginous, clay-rich matrix upwards these pass into a conglomeratic arkoses; then follow a homogenous, cross-stratified sandstone sequence, which comprises the majority of the succession. Sub-angular and sub-rounded, coarse-grained sandstones pass up to finer-grained sandstones in the upper part of the succession, where Tigillites, trace fossils are present. Tigillites (vertical, horizontal and sometimes annulated tubes or burrows in sandstone) is the most common trace fossil. The platform covered at Upper Cambrian, by a very shallow sea sediments to sub-tidal to intertidal environments referred to Hasawnah Formation.

The Hasawnah Formation is generally apparently conformably overlain by the Hawaz Formation or (Achebyat Formation), but in the Qarqaf region Massa and Collomb (1960) noted that the relationship is unconformable. In the Dur Al Qussah sub-basin Klitzsch (1963) recorded a major angular unconformity at the top of the Hasawnah Formation. This sub-basin was a region of relative crustal instability in the Cambro-Ordovician where a similar, but much thicker, sequence to that of the Qarqaf region lay down. The deposition environment of Hasawnah Formation has been studied by many geologist as Collomb (1962), Jacqué (1962, and Klitzsch (1966), Klitzsch (1970, 2000) and Čepek (1980).

Čepek (1980) studied the formation in more detail, he ended up that these sediments are deltaic environment in the lower part, intertidal in the middle part, and with an offshore bar environment in the upper part.

At NC115 Block the formation unconformably overly the Pre-Cambrian crystalline basements (Mourizidie Formation) and overlain by the Middle Ordovician Hawaz Formation. The Formation is consisting of quartz pebbles in fine-grained sandstone matrix of fluvial environment. Moreover, gradually changed to a fluvial-deltaic, intertidal to sub tidal palaeoenvironment with offshore bares of clastic sediments.

A few wells have penetrated the Hasawnah Formation in NC115 (H27-, H28- and H29-NC115) with average thickness 80m. The upper part of the formation characterized by light grey, greenish to brownish, fine to medium-grained sandstone with occasional interbeds of mudstones and siltstones, while the lower part is dominated by medium to coarse-grained sandstone. However, the Hasawnah Formation is display a distinctive fining-upwards character. Aziz (2000) reported a three sedimentary lithofacies from as:

1. A cross-bedded sandstone lithofacies consisting of kaolinitic quartzarenite, gray to white, hard, medium to coarse-grained, quartzitic sandstone;
2. Fractured, fine-grained sandstone comprising argillaceous quartz wacky, pale green to white, hard, fine grained quartzitic sandstone;
3. In addition, a siltstone lithofacies comprising dark grey, very hard, tightly cemented siltstone, often abundant brittle fracturing.

2-3-2 Upper Cambrian (Achebyat Formation):

The Achebyat Formation was established by Havlicek and Massa (1973, p 270) for Upper Cambrian to Lower Ordovician section of a silty sequence on the Al Qarqaf Arch occurring between the Hasawnah and Hawaz Formations. They identified the section as sandstones with frequent *Tigillites*, *Cruziana* and *Harlania.* In type section, it represents a maximum flooding interval and is essentially silty marine sandstone containing abundant with above fossils traces (*Tigillites*, *Cruziana* and *Harlania* trace fossils) overlies the Hassaouna fm; and is conformably overlain by the Hawaz Fm.

In the study, area of the 'H' Oil field the contact with the underlying Hasawnah Formation is conformable. The Achebyat Formation has general smooth well-log reading characteristic than the overlying the Hawaz and underlying Hasawnah Formations. The formation formed part of the overlying Hawaz Fm and is very difficult to differentiate from the Hawaz Formation from well log data only.

The formation is consists of ferruginous sandstones rich in *Tigillites* and representing shallower marine environment unit or maybe a generally deeper water aspect than the Hasawnah Formation especially at medial part of the Hasawnah formation section. (Hallett, 2002) reported that The age is assumed to be Tremadocian, on the basis of stratigraphic position and supposed correlation with Tremadocian dated rocks study in the subsurface, palynological analysis of this sequence gives a probable mid-Ordovician age.

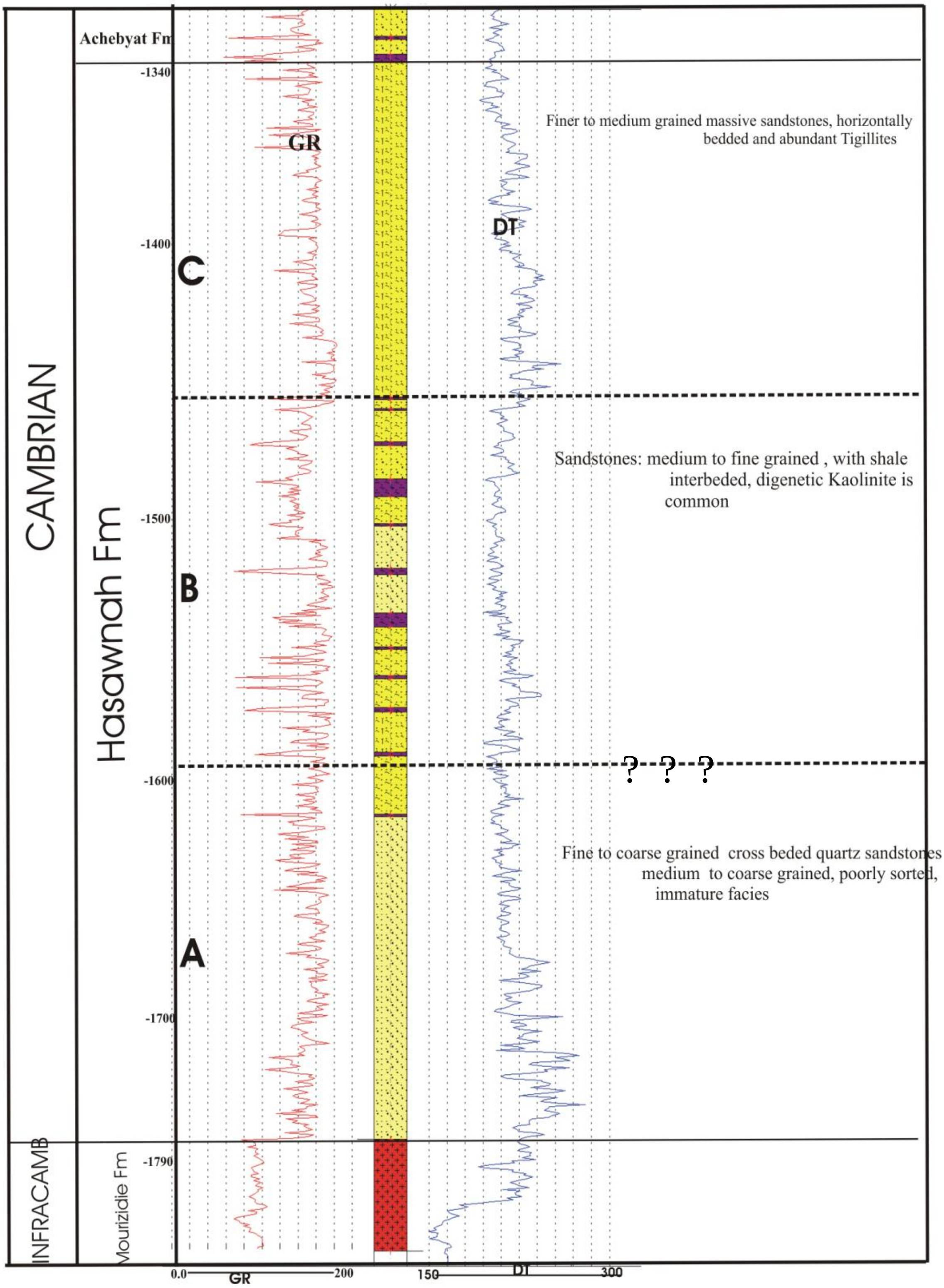
2-4 Ordovician:

2-4-1 Lower to Middle Ordovician (Hawaz Fm):-

Massa and Collomb (1960) first introduced the Hawaz Formation; it is named after the Jabal Hawaz in the west of the Qarqaf region (Fig.1-2, 2-4 &2-9) where its type section. It consists, of mudstone and fine to medium-grained bioturbated sandstones interbeds in part. It is common with feldspar, orthoquartzites. Kaolinitic within thin shaly intercalations at the upper parts or with high gray shale content characterized by the presence of many *Tigillites sp* beds. While the lower part has less shale content, fine to coarse sandstone with siltstone grained interbedded in cross-bedded quartzitic sandstone. At type locality, the formation conformably overlies the Hassaouna Formation and conformably overlain in turn by the Memouniat Formation. Vos (1981b) interpreted the succession as resulting from deposition within a braided delta, delta front and nearshore fine-grained fades alternate with relatively coarse-grained delta plain. While Sikander (2003) reported (after Sirte oil co. geologist) that the formation has greater thickness and more complete succession in well C1-NC151, and was deposited in a shallow marine palaeoenvironment rather than a prograding delta front as proposed by Vos (1981).

In ‘H’ field the Hawaz Formation unconformably overlain directly by the lowermost Silurian Tanezzuft shale and overlies the Hassaouna or Achebyat Formation as well as in most eastern part of H-NC115 structure and probably in all eastern Murzuq Basin (see fig. 2-9).

The Hawaz Formation distinguished from the underlying Achebyat and/or Hassaouna Formation by a sharp decrease in gamma ray reading on well log and in grain-size in petrography; and increase in sorting and definite biogenic structures. The succession is composed primarily of fine to very fine-grained, micaceous sandstones with subordinate medium-grained sandstones, and grey shales and siltstones. Well-bedded horizontal bedding is predominant with some cross-bedded interbeds.



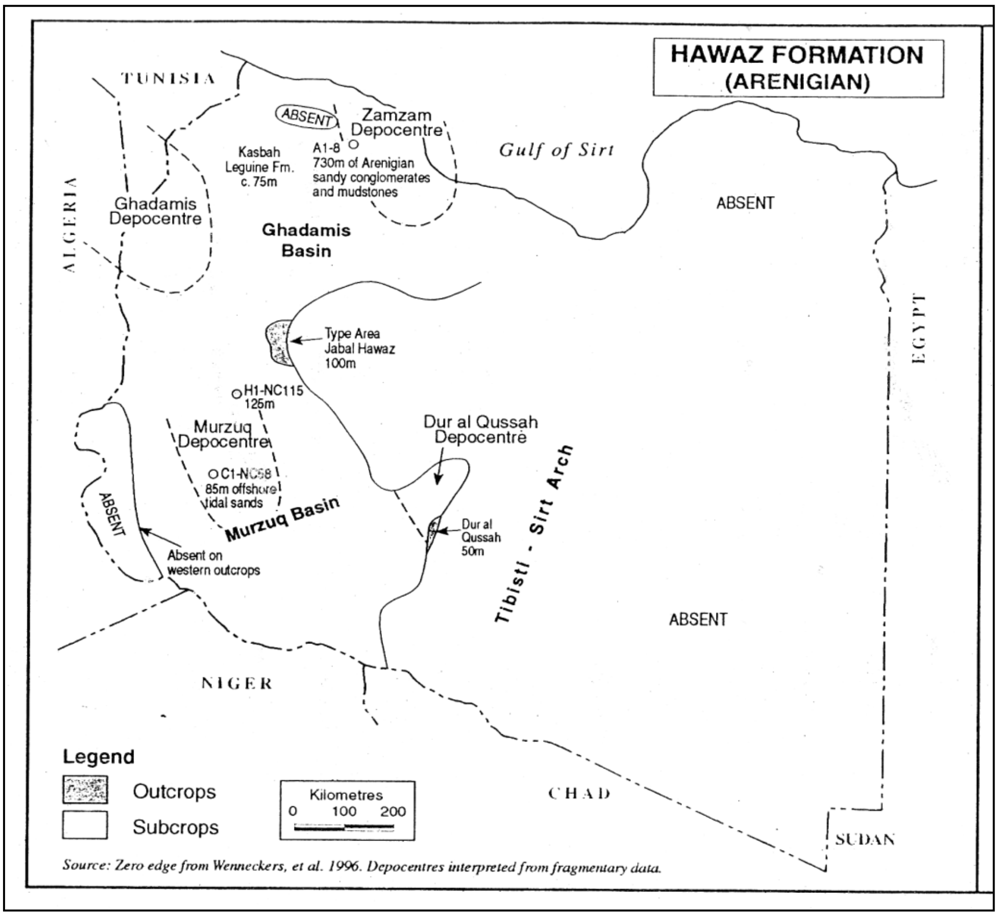
(Fig.2- 3) Showing main facies characteristic of Hasawnah Fm and Mourizidie Formation.

Horizontally bedded sandstone units with abundant *Tigillites*, rippled surfaces and interbedded thin silty beds (more detail well discussed in anther chapter). In the 'H' field the alternations of these lithofacies as seen on cores and well log characteristic indicate that regularly fluctuating sea-level conditions prevailed on the shelf during deposition of the formation and see level change; however, the depositional environment is probably transitional from fluvial to shallow marine, with increasing marine influence upwards.

As a summary of general composition of Hawaz formation, is a sequence of sediment fine to medium-grained sandstone beds, with siltstones and shales interbedded occasional with Tigillites; is present above the coarser-grained delta plain facies (Hasawnah Formation).

The petrographical study of the formation mineralogy and their texture of the sandstones indicates that these shallow marine sediments were not extensively reworked or under high currant deposition condition. (Klitzsch 1963) suggested that the shallow marine interpretation for these strata supported, by the presence of poorly preserved casts of brachiopods and bivalves on the northeast flank of the basin where 50m of the formation is present.

(Havlicek & Massa, 1973, and other) come out with the age of the Hawaz Formation attributed to the Middle Ordovician, Llandeilian to Llanvirnian see (fig. 2-1& 2-9).



(Fig. 2-4) Showing the location of Hawaz Formation type section in SW Libya.

2-4-2 Upper Ordovician (Mclez Chograne and Memouniat Fms):-

The type section of the Melez Chograne and Memouniat Formations lie in the Qarqaf region, where they have the maximum thickness (Massa & Collomb 1962). They characterized by sharp boundaries at the top and bottom on well log data. These formations are generally brachial to completely missing in the ‘H’ field, especially in the eastern and NE portion of the field as in well H3-NC115; in general the Tanezzuft Formation immediately overlies the Hawaz Formation and directly underlying the Silurian Tanezzuft Formation shales.

The Upper Ordovician Melez Chograne and Memouniat Formations lie above the Hawaz Formation on an irregular unconformity reflecting considerable palaeorelief (Beuf et al. 1970). The base formation generally displays a fine clastic sequence, consisting of varicolored, chloritic, thinly bedded shales and siltstones intercalated with fine-grained sandstone. (Fairbridge 1970) suggested that Epeirogenic movements occurred in the Caledonian activity with the advance of a continental ice cap was responsible for the erosion and for the deposition of the Melez Chograne and Memouniat Formations.

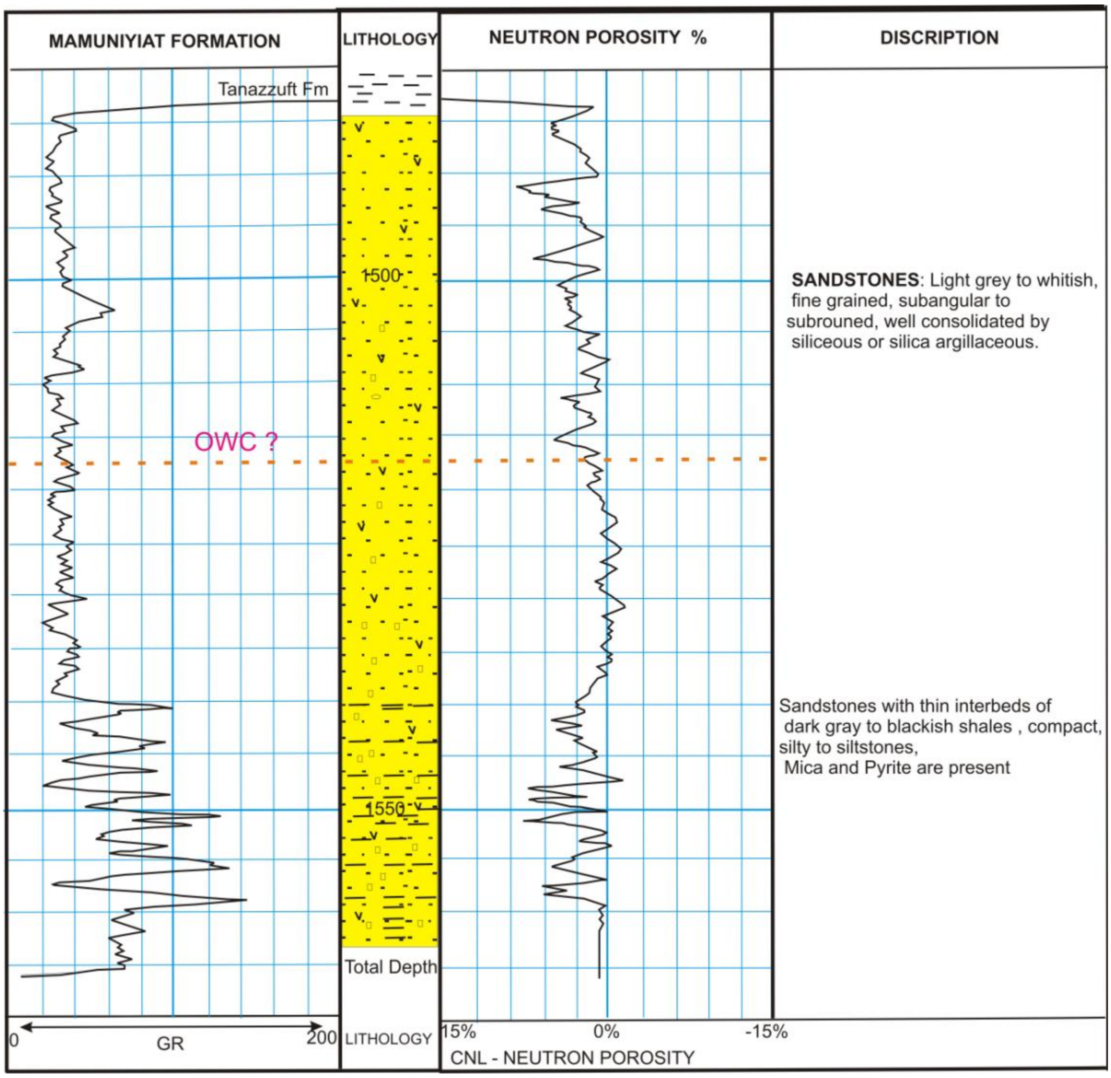
In summary, the formations are missing in parts of 'H' field, especially at eastern part. However, this probably due to erode activity or marine regression in these areas, in addition possibly related to tectonic adjustments following the break away of the Murzuq Basin.

The formation is representing in western part by thick section of fine to medium-grained sandstones and siltstones cross bedding. However, the Melez Chograne and Memouniat formation are highly variable, in both composition and thickness over relatively short distances between the two strictures fields (A & H) in NC115. The lower part of the Memouniat Formation can be organized above Hawaz formation in some wells at western part between “A and H” fields, as in (Fig.2-5). Consists of a fine to medium-grained sandstones of massive to slightly cross bedded structures.

2-5 Silurian

Silurian rocks are widespread in Libya as well as in most North Africa. In Murzuq Basin, the Silurian section comprises two units: the graptolitic shales of the Tanezzuft Formation mainly light to dark gray graptolitic shales and upper sandstones unit of the Akakus Formation. There is a very sudden or sharp boundary transition contact from sandstones of the Hawaz / Memouniat Formation to the overlying graptolitic shales of the Tanezzuft Formation (Fig. 2-5, 2-6 & 2-7). The shales, assigned to Tanezzuft Fm pass transitionally up into predominantly fine-medium grained sandstones of the Akakus Formation; these form a generally regressive progradational, coarsening-upward succession.

(Castro et el 1991) reported that the Silurian sequence represents a perfect example of transgressive and regressive conditions present in the same cycle of relative rise of coastal onlap during the formation of a clastic wedge.



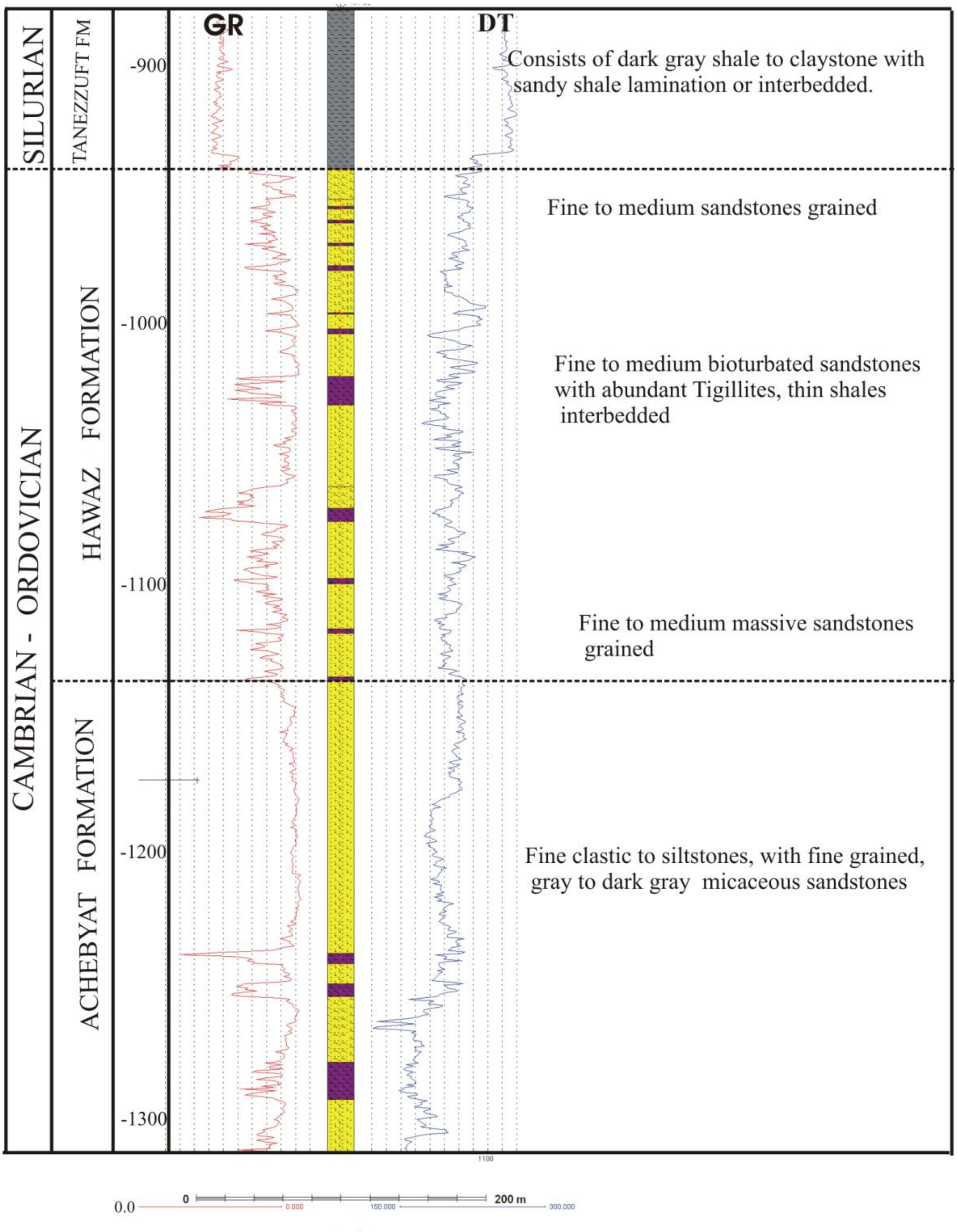
(Fig. 2-5) Showing Lower Part of Memouniat Fm in western side of 'H' field, H2-NC115

A disconformity marks the contact of the predominantly marine Silurian with the continental Lower Devonian strata.

(These situations reported by many authors studded Stratigraphy of southern Libya as (Massa and Collomb 1960, Klitzsch 1965b; Freulon 1964; Turner 1980, Davidson, and other 2000, Don Hallett 2002, Carr 2002, El-Hawat, and other 2003, Sikander 2003, Fello 2006, among other). They are suggested or argued in general that Silurian sediment reflects a very rapid transgression as unstable glacial and periglacial landforms were fossilised by the first shale layers of the Tanezzuft Formation.

The relationship of the facies from the deltaic or marginal continental environment conditions of Ordovician sandstones to marine transgression of Tanezzuft is illustrated in (Fig 2-7), showing the strong unconformity between Tanezzuft Formation and underlying Ordovician sediments (Hawaz Fm) which is maybe affected by process of glacial erosion and/or geology environments between Late Pan African activity and Caledonian orogine.

The typical log response of these formations is showing in (Fig 2-7). The base is easy to identify of the base of the Tanezzuft shale zone, while the tops maybe difficult to distinguish clearly from top of Early Devonian sandstones, due to the gradational character; the Silurian sequence is thicker at Westwards and there is a progressive facies change accompanied by a general thinning to Akakus Formation in Eastward.



(Fig.2-6) showing the main Lithology of Cambrian-Ordovician at subsurface in the H Oil field.

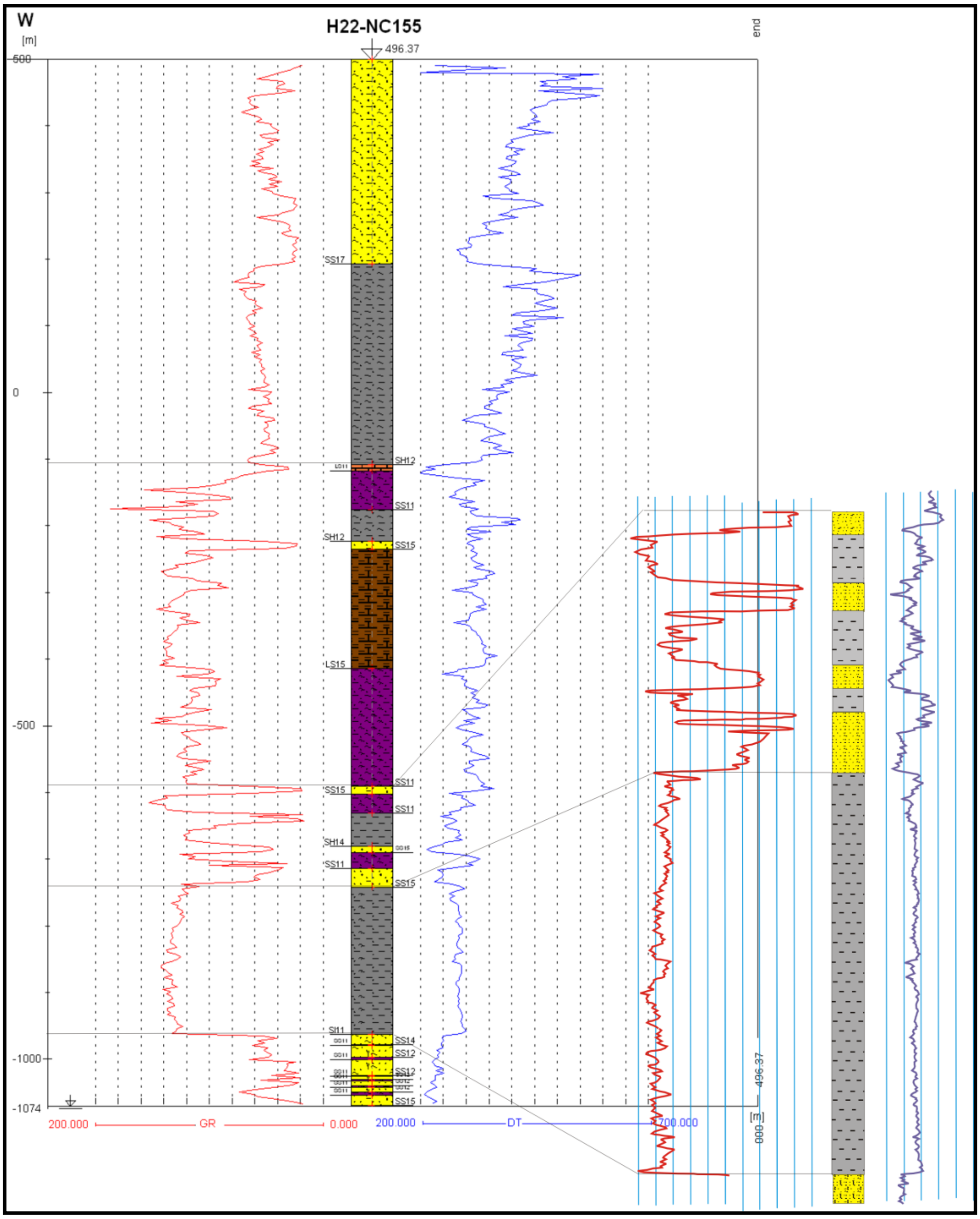
2-5-1 Tanezzuft Formation:

The formation formally introduced by Desio (1936) after Wadi Tanezzuft in northeastern Ghat Libya. The main body of the Tanezzuft Formation originally defined to include the shale between the Memouniat and Akakus sandstones. The Tanezzuft Formation is a sequence of dark gray to black, graptolitic shales with intercalations of siltstones and fine-grained sandstones, and with shaly inter-laminae or thin beds, frequently micaceous and pyretic. In addition, the facies pass transitionally up into predominantly fine and medium-grained sandstones of the Akakus Formation; these form a generally regressive progradational, coarsening upward succession. The formation characterized by high response of GR log reading, and very sharp change between Hawaz/Memouniat to Tanezzuft Formations. Alternatively, in anther word a rapid rise in sea level with a major transgression, which thought to have resulted from the melting of the ice at high areas. The subsequent sea level rise left a condensed shale section in the deeper parts of the basin while silts to fine grained sands were deposited in high parties. The thickness varies between 170 up to 250m at low section. (Castro et el 1991) reported that the Tanezzuft represents the board marine transgression of the Silurian sea over the North African carton, the thickest occurs towards the outcrop belt in SW Murzuq, and over the NE portion of the basin an erosion or pinch out. The thick basal Tanezzuft shale overlies and seals the main reservoir interval and therefore functions as a good cap rock, while the radioactive "hot shales" in the same interval represent the main hydrocarbon source rock, both regionally and locally (Aziz, 2000). The lower part of the Tanezzuft Formation contains anomalously high levels of radioactivity (hot-shales) reflecting the presence of uranium, which probably originated as wind transported fine volcanic ash (Hallett, 2002). However, this means that the Tanezzuft Formation is an important stratigraphic unit from the standpoint of petroleum exploration as far as its represent both the cap and source rocks in the basin. According to Aziz, and Bellini and Massa the age of the formation is an Early to Middle Llandoverian age.

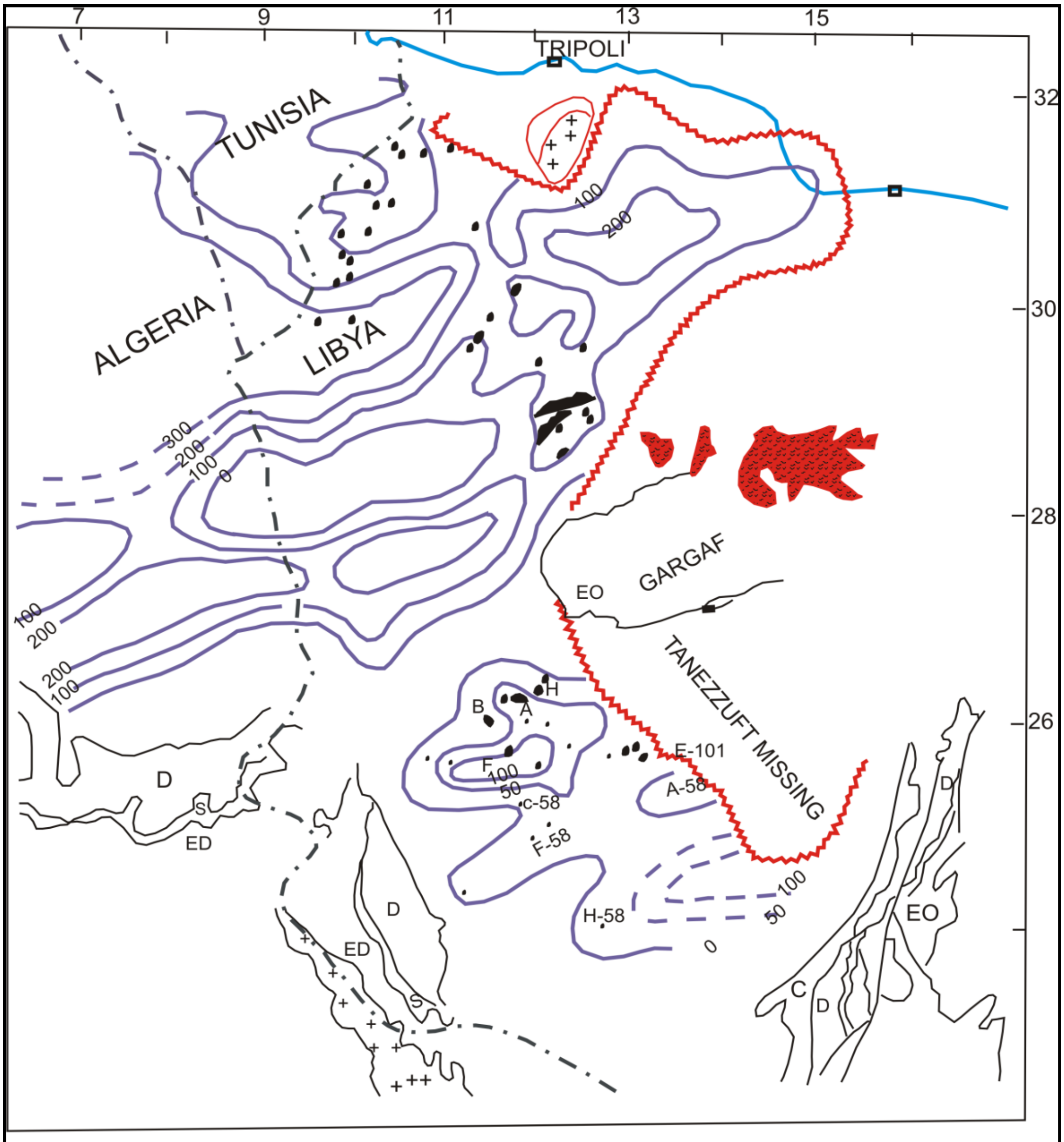
Echikh and Sola, (2000), presented an isopach map of the Tanezzuft basal radioactive zone distribution including the concession NC115 and adjacent area on the northern edge of the Murzuq basin and western Libya. Showed the developed and distribution of lower Silurian (Fig.2-8) and they suggesting that the hot shales present only at low area and is missing over some palaeohighs positive features.

2-5-2 Upper Silurian (Akakus Formation):

Desio (1936) introduced the term after Jabal Akakus in southwestern Libya at Ghat area, as a thick sandstones formation consist of quartzitic sandstones. The formation conformably overlies the Tanezzuft Fm, showing regressive coarsening upward development light gray sandstones with thin beds of shales and siltstones interbeds.



(Fig.2-7) showing the main lithology at subsurface of Silurian (Tanezzuft and Akakus Fms) in study area.



Taneaauft basal radioactive zone distribution in western Libya

(Fig.2-8)

In the 'H' field the Akakus Formation is consist from alternation of dark grey to blackish compact shaly siltstones and light grey to whitish, fine to coarsen grained, subrounded; well consolidated upward sandstones, which represent the regressive phase of the early Silurian transgression. There are four beds of sandstones sections with shale layer in between (Fig.2-7). In addition, the section is highly variable, both in composition and in thickness; these would not allow for a clear-cut subdivision of the formation in the area. On the well log, they show a gradational change with Tanezzuft Formation and sharp contact to Tadrart Formation. The sandstones has well cemented with siliceous or argillaceous cement. The thickness is less than 70 m decreasing to east and southeastward. The environment of deposition interpreted in the Murzuq Basin as ranging from fan deltas with local turbidities flows to offshore bars and fluvial plain deposits (Hallett, 2002). He also shows palynological evidence gives a Wenlockian to Ludlovian age.

2-6 Devonian (Tadrart & Awaynat Wanin Fms):

The stratigraphic nomenclature for the Early Palaeozoic is showing on (fig. 2-1 &2-2); display the Silurian Devonian boundary unconformable. (Beuf et al. 1971) suggested that a complex history of epeirogenic events during late Silurian and early Devonian times. This is indicating by disconformities and local unconformities within the successions of the central Sahara. (Sikander, 2003) said that the Devonian succession consists of a transgressive series overlying the Silurian Akakus or eroded Tanezzuft.

However, at study area, they consist mainly from light grey to whitish sandstones fine to very fine grained rounded to subrounded, well consolidated by siliceous or silica argillaceous cement, and with thinly interbedded shale upwards or calcareous cement in alternance with dark grey blackish. The shale is micaceous and grey brown siltstones. In addition, the section is representing transgressive deposition to shallow marine to lagoonal environments. Abugares and Ramaekers (1993) indicated that the Tadrart Fm mainly deposited as a marine tidal sand ridge.

The type section of the Awaynat Wanin Fm is in the Al Awaynat Wanin area on the NW flank of Al Qarqaf Arch. The formation is mainly shale, fine to very fine-grained sandstones with siltstones. Aziz, (1999) reported that the Awaynat Wanin Fm age is a Late Devonian.

2-7 Carboniferous (Marar, Assedjefar & Dembaba Fms):

The Early Carboniferous formations overlie unconformably the Devonian formations. The Marar Fm is predominantly dark to grey shale with interbedded of compact in alternance with light grey, fine-grained sandstones, cemented by argillaceous, mostly of coarsening-upward regressive sequences, with thin interbeding of grey siltstones. However, the thick succession of shale and sandstone in the Marar Formation consists mostly of coarsening-upward regressive sequences. At the top of the formation, consist of sandy to limestones. Abugares (2003), a cap of thin small stromatolitic limestone, known as "Collenia beds", was deposited because of transgression or abandonment of the tidal ridge complex of cross-bedded sandstone below.

The Assedjefar Formation conformably overlies the "Collenia beds" of the Marar Formation, and consists of stacked sequences of grey whitish sandstones, fine-grained well cemented with calcareous cement dark-grey shales with more siltstone/ sandstone and limestone beds upwards. Sandy oolitic and bioclastic sparite is common upward in the formation. Prograding deltas give far upward to 'ramp' coquinoid limestone deposition. Generally, the Assedjefar Formation deposited in a shallow marine to nearshore environment (Abugares and Ramaekers, 1993).

The type section of Dembaba Formation is in Wade Dembaba on the NW flank of Al Qarqaf Arch (Lelubre, 1952). The Late Carboniferous Dembaba Formation (Fig. 2-1 & 2-2) overlies conformably the Assedjefar Formation. The main consist lithology of the formation is limestones microcrystalline light grey to whitish or yellowish argillaceous often passing to marl with interbeding of shale grey compact locally sandy or silty with variable thickness. This sediment is representing the last marine transgression over the area with marine environment.

2-8 Mesozoic and Quaternary strata:

Mesozoic and Quaternary sediments, is mostly flat lying in all the area. The Late Paleozoic Mesozoic continental sedimentation started with an unconformity over the Upper Carboniferous rocks. They are composed almost entirely of continental clastic sediments with an average thickness of 550 meter. However, the general lithology of Mesozoic strata from continental deposits alternance of claystone, siltstone and sandstone; the claystone is reddish grey whitish sandy to silty soft with thin interbeding of reddish yellow reddish, fine to coarse grained sandstones, rounded medium to hard cemented locally interbeding of grey yellowish siltstones to slightly calcareous.

The Quaternary sediments consists mainly of yellowish reddish, medium to coarse grey rained rounded sands, with interbeding of reddish brown or reddish yellowish sandy claystone.

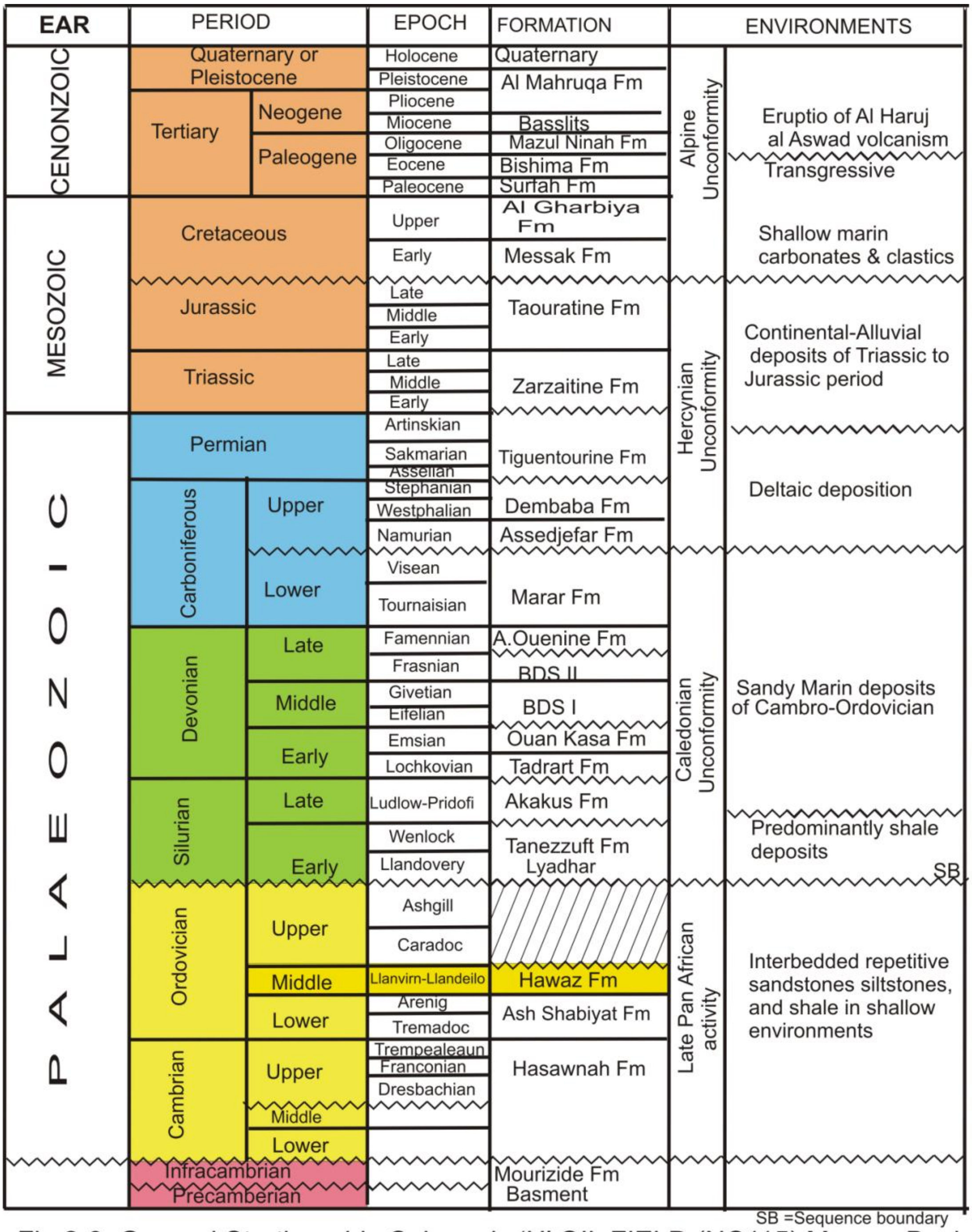


Fig.2-9 General Stratigraphic Column in 'H' OIL FIELD (NC115) Murzuq Basin

CHAPTER THREE

LITHOLOGY AND PETROGRAPHY OF THE HAWAZ ROCKS

INTRODUCTION

3-1 Introduction:

The aim of this chapter is to introduce the reader to some of the basic aspects of Hawaz sandstones petrography, sedimentary processes and their products. The most common of siliciclastic sediments rock found within this formation is sandstones, and the main components which can be identified are grains matrix and cement. The grain types can be further subdivided into fine grains and course grains, but the most common sandstones cement types are sparitic calcite and overgrowth, as will be described later in more detail

The petrographic analysis of the formation was accomplished by thin sections in all the cores available in the area, supplemented by acetate peels (providing an impression of an etched rock surface), polished surfaces or slabbed cores, cutting samples, and hand specimen examination to provide a standard description for all the available layers. The clays and shales are too fine grained for detailed study using normal petrographic techniques. However, in the present study identification of clay minerals was made by (XRD) x-ray diffraction and under SEM (Scanning Electron Microscopy) as described later (chapter four).

The main sandstones grain types are discussed and can be divided into six categories as in the following section: (a) quartz, (b) feldspar; (c) rock fragments; (d) heavy minerals; (e) micas and clays and (f) other constituents. These don on the basis of their detrital and several factors as grain propriety (size, morphology; surface texture; fabric and textural maturity), sediment source and the depositional mechanism components.

In the Hawaz Formation, each thin section was analyzed according to standard modal analysis techniques in order to determine the propriety of the following minerals: quartz, feldspar, rock fragments, heavy minerals, mica, and clay mineral as kaolinite, illite, chiorite, pyrite, matrix and bitumen. Grain-size was determined in thin section by using a micrometer. Also, hand piece-big slap cores samples were finished at the Akakus Oil Operations, Laboratory in Libya. The thin sections were not used for determining the quantitative mineral content, since the risk of high failure quotes by point counting minerals. In addition, the thin sections served as a control implementation for the evaluation of the XRD values. As guidance for determining minerals in the formation the books (atlas of rock-forming minerals in thin section, (1980), atlas of sedimentary rocks under the microscope (1984), Microfacies of Libya (1967), and Tucker (1991) Sedimentary Petrology and other references were used.

3-2 Methodology:

Characterization and zonation of the reservoir are based on the following data:

1. Description of more than 380 feet of core material and identification of different sedimentary facies (see Fig. 3-3);

2. Conventional and special thin section description and analysis from tow well where core available at reservoir section. These results have been tied to the sedimentary facies to provide a rigid frame for quantification of reservoir parameters and calibration of log-derived data;
3. Thin-section petrography used to serve a number of functions in studies of cultural objects. It is used to characterize and identify inorganic materials, locate the specific source of materials, group objects that may have a common source, and, less commonly, provide information on object deterioration and the effects of conservation treatment.
4. Wireline log interpretations that have been used to estimate log-derived clay volume (Vsh), sonic porosity, density porosity, neutron porosity than main porosity and saturation for the entire reservoir section. Logs of reasonably good quality are available from all wells and the gamma, neutron/density/ Sonic logs and resistivity logs, all these information have been used to correlation between the logs character with petrographic analysis, estimate clay content, and porosity

3-3 Quartz:

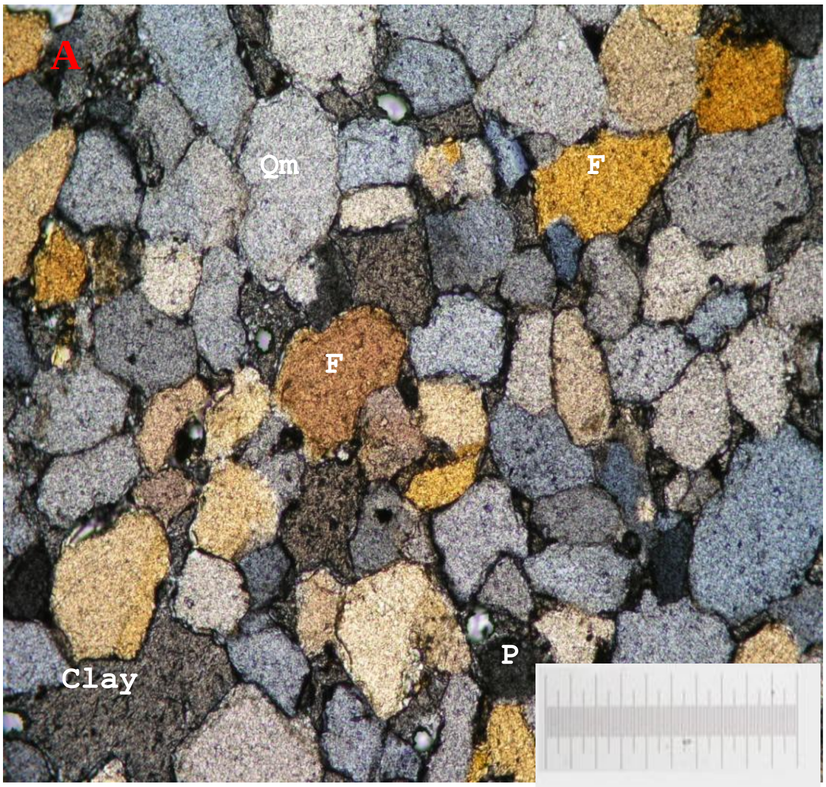
The most common mineral in Hawaz sandstone Formation is whitish grey quartz, which represent the most stable of all minerals under sedimentary conditions in the basin. However, it occurs in a wide range of sizes and shapes. The dominant size varies between very fine sand to coarse sand, with sub-ordinate to minor quantities of medium to coarse sand. In general, the shapes are sub-angular to sub-round with some amounts of very rounded, polished grains. The colour of these quartz grains ranges from colourless, whitish grey, yellowish and reddish, with colourless grains being the most common. The average sandstone contains some more than 75% quartz, but some are practically 90% quartz. The majority of quartz grains of Hawaz Formation has various types of quartz and can be distinguished as:

1. Monocrystalline quartz grains (Qm) (are composed of a single crystal). Where most quartz has concavo-convex contacts, with good indicator that the grain has undergone considerable compaction during burial process. Monocrystalline quartz is the dominant grains type. (Fig. 3-1 & 3-2).
2. Polycrystalline grains (Qp) (are two or more crystals, may be indicator of a metamorphic source)

Quartz Cement: A third major component, in addition to the grains and matrix, is the cement introduced between the particles during diagenesis. Quartz cement is common (especially in facies five), which often occurs as ***overgrowths*** on the original grains or between the grains, where the compaction and packing degree relatively is not very high.

(Fig. 3-1) Showing thin section under cross polarizer of H27-NC115 at depth 1510m (A) X10, (B) X4, & (C) X20. Quartzarenite: Monocrystalline fine to medium; fair to well sorteded quartz grained, as well as subrounded to rounded grained. The detrital grains are clay mineral matrix and fine crystal with cemented material; pyrite is present.

(Fig. 3-2) H5-NC115. At depth 1473(-970) m; crosse polarizer and 20X & 10X. Quartzarnite: monocrystalline fine to medium; fair to well sort, subrounded to rounded quartz K-feldspar grained. The detrital grained are clay mineral, fine crystal and cemented material; pyrite is present.



Quartz grains in Hawaz Formation occur as both monocrystalline grains and polycrystalline grains, while the majority dominated is the monocrystalline grains in most facies. Polycrystalline quartz grains and quartz with undulatory extinction are less stable in the sedimentary environment than monocrystalline non-undulatory quartz. Thus, sandstone consisting of monocrystalline quartz that does not show undulatory extinction is mineralogically the most mature.

Three type of grain size can be distinguished in the formation as:

1. Silt to very fine sand sized grains which are common in the second and forth facies in the formation. Fine grained with detrital quartz grains. Immature stage. Sediment contains over 5 percent ferruginous clay matrix; Sand grains usually poorly sorted and angular to sub-round.
2. Fine to medium sand sized of grains and is common in the first and third facies of Hawaz Formation. Represent sub-mature stag sediment contains fewer than 5 percent clay, but sand grains are still poorly sorted.
3. Medium to coarse sand sized grains which are common in the medal facies, mature stage. Sediment contains little or no clay, and sand grains are well sorted but still not total rounded to super mature stage where sand grains are well sorted and well rounded. This present in facies five.

However, quartz, the most common siliceous component in Hawaz sandstones, varies in abundance from over than 50% in the shaly facies to more than 85% in the quartzose facies (facies three and five). This reflects its mechanical and chemical stability (during or after deposition) under a wide range of sedimentary conditions; and that because quartz is the most mineral resistant to weathering and abrasion during transport. The most diagenetic condition seen in the thin section is the compaction and fluids pressures. In the study area the grain size ranges from very fine-grained to coarse-grained; fine to medium grained is the average size. Grains are subrounded to rounded and are relatively well sorted to poorly sorted, and they are texturally and compositionally the good to fair mature. Monocrystalline quartz grains are the dominant type while polycrystalline very locally present (Fig.3-1 & 3-2), which may indicated that quartz grains are derived in grater abundance from plutonic rocks than other rock types. In relatively "clean" sandstones, most quartz grain are rimmed with quartz overgrowths, while corroded grain outlines are present in "dirtier" units, with up to 10% matrix. Quartz overgrowth is common in the cleaner facies of Hawaz sandstones.

Particle size (both the average size and range of sizes of the particles), composition of the particles (mostly quartz), the matrix of the rock (fine grained materials between grains may composed largely of clay mineral), and the cement material composition (intergranular cements are commonly silica); all these characteristics are readily observable through thin section and on core or core slab.

Quartz in mud rocks is chiefly of silt-grade although coarser, sand-size grains do occur, especially where the mud rocks grade laterally or vertically into sandstones. Quartz silt is invariably angular in comparison with the typically more rounded quartz sand. Silt-grade quartz is derived from grain collisions in aqueous and aeolian media. Some quartz in mud rocks is diagenetic rather than detrital. The regional variation in grain size and percentage of quartz in a mud rock sequence can be used in palaeogeographic studies (e.g. Jones & Blatt, 1984).

3-4 Feldspar:

Feldspar is not a single mineral. It is a group of minerals that have similar characteristics due to a similar structure as (potassium or K-feldspars). In addition, they have relation to each other in structure and chemical composition. Feldspar minerals are aluminum silicates of potassium, sodium, and calcium.

Feldspars are the second most commonly occurring mineral next to quartz in the formation. Feldspars may be distinguished between each other by a number of properties, but the one most likely to be effective in pottery thin-sections is the twinning (quartz does not have twinning that can seen in thin section):

- Feldspar with lamellar twinning is plagioclase
- Feldspar with tartan twinning is microcline
- Feldspar with no twinning is orthoclase

The Feldspar minerals form similar crystals and contain cleavage planes along. However, it's difficult to identification between them by ordinary methods (needs x-ray analysis and chemical tests); in many cases it is practically impossible to distinguish one from another. Since feldspars are softer and less mechanical stability than quartz they oven replacement partly or completely by clay minerals such as kaolinite and Illite. In study area, a feldspar mineral makes the most widespread minerals after quartz grains. In addition, the formation content of the potassium feldspar, this has averages between 10 and 15% from the feldspar content. This may indicated that the feldspar content of sediment is largely controlled by the rate of erosion and the climate; or may be because of their low resistance for reaction during or after transport. The relative abundance of potassium feldspar minerals sometimes may be a possible indication of source sediment or distance of transport. (Boggs, 1995), feldspars are the second most abundant mineral in most sandstone, although their mechanical stability is less than quartz, because they are softer and strongly cleaved. The potassium feldspars are much more common in the formation than the plagioclases. (Tucker, 1991), the K-feldspar is much more common in continental basement rocks (granites and acid gneisses). In general: the alteration of plagioclase feldspar is more common in the coarser grained sandstones facies and tends to take place initially along the borders of grains, which become frayed and corroded, or along twin planes.

At the Hawaz Formation quartz and feldspar has varies considerably in abundance throughout facies; and their grains from the formation are angular to subangular to subrounded. However, The thin section microscopy and XRD analysis of Hawaz samples reveals that the main mineral content of all sampled sandstones are represented by quartz grains, which are associated with various feldspar types, mica (muscovite and biotite), chlorite, calcite and a very few dolomite. Additionally, accessory minerals have been recognised, like: zircon, pyrite, and hematite. Since the total mineral content of the sandstones are represented by a quartz at average 70 to 85% and feldspar with an average of more than 20% and all samples are poorly to well sorted (from facies to another), whereas the grains are rounded angular - sub-angular; the sandstones are assigned as textural immature and mineralogical moderately mature. When applying thin section microscopy, an average of approximately 4 - 10% of the total rock is estimated to contain matrix of clay and silt; which present more at shaly sandy beds and muddy facies. The cement of the sandstones is mainly silica-supported with significant proportions and varying amounts of carbonate material. Silica is precipitated mostly as overgrowths, while carbonate usually as a calcite fillings of intergranular spaces.

In addition, the mineralogical compositions of whole rocks samples for Hawaz Formation, shows quartz is the major constituent mineral followed by feldspars. Where the feldspar is less a banded in clear facies as in facies (three); and moor commend at other sandstone beds; which may indicated stability environments during or after deposition.

3-5 Mica:

The term "mica" is group of minerals and most people who are knowledgeable about minerals know the three most common mica minerals: muscovite, biotitic, and lepidolite. It has very shiny faces and can be easily recognized in a granite or similar rock.

Mica is a minor constituent of the Hawaz Formation and rarely forms more than a few percent, with more muscovite being the dominant type, since it is more resistant to weathering. Mica is easily identified by its platy nature and parallel extinction. It is colorless in plane-polarized light and shows bright second-order colors under crossed polars, lie on bedding planes in parallel extinction and characterized by their platy and flaky habit in thin section (Fig.3-3). The average abundance of coarse micas in formation rocks is less than 2%, although some fascias sandstone may contain 2 to 5%.

Muscovite is commonly clear in plane polarized light; excellent cleavage. It may be derived from igneous source rocks around the area. It's easy to recognize in thin section with mica. The medium grained sandstone in facies three associated with an alignment of grains, especially by the mica sheets, which do align parallel to the bedding plane (see fig.3-3). The major mineral grains display less characteristic imbrications, but nevertheless, also these grains arrange in internal laminations.

3-6 Rock fragments:

In sandstones the fragments are commonly of fine-grained sedimentary and meta-sedimentary rocks such as mudstone, shale and siltstone, and slate, siliceous sediment. Rock fragments are very useful in studies of the provenance of a sandstone, but intra-basinal lithics, which are commonly grains of mud and carbonate. The composition of rock fragments depend basically on source rock geology and the durability of particles during transportation and deposition conditions of particles.

Rock fragments in Hawaz Formation facies making in average between 10% - 15% of the detrital grains. Meanwhile, the major types of rock fragment in sandstones are composed of fragments of other rocks, with argillaceous group including shale, schist and carbonate fragments, and heavy minerals as zircon grains. In addition, some silica group of quartz rock fragments occur or consisting of fine quartz. These fragments are decrease in shaly facies up to 5% up to 10%. Some of polycrystalline quartz grains in thin section are subrounded to round can be recognized in many depths. The percentage of rock fragments increases with increasing un-homogeneity of grain size (as facies two). The course rock fragments may represent reworked fragments of at least partially consolidated material of sediments. These particle types are not very common in the study area, and are observed mainly in only a few thin section (at top formation) and cores slap at a very few instances.

These may represent the reworking from within the area of deposition during times of enhanced current activity (possibly by occasional storms), or perhaps reworking of early lithofication surfaces (hard grounds).

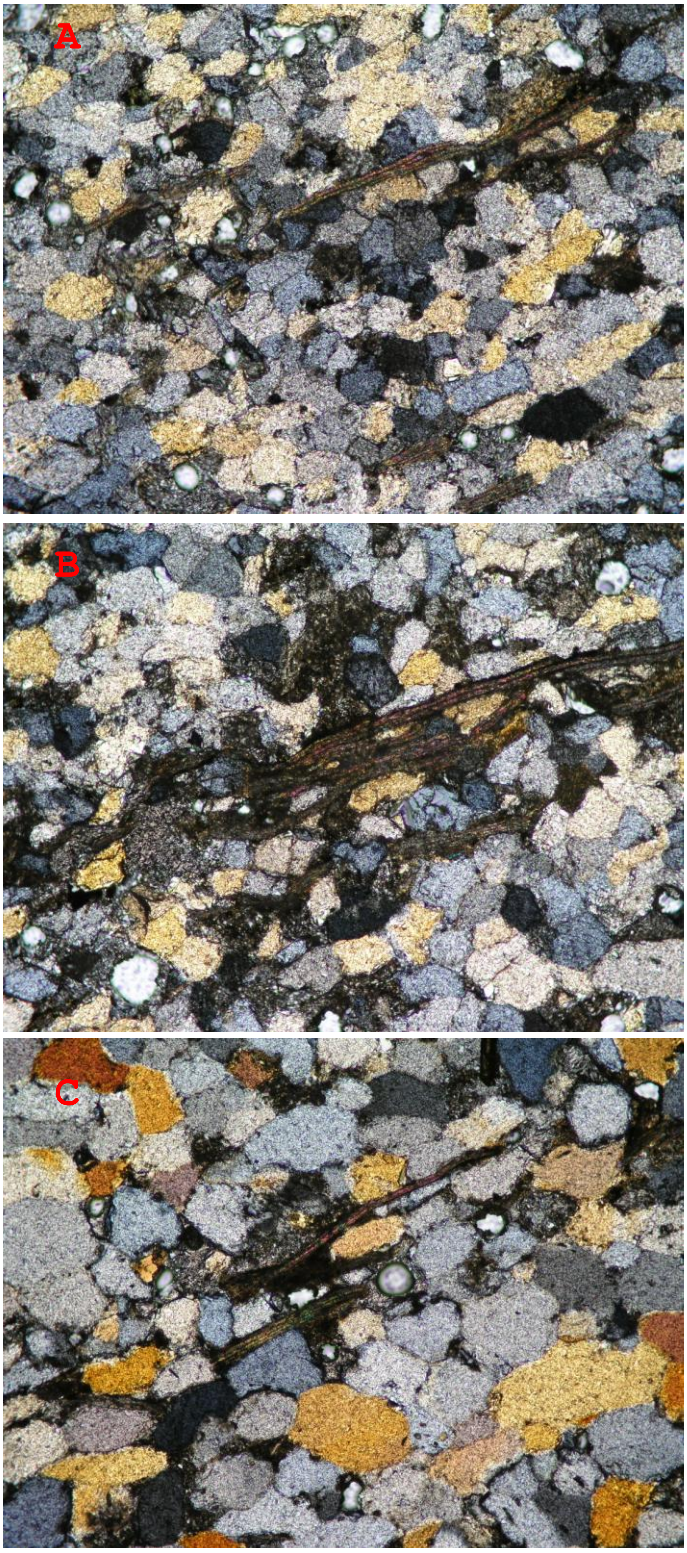


Fig. 3-3 **Sandstone (with mica)**

Thin sections (A&B) in well H5-NC115 at depth 1523.3m and 1524.5m respectably, while (C) in well H27-NC115 at depth 1499.5m (facies 3).
Showing a fairly fine-grained sandstone mode of rather angular grains of quartz and feldspar (feldspar looks more cloudy). Narrow feldspar of mica, seen edge-on, and slightly crumpled, lie on bedding planes.

3-7 Bitumen:

Bitumen's are soiled organic substance occurring in groundmass. Bitumen is almost accepted as indicator for precursor for petroleum in the rocks. However, they are apparent in thin section at plane polarized as black to dark brown seepages, as well as in reflected light. In addition, they occupying some pores and coating detrital grains in many samples. Bitumen is more variable in morphology, occurring as small, isolated nodules or massive (<2 mm in width) veins that cross-cut all foliations, as discrete individual nodules in an irregularly distributed or as elongate seams (up to 500 µm in length), interpreted to represent a series of coalesced individual nodules. In all cases, the bitumen nodules are nonfluorescent under UV-light.

3-8 Matrix and Quartz cement:

(Tucker, 1991), the term cement refers to any mineral that is precipitated after the grains and matrix have been deposited. (Adams, and other 1984), on deposition, many sandstones contain little sediment matrix between the component grains. Some terrigenous mud may be deposited with the grains and those sediments with more than 15% clay matrix are classified as greywacks. In Hawaz, facies fine-grained materials between grains may be composed largely of clay minerals and silica cementation, but may also contain very fine particles of quartz and feldspar. At muddy facies (F1&F4), the carbonate mud matrix which was probably deposited at the same time as the grains, rather than being introduced later as cement.

However, intergranular cements are commonly silica and carbonate matrix. Silica is precipitated as overgrowths, or layers, on quartz grains so they are extinguish together under crossed polarisers. Quartz cement postdates is significant compaction and may has precipitated during lat diagenesis. (Adams, and other 1984) the most important process of compaction is pressure-solution see (Fig 3-5 and 4-4).

It is likely that most of the silica required for quartz cementation was internally sourced by the pressure or clay induced dissolutions of detrital quartz grains. Other possible additional source of silica for quartz cementation is the dissolution of feldspar during burial diagenesis, especially for sandstones which are not cemented early in diagenesis. This source of silica for quartz cement is suggesting by the alternation of (1) relatively clay poor sandstones rich in quartz cement as facies five, and (2) clay coat rich more tightly compacted sandstones with little quartz cement, and quartz dissolution features as in sandy shale facies. This is very clear or especially in the lower part of formation sandstones.

(Thyne et al., 2001) said that if kaolin is present in the system, the dissolution of K-feldspar might cause the illitization of kaolin, providing additional silica.

However, the cements are formed during or after deposition and burial process. The grains and matrix are commonly altered by the physical effects of compaction and by chemical changes. The depositional of clay in the formation is maybe one of the primary control vectors on the distribution of quartz cementation. As well as, the clay distribution is controlling the facies variations, and the porosity and permeability of the formation, which in turn depends on depositional facies and environments.

3-9 Clay minerals:

The mineralogical study covering the clays included the samples which were studied in thin sections under a polarizing microscope. Detrital clays reflect the source-area geology, climate and weathering processes (Tucker, 1991). Clay minerals will be discussed in detailed in anther section, because of their small size to be study in normal way.

Shales in the Hawaz Formation sandstones can be divided into two categories: allogenic and authigenic (as can be seen in core sample and thin section). In both cases the clays can be distributed structurally (grains of mudstone), as laminations (layers and fracture fill) and dispersed (grain supported and pore fill). Laminations of clay occur at all scales from the finest of layers to massive layers. The distribution of the clay may have been depended on the conditions at deposition, on compaction, bioturbation and diagenesis.

Clay minerals are various percentage between less than ($\leq$ 5%) of most clean sandstones facies, where they are present as part of the matrix to more than 50% with carbonate fabric at shaly section. Most clay minerals originate through subaerial weathering of silicate minerals. (Pettijohn et al., 1987) surmise the environment deposition of clay as humid climates and well-drained topographies lead to extensive weathering of feldspars and their silicates to kaolinite. Main silicates in many climates will weather to smectite, whilst illite forms mainly in intermediate to humid climates.

Clay minerals have been identified in the Hawaz Formation sandstones by XRD and scanning electron microscope analyses. In addition, they are consisting mainly from kaolinite and miner illite as well as montmorillonite. However, the clay minerals in thin section show colorless in piane-polorized light and grey-dark grey in cross-polarized light, with weak birefringence. It partly fills both primary and secondary pore space. Secondary porosity probably formed from feldspar crystals which were subsequently dissolved, leaving a residue of clays.

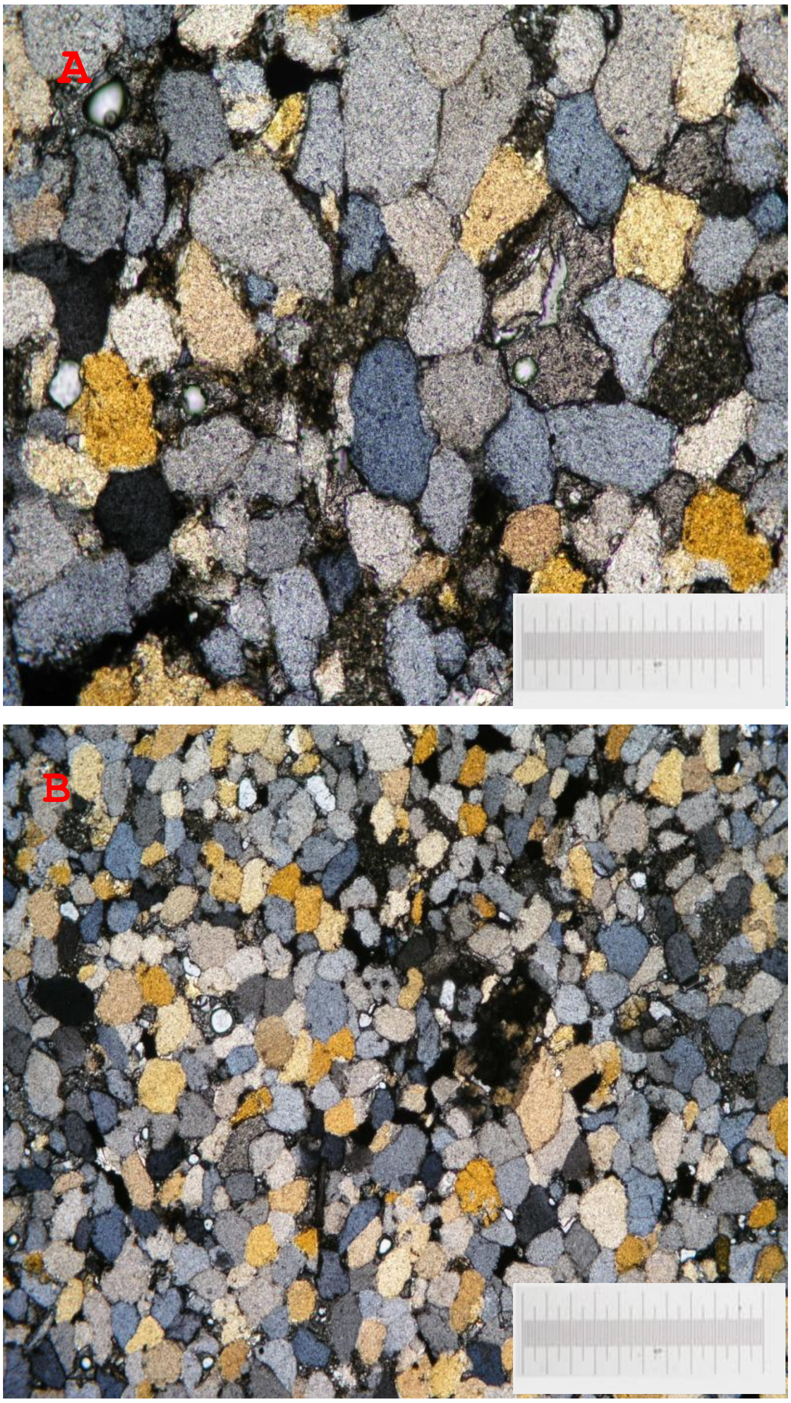


Fig. (3-4) Showing H5-NC115 at depth of 4825(-3211) ft; in crosse polarizer and 10X & 4X (A&B). Quartzitic sandstone, fine to medium; fair to well sorted single crystals grained; Feldspar with calcite and clay matrix minerals, black bitumen and pyrite occurring in groundmass, good porosity (>10)

In addition: authigenic clay minerals comprises 2 to 5 wt% of the reservoir rock and which occur as pore-lining, pore-filling and pore-bridging crystals. Pore-lining clay is recognized in thin sections by a continuous outside around the grains. However, since the fine material are not completely identified by using an ordinary light microscope, because for that, it is studied by used the electron microscope and by x-ray diffraction. SEM photomicrographs show clay occurrences in detail (Fig 5-21 to 5-25).

Kaolinite may be derived largely from the weathering of feldspar and is the most stable under conditions of burial. Montmorillonite is derived from a variety of minerals but especially from fine-grained volcanic materials such as ash. This mineral contains abundant interlayer water, which may be removed during burial by the influence of temperature; montmorillonite may be converted rapidly to the clay mineral illite.

Diagenetic changes may add significantly to the total cement material by altering other minerals. It is believed that feldspar grains can alter in place to kaolinite by reaction with ground water, and some kaolinite may form by precipitation from solution.

The interpretation of clay minerals as related to depositional environment is dangerous without a knowledge of diagenetic history. Nevertheless, large amounts of detrital matrix may be significant to the interpretation of source terrain, distance of transport, and velocity or constancy of transporting currents.

3-10 Pyrites:

Pyrite occurs in minor amounts (<1 % of vol.), especially in sandy shale beds, or where it forms mm-scales patches, preferentially within argillaceous grains and laminate, as well as pyrite is locally abundant along the contacts between sandstones beds and underlying mudstone (shaly facies), where it occurs as nodules of up to few mm in size. Locally, pyrite also occurs as isolated pyritohedrons, up to 50μm in diameter, that rim detrital grains cements. In addition pyrite occurs as a minor cement but widespread constituent of the Hawaz sandstones reservoir rocks, and occurs throughout the sequences examined (especially in the lower facies). Pyrite frequently forms cavity fillings, with silt to sand crystal sizes. It is characterized by the development of cubic crystal faces and forms crystalline aggregates and irregular patches in the groundmass. The pyrite is conspicuous under reflected light from other opaque iron minerals. Pyrite is present as disseminated grains and cubic crystals (Tucker, 1991).

The occurrences of pyrite are quite rare at upper facies, but more common in the lower and middle facies in the central parts of the field as in wells H27-NC115 cores. (Jackson, 1970) pointed out that the deposition of quantitatively minor chemical sediments (such as pyrite) is controlled by the ***Eh*** of the depositional environment. A negative ***Eh*** means that a reducing condition exists, and under intense reducing condition ferrous iron will be deposited as the sulfide pyrite. The presences of pyrite are generally apparently attributed to a restricted or semi-restricted, calm and undisturbed depositional environment which is poor in oxygen and low activity.

3-11 Porosity:

Porosity of a rock is an important primary and secondary property is defined as the percent of void space, or non mineral space that occurs within or between the grains, matrix, and cement. However, in the subsurface reservoirs, all voids are filled with fluids. Thus, porosity is a measure of the capacity of a reservoir rock to store oil, gas, and water. In anther word it's to determine by measuring the amount of fluid that a sample displaces.

(Tucker , 1991).Two major porosity type the primary and secondary porosity, primary porosity is development as the sediment was deposited and included inter and intra-particle porosity, secondary porosity develops during diagenesis. In study area a routine laboratory measurement of porosity commonly have been made for core sample through thin section at selected samples, and shows both primary intergranular porosity and secondary porosity are present in Hawaz sandstones rocks.

The porosity of detrital rocks depends on grain size, shape, sorting, packing and the amount of intergranular matrix or cement. In Hawaz facies the total porosity is measured of all sandstone facies, and has porosities range from 10 to 20 percent. Facies (three and five) have the highest porosities, clayey sandstones or shaly sandstone facies have less porosity (facies one), and siltstones have the smallest grains and the least amount porosity (facies four). Because composition and grain size are interdependent, porosity may be largely a function of median grain size for most sandstone. However, the porosity of the homogenous fine – medium-grained sandstones from the lower section southern areas is estimated as varying from 10 - 17%. In contrast, the upper section is poor to very poor porosities that definitely do not exceed 5% at shale section. In general the porosity increases as the grain size increases and the sediment is more homogeneous or more matshore sandstones. (Details of porosity analysis are discussed in detail with petrophysical analysis).

3-11-1 Primary Porosity:

Primary porosity (e.g., complete preservation of intergranular porosity or slight modification of original porosity by minor cementation) is estimated average at 7%. Cleaner sandstones facies are commonly cemented with quartz cement, overgrowths and calcite; also kaolinite occurs in the some of remaining pore space. However, in some depths on cores and core slabs remnant primary porosity can be identified.

3-11-2 Secondary Porosity:

This type of porosity is very common in Hawaz sandstones rocks. The development of this type is directly related to dissolution of framework constituents, matrix, and cements It appears that remnant primary porosity is very important in the evolution of secondary porosity because some of the original pore was required for movement of pore fluids in order to initiate various dissolution reactions. Quartz grains very commonly show some corrosion and partial dissolution, which is probably related to the diagenetic processes (physically or chemically) removal or precipitation of cement minerals between grains (see Fig. 4-11).

It is also possible to speculate that some of diagenetic fluids may have originated from the shale during compaction and thermal transformation of these shales. On the other hand, chert and quartz need a slightly alkaline solution to be corroded or partially dissolved. The alkaline solution may have evolved from the total consumption of hydrogen ions during the previous reactions. Textural evidence of quartz corrosion tends to support the above conclusion, for corrosion is present only in areas where detrital matrix remnants still exist.

The Hawaz Fm (Cambro-Ordovician) at great depths and temperatures (1500 m subsea, 200°F) may have good pressure solution (as indicated by stylolites) of quartz grains to be responsible for many silica overgrowths and reprecipitation of the mineral in adjacent pores, or for a replacement of other mineral grains such as feldspar and quartz. (Burst 1969) This phenomenon is commonly at tribute to clay dehydration at temperatures greater than 200°F.

3-12 Stylolites:

These are a prominent feature of many sedimentary rocks and are represented a serrated interface between two rock masses. They may yield relatively high permeability (if open at all) and low porosity (Longman, 1981). The most common stylolites present in the study sequence are the sutured type (Fig.3-5). This is especially common in the more dense sandstones rock types, more than in the other units. Stylolites transect the rock fabric, cutting across grains, cement and matrix indiscriminately. Glover (1968) confirms that the stylolites were developed when the reservoir was fully permeated with oil. They are often fully saturated with flood, and show significant pathways for the migration of oil. They are important in many hydrocarbon reservoirs in part because they are often associated with fractures. However, stylolites formed during or after burial sediments deposition process probably by dissolution associated with either subsurface fluid migration, or with sub-surface pressure solution.

3-13 DIAGENESIS:

The term diagenesis is generally used to include all processes that take place in the sediment after deposition. Both the grains and matrix represent the products of weathering that were carried as sediment to their site of deposition. After deposition and burial, the grains and matrix are commonly altered by the physical effects of compaction and by chemical changes. In addition, is the cement precipitated between the particles during diagenesis process. This change may greatly affect the reservoir properties (porosity and permeability)

The general condition of particles shows and determines the degree to which these materials may be altered, either physically or chemically, by diagenesis. These processes under subsurface conditions greatly affect the reservoir properties of porosity and permeability by decreasing or increase of reservoir quality. Tucker, (1991) any change of these conditions, such as by deep burial or by the withdrawal or injection of fluids, may promote some change in the character of grains and matrix.

As far as the main majority quartz gained in the formation is monocrystalline quartz grains, which may derived in greater abundance from plutonic rocks such as granite than from other rock types. The monocrystalline grains are showing more resistant and unwilling to separation or parting than are the polycrystalline grains. A polycrystalline grains are less common presenting in the formation (contain numerous crystal) may be more susceptible to breakage during transport than are the monocrystalline grains.

Many authors believed that the feldspar minerals are largely derived from the weathering of igneous and metamorphic rocks; and easily degraded by both weathering and transport processes during deposited or after diagenesis. In study area the sources of feldspar is the nearest massif area around the basin, these may indicated that the abundance of feldspar is generally much less than the quartz mineral. In addition; the thin section showing the potassium feldspars, seems to be more resistant than plagioclase to weathering and transport. Tucker (1991), Plagioclase feldspars, which contain sodium or calcium, are especially susceptible to chemical weathering, and these grains are less likely to survive during transport than the orthoclase feldspars.

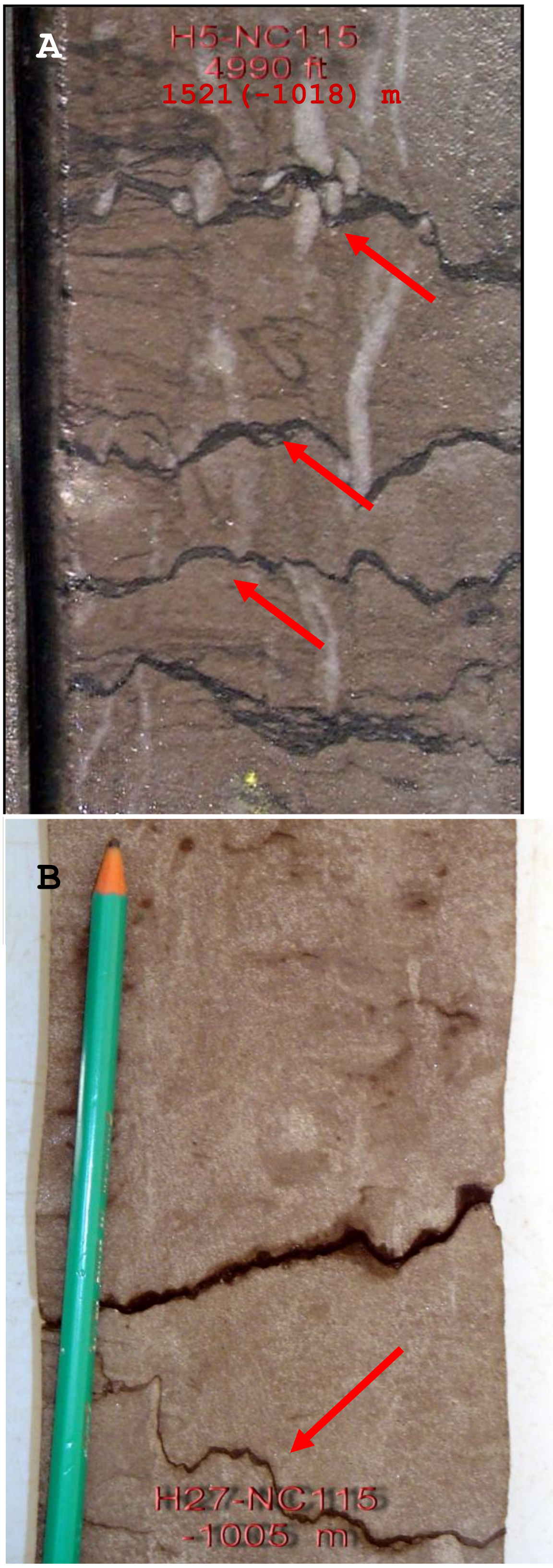
Rock fragments which may be the result of weathering of rocks grained or sedimentary rock; shows more homogeneity and generally same character in thin section. Nevertheless, the diagenetic features in thin section can be recognised in the effects of physical, and mechanical, dissolution of framework grains and precipitation of authigenic minerals (as kaolinite). These diagenetic processes are responsible for destroying much of the primary intergranular porosity and permeability in the sandstones. Furthermore, of the dinginess processes the effective of the bioturbated (burrowed) activity by *Tigillites* on the primary sedimentary structures at muddy sandstones facies; where particularly the primary sedimentary structures are dispersed. (This will discuss in next chapter).

However, the main phase's diagenesis of the Hawaz Formation sandstones has been reviewed and studied. The main results are:

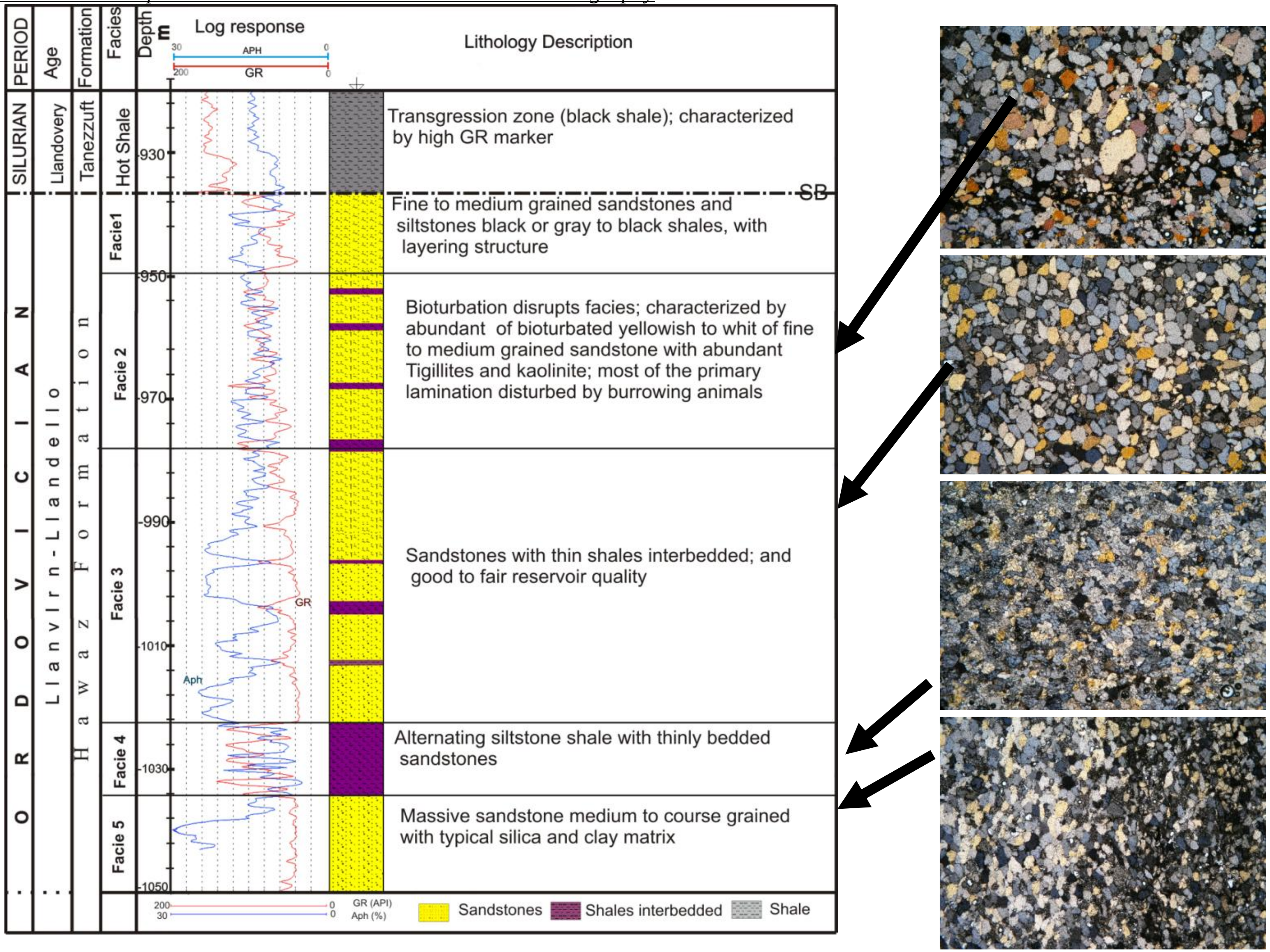
1. Intergranular kaolinite phase sedimentation;
2. Quartz overgrowths;
3. A major phase of cementation and;
4. Dissolution of feldspars.
5. The bio-activity processes on the primary sedimentary structures.
6. Other opaque minerals with pyrite may be present as result of diagenesis such as iron oxides.

The extent and significance of the various diagenetic episodes vary from facies to facies and from place to place across the field. The diagenesis which may toke places in the facies are both physical and chemical, where the major mineral grains shows more or less some modification during diagenesis, such as compaction of the grains; leaching and growth on quartz grains; feldspars do also tend to be modifying their pre-diagenesis habit and composition. Porosity and permeability properties are altered by diagenesis.

(Fig.3-5) Photographic of slabbed core: (A). Showing poorly-sorted sand- and siltstones at boundary between facies two and facies three. Fine grained sandstones with highly stylolitized future; field with muddy material. (B) Showing same facies at well H27_NC115, but more massive sandstones and thicker sand bodes than above core.



(Fig. 3-6) showing GR log, average porosity, main lithology and the main petrographic thin section in each facies of Hawaz Formation



CHAPTER FOUR

FACIES DESCRIPTION AND DEPOSITIONAL ENVIRONMENTS

SEDIMENTARY FACIES

4-1 Introduction:

The Hawaz sandstone succession forming the reservoir of the H-NC115 Field consists of sand-grained sediments ranging from weakly calcareous clay-stones to relatively pure non-fossil course sandstones. However, the main grains sizes range of very fine to medium grained, argillaceous sandstones interlaminated and interbedded with silty, micaceous mudstones. All gradations between these end-members are represented, such that facies boundaries are somewhat arbitrary and, in many cases, are difficult to determine. The following facies classification is a practical subdivision that has proved to be applicable in the Lower Middle Ordovician of the Hawaz Formation; the fine-grained sediments are the result of suspension settling in a low-energy environment, but the course grained is very likely higher enrage regime. The range of facies represented, with respect to sandstone/clay ratio. Petrography and regional facies patterns suggest that the Hawaz sandstones may were derived from a nearby, tectonically source terrain in the area.

4-2 The Purpose of Study:

The study includes physical, chemical, and biological aspects of the facies sedimentary in the Hawaz Formation; vertical and the lateral change within the sequences. Their for the main objective of this study is to undertake a detailed investigation of the facies and microfacies present within the formation (Lower Ordovician) and associated sediments, within the subsurface of the Hawaz Formation at "H" Oil Field in the Murzuq Basin, with particular emphasis on the main following aspects of petrographic character to the sandstones and other rock types present; the nature and distribution characteristic of bio-facies in the Hawaz Formation and their paragenesis:-

1. Vertical and lateral variation in lithofacies associations;
2. The distribution of clay minerals types within different facies and their responses to the depositional and post-depositional history of the Hawaz Formation.
3. The consequential effects of facies and other lithological variations on the petrophysical attributes and reservoir quality of the Hawaz sandstones bodies;
4. The gross petrophysical aspects of the Hawaz Formation reservoir.

4-3 Material and Methods

However, the reservoir zonation presented in this chapter is based on the study of core material and wireline logs conventional wells. The wells locations are present in (Fig. 4-1). The H5-NC115 and H27-NC has good cored interval in Hawaz Formation for that they are used as reference wells for core-log correlation, supplemented by additional material from the other wells. All data have been tied to the lithostratigraphic and sequence stratigraphic frame-work established.
Characterization and zonation of the reservoir are based on the following data:

- Description of more than 380 feet of core material and identification of different sedimentary facies (see Fig. 4-1 & 4-2) at Akakus oil operation geology laboratory;
- Conventional and special peels and thin section description and analysis from two well, where core available at reservoir section. These results have been tied to the sedimentary facies to provide a rigid frame for quantification of reservoir parameters and calibration of log-derived data;
- Wireline log interpretations that have been used to documented the each facies characterization.

4-4 Sedimentology Observations

The main influence affecting the Ordovician sedimentary process had the Caledonian event, which started from Ordovician period. It are manifested by contribution of detrital material with extra, supplemental tiles material, which is present in Ordovician sediments only and absent in Early Silurian sediments, where marine transgression of the Silurian Tanezzuft Formation takes place. The Caledonian event caused that this glacial matter was dissolving and melting and consequently settled, generally in northern part of the highland area in Upper Ordovician period; the sea level had changed and started the transgression period. The Ordovician sediments thus represent upward Finning cycles shallow marine to delta fan environment, with sea level oscillations between high and low. Offshore marine sediments were deposited in the Murzuq Basin (Bellini and Massa, 1980; Pierobon, 1991; Clark-Lowes and Ward, 1991), on the Gargaf Arch between Murzuq and Ghadames basin (Vos, 1981a). The shallow marine deposits are characterized by hummocky cross stratification and are interpreted to be storm-influenced shelf deposits (Carr, 2002). Late Llanvirn (Hawaz Fm) to late Caradoc in age is characterized by shallow marine deposits prograding into more basinal area, and is capped by the point of maximum regression within the sequence, characterized by an angular unconformity on the Saharan Platform (Legrand, 1985), aggradations of shallow marine deposits in the Murzuq Basin and followed by a major transgression (Carr, 2002). The Silurian Tanezzuft Formation (“hot shales”) represents a maximum flooding surface. High uranium values are due to the great organic matter production that usually keeps pace with sea level rising.

4-4 Reservoir Characterization:

Hawaz Fm sandstones of Lower Ordovician age were studied on the H-NC115 in order to reconstruct their depositional history, depositional environments, including both physical and organic characteristics, and geometry of sandstone bodies. Detailed logging data and mapping revealed the response of depositional systems to frequent relative sea-level changes, and facies depositional respected.

The H-NC115 reservoir interval has been characterized on the basis of analyses of logs and core data. Wireline logs have been used to estimate log-derived porosity, clay volume and saturation for the entire reservoir section. Core converge the entire reservoir and is in good condition. Most core data are from wells (H5 and H27-NC115); these wells are-regarded as the most representative reservoir section. However, the other section depended on the parameters such as depth, porosity, shaliness, et al, which calculated estimated on the basis of log data.

The reservoir zones are characterized with respect to Lithology, petrophysical properties and diagenesis, and average properties have been assigned for each zone at the central part of the H-NC115 structure.

4-6 Facies description and depositional environments:

Within most wells in the field in the study area, a sequence of six to seven facies associations are recognized and identified all available characteristic based on particular associations of rock type, sedimentary structures, cores descriptions and log characterized. A special attention has been made for only five facies within most wells in the field in the study area, which represent the reservoir potentiality in 'H' Oil Field. The stratigraphic positions of these intervals are shown in the fig. (4-1 & 4-2); the main description and interpretation are summarized as following:-

4-6-1 Facies one:

The main component of this facies is fine to medium quartz grains sandstone to fine grained siltstones with laminated claystone and gray to black shales interbedded. These facies is often associated with fine-grained wave rippled sandstones or thin silty laminations, where siltstones often show layering but laterally discontinuous from well to other in the study area. Thicker sandstone beds become more abundant at east direction within the field.

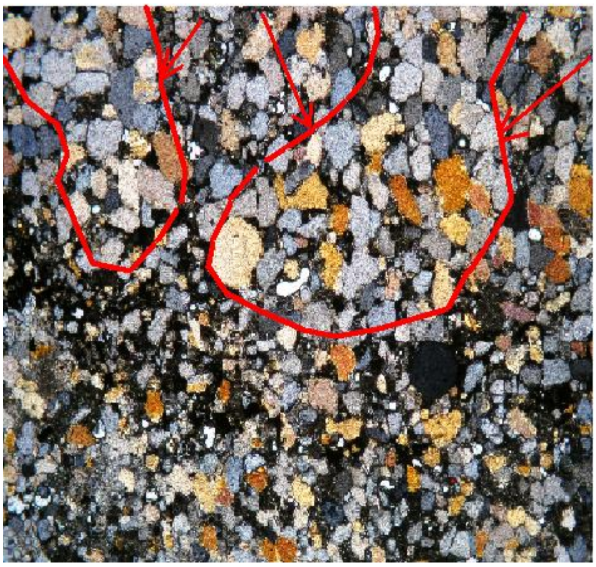
Shale, mudstone, and siltstone are making up to (in general) 40 percent of the facies sediment volume see tables (4-1 & 4-2). The upper part of the facies is sandier, highly consolidated displaying lower porosity and permeability; while the lower part is muddier than upper. Therefore, the facies can be divided into sandy and shaly sections (see Fig. 4-1& 4-2). The shaly part has some bioturbation increasing with depth and the thicknesses show local lateral variation between the wells field. This facies is represented in the tops core in type well H5-NC115 showing a thinning upward sequence trend.

4-6-2 Facies two:

Bioturbation disrupts facies; Fine to medium grained sandstones beds with discontinuous laminated laterally siltstones, and shale interbedded, fingering out into shales. It is characterized by an upward decrease in grain size. The grain size is fine to medium at the bottom and finer at top, demonstrating a fining upward sequence. The mineralogical composition is dominated by quartz and clay (see chapter four). Additionally, the facies shows less subtle or unsubtle grain-size differences between burrow and surrounding sediment sandstones (see Fig. 4-3).

The gray to brown gray shales beds occur throughout in thin beds (from a few centimeters to less than a meter), in parallel laminated or with low angle stratification. However, the fine-grained layer is commonly slightly more argillaceous in character and is interbedded with cleaner thin sands beds.

This facies has low to fair reservoir quality; depending on the amount and fabric of clay in the pores (see table 4-2 which shows high shale contact within the facies).



(Fig. 4-3), showing differences in grained between burrows and surrounding sediment sandstones, the dark chunks are a fine clay and the light ones are the larger grained sand component (mainly quartz). Polarized light, 32x

4-6-3 Facies three:-

This facies represents the main reservoir in an overall field and has good distribution and thickness in all field .The facies can be divided into two sub-facies; the upper sub-facies consists of yellowish grey to whit grey, very fine to fine, partially to medium grained sandstones with abundant grey to brown siltstones matrix, and thin irregularly interbedded shales. One of the main characterize in this sub-facie is the vertical and subvertical burrowed throughout section especially at shale lamination. . The primary bedding and lamination mostly destroys by those highly and intensely burrowed (1-90 cm) within horizontal bedding units (see Fig. 4-10).

However, the main burrowing activates (bioturbated) animals such as worms, clams, and crabs in the facies is by Tigillites; which characterized by abundant of disturbed the laminations in the mudstone and claystones units. Bioturbation are more preserved in the silt and shale or fine sandstones intervals than cleaner sandstones. The most biogenic activities are represented by vertical and a few horizontal burrow traces. Those are in filled with different material to surrounding see (fig.4-3).

Occasional small scale cross bedding is also present at lower unit, but the bases with borrowing most prolific in the upper part of units. These sub-facies deposits record an upward increase followed by a decrease in flow velocity (waning current events between discharge and storm winnowing), and may indicated to shallower water column depth than the lower sub-facies.

The lower sub-facies is massive sandstones, consists of homogenous with well sorted, medium to fine course-grained sandstones; shows fining upward trend from coarser-grained at the base to finer-grained at the top. The sub-facies are occurring within a thicker succession (0.5 to 2m). Some thicker bedding may be present. The facies thicknesses show a good local lateral variation extending crossing the field. The appearance structures occasionally plane homogeneous, a few scattered dark clay clasts present throughout the sandstones facies; this is clearer in at H5-H115. (See Fig. 4-7). All this features properties of sub-facies may indict to the depositional processes in marine shelf to deeper environment than other facies. The main petrophysical analysis showing good intergranular porosity; and good to fair porosity in general; average shale less than 20% (see table 4-1).

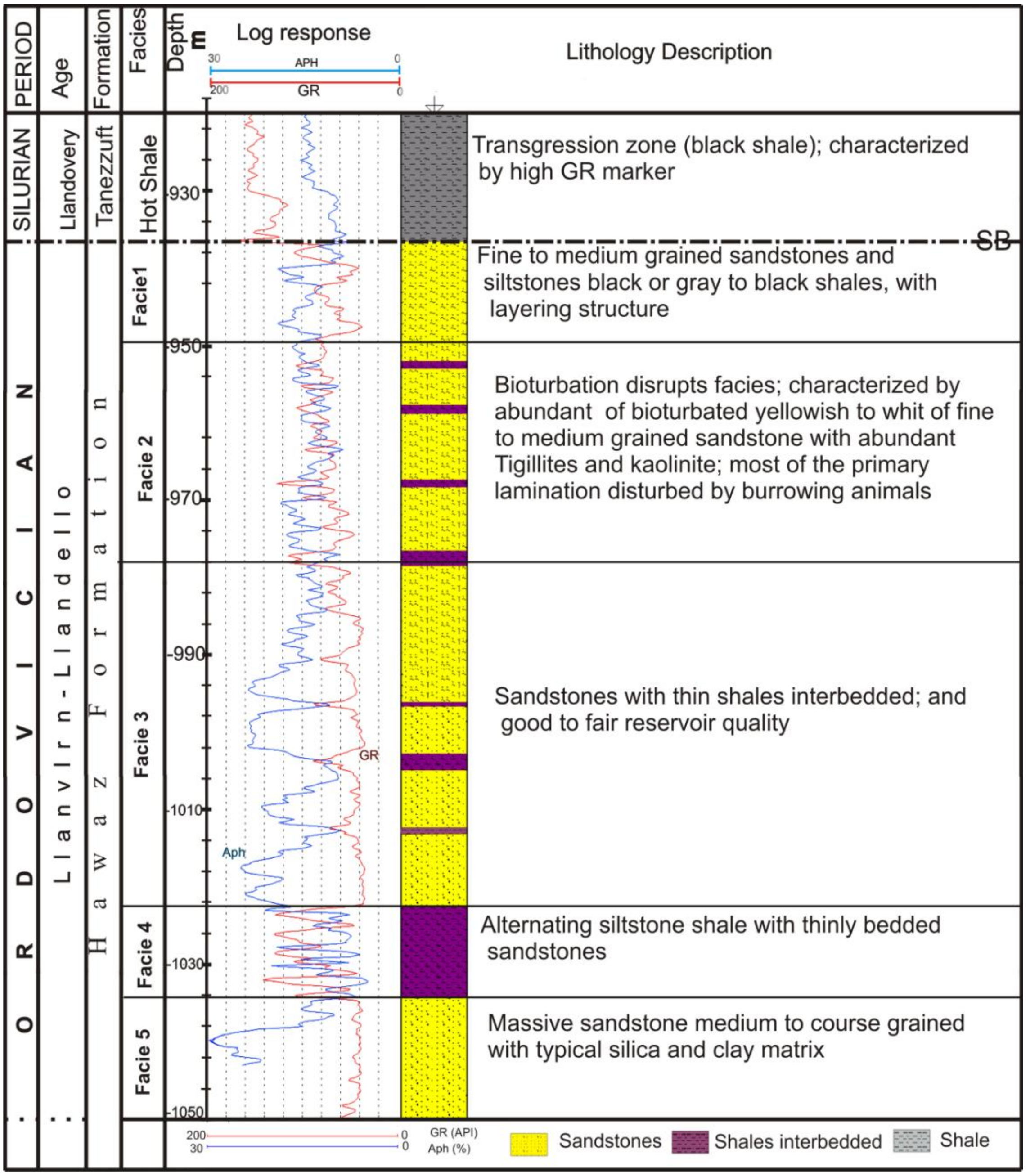
4-6-4 Facies four

Bioturbated sandstone facies: consists mostly of very fine to fine grained sandstone with abundant of burrowed laminated interbedded siltstones shale alternating beds. The facies shows a general fining upward development trend from fine grained sandstone to very fine-grained siltstone at top. The dominant features of this facies is irregular horizontal bedding continuity from well to other; which are up to 2-80 cm thick, and some thicker may be present in the lower part of the facies. Occasional vertical intensely burrowed through facies. The burrowing and biological action that abundant associations of facies are completely destroyed the original primary sedimentary structures (See fig. 4-10). The facies may represent change between high charge and lower discharge condition deposition or progressive rise in the marine level environment condition (transgression). Similar facies have been described by (Vos, 1981), the dominant feature of this facies is vertical burrowing which passes through beds and destroys most internal sedimentary structures. Individual burrows are 0.5-3 cm in diameter and may be traced vertically for over 2m, a few horizontal burrowing is also present (See Fig. 4-8 & 4-10).

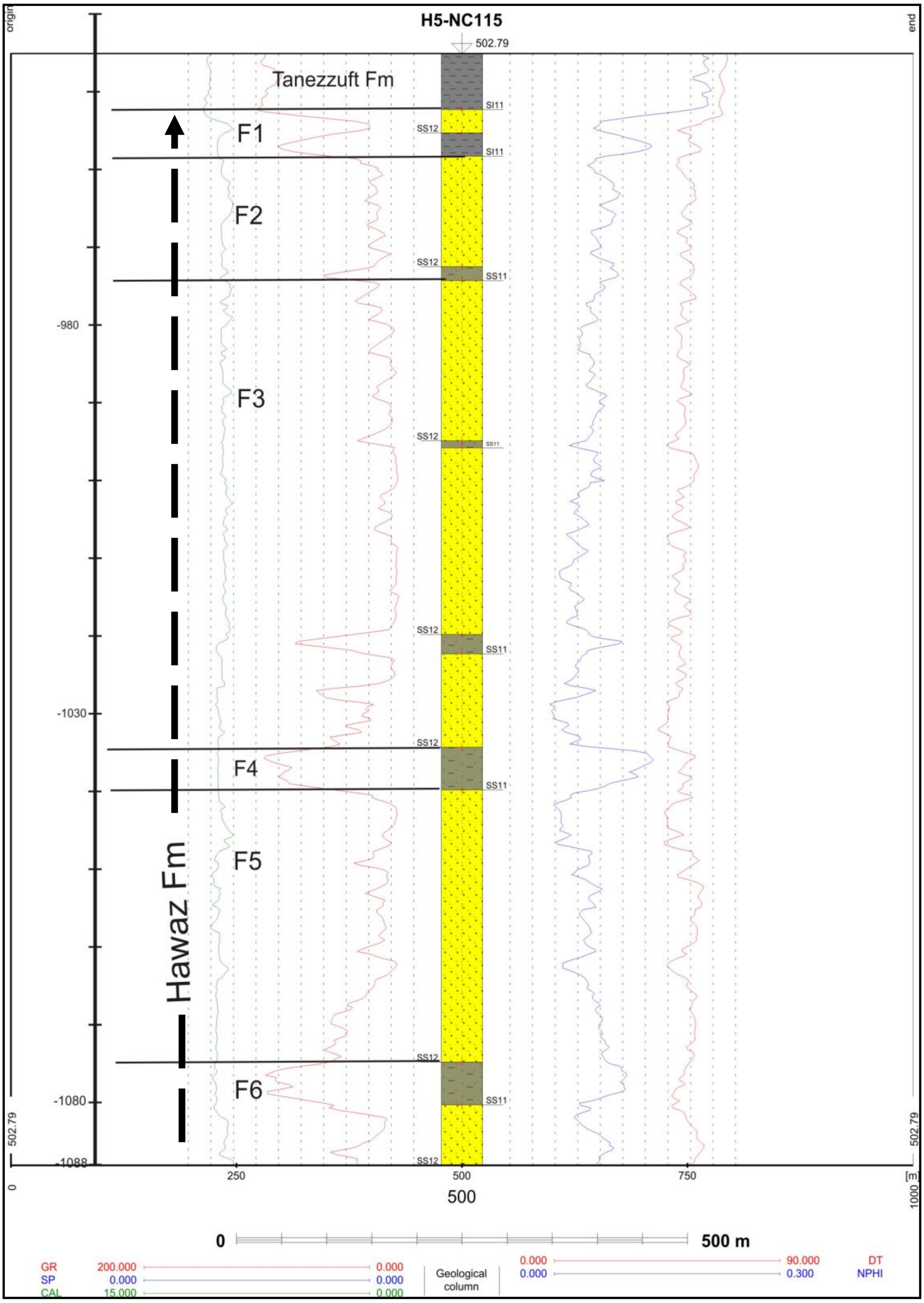
Stratification and other depositional structures of shoreface environments produced during fair-weather conditions are generally destroyed during storms (Dott and Bourgeois 1982, Dott, and et al 2006).

The interbedded bioturbated sandstone and shale facies contains similar features maybe indicator that they have been deposited in a quieter shelf or shorelines environment; and this facies is represents transgressive conditioner comparing to the other facies.

Interbedded sandstone and shale with such features record deposition between low storms influenced energy events FWWB and SWB along storm-dominated shorelines, and the shale beds (commonly bioturbated) record periods of quiet water suspension deposition (Dott and Bourgeois 1982; Walker 1984).



(Fig. 4-1) General lithology and particular facies in the 'H' Oil Field, Murzuq Basin.



(Fig.4-2) showing the facies distribution in the H5-NC115 ("H" Oil Field, Murzuq

4-6-5 Facies Five

The facies may subdivided to upper sub-facies: which consist of thick sequence of white to gray, fine to medium grained; fair to well sorted, friable in part micaceous, to very micaceous; with typical silica cement and clay matrix, good to fair reservoir quality (intergranular porosity main type). However, quartz makes up between 90% and 80% of the total volume of the rock; orthoquartzites do exist in the sequence.

Massive homogenized bedded; the massive bedding refers to beds without any apparent internal structure or structureless, scattered of a few striation can be seen on core sample. This sub-facies comprises mainly plane bedded in general; with a few of a striation and fractures can be seen on core. The sequence passes un-gradationally to siltstones and silty shales above.

Lower sub-facies is thinner than above and consists of bioturbated sandy shale: (as facies 4) very fine to fine grained micaceous sandstones with various thicknesses laminated / interbedded gray to dark grey shale. The burrowing in the sub-facies consists of smaller tubular vertical burrows (with a few horizontal). However, this unit is characteristic with highly vertical burrowing, which destroyed most internal sedimentary structures as that can be seen in Fig. 4-10). The main thickness is increasing at center of the field.

The dominated of the laminated gray to dark grey shale with very fine to fine grained sandstones lances in the in lower sub-facies may good indicator to the facies sediments probably accumulated in a shallow marine shelf environment.

Table (4-1) Criteria for facies discrimination on logs*:*

Facies	Gamma Ray	Resistivity	Porosity
Facies 1	Between 20-60API	High reading > 150 Ω.m	Shown a fair amount of porosity but fair permeability
Facies 2	Changeable between low and high through all the facies	**a**-The deep resistivity gave high reading especially at oil well (0 up to >200 Ω.m **b**- the medial reading	Shown a fair of porosity but low permeability. This is due to the fine grained sandstones and clay, which gives rise to porosity
Facies 3	Low, except a few scattered beds with high reading.	High reading of resistivity may be due to oil exists.	Shows good to fair porosity > 17% and permeability up to hundreds of mD.
Facies 4	High more than 80 API, close to shale line response	Changeable reading maybe due to variability in the pore network flood.	Low porosity and permeability due to high percent of siltstones and clay matrix within the facies or to the facies heterogeneity.
Facies 5	Nearly constant which indicated to massive facies	Low reading	Shows fair to good petrophysical quality, (may be due to the facies homogenous).

4-6-6 Facies six:

The rest of formation consist of sandstone, quartzitic, fine to medium grained, fair to well porosity from log analysis. No core data available.

Table (4-2) Average Petrophysical parameters for the facies in the "H" Field at Hawaz Formation.

Facies	Average thickens	Average V_{sh}	Average Θ	$Θ_{Sonic}$	$Θ_{Density}$	$Θ_{Neutron}$	$Θ_{Core}$	Average H. K_{Core}	Average V.K_{Core}	Grain Dens
Units	m	%	%	%	%	%	%	mD	mD	$g.cm^{-3}$
F- 1	11	10-35	6-14	8-15	6-15	3-15	11.5	16	23	2.65
F - 2	30	10-35	10-13	10-15	9-14	5-12	13.5	5	6	2.66
F - 3	42	3-25	10-20	9-19	9-21	12-21	14	215	185	2.65
F - 4	12	45-85	3-9	6-10	3-15	3-9	7	55	25	2.66
F - 5	32	5-15	10-27	8-25	12-27	10-25	-	-	-	-
F- 6	76	25-30	-	-	-	-	-	-	-	-
Aver	204		6-25	7-20	5-25	5- 24	7-14	2-215	0.8-185	2.66

(Vsh = shale volume, H.K_{Core} = core horizontal permeability, V.K_{Core} = core vertical permeability)

Table (4-3): Average values from analysis of selected wells in the 'H' Field at Hawaz Formation. Formation represents all thickness, reservoir is a thickness between top and OWC, Net pay is the thickness of productive zone.

Well	Formation			Reservoir				Net pay			
	Top	Bottom	Thic.	Thic.	$Θ_{total}$	$Θ_{Av}$	V_{sh}	Thic.	$Θ_{total}$	$Θ_{Av}$	V_{sh} Av
H1	1435	1550	115	87	29	15	27	50	27	17	13
H5	1456	1588	132	72	28	16	10	55	25	16	7
H16	1441	1550	110	60	27	14.5	17	40	18	15	16
H20	1452	1570	118	65	26	17	19	64	19	22	18
H22	1463	1568	105	65	15	12.	12	34	14	12	12
H27	1435	1640	202	82	27	17	20	50	27	17	18
H4	1586	1654	68	18	18	14	20	10	17	10	20

4-7 Sedimentary environment:

The main influence affecting the Ordovician sedimentary process had the Caledonian event, which started from Ordovician period. It is manifested by contribution of detrital material with extra, supplemental tillites material. (Tucker, 1991) a late Ordovician glaciation evidence for which is particularly well displayed in North Africa. The glaciation has been interpreted to have occurred during the late Ashgillian Hirnantion Stage (Hirst, et al. 2002). The tillites material is present in Ordovician sediments only and absent in Early Silurian sediments, where marine transgression of the Silurian Tanezzuft Formation (hot shales) takes place. During the Early Ordovician the offshore marine sediments were deposited in the Murzuq Basin (Bellini and Massa, 1980).

The reason is firmly rooted in the fact that during Silurian period the south and western high mountain (beside the basin) were high and covered with ice. The Caledonian event indicative of a warm climate, which caused that this glacial matter was dissolving and melting and consequently settled, generally in northern part of the highland area in Upper Ordovician period; the sea level had changed and started the transgression period. The Ordovician sediments thus represent upward Finning cycles shallow marine to delta fan environment, with sea level oscillations between high and low. The Silurian Tanezzuft Formation ("hot shales") represents a maximum flooding surface. High uranium values are due to the great organic matter production that usually keeps pace with sea level rising. The Silurian Tanezzuft Fm is representing the deepest sediment marine environment and a source and cap rock for hydrocarbons potentiality in the area.

4-8 Summary and conclusion

The Hawaz sandstone formation forming the reservoir section consists of fine to medium grained sediments ranging from weakly calcareous clay-stones (argillaceous) to relatively pure non-fossil fine to medium coarse sandstones, sporadically interbedded with silty, micaceous mudstones. All gradations between these end-members are represented, such that facies boundaries are somewhat fluctuating, and, in many cases, are difficult to be determined. The following facies classification is a practical subdivision that has proved to be applicable in the study formation; the fine-grained sediments are the result of suspension settling in a low-energy environment, but the coarse grained sediments correspond very likely to higher energy regime. The range of facies respects often the sandstone/clay ratio. Petrographic analysis of the rock facies patterns suggest that the Hawaz sandstones were carried away a nearby mountain source and that were deposited in alluvial fans to shallow marine environment.

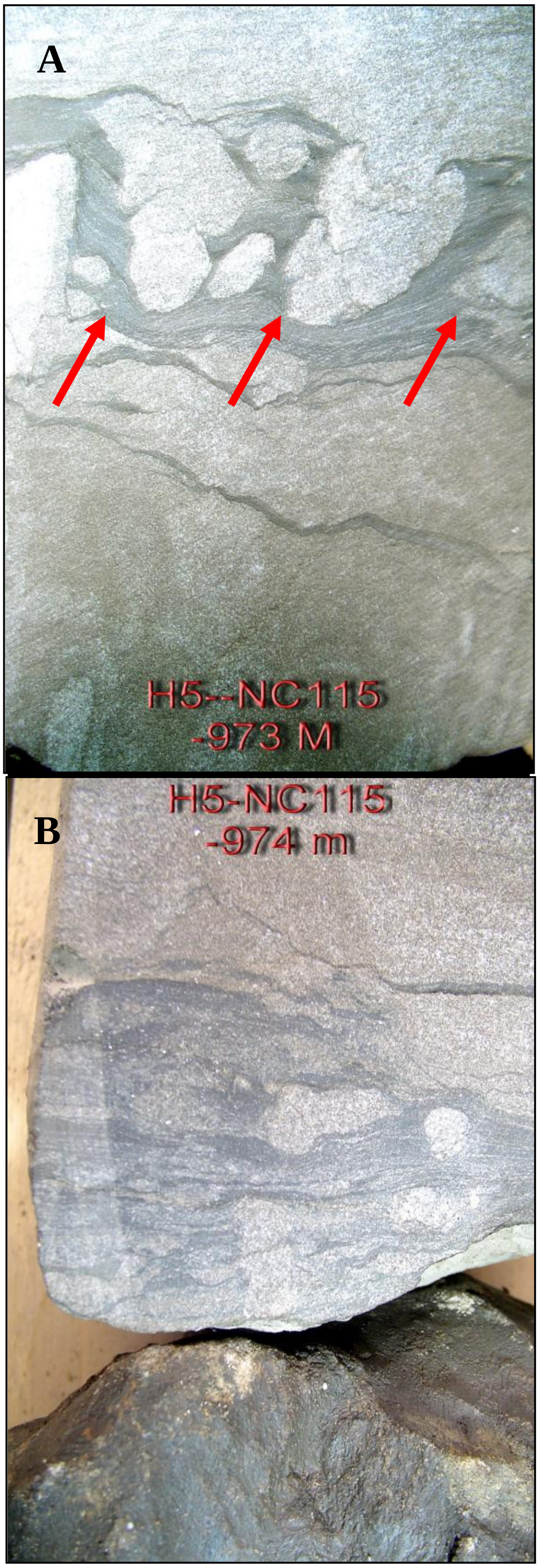
All available data allows dividing the Hawaz Formation into 5 facies which can be recognized in all wells. Facies thickness range from 10-60 m, two from them being the most important and perspective; they are represented by coarse sandstones with well rounded grains; and good to fair reservoir quality. The facies three contains in addition to sandstones thin layers of very fine silty clay laminations (Fig.4-1). Homogeneous sandstones is mostly hard massive appearance with medium to coarse grains, including higher content of feldspar, mica and clay matrix, mostly presenting in the facie five and lower part of facies three (Fig. 4-1). These two types of facies sequences represent the Hawaz reservoir potentiality with fair to good vertical and lateral continuity and connectivity. The both facies have a typical minimum values on gamma-ray curve (low Vsh) and relatively maximal porosities.

Lower Cambro-Ordovician sediment has been studied by many others in south and western Libya as with (Bellini and Massa, 1980; Vos, 1981, Pierobon, 1991; Clark-Lowes and Ward 1991; Echikh and Sola, 2000; McDougal and Martin, 2000; Davidson et al., 2000; Aziz 2000; Remy, & Loup, 2000; Carr, 2002 & 2003; Dardour, et al., 2004; Fello, et al., 2006, among others. The sequence is characterized by shallow marine to delta deposits in most parts of western Libya.

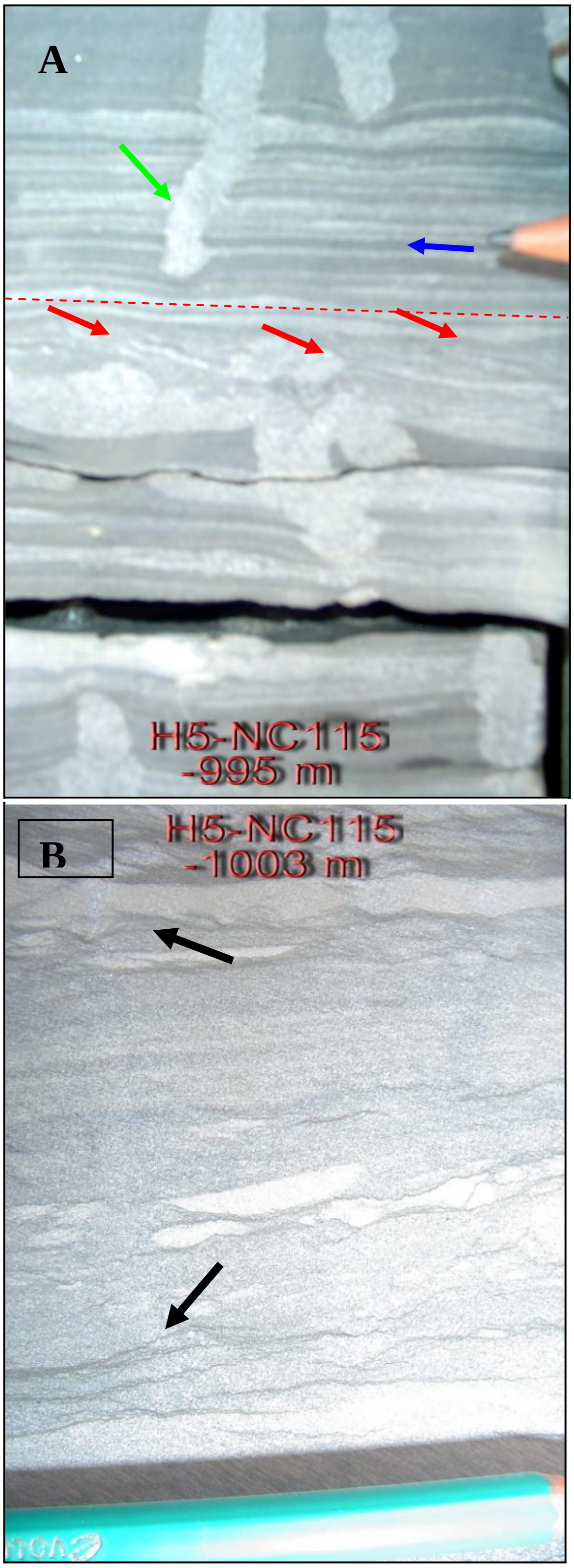
The Hawaz Formation sediment as showing above is changing between sandy shale to massive sandstones sediment, or with regressive and transgressive cycles with irregular regime through out the formation. This was may be caused by general change in sea level column in the Ordovician time. The well log analysis with GR, SP and Vsh shows that the increasing of reading is indicators of increasing of fine sediment (silty and shales). This relation was good tools to distinguish between the facies within the sequence, and facies variation characterize. The analysis of sequence prosperity as upward and downward fining subsequence cycles, some of cross-bedding; the presence of thin horizontal laminations in upper and medial part of fine material (silt & shaly sandstones); in addition, the vertical and lateral variability of the sequence over short distances; all that evidential may indicates of an upward decrease in depositional energy; and to thicker water column with slightly deeper environment.

However, this sequence is interpreted as shallow marine to deltaic complex as indicator by all above factors. Deposition of this formation sequence took place in a shallow-marine environment to deltaic sediments. (Vos, (1980) studied the Hawaz Formation in western-central Gargaf Arch area (between Murzuq and Ghadames Basis) and come out with example of an ancient fan delta complex system prograding across the Gargaf Arch.

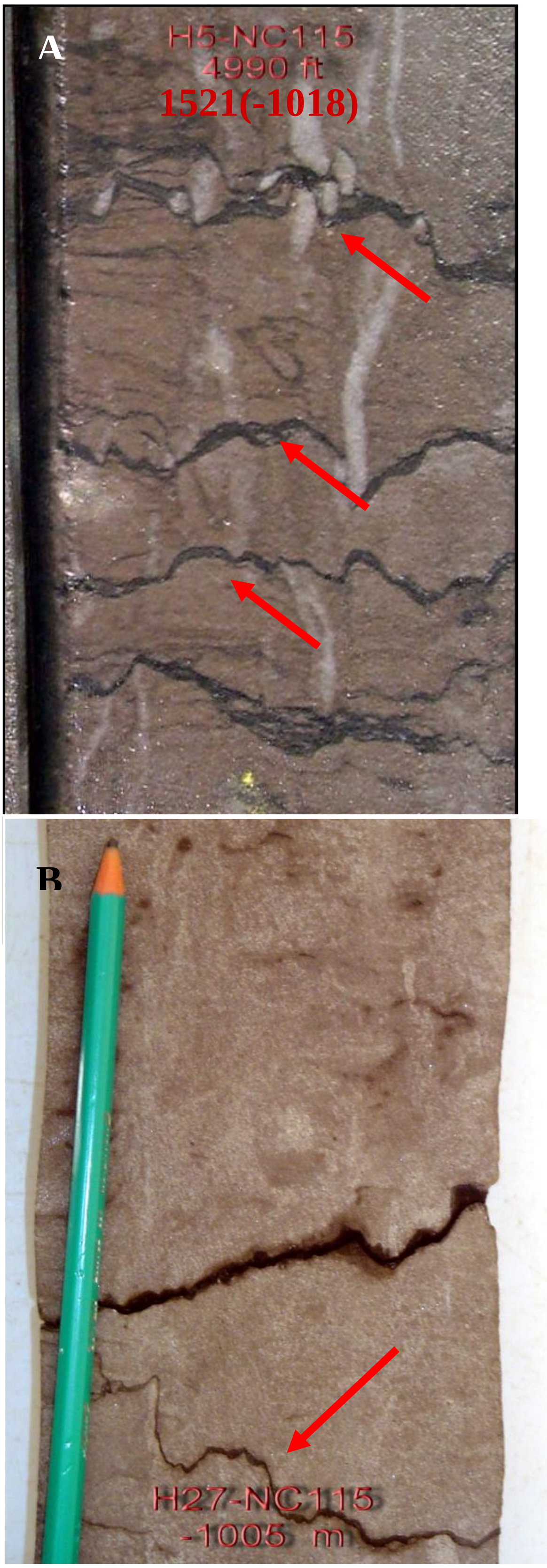
Fig. 4-4 Photographs of slabbed core for selected intervals illustrate interlaminated sandstone and shale with high pressure flood deformation internal structures of upper facies two.



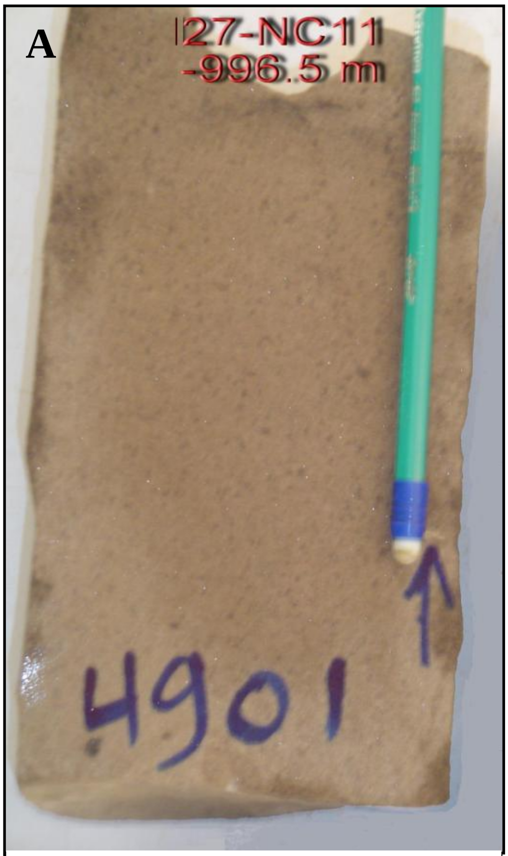
(Fig. 4-5) Photographic of slabbed core samples in facies two: part (A) showing the thin parallel laminated shale and sandstones (blue arrow), with some vertical burring (small green arrow). In addition, a cross-bedding (below red line) with minor low angle. At part (B) same interbedded facies with larger scale included very thin stylolites at upper and lower part.



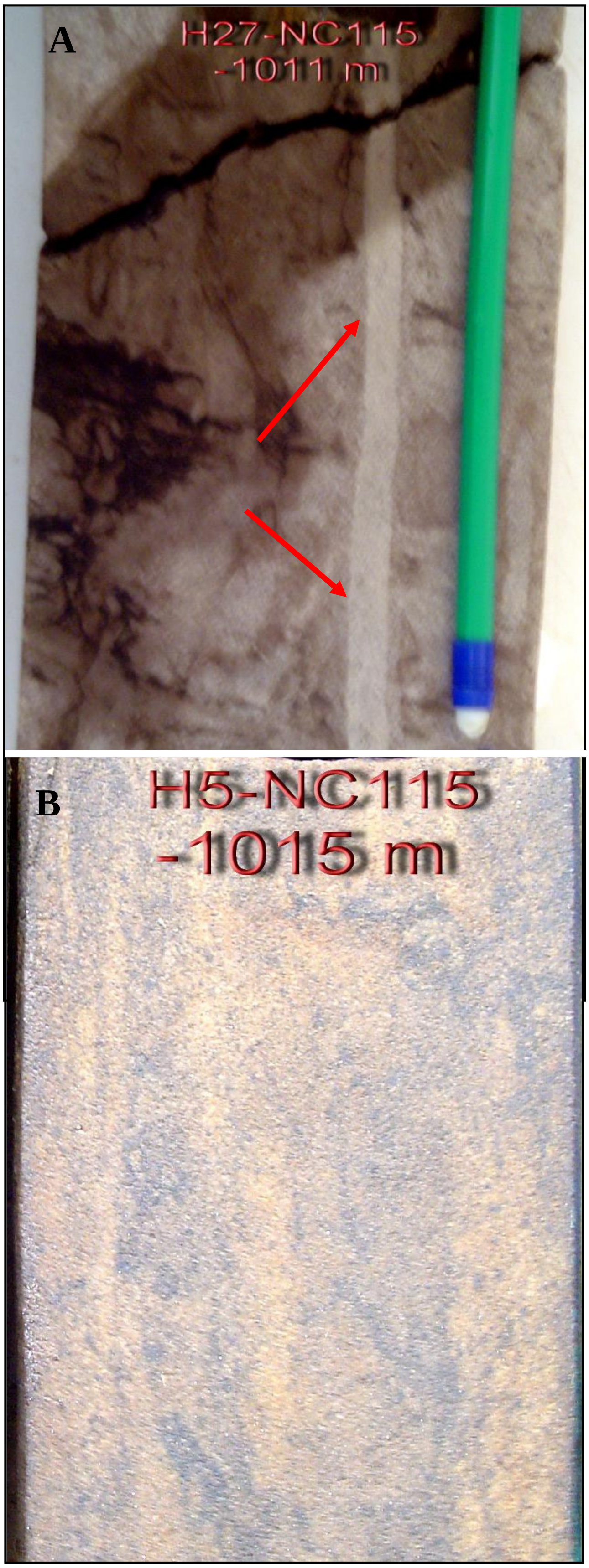
(Fig.4-6) Photographic of slabbed core
(A)- Showing poorly-sorted sand- and siltstones at boundary between facies two and facies three. Fine grained sandstones with highly stylolitized characters, field with muddy material. (B)- showing same facies at well H27-NC115, but more massive sandstones and thicker sand bodes than section (A) above.



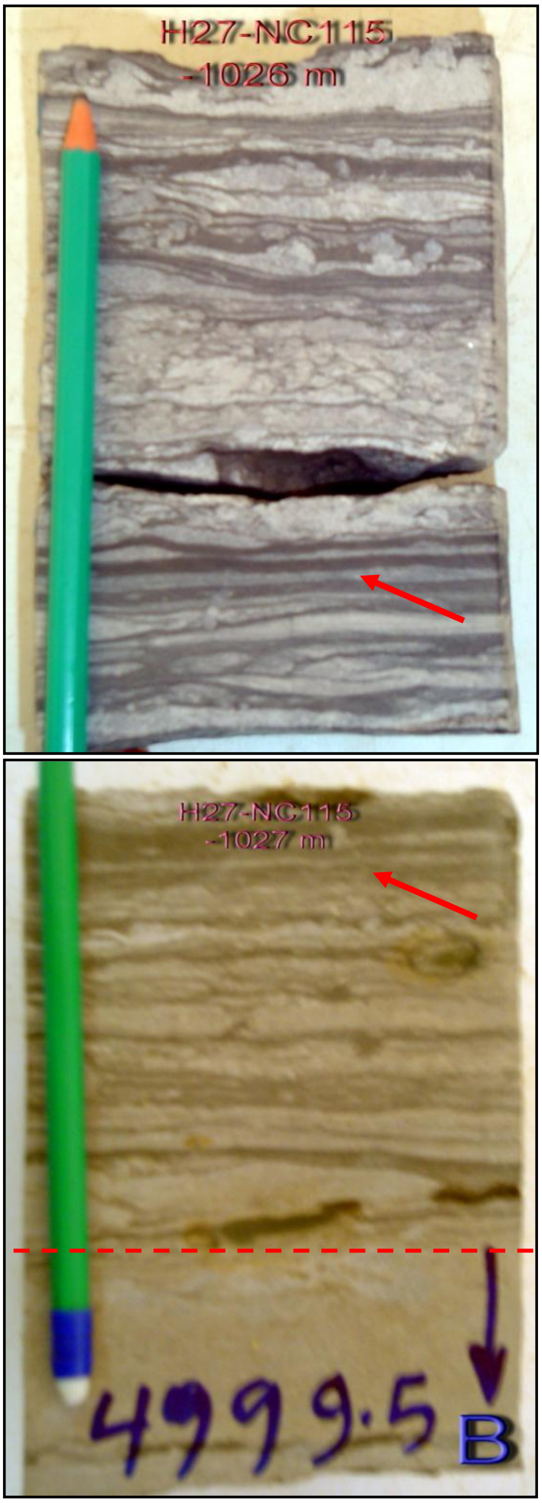
(Fig. 4-7) Photographic of slabbed core illustrated the massive sandstones facies characters, generally homogeneous occasionally and structureless to very rare sedimentary structures, some scattered dark mud are present. This type of facies is common present in facies five and lower part of facies three.

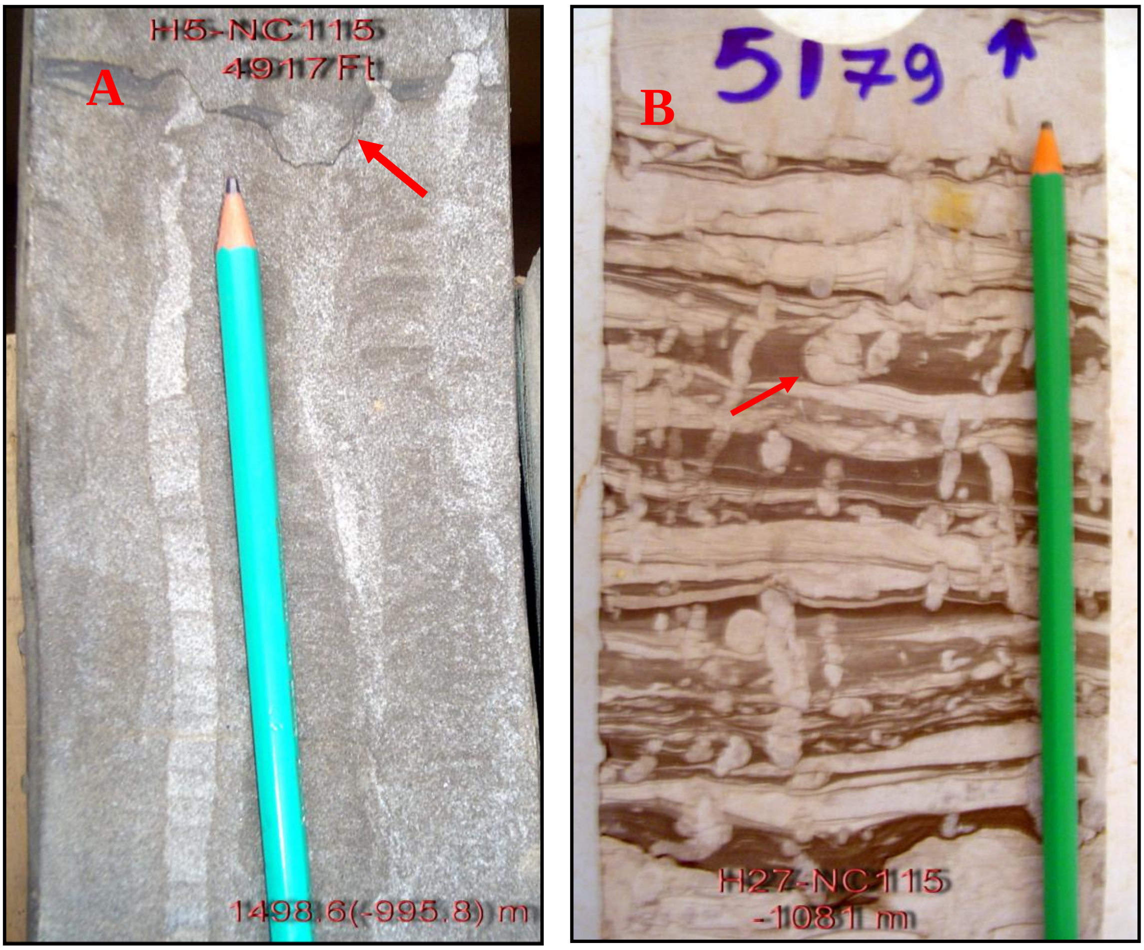


(Fig. 4-8) Photographic of slabbed core illustrated facies three character where at (A)- At facies 3 vertical burrows retch more than 50cm long and more than 5 mm wide, with occasional bioturbation characters, notice the vertical burrowing passes through internal beds (B) lower core containing abundant mudstone and siltstone poorly sorted sandstones (medial of facies 3).



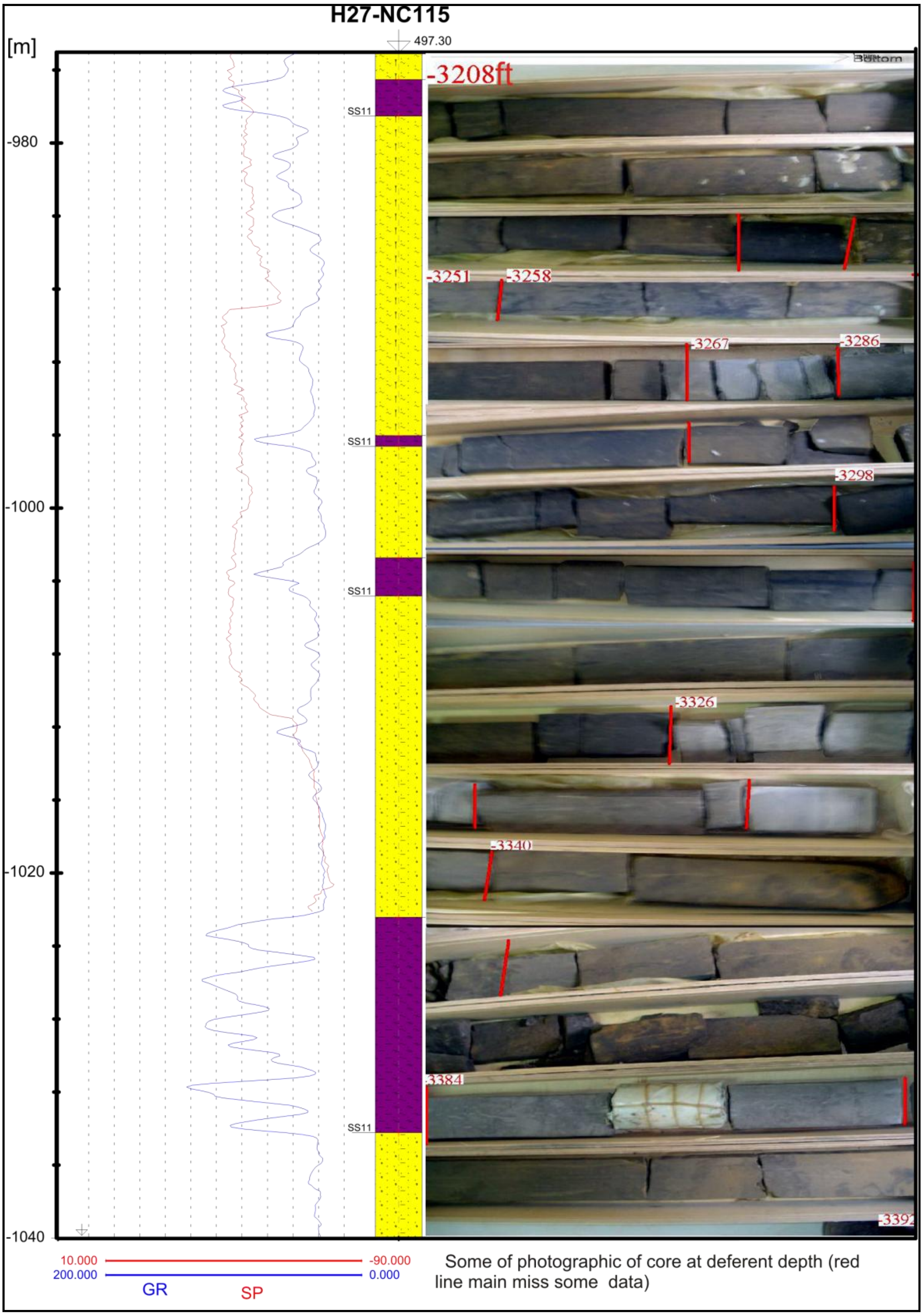
(Fig. 4-9) Slabbed core sample from well H27-NC115 at Facies four: (A) showing thin horizontal silty shale sandstones interbedded, and the flood pressure movement. (B) Same character of facies at top and then changing to massive facies at lower part (below the red line).





(Fig. 4-10) Slabbed core sample in H27-NC115 showing two types of burrowing present in the formation: (A) Illustrated vertical burrows at average 15-20 cm long and a few millimeters wide, also some stylolites at upper section (red arrow).
(B) High intensity of bioturbation, and burrowing activity at siltstones shale interbedded facies type. The section illustrated the next most characteristic type of burrows (Tigillites) in Hawaz Fm. The burrows may be simple vertical tubes with U-shaped or more complicated burrow systems. Some U-shaped burrows, formed through upward or downward movement of the animal in response to sedimentation or erosion.

(Fig.4-11) showing the visibly secondary porosity development by dissolved original matrix material and increasing of the pore network (Well H5-NC115).



(Fig. 4-12) Showing the some core in the well H27-NC115 and the log GR respond. (Red line on the core photographic means some core not included)

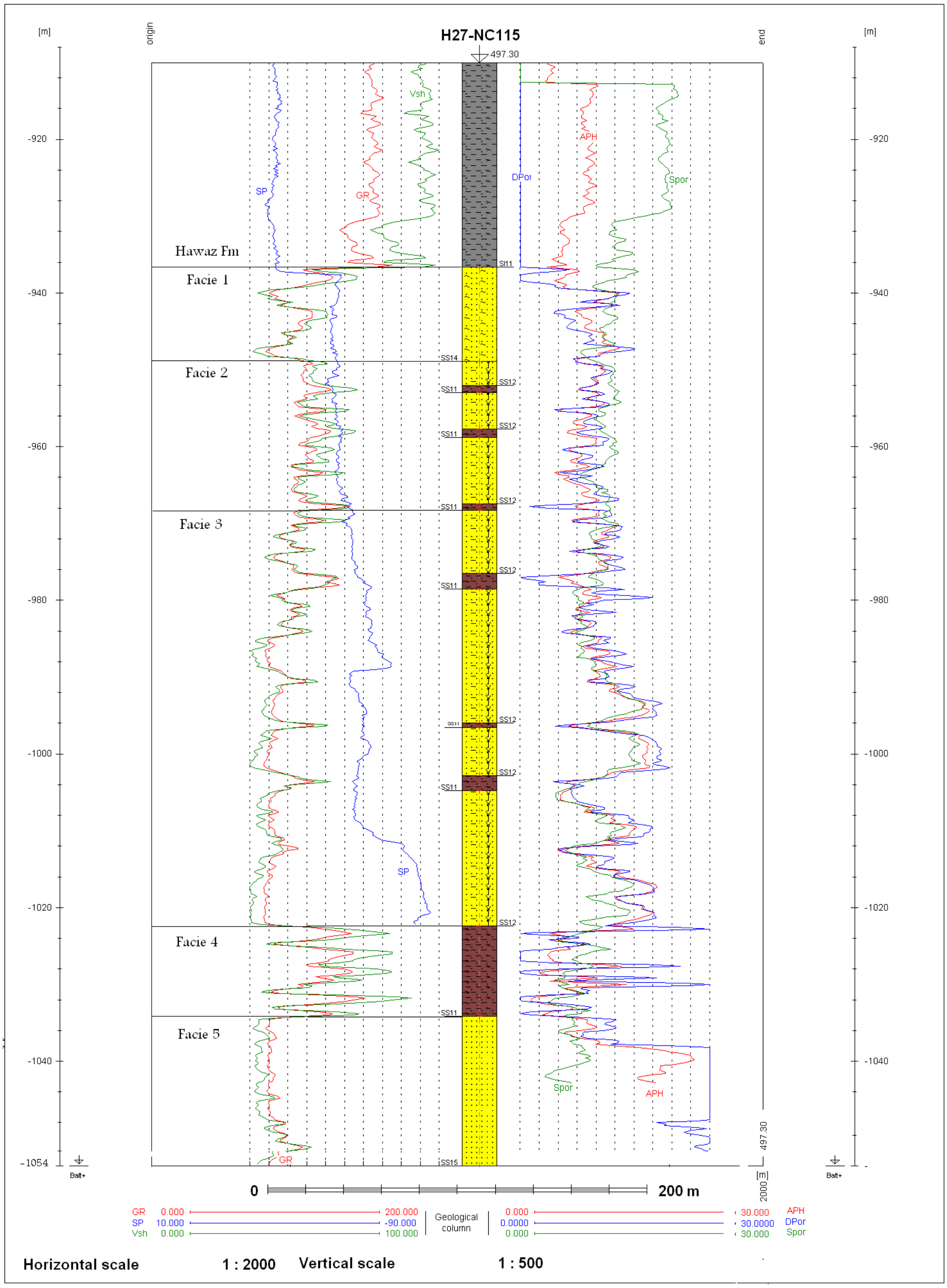


Fig. 4-13) H27-NC115 shows the facies and porosity distribution in upper part of the Hawaz Formation

CHAPTER FIVE

X-RAY DIFFRACTION AND ELEMENTAL ANALYSES

X-RAY DIFFRACTION ANALYSES

5-1 INTRODUCTION:

Clay minerals are considered to be one of the most important components in sediments and are used as tracers for very distinct purposes: for many indicators as palaeo-environmental indicators, stratigraphic markers, and they record diagenetic process (Zuther and other 2000).
In connection with my study of the ‘H’ Oil Field, Murzuq Basin, a mineralogical study was undertaken, covering the clay and bulk fractions from selected samples, but these have provided a very good indication of the clay minerals concentrations and distribution through the formation under study. All samples were simultaneously studied in thin section under a polarizing microscope, and selected samples run under SEM (Scanning Electron Microscopy) as well as chemical analysis. This investigation of clay minerals may enable a better understanding of depositional environments of the formation.

5-2 Methodology and object of study:

The procedure was to crush the sample by hand to obtain fragments ≤ 2 μm (after it was first broken into small pieces). All the samples analyzed by X-ray diffraction were divided in two groups one for bulk fraction (whole rock) analysis, (this involves quantitative analysis of rock forming minerals) and other for clay. By using powder, for both type samples (bulk and clay) rock to prepare of powder slides. The clay samples were run at (I) air-dried, (II) glycolated. The samples were run over a 2 theta range of (3º-14º), for clay glycolated analysis and over a 2 theta range of at (3º-60º) for the standard mineral analyses. The ***d*** spacing obtained on the computer generated diffractogram was then compared with the ***d*** spacing of standard minerals by computer. However, the x-ray diffraction analysis has been done in the Applied Geology Institute, Charles University. Subsequently the patterns results were calculated by using computer program XRD spectra were processed through Bede ZDS 4.17 computer program (Ondruš, 1997). In addition, the mineralogical composition was calculated using CQPA recalculation program (Klika and Weiss, 1993). Recalculation tests with the accuracy of .5 wt percentage.
The analysis shows the Quartz is the main components in bulk mineral, while the clay study shows Kaolinite to be the most common single species, but Illite and quartz are important components too.
A final data includes calculation of weight percent and volume percent mineralogy, SEM analysis put together (with other data) in order to obtain some of main X-ray Diffraction objective as:

- Volume percent mineralogy/density, weight % and volume % of clay.
- Shale stability and clay mineralogy.
- Shale diagenesis.
- Reservoir quality and sensitivity.
- Analysis of primary siliceous sediments.
- Wireline log interpretation and calibration
- Mixed-layer clay characterization.
- Calculated grain densities and Vsh.

5-2-1 **Sample Preparation**

X-ray techniques are thus usually required to identify the clay minerals. First, however, the clays have to be separated from other constituents. To do this, we first disaggregate the sample and place it on the glass slide with water or as a very thin film on to a glass slide with water. Particles will settle down in the water according to gravity.

Samples submitted for XRD analysis are first disaggregated using a pestle and mortar, and then dispersed in dilute water. The clay suspensions samples are next dried under lab temperatures and deposited on class metal to produce clay material. The clay minerals are placed on a glass slide ready for X-ray diffraction analysis, and at the next run all clay samples were treated with ethylene glycol to detect expandable clay minerals.

Normally in powder X-ray diffraction studies, we would want the mineral grains to be oriented randomly on the glass slide. Nevertheless, for clay minerals, the most diagnostic "*d*" spacing is between the {001} planes. Therefore, when the grains are placed on the glass slide they are usually placed in a few drops of water, as a result they will settle onto the slide with their {001} planes parallel to the slide. Consequently, the samples run under X-ray system. The output is to get diffraction predominantly off the {001} planes and can measure the "*d*" spacing between these planes. However, this method obtains clay films of optimum thickness, while achieving an orientation of the clay plates parallel to the glass slide surface, and avoiding size segregation effects.

The samples were scanned under the following conditions on the XRD instrument:

1. 3.043º to 60º, Step size, sample time 0.020 deg, 1.00 s, 50 s/deg
2. 3.043º to 14.943º, Step size, sample time 0.05 deg, 1.00 s, 400 s/deg

5-2-2 **Analytical Procedures**

XRD analyses of the clay-size fractions of the samples are performed using a powder diffractometer equipped with a Cu X-ray radiation source (40 Kv, 35 mA) and a solid state or scintillation detector. The glycol-solvated oriented clay mounts are analyzed over an angular range as above .

Clay size analysis by XRD (X-ray diffraction, this involves quantitative determination of clays and other minerals in the ≤2 micron fraction. The clay quantitative determinations of clay minerals are presented in recorders for each sample (Figures 5-2 to 5-20). A final data table (Tables 5-2 to 5-4) includes calculated weight percent and volume percent mineralogy and calculated grain density.

5-2-3 Main behavior of *d* Spacing for clay minerals:

The table below shows the *d* spacing for the {001} plane as measured for various clay-type minerals and their behavior character. Untreated is for the minerals in their natural state, Ethylene Glycol is for the minerals in a solution of Ethylene Glycol as:

(Table 5-1) shows the **d** spacing for main clay mineral at existing conditions.

d **Spacing on** ***{001}*** **for Clay-Type Minerals in** ***(Å)***		
Mineral	Untreated	Ethylene Glycol
Kaolinite	7.1	No Change
Montmorillonite	14 – 15	17
Illite	10	No Change
Chlorite	7	No Change
Mixed Layer	11	12

5-3 **Identification and Estimation of Abundance of Clay**:

The clay minerals fractions were identified by a combination of X-ray diffractogram techniques, and with untreated glaciated samples. The samples show the average mineralogical composition distribution of the clay fraction in the Hawaz Formation. The clay minerals are a part of a general composition but important group within the facies that contain large percentages of clay (as facies four). The main components of clay minerals in most samples are approximately in average 50 percent of kaolinite, 17 percent illite, 5 percent montmorillonite, 4 percent to other minor clay mineral components. In addition, more or less 24 percent of non-clay minerals (such as quartz) included. The significance of the variations in clay fractions abundance throughout the field may be important of the relative permeability and porosity distribution in different formation micro-facies. This may be indicating either to the original depositional environment or dia-genetically modified (chemical or physical) environment condition. A summary of the XRD analysis data for most common clay minerals analysis and their distribution in the study area, are integrated as the follow:

5-3-1 ***The Kaolinite Group:***

This group has many members with general formula of $Al_2Si_2O_5(OH)_4$. They have the same chemistry but different structures. Kaolin is an important industrial mineral and geological indicator. It occurs in hydrothermal residual as primary and in sedimentary deposits as secondary. However, it is a clay mineral which formed mainly by weathering of feldspar and mica group minerals. In addition, kaolinite is not prone to shrinking or swelling with changes in water content. In the Hawaz samples the kaolinite group minerals frequently found in each sample at bulk and clay mineral analysis; were represented by the values 001 (6.2221), reflections main average of ($2\Theta = 12.4$ and 29.1488). These are present in each sample under study and have been chosen for their characteristic expression in diffractogram, see figures (5-2 to 5-20). Kaolinite abundances increases in sandy shale or muddy facies as facies two and four, and relatively less in sandstones facies as facie three and five, but it is almost present principally in all facies of the Hawaz Formation. At SEM analysis Figures (5-21, & 5-25) kaolinite is present as covering of a quartz grain and overgrown with authigenic quartz.

Kaolinite (in thin section observation) with the characteristic texture occurs both as pore filling matrix and as a replacements product of feldspar. In fact, the XRD analyses of selected clay fraction from Hawaz Formation are conformed the presence of kaolin as abounded clay mineral in the formation. However, kaolinite may have formed relatively early in paragenesis. This is consistent with the observation that some kaolinite masses (seem to be replaces of feldspars) have been deformed be mechanical compaction. Particularly, in the Hawaz Formation, due to the higher original feldspar content in the sandstones lithology. The XRD analysis indicates that illite is the second most abundant clay mineral in the formation after kaolinite.

5-3-2 ***<u>The Illite: (or the clay-mica):</u>***

The Illite clays have a structure similar to that of Muscovite, but are typically deferent in alkalies, with less Al (aluminum) substitution for Si. (silicates). Illite type clays are formed as an alteration product of muscovite and feldspar in weathering and hydrothermal environments under high pH conditions. Thus, they form by alteration of common minerals like muscovite and feldspar in the formation.

Illite is essentially a group name for non-expanding, clay-sized, dioctahedral, micaceous minerals. It is structurally similar to muscovite. Its basic unit a layer composed of two inward-pointing silica tetragonal sheets with a central octahedral sheet. (Bailey, 1980), illite has on average slightly more *Si, Mg, Fe*, and water and slightly less tetrahedral *Al* and interlayer *K* than muscovite. Herron and Herron (1998) showed that there is a strong positive correlation between clay and *Al*, and they used *Al* as a quantitative clay indicator.

Illites, which are the dominant clay minerals in argillaceous rocks, form by the weathering of silicates (primarily feldspar), through the alteration of other clay minerals, and during the degradation of muscovite (Deer and others, 1975).

The Illite clays minerals distribution in Hawaz Formation as showing in the x-ray analysis are the frequently clay minerals in argillaceous rocks or in muddy facies as facie two and four, but less regularly at other facies. This is maybe good indicator for weathering of silicates (primarily feldspar), through the alteration of other clay minerals, and during the degradation of muscovite.

Intense peaks that remain unaltered by ethylene glycol (figures 5-2 & 5-6) are the main characterize of the Illite group.

5-3-3 ***The Montmorillonite Group:***

This group is composed of several minerals as well but them different mostly in chemical content. The montmorillonite mineral is the main constituent of Bentonite, and it is the most common mineral of this group. The mineral derived by weathering of volcanic ash. The most important aspect of this group is the ability for H2O molecules to be absorbed, causing the volume of the minerals to increase when they are exposed to water. This can expand by several times its original volume when it comes in contact with water. However, that is a dangerous type of clay of reservoir petrophysical property; that can reduce or destroyed the reservoir quality of porosity and permeability; because of its expandable nature. This type of clay mineral is present in a few samples at Hawaz formation, especially at muddy section with minor intensity; particularly at facies two and four.

5-4 ***Distinguishing Clay Minerals:***

Generally, the clay minerals occurs as such small mineral grains that they cannot be easily distinguished in either hand specimen or thin section. However, X-ray techniques, are thus usually required to identify the clay minerals. From output X-ray, data which showing that Hawaz reservoir rocks are low in clay matrix content especially at clean sandstones facies as (F3), and has good presentation in other facies. However, at Hawaz Formation the clay mineral play an insignificant controlling factor in reservoir quality; where porosity and permeability has an average variation between (2-19% and 0-1200mD) respectively.

The majority composition of the formation is sandstone intervals; with shaly or detrital sandy/clay minerals beds in between; that representing as laminated sediments. However, the defined reservoir intervals contain authigenic clay minerals and are some of detrital clay. At all samples quartz comprises about 90-98% of the total framework grains as determined in thin section; XRD analysis and elemental analyses (Table 5-2, 5-3 & 5-4). Peaks in the XRD spectra indicate kaolinite as a most clay mineral intensity; and this generally occurs in all section. The other clay minerals varieties include illite, minor montmorillonite, and muscovite. The study showing dominant element in the formation reservoir rocks is silica *Si* which was derived mainly from quartz, although feldspar and clay minerals; also contributed to the *Si* concentration. Feldspars and clays are sources of *Al*. Herron and Herron (1998) showed that there is a strong positive correlation between clay and *Al*, and they used *Al* as a quantitative clay indicator.

5-5 ***Elemental analyses of clay mineral:***

The weight percentage of the clay minerals are determined for the clay mounts of selected sample and normalized to the weight percent clay-size material determined by the weighting procedure.

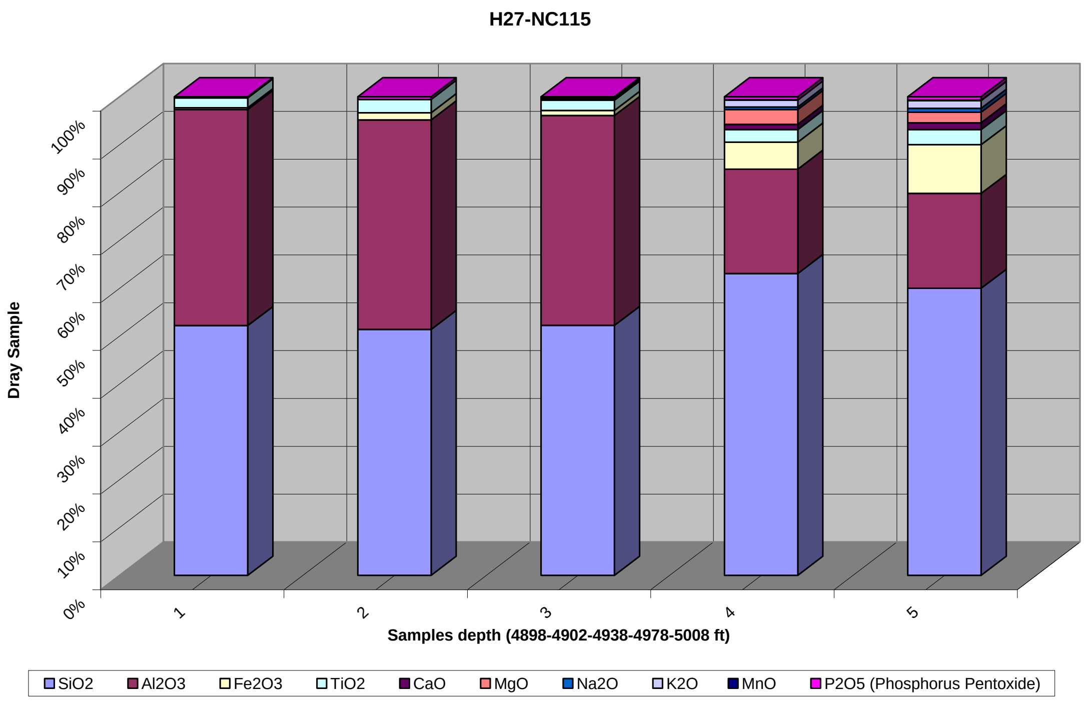
The weight fractions of the minerals present in the powder mounts are calculated and normalized to the weight percent sand/clay material. The whole-rock compositions are then determined by mathematically combining the XRD data from both size fractions. Determinations results of samples are present in the tables (5-3 & 5-4).

(Table 5-2)Clay Fraction results (weight percent).

Well	Depth in m	Facies	Quartz	Kaolinite	Illite	Montmorillonite
H5- NC115	1471(-968)	F2	26	45	24	5
H5-NC115	1506 (-1003)	F3	25	47	5	23
H27-NC115	1493 (-996)	F3	29	61	10	-
H27-NC115	1494 (-997)	F3	32	68	-	-
H27-NC115	1505 (-1008)	F3	28	59	13	-
H27-NC115	1517 (-1020)	F3	35	65	-	-
H27-NC27	1526 (-1029)	F4	30	54	16	-

(Table 5- 3), Results of elemental analyses of clay mineral (weight percent) in well H27-NC115 at fixed temperatures 105°C.

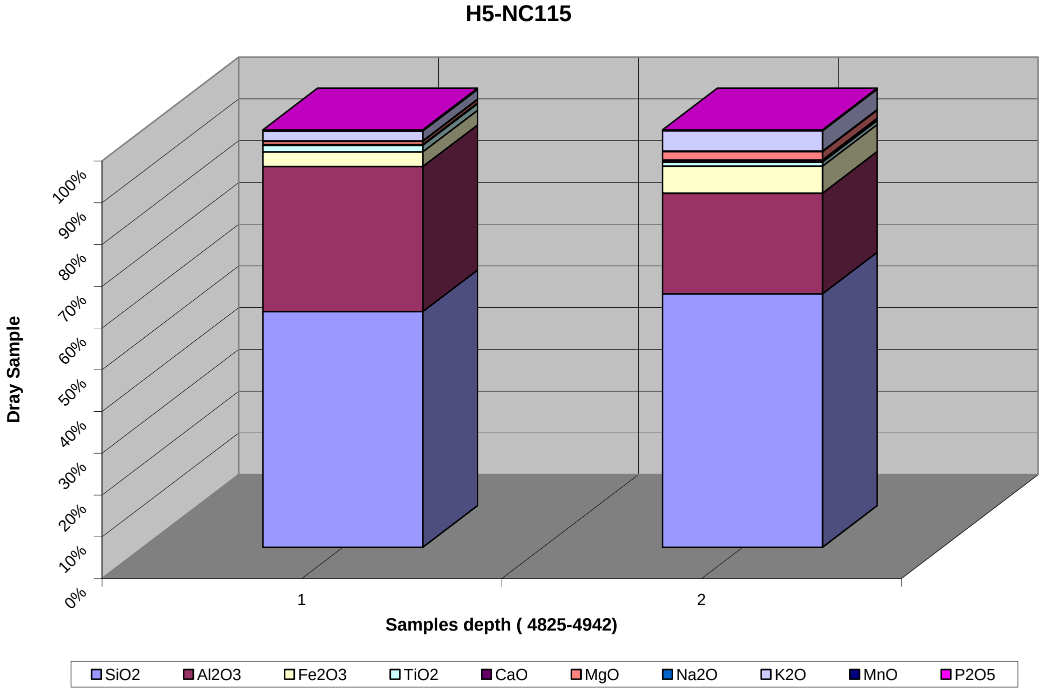
H27-NC115	Sample Depth in m.					
Element	**1493**	**1494**	**1505**	**1517**	**1526**	
Z. Žih. 1050°C	14.09	14.01	14.12	10.84	9.56	%dray sample
SiO_2 (Silicon Dioxide)	44.49	44.23	44.72	55.58	53.72	%dray sample
Al_2O_3 (Aluminum Oxide)	38.51	37.70	37.55	19.20	17.75	%dray sample
Fe_2O_3 (Iron Oxide, Ferric)	0.32	1.28	0.91	4.99	9.12	%dray sample
TiO_2 (Titanium Dioxide)	1.76	2.41	1.84	2.31	2.82	%dray sample
CaO (Calcium Oxide)	<0.10	<0.10	<0.10	0.97	1.29	%dray sample
MgO (Magnesium Oxide)	<0.10	<0.10	0.13	2.71	1.96	%dray sample
Na_2O (Sodium Oxide)	0.05	<0.05	0.10	0.48	0.74	%dray sample
K_2O (Potassium Oxide)	<0.10	<0.10	0.21	1.29	1.46	%dray sample
MnO (Manganous Oxide)	<0.005	<0.005	<0.005	0.012	0.073	%dray sample
P_2O_5 (Phosphorus Pentoxide)	0.14	0.47	0.17	0.58	0.63	%dray sample



(Fig. 5-1) Graphic presentation of elemental analyses of clay mineral (weight percent) in well H27-NC115

(Table 5-4), Results of elemental analyses of clay mineral (weight percent) in well H5-NC115 at fixed temperatures 105°C.

H5-NC115	Sample Depth in m.		
Element	**1471**	**1506**	
Z. Žih. 1050°C	12.11	8.80	%dray sample
SiO_2 (Silicon Dioxide)	49.06	54.93	%dray sample
Al_2O_3 (Aluminum Oxide)	30.19	21.82	%dray sample
Fe_2O_3 (Iron Oxide, Ferric)	3.06	5.83	%dray sample
TiO_2 (Titanium Dioxide)	1.36	0891	%dray sample
CaO (Calcium Oxide)	0.17	0.48	%dray sample
MgO (Magnesium Oxide)	0.69	1.77	%dray sample
Na_2O (Sodium Oxide)	0.08	0.14	%dray sample
K_2O (Potassium Oxide)	2.03	4.41	%dray sample
MnO (Manganous Oxide)	0.008	0.016	%dray sample
P_2O_5 (Phosphorus Pentoxide)	0.25	0.19	%dray sample



(Fig. 5-1a) Graphical presentation of elemental analyses of clay mineral (weight percent) in well H5-NC115 at fixed temperatures 105°C.

5-6 __Bulk (whole rock) analysis by XRD (X-ray diffraction)__:

The bulk (whole rock) analysis by XRD (X-ray diffraction) involves quantitative determination of rock-forming minerals, total clay minerals and determines the general characteristics of the different lithology. However, The XRD analysis is used to determine the relative abundance of the major mineralogical components in the Hawaz Formation and documenting the gross mineralogy, and clay mineralogy. A final data table includes calculation of weight percent mineralogy are included in tables (5-2, 5-3 & 5-4). Bulk analysis runs at rocks that have low clay content or where the clay mineralogy is les present (at sandy facies). However, a bulk analysis done with combined by a clay analysis to get the completely characterize of the samples.

The figures (5-15 to 5-20) showing the bulk XRD analysis. Quartz forms one of the most abundant minerals in most of the samples. The peak of quartz was more intense than the other peaks. There was a coinciding in some samples, with a less strong reflection of illite and kaolinite. Due to quartz is abundance. The variation in the samples of well samples does not show major variation.

5-7 **Scanning Electron Microscopies:**

The maim object of this analysis involves with evaluation of porosity and pore connectivity; pore throat size, shape, and roughness of the grains; as well as origin, distribution, morphology, and chemical composition of clays minerals and cements behavior.

A Scanning electron microscope (SEM) has been used in the present study to analyses their composition morphology, textural relationship and growth. The very high resolution obtained in the SEM readily describes the minerals.

To provide an indication of the shapes of the particles and the relation between clay and other constituents in the formation (figures 5-21 & 5-25). These figures of scanning electron microscope images showing the clay mineral is covering the sandstones grains. SEM revealed the quartz outgrowth.

5-8 **DISCUSSION AND SUMMARY:**

The clay minerals have significant controls on the porosity and permeability properties of sandstones, and this may have implications on reservoir performances during drilling, production and well stimulation operations (Imam 1989). The pore systems of sedimentary rocks may be lined or filled with a variety of different clay minerals. These clays can greatly reduce porosity and permeability.

Clay minerals can cause formation damage and production problems during drilling, production and well stimulation operations. Clay minerals can absorb water or lose water, when water is absorbed; clays will often expand as the water fills the spaces between the stacked silicate layers, and may be dislodged, migrate and block a pore throat. This is representing by clay as when montmorillonite mineral precipitates in the formation that could damage reservoir performances.

However, from all samples of clay result and thin section petrography can see the general intensity of clays in the formation. Those results pointed out the essential clay minerals are kaolinite and illite, In addition, mica, montmorillonite muscovite are important components, while ferruginous minerals is subordinate or accessory. This may suggests that marine condition were responsible for kaolinite as the essential component of clay sediments. The kaolinite in the study area in my formed from weathering of feldspars, since it is abundant in the parent material and in the silt fraction of samples studied. Abdelgawad, and Ben Mahmoud, (1991) discussed the clay mineralogy of the Fazzan area (Murzuq area), Libya, and they pointed out that the Kaolinite is the dominant clay mineral, followed by mica, smectite and palygorskite. However, they also pointed out that the relict fabrics of primary feldspar indicate that the kaolinite is mainly formed from the alteration of feldspar during the palaeoclimate weathering. However, the kaolinite is generally considered to have resulted from a combination of hydrothermal and weathering processes. Carroll, (1970) pointed out that Kaolinite is generally more abundant in regions of tropical weathering than in more temperate zones, and occurs in detrital deposits derived from tropical weathering. In addition, Ford, Parrott, and Ritter (1970) that the dominance of kaolinite indicates deposition in acidic or pure water, as deposition in alkaline water tends to yield montmorillonite pointed it out.

Kaolinite is mostly clearly formed and derived by tropical weathering conditions during late Ordovician times, probably from feldspars and mica in local sandstones or volcanic rock to the south (Jabal Tibesti or Hagahr massif) see Murzuq Basin map. In addition, it is may be formed from the alteration of feldspar and mica, since they are very common minerals in the formation. Millot (1970) reported similar finding, for the weathering of the Cambro-Ordovician sandstone in the area of Hassi Messoud and Hassi El Gassi in Algeria.

The principal vertical and lateral variations in clay minerals through the sequence formation illustrated in figures (5-2 to 5-21) showing main distribution of clay minerals. One of important features of the distribution is the high content of clay in the muddy microfacies as (F4) compared to the other microfacies, and the progressive decrease in abundance in lower units. The vertical changes in the proportions of clay minerals in the succession may result from differential flocculation or may be due to a progressive change in depositional conditions. The primary clay depositional as revealed by initial clay abundance and distribution shows that the great clay abundance is often associated with the pelagic sediments and the initial environment of deposition (water depth). The facies two and four has higher clay content than the other microfacies, probably because it was deposited under deeper, quieter conditions, as suggested also by petrographic evidence (see petrographic work).

The lateral variation of clay minerals is attributed to a decrease in the clay contribution in the central part of the field where less shaly facies as well; and an increase in the marginal areas. This confirms that the surrounding area was deeper than the centre while the structural ridge provided more energetic conditions, keeping clays in suspension. The dominance of shale with sandstone may be reflects a low-energy depositional environment.

Clay mineral analysis indicates that major components of the rock studied are quartz and clay minerals together with small amounts of feldspar. The principal detrital clay minerals are kaolinite, illite. Clay mineral distribution provides the evidence on diagenesis and clue to the provenance. A clay mineral suite with abundant kaolinite and illite reflects the composition of the sediment under humid tropical conditions and may be chemical weathering predominates.

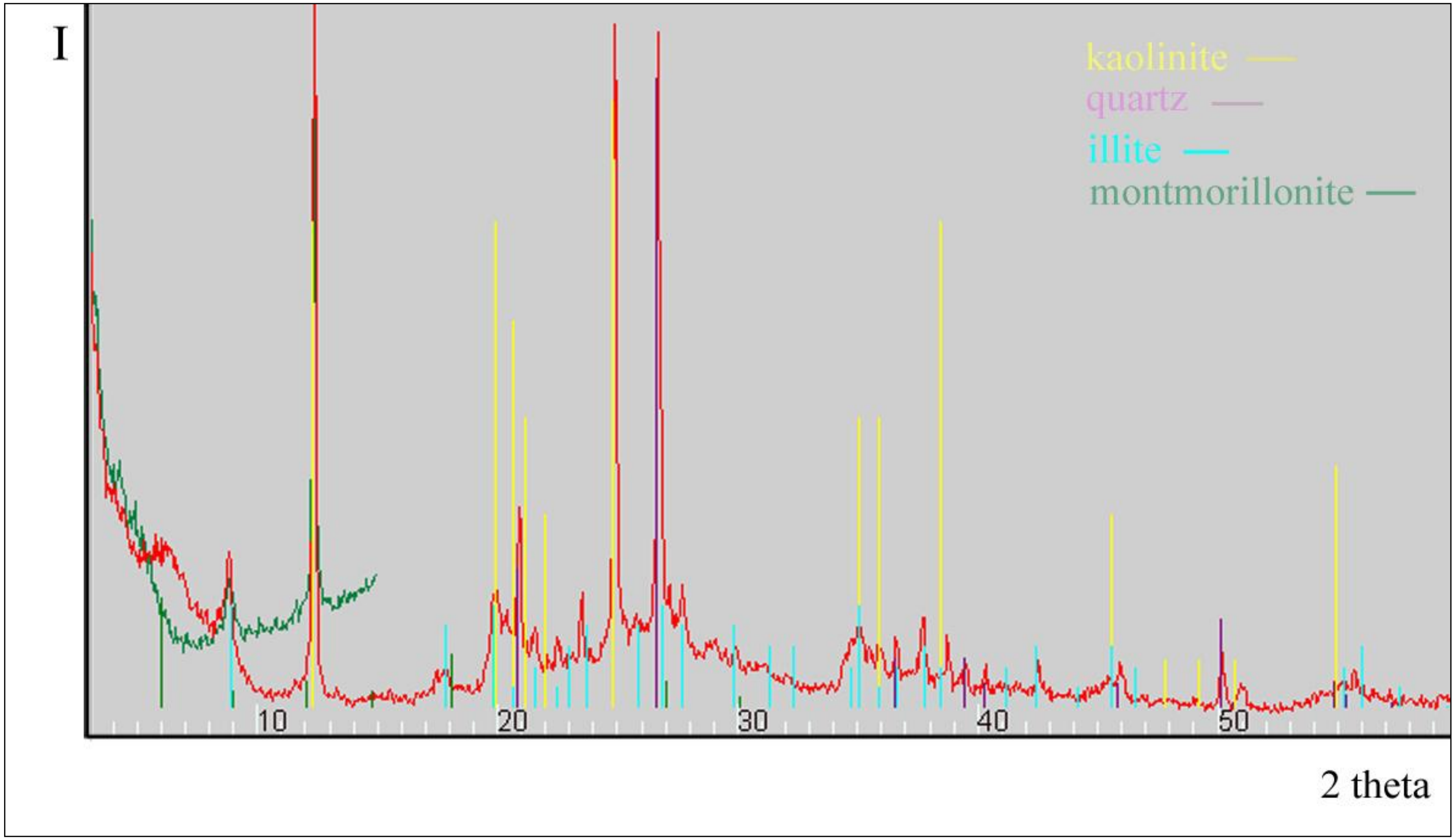
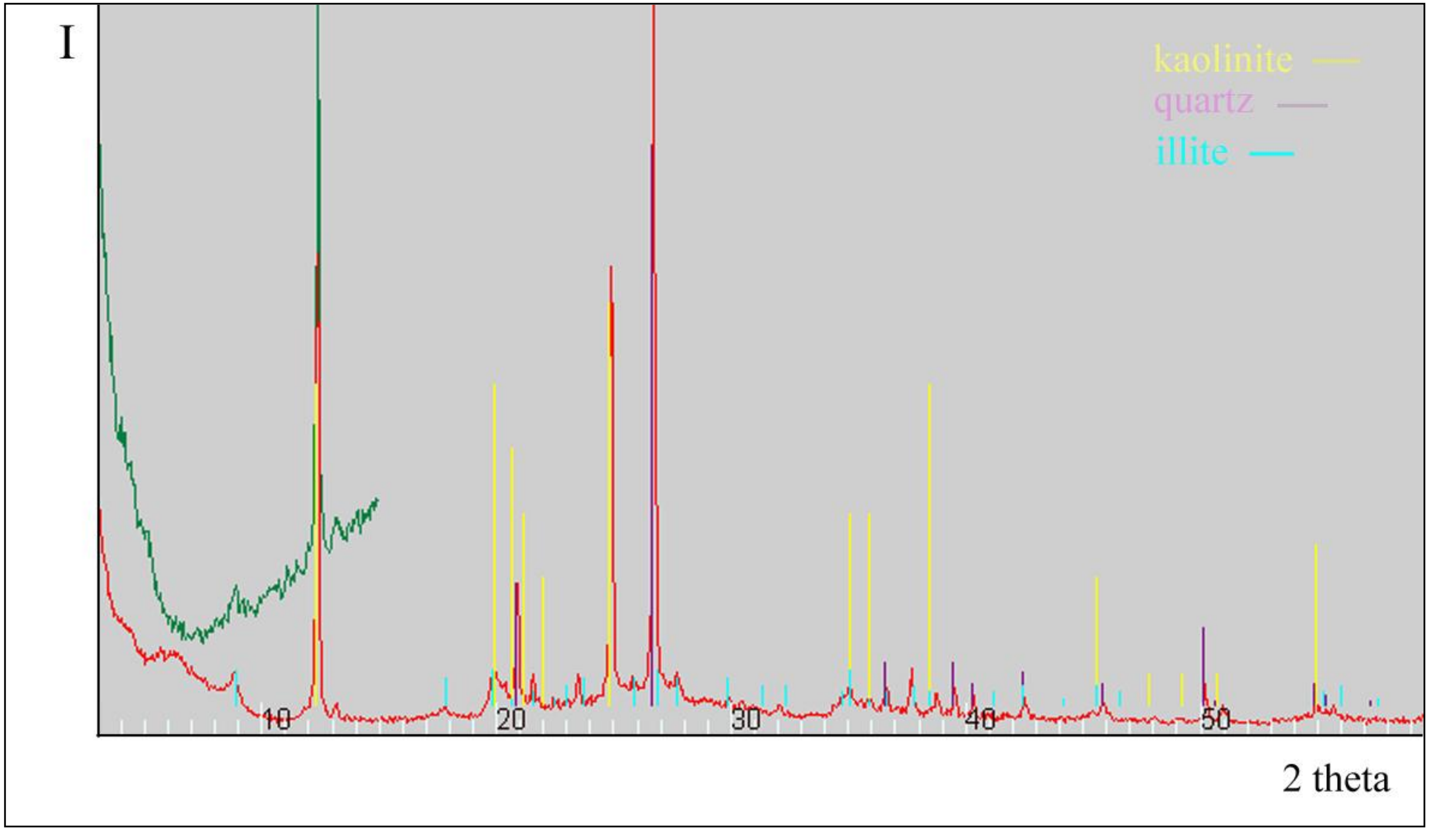
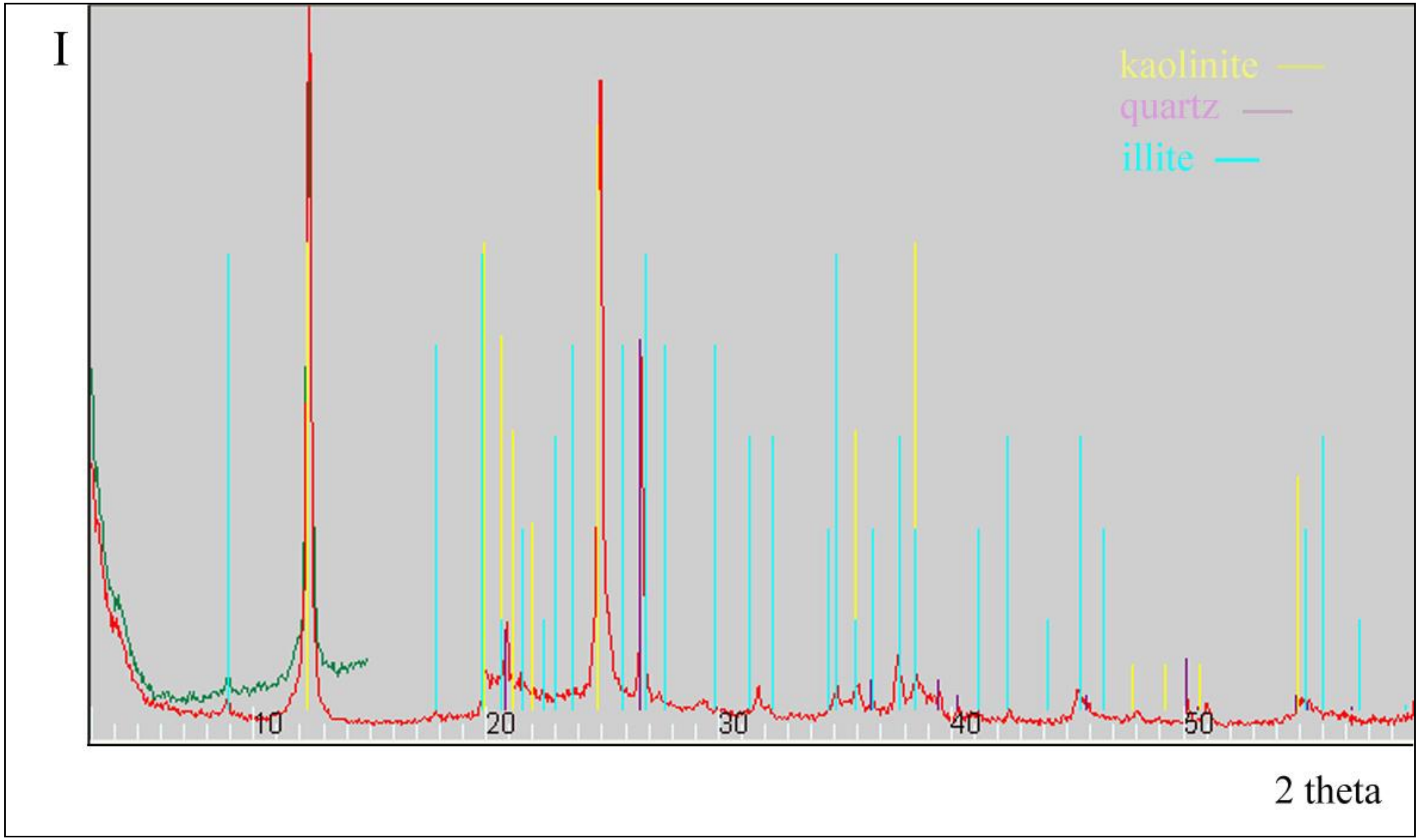


Fig. 5-2 XRD (clay analysis) for sample at depth 1471 m in H5-NC115, kaolinite with montmorillonite are the conmen clay mineral.



(Fig.5-3 XRD (clay analysis) for sample at depth 1406m in H5-NC115, kaolinite and quartz are the conmen clay mineral.



(Fig. 5-4) XRD (clay analysis) for sample at depth 1493 in H27-NC115, kaolinite is the conmen clay mineral.

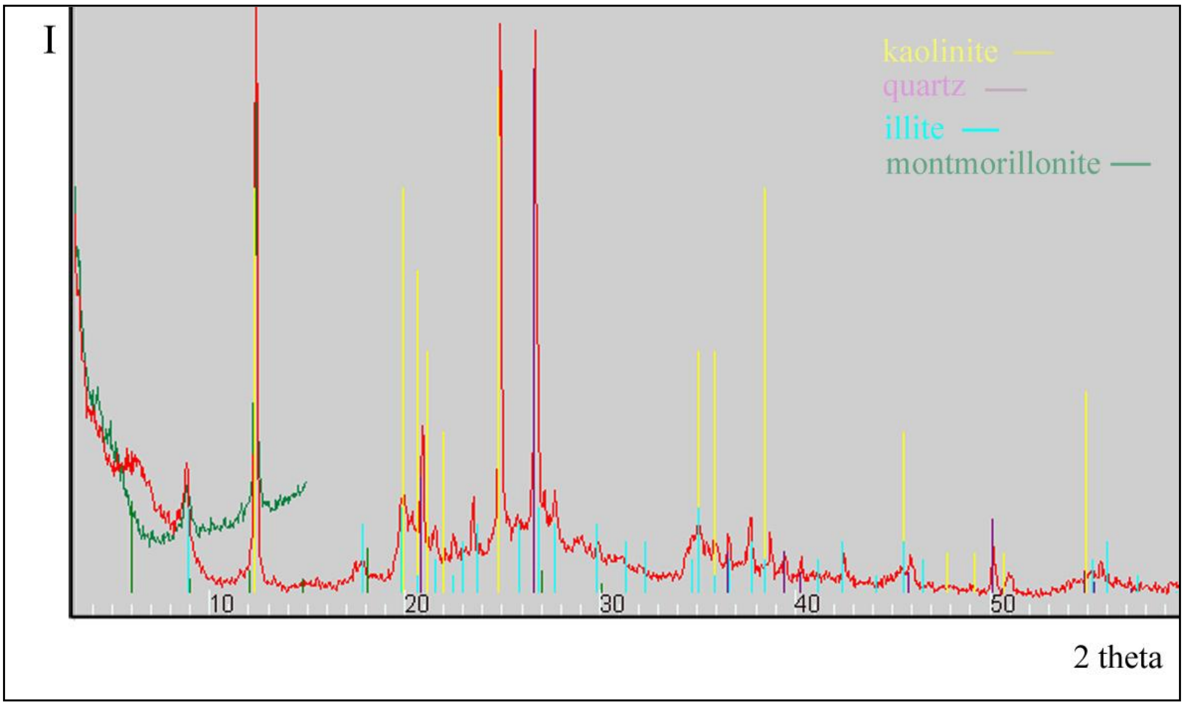


Fig. (5-5) XRD (clay analysis) of H5-NC115 at depth 4825 (-4322.2) ft, or 1470.6 (-967.8) m. at facies two showing the main clay mineral.

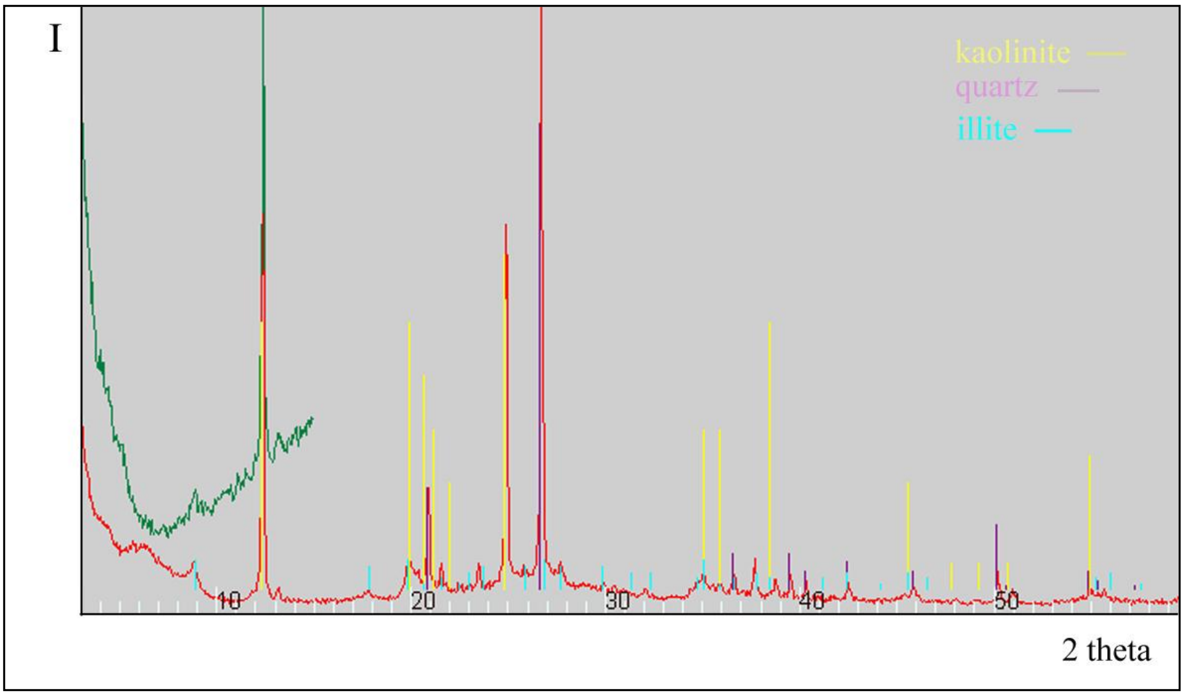


Fig. (5-6) XRD (clay analysis) of H5-NC115 at depth 4886 (-4383.2) ft, or 1489.2 (-986.4) m. at facies three showing the main clay mineral.

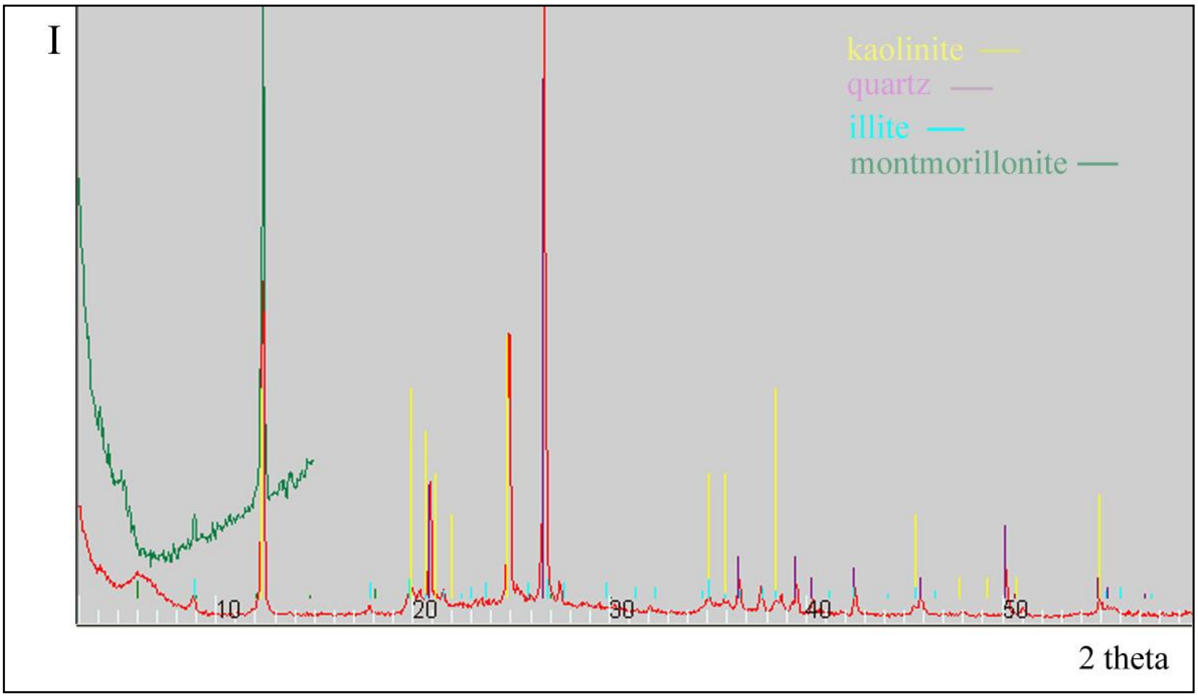


Fig. (5-7) XRD (clay analysis) of H5-NC115 at depth 4942 (-4439.2) ft, or 1506.25 (-1003.5) m. at facies three showing the main clay mineral.

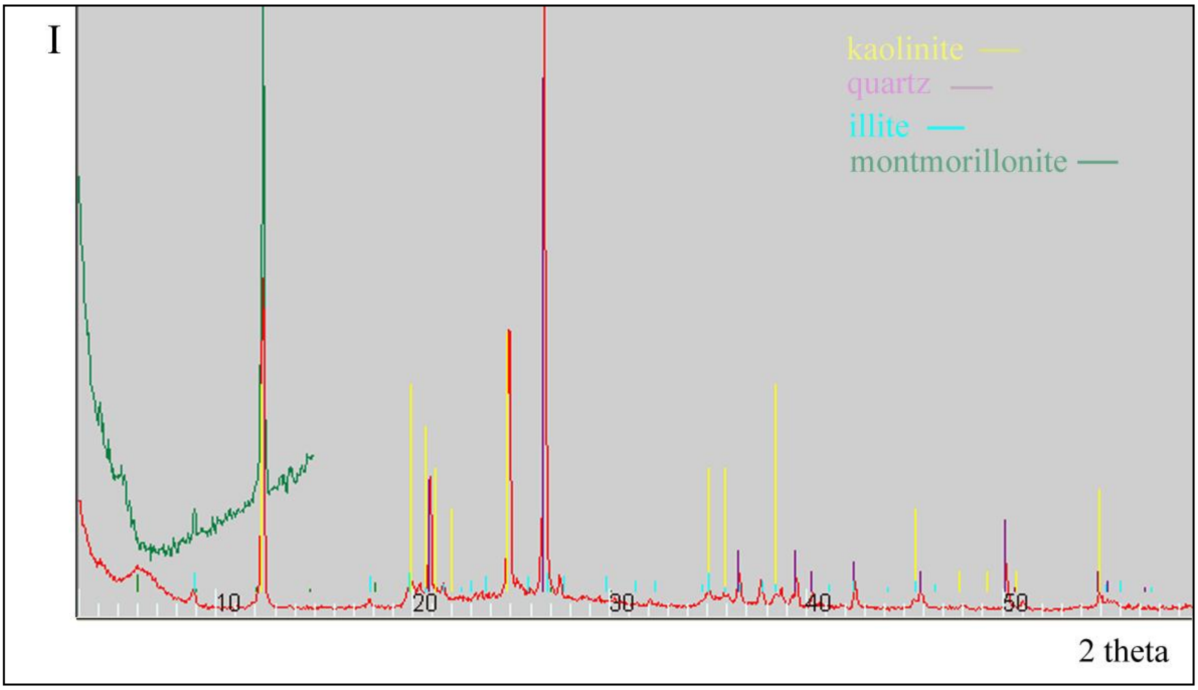


Fig. (5-8) XRD (clay analysis) of H5-NC115 at depth 5002 (-4499.2) ft, or 1524.5 (-1021.8) m. at facies four showing the main clay mineral in the facies.

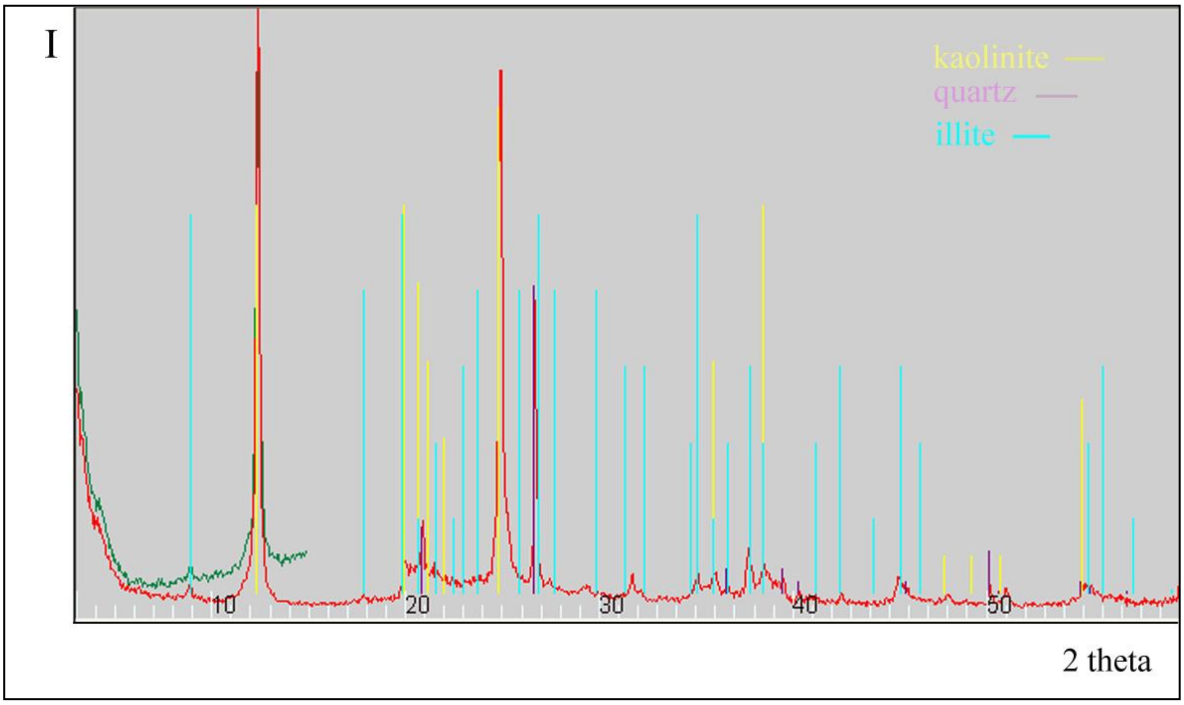


Fig. (5-9) XRD (clay analysis) of H27-NC115 at depth 4898 (-4400.7) ft, or 1492.8 (-995.5) m. at top facies three showing the main clay mineral.

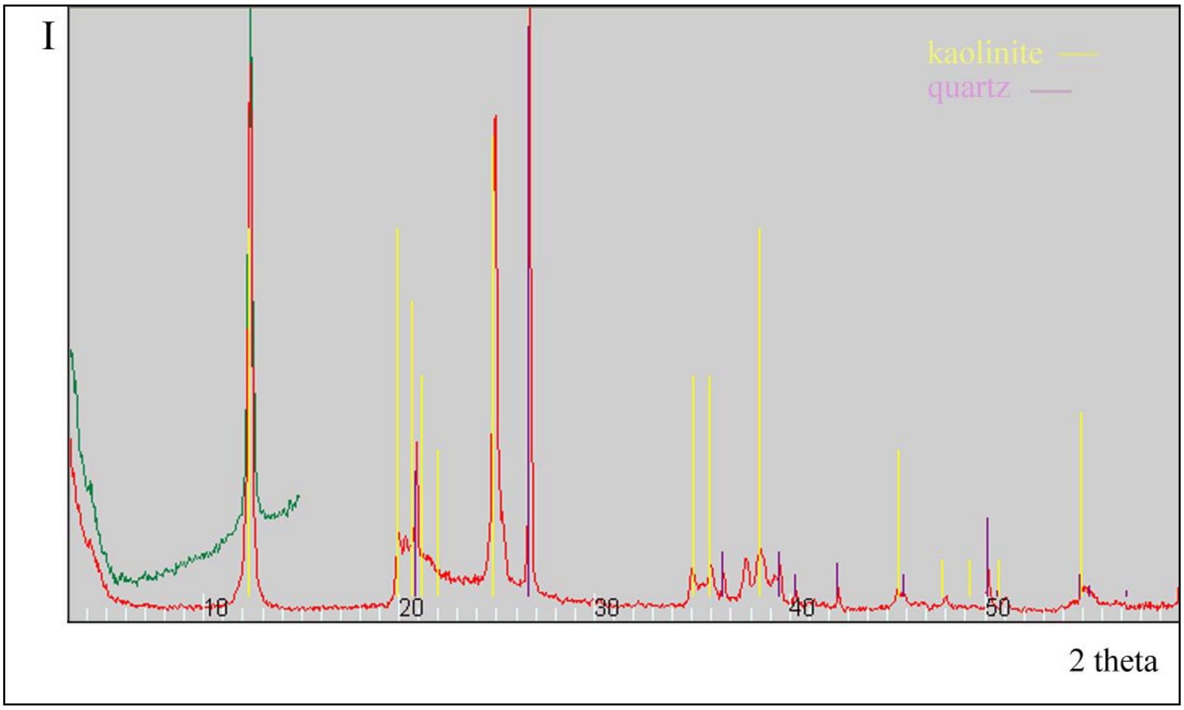


Fig. (5-10) XRD (clay analysis) of H27-NC115 at depth 4902 (-4404.7) ft, or 1494.1(-996.8) m. at facies three showing the main clay mineral.

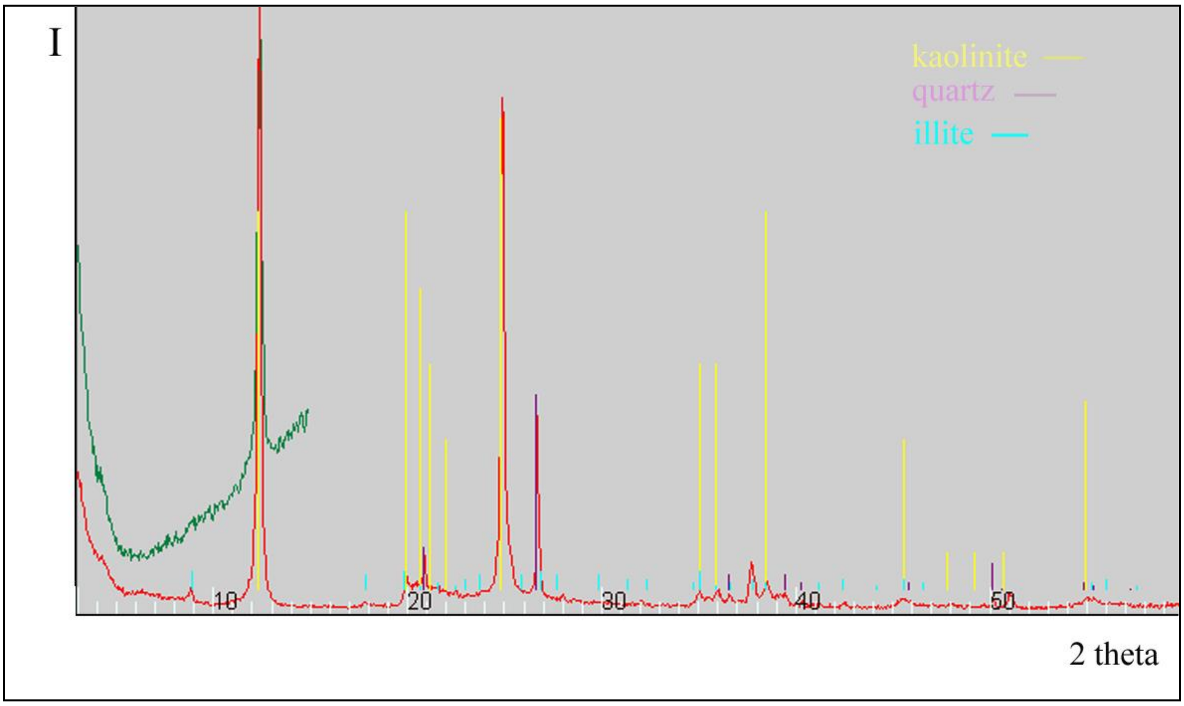


Fig. (5-11) XRD (clay analysis) of H27-NC115 at depth 4938 (-4440.7) ft, or 1505.1(-1007.7) m. at medial facies three showing the main clay mineral.

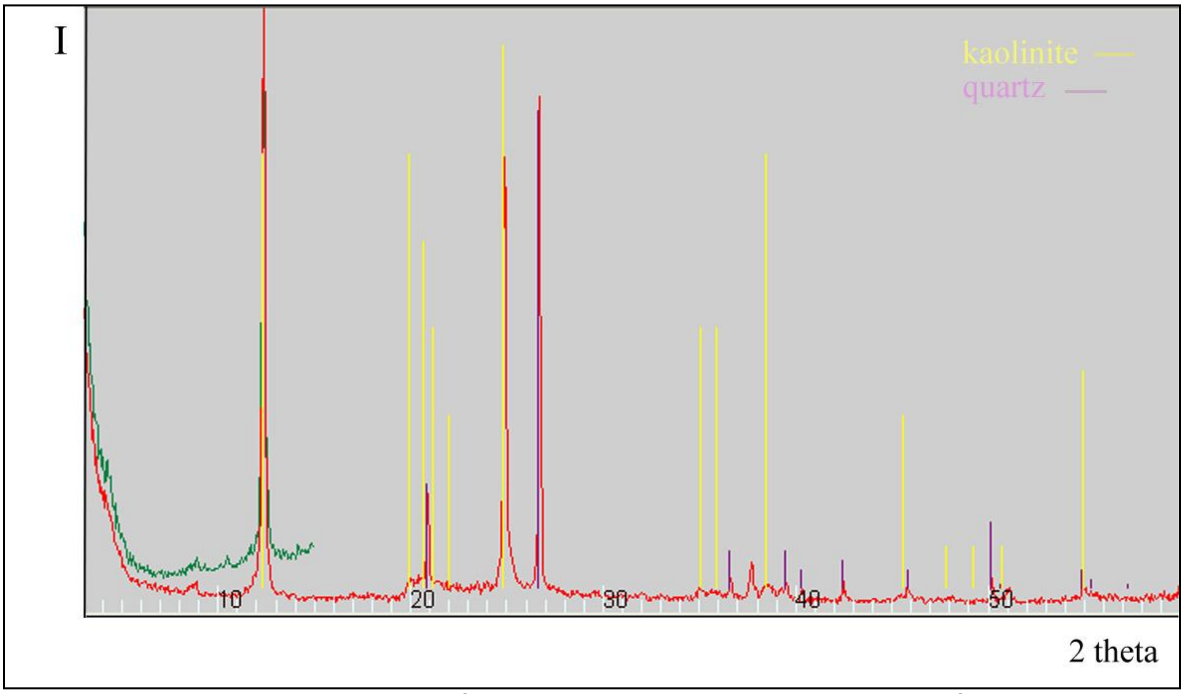


Fig. (5-12) XRD (clay analysis) of H27-NC115 at depth 4978 (-4480.7) ft, or 1517.2 (-1020) m at facies three showing the main clay mineral.

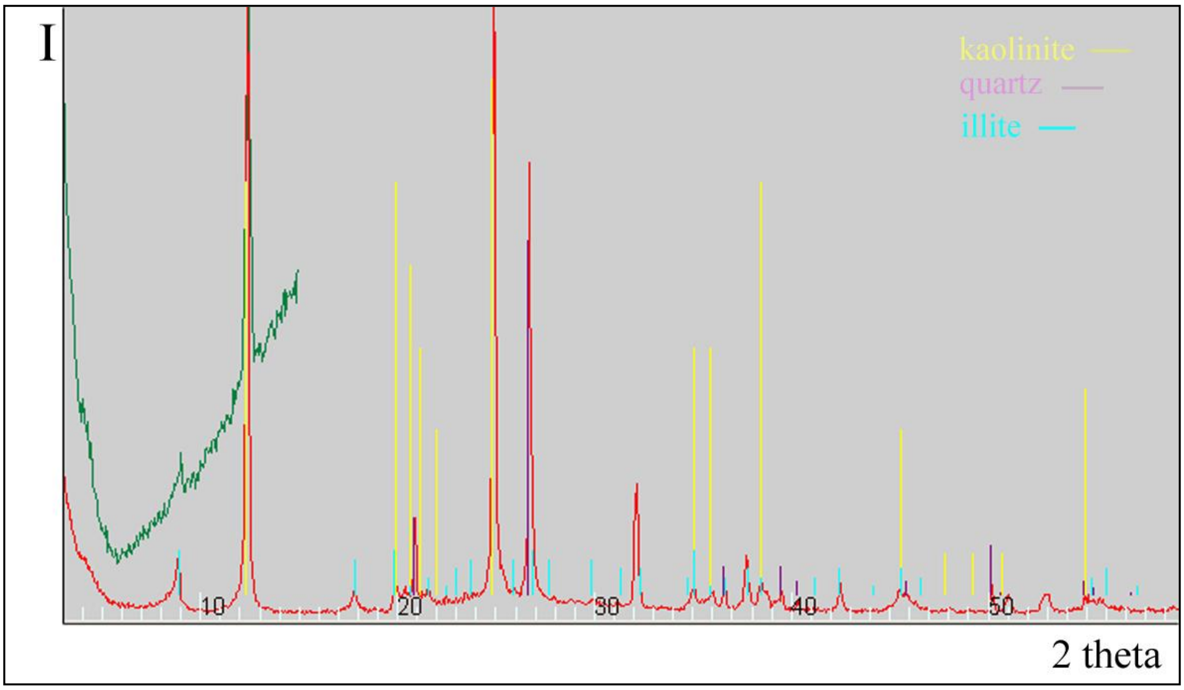


Fig. (5-13) XRD (clay analysis) of H27-NC115 at depth 5008 (-4510.7) ft, or 1526.4 (-1029.1) m at top facies four showing the main clay mineral.

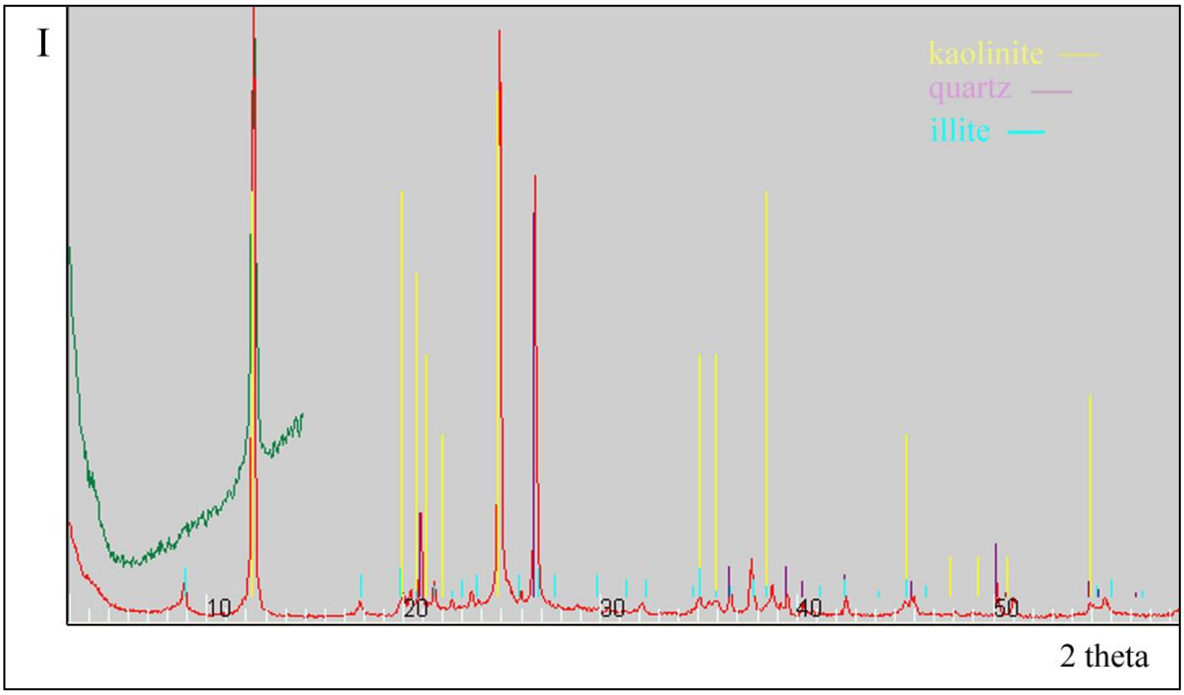


Fig. (5-14) XRD (clay analysis) of H27-NC115 at depth 5188 (-4690.7) ft, or 1581.2 (-1089) m at facies three showing the main clay mineral.

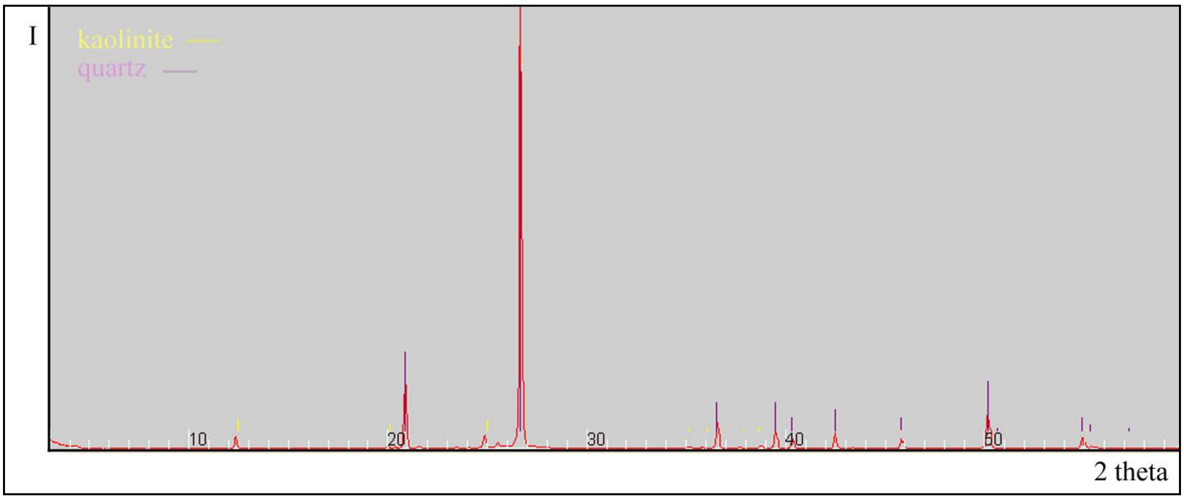


Fig. (5-15) XRD (Bulk analysis) of H5-NC115 at depth 4822 (-4319.2) ft, or 1469.7 (-966.9) m. at top facies two showing the bulk mineral diffraction.

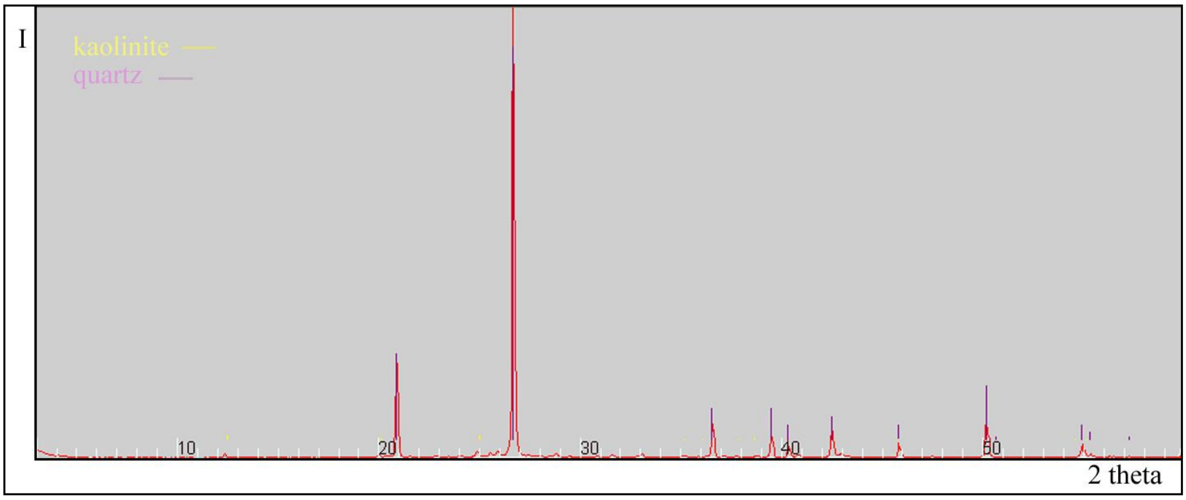


Fig. (5-16) XRD (Bulk analysis) of H5-NC115 at depth 4833 (-4330.2) ft, or 1473 (-970.2) m at facies two showing the bulk mineral diffraction.

Fig. (5-17) XRD (Bulk analysis) of H5-NC115 at depth 4846 (-4343.2) ft, or 1477 (-974.2) m at facies two showing the main conmen bulk mineral.

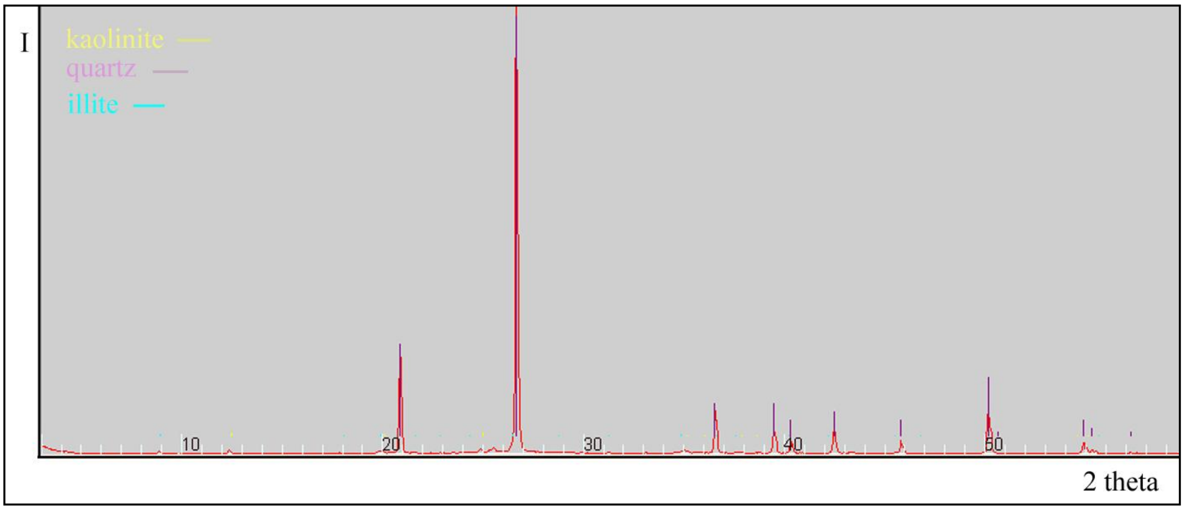


Fig. (5-18) XRD (Bulk analysis) of H5-NC115 at depth 4874 (-4371.2) ft, or 1485.5 (-982.7) m. at top facies three showing the main conmen bulk mineral.

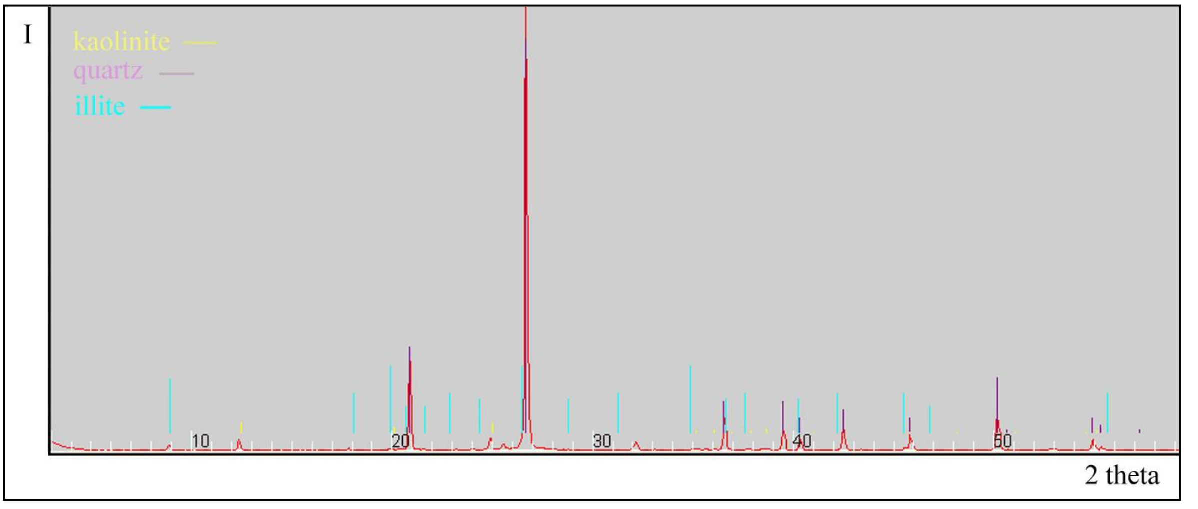


Fig. (5-19) XRD (Bulk analysis) of H5-NC115 at depth 4998 (-4495.2) ft, or 1523.3 (-1020.5) m. at top facies four showing the main conmen bulk mineral.

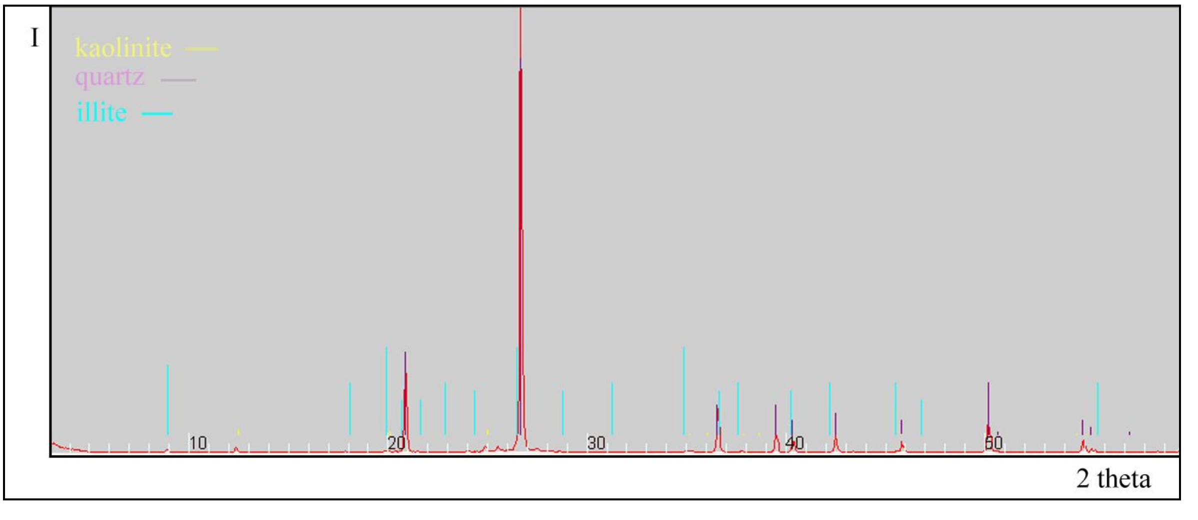
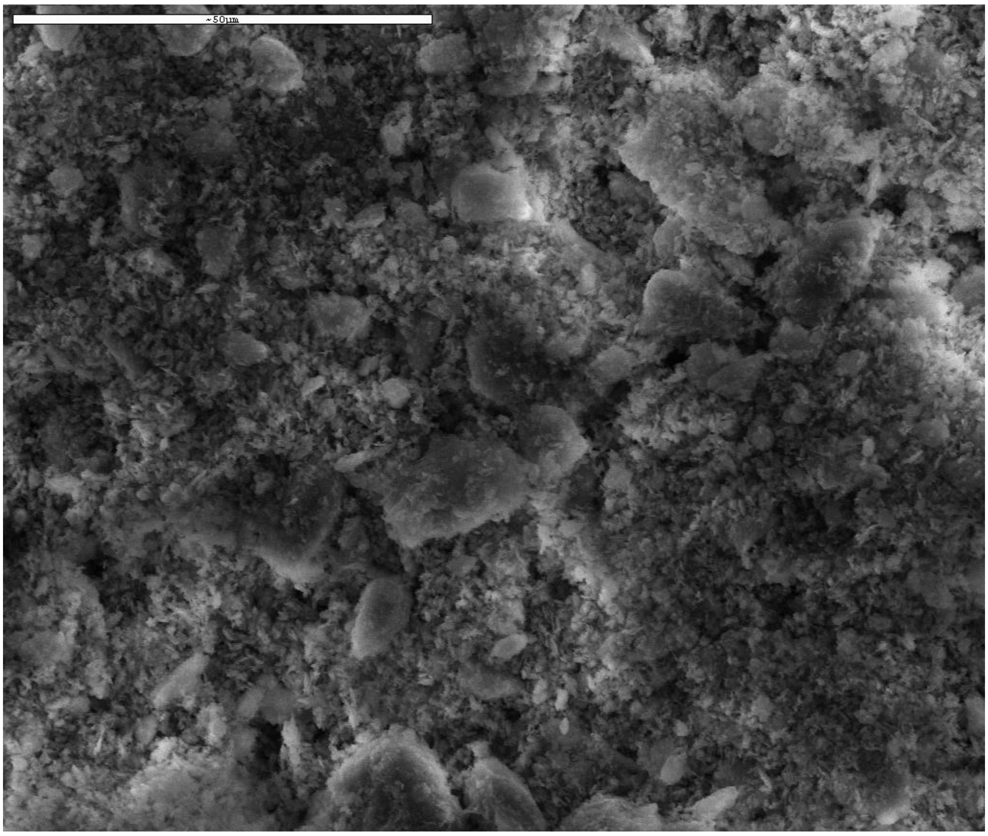
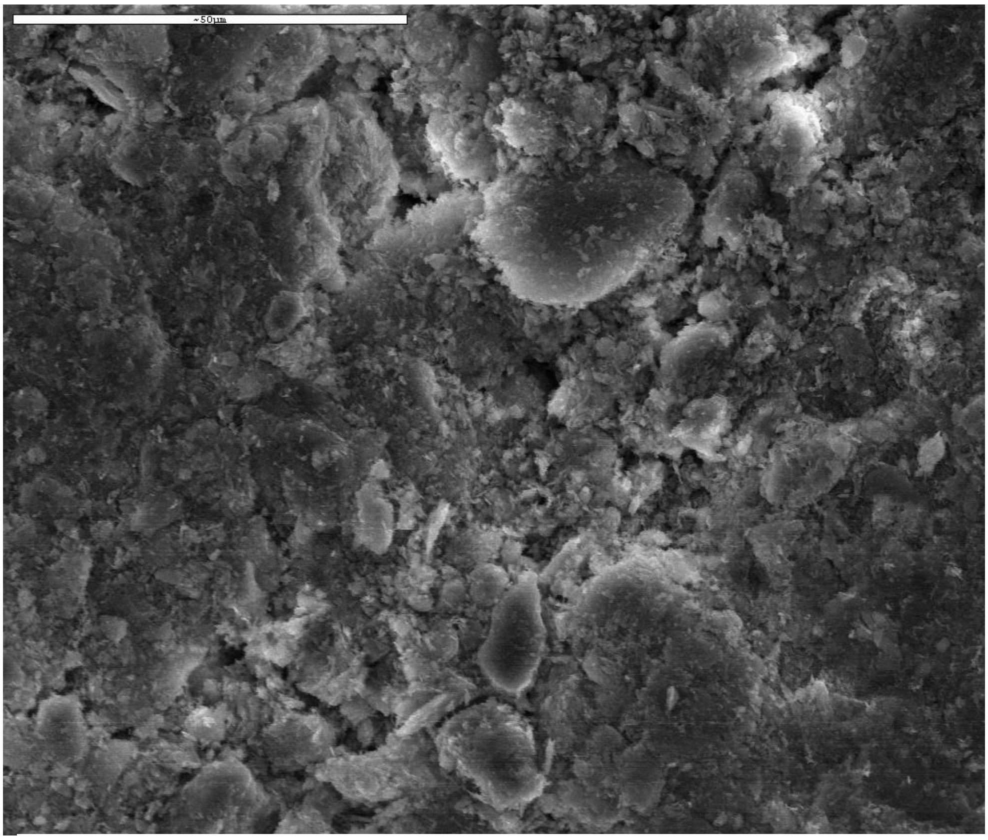


Fig. (5-20) XRD (Bulk analysis) of H27-NC115 at depth 4920 (-4422.7) ft, or 1499.5 (-1002.2) m at facies three showing the main conmen bulk mineral.



(Fig. 5-21) SEM at depth 4902 ft well H27-NC115



(Fig 5-22) SEM at depth 4938 well H27-NC115, quartz overgrowth

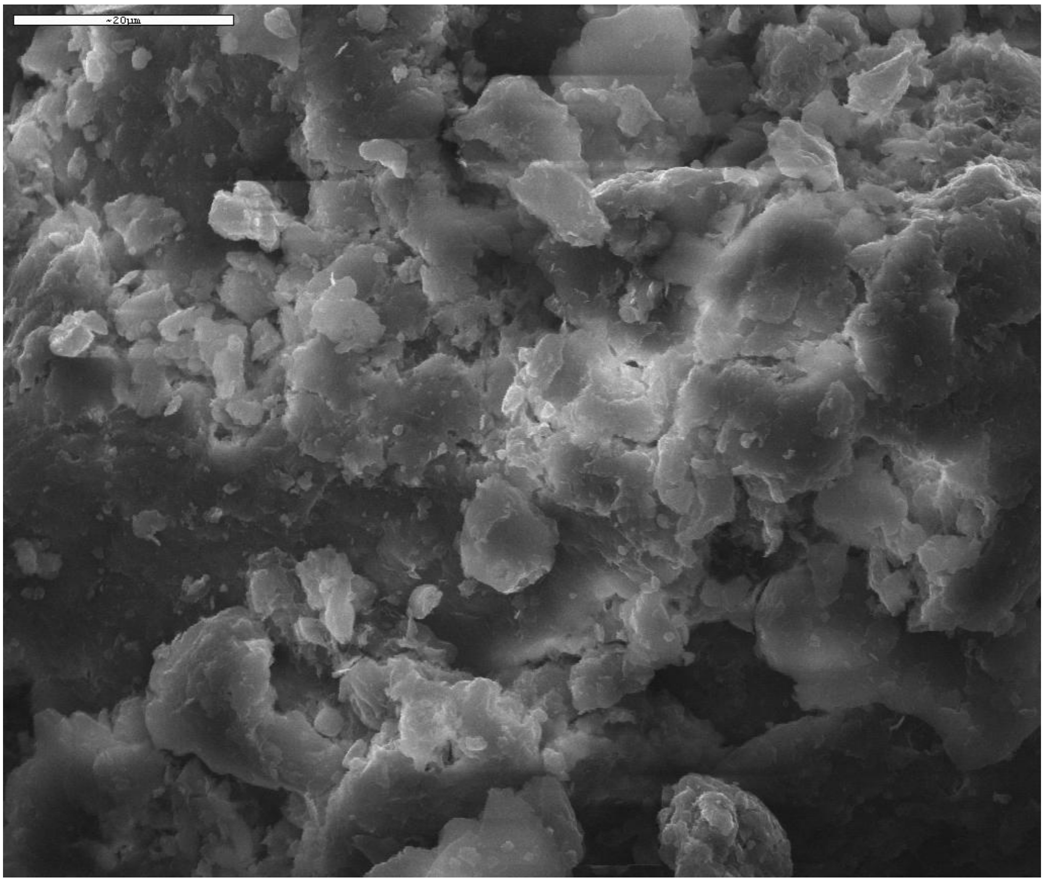


Fig 5-23) SEM at depth 4942 well H5-NC115, Kaolinite & quartz

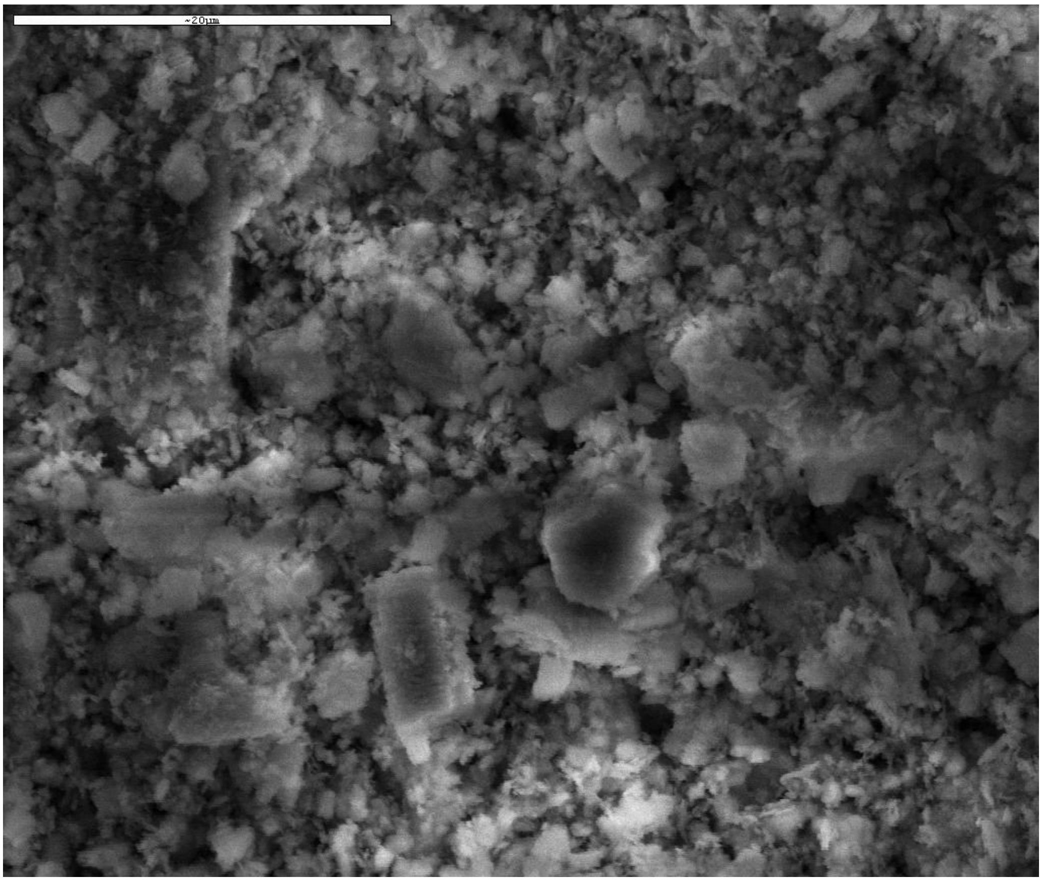


Fig 5-24) SEM at depth 4978 well H27-NC115

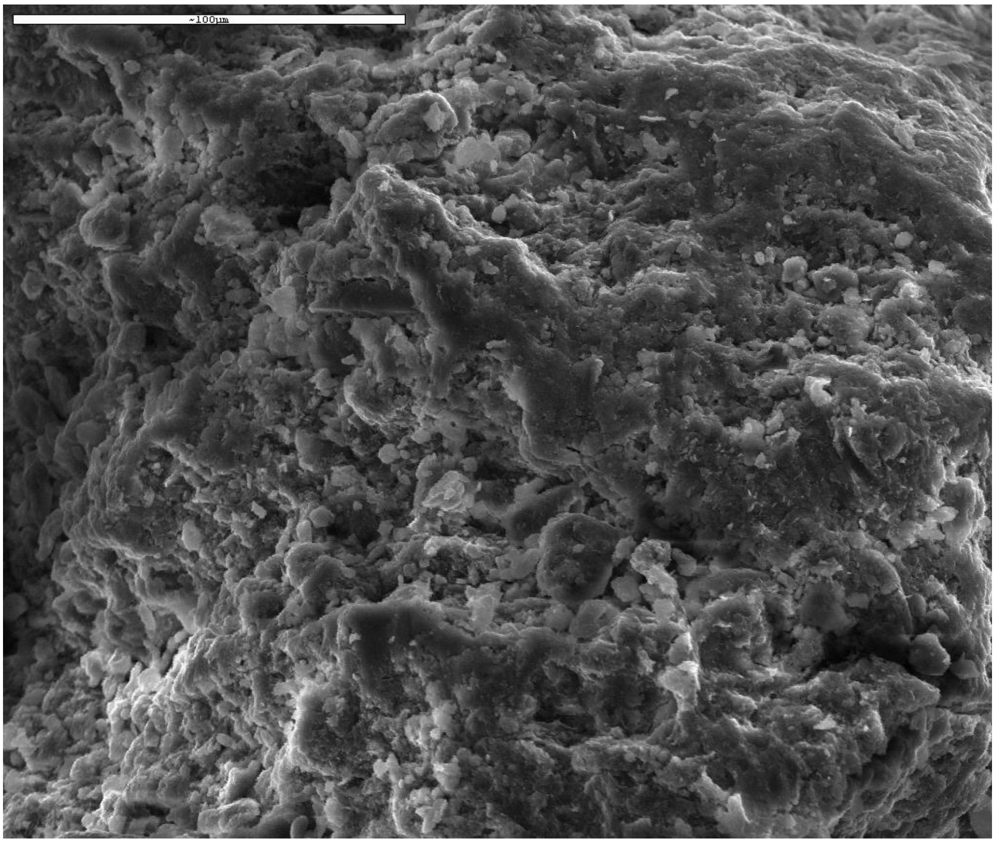


Fig 5-25) SEM at depth 5002 well H27-NC115

CHAPTER SIX

PETROPHYSICAL AND GEOPHYSICAL EVALUATION

Petrophysical Evaluation

6-1-Introduction:-

The purpose of reservoir petrophysical analyses was to quantify the geometry of reservoir rock, saturation of water and / hydrocarbons and to determine the ability of the fluids to flow through the rock. Well log, special core analyses data, and petrographic identification of the type and distribution of clay minerals were used to:

1. Establish net sandstone and shale volumes;
2. Shale distribution throughout the formations;
3. Calculate reservoir porosity and permeability;
4. Identify porosity, permeability, and Vsh relationships;
5. Determine water saturations, and;

The well log suites that include radioactive logs, electro logs and acoustic log curves were available in most wells in the study area. Two of these wells have routine core analysis data. These two wells (H27-NC115 and H5-NC115), are located nearly at the center of the study area (see location map). However, they were used as reference for data sets, and the special core analysis data were obtained to supplement existing information for the remainder wells. Porosity values derived from well logs and porosity values from the reference wells were used as a quality control check (Fig.6-2, 6-11, and 6-11a). Porosity-permeability relationships established on a facies-by-facies basis from the abundant routine core analysis data were then used to calculate permeability in wells where no core data were available.

Special samples through the cores were selected for more analysis for clay and sandstones propriety in the area, that represent the range of petrophysical rock types identified from core description and porosity-permeability data from conventional core analysis. Samples were chosen to demonstrate differences (if any) in measured values (1) between the main facies through the sandstone unit in Hawaz Fm, (2) in a thin crevasse splay sandstone. Samples were taken from the cores from well H5-NC115 and H27-NC115 reservoir section. Petrographic thin sections were prepared from all cores available and selected for special core analyses in order to identify clay mineralogy and habit.

6-2 Objectives:

The primary objectives of initial reservoir studies in ‘H’ Oil Field were to:

1- Identify general styles of inter-well stratigraphic heterogeneity;
2- Evaluate production behavior;
3- Complete a preliminary assessment of additional resource potential of individual reservoir units; and
4- Select individual reservoir zones with significant potential for incremental recovery for further analysis to delineate specific locations and volumes of un-recovered mobile oil.

From the main objects are to find out the relationships between permeability with porosity, which may be infected and complicated by diagenetic processes like compaction, cementation, dissolution, and occurrence of clay minerals. These diagenetic alterations can reduce total porosity, and more importantly, reduce effective porosity available for fluid flow.

6-3- Methodology and available material:

A large amount of material was available for this study, including wireline log data from 8 wells and conventional core analysis from two wells, slabbed cores, core samples description, core photographs, and samples for petrographic analysis (thin section) of the Hawaz Siliciclastic Upper-Ordovician sediments, which attain a total thickness of about 135m. Description has been done for more than 495 feet of core material, identification of different sedimentary facies and all character with in the formation. The wells H5-NC115 and H27-NC 115 have a good cored interval in Hawaz Formation (fig. 6-1), for that they are used as reference wells for core-log correlation, supplemented by additional material from some other wells. All data have been tied to the petrophysical lithostratigraphic and sequence stratigraphic frame-work established. However, porosity and permeability calculated by the well logs method is compared to that obtained in a laboratory analysis approach.

The calculation of porosity and permeability involves the identification of a set of variables that are related to porosity or permeability table (6-1).

The reservoir properties were calculation and evaluated (porosity, permeability, net sandstone volumes or shaliness (Vsh) and water saturation) through computer by GD Base program, (a software package by Dr. J. Křestan based on general published equation).

6-4- Main log Suite used in study:

There are many different types of well logs. Some of the logs are used to interpret the rocks (facies classification), and other for petrophysical evaluation in the study area. All the logs were handled as digitized format at uniform intervals between 10 cm intervals, showing fine significant variations of the logs with depth.

Depths are measured from an arbitrary reference datum, normally the Kelley Bushing (KB) above ground level, than converted to sea level. In addition, the digitized logs depths data were converted from feet to meters for each well. The main logs which have been used are:-

6-4-1 Gamma-ray logs (API):

GR-logs are frequently used to determine the sand to shale ratio, the mean grain size and sand content. At study area, the gamma-ray log has been used as a record to locate the depth of key stratigraphic formations (Figure 6-1) and to subdivide the Hawaz Formation into facies of sandstone and shale. However, the GR logs are available in all wells under study and showing very good indication. The thick sandstones beds have typical gamma ray values averaging at 20-25 API units. Low GR reading indicates a clean sandstones facies (no/very low shale exists). Thin interbedded shale and silt in sandstones may present with higher reading at same facies. The shale or shaly sandstones facies as (Facies two) showing relatively higher reading at several shaly streaks 60 API, while at more shale facies (F4) the GR reading showing nearly as well as shale section up to 120 -140 API see (Fig. 6-1, and 6-2). The high total gamma-ray reading value is recording at shale beds (Tanezzuft Formation of the lower Silurian) in average of 150-180 API. Furthermore, the higher values were especially at (hot shales) up to > 250 API.

However, a quick comparison between GR logs in front of the two main sandstone and shales bodies is sufficient to illustrate the fair limitations of GR to sort out sedimentary facies in sandstone material. Additionally, it is clear that clean well sorted sandstone material may exhibit different grain size, hence comparable porosity and bulk density while their permeability will strongly different. This again exemplifies how efficient is a curve formed of single values to convey information about the structure of a formations formed of groups (facieses). Facies "relative" evolution is clearly shown by GR-log; also can provide with the information needed to identify the absolute position of each facies.

As a summery the thick sandstones beds have typical GR values average reading at 20-25 API and higher reading at shaly facies up to 60 API. Thin interbedded shale and silt in sandstones shows several streaks (thicker than 2foot).

6-4-2 Spontaneous potential SP (MV):

At study area in addition to calculate and determine the facies in Hawaz Formation distribution, the SP curve is used by system to determination of formation water salinity $\boldsymbol{R_w}$; and used to estimate the conductivity of the formation water, as well used to calculate the shaliness in the formation or separation of clay to other minerals by program system; and as an important variable in the petrophysical equation computation at log analysts.

6-4-3 Neutron logs:

At Hawaz Formation the neutron log CNL (compensated neutron) logs is primarily used to evaluate formation porosity, and to calculate the shaliness in the formation. Since neutron log is a type of porosity log that measures the hydrogen present in the water atoms in a formation. And because the hydrogen measured by the tool is present not only as free water but as bound water in clay minerals as well. Beside the porosity curve, the log combined with the gamma ray log, has been used to detect shaly intervals.

Since shales contain a lot of water, bound up tight in their tiny pores, the neutron log reads very high porosities in shale formations. Therefore, the Gamma-Ray log used to correct that if the rock is shale type. At study area the neutron porosity does not read much, where sandstone neutron log showing les reading than density log but at shale facies may be present the same/more reading. The presence of sandstone and shale causes the two curves to spread, but not nearly so much as gas effect.

In addition, those neutron logs have been used by system for lithology and shaliness definition. In combination with the neutron log, density log and gamma ray are allow for the definition of the lithology, lithological boundaries and calculated of shale volume.

6-4-4 Density logs: FDC (formation density compensated) logs:

It is the second log of determine porosity by measuring the density of the rocks. The combination of density and neutron logs is now used commonly as a means to determine porosity that is largely free of lithology effects. Since each individual log recording an apparent porosity that is only true when it matches typical zone lithology (limestone or calcite equivalent porosity).

The main character at study area that density log is reading higher values of density at shale fascias or interbedded shales; while the average density of quartz (sandstones facies) is about 2.65 to 2.66 grams per cubic centimeter. These values correspond to the density of sandstone as it shows in facies three and five.

By superimpose or overlay the density and neutron logs they allows shales, sandstones, and other lithology to be distinguished and a better estimate to be made of the true porosity of the formation at any depth. However, the separation between density porosity and neutron porosity was an excellent shale indicator, especially in thin interbedded (laminated) sand-shale sequences as in (facies two).

The other main notice that is the overall shale composition estimated from the density-neutron log combination is nearly similar to shale indicated by the gamma ray log, but with main different that while both measurements are sensitive to shale content, the gamma ray log responds to the natural radioactivity of the shale, while the neutron-density logs are influenced by the bound water and density of the shales.

6-4-5 Sonic (Acoustic) logs: BHC (borehole compensated) logs

The sonic logs, shows high reading at high-density shales than lower-density through sandstones. The comparing between reading in formation shows that the min reading is in average (<40 µs/ft) and the maximum reading at in average of (180 µs/ft) at shale of Tanezzuft Fm. In general, the sonic logs, picked transit times (µs/ft) as a function of depth down the well (converted to µs/meters); and with computation of basic porosity parameter as matrix mineral transit time.

6- 4-6 Resistivity logs:

This includes different types of resistivity logs as short, medium, and deep investigation. The main objective of resistivity log was to determine properties of the formation water, brine in the reservoir and what types of fluids are present in the reservoir rocks by measuring how effective these rocks are at conducting electricity. Because hydrocarbon present at study formation have low conductors of electricity, and high resistivity up to 1000 ohmm. All water formation is salty enough that they conduct electricity with no difficulty. Thus, the formation at water saturation (below OWC) generally has low resistivity les than 10 ohmm (see fig 6-2). In general, the resistivity logs different types, have been used to showing and detected the water saturation of drilling fluid and original fluid behave movement in reservoir formation.

6-4-7 Porosity logs:

The porosity has been measured both from a single "porosity log" (sonic, neutron, or density logs) and by combination of porosity logs (with shaliness log), in order to correct the output at variable lithology effects in complex reservoirs. (See table 6-1).

Table (6-1) Average result for the Hawaz Formation in the "H" Field on base of studied borholes

Facies	Average thick	Average V_{sh}	Average Θ	Θ_{Sonic}	Θ_{Den}	Θ_N	Θ_{Core}	Average H. K_{Core}	Average V K_{Core}	Grain density
Units	m	%	%	%	%	%	%	mD	mD	$g.cm^{-3}$
F- 1	11	10-35	6-14	8-15	6-15	3-15	11.5	16	23	2.65
F - 2	30	10-35	10-13	10-15	9-14	5-12	13.5	5	6	2.66
F - 3	42	3-25	10-20	9-19	9-21	12-21	14	215	185	2.65
F - 4	12	45-85	3-9	6-10	3-15	3-9	7	55	25	2.66
F - 5	32	5-15	10-27	8-25	12-27	10-25	-	-	-	-
F- 6	76	25-30	-	-	-	-	-	-	-	-

6-5 Data Correlation:

6-5-1 log Correlation:

The reservoir zonation is based on well logs and lithological data, which calibrated to the analytical data derived from the cores and thin section. The example of an extended laboratory analysis of samples from core plugs is shown in Fig. (6-11 & 6-11a) demonstrates the sensitivity of the gamma-ray log readings to variations the clay content. Alternatively, a suite of different logs in combination have been used to quantify a given petrophysical property, which can provided its relationship to the log readings. Moreover, by adding the resistivity to the suite of logs, the accuracy of the porosity transform may be further improved since resistivity is normally the best indicator for the type of pore fluid. (See fig.6-2 & 6-3).

6-5-2 Comparison of log and core data:

Porosity based on log measurements and core data were correlating and analysis at the same depths in well H27-NC115. The values of both results are expected to be slightly smaller through most points, and have identical porosity values for both datasets, except a few points reading of cored which showing higher reading. This may be indicated that the situation of these samples was not representing the main reservoir conditions (fig. 6-11 & 6-11a).

Ehrenberg et al. (2006), Helle et al. (2001), and Worthingto (1991) provided a review of the problems encountered when comparing downhole log reading data and core measurements. They come out with some interpretation for these differences as: While the wireline tools measure properties in situ as elevated temperature and pressure, the core data are normally obtained in the laboratory at room conditions. In particular study, cores collected at great depths are may exposed to mechanical deformation and micro-cracking that significantly increases the surface values of permeability and porosity compared as can see significant scatter reading in the porosity and permeability data since the mechanical impact may differ for individual rock samples due to different composition and sampling history of the core; but the most errors in well log data are caused by poor borehole conditions (as enlarged hole diameter). In addition, the log reading is representing the all effecting condition in the formations or this could be due to an averaging effect of the log tool.

Ehrenberg et al. (2006) a possible for the higher permeability range of the plug samples is that the highest permeability plugs may contain large vugs that effectively.

In the study area, the correlation between the dates which estimated from well logs and core measurements is good to excellent at general values for same facies depth. There are a few scatter reading between both porosity and permeability data in laboratory and well log data. Though most of the data tend to have similarity and fairly homogeneous in most depths. This makes our porosity predictions are sufficiently accurate and satisfy output.

In addition, the computer calculations were made on 10 cm increments than averaged for the depth intervals corresponding to the reservoir facies.

6-6 Evaluation of petrophysical reservoir quality.

Porosity and permeability are the key variables in characterizing a reservoir and in determining flow patterns in order to optimize the production of a field and for evaluating hydrocarbon accumulations. (Helle, H.B. et al: 2001). Porosity and permeability of sandstones are the result of a sequence of geologic processes affecting the original sediments (Bloch, 1991).

The main objective of reservoir characterization is to identify the most significant vertical and lateral heterogeneities within a reservoir, especially those properties which related to influence fluid flow. The methods have been proposed to characterize reservoir quality and to subdivide Hawaz reservoirs into layers or flow facies based on descriptions rock fabric or rock characterization. By these methods, involve establishing relationships between reservoir quality and rock fabric or rock type using core, thin section and log information. Flow-unit boundaries are in general facies-dependent and can be defined by comparing accurate data from petrography and well-log data from well to another.

6-6-1- Determination of shaliness:

Calculation of net sandstone volumes or shaliness (V_{sh}) within the Hawaz reservoirs has been calculated through computer (GDBase program package). The volumes of net sandstone were calculated by subtracting volumes of shale (V_{sh}) which identified by well logs, from total reservoir interval thicknesses. GR, SP and Neutron curves logs data were used as a primarily tools. The databases for these logs are available and very well in all wells at study area.

In addition, before calculating shale volumes, all logs were depth adjusted to corresponding core data, and appropriate shale baseline was identified for the reservoir interval, consequently all logs reading were normalized to that standard shale baseline. The scale in all well logs were unified with the system by using transformation of well logging data equation to get same format output in all wells, as neutron porosity log to percent (%) porosity.

Table (6-2) showing the main parameter used in calculation of Vsh with program system GDB4

Well	H1	H3	H4	H5	H16	H20	H22	H27
GR mix (API)	170	140	127	130	122	127	140	125
GR min (API)	14	15	18	18	18	15	17	10
SP at clay	15	10	29	25	20	25	28	10
SP at sand	-40	-60	-38	-28	-59	-126	-37	-85

Some parameter were used connected with upper table calculation in the system as shale density 2.5 g/cm ^{3}, matrix sandstone density 2.65 g/cm ^{3}, transit time of clay 320 µs/m, transit time of water 645 µs/m, matrix transit time 176 µs/m.

(Table 6-3) presenting the average of Vsh (sandstones shale ratio) at different facies in Hawaz Fm at selected wells.

well	Facies one	Facies two	Facies three	Facies four	Facies five
H1	37%	33	10.1	31.5	4.2
H5	40.3	22.9	2.5	87.8	12.7
H16	10	15.5	2.3	31.2	2.3
H20	40	20	15	70	2.8
H22	15	36.8	2.9	35.5	3.5
H27	10	27.4	2.8	43	5

The location and volume of reservoir rocks are coincident with volumes of net sandstone. However, shale disturbance in the rock formation influences not only well logs reading but the reservoir quality as well see in anther section. In another word, the distribution and quality of reservoirs in the field are most directly related to major shale distribution and their digenesis. (Imam 1989) The pore systems of sedimentary rocks may be lined or filled with a variety of different clay minerals. These clays can greatly reduce porosity and permeability.

Sandstones are rarely clean; they often contain minerals other than quartz, such as clay minerals, which can affect their reservoir qualities as well as their elastic properties. Clay can be located between the grain contacts as structural clay, in the pore space as dispersed clay, or as laminations (Sams, M.S. and Andrea, M., 2001)

However, as a geophysical well log generally provide a widespread representation of the reservoir conditions in a lithological than the most wells laboratory measurements. In addition they dealing with larger volume of rock around the well and provide a continuous record, therefore a combined wireline readings and core data laboratory data are used in study when ever that possible.

Shale volume (Vsh) has been calculated for all wells in order to eliminate the shales interval from net thickness of pay zone; used the gamma-ray, SP, neutron and resistivity logs. A cross-plot of gamma ray and/or SP versus neutron, density, acoustic and resistivity was plotted for each well to calculate shale volume.

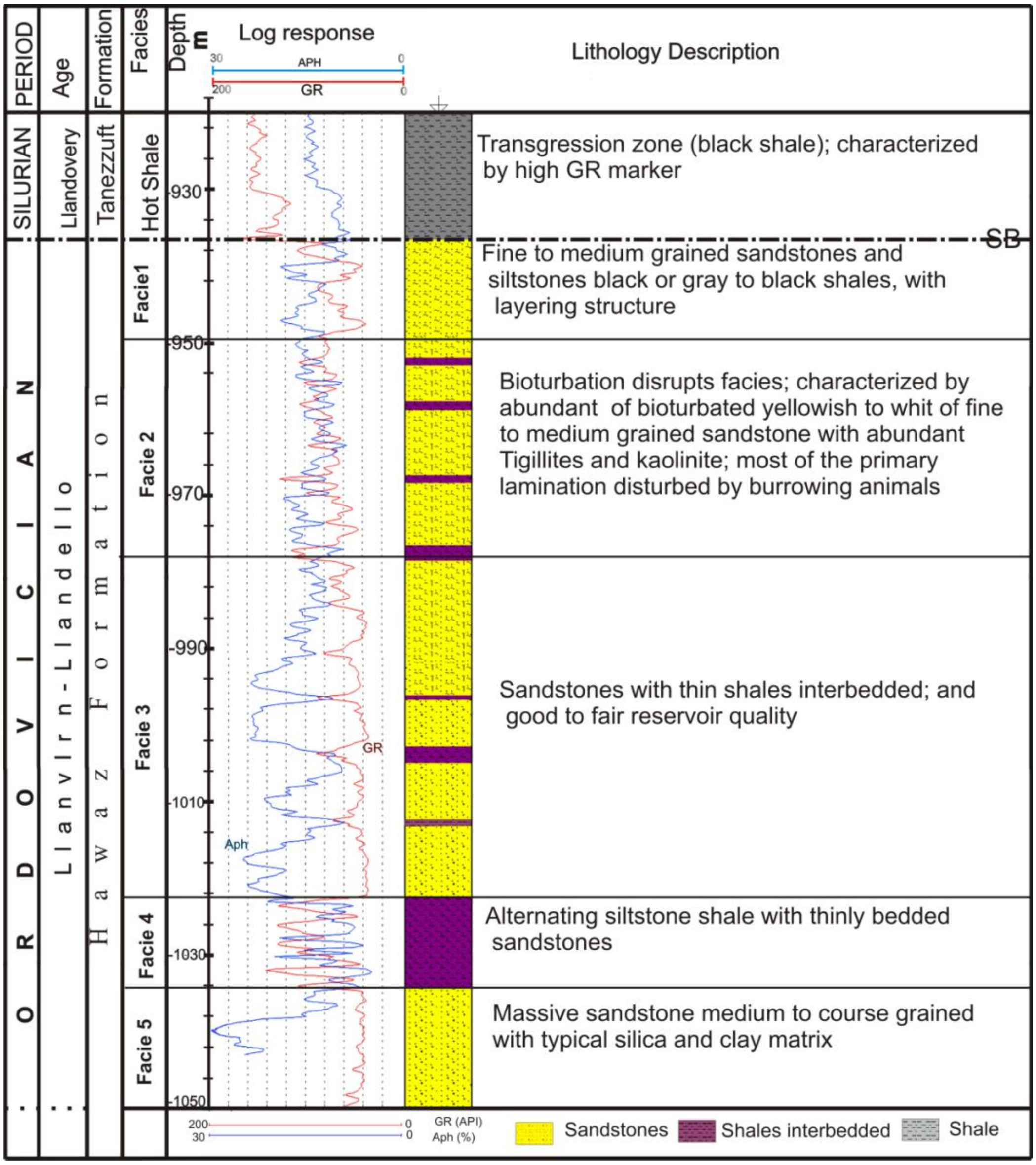
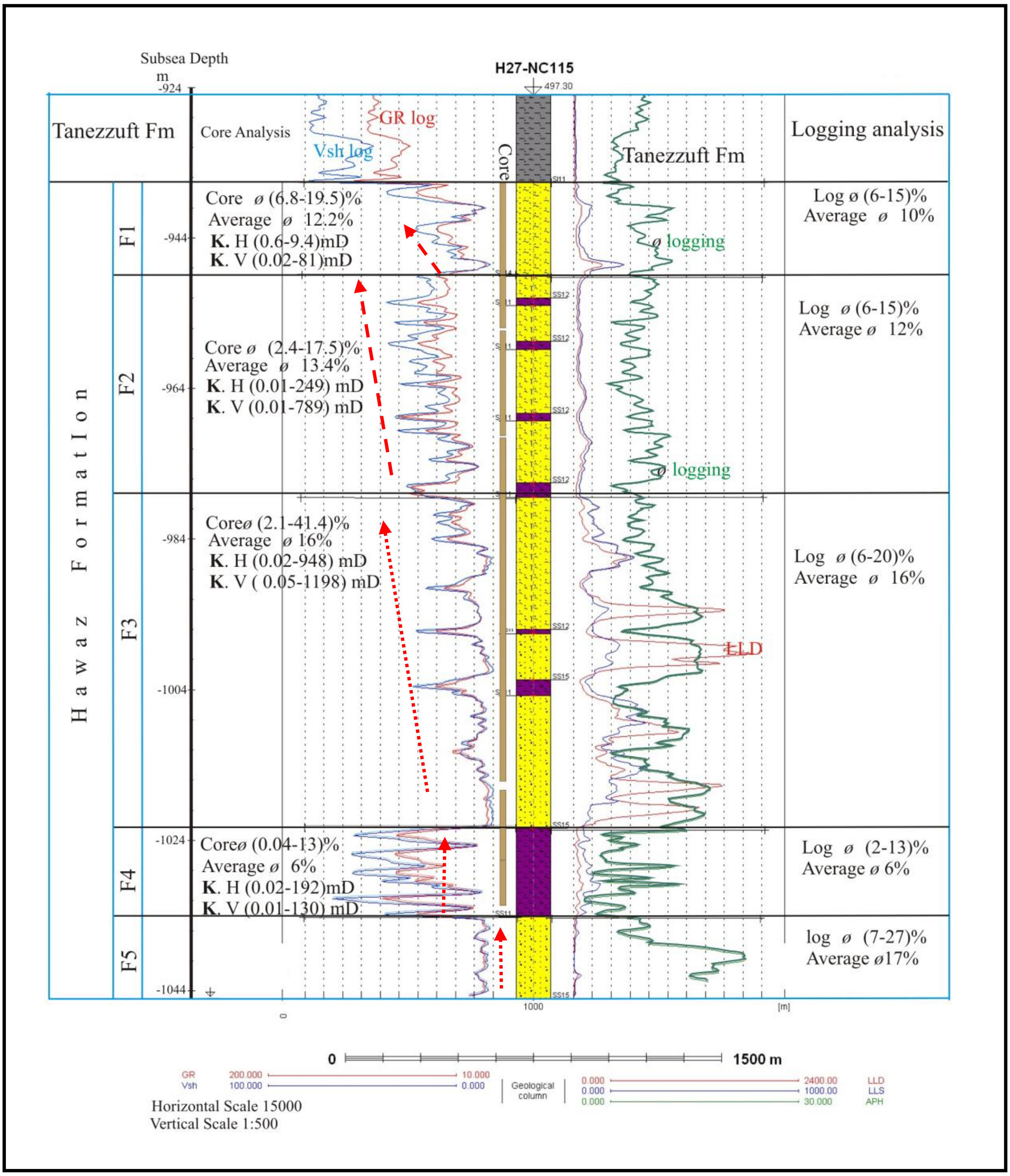
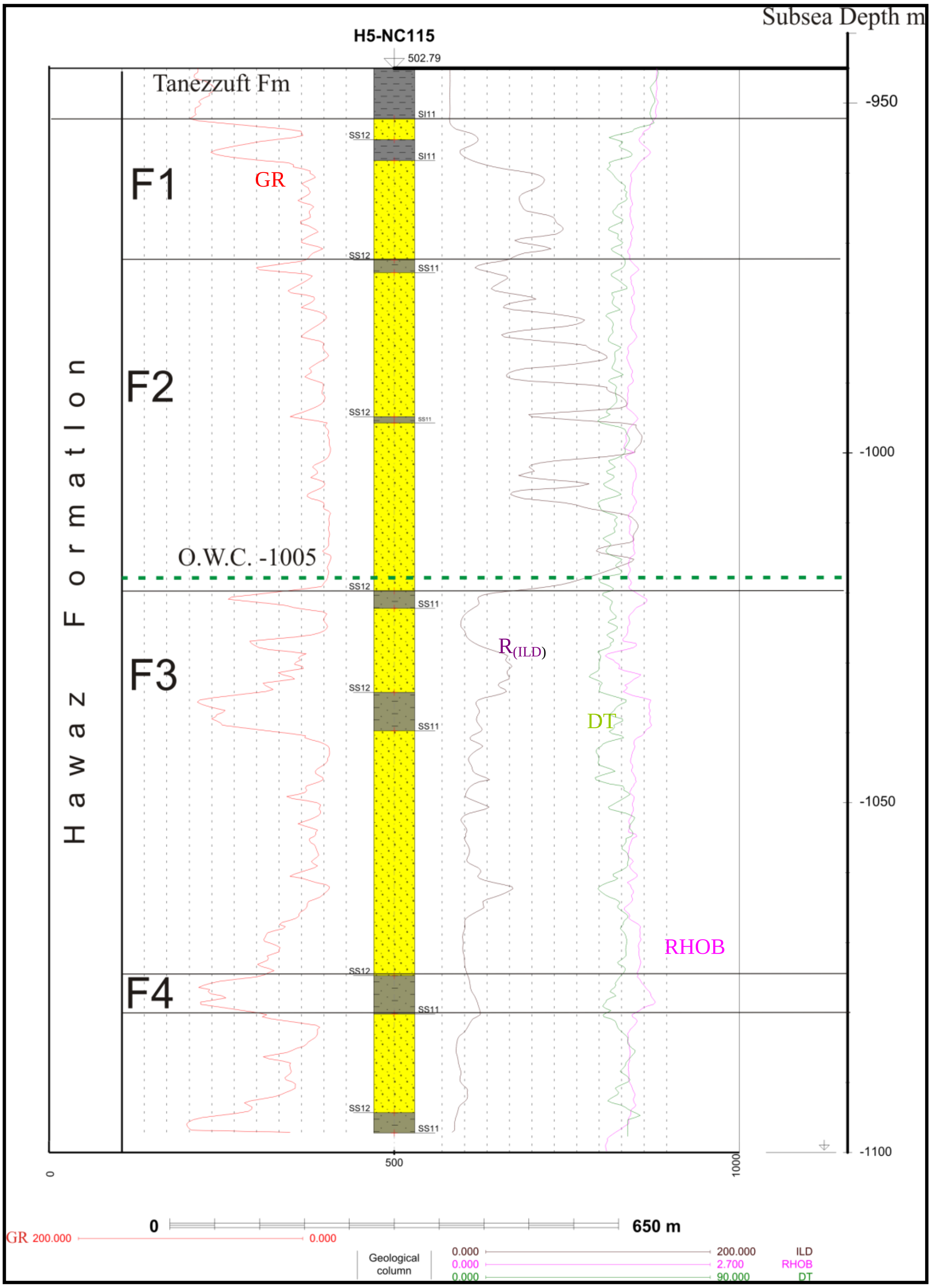


Fig. (6-1) General lithology and particular facies in the 'H' Oil Field, Murzuq Basin. (APH) = is average porosity in percent, GR = Gamma Ray in (API)

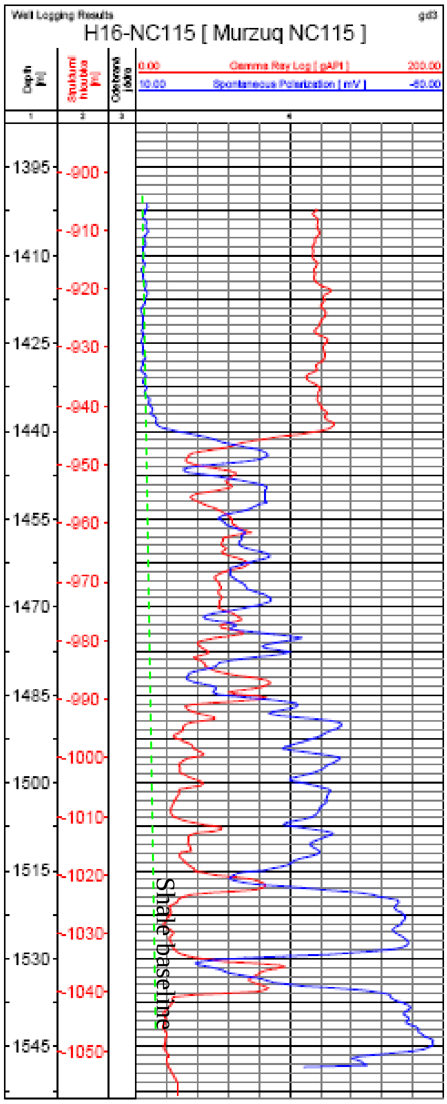


(Fig. 6-2) Showing the main facies, petrophysical parameter and the core location with depth in the Hawaz Formation at H27-NC115, as well as summary of the relationships between core porosity – permeability (left)and log measurement (right)



(Fig 6-3) Showing the facies distribution and oil-water contact at well H5-NC115. GR- Gamma ray log (API), R_{ILD}- Induction log (Ωm), RHOB- Density log (g.cm^{3}) and DT- Acoustic log (m/s)

(Figure 6-4). Showing similarity of Spontaneous potential (SP) and Gamma-ray logs in the Hawaz Formation "H" Oil Field. Although they record different physical properties, the two logs are comparable because of their sensitivities to shale and so both can be used to differentiate between sandstones and shales, and shaliness. The stronger sandstone differentiation at greater depths on the SP log is may be caused by higher salinities in the deeper sandstones.



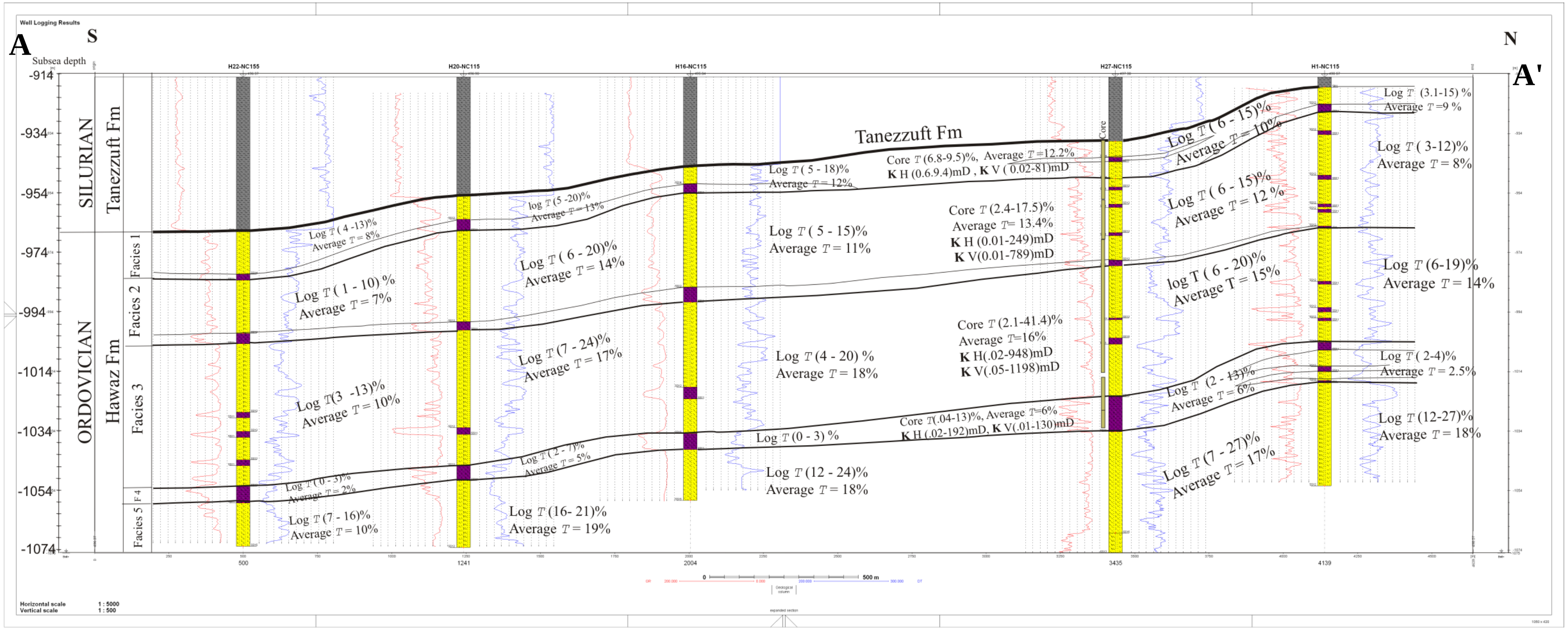
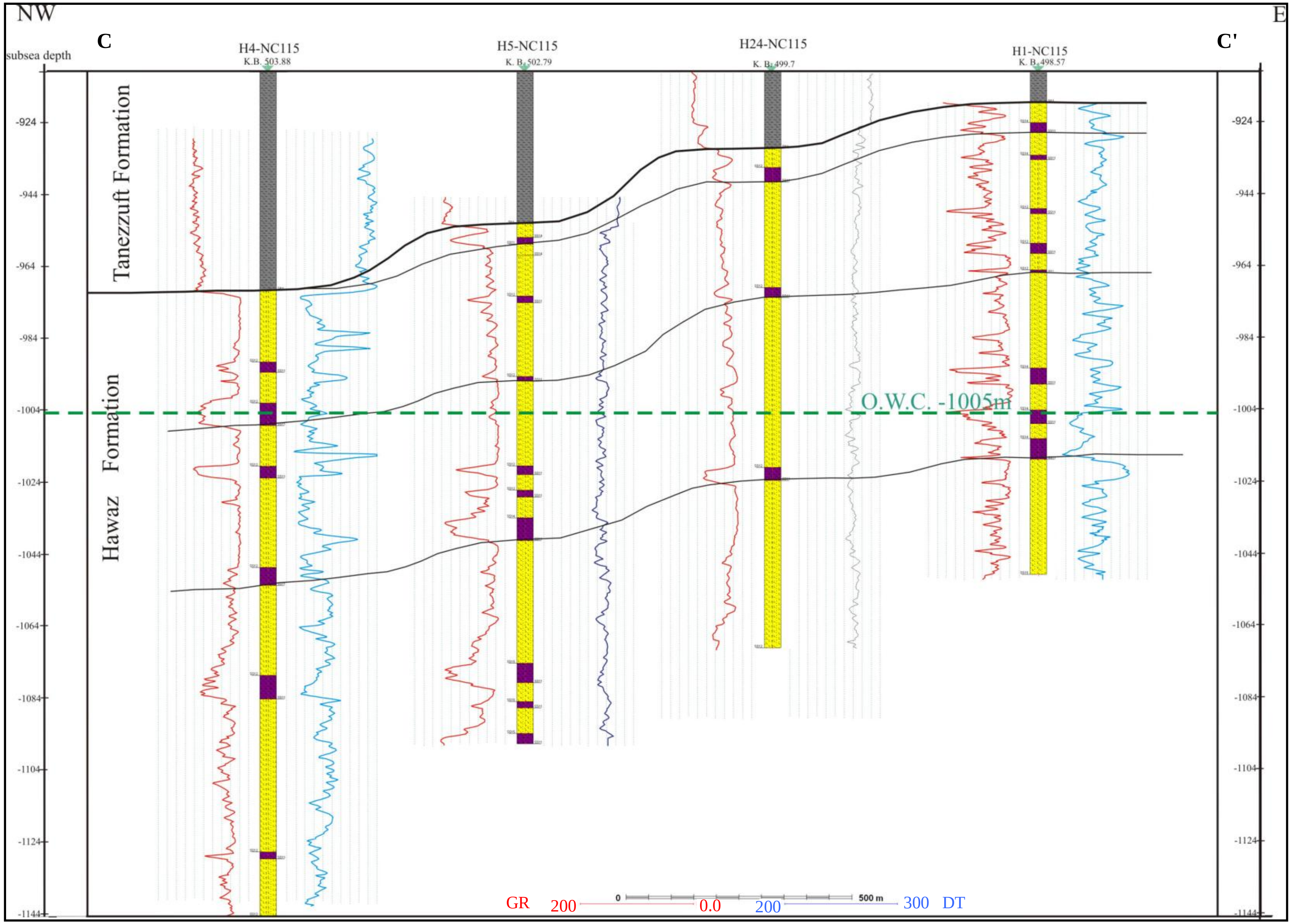
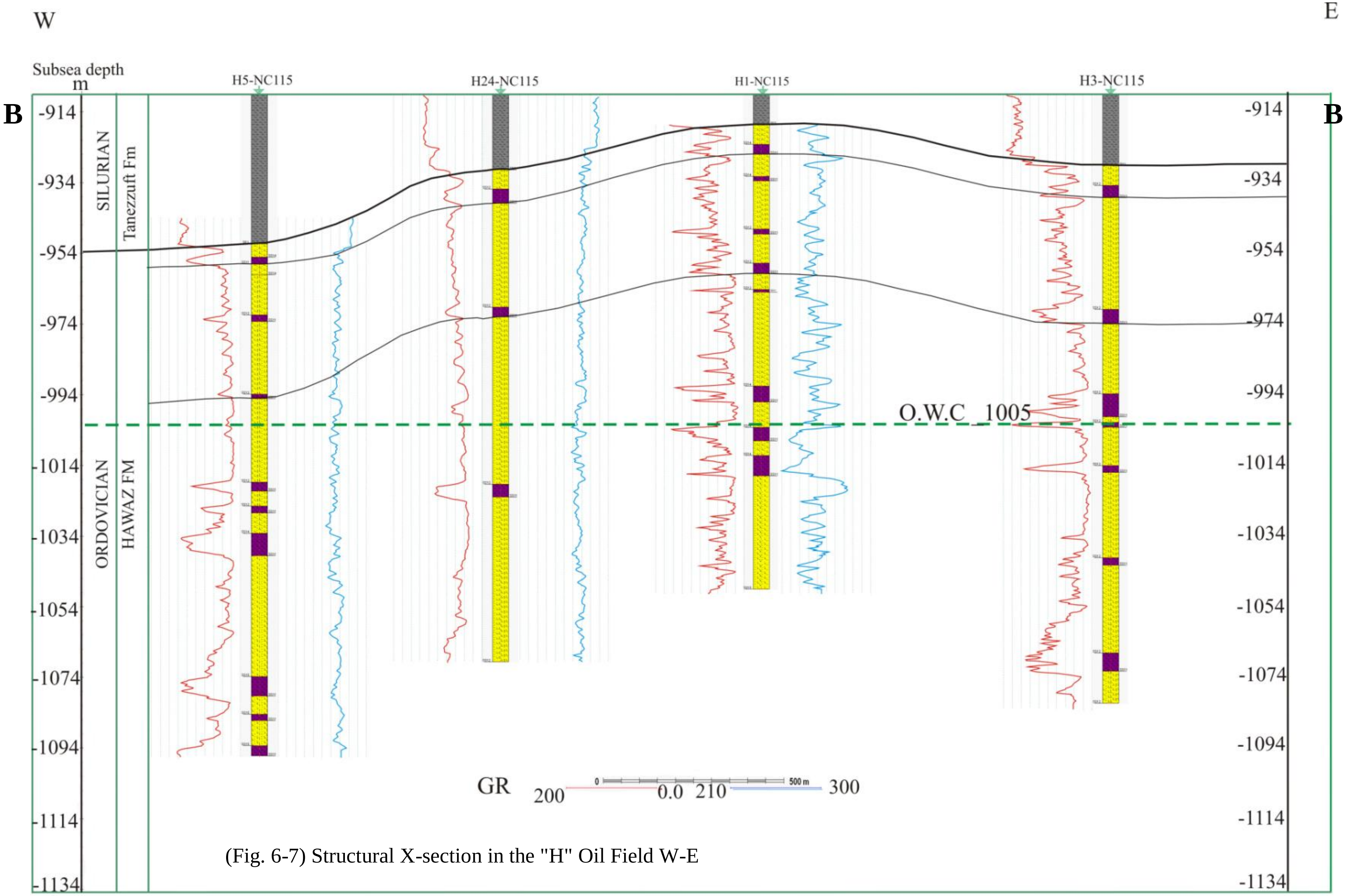


Fig. 6-5 showing x-section S-N with main porosity distribution in facies



(Fig. 6-6) Structural X-Section in the "H" Oil field



(Fig. 6-7) Structural X-section in the "H" Oil Field W-E

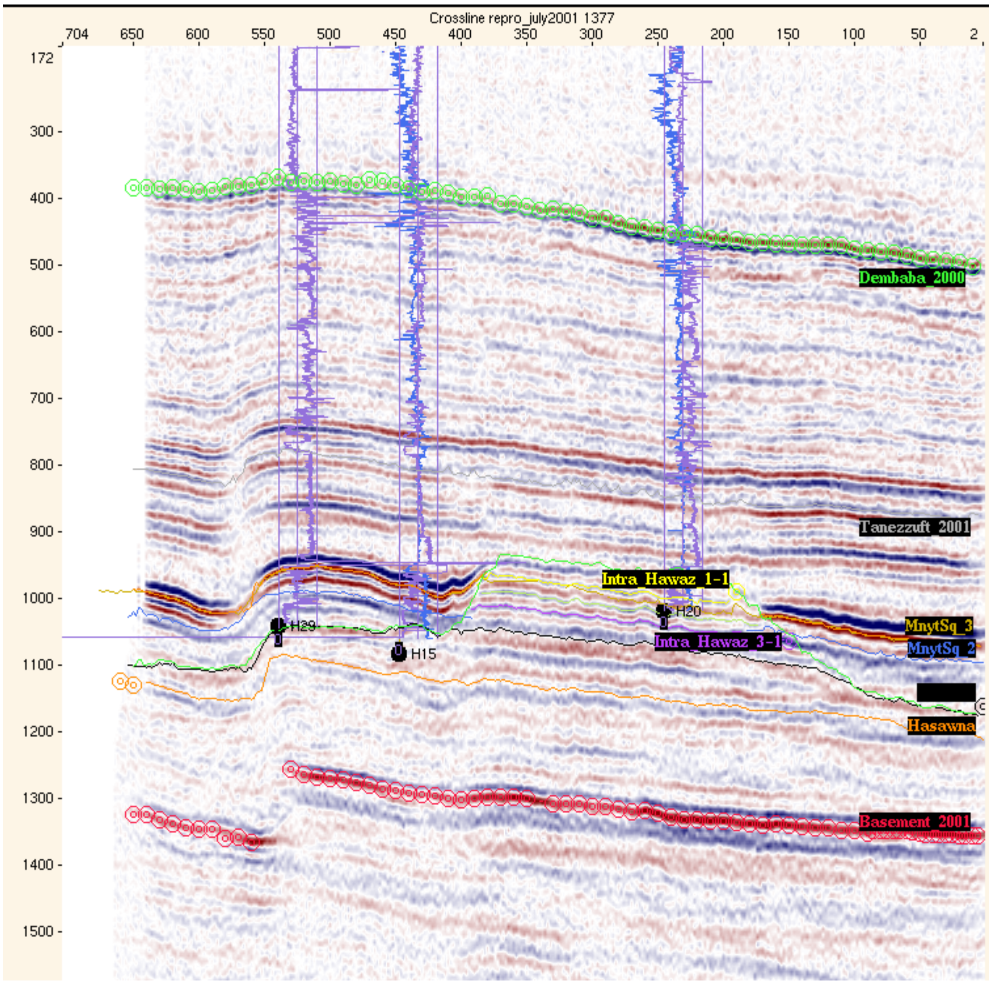


Fig. 6-8 Seismic cross-section (N to S) through the field, passing through the wells (H20-NC115, H15-NC115 and H29-NC115) and are highlighted to shows main character of sedimentary and structure, also shows that H29-NC115 is separated structure. (Courtesy of Akakus Oil Operations Company of Libya).

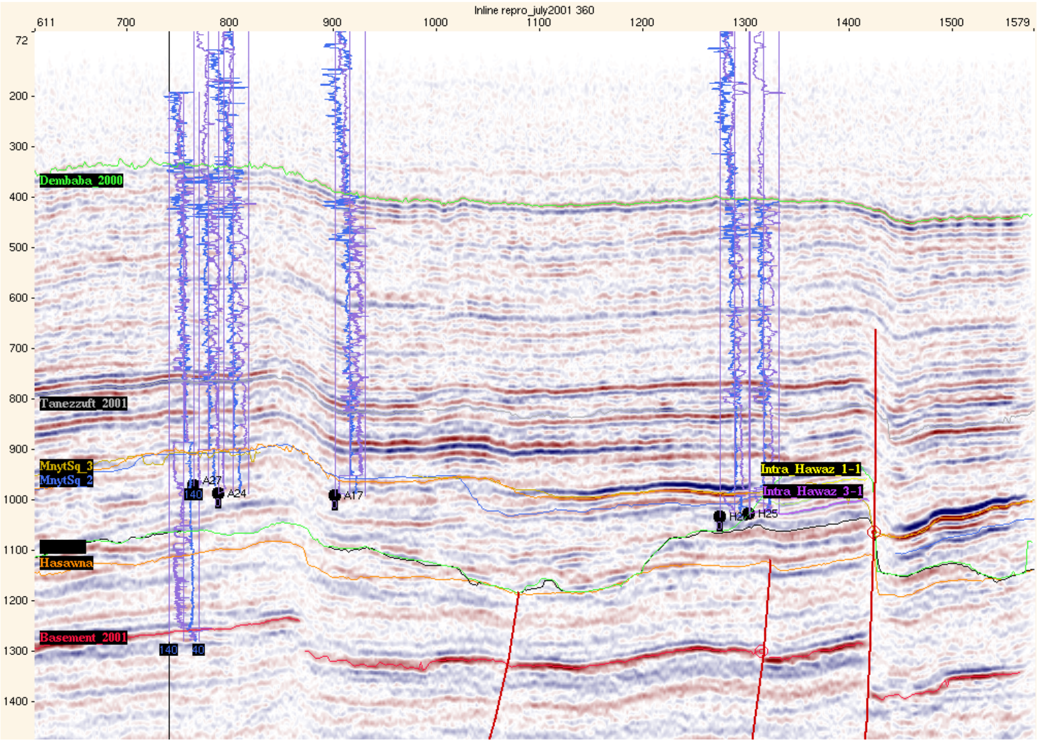


Fig. 6-9 Seismic cross-section through the field, are highlighted to shows main character of structure, also shows the boundary between the "H" lift and "A" right fields structures. (Courtesy of Akakus Oil Operations Company of Libya).

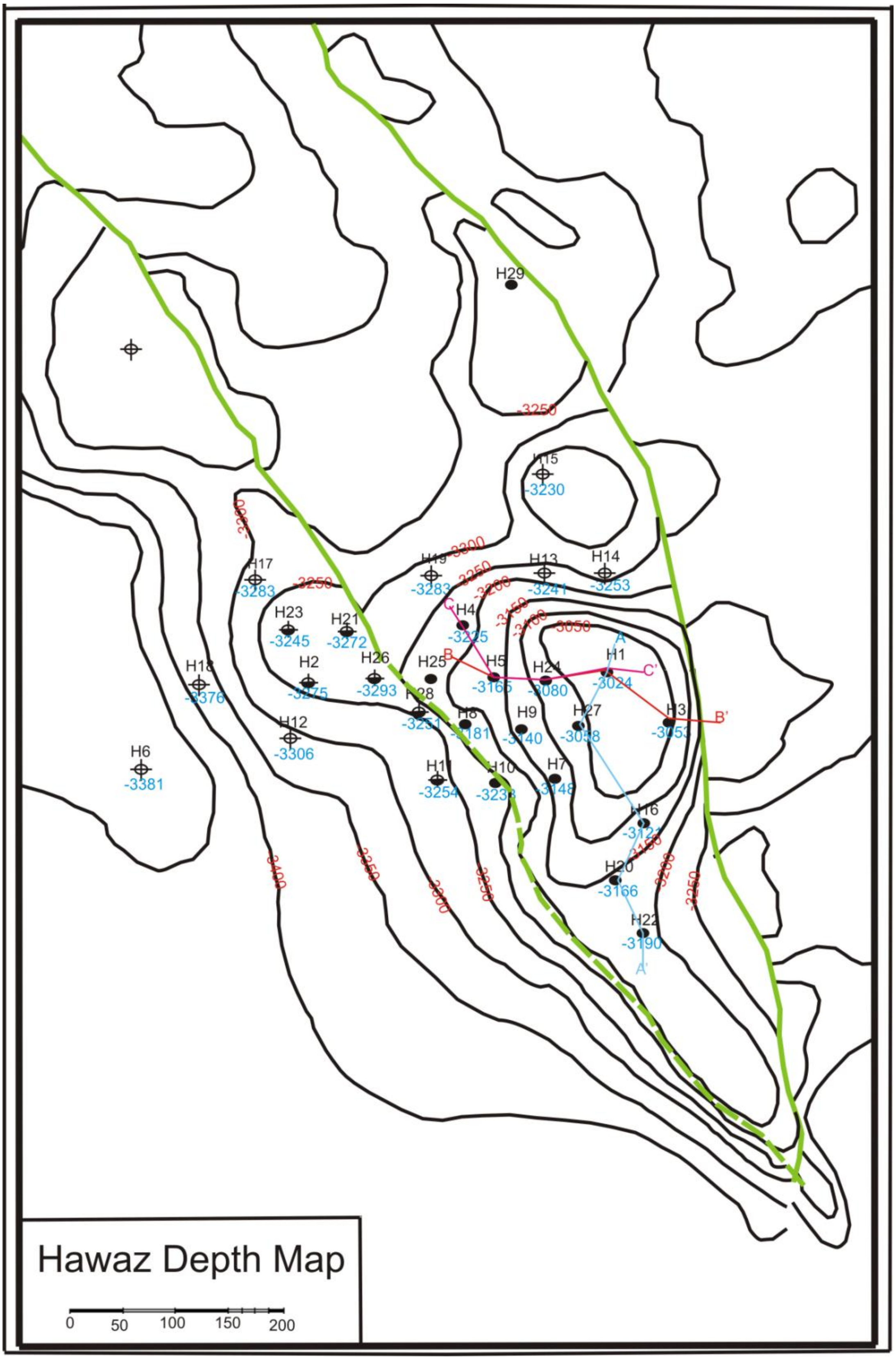


Fig. 6-10 Structure map of Hawaz Formation (isolines of depth at top Hawaz Fm), and direction of X-sections

6-6-2 **Evaluation of porosity (Ө)**

6-6-2-1 Log Determination of Porosity

There are three types of logging tools that are used by (GDBase) program system to calculate the amount of pore space in a rock: the neutron, density, and acoustic (or sonic) tool, as well as gamma ray and spontaneous potential logs to determine the shale volume. In the study area the porosity has been calculated by petrophysical evaluation of logs and correlated with core porosity data.

That was used to develop a porosity model of the reservoir rocks in Hawaz Formation study. A plot of core porosity data from well log data and core data has been used to examine the difference between two methods on porosity (see fig. 6-2 & 6-5). The data presented porosity relation as an example of core and porosity log data over the ‘H’ reservoir. The figures are for one of two wells, which have whole core, conventional core analyses, and a complete modern log suite.

A summary of the porosity and permeability data distribution in the field are given on X-section figures (6-5, 6-6 & 6-7). The samples from wells show greater variations in porosity and permeability, which are a consequence of their higher clay content and the presence of fine martial in the facies. In general, the lower porosity of facies is mainly caused by amounts of clay and cemented material.

A summary of the open hole log analysis for total interval in each well and in each facies are presented on (tables 6-1, to 6-11).

6-6-2-2 Determination of Porosity in thin section

Total porosity observed in thin section varies from 2.5 to 9.5 percent of whole-rock volume, with an average value of 16-17 percent. Secondary porosity composes also visible in thin-section porosity samples. It exists as small intergranular voids. However, in most cases it is difficult to identify primary porosity in thin section, because such textural relations are not present.

Porosity exposed in thin section commonly occurs in variable shape type and vary in size but the intergranular porosity was the common type. Comparing between porosity differences within facies indicated that there is great variation between them. This gives good evidence that the reservoir quality in study area was primarily controlled by depositional fabric especially detrital mud or shale content and the depositional process, than by post-diagenesis.

On the other hand, in the study area by comparing the petrophysical of the reservoir and the rock petrographic characteristic property get; in the medium-coarser grained sandstones facies the main controlling of the porosity is maybe the strength imparted by abundant early diagenetic as quartz overgrowths, and quartz cementation (as in facies five and facies three. But at fine-medium grained facies the main controlling is the sediment texture and detrital clay content, which may reduce both the porosity and permeability in all the formation.

6-6-2-3 Determination of porosity at laboratory measurements

Helium porosity and air permeability for each core plug were measured at the Laboratory, providing data which were used as a basis for petrophysical interpretation and reservoir rock type definition. The compressibility of helium gas was preformed on rock plugs. This method gives the effective bulk porosity and permeability; the measurement by using helium gas method on core rock plugs taken from H27-NC115.

It is difficult to conduct laboratory experiments precisely at reservoir conditions. The clean samples were subjected to various analyses to determine porosity, permeability and grain density values where possible. The main analytical procedure of core samples are summarized below: by using a twin cell helium expansion gas porosimeter for the measurement of the grain volume of the core samples. The porosimeter operates for the principle of Boyle's Law. In the instrument, a sealed reference chamber is filled with helium gas at ambient temperature to pressure of 100 psig. A sample is located in a sealed chamber connected to a reference chamber by a two way valve. This valve when opened allows the gas in the reference chamber to expand into the combined volume of the two chambers. From Boyle's Law, the volume of the sample chamber can be calculated if the volume of the reference chamber, the initial pressure and the final pressure are known. Pressure drop is measured along the core using a quartz crystal transducer.

By determining the bulk volume, and the weight of the sample, the porosity and the grain density were calculated.

The porosity of a plug sample was calculated by using the following equations:

Pore volume = Bulk volume – Grain volume.

Porosity (%) = {(Pore volume / Bulk volume) * 100}

And, Grain density = {Sample weight / Grain volume}

6-7 **Permeability at laboratory measurements**:

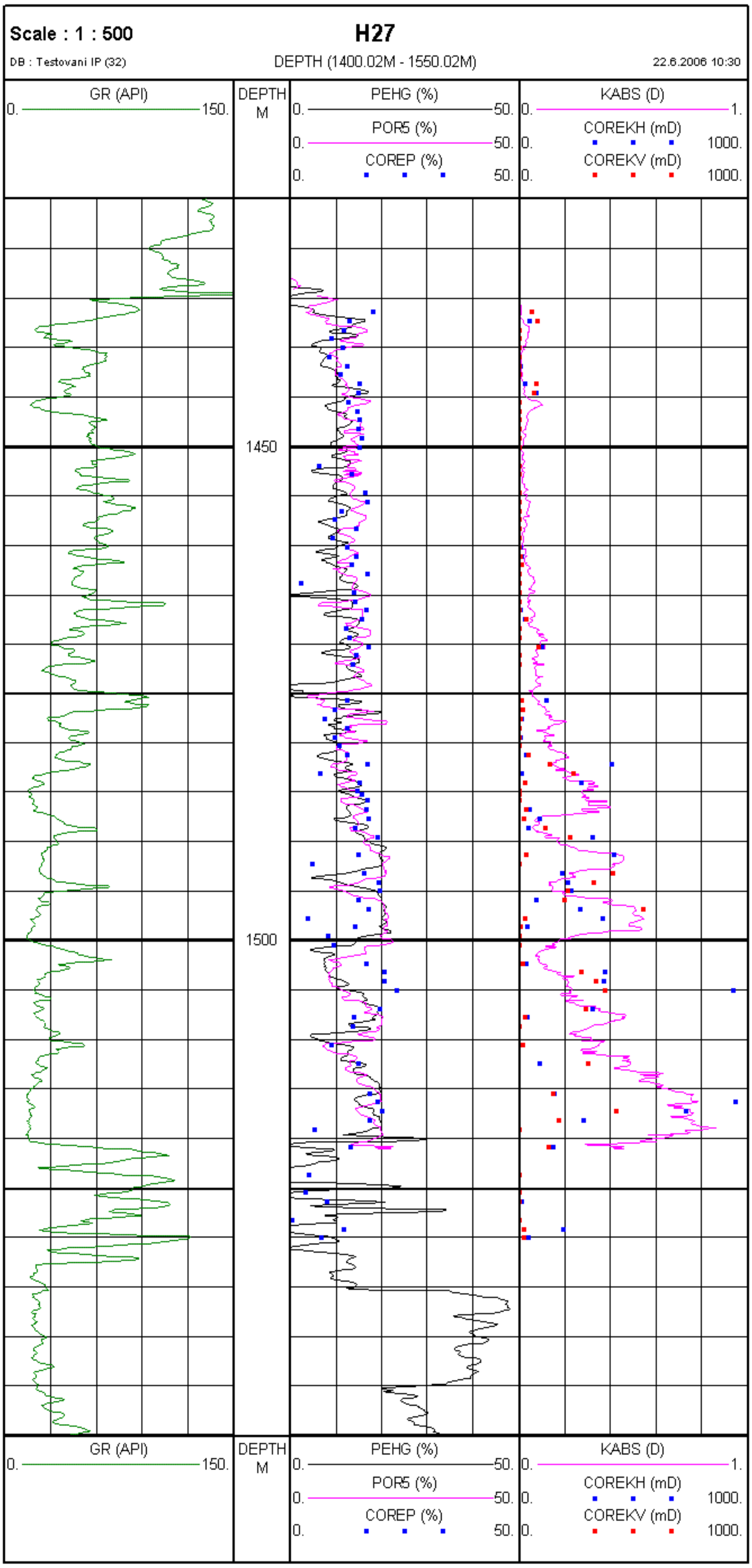
Permeability is the property that permits the passage of a fluid through the interconnected pores of a rock with out damage to or displacement of the rock particles (Leverson, 1967).

Permeability, a key factor in making production decisions in the petroleum industry is usually linked to various properties of porous media, such as the porosity and several structural parameters (Cerepi 2004).

The clean, dray samples were placed in core holder and an overburden pressure of 200 psig applied to the cell. The gas pressure was applied to one end face of the sample, whilst the other end face was open to atmospheric pressure, causing the gas to flow through the sample. The flow rate was measured by passing the gas through and measuring the differential pressure developed across to the other side.

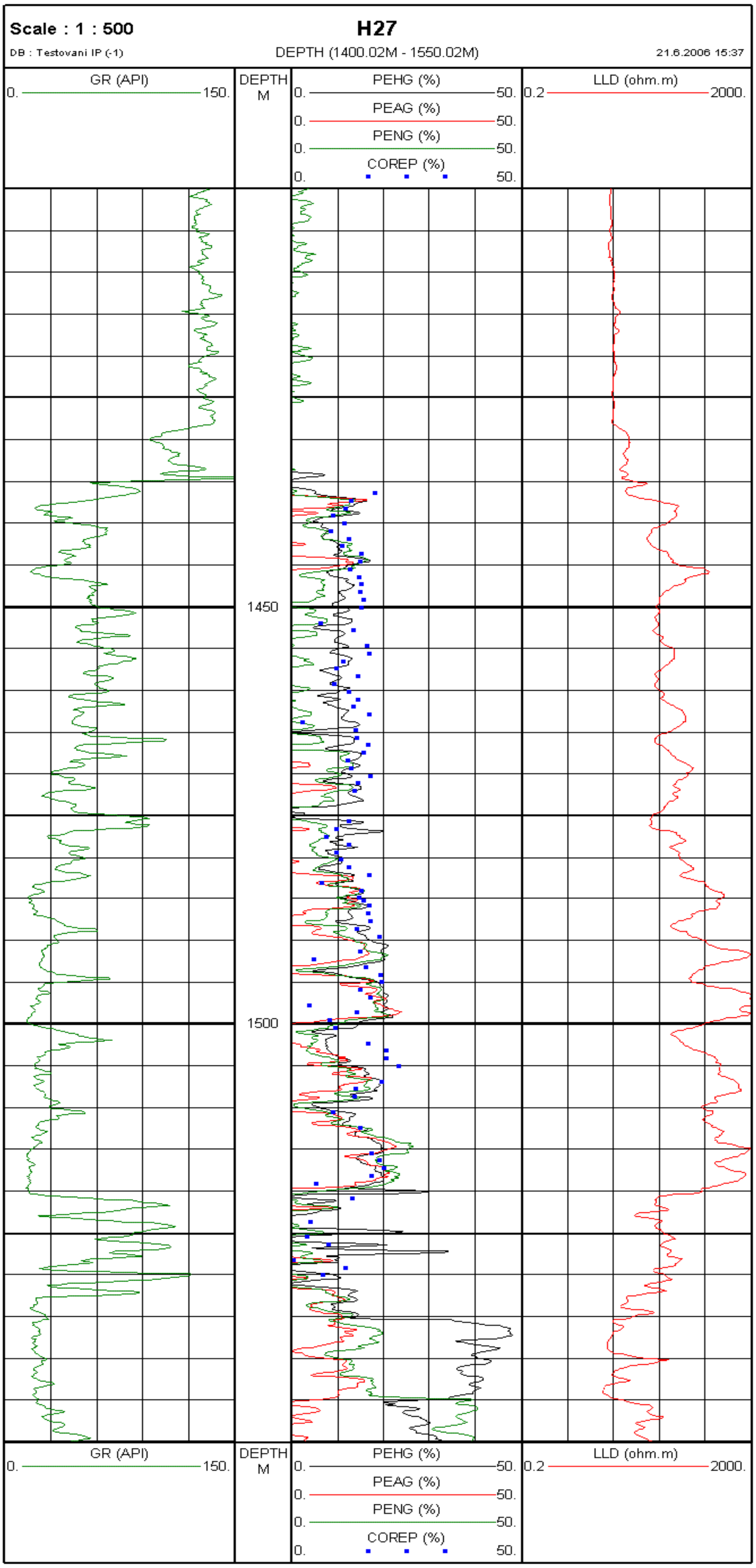
The length of the sample, upstream and down stream pressures, flow rate, viscosity of nitrogen, barometric pressure and temperature were entered into Darcy's equation for gas permeability and the permeability of the sample calculated.

Gas permeability (mD) = {barometric pressure * gas flow rate * gas viscosity * sample length * constant} / differential pressure * cross sectional area.



(Fig.6-11) Showing the relation between the core and logs of porosity and permeability in H27-NC115 (KABS = Absolute permeability in mD), PEHG = Electrical density porosity, POR5 = Electrical average porosity, COREP = Helium core porosity, COREKH =core Horizontal permeability

(Fig.6-11a) Showing the relation between the core and logs of porosity in H27-NC115 (GR = Gamma ray, PEHG = Electrical density porosity, PEAG = Electrical Acoustic porosity, PENG = Electrical neutron porosity, COREP = Helium core porosity, and LLD = Lateral deep resistivity log



6-8 Petrophysical parameter relationships

6-8-1 Porosity and shale volume (Vsh):

In the Hawaz Formation sections studied, the highest aggregated sand thicknesses and reservoir quality are encountered in the facies three and five in the reservoir than any other high values occur in the section see figures (6-1, 6-2 & 6-4). However, this sequence has an average of net-to-gross values up to (97% sand), 16-27% porosity; followed by sections of facies (F1), and (F2) average up to (60%, and 87% sand, respectively) and 15% porosity. The lowest net sand percentages (20% to 25%) are observed in the shaly facies (see table (6-3). However, the net-to-gross values sand-body thickness (i.e. thickness of sand sediment without intervening of shale) is greatest in the facies sections (F5), (F3) and (F2) respectively, but the smallest at the section of facies four (see fig. 6-2).

Nevertheless, the nature and geometry of the sand bodies vary greatly among these associations. These are likely to offer good vertical and lateral connectivity. The strongly bioturbated facies, especially in facies sections (F2), and (F4), which has obscured mostly the original boundaries of some of these compound bodies (and has introduced significant textural heterogeneity).

The relationship between V_{sh} and net sandstone thickness (Fig. 6-2) was based on the standard cutoff value of 20% to 25%.of shales. Values of net sandstone and percentage sandstone derived from these calculations were used as second document for distinguish between sand and shale facies in the reservoir formation. The relationship between Vsh and porosity dominated in the relation plot figures (6-12, 6-13 & 6.14), which showing that the shale volume is the main controlled on the porosity in the formation. This trend has been proved in all wells with same result.

It is therefore of considerable importance the location of clay within a reservoir sandstone must being determined. The shale description in Hawaz reservoir characteristics is therefore largely concerned with the regional distribution of other factors, such as total sand-shale thickness and percentage of sand cementation, together with the geometries, internal architecture and heterogeneity of major sand-bodies and their constituent facies. However, at the reservoir production is controlled with the porosity, permeability and shale contact, or by the facies propriety in Hawaz Formation.

6-8-2 Porosity-permeability relationships:

Porosity-permeability analyses are supporting petrographic and sedimentologic description from the facies successions. Table (6-1) & fig. (6-11 & 6-11a) shows the distribution of porosity and permeability values with respect to depth in each facies.

The relationship between porosity/ permeability in each facies and as all section measurements is graphically illustrated in figures 6-15 & 6-15a. . Both horizontal and vertical permeability of Hawaz reservoir rocks types were used in study. The studied samples, in plot of permeability (on a logarithmic scale) against porosity is not shows a general very strong connection between the reservoir porosity and permeability.

Data analysis for each facies rock type shows that the permeability is controlled by both porosity and other factors including facies shales contents and pore connectivity. In addition to other significant factors controlling porosity as pore throat size distribution and cementation, grain characteristic. Generally, low values of porosity and permeability appear to be occurring at clay matrix, post-cementation, and maybe bioturbation facies. In the lower part of the sandstone, silica cement is dominant in the facies five and reduced the reservoir quality, while in the upper part was limited. (Fig. 6-12 to 6-16) Showing the cross plot for log porosity versus linear (Vsh) shale volume, their distributions and relationship in Hawaz Formation, than the relationship between the porosity and permeability in logarithmic scale.

Table 6-4 shows the summary analysis for main well in the H Field at Hawaz Fm.

Well	**Formation**			**Reservoir**				**Net pay**			
	Top	Bottom	Thic.	Thic.	Θ_{total}	Θ_{Av}	V_{sh}	Thic.	Θ_{total}	Θ_{Av}	V_{sh} Av
H1	1435	1550	115	87	29	15	27	50	27	17	17
H4	1586	1654	68	18	18	14	20	10	17	10	20
H5	1456	1588	132	72	28	16	10	55	25	16	12
H16	1441	1550	110	60	27	14.5	17	40	18	15	16
H20	1452	1570	118	65	26	17	19	64	19	22	18
H22	1463	1568	105	65	15	12.	12	34	14	12	12
H27	1435	1640	202	82	27	17	20	50	27	17	18

(V_{sh} Av = is the average shale volume)

Table 6-5 showing the summary of facies analysis (all values in percentage %):

well	Facies 1		Facies 2		Facies 3		Facies 4		Facies 5	
	ϴ	Vsh	ϴ	Vsh	ϴ	Vsh	ϴ	Vsh	ϴ	Vsh
H1	10	37	13	33	18	10.1	5	32	17	4.2
H4	10	25	9	25	13	10	5	60	10	15
H5	12	40.3	13	22	16	3	8	88	17	13
H16	12	10	12	16	18	3	5	32	18	3
H20	13	40	14	20	17	15	6	70	19	3
H22	8	15	7	37	10	3	32	60	10	4
H27	10	10	12	28	15	3	6	43	17	5

The previous table's calculations were based on:

- O.W.C. for Hawaz Formation = ± - 3350 ft (± - 1021 m);
- The Sw at sub-facies at (Sw cut off Sw < 50%) only;
- Petrophysical parameter used in calculation (n = 1.8, m = 1.7, a = 1, & Rw = 0.372@170º F);
- The cut-off for porosity = 8%, and Vsh = 25%;
- The water saturation (Sw) below O.C.W. is 100% and;
- The O.W.C. is in horizontal saturation and the cut-off of O.W.C (-1005m).

6-9 Generalized structure and stratigraphic of the reservoir:

Several cross-sections as (Fig. 6-5 to 6-9) have been drown through the "H" oil field to detect the main characterizations of the facies distribution, thickness, porosity / permeability, and shale volume in the field. In addition, the structure map of top Hawaz Formation to show the main structure features configuration in the study area (Fig. 6-10). The reservoir structure as shown on map and cross-section is an anticline combined by two faults axis trending north to south, these make the reservoir is mainly a structure and stratigraphic trap type, and are locally or controlled by major fault zones, and by palaeotopographical highs. The structural contour map of the top of the Hawaz Formation is an important feature in terms of reservoir delineation. The oil water contact is determine from well log analysis and from open hole measurements DST (drilling stem test) at ± (-1005 m) DST

All available data allow dividing and documented the Hawaz Formation into five facies which can be recognized in all wells. Facies thickness range from 10-60 m, two from them being the most important and perspective; they are represented by medium to coarse sandstones with well rounded grains with good to fair reservoir quality (as seen in tables and figure above). The facie two contains in addition laminated shaley sandstones of very fine aleuritic sandstone or silty laminations (tables.6-1 to 6-5); Homogeneous sandstones mostly massive appearance with fine to medium grains, including higher content of feldspar, mica and the lower clay matrix at the facie three and five,. These two types of facies represent the Hawaz reservoir potentiality with fair to good vertical and lateral continuity and connectivity. The both facies has typical features by minimum values on gamma-ray curve and relatively maximal porosities.

6-10 Summary and Conclusions:

By using the well logs characterization through the Hawaz Formation to get the logs consistently responses vertically and horizontal continues, depositional trend regime, sequence stratigraphic units and petrophysical parameters. In addition with other data from core and thin section come out with that:

1. The Hawaz formation is may be divided into five facies. Which controlling by deposition process system such as sea level change, or transgressive and regressive succession. This was documented by type lithology for each facies and the upward coarsening sandstones.

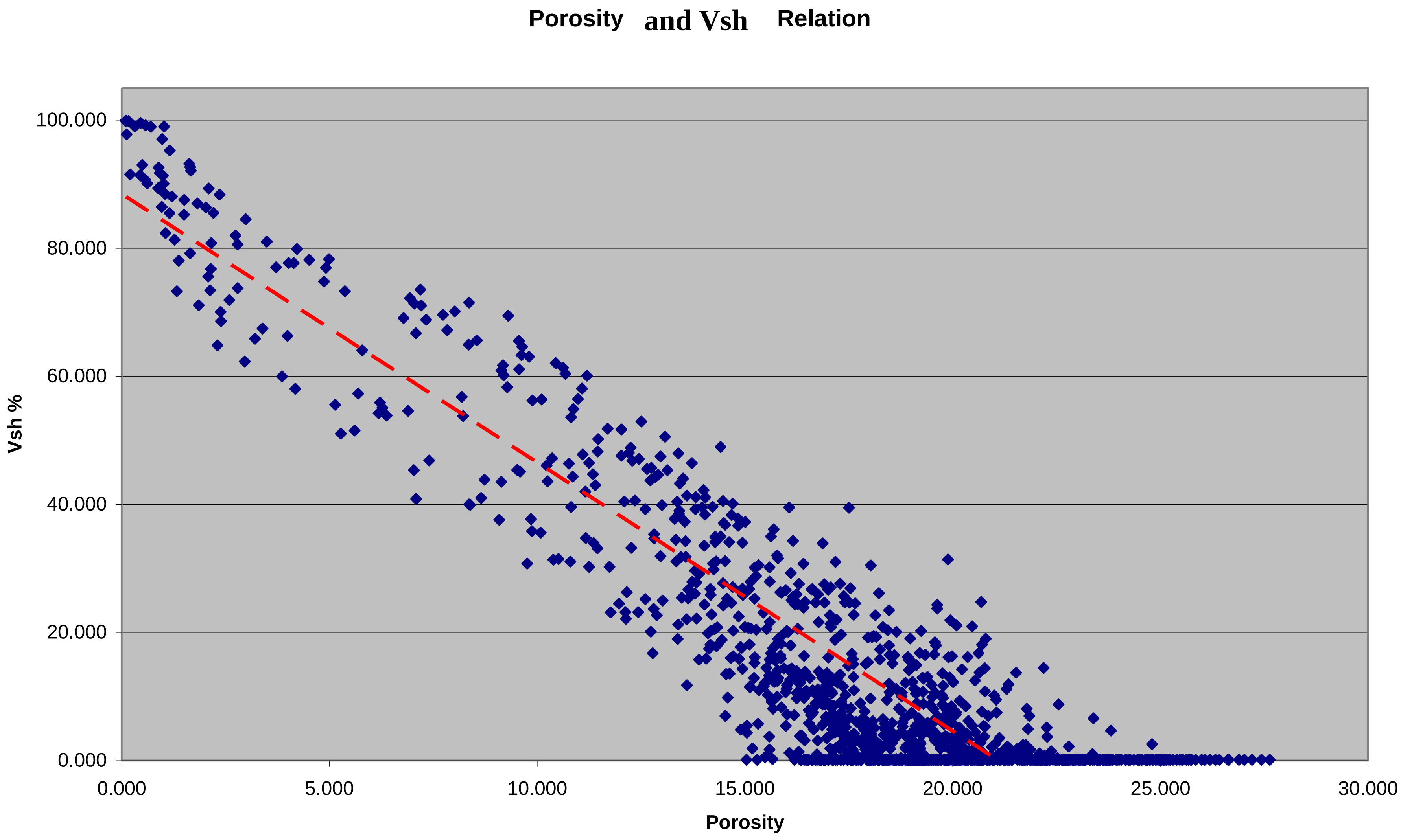
2. The Hawaz Formation in the 'H' Oil Field consists of fine to medium grained sandstone, sporadically appears enrichment by feldspar and/or mica in sediments. Generally the clastic sediments of the Hawaz Formation it is possible to characterize as ranging from weakly calcareous shales (argillaceous) to relatively pure non-fossil fine to medium grained sandstones.
3. The facies has been interpreted based on the sandstone/clay ratio, grain size, wireline log response, dominated structure, and petrophysical character for each facies. The summary of facies

characterization and prosperity were present in tables (6-4 & 6-5) and in (fig. 6-5), those showing in detail propriety for each facies.

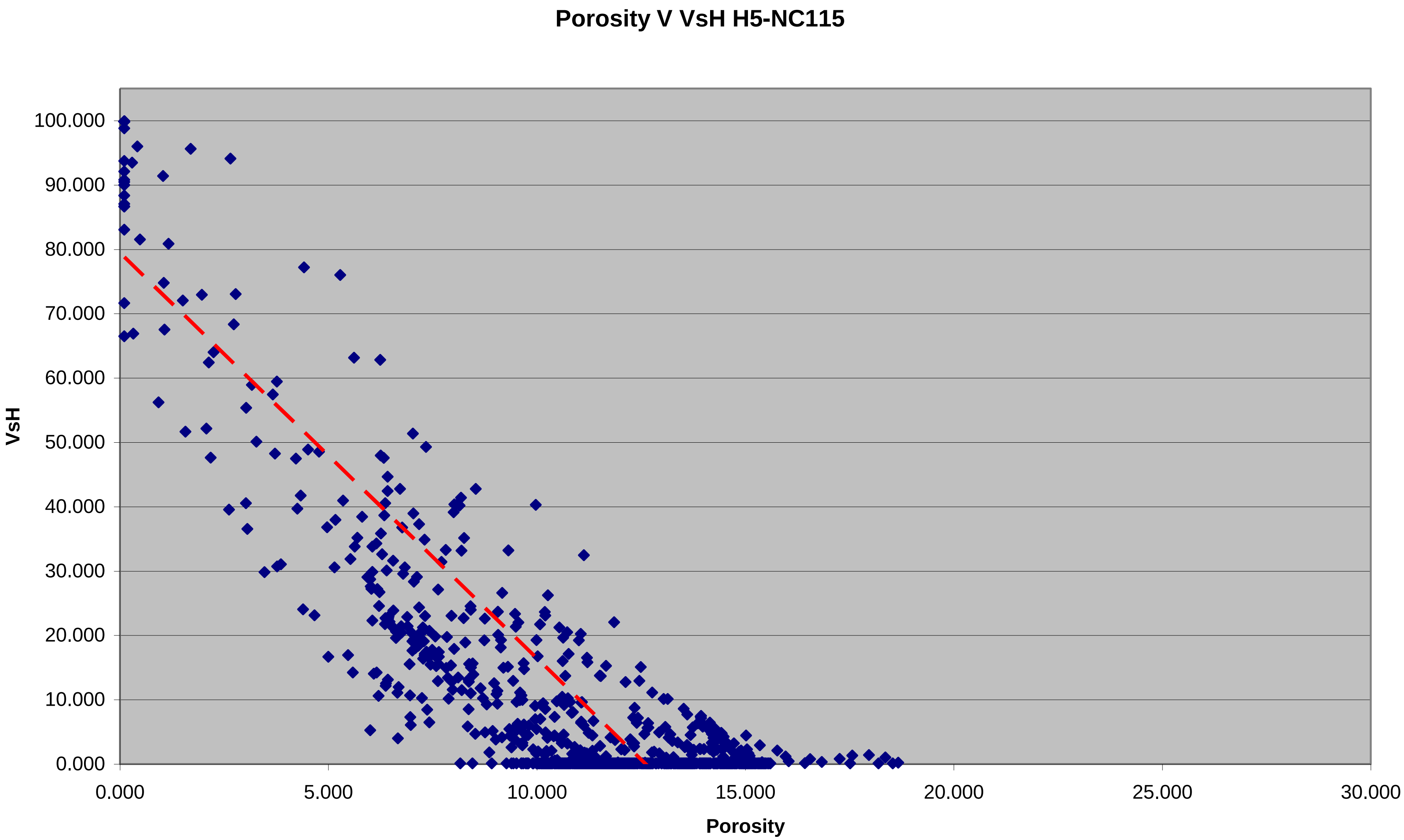
4. However, the study obtainable that Hawaz reservoir sequences have an average thickness up to (160-200 m) with an average net pay thickness (17-27m) in the reservoir. The facies three has about (97% sand); followed by facies one (F1), and facies two (F2) average up to 60%, and 87% sand, respectively. The lowest net sand percentages (20% to 25%) are observed in the shaly facies four (see table (6-3). Sand-body thickness (i.e. thickness of sand sediment without intervening argillite) is greatest in the facies sections facies five, three and two respectively, but the smallest at the deepest deposition section facies four as well.

5. Reservoir quality in the Hawaz Fm in "H" Oil Field was primarily controlled by depositional fabric, especially detrital mud content. The clean sand deposits form the highest quality reservoirs. While the poorest quality flow features were the muddy shaly facies; porosity shows some good reading in the muddy facies. The permeability only improved in those of clean sand facies see (fig. 6-1) at the relation between porosity and volume of shales.

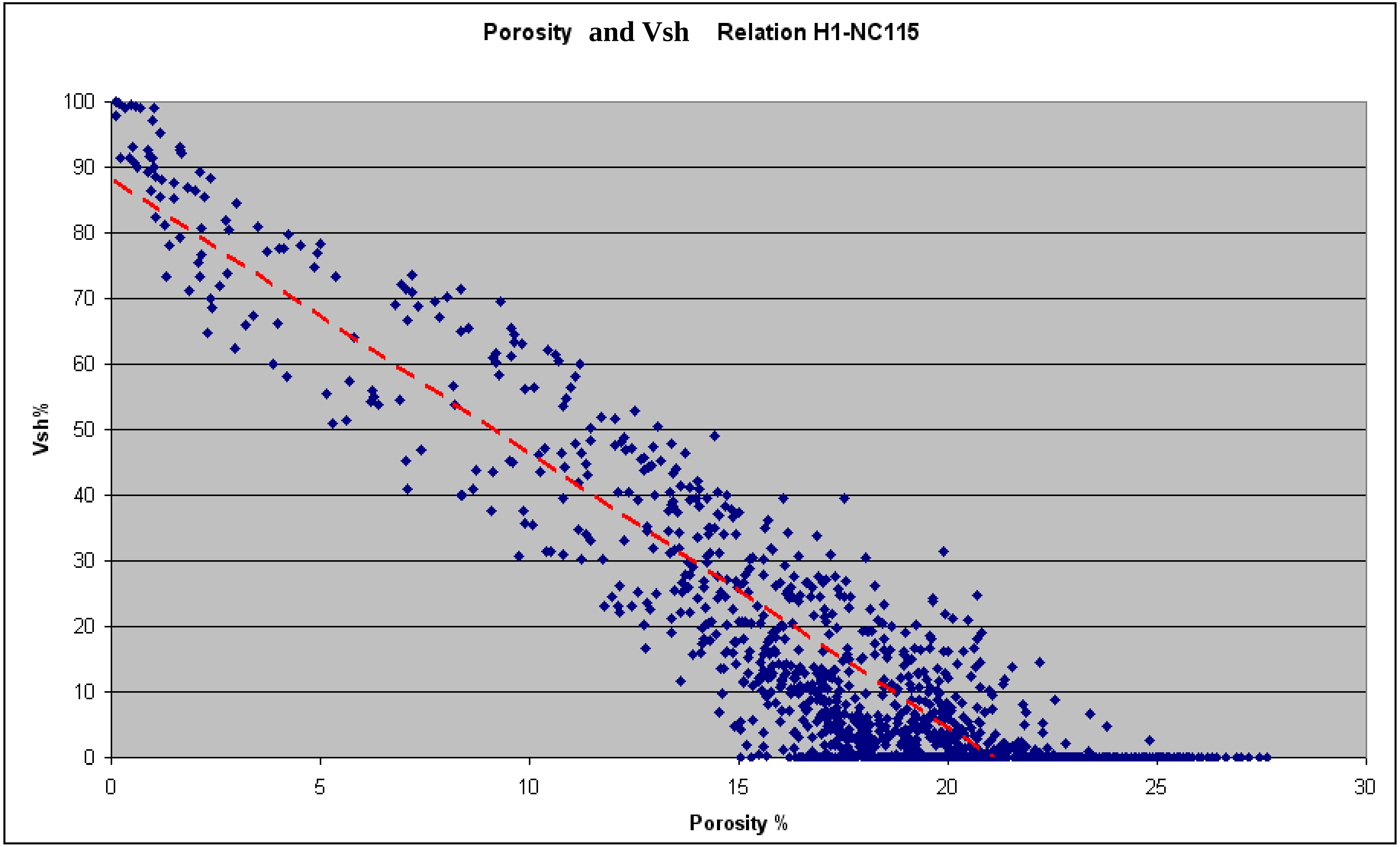
6. In general, the reservoir properties such as porosity and permeability vary greatly from one lithofacies to another. And the determination of these properties without taking lithofacies into consideration is inadequate and may lead to unreliable conclusions. Consequently, it is recommended that the Hawaz Formation to be treated as semi-different sedimentary unit (facies) not as one unit at perforations.



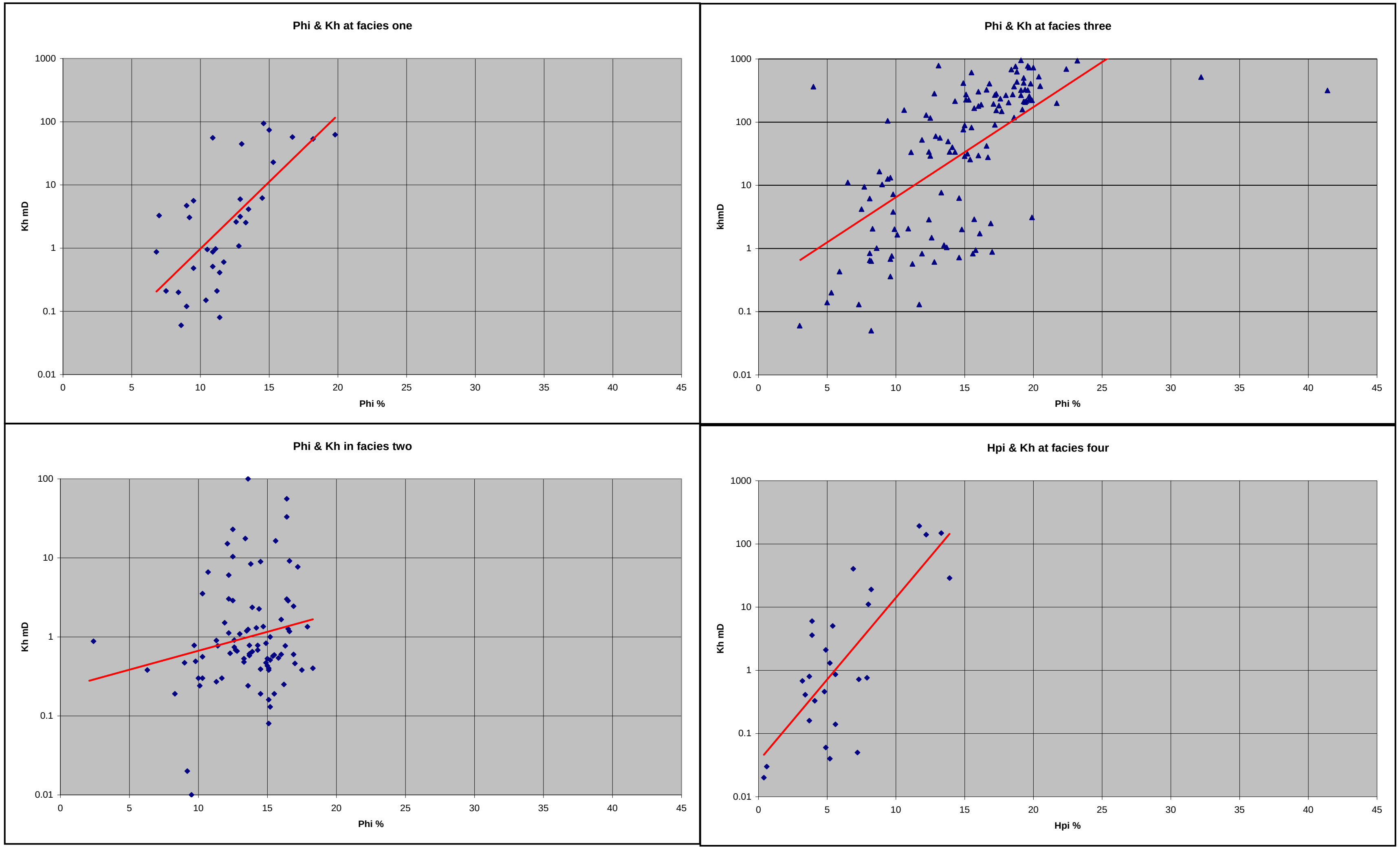
(Fig. 6-12) showing the relationship between the porosity and clay content in the Hawaz formation (well H27-NC115



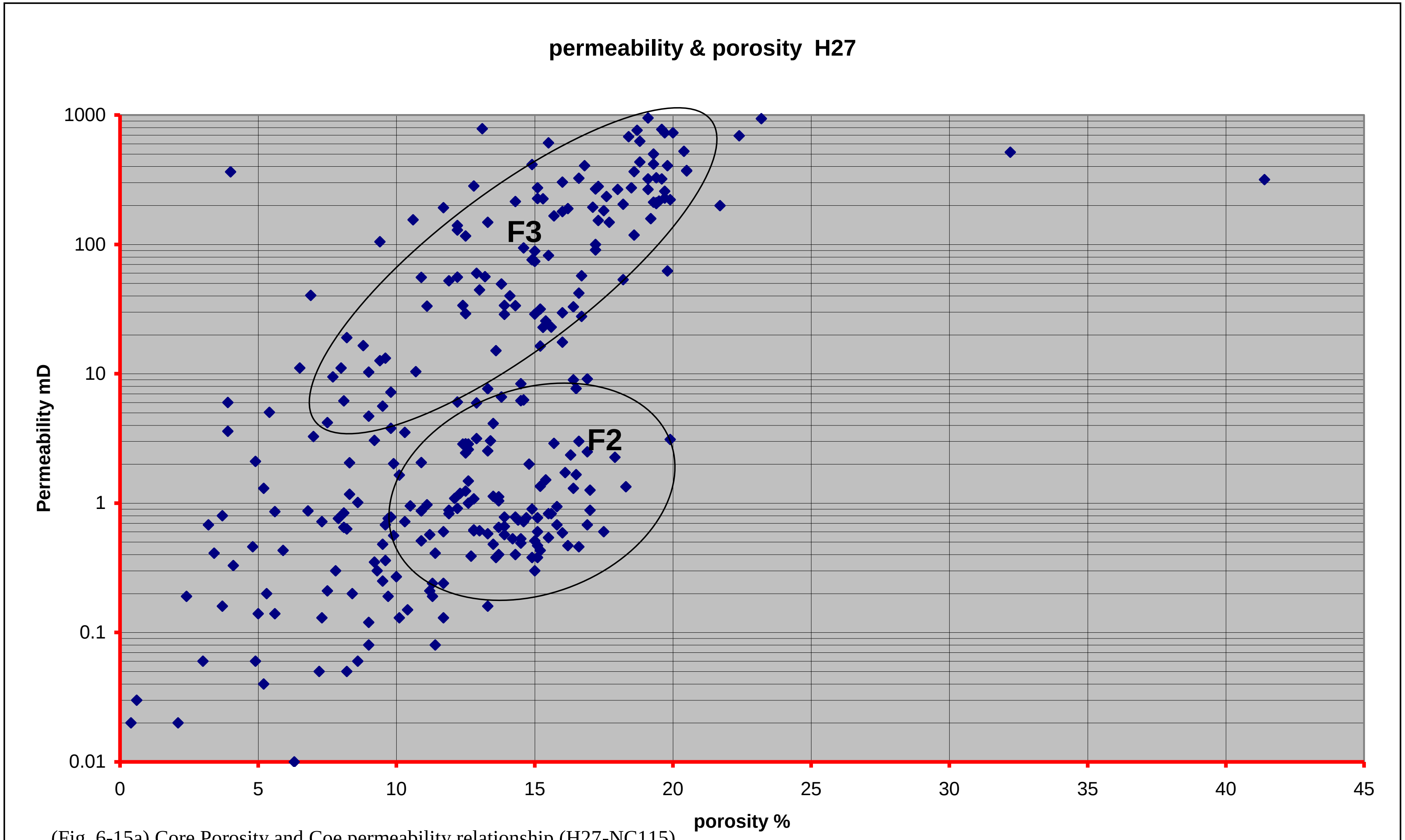
(Fig. 6-13) showing the relationship between the porosity and clay content in the Hawaz formation (well H5-NC115



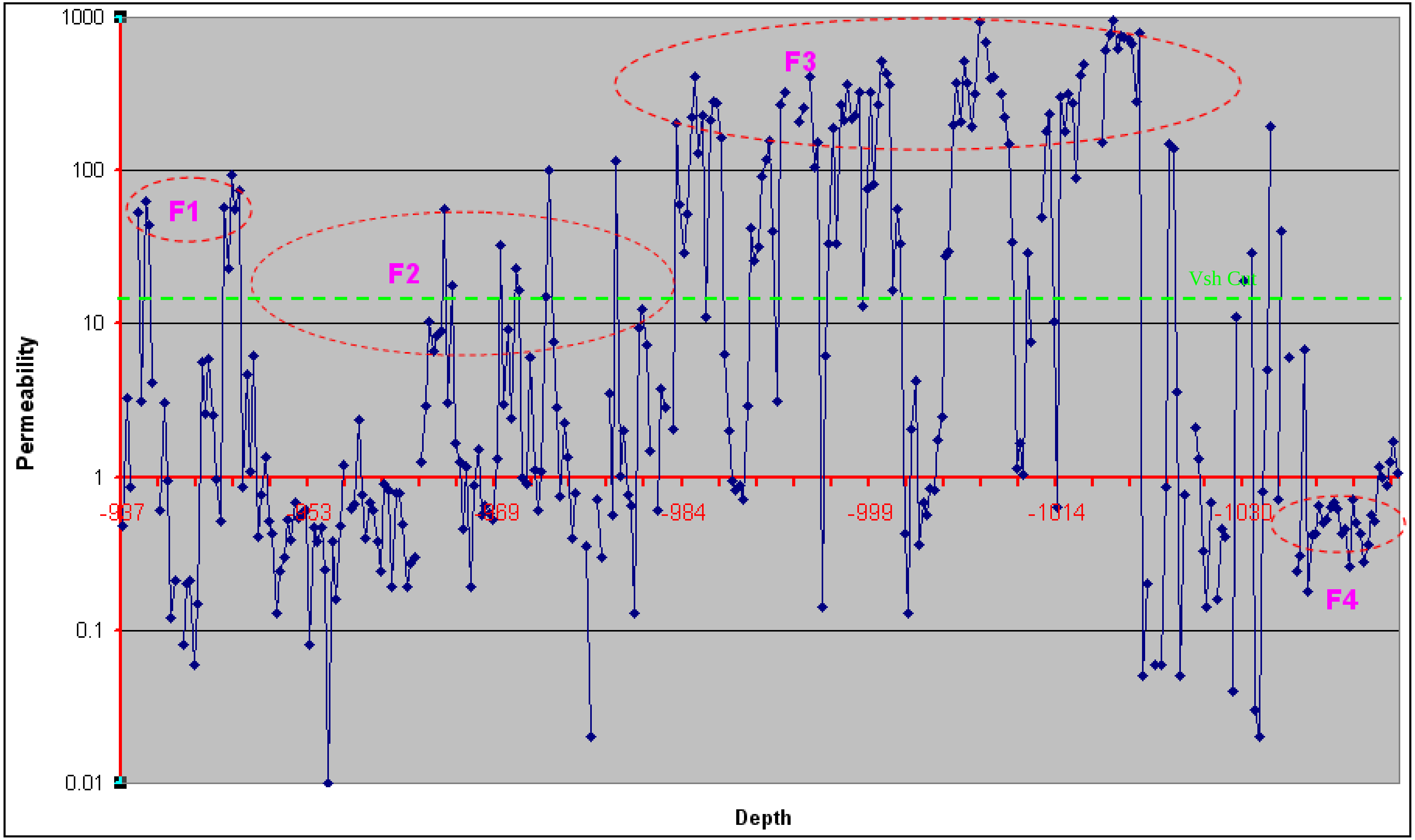
(Fig. 6-14) showing the relationship between the porosity and clay content in the Hawaz formation (well H1-NC115)



(Fig. 6-15) showing the relationship between the porosity and Permeability in each facies (well H27-NC115)



(Fig. 6-15a) Core Porosity and Coe permeability relationship (H27-NC115)



(Fig. 6-16) showing the distribution of the permeability within facies in the Hawaz Fm (well H27-NC115). Note the Cut of Vsh

CHAPTER SEVEN

SUMMARY AND CONCLUSIONS

DISCUSSTION AND SUMMARY

1. The Murzuq Basin of SW Libya is an immature exploration area, which has attracted extensive interest in the last few years since the discovery of recoverable of oil reservoirs. The basin has sedimentary units forming the stratigraphic column with good correlation in the subsurface and outcrops. The basin has been affected by four main periods of tectonic activity uplift, Late Pan African orogeny, Caledonian orogeny, Hercynian orogeny, and Alpine uplift.

2. The Palaeozoic section can be subdivided into three major groups of depositional sequences (Cambro-Ordovician, Early to Middle Silurian and Middle to Late Silurian). The study focuses on Cambro-Ordovician and only on lower Ordovician Llanvirnian/Llandeilian Hawaz sandstones. The Hawaz Formation is one of primary interest predictive reservoir, while the lower Silurian radioactive shale of the basal Tanezzuft Formation is the main source and seal rock within the area. The formation is conformably situated over the Hassaouna Formation and is unconformably overlained in turn by Silurian Tanezzuft Formation.
   A conventional facies analysis was combined with lithofacies, petrophysical analysis to identify facies successions characteristic. The geometry of these sequence and the lateral relationships between the facies successions have been constrained by well log and core analysis. The Hawaz Sandstones Formation is an intensely bioturbated and represents a delta to shallow-marine depositional. Facies analysis suggests that the formation represents progradation of a low-energy, siliciclastic shoreface dominated with beds reworked by bioturbation.

4. All available data allows dividing the Hawaz Formation into five facies which can be recognized in all wells. Facies thickness range from 10-60 m, the facies ranging from massive sandstones body to intensely laminated bioturbated siliciclastic sediments (sandy shale). This is the common features of the formation sediments. The bioturbated facies is upward-coarsening and the composed of friable very fine- to fine-grained siliciclastic sandstones of variable silt content. In addition primary sedimentary structures have largely been destroyed by pervasive bio activity (Tigillites) with regular U-shaped, but where sedimentary structures preserved, they are many wave and/or storm processes recording maybe interpreted. Based on conventional facies analysis of cores and well log characterization the formation consists from the main facies associations as following:

   - Bioturbated Siliciclastic sandstones which is presented in facies four; and characterized by grey to dark grey, highly to completely bioturbated siltstone with thin beds of fine to very fine-grained silty sandstone; common in parallel lamination; and high silt content up to (60–70%). Deposited in marine low energy environment.

   - Weakly bioturbated siliciclastic sandstones presented in facies two and three, characterized by thinly parallel bedded siltstones, cross-bedding, some wavy laminated and fine grained sandstone. The bioactivity in the formation where (Tigillites) as a trace fossils and present vertical and sometimes annulated tubes or burrows is the most common trace fossil found. The facies was deposited in shallow marine environment; in addition, this facies maybe has been deposited in deeper water column than shallower water conditions of massive sandstones facies.

- Massive sandstones represented in middle facies three and five. Which characterized by fine to medium grained sandstones, appear more uniform, with out any sedimentary structures (structureless), slightly upward coarsening in grain size.

The bioturbated siliciclastic sandstone facies association with homogenous massive sandstones beds, which generally indicated to gradational sequenc transitional marine facies. In these transitional marine facies, cross bedded and channelled sandstones typical of fluviatile facies with unidirectional paleocurrents, are interbedded with fine-grained sandsetones and subordinate siltstones. These are horizontally bedded and display a variety of paleoeocurrent directions and trace fossil ichnofacies indicating shallow marine enviroment (Seilacher 1967, & 1969).

5. The petrographic study, XRD analysis, SEM (Scanning Electron Microscopy) and clay fraction results show that the main mineral content of all sampled sandstones are represented by quartz grains, which are associated with various feldspar types, mica (muscovite and biotite), chlorite, and calcite. Additionally, accessory minerals have been recognized, like: zircon, pyrite, and hematite. Since the total mineral content of the sandstones are represented by a quartz at average 70 to 85% and feldspar with an average of more than 20%, whereas the grains are rounded angular - sub-angular; the sandstones are assigned as textural immature and mineralogical moderately mature. When applying thin section microscopy features for composition, an average of approximately 4 - 20% of the total rock is estimated to contain matrix of clay and silt; and higher values present at shaly sandy facies. The main cement of the sandstones is silica-supported with significant proportions and varying amounts of carbonate material.

6. However, the cements are formed during or after deposition and burial process by either physically or chemically digenesis. The depositional of clay in the formation is maybe one of the primary main control vectors on the distribution of quartz concentration, controlling the facies variations, and the petrophysical property of the formation, which in turn depends on depositional facies and environments conditions. When all stayed data coded together give an evident idea that the facies three is appearance the highest reservoir quality. This idea is directly related to the detrital shale content within the facies. The petrophysical parameter was improved when ever the Vsh is decrease. Visibly secondary porosity probably formed during post-diagenesis as from feldspar mineral, which were subsequently dissolved, leaving more space for floods and a residue of clays.
7. The clay is consisting mainly from kaolinite, miner illite and montmorillonite. Nevertheless, the clay minerals in thin section show colorless in piane-

polarized light and grey to dark grey in cross-polarized light, with weak birefringence. The clays partly fill pore space network, which was further modified by cementation process and development as in the lower part of the formation.

8. The principal vertical and lateral variation in clay minerals through the sequence formation is one of important features of the distribution is the high content of clay in the muddy microfacies. The progressive of clay is decrease in abundance in lower units (facies three and five). However, the vertical changes in the proportions of clay minerals in the succession may result from differential flocculation and sec level change or may be due to a progressive change in depositional conditions. The primary clay depositional as revealed by initial clay abundance and distribution shows that the great clay abundance is often associated with the pelagic sediments and the initial environment of deposition (water depth). The facies two and four shows higher clay content than the other microfacies, wherever high content of kaolinite, illite, and montmorillonite is present, although in other facies the kaolinite is only common manorial with very traces for other mineral. Probably because these facies was deposited under deeper, quieter conditions, as suggested also by petrographic evidence (see petrographic work).
9. The lateral variation of clay minerals is attributed to a decrease in the clay contribution in the central part of the field, where less shaly facies existing; and an increase in the marginal areas. This confirms that the surrounding area was deeper setting than the centre. The structural ridge provided more energetic conditions, keeping clays in suspension.

10. Kaolinite is mostly clearly formed and derived by tropical weathering conditions during late Ordovician times, probably from feldspars and mica in local sandstones or volcanic rock to the south (Jabal Tibesti, Akakus or Hagahr massif) see Murzuq Basin map (fig 1-1). In addition, is it may be formed from the alteration of feldspar and mica, since they are very common minerals in the formation.

11. The most important aspect of clay mineral is the ability for water absorption, causing the volume of the clay minerals to increase when they are exposed in the reservoir fluid. Similar to other clays, montmorillonite swells with the addition of water. However, some montmorillonite expand considerably more than other clays due to water penetrating the interlayer molecular spaces and concomitant adsorption. In addition, this can expand by several times its original volume when it comes in contact with water. This is a dangerous type of clay on reservoir petrophysical property; that can reduce or destroyed the reservoir quality of porosity and permeability; because of its expandable nature. Nevertheless, this type of clay mineral is present in a few samples at Hawaz formation, especially at muddy section with minor intensity; particularly at facies two and facies four. However, Clay minerals can cause formation damage and production problems during drilling, production and well stimulation operations.

12. The main diagenetic events were: kaolinite and illite occurs in almost all samples, quartz overgrowths. Diagenetic pyrite, feldspar overgrowths and

bitumen are occurs relatively common especially at low porosity muddy facies. Kaolinite executes either as intergranular precipitations in the finer grained facies or as patches which probably derived from feldspar replacement. The Scanning electron microscope (SEM) has been used in the present study to analyses their composition morphology, textural relationship and growth. The very high resolution obtained in the SEM readily describes the minerals and shows more continuous clay coatings to sand grains in the finer facies. The coarser grained sandstones also have enhanced the reservoir porosity but mostly have been reduced by early diagenetic quartz overgrowths (as in facies five).

13. A summary of Hawaz Formation sections studied, shows that the highest aggregated clean sand (net sand) thicknesses are encountered in the facies three and facies five, the average up to (97% sand); followed by facies one, and facies two average up to (60%, and 87% sand, respectively). The lowest net sand percentages (20% to 25%) are observed in the shaly facies four. As a summary of net sand thickness the greatest net sand thickness is in the facies five, facies three, and facies two respectively, but the smallest at the facies four.

14. The cores and well logs studies provide access to a detailed vertical resolution and lateral continuity to the sequence sedimentary framework. All these different sequence facies have been used to produce accurate interpretations of the depositional character of the sedimentary of the Hawaz Formation. The characters of electric logs reflect in details even the change in grains size, which were easy to calibrate with core samples. The interpretation of the maximum flooding surfaces and transgressive surfaces sediments are correlated with shales volume in the formation by using gamma ray and neutron logs, then established and tied with cores characteristic, then the facies boundaries are identified. The vertical patterns occurrence illustrates repeated cycles of coarsening or fining upwards sediments of the identified facies. These cyclic patterns are identified on the basis of variations in grain size. Regressive cyclic shale to sand bodies of that tends to be coarsening and thinning upward.

15. The calculations of petrophysical parameters are an important variable in the potential hydrocarbon. It has been approved on based of log measurements and core data were correlating and analysis at the same depths. The values of both results are expected to be considerably smaller through most points, and have nearly identical values for both datasets, except a few points reading on cores which showing slight higher reading. This may be indicated that the situation of these samples was not representing the main reservoir conditions. The correlation between the dates which estimated from well logs and core measurements is good to excellent at general values for all facies depth.

16. Wireline log interpretations that have been used to estimate log-derived parameters, such as clay volume (Vsh), Sonic + Density + Neutron porosity, and an average porosity and water saturation, have good quality reasonably in general. However, the average porosity and permeability in the Hawaz reservoir is between (8-18%) and (0- 1200mD) respectively. The logging porosity has an average between 8-18 % at study area center and decreasing

at flank up to 5-12 % only. While the oil water contact is in average ± (-1004) m, this making that all wells in oil bearing zone (see fig. 6-10), and have production possibility, but extremely are depending on the facies and thicken of net-pay zone respecting to oil-water contact.

17. In the last section we focus primarily on well-logging data, and it is analogous to core data reading, and to test whether our electrical data are enough for applicable on other study area. The rock formation is characterized mainly by interbedded deposits of sandstones and shale. The grain size vertical profile in sand-shale sequences was indicated by both SP and gamma ray carves. This profile of grain size, as the clay content in sandstone is increases with decline of grain size. In addition, as the gamma-ray log is sensitive to sand-shale changes in rock formations, it is used as a primary analytical tool in this study. By combining an analysis of logs, the identification of permeable layers and estimation of their water saturation characteristics has been estimated. However, wel1 logs contributed to better resolution of subsurface lithology, structure and fluid flow characterization. The porosity distribution has successfully brought out form well logs, and it indicates a general of higher porosity in the central part of study area and it brings out detailed porosity heterogeneity areas where sufficient well data is available. These are very helpful in understanding the general porosity distribution pattern in the study area for Hawaz reservoirs.

18. At a general, the Palaeocurrent data in the basin is very limited to understanding the environment of deposition which help to dictated the reservoir geometry and shale overlain the sandstone within the study area and even in the basin. More Regional study of the basin is desirable which is important for the basin exploration development.

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Appendix "A"

SUMARY OF THIN-SECTION PETROGRAPHY IN HAWAZ FORMATION

DETRITAL MINERALOGY

Quartz, feldspar and rock fragments

The main framework detrital grains within the Hawaz Formation sandstones comprise a relatively simple assemblage, which shows little variation across the field. Quartz forms 65-90% of the rock and is mostly monocrystalline, fine to coarse-grained Quartzarnite which is poorly moderately to well-sorted, subangler to subrounded. Detrital components are dominated by monocrystalline quartz, but some lithic grains also occur. Polycrystalline grains usually comprise either aggregates of equant grains or metamorphic quartzites. The former include occasional relatively low-grade meta-quartzites. The sandstones are generally sub-arkosic (to arkosic), containing around 5-35% of feldspar. Plagioclase is present mostly everywhere, whereas alkali feldspar, although quite abundant in places and present in most samples.
The polycrystalline quartz grains grade into other metamorphic lithology, especially quartz-mica schist. Granitic aggregates occasionally composed of quartz, also the common diagenetic components are quartz overgrowth, two feldspars and mica, but most commonly containing only two or three of these, also occur. Obvious volcanic fragments, such as aggregates feldspar / orthoclase up to 10% are present with sand size and in a fine-grained matrix. However, we think that volcanic components were a more abundant original detrital component of the sandstones.

Mica and glauconite

Mica is very widespread and appears especially in lower part, where to be ubiquitous in the banded facies (see thin section), where locally it forms over 10% of the rock. The most common mica species is an original biotite. Minor amounts of glauconite (yellow green), and muscovite also occurs.

Heavy minerals

A few heavy minerals observed in most standard thin sections are a stable suite of zircon (in detrital deposits), which are present especially at the mud- siltstones.

Mud

'Mud' matrix is a virtually ubiquitous component of the Hawaz sandstones, so that many are strictly grainstones. The mud occurs in two main forms. One is compact, usually dark-brown and forms discontinuous pellets within the siltstone, mudstone and fine sandy interbeds with sandstones. This grade in size very fine to fine, longer than the core width typically >10 cm and, mostly are up to several millimeters or less in size. Some of these clay fragments are intra-formational.

Next laminated structures of muddy argillaceous; shows widespread development. Detrital clay occludes most of porosity in these intervals. The most clay mineral is Kaolinite and Illitie up to 5-20%. However; the clays play an important role in both the deposition and diagenesis of the Hawaz sandstones.

DIAGENESIS

The diagenesis of the Hawaz sandstones has been reviewed and studied for the main occasional diagenesis. The main phases recognized are:

- Calcite precipitation;
- Recrystallization of detrital clay to form a widespread microporous intergranular;

- Kaolinite /illitic phase; quartz overgrowths and;
- A major phase of cementation and/or dissolution of feldspars.

The extent and significance of the various diagenetic episodes vary from facies to facies and from place to place across the study area. The earliest diagenesis is;

Pyrite

Pyrite is the earliest phases to form. Pyrite is commonly associated with activity in the shallow sulphate-reduction zone and is most conspicuous in relatively argillaceous sediments (including Mudstone and claystones), its formation continued in very small amounts during deeper burial by the breakdown of biotites and other minerals; the pyrite is often associated with the patchy kaolinite, but it is not certain whether this is due to co-genetic formation.

Overgrowths

The most diagenesis is overgrowths; the main phase of quartz overgrowth and minor feldspar, are formed. They are abundant (up to 5-10%), but are widely observed throughout the Hawaz sandstones. Quartz overgrowth development started prior to major burial, preventing compaction in the coarser sandstones where quartz overgrowths are relatively abundant. Quartz overgrowths are generally less abundant in the finer sandstones (facies one and two); it may be that the grain coating clay prevented 'seeding' of quartz overgrowths. In the absence of the additional strength imparted by abundant quartz overgrowths, the finer sandstones have suffered greater grain contact dissolution during compaction. Although such alteration is normally regarded as a later-stage of diagenetic event.

Quarts cement

Quartz overgrowths are the dominant cement phase in clean sandstones. They are present within the sandstone fades, although restricted where microporous clays is abundant. Some early overgrowths are probably related to feldspar dissolution, but the main source is associated with pressure solution between grains at depth. It is observed between adjacent quartz grains and particularly intense where thin clay occurs or mica between the grains

This authigenic silica and ferroan are banded fades; they are may be derived largely from pressure solution promoted. Textural data from thin sections indicate that this pressure solution began at a relatively early stage and had reduced porosity considerably, in zones where it occurs, before the precipitation other sources of silica within the Haouaz sandstones.

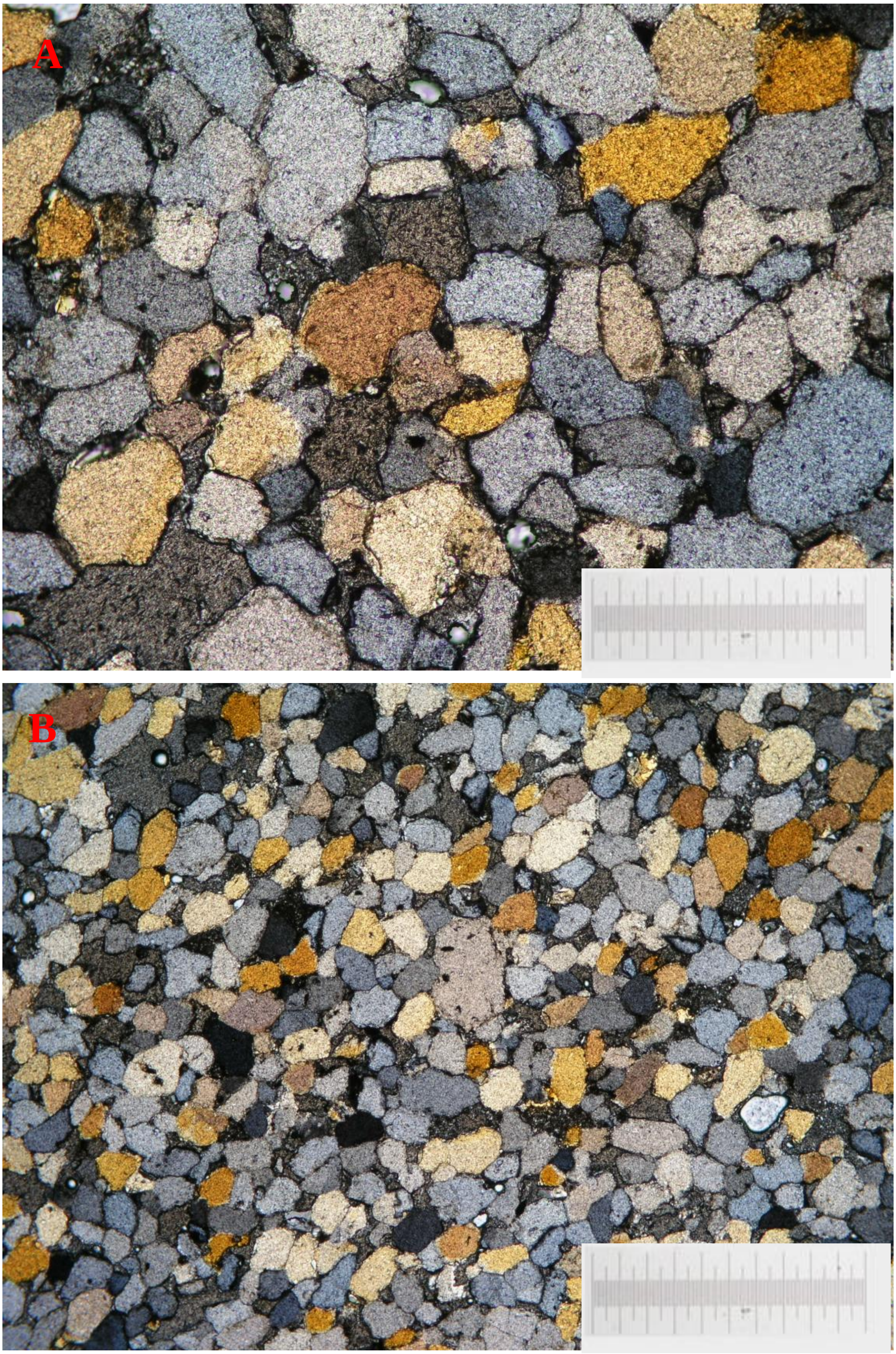
The cement varies from a minor patchy phase, to some pervasive cement forming 5-8 % of the rock; concentrated in originally more permeable zones, and towards the tops and bases of sandstone beds adjacent to shales and other depositional interfaces.

This gives the samples a hard, compacted appearance and seriously reduces reservoir quality.

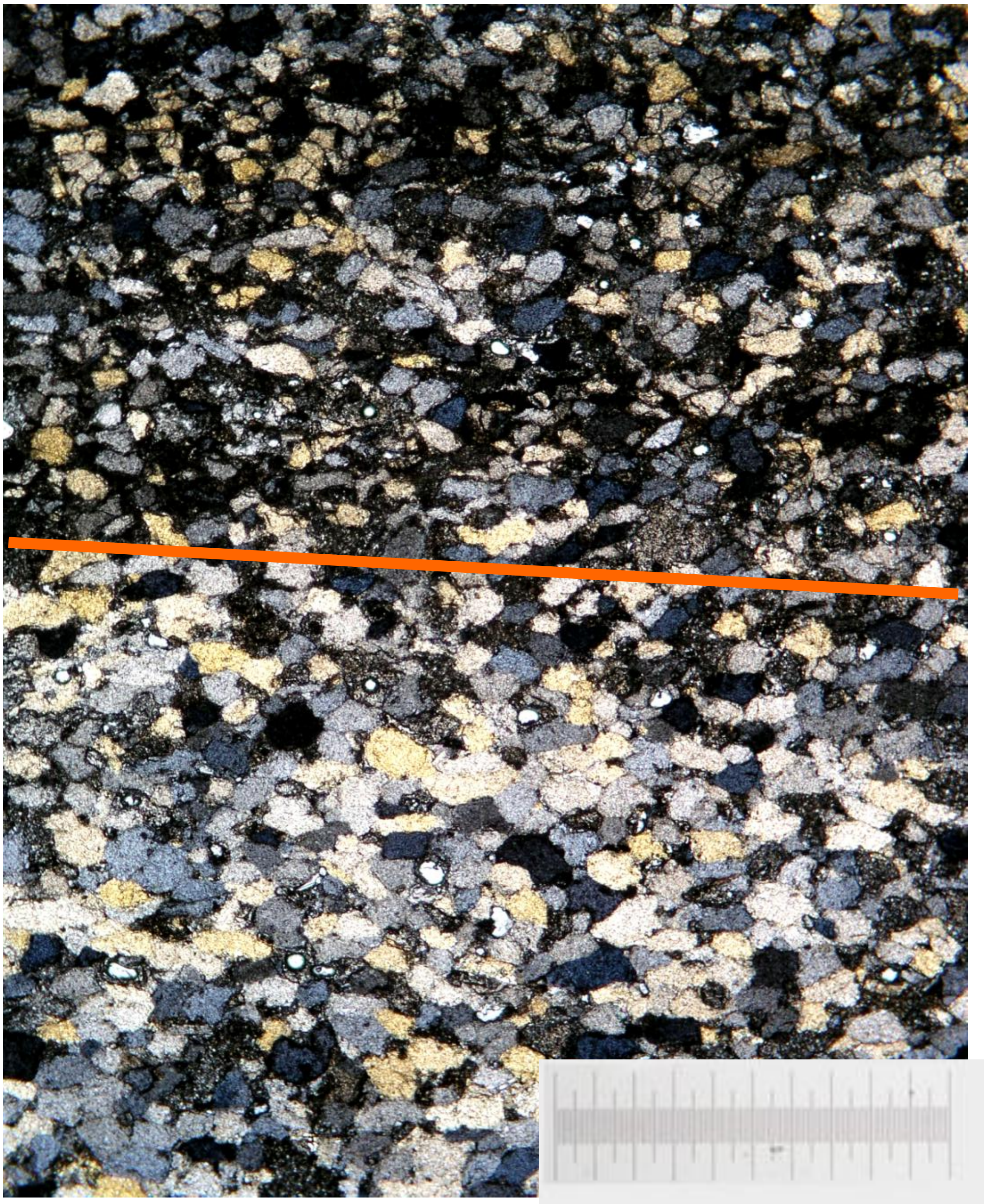
Porosity development

The main effect porosity has been reduced in the coarser grained sandstones because of the strength imparted by abundant early diagenetic quartz overgrowths or other process of diagenesis; as silica cementation or compaction. However, other diagenetic of porosity development is comparatively minor as dissolution of lithic and feldspar grains.

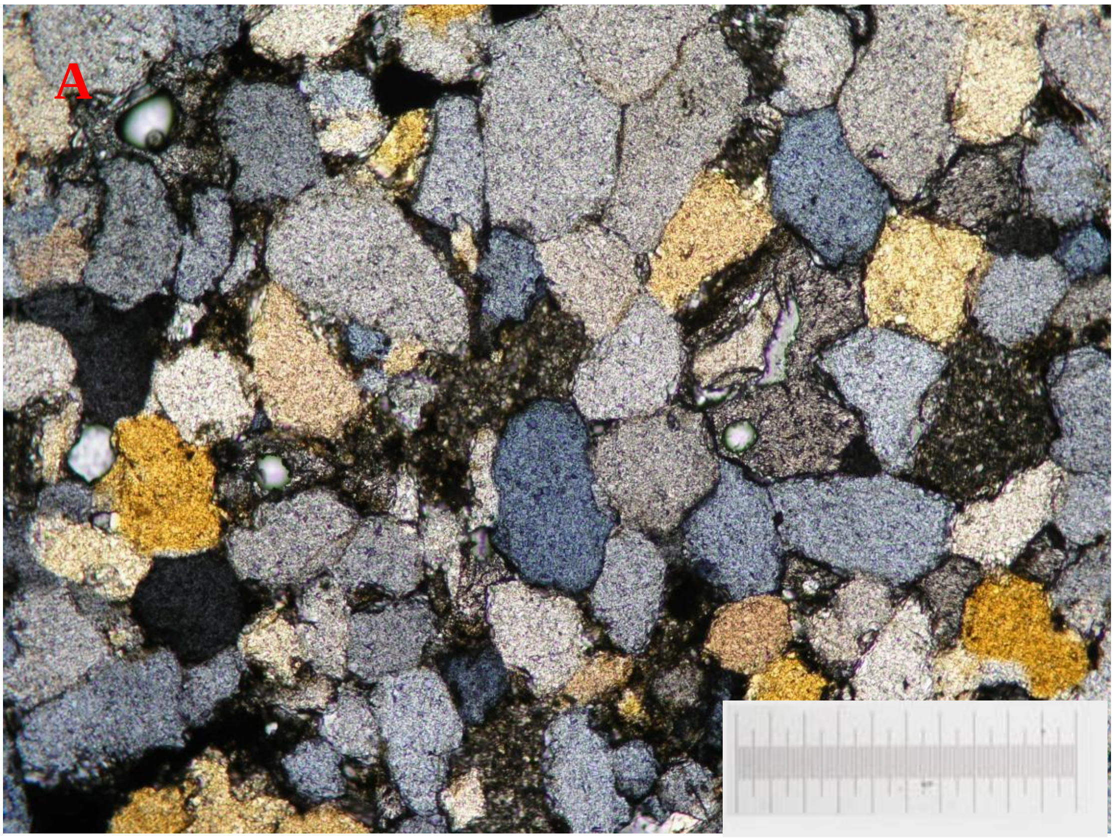
The samples of thin section and also on the core slab analyzed, shows increasing of porosity and maybe permeability with increasing of grain size. The relation of coarser grained facies is very important to successful exploration for producible hydrocarbons in the area.
Some example of thin section with very briefly description at deferent depth showing common factures in the Hawaz Formation "H" Oil Field Murzuq Basin.



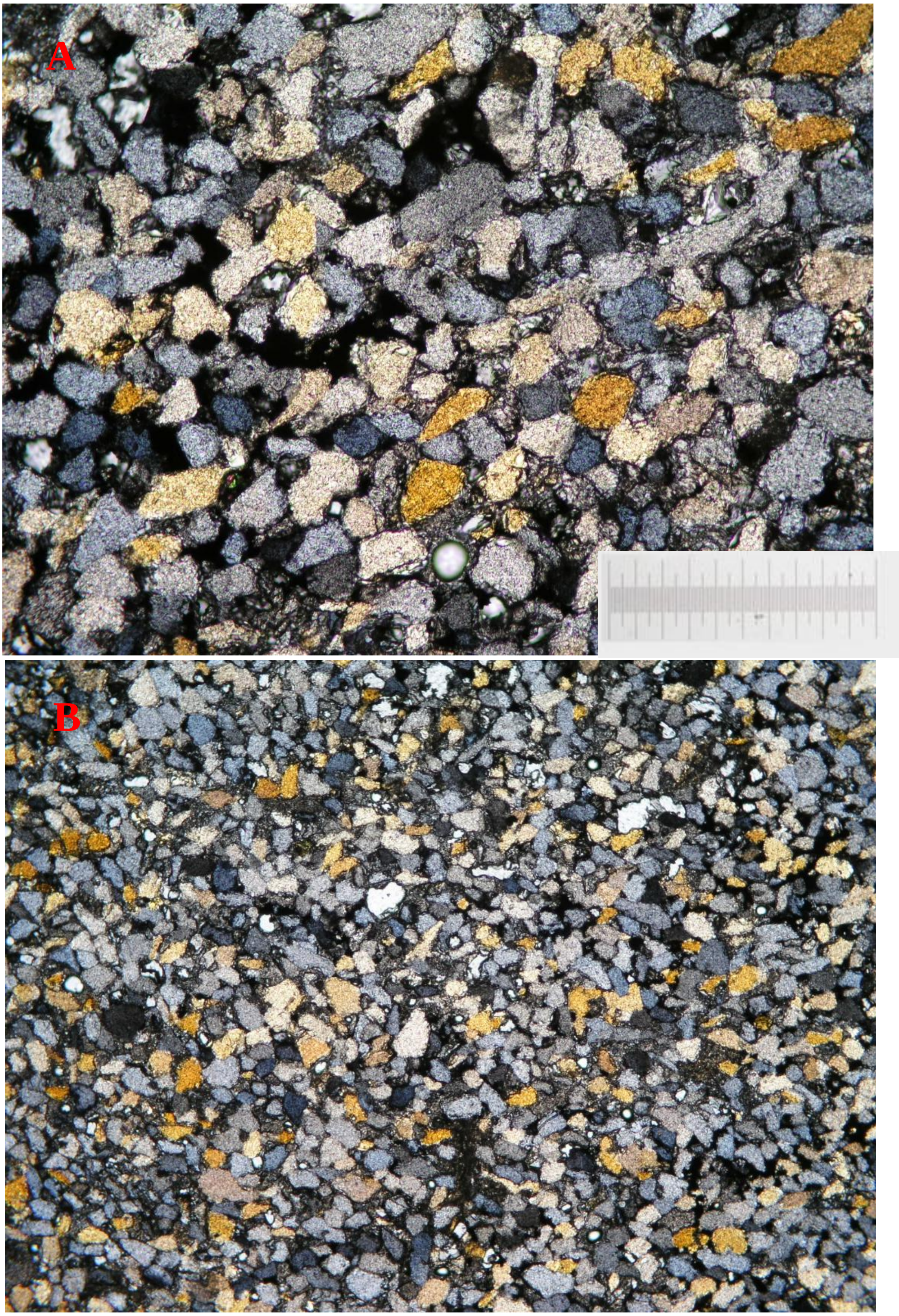
(H5-NC115) 48333 (-3219) ft; -981.12 m at crosse polarizers and 10X & 4X. Quartzarnite: monocrystalline fine to medium; fair to well sort quartzes grained. The detrital grained are clay mineral and fine crystal as matrix material. Pyrite is present.



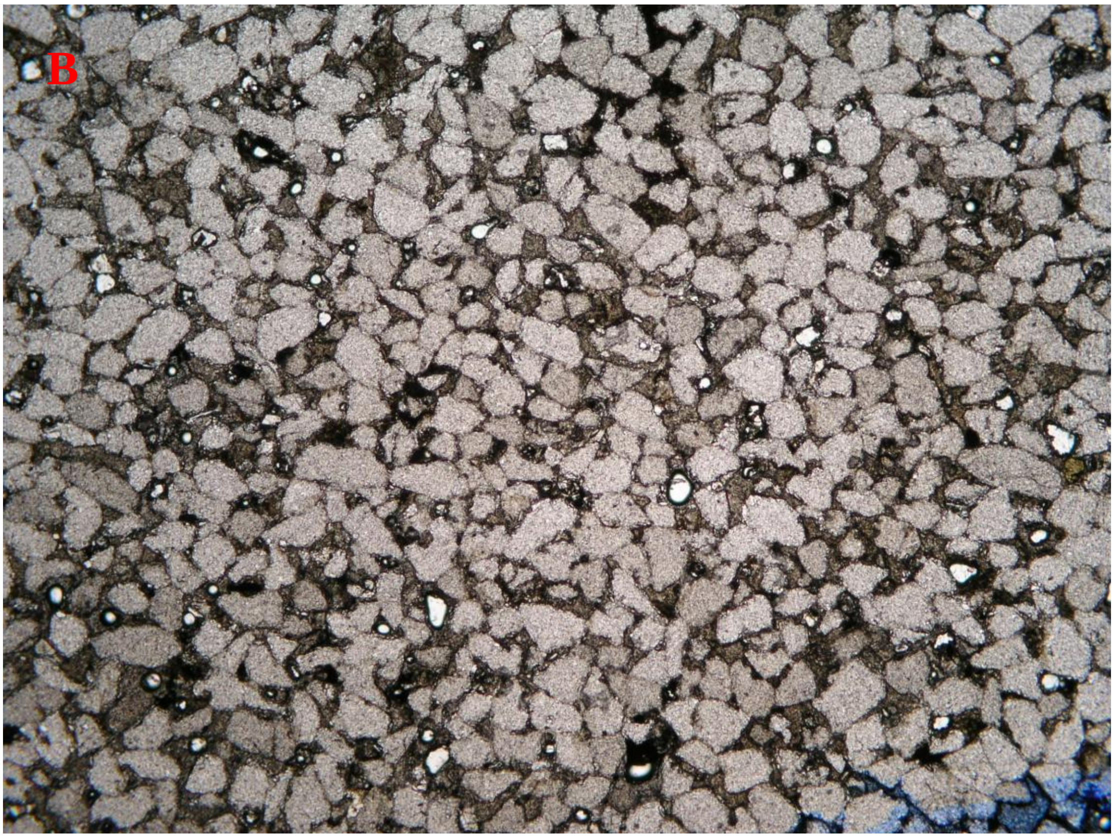
5188(-3580) ft; (-1091.184) m. at crosse polarizers and 4X
This thin section from transition zone between two lithofacies upper section in muddy sandstone where higher fine material with clay material is common, and the lower zone is more cleaner facies of sandstones better sorted grained quartzes.



4825 (-3211) ft; -978.71 m; at crosse polarizers and 10X
Quartzitic sandstone, fine to medium; fair to well sorted single crystals grained; with calcite and clay matrix mineral. Feldspar and pyrite are present. Good porosity (>10%).

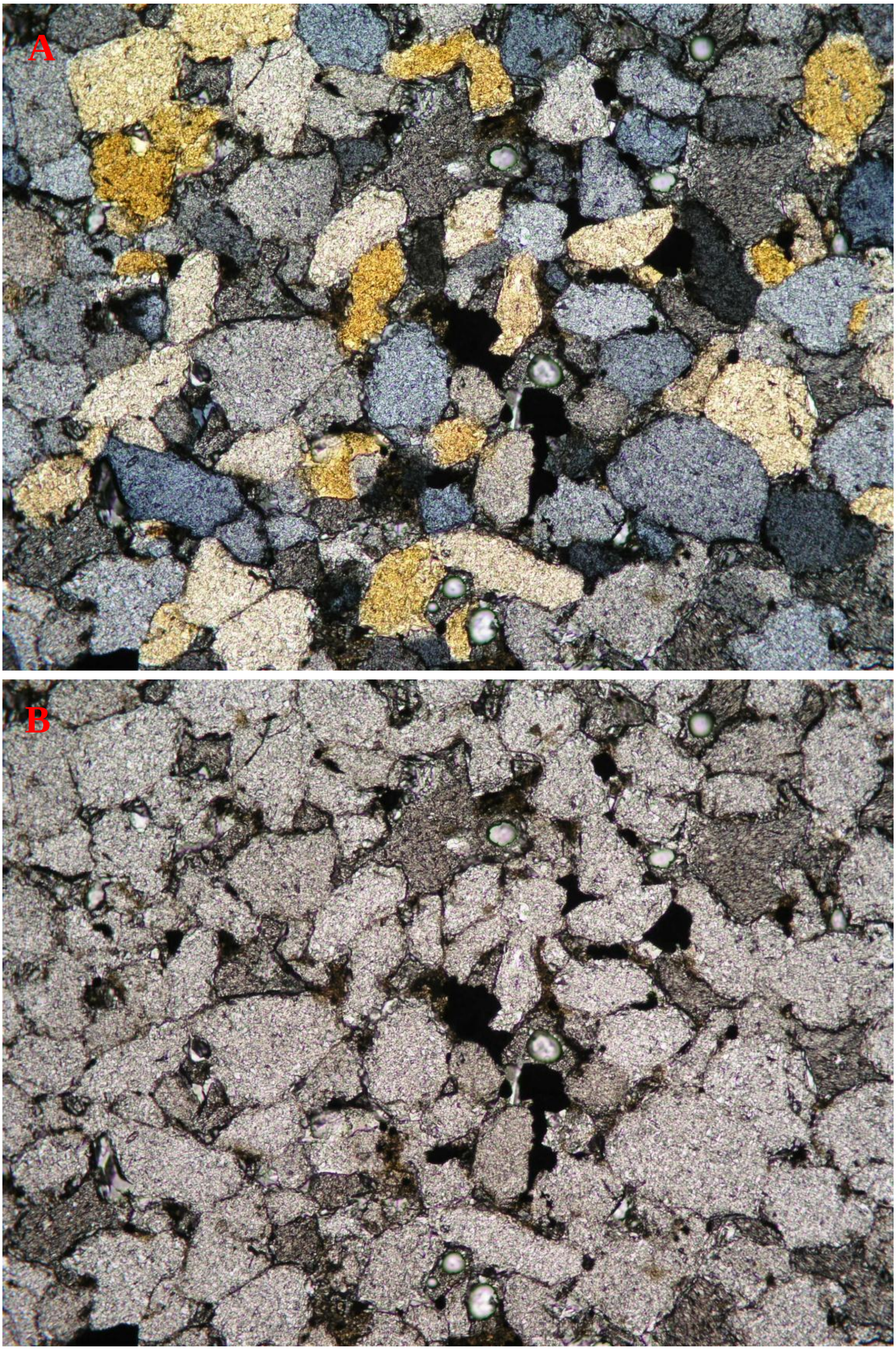


H27-NC115 5428(-3820) ft, -1164.34 m; at crosse polarizers and 10X, 4X. The thin section consist of fine to medium-grained; poorly sorted quartzes sandstones; with clay in derided components; also redeposit fragment material are present.

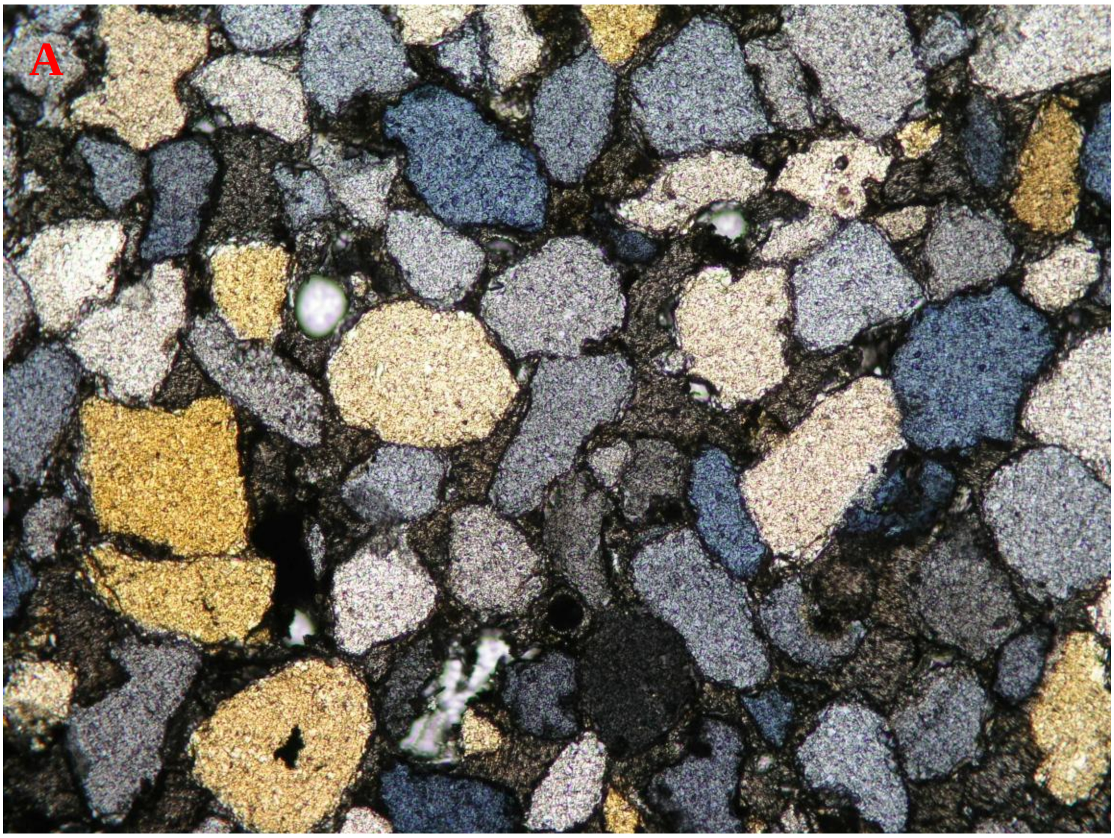


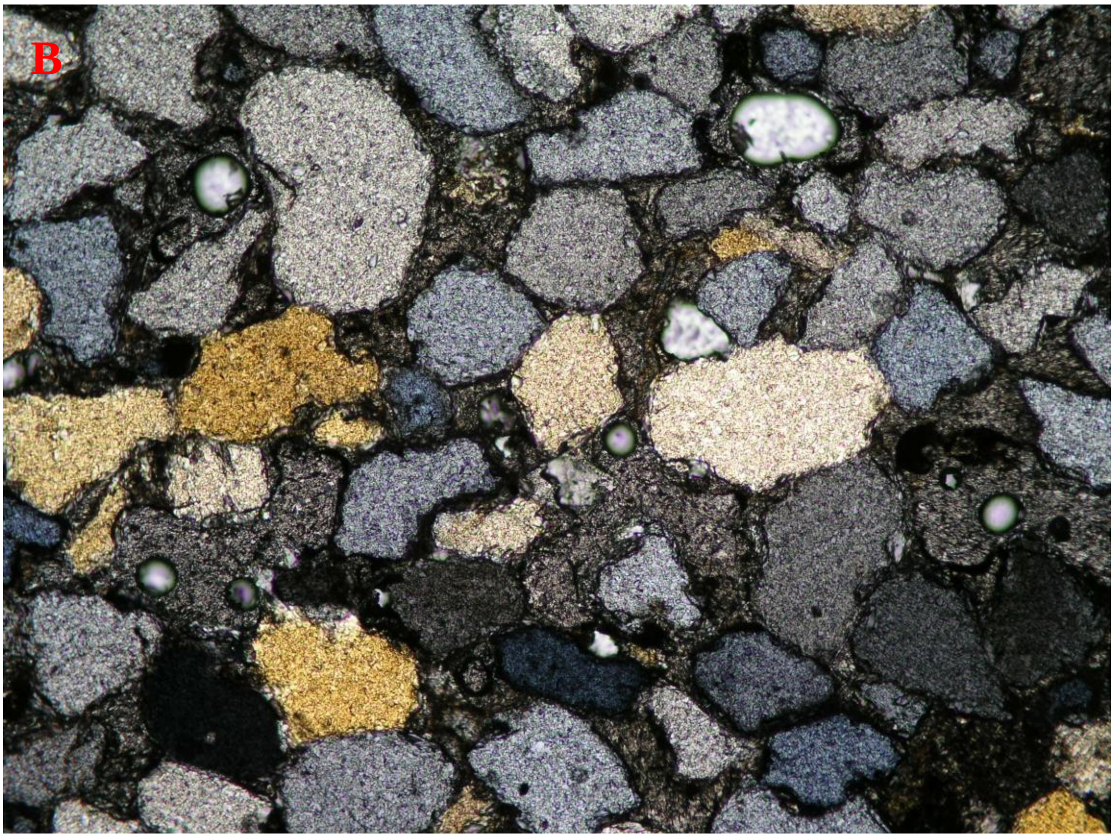
4978(-3370) ft; -1027.18 m; (A) at crosse polarizers and 4X
Rounded to subrounded and subangler quartz grains; fair to good porosity; but some pores are filled with silica and clay or fine material; also with fair compact fabric of grained which reduced the porosity in general. Feldspar and Pyrite are present.

4962 (-3290 Ft); (-1002.79) m; (A) at crosse polarizers and 10X
Quartzarenite under Crosse polarizer, showing pure sorting of quartz sandstones (>85% quartz), maybe representing reworked sedimentary deposits. In addition, The subrounded quartz grains main grains and cemented by clay silica and quartz overgrowths around individual grains and around some original grain boundaries is common; good porosity.



4948 (-3340 Ft); (-1018.03) m; (A) crosse polarizers at 10X Subrounded to subangler monocrystals quartz grained; are in a matrix of spray calcite cement and fine clay material t; poorly sorted; some opaque mineral (probably pyrite) are in a matrix; with minor ferromagnesian minerals; also a trace amounts of several other heavy minerals



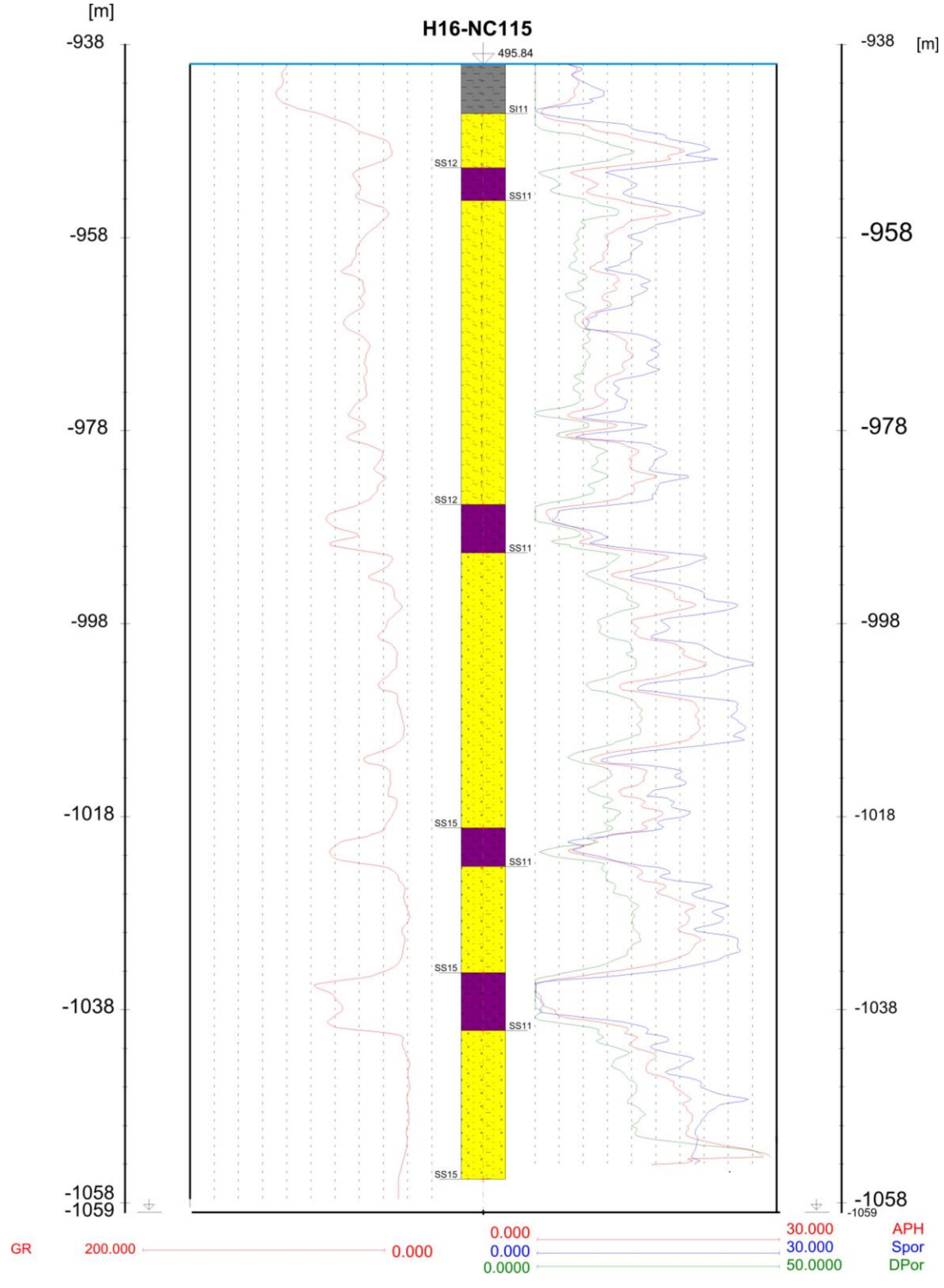


4938 (-3330 Ft); (-1014.98) m; crosse polarizers and 10X; Subrounded to subangler monocrystals quartzitic sandstone; with more clay matrix than above section; well to poorly sorted; good porosity; pyrite is present.

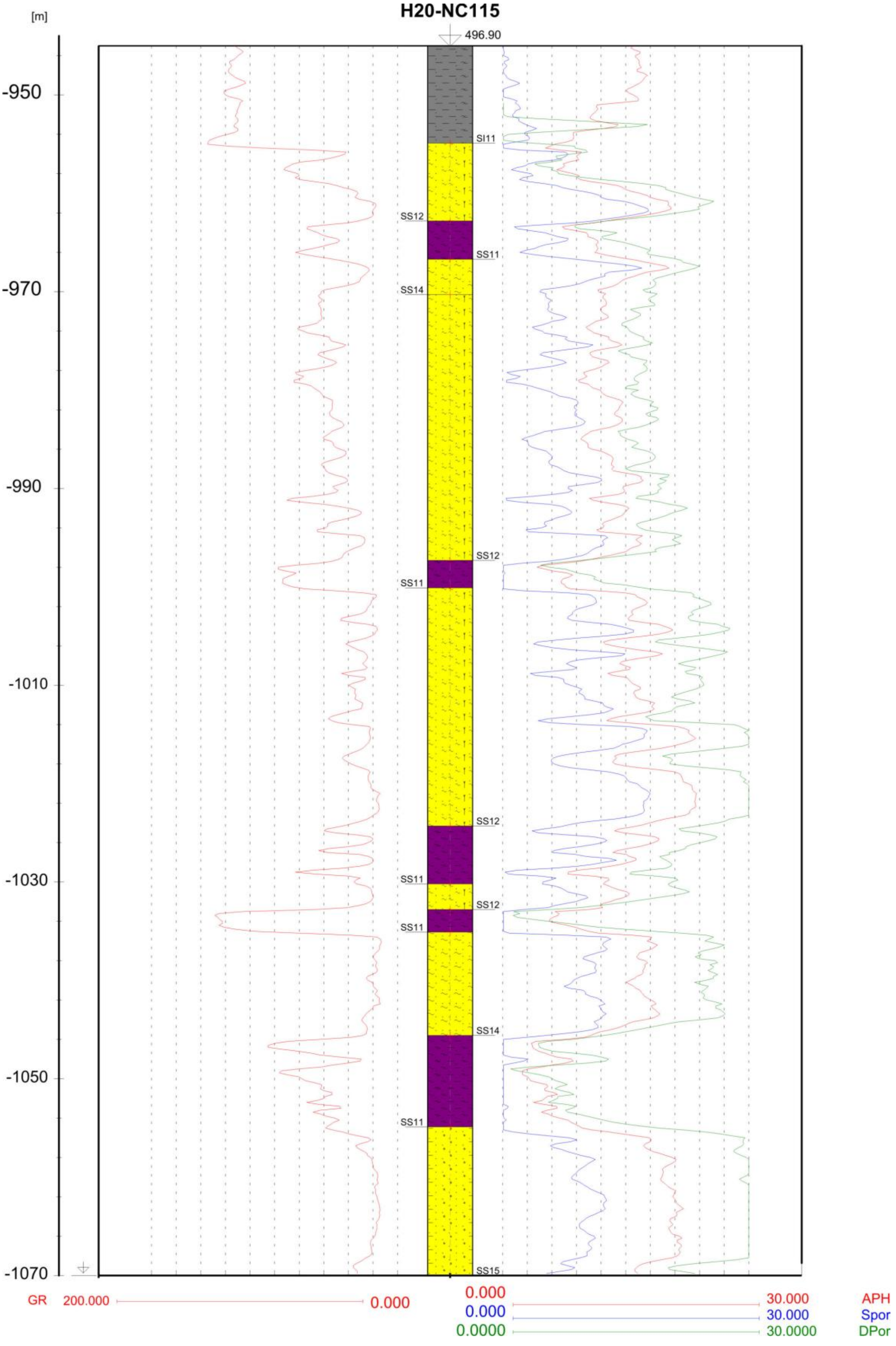
4920 (-3312 Ft); (-1009.50) m; (A) H27 crosse polarizers and 10X; and (B) H5-NC115 at depth 1523.3m and 1524.5m Sandstone (with mica); a fine to medium angular grained of quartz and feldspar. Narrow flakes of mica, (see in medal) and slightly crumpled, lie on bedding planes.

Appendix "B"

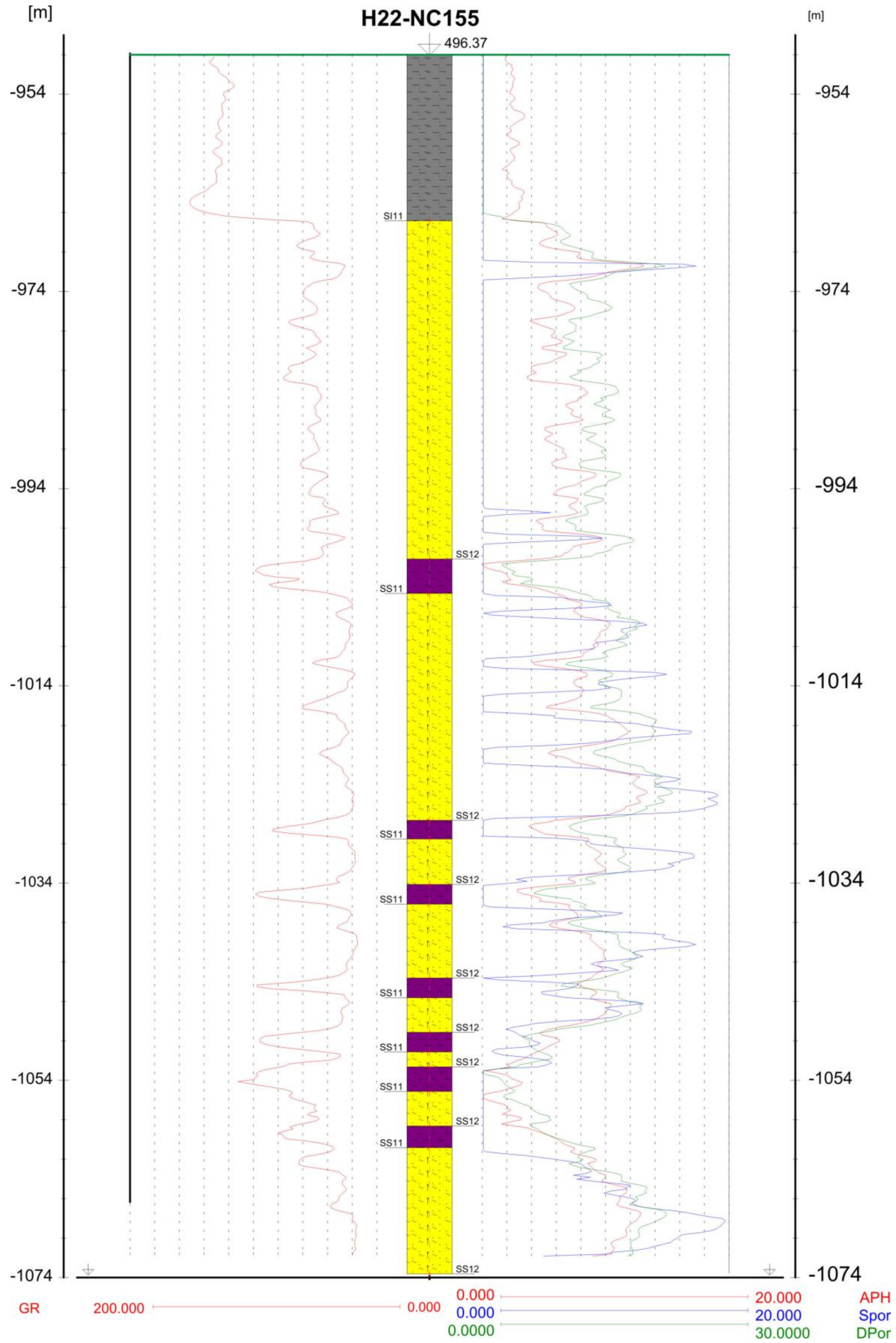
POROSITY LOG ANALYSIS



H16-NC115
[m]
495.84
SI11
SS12
SS11
SS12
SS11
SS15
SS11
SS15
SS11
SS15
-938
-958
-978
-998
-1018
-1038
-1058
-1059
GR
200.000
0.000
0.000
30.000
APH
0.000
30.000
Spor
0.0000
50.0000
DPor



H20-NC115
[m]
496.90
-950
-970
-990
-1010
-1030
-1050
-1070
SI11
SS12
SS11
SS14
SS12
SS11
SS12
SS11
SS12
SS11
SS14
SS11
SS15
GR 200.000 0.000
0.000 30.000 APH
0.000 30.000 Spor
0.0000 30.0000 DPor


H22-NC155
[m]
[m]
496.37
-954
-974
-994
-1014
-1034
-1054
-1074
SI11
SS12
SS11
GR
200.000
0.000
0.000
20.000
APH
0.000
20.000
Spor
0.0000
30.0000
DPor