# MINERALOGY, GEOCHEMISTRY AND GENESIS OF THE FERRUGINOUS SANDSTONE IN BATN AL GHUL AREA, SOUTHERN JORDAN

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**ABSTRACT.** Ferruginous Sandstone Deposits (FSD) of Batn Al Ghul Area, Southern Jordan are studied in detailed for the first time in this work. These deposits occur as summit capping on residual hills or ridges which run subparallel to the main faults in the area. They represent the upper parts of a formerly continuous late weathering surface of Cretaceous Kurnub Sandstone and Batn Al Ghul groups. The iron rich packages are concordantly interbedded with silica-clastic rocks. Up to 15-20 cm thick ferribands are distributed randomly throughout the undifferentiated Kurnub/Batn Al Ghul groups. Most of the silica-clastic of these groups are dominated by reddish brown and yellowish brown colors. The ferribands are ferruginized by impregnation of iron oxides and oxihydrooxides. Petrographic examinations revealed that the ferruginous sandstones are composed of quartz grains and iron oxides mineralization. The results of X-ray diffraction analyses indicate that the main oxide mineral is goethite, while the hematite and limonite oxides are amorphous. Chemical analyses of selected bulk samples of ferruginous sandstone indicate that the $Fe_2O_3$ content ranges from 4.24 to 44.46%, whereas through SEM the $Fe_2O_3$ content is up to 53.65%. The ferribands and iron crusts predominantly occur at the contact of different lithologies, e.g. sandstone/claystone contact, and are not associated with sediments of particular environmental facies types.

**МИНЕРАЛОГИЯ, ГЕОХИМИЯ И ГЕНЕЗИС НА РЪЖДИВОКАФЯВИТЕ ПЯСЪЧНИЦИ В РАЙОНА БАТ АЛ ГУЛ, ЮЖНА ЙОРДАНИЯ**

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**РЕЗЮМЕ**. Находищата на ръждивокафяви пясъчници (FSD) от района на Бат ал Гул, Южна Йордания се изучават детайлно за първи път с настоящата работа. Тези находища са представени като покриваща шапка на остатъчни хълмове или хребети, развити субпаралелно на главните разломи в района. Те представляват горните части на предишна късна изветрителна повърхност на кредните пясъчници "Курнуб" и групите Бат Ал Гул. Богатите на желязо пачки са конкордантно прослоени със силифицирани скали. Ожелезнени слоеве дебели до 15-20 m се разполагат често върху недеферинцираните групи Курнуб/Бат Ал Гул. Повечето от силифицираните класти в тези групи се доминират от червено-кафяви или жълто-кафяви цветове. Ожелезнените слоеве са богати на импрегнации от железни оксиди и хидрооксиди. Петрографските изследвания разкриват, че ожелезнените пясъчници са съставени от кварцови зърна и железноокисни минерализации. Резултатите от рентгеноструктурния дифракционен анализ индикират, че главните окисни минерdли са гьотит, докато окисите хематит и лимонит са аморфни. Химичните анализи на избрани проби от ожелезнени пясъчници показват съдържание на $Fe_2O_3$ в диапазона от 4.24 до 44.46%, докато чрез SEM анализи съдържанието на $Fe_2O_3$ е до и около 53.65%. Железосъдържащите прослойки и железни кори преимуществено са разпространени на контакта на скали с различен литоложки състав, например пясъчници-глини и не асоциират със седименти със специфични фациални типове на отлагане.

## Introduction

Ferruginous Sandstones Deposits (FSD) belong to the red beds sediments that posses red coloration due to the presence of finely divided ferric oxides, chiefly hematite. The origin and significance of their distinctive coloration has been debated for more than a century. Most of the red beds represent iron-stained or cemented clastic environment (Pay, 1983). According to Dawson (1848), Barrell (1908; 1916), Krynine (1949; 1950), and Van Houten (1961) red beds are common in both modern and ancient sedimentary environments. Reviews of the geological literature on the red beds have previously been undertaken by Van Houten (1964; 1968; 1973), Turner (1980) and Pye (1983), while work on the nature of iron oxides in soils and sediments has been summarized by Schwertmann and Taylor (1977) and Kogbe (1978). The abundance of the ferrugenized sandstone has been known for a long time in Jordan (Burdon, 1959; Bender, 1974; Abed, 1982; Powell, 1989a, b; Masri, 1998; Moumani, 2002). The ferruginous sandstones are widespread in Jordan within the Cambrian, Ordovician, Triassic, Jurassic and Cretaceous sediments. The ferruginous sandstones described in this study occur in the upper part of the early Cretaceous Kurnub Sandstone (KS) and Batn Al Ghul (BG) groups. The KS and BG groups are up to 220 m thick in south of Jordan and rests unconformably on the Paleozoic strata (Fig. 1). The iron rich packages are concordantly interbedded with silica-clastic rocks, relatively up to 6 m thick, whereas 15-20 cm thick ferribands are distributed randomly throughout KS and BG groups. Most of silicaclastics of theses groups are dominated by red, reddish brown and yellowish colors. The ferribands predominantly occur at the contact of different lithologies and the sediments are ferruginized by impregnation of iron oxides and oxihydrooxides. Due to the scientific and economic importance of these deposits, this paper focuses on the FSD of the KS/ BG groups in Batn Al Ghul/southern part of Jordan, with the aim to identify their mineralogy, petrography, geochemistry and genesis.

## Geological Setting

The study area is mainly covered by Kurnub Sandstone and Batn Al Ghul groups (early –upper Cretaceous), which rests with a regional angular unconformity on the Ordovician rocks. The KS/BG groups are up to 220m thick and consist mainly of white, yellow and pink cross-bedded sandstone intercalated with grey and green silty mudstone with bivalves, plant fossils and Thalassinoides burrows. The upper 26 m of BG group are composed of greenish grey silty clay intercalated with sandy limestone beds bearing chert nodules and thin lamina of light grey chert. The KS/BG groups are overlain by 35 m of the Amman Silicified Limestone Formation (Campanian) (Fig. 1).

Structurally, faults are the most important structural element present in the study area with a regional dip of the Cretaceous strata is gently oriented toward north-north-east. Impregnation of the sandstone by iron oxides is a dominant feature along the main faults in the area. The ferruginous sandstone beds of the study area form a capping of considerable thickness on top of the KS\BG formations. A band of pale clayey material is usually found between the ferruginous sandstone and unaltered rock in many localities. Based on grain size differences and the palaeohydrologic regime, the laying or hanging bed displays a several centimeter to decimeter thick ferribands varies from reddish brown, yellow, brownish yellow to black, most likely representing different iron-oxides phases like hematite ($\alpha$-$Fe_2O_3$; reddish to black colors) and goethite ($\alpha$-FeOOH); brownish-yellow color) (Scheffer, Schachtschabel, 1992; Baaske, 1999; 2003). It could be observed that there were several levels of the ferruginous sandstone indicating several episodes of laterization. Up to 6 m thick iron rich silicaclastics are dominated by reddish brown and yellowish brown colors. Thin layers of up to 15-20 cm thick ferribands are distributed randomly throughout BG group and not associated with sediments of particular environmental facies types. According to Baaske (2003) the ferribands (iron-crusts) predominantly occur at the contact of different lithologies. Most of the sediments are ferrugenized by impregnation of iron oxides and oxihydrooxides.

## Analytical Methods

The analytical work includes macroscopic inspection of the sediments in the field. Petrographic and mineralogical studies were also carried out. For this purposes different thin and polish section of FSD were performed using polarizing optical microscope type Leica-DMLP. Mineral composition was obtained employing X-ray diffraction (XRD) using a Philips 1370 X-ray diffractometer, using Co- Cu X-ray tube. Major and trace elements were examined by X-ray fluorescence (XRF) and Scanning Electron Microscope (SEM). The SEM utilized is Jeol 6060 instrument-high vacuum, equipped with a link 10000 Energy Dispersive Spectrometry (EDS) system and coupled with back-scattered electron (BSE) and secondary electron image (SEI) microanalyses. The later were used to identify the elementary analysis content of the iron oxides and their distribution in the parent rocks using line-scan, point and map methods.

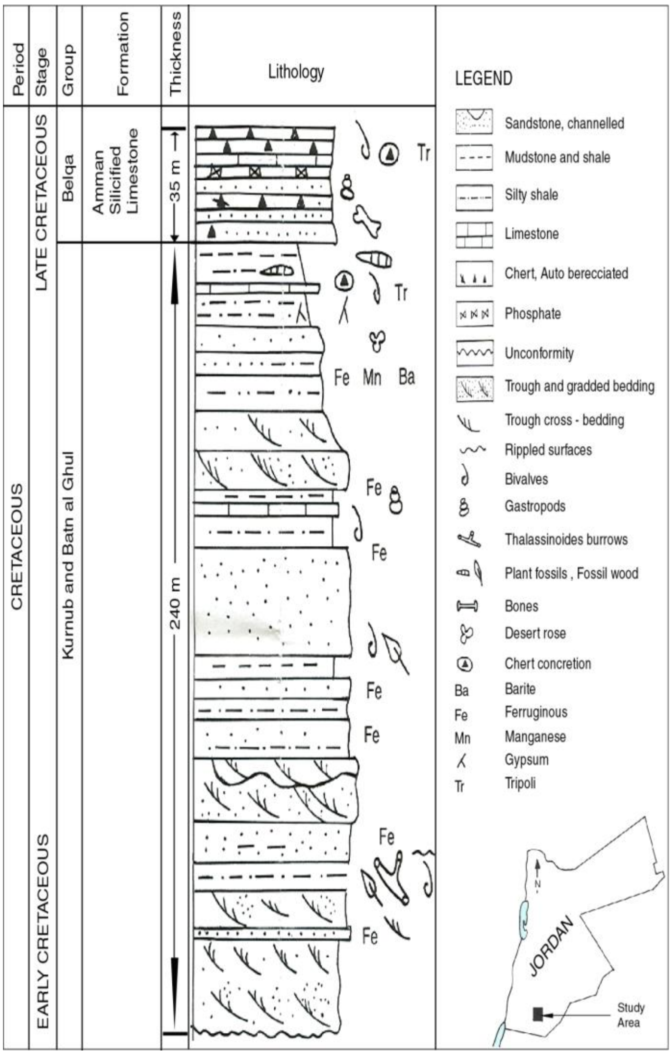


**Fig. 1. Graphic log of the early Cretaceous Kurnub Sandstone and Batn al Ghul groups overlain unconformably by Amman Silicified Limestone Formation of the study area (after Masri, 1998), and location of the study area**

## Field Work and Sampling

The results presented in this work are based on detailed measurements and sampling of selected samples from different localities in the study area. According to the field observation two main types of colors of FSD can be recognized; the reddish-brown to black as hematite and the yellowish brown as limonite. The sandstone with reddish brown-black colors is very dense (2.9 SG), hard, well cemented, compacted and relatively have thick beds up to 6m, form a capping of the top of hills and ridges of the CKS and BG groups/Harad Formation. Globular texture like bunches of grapes accumulations are coming at the surface of the sandstone beds (Fig. 2).

**Fig. 2. Globular, like bunches of grapes accumulations texture of ferruginous oxides with reddish black color at the top of the Kurnub Sandstone Group in the study area**

The yellowish brown ferruginous sandstone is typically thinly bedded or laminates, soft, poorly sorted and have continuous rich reddish iron crust up to 15-20 cm thick within BG groups/Harad Formation (Fig. 3).

**Fig. 3. Ferribands of iron oxides with reddish brown color (Hematite) within ferruginous sandstone**

This type of FSD is found with other varicolored sandstone and is often laterally extensive and can be followed several tens of meters at the base of the geological succession. Limonite occurs in oolitic form in some iron formation, associated with the iron silicate facies. It is composed of a mixture of yellow to dark brown ferric hydroxides.

## Results and Discussion

Petrographic examinations revealed that the FSD are composed mainly of quartz grains impregnated or cemented by iron oxides mineralization. The sandstones are of quartz arenite type and are usually well cemented by iron oxides that are dominant in the most types of sandstones. Quartz grains are mostly rounded to subrounded and well sorted. It is believed that these sandstones are mineralogically and texturally mature. The source of quartz grains is most probably formed by the Paleozoic Nubian Sandstones and not directly by the Pre-Cambrian basement rocks (Abed, 1982). Cement consists of iron oxides of different colors and it is vary from red-black, yellow, brownish to violet that makes the color of KS/BG rocks varicolored. This can be shown at different sedimentary stages during the cementation of the sandstones. Most of the studied samples show microcrystalline or structureless interior, while some samples show an obscure mottling in thin sections.

X-Ray Diffraction (XRD) results revealed that the major minerals are quartz and iron oxides, i.e. as goethite, while hematite and limonite are amorphous. Meanwhile, trace of calcite and clay (smectite) are present in some samples of the lower part of KS/BG groups. X-Ray Fluorescence (XRF) of selected bulk samples indicate that the main facies of the FSD is composed of $SiO_2$, $Fe_2O_3$ and $Al_2O_3$ with minor and trace oxides of MnO, $TiO_2$, CaO, $P_2O_5$, MgO and $Na_2O$. The $Fe_2O_3$ content ranges from 4.24 to 44.46%, $SiO_2$ from 54.69 to 93.80%, and $Al_2O_3$ ranges from 0.49 to 3.94% (Table 1).

On the basis of bulk geochemical affinity and rock association, it could be argued that the relatively high values of $Fe_2O_3$ (i.e. 44.46%) are related to FSD with reddish brown and black colors of both KS and BG groups, particularly to the Harad Formation. This is due to high enrichment and impregnation of the iron oxides. The low percent of $Fe_2O_3$ of less than 10% is related to the yellowish brown FSD occurring in lower layers of both groups.

Table 1. *Chemical analyses of selected samples of ferruginous sandstone (samples with stars after Abu Snober, 1995)*

| Sample ID | $Fe_2O_3$ | MnO | $TiO_2$ | CaO | $K_2O$ | $P_2O_5$ | $SiO_2$ | $Al_2O_3$ | MgO | $Na_2O$ | L.O.I |
|---|---|---|---|---|---|---|---|---|---|---|---|
| I- KH | 20.10 | 0.05 | 0.23 | 1.19 | 0.04 | 0.25 | 70.50 | 3.22 | 0.21 | 0.001 | 4.20 |
| 2-KH | 8.79 | 0.01 | 0.11 | 0.25 | 0.001 | 0.10 | 88.00 | 0.96 | 0.1 0 | 0.001 | 1.70 |
| 3-KH | 8.90 | 0.01 | 0.10 | 0.44 | 0.001 | 0.10 | 87.60 | 1.05 | 0.08 | 0.001 | 1.70 |
| 4-KH | 8.36 | 0.01 | 0.14 | 0.26 | 0.001 | 0.10 | 88.40 | 1.10 | 0.09 | 0.001 | 1.50 |
| 5-KH | 9.08 | 0.01 | 0.11 | 1.64 | 0.001 | 0.12 | 86.30 | 1.02 | 0.10 | 0.001 | 1.60 |
| 6-KH | 4.24 | 0.08 | 0.08 | 0.13 | 0.001 | 0.05 | 93.80 | 0.77 | 0.05 | 0.001 | 0.90 |
| 1-HR | 31.50 | 0.17 | 0.06 | 1.57 | 0.001 | 0.46 | 60.90 | 0.30 | 0.13 | 0.001 | 4.90 |
| 2-HR | 37.30 | 0.06 | 0.07 | 2.19 | 0.004 | 0.32 | 52.80 | 0.78 | 0.34 | 0.001 | 6.10 |
| 3-HR | 39.20 | 0.09 | 0.09 | 0.59 | 0.001 | 0.86 | 53.20 | 0.63 | 0.26 | 0.06 | 5.01 |
| 4-HR | 17.90 | 0.13 | 0.20 | 2.39 | 0.05 | 0.14 | 72.50 | 1.53 | 0.26 | 0.02 | 4.90 |
| AN*278 | 33.43 | 0.01 | 0.03 | 1.58 | 0.002 | 0.04 | 60.22 | 0.49 | 0.13 | 0.06 | 3.69 |
| AN*279 | 29.95 | 0.01 | 0.09 | 0.78 | 0.003 | 0.3 | 60.28 | 3.94 | 0.18 | 0.62 | 2.94 |
| AN*280 | 44.46 | 0.01 | 0.94 | 2.31 | 0.03 | 0.03 | 54.69 | 0.73 | 0.15 | 0.62 | 6.21 |
| AN*281 | 11.83 | 0.01 | 0.42 | 1.85 | 0.23 | 0.02 | 76.04 | 0.59 | 0.44 | 0.62 | 2.30 |

SEM, coupled with EDS system, BSE and SEI microanalysis were used to identify the composition of individual ferruginous sandstone grains and to obtain more details about the mineral content, in addition to the major, minor and trace elements of these deposits (Table 2). These results were obtained from the cement, matrix and coated ferruginous grains. The SEM results indicate some differences in chemical composition of both types of FSD as shown in Table 2. In the BSE-image-mode of SEM, the groundmass of the studied samples consist of fine to medium grained sand (0.1-0.5 mm), and most of the sand is coated and impregnated by iron oxides.

Based on SEM microscopy results, the iron oxides in the ore occurs in three forms (Fig. 4): The first form coated and impregnated ferruginous sand grains; The second as matrix with low crystallinity coming as small globules and the third form is coming as cryptocrystalline cement between the sand grains. The dominant form of iron oxides is the coating and impregnation of the sand grains, while the two others are less common. The line scan have been taken as base for the element distribution and give a clear picture for the presence of the elements associated with the sandy and iron oxide facies. The high peaks are reflected the percent content of the element distribution and reflect their high or low intensity in the studied samples. SEM-EDS analyses confirm that the ferruginous sandstone facies is mostly made of Si, Fe, Al, in addition to O (Fig. 4).

Small amounts of C, K and P are also present. The accumulations of the major elements involved in iron oxides facies show that the Fe content has a random distribution (Table 2). The Fe content in the matrix varies from 10.49 % to 53.65%, while in coated sands is up to 18.79%. The Al content is up to 0.32%. The Si content is quite high in the groundmass and very low in the cement. It varies from 2.56% (in the cement) to 45.77% (in the groundmass) (Table 2).

The distribution of the "O" show continuous presence through the line scan, but there is an absence of the elements of Fe and Al at some stages of the line scan. Most of the "O" in the studied samples could be associated with the elements of Si, Fe and Al to form the oxides of $SiO_2$, $Fe_2O_3$ and $Al_2O_3$, respectively. Small amounts of "C" is present in some samples and could be related to the processes of coating of the samples by carbon, while small amounts could be related to carbonate materials such as calcite, that is coming as cement material in some cases. The presence of K, P and F in some samples is related to accessory and clastic minerals like glauconite and apatite, respectively, whereas presence of Cl is related to halite mineral.

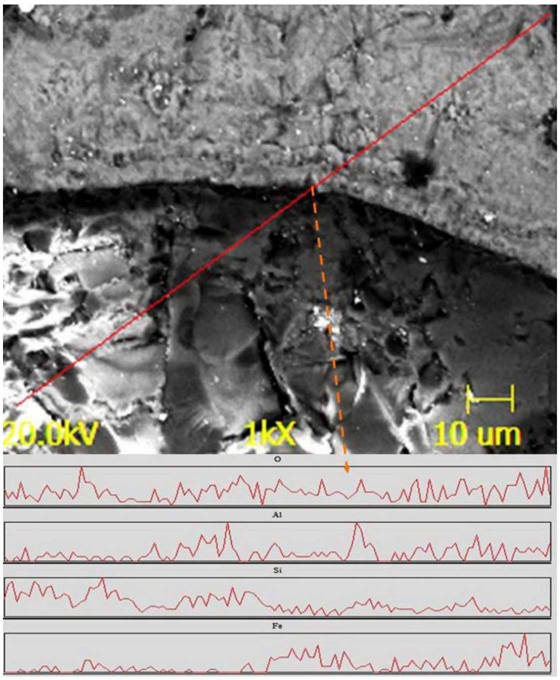


**Fig. 4. SEM-EDS line scan in the matrix of the ferruginous sandstone (upper part of the photo) and the crystalline sand grain (the lower part of the photo) illustrates the major elements distribution**

## Genesis

Several hypotheses have been put forward the mode of formation or origin of the ferruginous sandstones. However, a widely accepted model exists may be summarized as the precipitation model. This model is based on the assumption that the minerals occurring within ferruginous sandstones packages are the result of direct precipitation or of early diagenetic origin of precipitated ferric/ferrous oxyhydroxides (Arno, Alexander, 2005). Jones (1948) considered that the ferruginous sandstones coming as crusty deposits that resulted from superficial alteration of post lithological age. Pettijohn (1957) recognized that such deposits has been considered to be derived either from the breakdown of ordinary rocks during the normal cycle of weathering or by hydrothermal waters or lava. According to Faure (1966) the crusty laterites and ferruginous sandstones are of superficial deposits of autochthonous and allochthonous origin. Ferribands can also be originated from subsurface enrichments of iron oxides resulting from soil processes (Germann et al., 1990), as well as, iron precipitation due to lateral influx of groundwater (Velton, 1988). According to Pay (1983) the red beds of FSD are divided according to their origin into in-situ/chemical red beds and detrital red beds. In-situ red beds form due to chemical precipitation or pedogenic and diagenetic processes, while detrital red beds result from re-sedimentation of older red beds after transport processes.

Table 2. *Element analyses study of the various types of ferruginous sandstones particles in percent using SEM-EDS-system*

| Element | Line scan | Cement 1 | Cement 2 | Coated sand | Groundmass |
|---|---|---|---|---|---|
| O | 40.97 | 31.11 | 35.55 | 46.28 | 46.96 |
| Al | 0.15 | 0.62 | 0.89 | 0.32 | 0.77 |
| Si | 39.87 | 2.56 | 11.88 | 34.58 | 45.77 |
| Fe | 10.01 | 53.65 | 45.69 | 18.79 | 6.49 |
| C | 5.05 | 5.03 | 5.03 | - | - |

Masri (1998) assumed that the depositional environment in the study area was represented by coeval meandering or low sinuosity fluvial facies, which intercalated with marginal marine facies in Batn Al Ghul area. The crusty laterites are most probably allochthonous, whereas ferruginous sandstones are most likely autochthonous. Meanwhile, both are of continental origin. It can be argued that due to the occurrences of FSD along and subparallel to the major faults in the study area could affect the upward migration of ferrous iron in solution and deposition of ferric compounds in the upper part of KS/BG groups. This is supported with the enrichments of the iron content in cement and matrix of these deposits, in addition to the presence of the reddish to black coloration. The ferribands or iron crusts predominantly occur at the contact of different lithologies, i.e. sandstone/claystone contact. Meanwhile, color mottled sediments occur in many parts of the lithological sections could be related to coastal plain facies association (Baaske, 1999; 2003). The oxidation and downward leaching of the glauconites that exist in the uppermost part of the Cretaceous Kurnub Sandstone Formation was the source of this iron coloration as mentioned by Abed (1982). In these cases, the occurrences of red colors is attributed to extensive post-depositional dissolution of iron bearing detrital grains and subsequent precipitation of hematite or its red precursor ferric oxides (Walker, 1974; 1976). The presence of goethite is the dominant reactive oxy-hydroxide phase in lake sediments (Van der Zee et al., 2003). Forms of pedogenic features include the formation of small iron oxides concretions or nodules are also present in both types of FSD that indicate alternating oxidizing and reducing conditions caused by variable soil drainage as mentioned by Bown and Kraus (1981) and Kraus and Gwinn (1997).

## Conclusion

Ferruginous Sandstone Deposits (FSD) of Batn Al Ghul area/Southern Jordan are studied in detailed for the first time in this work. They represent the upper part of a formerly continuous late weathering surface of Cretaceous Kurnub Sandstone (KS) and Batn Al Ghul (BG) groups.

The iron rich packages are concordantly interbedded with silica-sandstone rocks relatively up to 6 m thick, whereas 15-20 cm thick ferribands are distributed randomly throughout KS and BG groups. Most of the rock units are dominated by reddish brown and yellowish colors. Petrographic examinations revealed that the FSD are composed of quartz grains and iron oxides mineralization. Most of the ferruginous sandstones are well cemented quartz arenites. Quartz and iron oxides (goethite) are the main constituents of the ferruginous sandstones as identified by XRD, while the oxides of hematite and limonite are amorphous. XRF analyses of selected bulk samples indicating that the $Fe_2O_3$ content ranges from 4.24 to 44.46%, whereas through SEM the $Fe_2O_3$ content is up to 53.65%. It can be assumed that the depositional environment was represented by coeval meandering or low sinuosity fluvial facies, which intercalated with marginal marine facies in Batn Al Ghul area. It could be argued that the source of the iron in the study area can be attributed to extensive post-depositional dissolution of detrital grains, i.e. iron bearing heavy minerals like glauconite. Occurrences of FSD along and subparallel to the major faults in the study area could affect the upward migration of ferrous iron in solution and deposition of ferric compounds in the upper part of the sequences of KS/BG groups.

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