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Research Article

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Morphology of Pores in Reservoirs of Some Oil Fields

S. ABRAKASA[1,2,3], Ani MEMUDUAGHAN[1], Michael M. INYANG[1]

[1]Geology Department, University of Port Harcourt, Nigeria
[2]Centre for Petroleum Geosciences, University of Port Harcourt, Nigeria
[3]Geology/Mining Technology Option, SSLT, University of Port Harcourt, Nigeria
E-mail: selegha.abrakasa@uniport.edu.ng

Abstract Some reservoir samples of the Agbada Formation and corresponding equivalent of the Nanka Formation outcrops were subjected to SEM (scanning electron microscopy) analysis to unravel the clay mineral and authigenic cements that could be present in the detrital grains and the inner surfaces of the pores. Samples were prepared in 10mm by 30mm sizes, samples were polished and coated for clearer imaging.

Photomicrograph of samples show the presence of webby smectite, needle-like chlorite and ribbons of filamentous illites on the detrital grains and pore space between the grains. Most frequently occurring clay minerals are smectite and filamentous illites. Smectite and illite are basically pore lining and pore bridging minerals, hence the fluid flow is not completely prevented but is restricted.

This observation explains why most reservoirs in Agbada Formation are generally fairly productive due to the non-sealing effect of the pore lining and pore bridging minerals.

Keywords Agbada Formation, Chlorite, fluid flow, illite, Kaolinite, Smectite

1. Introduction

Reservoirs are thick sequences of sandbodies that provided pore volume for the accumulation (storage) of petroleum. In addition it also provides the interconnectivity of pores that allows for the migration/flow of petroleum through the sandstones [1-2]. These functions can only be achieved by the properties of permeability and porosity of the reservoir sandbodies. Reservoir sandbodies could be deposited in various environments and each of these sandbodies bear particular characters that reflect the environments on which they are deposite [3]. The sandbodies vary from eolian, deltaic to marine and marine reservoirs have high clay content while eolian reservoirs are highly sorted with little or no clay [4-5]. Over time subsidence and burial provide for diagenesis which could be physical and chemical. The processes include compaction, dissolution, cementation, authigenesis and replacement. During diagenesis pore fluids are modify by reactions with clay minerals, dissolution of unstable grains, and precipitation of authigenic minerals.

During compaction, dewatering of the sandstone body takes place and the grain to grain contact becomes more closer leading to fracturing, bending of weak grains and dissolution of grains at point of contact [6]. The formation of solutions can lead to suturing, this is a situation where the surface of adjacent grains are welded together. This observation has great potential for compromising the efficiency of reservoirs transmissibility of oils. Authigenic alkaline pore water that are rich in Na, K, Al and Si may flow into the pores and precipitate therein, the porewater are generated from hydrolysis and dissolution of less stable grain in the matrix. Clay mineral may also be carried by pore water from muddy interbed, illite and kaolinite are the most common authigenic clays in sandstones [7]. Authigenic clay minerals occur as pore filling cement and clay rims around grains.

Generally, large grain sizes contribute to increase in porosity, highly sorted sediment is mostly loosely packed and clay content is reduced; beach sands and aeolian dunes are good examples and they may increase porosities up to 50% and relatively high permeabilities. However, fine grain sediments, example siltstones and chalks most often have lower permeabilities and fluid flow is always constraint due to their small pore throats and accompanying capillary forces.

Overtime subsidence could result in breakdown of unstable grains, increasing porosity by dissolution of the grain, however porosity could also be reduced by formation of clay minerals.

The most common of clay minerals is the kaolinite, it occurs as stacks of books as its characteristics appearance, it serves as a pore filling mineral. Illite has a filamentous (fibrous), platy, and lathy in occurrence, characteristically they bridge the pores and also line the internal surfaces of the pores, overall there is a resultant decrease in pore volume, though porosity is limited but permeability is highly effected. Chlorite is another mineral, it occurs in platy form, kind of honeycomb structure, it reduces both porosity and permeability. It is also porelining. Smectite is another clay mineral, it appears webby in the scanning electron microscope, it has been observed to line the internal surfaces of pores as well as bridge the pores. Calcite is carbonate mineral and could also be generated during diagenesis, it occurs mostly as patches, cementing spaces between grain, overgrowths and can also line the internal surfaces of pores in addition to filling the pores (Ul-Hamid, 2018).

The nature and occurrences of these minerals to a great extent do affect the efficiency of the reservoir sandbody with respect to fluid flow. Their true nature can only be revealed by scanning electron microscopy.

2.0 Material and Methods

Materials and methods entail specifically samples, sampling techniques, analytical equipment and methods that were employed in generating data used in this study. Samples were particularly core and drill cuttings, samples were stored in sample bags properly labelled. Analytical equipment used is PAN Analytical model of Scanning Electron Microscope (SEM). The core data were obtained from Nigerian Geological Survey Agency Core Shed at the National Geosciences Research Laboratories at Kaduna.

SEM analysis was for the purpose of 3D pore visualization and diagenetic cementation [8-9]. It is an analytical process that enlarges tiny features that are invisible to humans, images are formed by the scanning function of high energy electron on sample surfaces, recent models of the equipment emits X-rays with unique energy that relates to the elemental and mineral composition of the cements [8]. It fits into material characterization providing information on 3D surface structure, composition and in geology the morphology of pores in the matrix of rocks this encompasses surface orientation, grain size, grain shape, inclusions, grain boundaries and authigenic precipitates.

2.1 Samples and Sample preparation.

Samples were reservoir thin sections that were about 10mm by 30mm in size, the samples were polished and coated for clearer imaging. Samples were stored in dust free environments to avoid contamination of the SEM chamber [10-11].

2.2 SEM Analysis

The main components of the scanning electron microscope are: the column for electron beam generation, specimen chamber, vacuum pump, monitor and control panel. Initially the vacuum pump control is switched to vent the specimen chamber, after pressure equalization the specimen chamber can be opened, specimen for analysis can be placed on the stage. The chamber is covered and the high vacuum pump is switched on, also electronic control panel [8]. The pressure in the chamber and the column equilibrates, the monitor is turned on together with the control panel. The high voltage thermionic cathode is switched on and an image can be observed. The magnification and the working distance (WD) are adjusted for image clarity. The high velocity beam of primary electrons generated is incident on the specimen, at the point of incident electrons from the analyte is emitted which are called secondary electrons. The secondary electrons are detected by the secondary electron detector which could be used in building a 3D image. High amount of secondary electron detected gives a bright image point, few gives a gray image point while none gives a black image point in the pattern image is built. In addtion during emission of the secondary electron, characteristic X–ray photon is released which bears the chemical properties of the analyte, where the energy and quantity of the X-ray photon (radiation) is measured by an X-ray detector the chemical composition of the analyte and the quantity can also be determined [8].

Figure 1: Scanning Electron Microscope (Model: JOEL–JSM 7600F)

3.0 Results and Discussion

The results of SEM analysis for reservoir rock sample are basically the SEM micrograph and the EDX analysis, if available. Each of the minerals and cements that usually occurs in the reservoir rock matrix during diagenesis as authigenic have specific characteristic crystal features under SEM, these features are characteristically diagnostic to the identification of the minerals. The thin section-based study is the microscopic scale of reservoir studies, others are mesoscopic (core based), macroscopic (inter well-based) and megascopic (field wide).

The micrographs are microscopic based pictures of the pores and the surrounding matrix, and the inner surfaces of the pores constituting the inner linings of the pores [9,12].

Figure 2 consists of micrographs a–d, these are SEM data of Akata Formation and outcrops of Nanka Formation. Micrographs (a) and (b) are of Akata Formation at different working distance and magnification. Micrograph (a) shows a sample composed entirely of a well-rounded quartz detrital grains, there is freely observed detrital and authigenic clay. Micrograph (b) is of higher magnification and it shows clearer features of some grain having concave–convex shape, which is normally attributed to high pressure environments. High pressure allows the grain to grain contact to give way for interstitial water to bear the overburden pressure, the pressure on the formation water leads to increase porosity and permeability. The grains also show high angularity, this indicates immaturity [4].

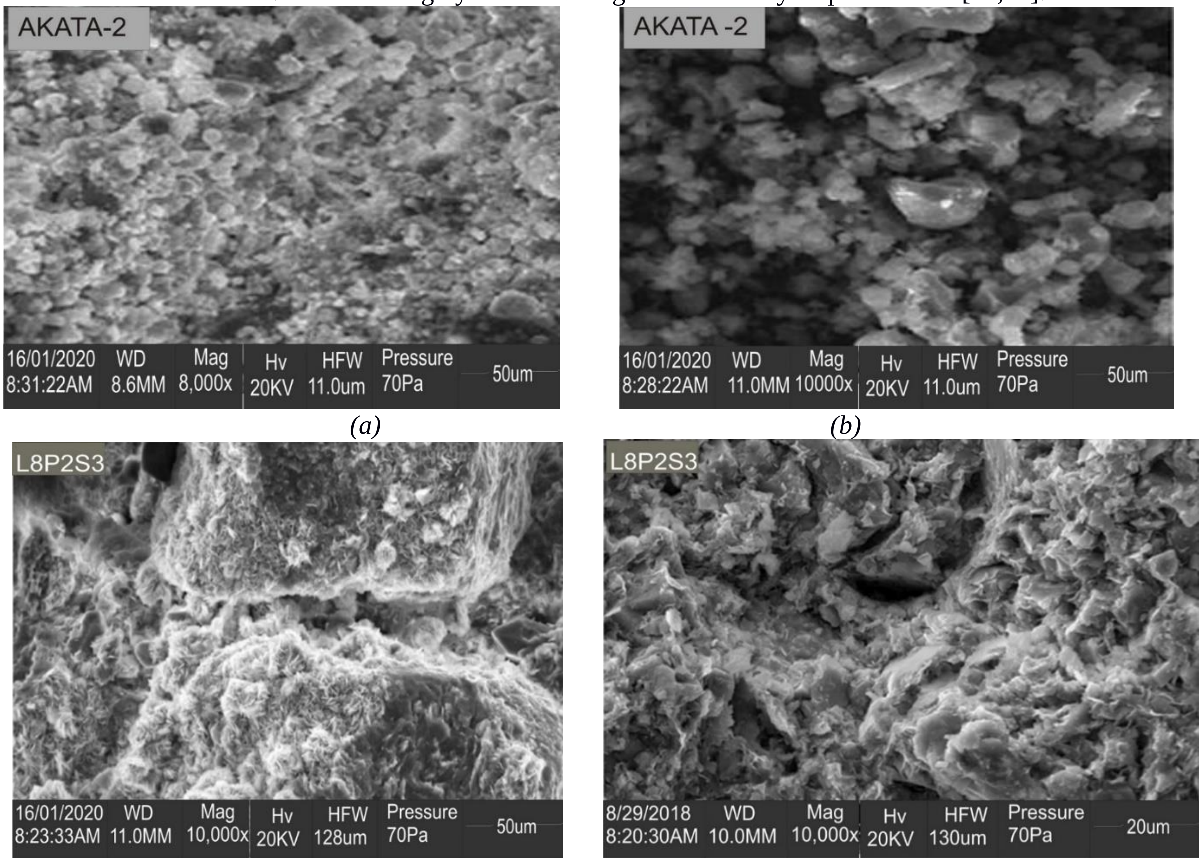
Micrograph (c) shows two grains that are adjacent to each, on the grains are precipitated needle like crystals and closely stacked set of booklets. Characteristically, chlorite bears needlelike morphological feature and kaolinites characteristically have stacks of booklet features, these features are diagnostic to the identification of these clay minerals.

Micrograph (d) is a higher magnification of (c). Micrograph (d) shows a smeary webby characteristic feature of smectite that is rich in Fe (Vejbaek, 2008). Figure 3 consists micrographs (e) and (f). Micrograph (e) is a magnification of micrograph (d), it bears a webby structure with some filamentous tendrils [9,12].

Micrograph (f) is that of Akata–2 Well at the depth of 7478ft, it reveals some grain with clay coatings and some fibrous rod-like tubular structures with long dimension that are perpendicular to the detrital grain and is synonymous with lacustrine tuff [12].

3.1 Implication of the findings

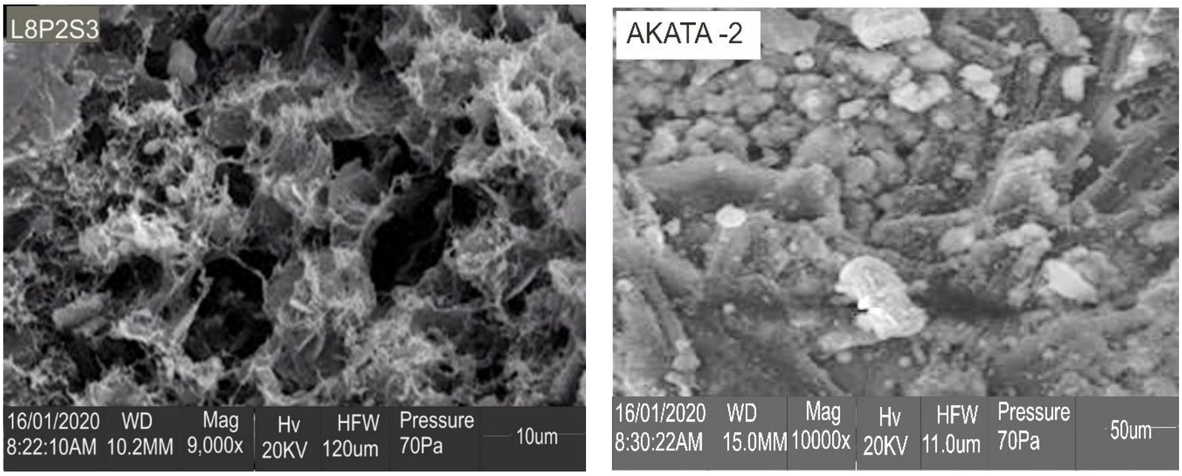
The well-rounded quartz detrital grains in micrograph of figure 3 (a) indicate maturity and good sorting, at higher magnification (figure 3b) the pressure effects on the grains are revealed.
This infers that the sample is obtained from high pressure environment, where there is possibility of overloading [13-14].
Micrograph (c) in figure 3 shows needlelike precipitate on the body of the adjacent grain having characteristic feature of chlorite, while the stack of booklets is kaolinite. Chlorite is a pore lining clay mineral, they are normally deposited on the inner surface of the pores, the resultant effect is the restriction of fluid flow [15]. The gradual precipitation overtime will reduce the flow circumference of the pores, thereby limiting flow efficiency. However, kaolinite is a pore filling clay mineral. It fills available pore space and completely or partially block/seals off fluid flow. This has a highly severe sealing effect and may stop fluid flow [12,15].



(a) *(b)*

(c) *(d)*

Figure 2: SEM Micrographs of reservoir samples and outcrops (a–d)



(e) *(f)*

Figure 3: SEM Micrographs of reservoir samples and outcrops (e–f)

Micrograph (e) of figure 3 is a magnification of micrograph (d), the clay mineral bears a webby feature indicating smectite, the webby structure is interwoven with mats of ribbons of filamentous illite which crosses from one side to another, bridging the pores. The smectite is precipitated on the inner walls of the pores, linning the pores, while the pore bridging illite could entangle with the webby smectite to extensively restrict fluid flow. However, illite has been observed to critical affect permeability without affecting porosity. Micrograph (f) of figure 3 is that of Akata–2 Well. The photomicrograph shows the presence fibrous rod-like tubular structures with long dimension which precipitate on the walls of the inner surfaces of the pores and classified as pore linning minerals.

All the samples are from different oil fields but of Agbada Formation. However, samples L8P2S3 are outcrops of Nanka Formation which are the grading out part of the Agbada Formation.

4.0 Conclusion

The samples were all of Agbada Formation which is the formation that houses the producing sandbody of the Niger Delta Petroleum System [7].

The SEM analysis shows clay minerals that are pore filling (kaolinite), pore lining (chlorite and smectite) and pore bridging (illite).

The most frequently observed minerals where pore lining smectites and pore bridging illites. Kaolinites which are pore filling were not frequently observed.

The characteristic features of smectite and illite modify the pore morphology such that they restrict fluid flow but do not prevent fluid flow.

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