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Clay Minerals and its importance on Hydrocarbon Production Potential in a part of Geleki oilfield of Upper Assam Basin

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Abstract:

Prediction of reservoir characteristics becomes a key challenge for hydrocarbon exploration and development. A thorough understanding of clay minerals is important in understanding the reservoir characteristics as well as oil recovery efficiency. The present study is based on the analysis of clay minerals and their role on hydrocarbon production potential in a part of Tipam Reservoir Sand of Geleki oilfield of Upper Assam Basin. The study shows the presence of smectite, kaolinite, illite and mixed-layer. Smectite is the dominant clay mineral and mostly occurs as coating over detrital grains whereas kaolinite occurs as loosely-attached, discrete particles and the mixed-layer occurs as patchy pore linings which are found to play a major role in variation of the reservoir characteristics of the study area. Due to the reduction of intergranular pore volume and creation of microporosity, sometimes it is observed that high irreducible water saturation zones are developed which showing low resistivity value against oil bearing zones and creating problems in log interpretation. Again, kaolinite preferentially adsorbs oil which makes the reservoir rock oil-wet. According to Tang and Morrow (1999) during EOR, especially in Low Saline Waterflooding (LSW), the migration of fines (kaolinite) in sandstone reservoir increases the water wetness in the reservoir rock by exposing new underlying rock surfaces which improves the oil recovery efficiency.

Key words:* *Reservoir, minerals, oilfield, basin, smectite, kaolinite, illite, detrital.

Introduction:

Clay minerals have an important role on improved oil recovery effeciency as these minerals have different effects in controlling the reservoir characteristics, wettability and mobility of oil. Both authigenic and allogenic clays have different roles in modifying the reservoir properties and as a result have different roles on oil recovery efficiency. The variation of reservoir rock characteristics depend not only on the framework mineralogy but also on authigenic minerals and the composition, texture and structure of the rocks. Authigenic clays occur as pore linings, pore fillings, pseudomorphous replacements and fracture fillings, the origin of which can be established on the basis of clay composition, structure, morphology, distribution and sandstone textural properties. The presence of authigenic minerals strongly influences and controls the sandstone reservoir characteristics at different stages of the diagenetic history. Based on earlier works of Grim, 1951 and 1953; Griffiths, 1946 and Cox, 1950; it is observed that the different properties of clays such as a) Adsorption and desorption of water b) Cation exchange capacity and c) Flocculation and deflocculation have different effects. These properties are exhibited by montmorillonite to a marked degree, by illite to a much less degree and by kaolinite to a relatively unimportant degree (Hughes, 1950). In addition, smectite have also different roles on oil recovery during improve recovery techniques. When the fresher water comes in contact with smectite clay particles, swelling of clay occurs and thereby partially blocks the capillary openings in the sand reducing the rate of flow of oil to the well bore. Mechanical plugging caused by dislodgement and transportation of particles within the sand is also a significant factor in permeability reduction in the reservoir rock. Thus, the loss of permeability of a reservoir is attributed either by clay swelling in the rock pores, clay particle migration or the combination of these effects. Allogenic clays originate as terrigeneous material or are introduced subsequent to deposition as a result of bioturbation or infiltration.

Clay minerals have important effect on oil recovery process as it affects the displacement efficiency by changing wettability and mobility of oil during the application of IOR techniques. The geochemistry of sandstone diagenesis and clay mineral authigenesis is routinely applied to the problems of reservoir stimulation and enhanced oil recovery (Almon and Davies, 1981; Hearn et al., 1984). The precipitation of diagenetic clay minerals within the pore space sometimes creates serious problems in log interpretation (William, 1979; William and Davis, 1981). In addition, clay minerals also can give geologic information on deposition, diagenesis, tectonics, provenance, transport direction and geographical distribution of the associate sands. To understand the effect of clay minerals on reservoir characteristics, one must identify not only the type of clay minerals but also their origin, distribution and surface textures (Hurst and Archer, 1986).

Hence, a thorough understanding of clay minerals and its role is important in understanding and developing the hydrocarbon production potential of a reservoir. Keeping these views in mind, the present study has been undertaken for identifying and analyzing the clay minerals and also to evaluate their role on hydrocarbon production potential in a part of Tipam Reservoir Sands of Geleki Oilfield of Upper Assam Basin which is one of the major hydrocarbon producing oil fields of Upper Assam Basin.

Experimental Works:

For this present study, we have collected six numbers of subsurface core samples from a depth range of 2850-2966 meter of the study area. Clay minerals were identified and studied with the help of X-ray diffraction analysis and Scanning Electron Microscope (SEM). The study shows the presence of both authigenic and allogenic clays in the rock matrix of the study area.

X-ray diffractometric plots of the rock samples are presented in Figure 1 & 2. These plots show number of peaks the height of which is a function of the amount of clay present (Weaver, 1958). A comparison of diffraction pattern of unknown mineral phases with a set of standard pattern leads to their identification. Relative abundance of clay minerals was determined from the peak areas with the help of tables provided by Caroll (1972) and criteria suggested by Biscaye (1965) and Weaver (1958). Major clay minerals in most of these rock samples are mainly smectite [$Al_2Si_4O_{10}(OH)_2.nH_2O$] and kaolinite [$Al_2Si_2O_5(OH)_4$]. Other minerals present in the study area are illite, mixed-layer, quartz, mica and feldspar.

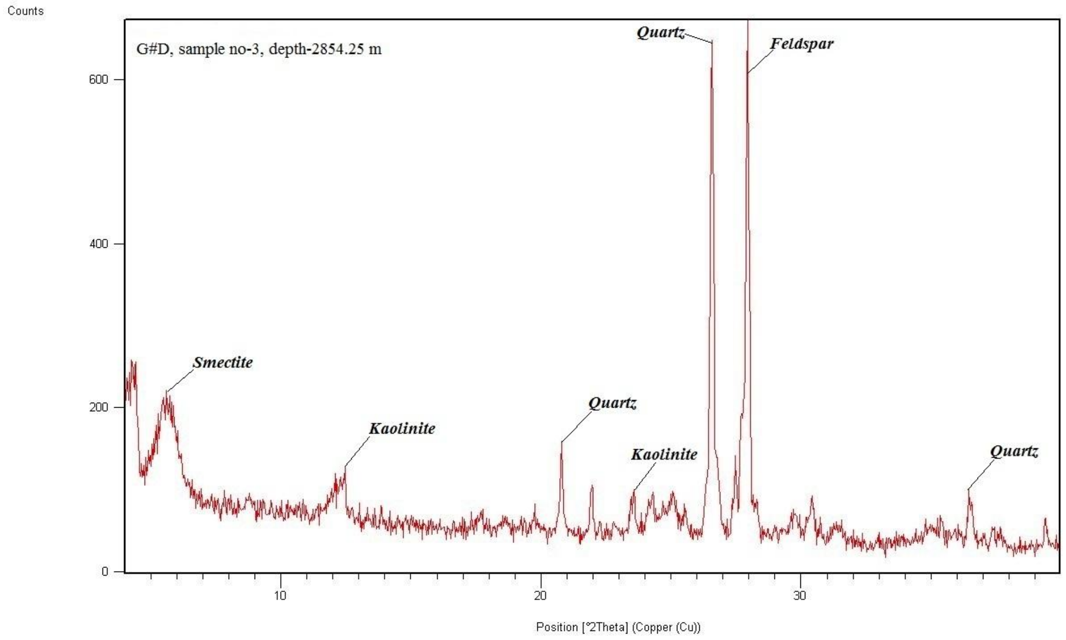

Figure 1: X-ray diffractogram of TS-5A of Geleki oil field containing Smectite, Kaolinite, Quartz and Feldspar

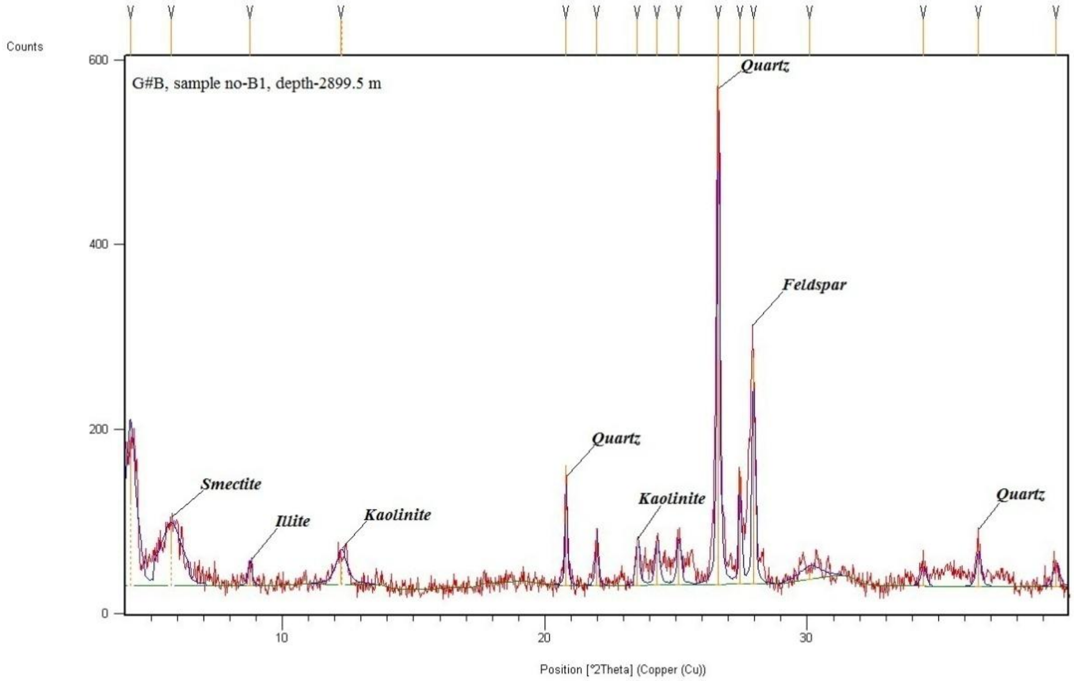

Figure 2: X-ray diffractogram of TS-5A of Geleki oil field containing Smectite, Illite, Kaolinite, Quartz and Feldspar

Scanning Electron Microscopic (SEM) analysis is done using Model- HITACHI S-3600N. Analysis is carried out using SE Detector and accelerating voltage of 20KV. Images are captured with scan speed (80/100s) / (50/60Hz) for micrograph. The SEM photographs of the selected rock samples are presented in Figure: 3, 4 & 5.

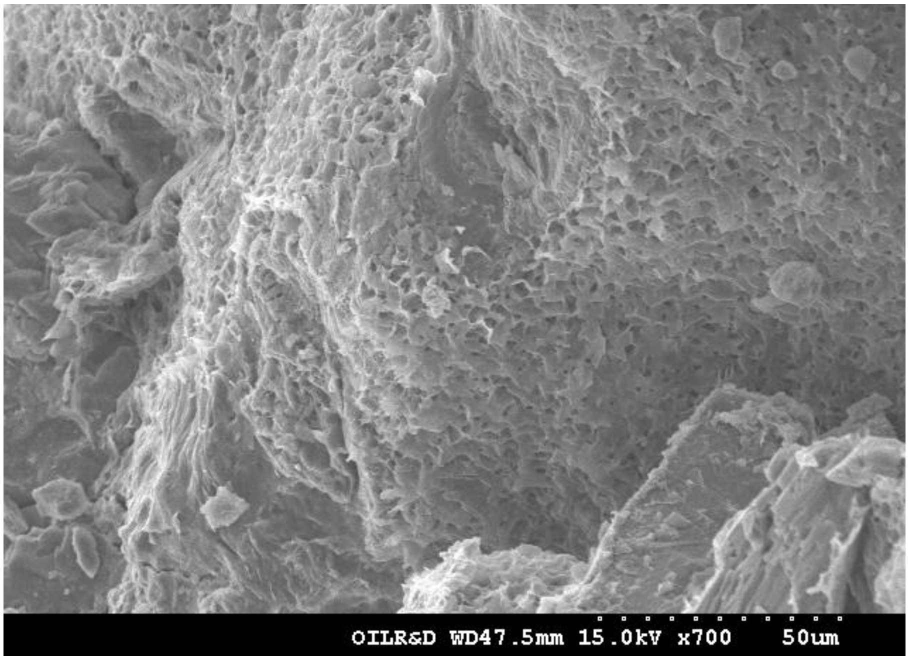

Figure 3: SEM photomicrograph of smectite showing wavy texture with spiny projection in the sample of G#B well of Geleki oil field (Depth: 2899.25 m).

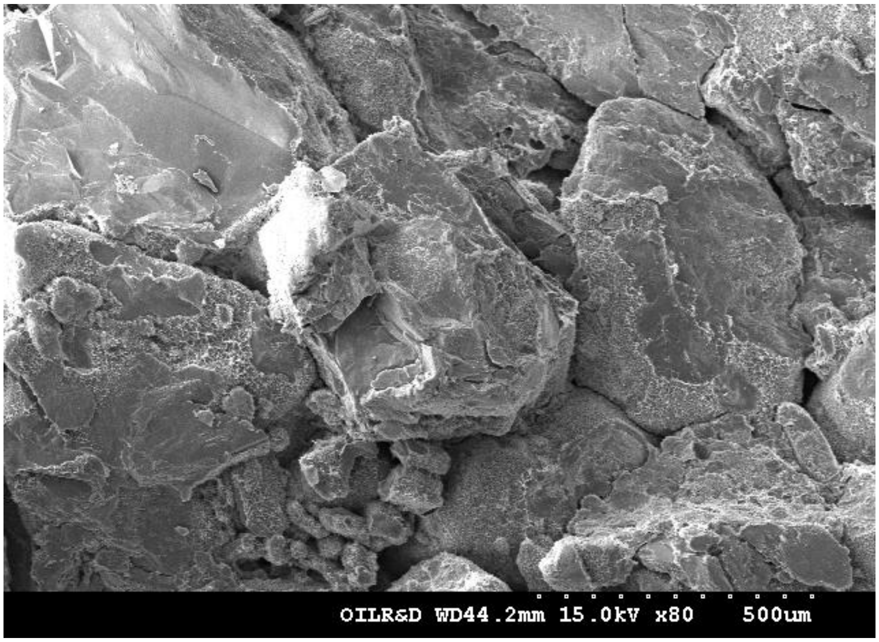

Figure 4: SEM photomicrograph showing smectite coated on detrital grains in the sample of G#C well of Geleki oil field (Depth: 2965.50 m).

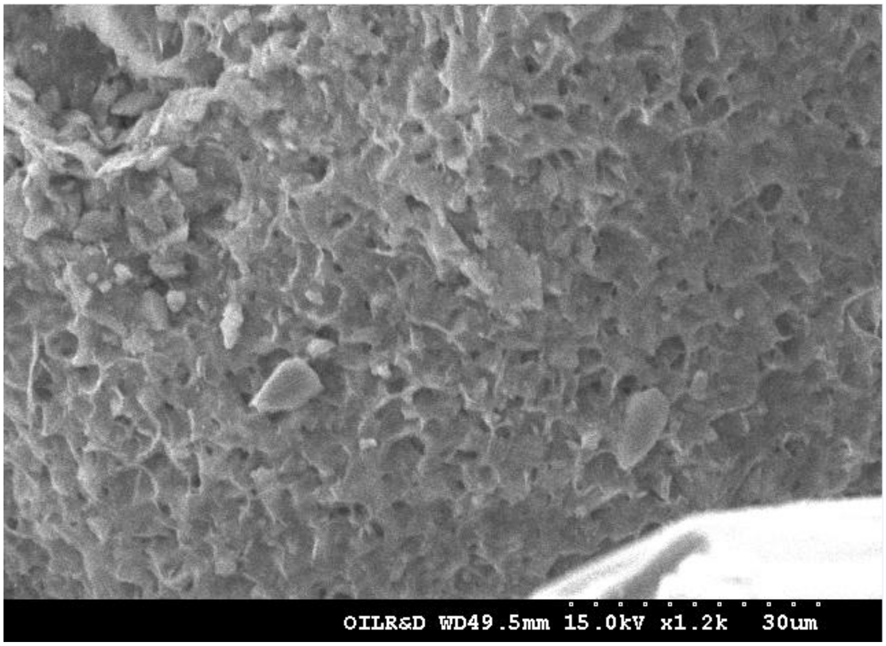

Figure 5: SEM photomicrograph showing illite-smectite and honeycomb like texture of the coating in the sample of G#B well of Geleki oil field (Depth: 2898.15 m).

SEM photographs shows that individual clay minerals are dispersed as matrix in the pore spaces and permeable channels of the sandstones. Sometimes intergranular pore spaces are partially blocked by clays which are mostly smectite and also smectite/kaolinite. Smectite is showing wavy texture with spiny projection (Figure 3). Smectite (dominant clay mineral) mostly occurs as coating over detrital grains (Figure 4), kaolinite occurs as stacked plates or in vermicular form and loosely-attached discrete particles and the mixed-layer occurs as patchy pore linings. Magnified SEM photograph of coating suggest this to be authigenic smectite showing honeycomb structure (Figure 5).

Discussion:

As mentioned earlier, clay minerals have a precise role in controlling the reservoir characteristics. Clay minerals were identified and studied with the help of X-ray diffraction analysis and Scanning Electron Microscope (SEM). Major clay minerals in most of these rock samples are found to be mainly smectite and kaolinite. Apart from these, illite, mixed-layer, quartz, feldspar and mica are also found to be present in the rock matrix of the study area. Reservoir characteristics such as porosity and permeability of reservoir rocks have been found to depend not only on the framework mineralogy but also on authigenic minerals and the composition, texture and structure of the rocks. The presence of authigenic minerals strongly influences and controls the sandstone reservoir properties. Most of the clay minerals occur as coating over the detrital grains and sometimes as dispersed matrix in the pore spaces and permeable channel of the reservoir rock. The fine, delicate honeycomb like structure of smectite (Figure 3) with finer outer edges indicates an authigenic origin.

The occurrence of clay minerals as dispersed matrix in the pore spaces and permeable channel of the reservoir rock affect the reservoir characteristics of the study area by reducing porosity and permeability. The precipitation of diagenetic clay minerals within the pore space degraded the original reservoir quality by creating microporosity. Smectite which mostly occur as coating and pore filling material on the detrital grains controls the physical and electrochemical properties of the rock due to their high surface area within the pore spaces. The occurrence of such clay coating may be due to the precipitation from pore fluid at certain pH and temperature conditions. As a result of the constrictions of inter-granular pore volumes and the permeable channels between the sand grains, primary porosity as well as permeability of the reservoir is reduced. Das (2006) and Medhi & Das (2014) also have observed similar observation in their study. This reduction of pore diameter affects the capillary pressure which in turn affects the oil recovery factor.

Earlier studies have also showed that clay minerals have important effect on oil recovery process as it affects the displacement efficiency by changing wettability of the reservoir rock and mobility of oil during the application of IOR techniques. Swelling of smectite clays reduce the permeability and thereby reduce the mobility of oil. Martin (1959), Bernard (1967) and Skauge (2008) have shown in their studies that, blocking of pore spaces improves the sweep efficiency by diverting the flow of injected water into new un-swept regions. Presence of smectite has also different roles on oil recovery during low salinity waterflooding. When low salinity water comes in contact with smectite, it swells and blocks some of the permeable paths of the reservoir rock (Das, 2006). This has two effects. Firstly, the injected water diverts its flow direction towards the un-swept area resulting in increase in oil recovery efficiency. Secondly, the swelling clays block the already existing permeable paths resulting in the adverse effect on injectivity.

According to Anderson (1987), during LSW, Multicomponent Ion Exchange (MIE) takes place which removes the organo-metallic complex and/or organic components from the clay surface and replace them with uncomplexed cations which lead to wettability modification toward more water-wet state. In 2006, Lager et. al. found exchange of cation between clay minerals and invading water during LSW where the mineral surface exchanges H^+ present in the liquid phase with cations previously adsorbed on the clay minerals and thereby increases the pH which in turn changes the wettability condition towards more water wet state.

Kaolinite, that occurs as stacked plates or in vermicular form suggesting authigenic structure which could also be counted as a significant constituent in determining the reservoir quality. Kaolinite preferentially adsorbs oil which makes the reservoir rock oil-wet. Tang and Morrow (1999) observed the migration of fines (kaolinite) in sandstone reservoir during LSW which increases the water wetness of the reservoir rock by exposing new underlying rock surfaces which in turn improves the oil recovery efficiency. Also, they observed a reduction of permeability in the reservoir rock which may be due to blocking some of the available pore spaces of the reservoir rock by the migrated kaolinite.

Thus, the success or failure of enhanced oil recovery (EOR) methods may be controlled to a large extent by the amount and type of clays in the formations to which the methods are being applied. Similarly, flakey habits of illite and kaolinite often bridge the pores which reduce the porosity and permeability. As per the earlier studies by Mohan et al, (1993), it is observed that kaolinite and illite which are non-swelling clay tend to detach from the rock surfaces and migrate with the injection water when the injection water has relatively low salt concentration. These migrating particles may get trapped in pore throats causing reduction of reservoir permeability.

From above it is seen that, the loss of permeability of a reservoir is attributed either by clay swelling in the rock pores, clay particle migration or the combination of these effects.

Again, the reduction of intergranular pore volume and creation of microporosity by smectite clay coating develops high irreducible water saturation zones in the reservoir. Due to which the resistivity log interpretation in the study area poses problems. The low resistivity value in logs against oil bearing zones sometimes mislead the interpreters about potential oil productivity and rather confuses them as water bearing zones. The primary reason for this low resistivity values is due to the development of high irreducible water saturation zones which could be developed due to the reduction of intergranular pore volume and creation of microporosity by smectite clay coating (Das, 1996).

Thus, it is seen that clay minerals play significant role in affecting the reservoir characteristics and resistivity of the reservoir fluid. These minerals also have important effect on oil recovery process as it affects the displacement efficiency by changing the reservoir rock wettability and mobility of oil during the application of IOR techniques.

Conclusion:

Based on the different studies on clay minerals, following conclusions are drawn.

1. Both allogenic and authigenic clay minerals are present and they play a definite role in modifying the reservoir characteristics of the study area.
2. Thick coating and bridging of clays over the detrital grains reduce the porosity and permeability. Hence the reservoir development in this study area is mainly controlled by series of porosity and permeability reduction and enhancement events.
3. Smectite in this sandstone reduces the permeability by creating microporosity. Due to the reduction of intergranular pore volume and creation of microporosity, sometimes high irreducible water saturation zones are developed which poses problems in log interpretation against oil bearing zones by showing low resistivity value.
4. Clay minerals also have important effect on oil recovery process as it affects the displacement efficiency by changing the reservoir rock wettability and mobility of oil during the application of IOR techniques.

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