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# Characterization of reservoir rock types in the upper rudeis reservoir rocks, Gulf of Suez, Egypt

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## ABSTRACT

*Identifying reservoir rock types and their most significant vertical and horizontal heterogeneities is an essential component of reservoir characterization process. A reservoir classification and rock typing study were carried out on the Upper Rudeis reservoir rocks (Asl and Hawara formations), of a mixed siliciclastic and carbonate lithology in the Gulf of Suez, Egypt, by integrating both large-scale geologic elements and small-scale rock petrology with the physical rock properties for the studied reservoir. The work-flow in this study integrates multiple data evaluation techniques and multiple data scales using a core-based rock typing approach supplemented by well logs that is designed to capture rock properties characteristic of Upper Rudeis reservoir rocks. The results reduce uncertainty and allow a better definition of the vertical variability distribution of petrophysically constrained rock types within the sequence stratigraphy constrained correlation and deliver cyclostratigraphic data of depositional facies interpretation.*

**Key words:** Rock typing, Reservoir characterisation, Core analysis, Petrography, physical properties, petrophysics.

## INTRODUCTION

The concept of rock typing is not new to the petroleum industry. In fact, the petroleum literature is replete with papers describing rock type techniques for conventional reservoirs, [1-10]. The most widely quoted definition is often attributed to [11] and [12], who defined a "rock type" as: “units of rock deposited under similar conditions which experienced similar diagenetic processes resulting in a unique porosity-permeability relationship, capillary pressure profile and water saturation for a given height above free water in a reservoir”.

Reservoir rock type determination has presented a challenge for cases whenever no direct measurements of reservoir rock type are available. The direct determination of reservoir rock type will be carried out through the core analysis while indirect determination will be carried out through the log analyses. Typically, few wells in a field may have laboratory information such as core analysis data whereas most of wells may have electric log data. Wells without core are usual due to various reasons such as, time and cost associated with coring, and or impractical coring in many situations, such as in horizontal wells. In some wells in the present study where core porosity and core permeability are not available, data are derived from previous work [12].

The main target of this research is to provide a detailed core description based on the established reservoir rock type scheme of the Upper Rudeis reservoir (Asl and Hawara formations), West area of the giant July oil field, Gulf of Suez, Egypt, Fig. 1. Fundamental to this process model are identification and comparison of three different rock type; depositional, petrographic, and hydraulic. Each rock type represents different physical and chemical processes affecting rock properties during the depositional and paragenetic cycles.

The stratigraphic succession of the Gulf of Suez is illustrated in Fig.2 [13]. The sequence ranges in age from Paleozoic to Recent. The Upper Rudeis Formation of Early Miocene age is dominated by silciclastic and carbonate sediments.

**1. Data Sources and Evaluation Techniques for Rock Typing Upper Rudeis Rocks.**

The primary objective of this research is to model the Upper Rudeis reservoir encountered in twelve key wells of thirty selected wells scattered in the study area. Well logs, core descriptions, routine core analyses (RCA) and special core analyses (SCAL) are available from one well (SG310-5A well), at limited intervals. A suit of well logs including logs of caliper, gamma ray, density, acoustic transit time, neutron and resistivity are also available for the other eleven wells. A total of 265 feet conventional core has been examined. Well log data are used to estimate porosity and permeability; moreover, the zonation of the reservoir was based, primarily, on gamma ray, sonic and the neutron-density logs. The basic analysis procedure we used involves the following steps:

-Megascopic core description: Cores were systematically described based on thickness, wet color, lithologic characteristics, and distinctive composition, sedimentary structures, bedding features, nature of overlying and underlying contacts, trace fossils, and post depositional diagenetic features.

- Depositional model: the principal source of data for the depositional model were produced by detailed examination and logging of cores penetrating the Upper Rudeis reservoir. Main core characteristics recorded on litho logs were lithology, the size of constituent grains and the depositional texture of the sediment.

- Macroscopic and microscopic petrographic characteristics: about, 362 polished stained thin sections from 1200 ditch samples of the study well were examined using transmitted light microscope, polarized microscope and petrographic image analysis (PIA), to study the texture, mineralogical composition and porosity.


**Fig. 1 Location map of the study area**

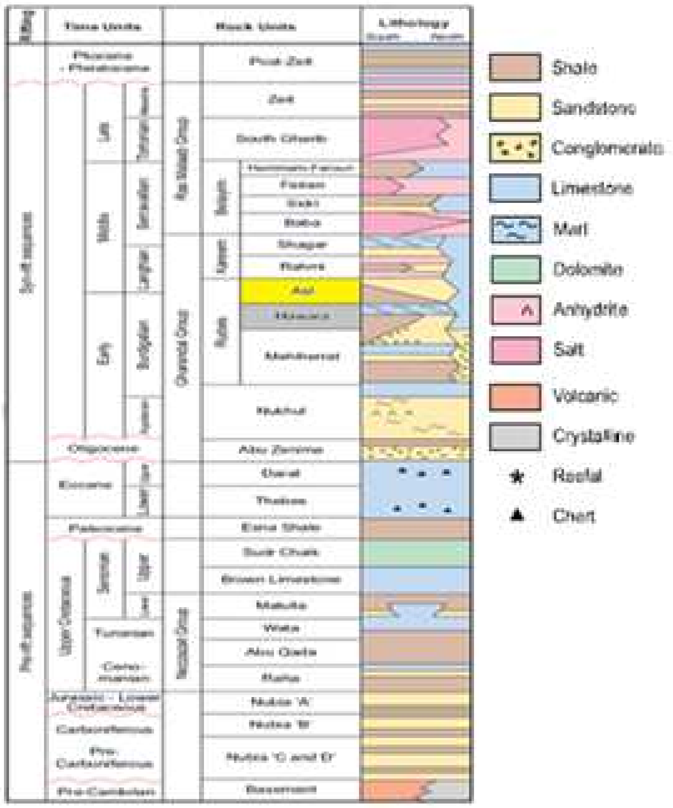
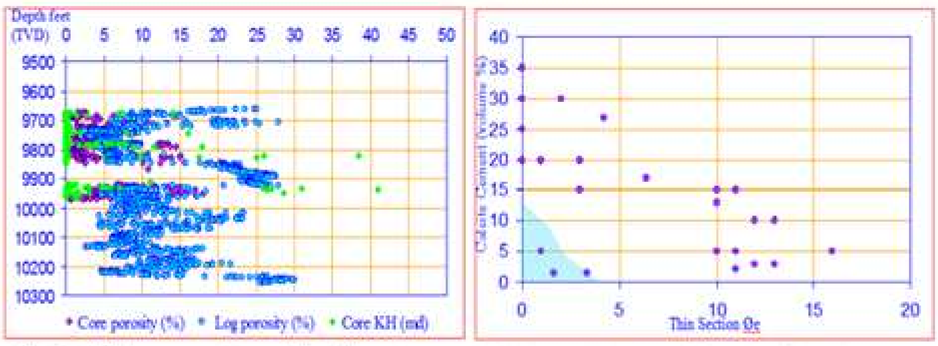



**Fig. 2 Stratigraphic column of the Gulf of Suez, [Abd El-Naby et al., 2009]**




(a) Depth feet (TVD) versus core porosity, permeability and log porosity

(b) Calcite cement (volume %) versus Thin-section effective porosity

**Fig. 3 Core, Log and Thin Section Porosity versus Depth**

## *2.* Porosity and permeability distributions

Initial porosity in the Upper Rudeis sandstone in the study area is 15% by volume for planar cross bedded facies. Because of poor sorting (more clay and mud) finer grained sandstones exhibit lower initial porosity and permeability. The porosity range is based on examination of 362 thin sections and is tied to analogs. This decrease resulted mainly from rearrangement of grains during early burial. Further reduction percent was due to later quartz pressure solution (dissolution of quartz grains and associated closer packing of grains), and emplacement in pores of dissolved quartz, clay, pyrite, and feldspar minerals. The average sandstone porosity and matrix permeability range up to about 22 % and 60 md., respectively, for cores from the studied well. Cored plus well log average porosity is 15 % for the entire interval of the Upper Rudeis sandstone, Fig.3a. The plot of volume percentages of thin section effective porosity (Øe) versus calcite cement, Fig.3b shows low porosity of the Upper Rudeis sandstone results from early diagenetic cementation by calcite (greater than 10%), below this amount porosity is variable. Samples with both minor calcite cementation and porosity (blue) experienced early porosity loss through extensive compaction. Upper Rudeis sandstone facies and mineralogy vary greatly at megascopic (field scale), and even more so at macroscopic (well and rock), and microscopic (thin section) scales. The most porous, permeable strata are the moderate-to high depositional energy trough crossbedded medium grained sandstones.

Amounts of calcite cements in the sandstone samples are ranged from 3% to 30%, and average 10%. Extensive loss of porosity and permeability due to compaction and prior to calcite cementation is indicated by the low percentage of calcite cement and large volume of mudstone and other soft sediments. Calcite cement is commonly spotty in thin sections, with evidence of extensive dissolution of cements in some intervals.

## 3. Identifying Reservoir Rock Types in SG310-5A well.

**3.1. *Depositional Rock Types (DRT).*** Depositional rock types are described within the context of the large-scale geologic framework and represent those original rock properties present at deposition and before significant post depositional diagenesis has occurred. The original rock properties will vary depending on many factors, including the depositional environments, sediment source and depositional flow regimes, grain size and distribution, type and volume of detrital clay and shale deposited, etc. Depositional rock types are based principally on geologic interpretations and physical descriptions of whole core.

The Upper Rudeis reservoir is divided into two units in the discussion of its geological evaluation. The division was taken at the level of a characteristic muddy unit which can be defined in most wells across the reservoir in the study area. The portion of the reservoir below and including this muddy unit has traditionally been referred to as the Hawara Formation and that above it the Asl Formation.

The cores reveal a mixed clastic-carbonate turbidities reservoir with sandstone average matrix porosities ranging from 10% to 25% and permeabilities ranging from 5 md to 60 md. Based on the arrangement of biological and mineralogical contents observed on cores, three depositional rock types were identified in the Upper Rudeis. The vertical distribution of lithofacies reflects a general rapid cyclicity.

*Depositional Rock Type 1(DRT 1)***:** Comprises a group of fine to medium grained sandstones, which indicate a stacked sequence of lenticular quartz arenites with fair to good porosity, separated by muddy sandstone and mudstone layers. These sands have abundant of calcite and dolomite detrital grains and/or cements. Strong oil staining tend to obscure depositional fabric detail, but imbricate clasts, disrupted laminations, convolute bedding and dewatering structures are present and are indicators of rapid deposition.

*Depositional Rock Type 2 (DRT 2):* Comprises shales that have a very characteristic appearance in slabbed cores, comprising dark grey, calcareous shale and grading upward to siltstone and fine sandstone. However, shale could be slow pelagic deposition between high energy sand bearing turbidity flows rather than a slump deposits.

*Depositional Rock Type 3 (DRT 3):* Comprises a carbonate group that includes grainstones, lime-mudstones, packstones and wackestones. The coarse bioclastic (skeletal) grainstones are varying in grain size from very fine to very coarse. The sediments are characterized by a diversity of grain-types, including shell fragments, foraminifera, and algal debris. The burrowed mudstones and wackestones are very fine-grained sediments, micritic and often porcellaneous. They may be faintly mottled, or have large individual burrows filled with coarser-grained sediment, and may be associate Within the lithofacies boundaries are reactivation surfaces that marked by a change in texture and or composition along bedding, which represent boundaries between fining upward turbidity flows. d with hard grounds. Packstones have a very fine grained texture with somewhat less diverse compositions.

***Petrographic Rock Types (PRT) and Hydraulic Rock Types (HRT).*** Petrographic rock types are described on the pore scale but within the context of the large-scale geologic framework identified from the depositional rock typing evaluation step. The primary tools used for describing petrographic rock types are microscopic imaging techniques, i.e., thin section descriptions, x-ray diffraction analysis, and scanning electron microscopy imaging. Included in these evaluations are descriptions of sediment source, rock composition and texture, mineralogy, and clay types. An important component of the petrographic rock typing is an assessment of the types of diagenesis and the potential impact on rock flow and storage capacity.

Hydraulic rock types are also quantified on the pore scale but represent the physical rock flow and storage properties as controlled by the pore structure. Hydraulic rock type classification provides a measure of the rock flow and storage properties at current conditions, *i.e*., reflecting the current pore structure as modified by diagenesis. The primary tools for identifying hydraulic rock types are routine core analysis which includes measurements of total and effective porosity, absolute permeability and pore size.

In our study, the Upper Rudeis reservoir is subdivided in to 30 sub-zones or layers at SG310-5A well, where the reservoir sub-zones separated by shale and often carbonates intervals. Effective porosity logs are computed from bulk density and neutron porosity logs and integrated with that derived from thin section petrography analysis. Other computed or raw logs were locally used in areas where effective porosity (PHIE) contrasts were not clear enough to define some of the layer limits.

*4.2.1. Petrographic Rock Types (PRT) and Hydraulic Rock Types (HRT) of Asl Formation at SG310-5A Well.*
Figure 4 list petrographic and hydraulic rock units in Asl Formation at SG310-5A well as well as their vertical continuity. The rock units of Asl cored interval consist of four hydraulic rock types and seven very low porosity and permeability, petrographic rock types.

Petrographic rock types (*PRT's 1, 2, 3, 4, 5, 6* and *7*) are burrowed bioturbated mudstone and very fine grained sandstones very low porosity and permeability, and forms permeability baffles and barriers.

Figure 5a is a thin section of *PRT 6*. The shapes and structures of foraminifera are typical, moreover, early diagenetic changes within depositional environment are illustrated (some alteration of wall texture has taken place with spar filled chambers and intergranular porosity has been lost). Angular glauconite indicates this glauconite grains may have been formed by alteration of detrital biotite. Traces of subangular detrital quartz grains are scattered in calcite cement. Portion of a single valve of an ostracode shows homogenous prismatic wall structure with a calcite and chitin composition.

In the thin section of *PRT 7*, foraminifera showing typical shapes and structures and illustrating some alteration of wall texture with spar filled chambers. Much of the intergranular porosity has been lost and some fractures filled with asphaltine. Traces of glauconite are resent. Traces of subangular to subrounded detrital quartz grains are scattered in a micrite matrix, Fig.5b.

*HRT 1* is a laminated and tabular bedded fine and medium grained sandstones. Reservoir favorability is further decreased by the interbedded, thin, calcite-cemented sandstones with numerous mudstone and glauconite drapes with permeability between 0.2 and 3 md and porosities between 4 % to 9 %. Thickness of this unit ranges up to about 8 feet. In thin section, the sample is a medium grained, moderately sorted quartz arenite with abundant calcite and dolomite grains. Grains consist of quartz (68%), dolomite (2%), calcite (10%) and traces of glauconite. Cements consist primarily of quartz overgrowths and calcite. Clays are common (5%) and consist of detrital and authigenic kaolinite. Traces of pyrite are present. Porosity is good (12%) based on visual estimates and consists of primary and secondary intergranular pores (7%) and secondary intragranular pores (traces) and microporosity (3%), Fig.5c.

*HRT 2* is a ripple, laminated, tabular, and very fine to fine grained sandstones. Reservoir favorability is further decreased by the interbedded thin calcite cemented sandstones, numerous mudstone drapes, and biologic reworking with permeability between 0.2 and 3 md and porosities between 4 to 9 %. Thickness is up to 20 feet. In thin section, the sample is fine grained, subangular to subrounded, poorly sorted quartz arenite cemented with calcite. Grains consist of quartz (67%), skeletal fragments (3%), calcite (17%) and traces of glauconite. Cements consist primarily of quartz overgrowths and calcite. Clays are common (5%) and consist of detrital and authigenic kaolinite. Organic matter and pyrite are present. Porosity is fair (8%) based on visual estimates and consists of primary and secondary intergranular pores (7%) and secondary intragranular pores (traces) and microporosity (1%), Fig.5d.

*HRT 3* is a ripple, laminated, tabular, and fine grained sandstones that commonly interbedded with thin trough crossbedded fine to medium grained sandstones and laterally discontinuous with permeability 18 md and porosity between 12 % and 15 %. Thickness of *HRT* 3 ranges up to about 8 feet. In thin section, the sample is a medium grained, subangular to subrounded, moderatlely to well sorted quartz arenite with partially dissolved calcite cement. Grains consist of quartz (75%), calcite (5%) and minor traces of glauconite. Cements consist primarily of quartz overgrowths and calcite. Opaque organic matter, pyrite, feldspars and polycrystalline quartz grains are present. Porosity is good (15%) based on visual estimates and consists of primary and secondary intergranular pores (12%) and secondary intragranular pores (traces) and microporosity (3%), Fig.5e.

*HRT 4* is a trough and planar crossbedded fine to medium grained sandstone that represents the highest depositional energy and greatest reservoir potential with permeability 52 md and porosity between 11% to 15 %. Thickness of this unit is generally less than 6 feet. In thin section, the sample is a medium grained, subangular to subrounded, moderately sorted quartz arenite cemented with poikilotopic calcite spars, which is filling the interstitial pore spaces. Grains consist of quartz (77%), skeletal fragments (2%), calcite (20%) and rare glauconite. Cements consist primarily of quartz overgrowths and calcite. Opaque organic matter and pyrite are present. Porosity is only present in trace amount as primary pores (3%) based on visual estimates and consists of secondary intergranular pores (8%), secondary intragranular pores (traces) and microporosity (traces), Fig.5f.

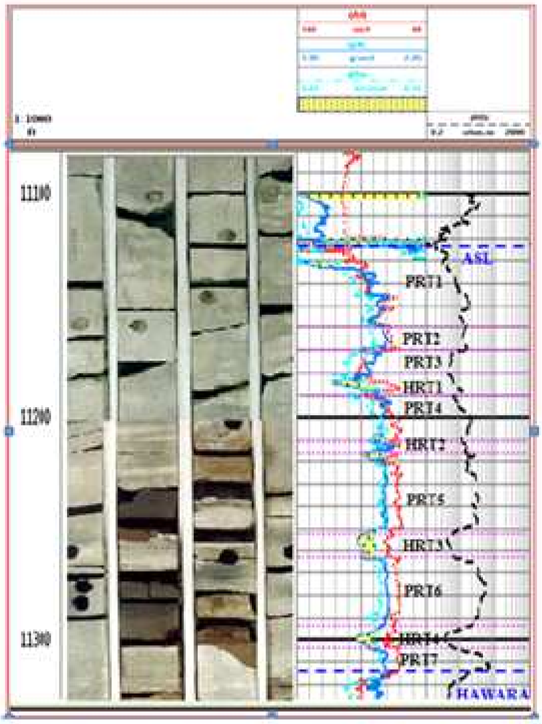



**Fig. 4 Core photo for Asl Formation**

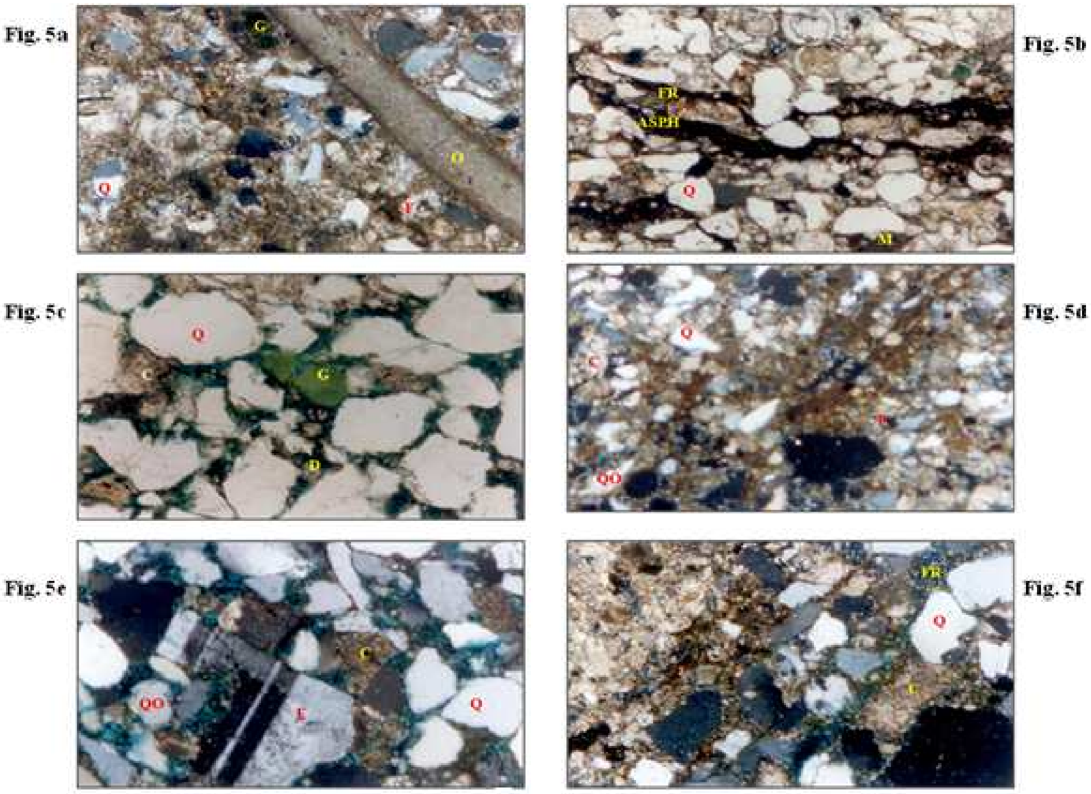



**Fig. 5 Thin section photomicrographs of some Petrographic and Hydraulic Rock Types**

*Q is quartz* *C is calcite* *F is feldspar* *G is glauconite*
*O is ostracode* *M is micrite* *P is pyrite* *ASPH is asphaltine*
*FR is open fracture* *QO is quartz overgrowth*

The hydraulic unit (*HRT4*) exhibits excellent reservoir and fluid flow properties with horizontal permeability (Kh) 52 md and porosity between 11% and 15 %. The (*HRT 3*) also contains good reservoir properties with horizontal permeability (Kh) 18 md and porosity between 12 %and 15 %., while the (*HRT's 1* and *2*) exhibits marginal to fair reservoir properties with horizontal permeabilities (Kh) between 0.2 and 3 md and porosities between 4 % and 9 %. Table (1) summarizes the characteristics of the different hydraulic rock types of Asl Formation in the study well.

*4.2.2. Petrographic Rock Types (PRT) and Hydraulic Rock Types (HRT) of Hawara Formation at SG310-5A well*
Figure 6 lists the petrographic and hydraulic rock units in Hawara Formation at SG310-5A well and vertical continuity of reservoir and non reservoir flow units. The rock units of Hawara Formation at SG310-5A well are represented by three rock types identified from the core (*PRT 1, HRT 1 and HRT 2*) and sixteen rock types identified from the well logs and sample cuttings (*PRT`s 2, 3, 4* and *HRT`s 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14* and *15*).

**Table (1): Summary of the characteristics of the different hydraulic rock types of Asl Formation**

| Hydraulic Rock Types / Petrophysical Parameters &Mineral composition | | HRT1 | HRT2 | HRT3 | HRT4 |
|---|---|---|---|---|---|
| Lithofacies | | laminated and tabular bedded calcite-cemented sandstones with numerous mudstone and glauconite | ripple, laminated, tabular, calcite cemented sandstones with numerous mudstone drapes, and biologic reworking | ripple, laminated, tabular sandstones | trough and planar crossbedded sandstones |
| Porosity characteristics | Porosity (%) | 4 – 9 | 4 – 9 | 12 – 15 | 11 - 15 |
| | Intergranular Porosity (%) | 7 | 7 | 12 | 8 |
| | Interagranular Porosity (%) | traces | traces | traces | traces |
| | Microporosity% | 3 | 1 | 3 | traces |
| Permeability (md.) | | 0.2 - 3 | 0.2 - 3 | 18 | 52 |
| Mineral composition | Quartz% | 68 | 67 | 75 | 77 |
| | Calcite% | 10 | 17 | 5 | 20 |
| | Dolomite% | 2 | ---- | ---- | ---- |
| | Clay% | 5 | 5 | ---- | ---- |
| | Glauconite% | traces | traces | Minor traces | rare |

*PRT's 1, 2, 3 and 4* are burrowed bioturbated mudstone that bound reservoir sandstones and concentration of carbonate nodules at the top 10 feet of *PRT 1*, which considered as mean flooding system in terms of sequence stratigraphy. The average thickness of *PRT 1* varies from 40 to 75 feet and is clearly correlatable in the field. These *PRT's* contain very low porosity and permeability and forms up dip and overlying reservoir seals.

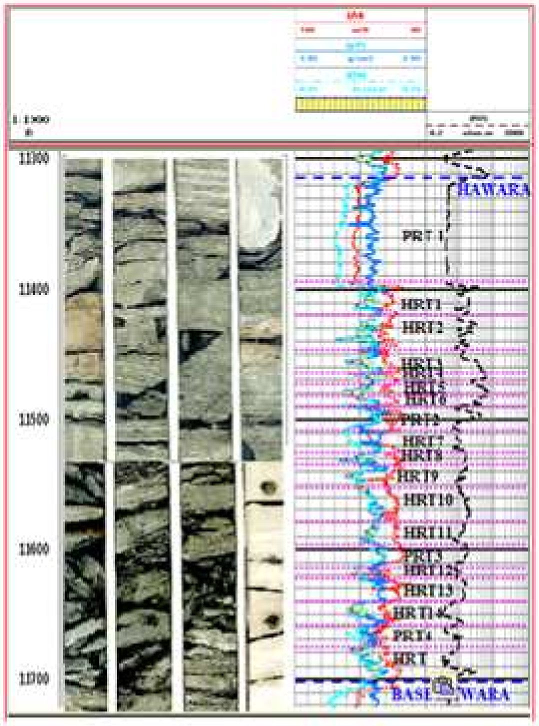



**Fig. 6 Core photo for Hawara Formation**

*HRT 1* is laminated and tabular bedded medium grained massive sandstones, which fines up to argillaceous sandstone. Reservoir favorability is decreased by the interbedded very thin calcite cemented sandstones with numerous mudstone and glauconite drapes. The permeability is 55 md and porosity between 11% and 16 %. Thickness of *HRT 1* ranges up to about 12 feet. In thin section, the sample is a medium to coarse grained, poorly sorted quartz arenite. Grains consist of quartz (77%), calcite (5%) and traces of glauconite. Cements consist primarily of quartz overgrowths and calcite. Clays are common (1%). Porosity is good (17%) based on visual estimates and consists of primary and secondary intergranular pores (14%) and secondary intragranular pores (traces) and miliolid foraminifera with large obliterated wall structure and partially cemented porosity (3%), Fig.7a.

*HRT 2* is crossbedded fine to medium grained sandstone that represents the highest depositional energy and greatest reservoir potential. Sandstones reservoir favorability is further decreased by the interbedded, numerous glauconite drapes, and biologic reworking with permeability 881 md and porosity between 14% and 18 %.Thickness of flow unit 2 is highly variable and generally less than 15 feet along and east of field axes to more than 20 feet along the northwestern margin of the field. Traces of pyrite are present. Traces of subangular to subrounded detrital quartz grains are scattered in the calcite cement, Fig.7b.

Petrographic rock types (*PRT`s 1, 2,3and 4*) have low porosity and low permeability so they considered as non reservoir units and forms permeability baffles and barriers.

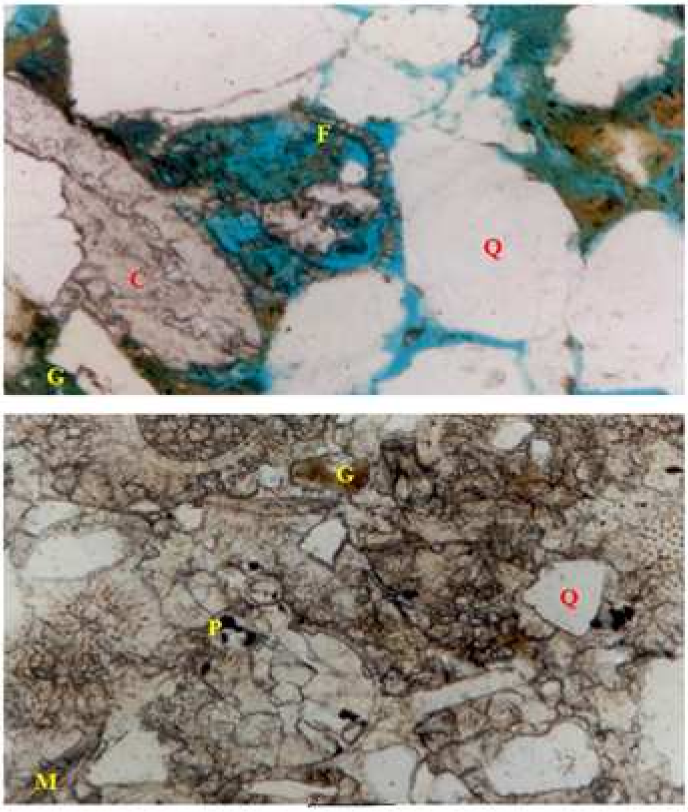



Fig. 7a

Fig. 7b

**Fig. 7 Thin section photomicrographs of Hydraulic Rock Types 1 and 2 (HRT 1 and HRT 2)**
*F is foraminifera* *G is glauconite*

The hydraulic unit (*HRT 2*) from core exhibits excellent reservoir and fluid flow properties with horizontal permeability (Kh) 881 md and porosity between 14% and 18 %. Also, *HRT's 4, 5* and *6* from log and sample cuttings are more or less similar to *HRT 2*. The (*HRT 1*) also contains good reservoir properties with horizontal permeability (Kh) 55 md and porosity between 11% and 16 %, while the (*HRT's 3, 7, 8, 9, 10, 11, 12, 13, 14* and *15*) exhibits marginal to fair reservoir properties. Table (2) summarizes the characteristics of the different hydraulic rock types of Hawara Formation in the study well.

**Table (2): Summary of the characteristics of the different hydraulic rock types of Hawara Formation**

| Hydraulic Rock Types / Petrophysical Parameters & Mineral composition | | HRT1 | HRT2 |
|---|---|---|---|
| Lithofacies | | laminated and tabular bedded sandstones interbedded with very thin calcite cemented sandstones with numerous mudstone and glauconite drapes | crossbedded fine to medium grained sandstone with numerous glauconite drapes |
| Porosity characteristics | Porosity (%) | 11 – 16 | 14 – 18 |
| | Intergranular Porosity (%) | 14 | |
| | Interagranular Porosity (%) | traces | traces |
| | Microporosity% | 3 | |
| Permeability (md.) | | 55 | 881 |
| Mineral composition | Quartz% | 77 | ---- |
| | Calcite% | 5 | ---- |
| | Dolomite% | ---- | ---- |
| | Clay% | 1 | ---- |
| | Glauconite% | traces | ---- |

## 4. Megascopic and macroscopic diagenetic model (field and well scales)

The Upper Rudeis sandstone exhibits a complex diagenetic history that strongly influenced porosity and permeability preservation, loss, and enhancement. These factors in turn affect emplacement, trapping, and production. The main diagenetic processes affecting the Upper Rudeis sandstones are porosity and permeability destruction or absence of porosity and permeability resulting from precipitation of calcite (C) linked with dissolution of feldspar (F) grains and peripheral dissolution of quartz (Q) grains. Quartz grains frequently show peripheral dissolution and only minor overgrowths. Pervasive cementation by quartz is most common in thin bedded, clean, well sorted sands with minimal evidence of prior cementation by calcite. Glauconite (green) rims some quartz grains. Because of the early cementation by quartz, mudstone clasts frequently exhibit only minor compaction. Porosity (blue) is minor.

Upper Rudeis sandstones primary, secondary porosities and microporosity are shown on the thin sections photomicrographs. Pore spaces in all photomicrographs are filled with blue dye. Porosity in the thin section is partially decreased by early diagenetic cementation of quartz grains. The original rounded quartz grains are outlined by green colored glauconite. Early diagenetic cementation preserves porosity and permeability in the Upper Rudeis sandstone by supporting the grain framework and decreasing porosity loss through compaction. Microporosity results primarily from breakdown of feldspar into kaolinite (K) and other clay minerals; this causes a mottled appearance of the blue dye that fills pore spaces. Blocky pore filling calcite(C) is much more coarsely crystalline and is observed within both interparticle and shell moldic dissolution pores. This cement is indicative of slow precipitation.

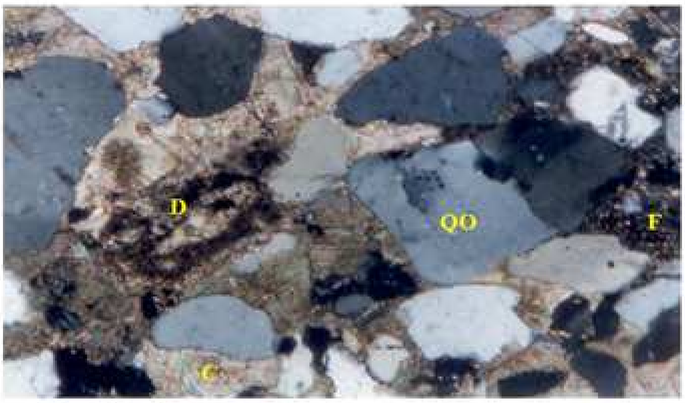



**Fig. 8 Thin section photomicrograph exhibits middle to late diagenitic stages**
*D is Dolomite*

A number of diagenetic stages are shown on the Pyrite (P) framboids which are black in transmitted light and crossed nicols views, Figs. 5d and 7b. These late diagenetic pyrite crystals are commonly associated with the dolomite and may result from changes in chemical composition of pore fluids resulting from migration of hydrocarbons into the Upper Rudeis sandstone. Quartz and feldspar grains in the thin section display well developed overgrowths, Figs. 5d, 5e and 8. Overgrowth formation was followed by precipitation of optically continuous, calcite cement (C). This was followed by filling of the secondary pore by dolomite and pyrite. Also visible are a glauconite pellet (G) that has been slightly altered to illite, and plagioclase feldspar (F) that underwent extensive late diagenetic dissolution and recrystallization. Original grain outline is indicated by brown dead oil (latest diagenetic emplacement). Dissolution of the calcite cements resulted mainly from changes in pore fluid chemistry, primarily organic and carbonic acids associated with hydrocarbon generation and migration into the reservoir. This created secondary porosity and provided the primary source of chemically reduced iron for pyrite and dolomite. Migration also resulted in dissolution of feldspar and subsequent precipitation of kaolinite in pores. Late stage influx of oil into the field area is indicated by petrologic analysis of thin sections. Thin sections that are oil saturated generally exhibit well developed quartz overgrowths, dissolution of unstable lithics, dissolution of feldspar and subsequent precipitation of kaolinite in pores and other stages characteristic of middle to late diagenesis.

## CONCLUSION

The Upper Rudeis reservoir rocks are extremely heterogeneous. The heterogeneity occurs in the following elements: Multiple lithologic types, porosity, permeability, pore fluid composition/distribution, rock type distribution, and depositional environment.

Three different depositional rock types and thirty different rock types are identified. Twenty two (22) of the rock types either produce or have the potential to produce oil in different wells. The results of the integrated reservoir characterization study show that well productivity in Asl and Hawara is predominantly controlled by the development of thin permeable calcareous streaks in a series of shallowing upward cycles, as well as Calcite and bioclastic grain stones of variable thickness in the Asl and Hawara sediments and the presence of thin streaks of early diagenetic dolomite within small scale shallowing upward cycles of the Asl sediments.

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