Bulletin of the Geological Society of Malaysia, Volume 70, November 2020, pp. 29 - 38
DOI: https://doi.org/10.7186/bg70202003

Green glauconitic marl bed as a sequence stratigraphical key for interpretation of contact between Qamchuqa and Bekhme formations in Bekhal area, Kurdistan region, NE Iraq

Mohammad Sadi Nourmohamadi[1], Rzger A. Abdula[1,2,*], Fawzi Albeyati[3], Arkan O. Sharezwri[1], Edres M. Perot[1], Shamsadin E. Jassim[1], Nechirvan H. Othman[1]

[1]Department of Petroleum Geosciences, Soran University, Soran, Kurdistan Region, Iraq
[2]Petroleum Engineering and Mining Department, Tishik University, Erbil, Kurdistan Region, Iraq
[3]Technical Collage of Kirkuk, North Technical College University, Kirkuk, Iraq
* Corresponding author email address: rzger.abdulkarim@tiu.edu.iq

Abstract: This study incorporates a study of stratigraphy and sedimentology of the green glauconitic marl bed between Qamchuqa and Bekhme Formations in selected section of the Iraqi Kurdistan region. The studied area is located in Gali Garukaju near Rwanduz in Erbil Governorate, northeastern Iraq. Instead of Basal Conglomerate bed, the thin beds of green glauconitic marl occurs along the contact between Qamchuqa and Bekhme Formations in the studied section. Six samples were collected from this section, two samples for XRD and four samples for petrography analysis. Samples for XRD and petrographic analysis were taken from green glauconitic marl beds at the contact between two formations and from upper contact of Qamchuqa Formation and lower contact of Bekhme Formation. XRD analysis data proved the presence of glauconite in green marl bed. General petrographic observations of other remaining four samples in thin sections reveal that the upper contact of Qamchuqa Formation and lower contact of Bekhme Formation are dolomite and dolomitic limestone. The dolomite bed represents type 1 or type 2 depending on the thickness and extension of dolomite bed. Color, morphology, maturity and abundance of glauconite grain were the dominant factors used in the determination of the surface between the two formations. The result emphasizes that the surface was not a gradational surface consisting of low stand and condensed system tract (LST/CS). Two factors, color and morphology, of glauconite grains were analyzed by binocular microscope under reflected light. The morphology of most glauconite grains in this section is ovoidal and tabular with green to dark green in color. Based on these two factors the glauconite grains were within stages 3 and 4 of McCracken *et al*. (1996) classification and can be interpreted as evolved and high evolved in view of maturity. The presence, increase in concentration and mature grains of glauconite (evolved and high evolved) in marl beds at lower part of Bekhme Formation indicate transgressive or maximum flooding surfaces.

Keywords: Glauconite, Bekhme Formation, Qamchuqa Formation, Cretaceous, Gali Garukaju, Iraq

INTRODUCTION

The names glauconite and glaucony originated from the Greek “glaucos” for blue green color (McRae, 1972; Compton, 1989). The term glauconite should be restricted to a dark green, mica-type glauconitic mineral, whereas the general term glaucony should be used to designate green pellets enriched in glauconitic minerals, especially when precise mineralogical connotation is lacking (Odin & Matter, 1981).

Glauconite is an iron rich variety of clay that can be found as individual pellets, composite grains, and intergranular cement. Identifying glauconite in the subsurface is important for depositional environment interpretation, stratigraphic correlation, dating, tracing of unconformities, and geochemical exploration for source and reservoir rocks (Srivastava, 1986). The glauconite is a puzzling mineral, it can replace different minerals such as quartz, calcite, dolomite, shell fragments, and phosphatic minerals. It can also form inside the intestine of animals on the bottom of the shallow shelf. Recently, it can be formed in the unconformity surfaces, replacing calcite and dolomite (Khalifa, 1983). Modern glauconite is commonly reported as forming slowly, under low-energy conditions, in mid-shelf to deeper-water environments (Dias & Nittrouer, 1984; Bornhold & Giresse, 1984; O’Brien *et al*., 1990; Rao *et al*., 1993). Glauconite-rich continental margin sediments are generally associated with condensed sections, unconformities, transgressive system tracts or maximum flooding surfaces (Loutit *et al*., 1988; Kelly & Webb, 1999; Harris & Whiting, 2000). Abundant glauconite indicates diagenesis of terrigenous material during periods of low sediment accumulation in water depths ranging from 50 to 500 m on the outer shelf/ upper slope (Kitamura, 1998; Chafetz & Reid, 2000; Hesselbo & Huggett, 2001). The formation of glauconite commonly occurs in mixed redox environments near the oxygen- minimum zone under regions of high productivity in association with other diagenetic minerals inorganic- rich sediment such as pyrite, carbonate fluorapatite and dolomite

(Mozley & Carothers, 1992; Stille & Clauer, 1994; Malone *et al*., 2002).

Within glauconite beds, this companion of dolomite, pyrite, and gluoconite can be seen. Glauconite is a common authigenic constituent of modern continental shelf sediments as well as of pre Cambrian to Pleistocene sedimentary deposits (Odin & Letolle, 1980). The formation of glauconite grains (glauconization) occurs commonly in shelf environments with low sedimentation rates, low terrigenous material supply, suitable substrates, and the requisite physicochemical conditions (e.g., low turbulence, low temperatures, slightly reducing conditions, and an abundant supply of iron and potassium (Odin & Matter, 1981). Thus, glauconite is not only a stratigraphic tool, but also an indicator of depositional environment type. In recent years, glaucony is commonly used as an index mineral in sequence stratigraphy. It especially gets concentrated during the periods of sedimentary hiatuses of rapid sea level rises or at maximum flooding surfaces (Amorosi, 1995, Udgata, 2007).

Wetzel (1950, in Bellen *et al*., 1959) believed that the conglomerate bed represents an unconformity feature between the Qamchuqa Formation and the overlying Bekhme Formation. At the type-locality, unconformable relations between the Qamchuqa Formation and overlying Bekhme Limestone Formation are demonstrated by the basal conglomerate which is very variable in thickness and character even over the very small exposed area in the gorge sections. Thus, on the mule track on the eastern bank of the Great Zab River, the conglomerate bed was approximately 3 m thick, passing laterally into marl bed (Bellen *et al*., 1959). At Peris Mountain and Zanta Gorge, there is no basal conglomerate or erosional surface between Qumchuqa Formation and Bekhme Formation (Ameen & Karim, 2008). The green marl bed between Bekhme and Qamchuqa Formations is representing a time gap (Karim & Baziany, 2007).

This study has a target to document the physical properties, mineralogy, and petrography of the glauconite grains as sedimentological implication by XRD, binocular microscope, and under polarized microscope. Elucidate the reasons for deposition of these glauconite grains in marl bed between Qamchuqa and Bekhme Formations. In selected section at Gali Garukaju near Rwanduz, the basal conglomerate cannot be seen and replaced by marls that contain glauconite grains.

STUDY AREA AND GEOLOGICAL SETTING

The study area is located at Gali Garukaju near Rwanduz at High Folded Zone, NE Iraq. For this study, one outcrop section has been selected. In this section, glauconite is present at the base of Bekhme Formation. The outcrop section was located at 4 km to the west of Rwanduz City with the latitude and longitude 36° 37' 27.0" N and 44° 28' 13.6" E, respectively (Figure 1).

Gali Garukaju is one of the strait, more appeared mountains within the series of rock units at Rwanduz area. Tectonically, the outcrop is located in the High Folded Zone (Figure 1) within Unstable Shelf in NE Iraq. The sedimentary cover of the High Folded Zone comprises Lower Cretaceous formations with a thickness about (250-1200 m) and Upper Cretaceous (800 m) (Jassim & Buday, 2006a).

The marl bed with glauconite grains was deposited at the base of Bekhme Formation at Gali Garukaju near Rwanduz City, NE Iraq. The lithostratigraphic units (Figure 2) in the studied area (Gali Garukaju) are represented by several depositional cycles, some of them are deep water cycles and others are shallow (shoal) water cycles (Buday, 1980).

The Hauterivian–Albian Qamchuqa Formation in the studied area from bottom to top comprises of: very coarsely crystalline dolomite without significant residues of original fauna; massive limestones; coarsely crystalline mosaic or

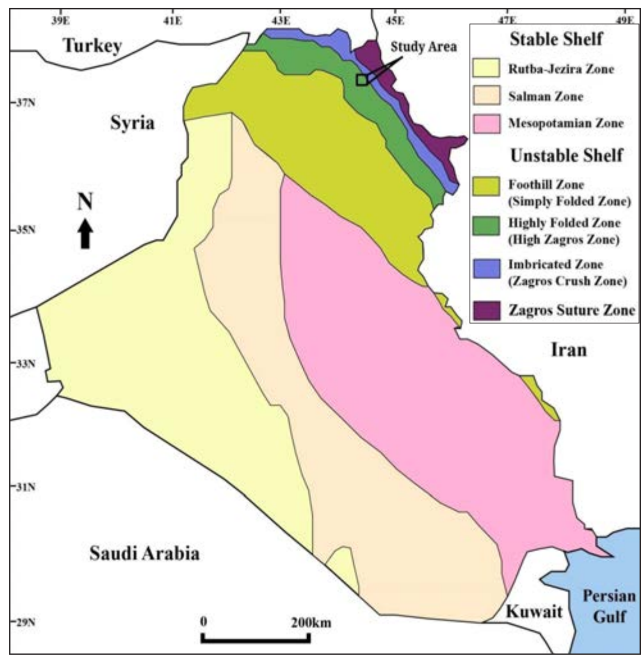

Figure 1: Location map of the studied area represent tectonic zones of Iraq (after Jassim & Buday, 2006a).

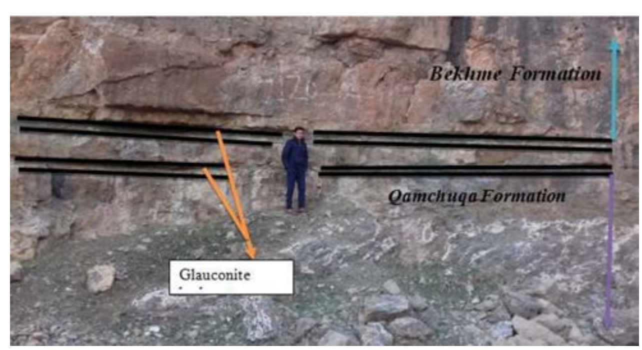

Figure 2: Unconformabe contact between Qamchuqa and Bekhme Formations, with glauconite beds above Qamchuqa and at base of Bekhme Formations, Gali Garukaju near Rwanduz.

saccharoidal dolomite with some interstitial calcite; massive rather argillaceous limestones; coarsely crystalline, granular, rhombic, and mosaic dolomites; organic limestones with molluscan detritus; and detrital limestones.

In Rwanduz area, the overlying formation is the Bekhme Formation and the nature of the contact with the Qamchuqa Formation is unconformable.

The Campanian-Lower Maastrichtian Bekhme Formation is one of the most widely spread formations of the Cretaceous Period in Iraq. According to Bellen *et al.* (1959), the type section of Bekhme Formation is located in the Bekhme Gorge with unconformable contact overlying the Qamchuqa Formation.

At the studied area, the Bekhme Formation from bottom to top comprises of: bituminous late burial diagenesis dolomites with dispersed glauconite; organic detrital limestones with some globigerinal limestone; and reef-detrital limestones with rudist debris alternating with fore reef shoal limestones.

In selected section at Gali Garukaju near Rwanduz, the basal conglomerate at the lower part of Bekhme Formation cannot be seen and is replaced by marls that contain glauconitic grains. This may be related to the presence of many isolated basins in that time with different characteristics.

The green marl beds with glauconite grains were deposited as beds at the base of Bekhme Formation at Gali Garukaju (Figure 2). The thickness of these green glauconitic marl beds at Gali Garukaju is about 15 to 20 cm. These two green marl beds are located beneath dolomitic limestone of the lower part of Bekhme Formation. The two green marl beds have wide aerial distributions in the eastern part of northern Iraq and Kirkuk embayment, but they appear between the Qamchuqa and Kometan formations in some areas.

Due to the unconformable contact between Qamchuqa and Bekhme Formations (Karim & Baziany, 2007), it is very hard to determine the exact age of these green glauconitic marl beds. The age of these green glauconitic marl beds can be deduced based on the stratigraphic position of its location beneath the lower part of Bekhme Formation. The age of the Qamchuqa Formation is Hauterivian–Albian and the age of Bekhme Formation based on fossils content is upper Campanian and perhaps Lower Maastrichtian at top; therefore, the age of these green marl beds should be younger than Albian and older than Late Campanian (Bellen *et al.*, 1959). These glauconitic marl beds are green in color and deposited above dolomite subunit of Qamchuqa Formation. The dolomitic limestone bed of Bekhme Formation is very hard to be weathered, but green marl beds are weathered and crashed to smaller pieces and particles. To study these green glauconitic marl beds, two samples were analyzed by XRD. These green glauconitic marl beds' distributions are related to the spreading of Bekhme (or its equivalent) Formations (Figure 3).

METHODOLOGY

This study is attained through field trip and laboratory works. Fieldwork was carried out on one outcrop section. Fresh samples were carefully collected from upper and lower contacts of these two formations, Qamchuqa and Bekhme Formations, and the green marl beds. Detailed petrographic study and XRD analysis were performed;

- The petrographic description was handled by polarizing and binocular microscope in reflected light in the Department of Petroleum Geosciences, Soran University;
- Four thin sections have been prepared and studied; and
- Two samples have been chosen for analyzing by XRD at Research Center of Soran University.

RESULTS AND DISCUSSION

Depositional conditions of glauconite

Glauconite can be formed in any condition where there are input of such elements - oxygen, Fe^{3+} and K and there are following chemical parameters of environment - pH

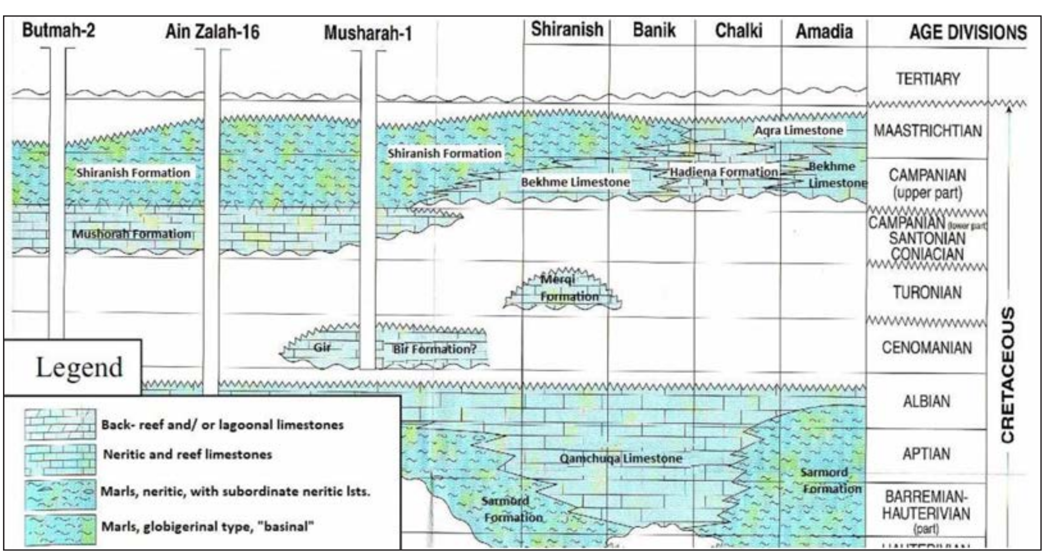

Figure 3: Bekhme Formation is intertonguing and equivalent with lower part of Shiranish Formation and older than Aqra Formation (Bellen *et al.*, 1959).

equal 6-8 and temperature range 3-50 °C (Mozherovsk, 2017, Pers. Comm.).

Glauconite is one of the few clay minerals that almost always have a marine origin in a specific microenvironment at the sediment-water interface (Millot, 1970; Velde, 1985; Odin & Fullagar, 1988). An explanation for the association of glauconite with marine bioforms becomes apparent under these conditions. Decaying organic material creates a local reducing environment which sufficiently counteracts the over-all oxidizing marine environment to produce the semioxidizing conditions necessary to glauconite formation.

Glauconitic minerals are relatively common authigenic constituents of marine sediments and are good indicators of low sedimentation rate. The water-sediment interface in marine setting constitutes the ideal place for glauconitization. A palaeodepth ranges between 60 and 550 m and an open marine environment is considered as ideal for glauconization (Odin & Fullagar, 1988). These are generally low-energy settings in which accumulation of sediment is relatively slow. Quite commonly glauconitic grains are found in shallower storm-dominated deposits as the result of transport and reworking processes (Amorosi, 1997).

Glauconitization leads to some modification in the authigenic minerals which evolve towards glauconitic mica owing to recrystallization. The modification of the whole glauconitization process takes more than 1 m.y. (Garzanti, 1991). After their formation, glauconitic grains can be transported and thus redeposited; transportation leaves a track in their morphology and creates peculiar sedimentary structures. Highly sorted and rounded granular facies indicate the transportation (Amorosi, 1997). The characterization of both evolutionary stage and genetic attributes of glaucony (Amorosi, 1995) allows the interpretation of the glaucony-rich units in a sequence-stratigraphic framework.

Color of glauconite

The color of glauconite is typically green, but the shade of green can differ from light green to yellow-green to blue-green to dark green to almost black. Very rarely glauconite grains can actually be close to red, white or grey (McRae, 1972; McConchie, 1978; Compton, 1989). Glauconite seen in thin section appears much more vividly green than the color seen in detrital grains and it may also be pleochroic (McRae, 1972).

Mineralogy

Mineralogy and petrography of marl bed, upper part of Qamchuqa Formation and lower part of Bekhme Formation, were determined by X-ray diffraction analysis and thin section petrography study:

X-ray diffraction

Green glauconitic marl beds in these selected sections have been studied by X-ray diffractometer and under binocular polarized microscope. The main technique used to classify the mineralogy of glauconite is X-ray diffraction (XRD). A technique based on the unique reflection angles of different minerals in addition to being a fast reliable and relatively inexpensive method of determining the bulk mineralogy of carbonate rocks. The X-ray diffraction of the two selected samples from green gluaconitic marl beds beneath the lower part of Bekhme Formation revealed the presence of the following minerals: dolomite, calcite, glauconite, and quartz. In this study, the green marl bed at basal division, but not all divisions of the formation is analyzed and interpreted. The environment of this part (condition of deposition) and its most possible place for formation of this glauconite grains related to changes of sea level are interpreted. For this aim, color and morphology (maturity) of glauconite grains have been used. By using this interpretation, it can be deduced that this condition can be mostly achieved at transgressive system tract (TST) in maximum flooding surface (MFS) or condensed section. At that time, the sea level was high and the basin due to the highest sea level remained free of detrital influx (sediment starvation). XRD results of two selected samples show that the main mineral is dolomite, some calcite, glauconite, and minor amounts of quartz (Figure 4a, b). The percentage of each mineral is shown in Figure 5.

Dolomite is the main mineral, comprising 69% - 76%; other minerals are calcite and glauconite in range of 17% - 20% and 7% - 8%, respectively. Small amount of quartz mineral with total of 3% occurs as well.

Thin section petrography

The petrographic study is one of the most important tools for interpreting and detecting depositional environments. For this study, samples were collected from the top of the Qamchuqa Formation and the base of the Bekhme Formation in Gali Garukaju section near Rwanduz, NE Iraq. Marl bed was analyzed by XRD to prove the presence of glauconite as mentioned before. The petrography of dolomite at top of the Qamchuqa Formation and dolomitic limestone at the base of the Bekhme Formation were analyzed in thin sections.

Dolomite has been extensively studied since it was described for the first time by a French naturalist Deodalt de Dolemieuin in 1791 (Hardie, 1987; Warren, 2000). It is the ubiquitous component of sedimentary strata from Precambrian to Cenozoic, but volumetrically less represented in younger strata (Given & Wilkinson, 1987).

General petrographic observations of these samples in thin sections are as the following:

- Upper part of the Qamchuqa Formation is dolomite. This dolomite is composite of euhedral-subhedral rhombs formed during the diagenesis which is typical features of replacement (Figure 6). These dolomites are replacing neritic organic-detrital limestones and of non-dolomitized detrital limestones locally argillaceous (Bellen *et al.*, 1959).

- Lower part of the Bekhme Formation is intercalation of marl and dolomitic limestone. The petrographic study

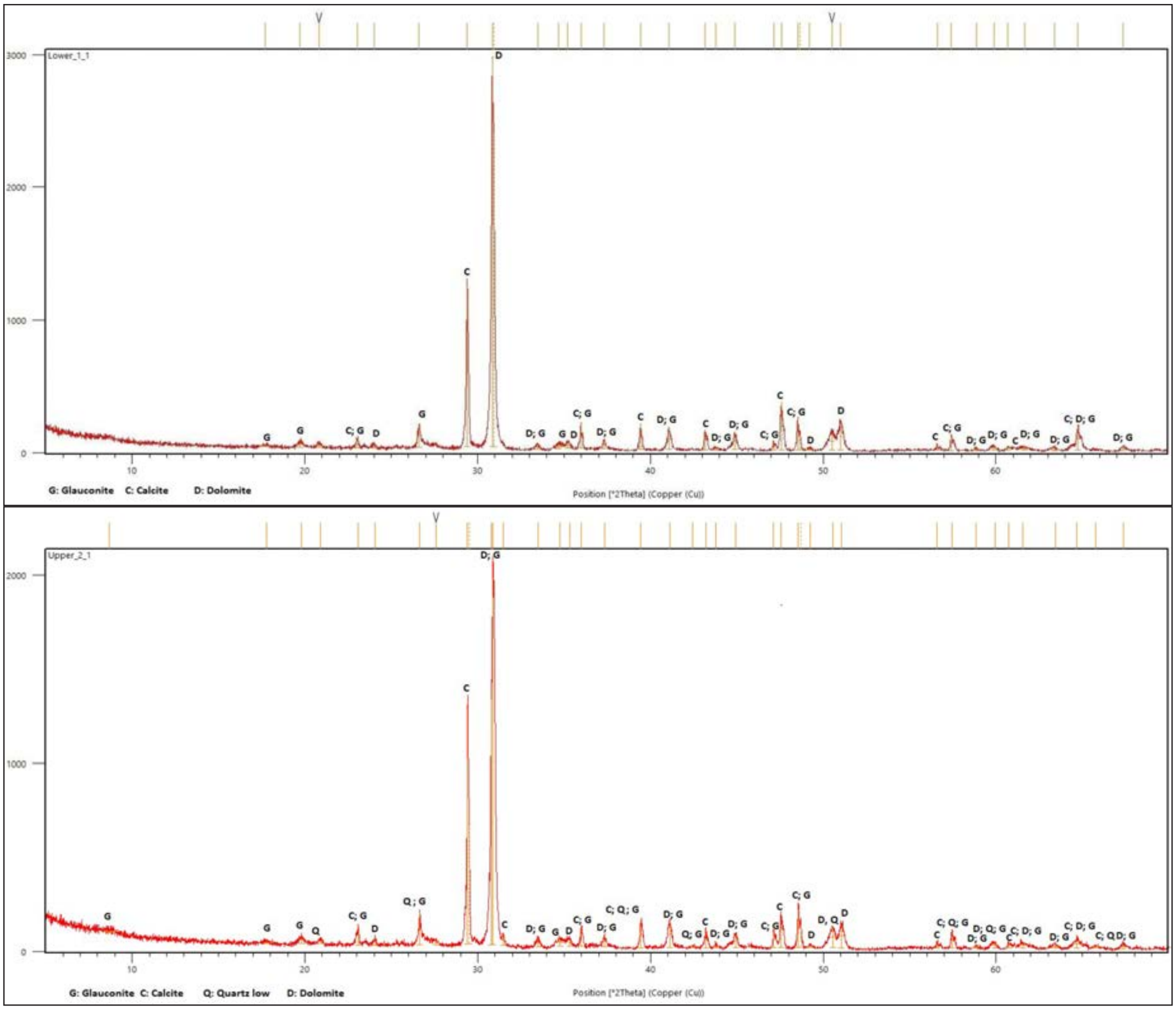

Figure 4a and 4b: X- ray diffraction of the marl bed in Rwanduz area, High Folded Zone, NE Iraq. D: dolomite, C: calcite, and G: glauconite.

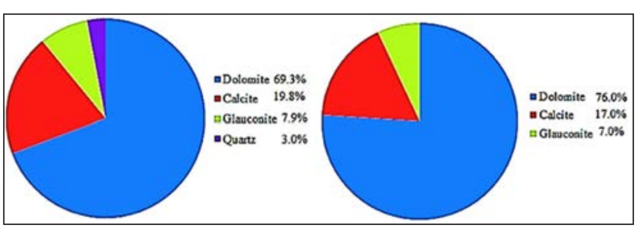

Figure 5: Chart showing the X- ray diffraction percentage of dolomite, calcite, glauconite, and quartz within the green gluaconitic marl bed in Rwanduz area, High Folded Zone, NE Iraq.

of dolomitic limestone revealed that dolomite is euhedral-subhedral rhombs (Figure 7). At this lower part, the pyrite is observed with dolomite (Figure 8). The presence of pyrite is supporting the activity of sulfate reducing bacteria. The formation of both dolomite and pyrite is associated with marine water incursions which does not only supply magnesium ion for dolomite, but also result in carbonate precipitation in this basin. The presence of pyrite indicates the development of an anoxic environment. The dolomite in the lower part of the Bekhme Formation is the result of marine water incursions, diagenetic replacement of calcareous carbonate, and sulfate reducing.

Pyrite (FeS_2), a common sulfide mineral in sedimentary rocks, can be formed in hydrothermal environment, low-temperature diagenetic environment or precipitate in anoxic waters. It is a typical mineral found in organic-rich sediments and also an indicator of euxinic depositional conditions (Wilkin *et al.*, 1996; Wang & Morse, 1996; Wilkin & Barnes, 1997; Wilkin *et al*., 1997; Wignall & Newton, 1998; Wignall *et al*., 2005; Shen *et al*., 2007). Pyrite can also be formed by diagenetic process. Secondary pyrite is concentrated at a "pyrite front" which marks the boundary between the alteration halo and the host rock (Andrews, 1979, Alt & Shanks, 2011). These observations suggest a relationship between iron oxidation and pyrite formation; therefore, it can be used as evidence for interpretation.

The presence of glauconite within the green marl beds at lower part of the Bekhme Formation was proved by X-ray diffraction. Glauconite, (K, Na) ($Fe^{+3,}$ Mg, Al)$_2$ (Si, Al)$_4$ O_{10}

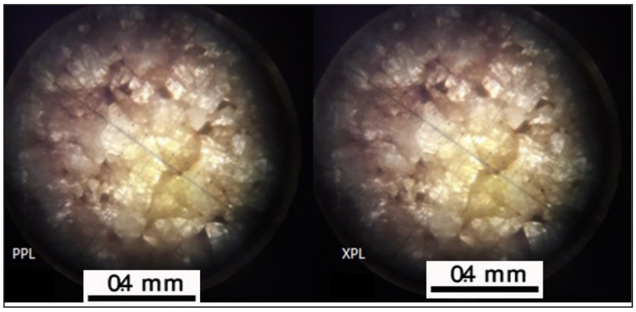

Figure 6: Euhedral-subhedral rhombs of dolomite, upper part of Qamchuqa Formation, Gali Garukaju section near Rwanduz, NE Iraq.

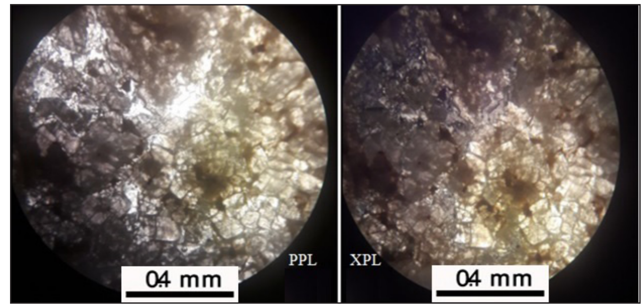

Figure 7: Euhedral-subhedral rhombs of dolomite, lower part of Bekhme Formation, Gali Garukaju section near Rwanduz, NE Iraq.

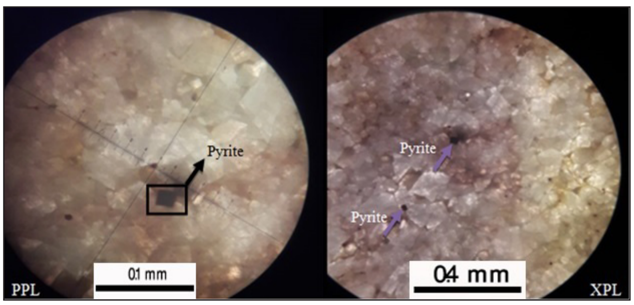

Figure 8: Pyrite with dolomite, at lower part of Bekhme Formation, Gali Garukaju section near Rwanduz, NE Iraq.

$(OH)_2$, is a clay mineral found only in marine deposits that forms pellets or granules in areas of slow sedimentation. It also precipitates as an early diagenetic mineral replacing clasts or filling porosity in shallow to deep marine settings that have high nutrient levels and low sediment accumulation rates.

Glauconite is green to olive green in color and has a greenish birefringence. It can look similar to chlorite, but chlorite is usually platier and has anomalously low birefringence.

In this study, two samples were analyzed to prove the presence of glauconite in the selected section, but for more detail analysis and determining the mineralogical composition of glauconite especially the amount of K_2O. The XRD analysis must be done just for these glauconite grains not for bulk volume of these rock samples. By XRD analyzing method for glauconite grain, it is possible to determine the composition and ratio of all minerals in glauconite. The amount of K_2O can be used to interpret the maturity of glauconite; hence, the better sedimentological interpretation.

Mineral color is a physical property controlled by a wide spectrum of mechanisms, despite this complexity; color is a classical criterion for identifying and classifying minerals. It currently is one of the features that is systematically observed and routinely catalogued in field and laboratory studies. Marine authigenic green clay minerals are characterized by their color and are usually divided into verdine and glaucony facies (Odin, 1988). The color of glauconite is mainly controlled by its chemical composition predominantly the amount of Fe and Al and the ratio of Fe^{+2}/Fe^{+3} (McRae, 1972).

Maturity of glauconite

As to the intensity of glauconitization, its color index has been used. Dark green colored grains are separated as strongly glauconitized grains while light green colored grains are distinguished as weakly glauconitized particles. Odin & Matter (1981) recognized four stages of maturity of glauconite: nascent, slightly evolved, evolved, and highly evolved (Figure 9).

Nascent grains are light green in color and are likely to retain the shape of the test or grain that is being replaced. Slightly evolved grains are green in color and show the beginnings of cracks from the growth of the glauconite minerals inside the grain. Evolved grains have distinct cracks and are a darker green. Highly evolved grains are smooth, very dark green, and in some cases may even appear black (Odin & Matter, 1981). Stage of maturity is one of the determining factors in narrowing the environment of formation. The maturity of glauconite reflects the amount of time that grains have been resting on the seafloor pre-burial (Odin & Matter, 1981). Levels of maturity of glauconite can be assessed based on chemical composition, grain color, and morphology, the longer the location remained free of detrital influx, the more mature the grains may become. Color and morphology were the dominant factors used in the determination of maturity (Odin & Matter, 1981).

These two factors were analyzed under a binocular microscope in reflected light for glauconite grains in selected section in the Rwanduz area. The morphology of most glauconite grains is ovoidal and tabular with green to dark green in color (Figure 10). Based on these two factors, the glauconite grains belong to stage 3 and 4 on Figure 9 and can be interpreted as evolved and high evolved in view of maturity.

Glauconite usage for interpreting depositional environment

The presence of gluconite has been used for analyzing the lower part of Bekhme Formation. At the lower part, Bekhme Formation consists of intercalation of dolomitic limestone and green marl beds that have been investigated in detail. Based on Al-Karadakhi (1989), Bekhme Formation at type locality section at Bekhme Gorge in north and northeast of Iraq was formed from well-bedding fossiliferous limestone at lower part and prevalently massive dolomitized and thick bedded limestones at the middle and upper parts. The Bekhme Formation belongs to the Late Campanian-Maastrichtian cycle (Figure 11). The cycle begins with a widespread transgression and almost covering the whole country which occurred after the termination of the unrest caused by the middle Cretaceous orogeneses. The cycle is terminated by another uplift and regression, caused by the paroxysmal phases of the Laramide Orogeny around the Cretaceous-Tertiary boundary.

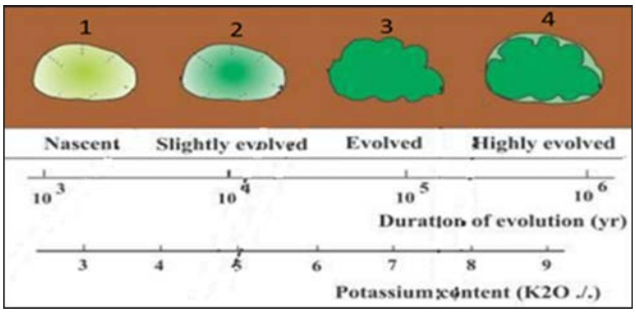

Figure 9: Four stages of glauconite maturity (after McCracken *et al.*, 1996).

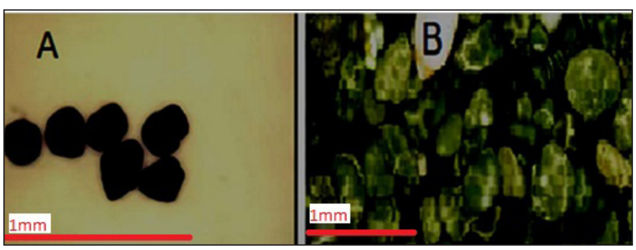

Figure 10: Different grain morphology as viewed in reflected light. Ovoidal dark green (A) and tabular light green to green grains (B). Glauconite grains from green marl beds at the base of Bekhme Formations, Gali Garukaju near Rwanduz.

At the selected section, the lower part of the Bekhme Formation is wholly composed of limestone and dolomitic limestone intercalation with marl beds. In this study, the lower part of Bekhme Formation was selected and analyzed so it is impossible to interpret the depositional environment of all parts of Bekheme Formation based on this little part. The marl beds have wide aerial distributions in the eastern part of northern Iraq and Kirkuk embayment, but it appears between the Qamchuqa and Kometan formations in some areas. Determining the maturity stage of these glauconite grains is one of the most important factors in narrowing the environment of formation. Glauconite grains in the selected section are in evolved and high evolved stage; hence, as mentioned by Odin & Matter (1981). This can reflect the amount of time (105-106 years) that grains have been resting on the seafloor pre-burial and show that the location remained free of detrital influx.

In general, the Bekhme Formation is unconformably overlying the Qumchuqa Formation in the selected section and in most sections at N and NE Iraq. Al-Karadakhi (1989) and Al-Rawi & Al-Ghreri (2009) assigned the deposition of Bekhme sediment to three sub-environments: back reef, reef and fore reef, in addition to the intertidal environment, which took place at the initial phase of formation (lower part). Conglomeratic unit can be seen at the lower part of Bekhme Formation in many sections at north and northeast Iraq, hence as mentioned by Al-Karadakhi (1989) and Al-Rawi & Al-Ghreri (2009), the conglomeratic unit indicative for the intertidal environment. The ascendant sequence of the

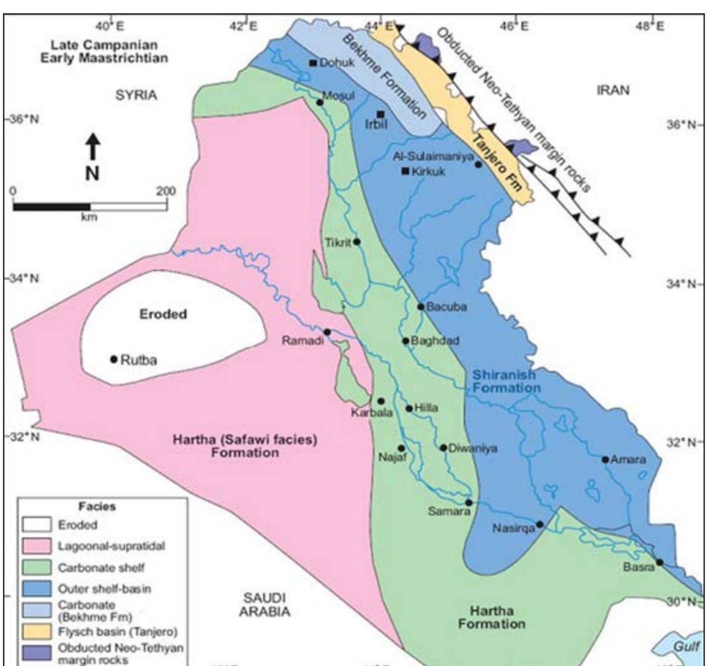

Figure 11: Palaeogeographic distribution of the late Campanian and early Maastrichtian rock units in Iraq (Jassim & Buday, 2006b).

environment from a tidal to lagoon, back reef, reef proper and finally fore reef might be due to a gradual transgressive phase within Bekhme Formation.

Palaeoenvironmental information has been deduced mainly from the characteristics of glauconite from XRD powder and petrographic analysis data. In recent times, these minerals demonstrated their utility for the reconstruction of different types of system-tracts in depositional sequences (Amorosi, 1995).

The lower part of Bekhme Formation and also Bekhme Formation in general show a very variable sediment thickness and different facies in NE Iraq clearly reflecting tectonic control.

The sequence stratigraphic implications of the glauconite

According to Amorosi (1995, 1997), glauconite can occur in most depositional sequences, but is generally most common in the deposits and its increases from lowstand system tract (LST) toward transgressive systems tract (TST) and condensed section (CS) where it tends to show an upward increase in concentration and compositional maturity. The glauconite content decreases in the high stand systems tract (HST) and is generally of low to moderate compositional maturity (Udgata, 2007). In condensed sections (CS), very high concentrations of glauconite occur compared to the over and underlying deposits. The glauconite in condensed sections is also usually of high compositional maturity (Amorosi, 1995; Udgata, 2007). Differing rates of supply of siliciclastic sediment is the primary control on the presence of glauconite in depositional sequences and, as such, glauconite is considered one of the most reliable indicators of low sedimentation rates (Amorosi, 1995). Glauconite is generally agreed to be a reliable indicator of low sedimentation rate, but little systematic work has been done to specify the role of glauconite in a sequence-stratigraphic framework. The exact sequence-stratigraphic significance of glauconite has long been problematic in part because a wide variety of depositional setting has been proposed (Table 1).

The occurrence of abundant glaucony at particular horizons in stratigraphic sequences is usually interpreted to be the result of slow accumulation due to sediment starvation typically in water depths ranging from 50 to 500 m (Odin & Fullagar, 1988; Amorosi, 1997). Glauconite in lower part of Bekhme Formation associated with marine transgressions, where rapid deepening starves the shelf of sediment, and maturity of glaucony may be an indicator of the intensity of a hiatus. In the selected section at the lower part of Bekhme Formation, in Gali Garukaju section near Rwanduz, NE Iraq glauconite grains are interpreted as evolved and high evolved in view of maturity; hence, high maturity of glauconite indicates the intensity of hiatus. These evidences can be used in sequence stratigraphic analysis. The presence increase in concentration and mature grains of glauconite (evolved and high evolved) in marl beds at the lower part of Bekhme Formation indicate transgressive or maximum flooding surfaces (e.g., Loutit *et al*., 1988; Baum & Vail, 1988; Galloway, 1989; Udgata, 2007).

Table 1: The possibilities of glauconite occurrence and its maturiry level (after Amorosi, 1995).

Sequence-stratigraphic setting	Glauconite maturity
Upper part of parasequence (HST)	Low to very high
Upper part of parasequence (HST)	Low to moderate
Maximim flooding surface (CS)	High to very high
Uppermost TST-lowermost HST (CS)	High to very high
Ravinement surface (TST)	Variable
Incised valley fill (TST)	Low to moderate
Upper part of parasequence (TST)	Low to moderate
Lower part of parasequence (TST)	Low to high
Shelf margin wedge (LST)	Low to moderate
Proximal lowstand wedge (LST)	Variable
Lowstand fan complex (LST)	Variable

HST = Highstand System Tract; TST = Transgressive System Tract; LST = Lowstand System Tract; and CS = Condensed Section.

Deposition of glauconite is typically inferred to represent slow rates of clastic influx and is most commonly associated with the development of condensed sections (Baum & Vail, 1988; Loutit *et al*., 1988; Amorosi, 1995; Udgata, 2007); however, there are many depositional settings in which glauconite will form such as maximum flooding surfaces, incised valley fill, shelf margin wedges, and proximal low stand wedges (Table 1) and more work is needed to constrain its range of occurrence in the stratigraphic record. In a systems-tract context, glauconite is often inferred to be present at the base of the transgressive system tract (TST) and in the entire TST marking the base of each component parasequence (Amorosi, 1995).

Based on Table 1, there are many depositional settings in which glauconite can be formed. These facts indicate that the glauconite, at the base of Bekhme Formation, represents maximum flooding surface because of the absence of Basal Conglomerate at the contact between the two formations. The green glauconitic marl bed at the contact between the two formations can be used as a key bed instead of Basal Conglomerate using it to make a spotlight to solve this case. If we put it in our mind that the two formations represent carbonate sequence stratigraphy and no silicaclastic input; therefore, the carbonate sequence stratigraphy models of Sarg (1988) can be applied to interpret the boundary status relationship with glauconitic bed existence. The thick dolomite bed at the contact refers to the sequence boundary of either type 1 or type 2 (LST). The differences between these two types depend on the thickness and extension of dolomite bed. Carstic features were recorded around the studied section. In addition to the existence of these ideas, the few centimeters of green glauconitic marl bed and abundant mature glauconite grain refer to the condensed section (CS) (Galloway, 1989; Udgata, 2007). The repetition of green glauconitic marl bed (twice at contact) (Figure 2) reflects the tectonic and climate effect on the sedimentation type and rate with the setting of the basin. If both formations are deposited, this means there is no gradational surface between the two carbonate formations which is represented by LST/CS surface.

CONCLUSIONS

Glauconite grains at the lower part of Bekhme Formation were studied from the viewpoints of sedimentology and stratigraphy interpretation under sequence stratigraphy subject evidence. Field, XRD, and petrographic observations led to the following conclusions:

1. According to the field work, the lower contact of Bekhme Formation with Qamchuqa Formation appear to have no gradation surface, it represents LST/CS surface.
2. The lower part of Bekhme Formation composed of green gluacontic marl interbedded with dolomitic limestone. The Basal Conglomerate Unit cannot be seen in this section.
3. XRD analyzed data shows the presence of abundant glauconite grains within the green marl bed. This glauconite is green to dark green in color and based on the McCracken *et al*. (1996), it belongs to maturity stage 3 and 4.
4. The few centimeters of green glauconitic marl beds, in this section, which were repeated twice during the flooding of the sea are equivalent to the Basal Conglomerate Unit that was deposited in Upper Campanian in the other sections.

ACKNOWLEDGEMENT

The authors appreciate the rapid turnaround time of the XRD analysis provided by Mohammed Peroui from Department of Petroleum Geosciences. The authors are also grateful to Samir Hamad from Research Center, Soran University for his help in preparing thin sections.

REFERENCES

Al-Karadaghi, A.I., 1989. Microfacies study of Bekhme Formation in selected section from north and northeast of Iraq, Unpublished MSc. thesis, University of Salahaddin, 130 p. (in Arabic).

Al-Rawi, D.Y. & Al-Ghreri, M.F., 2009. Microfacies interpretation related to tectonical concept in Bekhme Formation. Journal of University of Anbar for Pure Science, 3(2), 5 p.

Alt, J.C. & W.C. Shanks, 2011. Microbial sulfate reduction and the sulfur budget for a complete section of altered oceanic basalts. IODP Hole 1256D (eastern Pacific), Earth Planet Sci. Lett., 310, 73–83.

Ameen, B.M. & Karim, K.H., 2008. New sedimentologic and stratigraphic characteristics of the Upper boundary of Qamchuqa Formation (Early Cretaceous) at Northwest of Erbil, Kurdistan Region, NE/Iraq. Iraqi Bulletin of Geology and Mining, 4(2), 1–13.

Amorosi, A., 1995. Glaucony and sequence stratigraphy: A conceptual framework of distribution in siliciclastic sequences. Journal of Sedimentary Research, B65, 419–425.

Amorosi, A., 1997. Detecting compositional, spatial, and temporal attributes of glaucony: a tool for provenance research. Sedimentary Geology, 109, 135–153.

Andrews, A.J., 1979. On the effect of low temperature seawater-basalt in teraction on the distribution of sulfur in oceanic crust. Layer 2: Earth Planet Sci. Lett., 46, 68–80.

Baum, G.R. & Vail, P.R., 1988. Sequence stratigraphic concepts applied to Paleogene outcrops, Gulf and Atlantic basins. In Wilgus, C.K., Hastings, B.S., Ross, C.A., Posamentier, H.W., Van Wagoner, J., and Kendall, C.G., (Eds.), Sea-level changes: an integrated approach. Society of Economic Paleontologists and Mineralogists, Special Publication, 42, 309–327.

Bellen, R.C., Van, Dunnington, H.V., Wetzel, R., & Morton, D.M., 1959. Lexique stratigraphique international, V. III. Asie, Fasc., 10a Iraq, Paris. 333 p.

Bornhold, B.D. & Giressse, P., 1984. Glauconitic sediments on the continental shelf off Vancouver Island, British Columbia, Canada. Journal of Sedimentary Petrology, 55, 653–664.

Buday, T., 1980. The regional geology of Iraq, Vol. 1, Stratigraphy and Paleogeography, Dar Al-Kutub Publication, University of Mosul, Iraq. 445 p.

Chafetz, H.S. & Reid, A., 2000. Syndepositional shallow-water precipitation of glauconitic minerals. Sedimentary Geology, 136, 29–42.

Compton, M.S., 1989. Morphology and geochemistry of glauconite from the Te Kuiti Group, South Auckland Region, New Zealand. Unpublished Msc. thesis, University of Waikato, Hamilton, New Zealand.

Dias, J.M.A. & Nittrouer, C.A., 1984. Continental shelf sediments of northern Portugal, Cont. Shelf Res., 3, 147–165.

Galloway, W.E., 1989. Genetic stratigraphic sequences in basin analysis: I, Architecture and genesis of flooding-surface bounded depositional units. AAPG Bulletin, 73, 125–142.

Garzanti, E., 1991. Non-carbonate intrabasinal grains in arenites: their recognition, significance, and relationship to eustatic cycles and tectonic setting. Journal of Sedimentary Petrology, 61, 959–975.

Given, R.K. & Wilkinson, B.H., 1987. Dolomite abundance and stratigraphic age: constraints on rates and mechanisms of Phanerozoic dolostone formation. Journal of Sedimentary Petrology, 51, 457–469.

Hardie, L.A., 1987. Dolomitization: a critical view of some current views. Journal of Sedimentary Petrology, 57, 166–183.

Harris, L.C. & Whiting, B.M., 2000. Sequence-stratigraphic significance of Miocene to Pliocene glauconite-rich layers, on- and offshore of the US Mid-Atlantic margin. Sedimentary Geology, 134, 129–147.

Hesselbo, S.P. & Huggett, J.M., 2001. Glaucony in ocean-margin sequence stratigraphy (Oligocene –Pliocene, offshore New Jersey, U.S.A.; ODP LEG 1. Journal of Sedimentary Research, 71(4), 599–607.

Jassim, S.Z. & Buday, T., 2006a. Units of the Unstable Shelf and Zagros Suture,chapter 6. In: Jassim, S.Z. and Goff, J.C. (Eds.), Geology of Iraq, first edition, Prague and Moravian Museum, Brno, Czech Republic, 70–83.

Jassim, S.Z. & Buday, T., 2006b. Late Turonian-Danian Megasequence AP9, chapter 12. In: Jassim, S.Z. and Goff, J.C.

(Eds.), Geology of Iraq, first edition, Prague and Moravian Museum, Brno, Czech Republic, 141–154.

Karim, K.H. & Baziany, M.M., 2007. Relationship between Qulqula Conglomerate Formation and Red Bed Series, at Qulqula area, NE-Iraq. Iraqi Journal of Earth Sciences, 7(1), 1–12.

Kelly, J.C. & Webb, J.A., 1999. The genesis of glaucony in the Oligo-MioceneTorquay Group, southeastern Australia: petrographic and geochemical evidence. Sedimentary Geology, 125, 99–114.

Khalifa, M.A., 1983. Origin and occurrence of glauconite in the green sandstone associated with unconformity, Bahariya Oases, Western Desert, Egypt. Journal of African Earth Sciences, 1(3–4), 321–325.

Kitamura, A., 1998. Glaucony and carbonate grains as indicators of the condensed section: Omma Formation, Japan. Sedimentary Geology, 122, 151–163.

Loutit, T.S., Hardenbol, J., & Vail, P.R., 1988. Condensed sections: the key to age determination and correlation of continental margin sequences. In: Wilgus, C.K., Hastings, B.S., Kendall, C.G.St.C., Posamentier, H.W., Ross, C.A., and Van Wagoner, J.C., (Eds.), Sea-level change: an Integrated approach. SEPM, Special Publication, 42, 183–213.

Malone, M.J., Claypool, G., Martin, J.B., & Dickens, G.R., 2002. Variable methane fluxes in shallow marine systems over geologic time: the composition of pore waters and authigenic carbonates on the New Jersey shelf. Marine Geology, 189, 175–196.

McConchie, D.M., 1978. Cretaceous and Lower Tertiary glauconite in the South Island of New Zealand. Unpublished M.Sc. Thesis, University of Canterbury, New Zealand. 245 p.

McCracken, S.R., Compton, J., & Hicks, K., 1996. Sequence-stratigraphic significance of glaucony-rich lithofacies at site 903. In: Mountain, G.S., Miller, K.G., Blum, P., Poag, C.W., and Twichell, D.C., (Eds.). Proceedings of the Ocean Drilling Program, Scientific Results, College Station, Texas, 150, 171–187.

McRae, S.G., 1972. Glauconite. Earth-Science Reviews, 8, 397–440.

Millot, G., 1970. Geology of clays: weathering, sedimentology, geochemistry, Translated by Farrand, W.R. and Helene, P., Springer-Verlag, New York. 430 p.

Mozherovsk, A.V., Pers. Comm., 2017. V.I. II'ichev Pacific Oceanological Institute, Russian Academy of Science, Vladivostok, Russia.

Mozley, P.S. & Carothers, W.W., 1992. Elemental and isotopic compositions of siderite in the Kuparuk Formation, Alaska: effect of microbial activity and water/sediment interaction on early pore water chemistry. Journal of Sedimentary Petrology, 62, 681–692.

O'Brien, G.W., Milnes, A.R., Veeh, H.H., Heggie, D.T., Riggs, S.R., Cullen, D.J., Marshall, J.F., & Cook, P.J., 1990. Sedimentation dynamics and redox iron-cycling: controlling factors for the apatite–glauconite association on the East Australian continental margin. Geological Society Special Publication, 52, 61–86.

Odin, G.S., 1988. The verdine facies from the lagoon off New Caledonia. In: Odin, G.S., (Ed.), Green marine clays. Developments in Sedimentology, 45, 57–82.

Odin, G.S. & Fullagar, P.D., 1988. Geological significance of the glaucony facies in green marine clays. Elsevier, Amsterdam, the Netherlands, 295–332.

Odin, G.S. & Letolle, R., 1980. Glauconitization and phosphatization environments: a tentative comparison. Society of Economic Paleontologists and Mineralogists Special Publication, 29, 227–237.

Odin, G.S. & Matter, A., 1981. De glauconiarum origine. Sedimentology, 28, 611–641.

Rao, V.P., Lamboy, M., & Dupeuble, P.A., 1993. Verdine and other associated authigenic (glaucony, phosphate) facies from the sediments of the southwestern continental margin of India. Marine Geology, 111, 133–158.

Sarg, J.F., 1988. Carbonate sequence stratigraphy. In: Kendall, C.K.K., Posamentier, H.W., Ross, C.A., and Van Wagnoner, J.C. (Eds.), Sea-level changes an integrated approach. Society of Economic Paleontoogists and Mineraogists, Special Publication, 42, 155–181.

Shen, Q.H., Song, B., Xu, H.F., Geng, Y.S., & Shen, K., 2007. Emplacement and metamorphism ages of the Caiyu and Dashan igneous bodies, Yishui County, Shandong Province: Zircon SHRIMP chronology. Geological Review, 50, 275–284.

Srivastava, R.A.K., 1986. Glauconite: Form and Function. Current Trends in Geology, 10, 267 p.

Stille P. & Clauer, N., 1994. The process of glauconitization: chemical and isotopic evidence. Contributions to Mineralogy and Petrology, 117, 253–262.

Udgata, D.B.P., 2007. Glauconite as an indicator of sequence stratigraphy package in Lower Paleocene passive-margin shelf succession, Central Alabama. Unpublished Master thesis, Auburn University. 125 p.

Velde, B., 1985. Clay minerals: a physico-chemical exploration of their occurrence, Elsevier, Amsterdam, pp. 225–256.

Wang Q. & Morse J.W., 1996, Pyrite formation under conditions approximating those in anoxic sediments: I. Pathway and morphology. Marine Chemistry, 52, 99–121.

Warren, J., 2000. Dolomite: occurrence, evolution and economically important associations. Earth-Science Reviews, 52, 1–81.

Wetzel, R., 1946. Stratigraphy section on Bekhme Gorge. MPC Report, INOC Library, IR/Rw/4 No. 19. 1-67.

Wignall, P.B. & Newton, R. 1998. Pyrite framboid diameter as a measure of oxygen deficiency in ancient mudrocks. American Journal of Science, 298, 537–52.

Wignall, P.B., Newton, R., & Brookfield, M.E., 2005. Pyrite framboid evidence for oxygen poor deposition during the Permian-Triassic crisis in Kashmir. Palaeogeography Palaeoclimatology, Palaeoecology, 216, 183–88.

Wilkin, R.T. & Barnes, H.L., 1997. Pyrite formation in an anoxic estuarine basin. American Journal of Science, 297, 620–650.

Wilkin, R.T., Arthur, M.A., & Dean, W.E., 1997. History of water-column anoxia in the Black Sea indicated by pyrite framboid size distributions. Earth and Planetary Sience Letters, 148, 517–525.

Wilkin, R.T., Barnes, H.L., & Brantley, S.L., 1996. The size distribution of framboidal pyrite in modern sediments: an indicator of redox conditions. Geochimica et Cosmochimica Acta, 60, 3897–3912.

Manuscript received 17 December 2018
Revised manuscript received 20 September 2019
Manuscript accepted 22 September 2019