Pakistan Journal of Applied Sciences 3 (10-12): 604-613, 2003
ISSN 1607-8926

The Types of Clay Minerals in the Kongdian Formation (Upper Part), South Slope of the Dongying Depression, East China

[1,2]Mutwakil Nafi, [1]Fei Qi and [1]Yang Xaing Hua
[1]Department of Petroleum Geology, China University of Geosciences, Wuhan 430074
[2] Faculty of Earth Sciences and Mining, Dongola University, Sudan

Abstract: The Upper part of the Kongdian formation of the Paleocene-Eocene age consists mainly of fine to medium feldspathic sandstone. Samples analyzed are from depths of 1572.55 to 2298m, representing a temperature range of 60.5 to 88.5°C. The authigenic clay minerals are composed of the following: illite-smectite mixed layer, illite, kaolinite, and chlorite (not detected in the samples). The dominant clay minerals are illite/smectite mixed layer, illite, and kaolinite respectively. The I/S mixed layer occurs as irregular flakes with short lath-like projection. The illite is also formed as irregular flakes with short lath-like projection. The authigenic kaolinite occurs as pseudohexagonal plates and pseudohexagonal-staked plates. The authigenic clays occur as pore linings and pore fillings. The major mineralogical change with depth takes place over the interval involving smectite conversion into illite or I/S mixed layer, increasing the amount of illite, and decreasing the amount of kaolinite.

Key words: Kongdian formation, bohai bay basin, dongying depression

Introduction

X-ray diffraction (XRD) is a basic tool in the mineralogical analysis of fine-grained material that is difficult to study by the other means (Tucker, 1988). The most common application of X-ray diffraction (XRD) on the sediments is for the analysis of the whole sample. This technique enables the structural identification of minerals combined with the Scanning Electron Microscopic (SEM) and also the thin section (Brindley, 1951; Brindley and Brown, 1980). The XRD is useful in the analysis of the whole powdered rock, which provides information on the main sedimentary components of the fine-grained clastic sandstone without supportive techniques. The XRD is used in the analysis of sandstone and mudstone for determining detailed clay mineralogy. The analysis of clay mineralogy can be useful for provenance studies and gives information on the burial history of the formation. The XRD can be applied to diagenetic problems, to study depth-related mud rock mineralogy, and is useful in identifying the authigenic clay minerals (Burst, 1959,1969; Hower, 1976; Willson and Pittman, 1977; Boles and Franks, 1979).

Geologists in the past have used thin sections of rock under the Petrographic microscope in two-dimensional rock. Now geologists are able to use the Scanning Electron Microscope (SEM) complemented with thin sections to study pores and to identify the smallest minerals within the pores in three-dimensional analysis. The SEM can be applied to the study of the quality and quantity of clay cement that affects reservoir properties, to provide a fairly good three-dimensional representation of pore cracks and channels, and to study the factors that affect reservoir properties (Sarkisyan, 1971). As a modern technique, the SEM is used widely in combination with standard methods for a variety of geological problems. These problems range from evaluation of reservoir quality through diagenetic studies to the investigation of production problems. The SEM is an essential tool used for the study of porous sandstones, diagenetic minerals, and the investigation of the morphologies and detailed textures of grain overgrowth (Wilson and Pittman, 1977; Burley ***et al.***, 1985).

Geological Setting

The Bohai Bay Basin belongs to the Eastern region basins (onshore) and is sometimes known as the Gulf of Bohai Basin. The basin is bounded by: the Yanshan in the north, the Taihangshan mountains in the west, and the Luxi and Jiaoliao uplifts in the east and northeast. The Bohai Bay basin is located in Northern China (115° to 122° E longitude, and 36° to 42° N latitude), and has an area of 200,000 sq km (Fig. 1). The Bohai Bay Basin is characterized by its formation in the Tertiary age as part of the Northern China Platform and comprises many depressions (such as Ba Xian, Raoyang, Jin Xian, Qiu Xian, Dongpu, Banqiao, Dongying, etc.). The basin contains rocks of the Archean, Proterozoic, Paleozoic, Mesozoic, and Cenozoic periods. The basin was center of major Tertiary tectonic activity and controlled primarily by the movement of the Pacific plate. The hydrocarbons present were generated during the time of basin formation and migrated over a short distance. The subsidence of this basin may be fault depressions or down warps. During

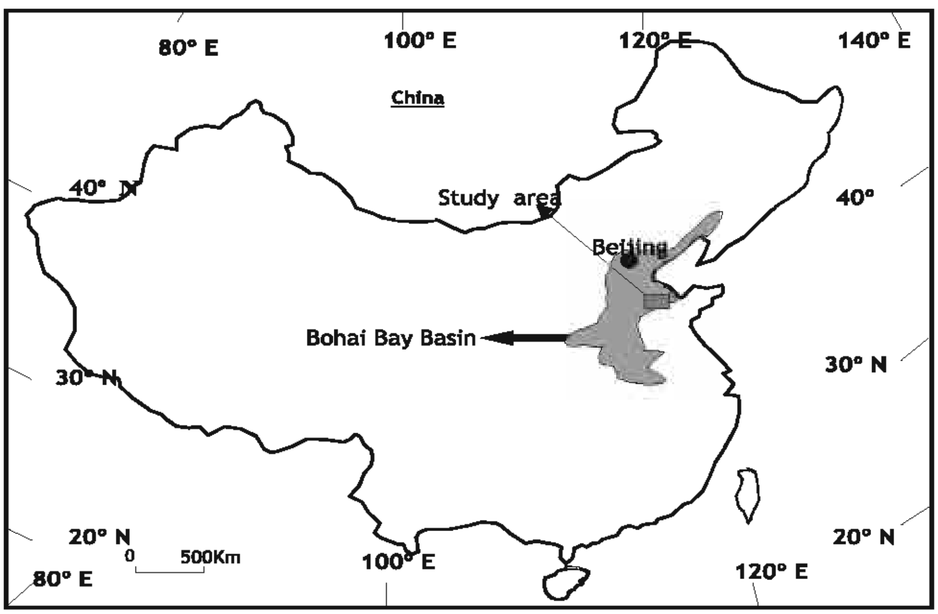

Fig. 1: Shows the location map of the study area

the tertiary period the depositional environment in the basin consisted of continental life in fresh to brackish water (Ma li ***et al.***, 1982; Tang Zhi, 1982; Hu ***et al.***, 1989). The Cenozoic strata in the Bohai Bay Basin are divided into the Kongdian formation of the Paleocene-Eocene age, the Shahejie formation of the Eocene-Oligocene age, the Dongying formation of the Oligocene age, the Guantao formation of the Miocene age, and the Minhuazhen formation of the Pliocene age (Hu ***et al.***, 1989).

The Kongdian formation is divided into three parts: lower, middle, and upper part. The lower part, of the paleocene age, is characterized by purple and brown mudstone interbeded with sandstone, basalt, and conglomerate at the bottom. The middle part, also of the Paleogene age, is characterized by fluvial marsh deposits, dark grey and light grey mudstone interbeded with siltstone, carbonate, oil shale, thin coal bed, and limestone. The dark mudstone might be the source rock in the basin. The upper part, of the paleocene-eocene age, is characterized by grey, green, brown and white fluvial facies (Nafi, 2003). The fluvial facies is composed of mudstones intercalated with sandstones and siltstones. This study is concerned only with the Upper part of the Kongdian formation of the paleocene-eocene age.

Materials and Methods

Eighteen samples of mudstones were taken from the upper part of the Kongdian formation. These samples were subjected to XRD analysis and the results are summarized in Table 1. The X-ray tube used is FK60 Cu anode type with a monochromatic filter. The scanning was carried out

Table 1: Shows the percentage of the clay minerals in the Upper part of the Kongdian formation for mudstone samples (X.R.D)

Well Name	Sample No.	Illite	Kaolinite	Illite-smectite Mixed layer	Depth (m)
Wang130	10	20%	10%	70%	2182.80
Wang130	12	20%	15%	65%	1970.00
Wang130	13	20%	15%	65%	1969.79
Wang130	17	20%	15%	65%	1953.78
Wang130	18	30%	20%	50%	1902.30
Wang130	20	30%	20%	50%	1900.05
Wang130	21	15%	15%	70%	1804.25
Wang130	22	20%	20%	60%	1754.35
Wang130	24	20%	20%	60%	1750.50
Wang110	1	10%	10	80%	2301.67
Wang96	2	25%	10%	65%	1919.66
Wang96	4	32%	23%	45%	2155.29
Wang96	7	30%	10%	60%	2190.50
Wang96	8	20%	15%	65%	2186.80
Wang96	9	25%	15%	60%	2161.29
Wangxie95	2	15%	20%	65%	1844.00
Wangxie95	4	15%	15%	70%	1836.90
Wangxie95	7	20%	15%	65%	1797.72

from 3° to 33°. Through the whole analysis, the voltage was 40 K.V, the current was 30 Am and the scanning speed was 1° min^{-1}. The minerals in mudstone samples were identified according to the behavior of D-spacing (Carroll, 1970; Thorez, 1975). The clay minerals identified include I/S mixed layer, illite, and kaolinite.

About 24 samples were taken from the upper part of the Kongdian formation representing different depths. These samples were subjected to SEM analysis. The samples were prepared with following criteria: (a) They must be from a fresh rock surface, (b) Contaminated with drilling mud must be avoid, © Avoid handing the samples with fingers, (d) The sample volume is generally 5mm*10mm*10mm, (e) The sample is attached to copper specimen plug with epoxy and dried overnight in a low temperature-drying oven, (f) The sample is coated with a conductive metal such as carbon or gold. After the coating the sample is ready for the SEM.

Results and Discussion

The sandstones of the Upper part of the Kongdian formation in the study area are characterized by a depth range from 1572.55 to 2298 m and geothermal gradient from 3.7 to 4.0°C/100 m, the geothermal temperature range is from 60.5 to 88.5°C, and represents shallow diagenesis stage (Hu ***et al.***, 1989; Nafi, 2003). The authigenic clay minerals in the reservoir sandstones of the Upper part of the Kongdian formation are composed of illite-smectite mixed layer, illite, and kaolinite (Figs. 4 to 17). The authigenic non-clay minerals consist of quartz overgrowth, calcite, dolomite, and feldspar overgrowth (Figs. 3, 4, 5, 11). The authigenic clay minerals are characterized by: (I) Pore filing and pore lining. (ii) Pseudomorphous replacement. (iii) Fracture fillings. The authigenic clays are differentiated from allogenic clays by the delicacy of clay morphology, the occurrence of clay as pore linings absent only at grains contacts, and composition. The authigenic clay was formed as a direct precipitation from formation water (neoformation) or formed by reaction between precursor material and contained waters (regeneration). The replacement clays are those that were partially or completely replaced detrital grains or infilling void left by dissolution of detrital grains (Wilson and Pittman, 1977). Kaolinite is the most commonly recognized minerals in sandstones and this mineral is characterized by: (1) The mineral occurs as pore filling or pore lining. (2) The morphology of this mineral may be as pseudohexagonal plates. (3) Pseudohexagonal-stacked plates. (4) Pseudohexagonal vermicular form. The kaolinite can be formed by recrystalline from solution or in situ by alteration of parent minerals, and by recrystalline of fine-grained detrital kaolinite material. The authigenic kaolinite minerals are found in various types of sandstones arenite, lithic, and arkosic sandstones. Authigenic kaolinite is found in various genetic environments: deltaic, alluvial, and shallow marine (Shelton, 1964; Wilson and Pittman, 1977). The authigenic kaolinite in the studied reservoir of the upper part of the Kongdian formation is characterized by: (a) Occurs as pore filling. (b) Its morphology occurs as pseudohexagonal plates and pseudohexagonal-stacked plates. The kaolinite may be formed by recrystalline from solution or formed in situ by alteration of parent minerals feldspar (Fig. 8, 9, 10, 12, 15). The source of the silica solution was derived from, (1) Siliceous shales, (2) Volcanic glass, (3) Decomposition of feldspar (Fig. 2) and mica. (4) Solution of silica organism. (5) Precipitation from river water or

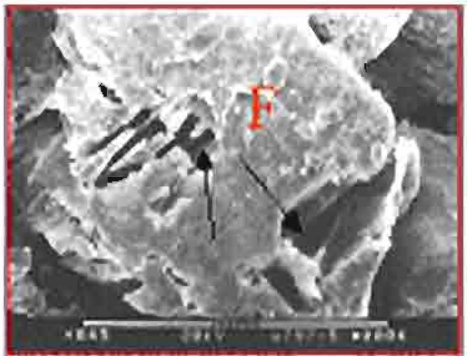

Fig. 2: Feldspar dissolute to release silica, (F) Feldspar, Arrows show porosity. Upper part of the Kongdian formation, depth at 1920.31 m

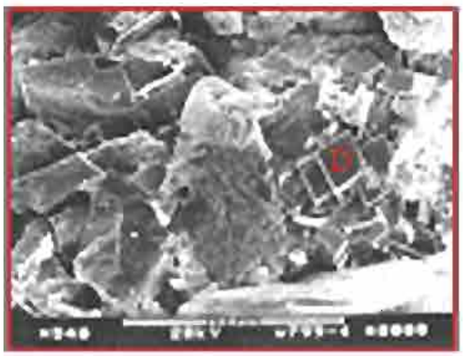

Fig. 3: Carbonate cement, (D) dolomite. Upper part of the Kongdian formation, depth at 2155.89 m

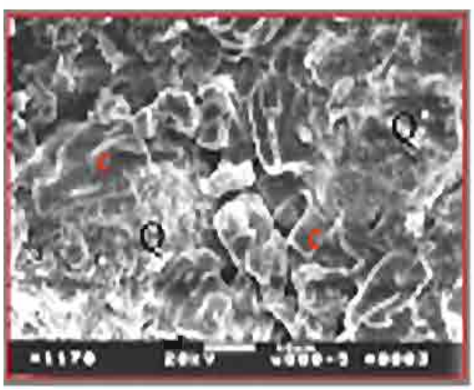

Fig. 4: © calcite, calcite dissolute to form secondary porosity, (Q) quartz coating by I/S. Upper part of the Kongdian formation, depth at 2192.10 m

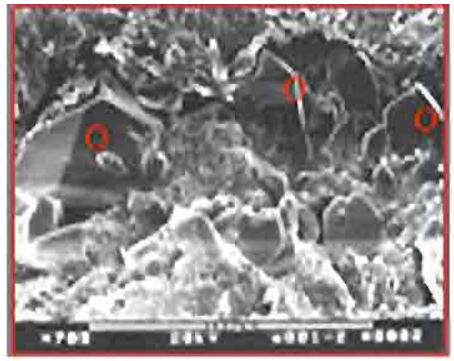

Fig. 5: Quartz overgrowth (O). Upper part of the Kongdian formation, depth at 2228.0 m

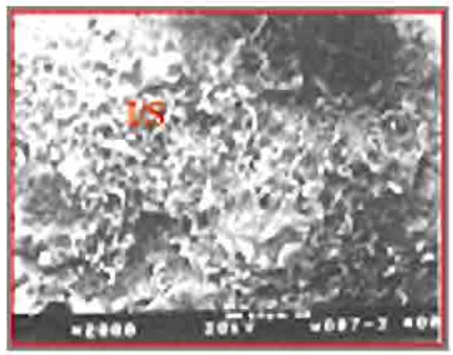

Fig. 6: Pore filling I/S mixed layer. Upper part of the Kongdian formation, depth at 2190.7 m

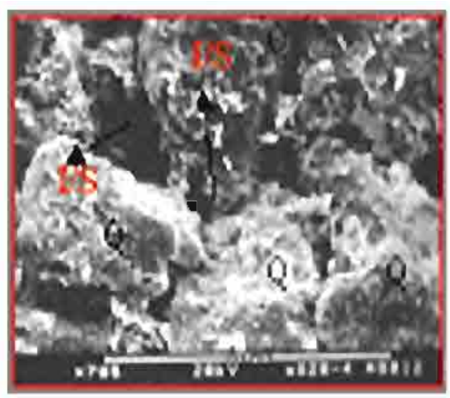

Fig. 7: Arrow shows I/S mixed layer is coating the grains of quartz (Q). Upper part of the Kongdian formation, depth at 1572.55 m

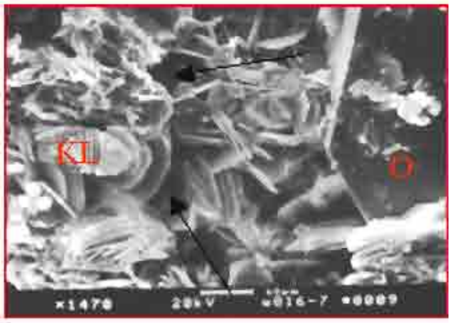

Fig. 8: Stacks of pseudohexagonal plates of Kaolinite (KL) from intercrystalline porosity (arrows), quartz over growth (O). Upper part of the Kongdian formation, depth at 1847.05 m

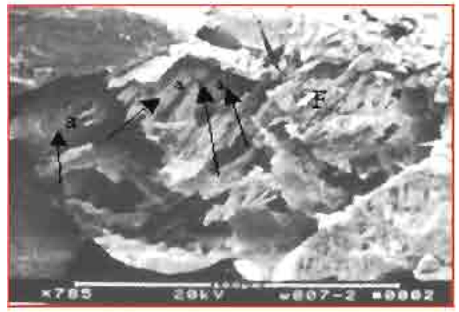

Fig. 11 Shows feldspar (F) dissolution, formation of feldspar overgrowth (a) (arrows). Upper part of the Kongdian formation, depth at 2190.71 m

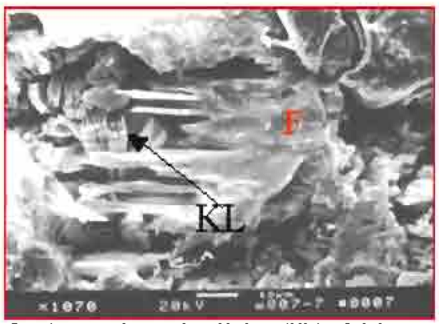

Fig. 9: Arrow shows kaolinite (KL), feldspar (F) Altering direct to kaolinite books. Upper part of the Kongdian formation, depth at 2190.71 m

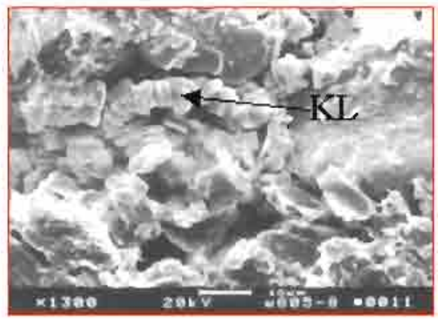

Fig. 12: Stacks of pseudohexagonal plates or books of pore filling of Kaolinite. Upper part of the Kongdian formation, at depth 2194.41 m

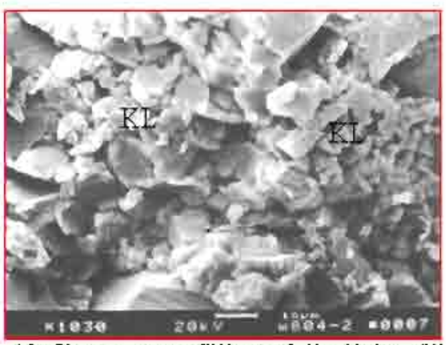

Fig. 10: Shows pore filling of Kaolinite (KL). Upper part of the Kongdian formation, depth at 2223.00 m

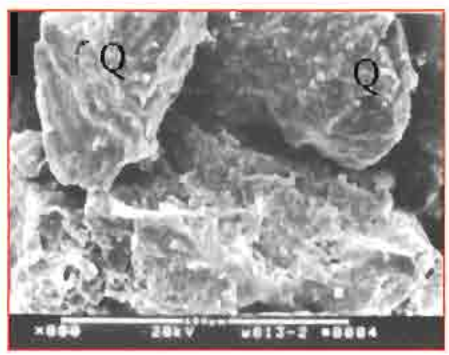

Fig. 13: Quartz (Q) grains coating by I/S Mixed layer. Upper part of the Kongdian formation, at depth 2194.41 m

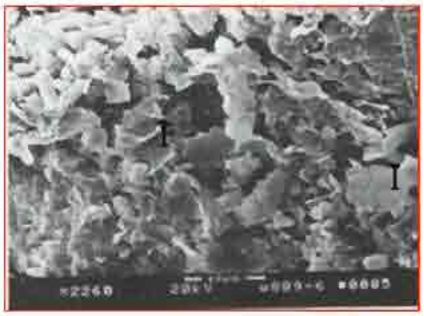

Fig. 14: Pore filling of illite (I) with short lath-Like projection. Upper part of the Kongdian formation, at depth 1964.35 m

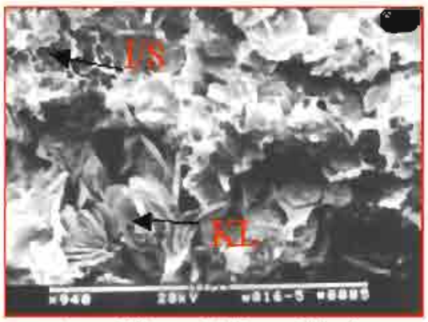

Fig. 15: Pore filling of I/S and Kaolinite (KL), the authigenic I/S mixed layer and kaolinite are formed together. Upper part of the Kongdian formation, at depth 1874.5 m

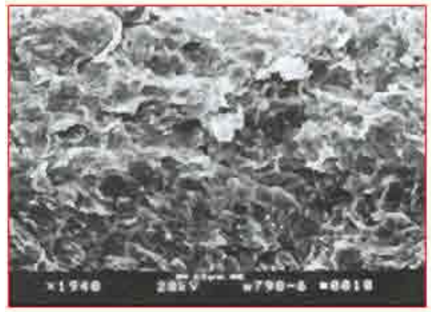

Fig. 16: Pore filling of I/S mixed layer, with short lath-Like projection. Upper part of the Kongdian formation, at depth 1938 m

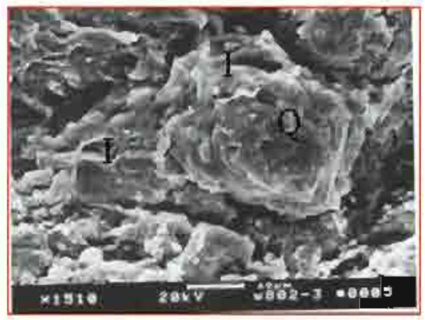

Fig. 17: Pore lining and pore filling of illite (I), quartz (Q) coating by illite. Upper part of the Kongdian formation, at depth 1938 m

seawater, (6) Silica released by the illitization of smectite, (7) The potassium was released from illite and reacts with CO_2 to form K_2CO_3, a high ph micro environment at grain contacts, which leads to the dissolution of the quartz (Waught, 1970; Pittman, 1972; Boles and Franks, 1979). The mixing of the fresh acidic waters with the more alkaline indigenous waters would decrease the acidity of the percolating waters, leading to decrease in the solubility of silica and alumina, and this would result in the precipitation of quartz overgrowths and possibly kaolinite (Al-Gailani, 1981). The authigenic illite, existing as pore filling and pore lining, generally occurs as irregular flakes with long lath-like projections or with short lath-like projections (Wilson and Pittman, 1977; Al-Gailani, 1981). The circulation of alkaline waters would result in the hydrolysis, carbonation or partial replacement of almino-silicates, and K-feldspar would lead to the liberation of K^+, bicarbonate and silicon into the pore system. Consequently, the fluid in the pore system would be enriched with K^+, Ca^{2+}, Al^{3+}, Si^{4+} and HCO^-_3, and this alkaline rich environment leads to formation of illite and depletion of K^+ and Al^{3+}, leading to the formation of authigenic feldspar

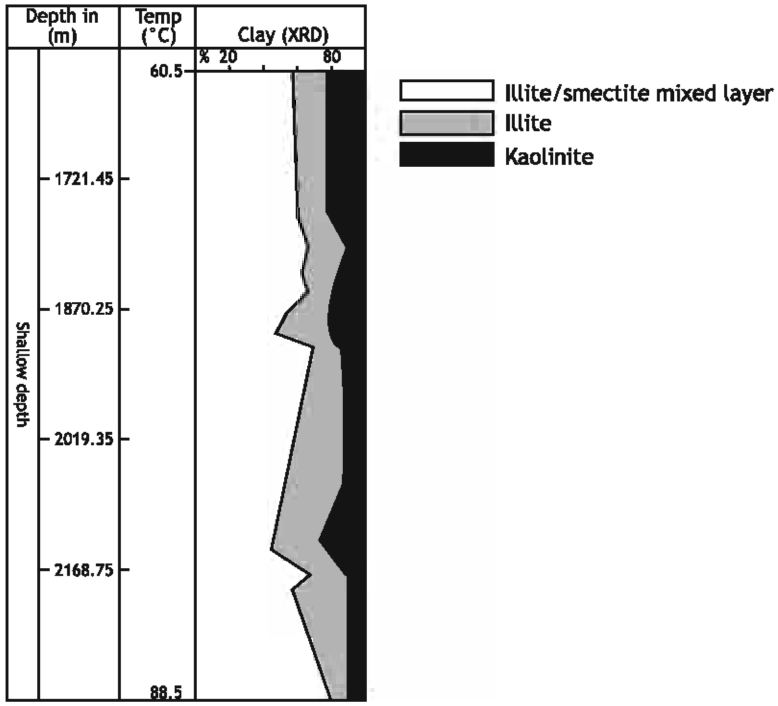

Fig. 18: Shows distribution of clay minerals through the upper part of the Kongdian formation

(Fig. 11) (Al-Gailani, 1981). The illite in the study area is characterized by: (a) Occurs as irregular flakes with short lath-like projection. (b) The illite occurs as pore lining and pore filling. © Forms in an alkaline environment (Figs. 14, 17). The authigenic I/S mixed layer occurs as pore lining or pore filing. The illite-rich mixed layer may resemble sheets with short lath-like projection. [Caution: distinguishing illite and smectite from the mixed layer using only the SEM can be misleading (Wilson and Pittman, 1977; Al-Gailani, 1981)]. The formation of illite, smectite, calcite and dolomite would also be favored by alkaline conditions, consequently increasing in depth of burial, accompanied by an increase in temperature leading to conversion of smectite to a mixed layer of illite-smectite (Al-Gailani, 1981). The I/S mixed layer in the study area occurs as irregular flakes with short lath-like projection and occurs as pore lining and pore filling. Its formation may be due to conversion of smectite to mixed layer illite-smectite with increase in depth and temperature (Figs. 4, 6, 7, 13, 15, 16).

Fig. 18 reflects that the clay consists of I/S mixed layer, illite, and kaolinite. The I/S mixed layer is the most abundant mineral in the clay samples. The chlorite was (not detected in the samples). Kaolinite content decreases with depth, and illite content increases with depth. The major mineralogical change with depth takes place over the interval 2000 to 3700 m involves: (1) The most abundant mineral I/S mixed layer undergoes a conversion from less than 20 to 80% illite. (2) Smectite conversion into illite or I/S mixed layer with a high portion of illite with an increase with depth. (3) The chlorite content increases with depth (Hower, 1976). The mineralogical change with depth simply results from dehydration of smectite under high pressure and temperature (Hower, 1976). Breakdown of detrital K-feldspar and some of smectite layers in I/S convert other smectite layers to illite (Boles and Franks, 1979). The mineralogical change includes: the conversion of smectite to illite, the decomposition of mica and potassium feldspar, the loss of kaolinite, and the formation of chlorite (Hower, 1976). As the depth-dependant mineralogical variation recognized, I/S is the most abundant mineral in shale, the potassium feldspar decreases with depth, the chlorite is absent in all samples from a depth shallower than 2500 m, and kaolinite content decreases abruptly below 3400 m (Hower, 1976). Weaver and Beck (1971) suggested that after the decomposition of potassium feldspar, potassium necessary for the conversion of smectite to illite intrudes into shale from greater depth, and the decomposing of feldspar and mica releases silicon to form quartz overgrowth. The younger shale and recent argillaceous sediments are relatively enriched in kaolin and mixed layer clay than the older shale (Pre Mesozoic). This old shale is depleted in these phases and enriched in illite and chlorite (Weaver, 1989). The decrease in kaolinite content may not be strictly due to proposal burial metamorphism, but this may at least partly explain its decrease in abundance at greater depth (Hower, 1976). Silica and calcium released by the illitization of smectite is transferred from shales to sandstones to produce quartz overgrowths and calcite cement at temperatures as low as 60°C (Boles and Franks, 1979)

Thus it can be concluded that the upper part of the Kongdian formation clay samples consist of I/S mixed layer, illite, and kaolinite. The I/S mixed layer is the most abundant mineral in mudstone. The absence of chlorite was because due to the fact that chlorite does not appear in a depth shallower than 2500 m. Potassium is of prime importance in the conversion of smectite to illite. The source of potassium was from: the decomposition of K-feldspar and mica, the breakdown of some smectite layers in illite. The decomposition of feldspar and mica released silicon and this silicon formed quartz overgrowth. Silica and calcium released by the illitization of smectite transferred from mudstone to sandstones to produce quartz overgrowth and calcite cement. The decrease of kaolinite may not be due to burial metamorphism, but the burial metamorphism may at least explain its decrease in abundance at greater depths.

Acknowledgments

I would like to express my appreciation to my friends Stephen Donyinah from Ghana and Neil Kirkland from Canada for revising the final manuscript.

References

Al-Gailani, M.B., 1981. Authigenic mineralization at unconformities: Implication for reservoir characteristics. Sed. Geology, 29: 89-115.

Boles J.R. and S.G. Franks, 1979. Clay diagenesis in Wilcox sandstone of southwest Texas: implications of smectite diagenesis on sandstone cementation. J. Sedim. Petrol., 49: 55-70.

Brindley, G.W., 1951. X-Ray identification and crystal structures of clay minerals, mineralogical society, London, pp: 345.

Brindley, G.W. and C. Brown, 1980. Crystal structures of clay mineral and their x-ray identification mineralogical society monograph, 5, mineralogical society, London, pp: 455.

Burley, S.D., J.D. Kantorowicz and B. Waugh, 1985. Clastic diagenesis, In brenchley, P.J. and Williams, B.P., Eds., Sedimentology: Recent and Applied Aspects: geological society of London special publication, pp: 189-226.

Burst, J.F., 1959. Post diagenetic clay mineral environmental relationships in the Gulf Coast Eocene. Clays Clay Miner., 6: 327-341.

Burst, J.F., 1969. Diagenesis of Gulf Coast clayey sediments and its possible relation to petroleum migration. Am. Ass. Petrol. Geol. Bull., 6: 73-93.

Carroll, D., 1970. Clay minerals: A guide to their X-ray identification. Geo. Soc. Am. Spec. Pap, Geological society of America, pp: 126.

Hower, J., 1976. Mechanism of burial and metamorphism of argillaceous sediment. I. Mineralogical and chemical evidence. Bull. Geol. Soc. Am. Am. Spec. Pap, 126. Geological society of America, 87: 725-737.

Hu, J., S. Xu, X. Tong and H. Wu, 1989. The Bohai bay basin. In: Zhuxia, Ed Chinese sedimentary basins: Elsevier, Amsterdam, pp: 89-105.

Ma Li, Ge Taisheng, Zhao Xueping, Zie Taijun, Ge Rong, and Dang Zhenrong, 1982. Oil basins and subtle traps in the eastern part of China, in the deliberate search for the subtle trap: AAPG Memoir, 32: 287-315.

Nafi, M., 2003. Diagenesis of Kongdian formation (upper Part), South part of dongying depression, East China: [Dissertation]. China. China Univ. of Geosciences.

Sarkisyan, S.G., 1971. Application of the SEM in the investigation of oil and gas reservoir rocks: J. Sed. Pet., 41: 289-292.

Shelton, J.W., 1964. Authigenic kaolinite in sandstone: J. Sed. Pet., 34: 102-111.

Tang Zhi, 1982. Tectonic features of oil and gas basins in eastern part of China: AAPG Bulletin, 66: 509-521.

Thorez, J., 1975. Pyllosilicates and clay minerals- a laboratory hand book for their X-ray diffraction analysis. Dison, (Belgique), pp: 582.

Tucker, M.E., 1988. Techniques in Sedimentology. Black Wells Oxford, pp: 191.

Waugh, B., 1970. Petrology, provenance and silica diagenesis of the Penrith Sandstone (Lower Permian) of north west England. J. Sed. Pet., pp: 1226-1240.

Weaver, C.E., and K.C. Beck, 1971. Clay-water diagenesis during burial: How mud becomes genesis: Geol. Soc. America Spec. Paper, 134: 96.

Weaver, C.E., 1989. Clays, Muds, and Shales. Developments in Sedimentology 44, Elsevier Publishing Co. New York, pp: 819.

Wilson, M.D. and E.D. Pittman, 1977. Authigenic clays in sandstone: recognition and influence on reservoir properties and paleoenvironment analysis. J. Sedim. Petrol., 47: 3-31.