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Clay Types and Reservoir Quality of the Hawaz Succession, Murzuq Basin, SW Libya

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Abstract

Hawaz formation present in the subsurface of Murzuq basin forms one of the most important hydrocarbon reservoirs in the area and comprise fine to medium grained sandstone with alternation of shale and siltstone beds. This succession is informally subdivided, from top to bottom, into 8 layers (H1-H8). The interpreted reservoir facies for the Hawaz units include fluvi-tidal channel sandstone, bioturbated sandstone, heterolithic sandstone and mudstone facies. The lateral facies variation is minor and well to well correlation is persistent for a field scale. Well logging data together with core information were analyzed in order to understand the reservoir quality of the Hawaz sandstone units with respect to the clay types. The clay types identified throughout the reservoir section include Illite, Kaolinite, Montmorillonite and mixed layers' clay. Clay types is generally related to reservoir facies types with fluvio-tidal channel being the high quality reservoir containing little amount of kaolinite and traces of Illite clays and the low quality reservoir is the bioturbated sandstones with dominant Illite and mixed layers' clays with traces of Kaolinite.

Keywords: Hawaz reservoir; Kaolinite; Illite; clay minerals.

1. Introduction

The Murzuq Basin represent large intracratonic sag on the passive margin of Gandwana during the Paleozoic Era, located on the Saharan Platform of North Africa (Figure 1) and covers an area of about 350,000km2 of southern west part of Libya and northern portion of Niger where it is known as Djado Basin [1]. The basin contains a sedimentary fill with a thickness of about 4000m in the basin depocenter and consists of fluvial to marine Paleozoic succession overlain by continental Mesozoic strata [2]. The tectonic evolution of Murzuq Basin passed through three phases: (I) Early Paleozoic time when the basin represented by several northwest-southeast troughs and uplifts, opened to the north. (II) Following the mid-Devonian tectonism a great part of the basin established but still opened to the north. (III) Hercynian orogeny closed the northward opening by formation of Al-Qarqaf Arch [3]. The stratigraphic column of the Murzuq Basin shows that many stratigraphic units are bounded by major erosive unconformities events resulted from tectonic activities. The main tectonic events that influenced the basin's development are Pan African Orogeny; Caledonian Compression; Mid Carboniferous Compression; Hyrcynian Uplift; Austrian and Alpine Compressions [4]. In the Murzuq Basin, Oil fields in Murzuq Basin produce from the Ordovician Mamuniyat and Hawaz clastic reservoirs. The reservoirs sourced with oil from and sealed by overlying Silurian shales. Oil was generated from an extremely rich source rock at the base of a thick Silurian shale section, and migrated directly into the underlaying sandstone reservoirs. The timing of the main phase of oil generation is be-

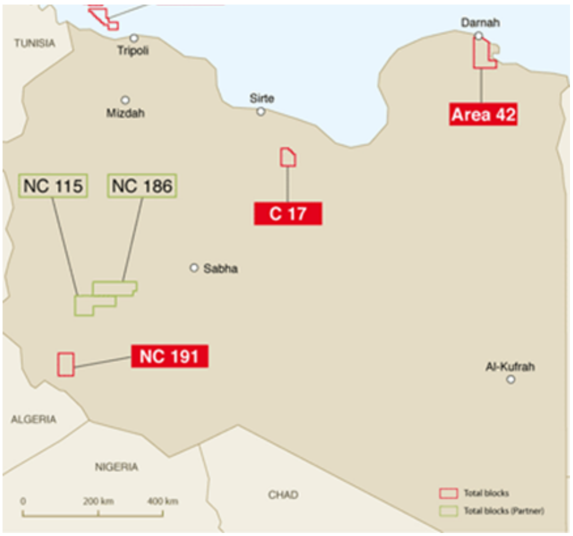

Figure 1.1: Sketch map of Libya showing the location of NC115 and NC186 Blocks [8].

lieved to have taken place from the mid-Cretaceous to early Tertiary. The relatively simple structure of Murzuq basin might have allowed long distance migration within the reservoirs. Hawaz reservoir show variations in reservoir properties that is related to depositional environments and diagenetic alterations including formation of clay minerals. The presence of low levels of clay minerals in pore space is generally controls the reservoir quality. Specific knowledge of clay minerals present in the reservoir sands is essential for formation evaluation. Almost all the log measurements are affected by clay minerals present in the formation and hence all the logs have some potential to determine clay mineralogy. This paper presents the results of clay typing analysis of the Hawaz reservoir within NC186 and NC115 blocks, SW Murzuq Basin, Libya. Geophysical well logs (spectral gamma ray and resistivity imager logs) and core data were analyzed in terms of mineralogical analysis and clay typing, reservoir facies and depositional systems, and subsequently examine the extent to which clay typing affected the reservoir quality of the Hawaz Formation. The study include revision and collation of relevant data from previous studies in the area (e.g. [2], [5], [6], [7].

2. Material and Methods

Spectral Gamma Ray logging Technique is commonly used in the industry for determining clay minerals content within hydrocarbon reservoirs. Natural Gamma Spectroscopy tool measures individual fractions of radioactive elements Uranium, Thorium and Potassium and also their ratios as function of depth and split into contributions from each of the major radio-isotopic sources. The amplitude of the output from the gamma ray sensor is proportional to the energy of the incident gamma ray. This information can be used to measure the proportion of the total gamma radiation coming from each of potassium-40, the uranium-radium series, and the thorium series for a particular formation. The spectral gamma ray tool uses the same sensor as the total gamma ray tool. The output from the sensor is fed into a multi-channel analyzer that calculates the amounts of radiation coming from the energies associated with each of the major peaks. This is done by measuring the gamma ray count rate for 3 energy windows centered around the energies 1.46 MeV for potassium-40, 1.76 MeV for the uranium-radium series, and 2.61 MeV for the thorium series (Figure 2.1). These readings represent the gamma ray radioactivity from each of these sources. Analysis of the sources of the natural radiation give us added information concerning the mineralogical composition of the formation. Various cross plots with different combinations (e.g. K (vs)T_h) of these parameters indicate the probable presence of clay minerals present in the formation to some extent. The clay types within the Hawaz reservoir were determined using an interpretative model for spectral gamma ray mineral identification (thorium/potassium cross-plot, [9]). The results obtained from spectral gamma ray log data for clay minerals identifications within the Hawaz reservoir were calibrated with core data.

3. Results and Discussion

The Hawaz Formation was first introduced by [10] after Jabel Hawaz, western Gargaf area and is unconformably overlying the Achebyat Formation. The Deposition of Hawaz Formation occurred when the continent was thoroughly peneplaned. The age of this unit is assigned to Llanviranian-Llandeilian (Middle Ordovician). The base of this unit is

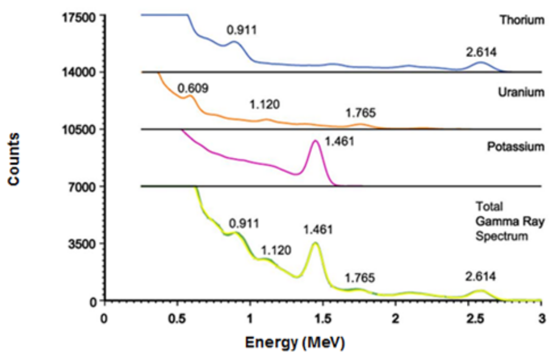

Figure 2.1: Standard Natural Gamma Ray Spectra (Potassium, Thorium and Uranium components).

transgressive and comprises mainly sandstone with thin levels of shale. The sandstone is fine to medium and locally coarse-grained occasionally micaceous with abundant diverse trace fossils, including Skolithos Siphonichnus, Asterosoma, and Teichichnus. The depositional environment of this unit range from lower shoreface-offshore transition to upper shoreface. Amalgamated fluvial-tidal channels sandstones are also observed. This time represents deposition on a stable shelf with very gentle slope. In fact, the Hawaz strata are well correlated throughout the area under invistigation with a thickness ranging from few hundred feet to more than 700 feet. The thickness variation is mainly controlled by the Middle-Upper Ordovician erosional event. The Hawaz unit was best preserved in the northwest of the NC115 block. The Hawaz Formation can be divided into lower and upper sections (Figure 3.1). The boundary between Lower Hawaz and Upper Hawaz was taken at the top of the shale unit (at the base of H5). In the Gargaf area, this boundary is clearly seen where stacked channel of fluvial dominated sandstone? sharply overlying shale package of lower shore face to offshore transition?. In study area, the lower Hawaz member reach a thickness of about 450 feet and comprises stacked retrogradational-progradational parasequences while the upper Hawaz has a thickness of about 277 feet and consists of finning upward succession.

3.1. Hawaz Reservoir Facies

Four main reservoir facies have been identified from the Hawaz succession. The characteristic texture, open-hole curve response, and resistivity image log are used together with detailed sedimentological core description are used to define these facies. In this study, facies are grouped into more comprehensive units with an environmental sense and simple to use in static reservoir modeling. Two out of four facies are sandstone lithologies. The remaining image facies are mudstone and heterolithics. These facies include Bioturbated Sandstone, Fluvio-tidal channels Sandstone, Heterolithic, and Mudstone Facies.

- Fluvio-tidal channels Sandstone : the facies is predominantly composed of various scales cross-bedded and massive to vaguely bedded, fine to medium grained, generally clean and well sorted sandstone (Figure 3.2A). The lower part of this facies is generally represented by massive sandstone with erosional base and containing scattered mud clasts (channel lag). This facies is interpreted to represent amalgamated fluvio-tidal channel deposits formed in a laterally extensive coastal plain system. Locally this facies displays bi-directional trends (shown in resistivity images). This bi-polarity trends probably indicate tidal influence.

- Bioturbated Sandstone: this facies composed of bioturbated sandstone, generally fine grained and argillaceous. Bioturbation is typically low to intense, and burrows are dominated by a vertical (Skolithos) ichnofabric, characterised by Skolithos and Siphonichnus traces. The moderate to intense bioturbation, with a Skolithos ichnofabric, is characteristic of a shallow to a relatively deeper marine environment (burrowed shelfal and lower shoreface & distal shelf storm sheets deposits).

- Heterolithic Facies: this facies comprises finely interbedded sediments of fine to very fine grained sand, shale and silt lithologies. The facies generally display a relatively high GR response. Image facies analysis shows a preferential cementation of sands, or isolated nodules as indicated by very bright (resistive) bands/patches. Flaser bedding and load structures have been identified within this facies [6], [11].

- Mudstone Facies. Litholigically: this facies comprises mainly laminated mudstone and argillaceous siltstone units. Rare, small sand-filled burrows are locally present, but bioturbation is typically of very low intensity or is absent. The muds and silts deposited from suspension under

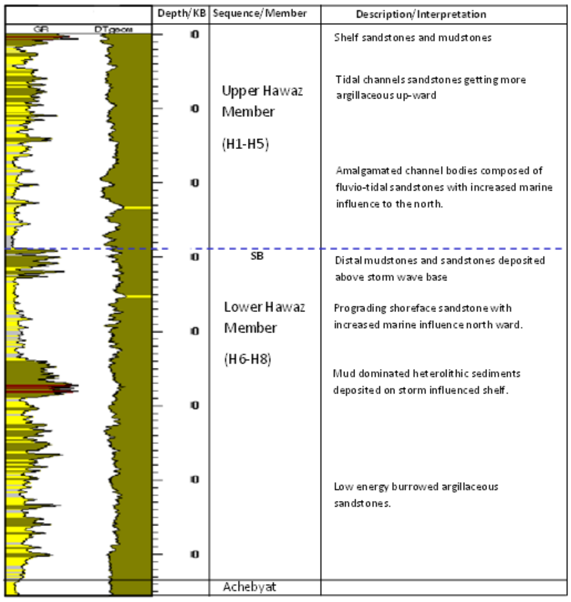

Figure 3.1: Typical Hawaz section from a well in Murzuq Basin [5].

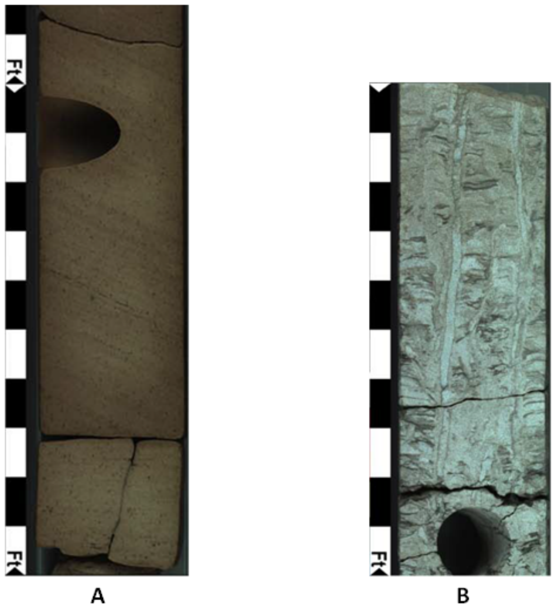

Figure 3.2: Fluvio-tidal channels Sandstone facies display cross-bedding structure; (B) Bioturbated Sandstone facies within the Hawaz reservoir.

low energy conditions. The sparse bioturbation is indicative of highly restricted conditions, possibly arising from abnormal salinities.

3.2. Clay Minerals Identification

The natural gamma ray spectroscopy data from the studied wells within the NC186 and 115 blocks were plotted in (thorium/potassium cross-plot). The results indicate the presence of different clay minerals in the Hawaz reservoir. The presence of clay minerals like Montmorollite, Illite, mixed layered clay and kaolinite are evident in the cross plot (Figure 3.3). The cross plot shows the dominance of Montmorillonite and Mixed layered clay. This finding is also corroborated by core studies. Petrographic analysis of the studied wells confirms the presence of clay minerals within the Hawaz reservoir and shows that the type of clay mineral present in the reservoir is mainly controlled by reservoir facies. The Fluvio-tidal channels Sandstone facies has very little authigenic clay minerals contents and when present is dominated by kaolinite books and traces of fibrous Illite (Figure 3.4A). The sandstone of this facies is quartz arenite, fine to medium grained, well sorted with dominant quartz overgrowth cement. Measured porosity of this facies is about 16% with

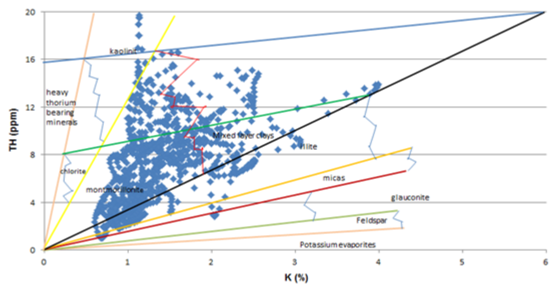

Figure 3.3: Thorium-Potassium cross plot depicting clay mineralogy within the Hawaz reservoir.

permeability of about 403Md. The Bioturbated Sandstone facies contains abundant authigenic clay minerals represented mainly by Fibrous Illite and Mixed-layered clay with little amount of Kaolinite books (Figures 3.4B, 3.4B2 & C). Reservoir properties of this facies is generally poor with permeability value of about 0.74 mD although the porosity is quite high, about 15%. The reservoir quality of this facies slightly improves with decrease in bioturbation intensity as the depositional setting becoming more proximal.

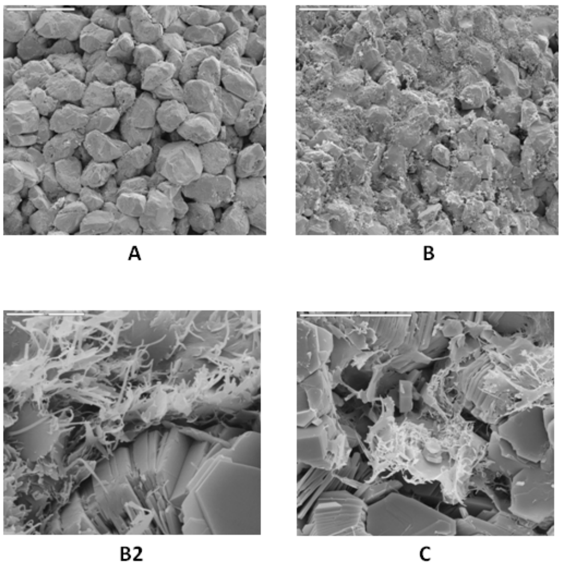

Figure 3.4: SEM micrographs for: (A) fluvio-tidal channel sandstone facies showing general view of grain surface with intergranular porosity, grains are mainly composed of quartz, some authigenic clays are locally present (Scale bar = 500 microns); (B) Bioturbated sandstone facies General view of a grain surface showing some intergranular porosity and well developed quartz overgrowths, Illite and kaolinite fill the intergranular pores (Scale bar = 500 microns); (B2 and C) Illit-Smectite, fibrous illite and kaolinite books present in bioturbated sandstone facies for the Hawaz reservoir, Scale bars = 5 microns and 20 microns, respectively.

4. Conclusion

The study of Hawaz reservoir indicates that well logs like natural Gamma Ray Spectroscopy are suitable for identifying the clay mineralaogy and when calibrated with core data provide a useful information for reservoir characterization. The thorium/potassium cross-plot indicate that the clay minerals present are Montmorollite, Illite, Mixed layered clay and Kaolinite. The petrographical analysis of core samples from the Hawaz reservoir confirms the presence of authuigenic clay minerals and shows that the distribution of authigenic clays is controlled by the reservoir facies. The higher quality reservoir facies is represented by Fluvio-tidal channels Sandstone that contain very little amount of Kaolinite and traces of Illite. Bioturbated Sandstone facies has a poor reservoir properties as it contains abundant authigenic clay minerals represented mainly by Illite and Mixed-layered clay with little amount of Kaolinite.

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