

Mineralogy of the Qarain Clay Deposits, Saudi Arabia

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ABSTRACT. The Qarain Clay deposits occur in the Qarain area, about 230 km W of Riyadh. The clay deposits lie within the Marrat Formation (Lower Jurassic). Mineralogical and chemical studies of the deposits establish the dominance of kaolinite with a lesser amount of illite in the clay fraction. The non-clay silicate mineral is quartz. The red colour of the deposits is due to hematite which has been identified from X-ray diffractograms.

It is suggested that partial laterization of the source rocks, mainly acid igneous rocks of the Arabian shield, is the process through which the clay minerals in the Qarain area were formed. Partial laterization of the source rocks probably operated under humid tropical conditions. The weathered products were transported to the present area and deposited in a shallow and near shore environment in the Toarcian sea.

The investigated clay deposits occur in the Qarain area, about 230 Km W of Riyadh, the capital of Saudi Arabia (Fig. 1). These deposits lie within the Marrat Formation named after the town of Marrat, about 30 km SE of Qarain village. The Marrat Formation extends approximately between latitude 22° 50'N and 28°N as a part of the Lower and Middle Jurassic clastic and carbonate rock sequence. The whole sequence of the Marrat Formation does not crop out at one place, but is pieced together from several sections, generally along lat. 25° 02'N (Assad 1973). It is underlain unconformably by continental sandstone of the Minjur Formation (Upper Triassic), and overlain conformably by the shallow marine limestone and shale of the Dhurma Formation. The Marrat Formation is almost completely of Toarcian age, belonging to lowermost Jurassic (Powers *et al.* 1966, Assad 1973). This Formation has been subdivided into three members based on lithology and faunal characteristics (Assad 1973). These members are:

Hadbah member (Upper Marrat).

Qarain member (Middle Marrat).

Shaqra Member (Lower Marrat).

The Lower and Upper Marrat are mainly composed of carbonate rocks whereas the Middle Marrat is dominantly composed of argillaceous rocks and subordinate siltstone and silty sandstones.

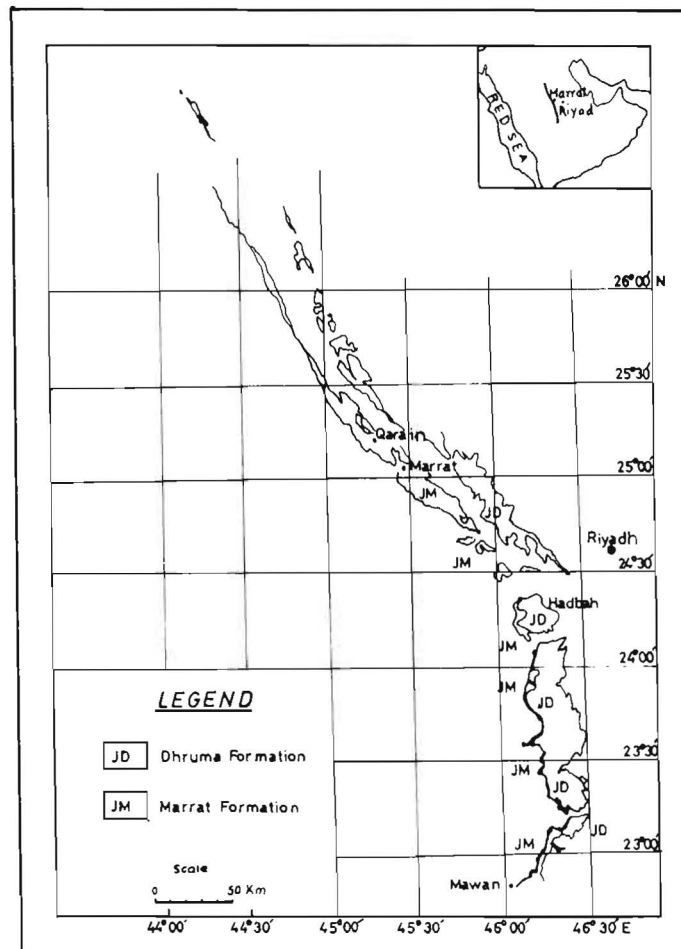


Fig. 1. Location map of the Qarain area and the extension of Marrat Formation, Saudi Arabia (After Assad 1973).

The Qarain member is made up of brownish-red to dark-red mudstone, shale, sandy and silty shale with occasional thin beds of calcareous sandstones. The thickness of the unit at the Qarain mesa is about 38m (Fig. 2).

About 30 samples were collected in the field, and a few samples were selected for detailed X-ray diffraction, differential thermal analysis and chemical analyses.

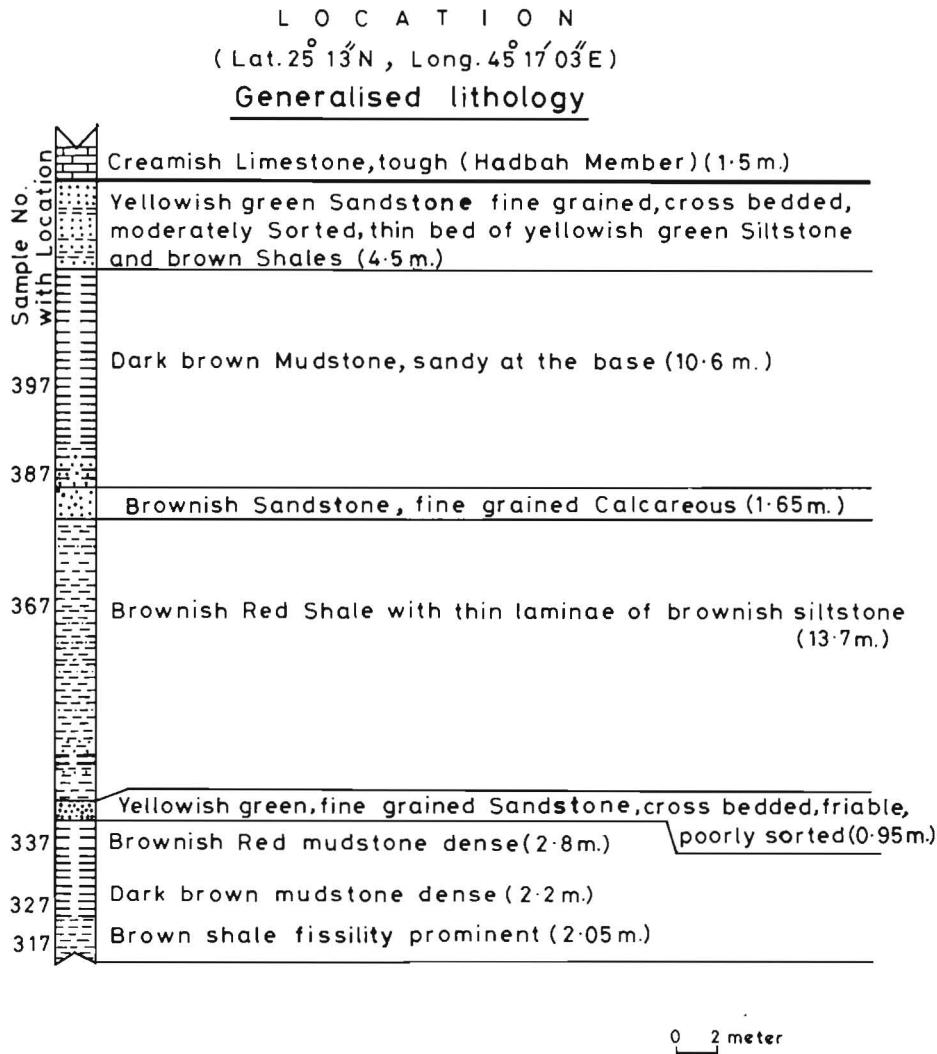


Fig. 2. Local stratigraphic column of the Qarain Member of Marrat Formation at Khashm Al-Qarain Mesa.

Partial chemical analyses and X-ray work for the Marrat red beds have been done by Abed (1979). The objective of this work is to characterize the Qarain clay deposits mineralogically and chemically.

Methods of Investigation

A total of thirty samples were collected from the Qarain area (Khashm Al-Qarain). Six samples were selected for chemical analyses, X-ray diffraction and differential thermal analyses.

Chemical analyses for major elements were done by wet chemical methods (Table 1). Na and K were determined by flame photometry.

Differential thermal analyses (DTA) were recorded under the following conditions: whole rock samples were ground to $< 150 \mu\text{m}$; heating rate of 10°C per minute in an atmosphere of nitrogen flowing over the sample. X-ray diffraction analyses were obtained using Philips PW 1050 diffractometer with CoK_α radiation (Table 2.). The goniometer was set at a speed of one degree $2\theta/\text{min}$, with a chart speed on the recorder equivalent to $1 \text{ cm}/\text{min}$.

Results

The results of chemical analyses of whole rock samples are presented in Table 1. The silica content ranges from 40.08 to 71.22 percent; sample QR-387 contains the highest percentage because it is highly arenaceous. Sample QR-317 contains the highest percentage of Al_2O_3 . Silica does not follow any definite trend with respect to stratigraphic position of the samples (Fig. 3). There is a general trend of decreasing Fe_2O_3 content in argillaceous rocks with depth. Alumina has antipathetic relation with Fe_2O_3 . K_2O generally increases with depth whereas TiO_2 has a decreasing attitude.

Higher Al_2O_3 and lower K_2O and Na_2O contents in the mudstones reflect their greater concentrations of kaolinite in them as compared to average shale. The smaller amount of Na_2O is probably due to the very small quantity of alkali feldspar. Higher values of CaO together with higher loss on ignition is mainly due to the presence of gypsum and calcite in the deposits.

Typical X-ray diffractogram (Fig. 4) indicates that the Qarain clays are dominantly composed of kaolinite with subordinate quantities of illite and quartz. Hematite is also shown to be present in small amounts in most of the samples.

The reflections at 7.15 \AA (001), 3.57 \AA (002) and 2.37 \AA (003) are the most diagnostic for kaolinite (Table 2). These reflections disappear and collapse upon heating of the oriented clay slide to 550°C . By heating, a differentiation between chlorite and kaolinite is also possible which otherwise may be difficult if 14 \AA

Table 1. Chemical Analysis* (Whole rock analyses).

Sample No.	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	MnO	P ₂ O ₅	H ₂ O	L.O.I.	Total
QR-317	44.40	1.75	23.01	11.98	3.50	1.25	0.05	2.20	0.02	0.05	1.52	10.84	100.57
QR-327	43.62	1.80	22.31	12.98	2.50	1.15	0.10	2.10	0.09	0.08	1.38	11.36	99.47
QR-337	43.78	1.75	22.40	13.98	3.50	1.40	0.47	2.30	0.01	0.05	1.24	10.74	101.62
QR-367	40.08	1.67	19.85	16.97	4.50	1.95	0.05	1.70	0.02	0.08	2.58	12.16	101.61
QR-387	71.22	1.90	3.79	6.99	7.50	0.50	0.05	1.40	0.02	0.02	0.30	7.54	101.23
QR-397	47.04	2.50	12.28	17.97	3.40	1.40	0.03	3.00	0.02	0.06	1.88	8.72	98.30

* Analysed at Chemistry Lab., Faculty of Earth Sciences, King Abdul Aziz University, Jeddah, Saudi Arabia.

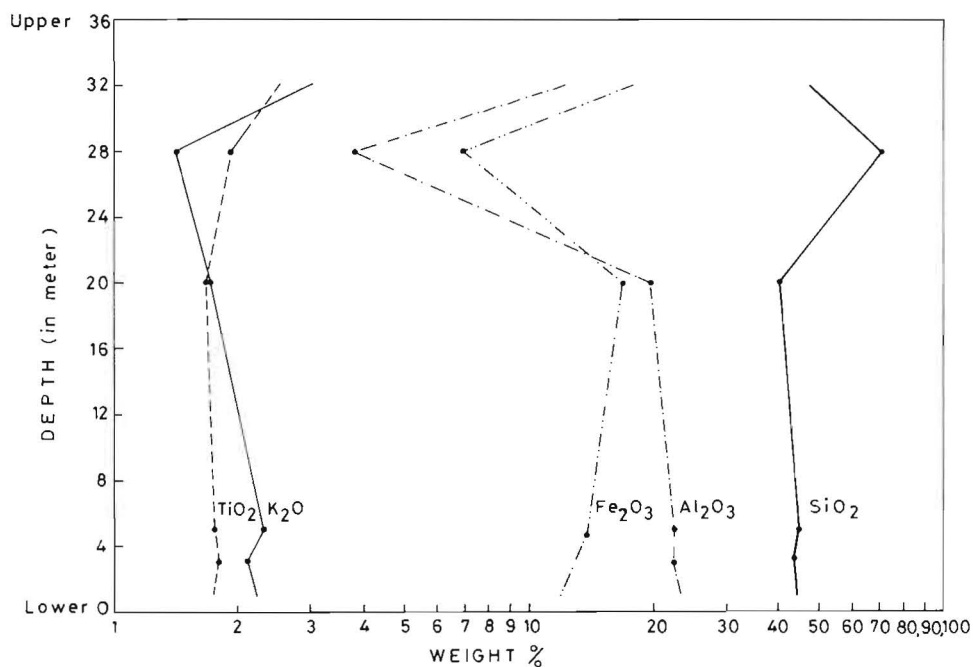


Fig. 3. Semilogarithmic plot of the progressive chemical variations of samples from the Qarain area, with respect to their order of superposition.

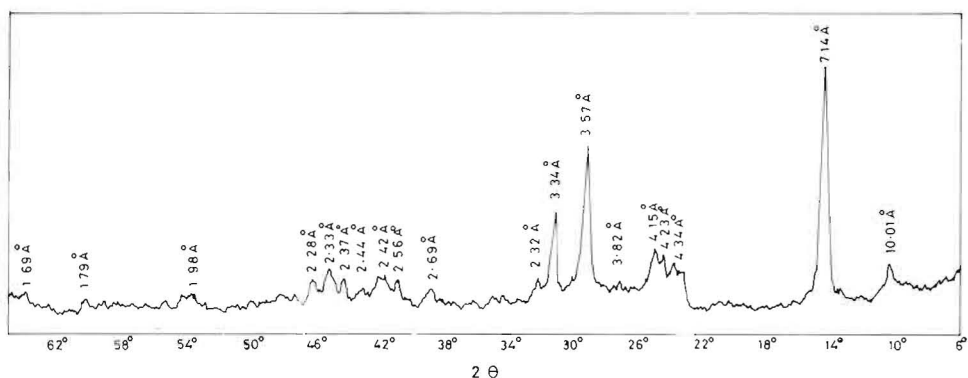
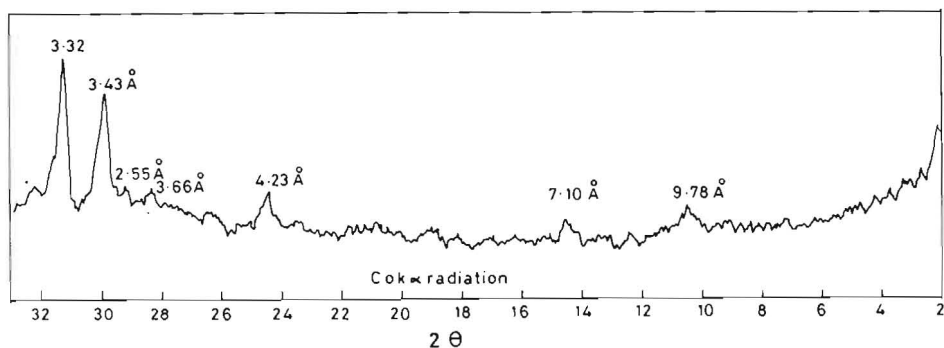


Fig. 4. Typical X-ray diffractogram of disoriented air-dried sample from the Qarain clay deposits.

reflection of chlorite is not prominent (Grim 1968). Two samples were subjected to heating up to 550°C for two hr. The results of only one sample (QR-397) have been incorporated in this paper (Fig. 5). The shape and the relative intensities of the reflections at 4.43, 4.34 and 4.13 Å reveal a moderately weak degree of crystallinity of kaolinite (Murray and Lyons 1956).

Table 2. D-spacings (Å) and intensities of disoriented, air dried samples from the Qarain clay deposits.

Samples											
QR-317		QR-327		QR-337		QR-367		QR-387		QR-397	
dÅ	I/I ₀	dÅ	I/I ₀	dÅ	I/I ₀	dÅ	I/I ₀	dÅ	I/I ₀	dÅ	I/I ₀
10.01	12	9.97	18	10.01	14	10.07	11	10.10	10	9.97	8
7.14	100	7.14	100	7.14	52	7.14	100	7.14	15	7.14	39
4.36	16	4.34	19	4.34	10	4.34	40	4.36	5	4.43	13
4.17	16	4.13	20	4.13	2	4.13	59	4.16	65	4.23	23
3.83	3	—	—	—	—	—	—	—	—	3.72	4
3.57	50	3.57	59	3.57	60	3.57	70	3.57	16	3.56	39
3.34	27	3.34	35	3.34	100	3.34	46	3.34	100	3.34	100
3.23	6	3.23	5	3.23	9	3.23	10	3.23	22	3.24	16
2.69	10	2.69	14	2.69	15	2.69	9	2.69	16	2.69	18
2.56	7	2.55	13	2.55	16	2.55	35	2.55	7	2.55	16
2.49	12	2.49	18	2.49	18	2.49	16	2.49	19	2.51	17
2.37	8	2.43	13	2.43	10	2.43	11	2.43	33	—	—
2.33	12	2.37	21	2.33	10	2.33	23	2.33	3	2.33	12
2.28	8	2.28	9	2.27	10	2.28	14	2.28	53	2.27	9
1.98	5	1.98	10	1.97	6	1.98	5	1.98	11	1.97	11
1.78	5	1.84	7	1.81	7	1.93	12	1.82	24	1.81	8

**Fig. 5.** Typical X-ray diffractogram of an oriented sample (QR-397) heated to 550°C.

Illite is recognized from reflection at about 10 Å (Bradely and Grim 1961) which does not change by thermal treatment (Molloy and Kerr 1961). It is difficult to determine whether the illite is di- or tri-octahedral. However, the reflections between 20-30° 2θ and the examination of the intensity ratio I(001)/I(002) shows that the illite present in most of the clay fraction is a 2M1 polytype and dioctahed-

ral (Bradely and Grim 1961, Carroll 1970). The 10 Å (001) basal reflection is quite sharp, hence it is most likely a secondary fine-grained dioctahedral mica 2 M1. This clay mineral possibly has been formed by the weathering and transformation of micas and primary feldspar (Stoch and Sikora 1976).

Quartz is present even in the clay fraction and is easily identified by its reflections about 3.34 and 4.26 Å.

Small peaks with reflections at about 2.69 and 2.55 Å indicate the presence of hematite.

DTA curves of the Qarain samples show endothermic peaks between 550 and 580°C and exothermic peaks between 930 and 955°C. All samples show moderately strong to strong endothermic peaks between 90 and 120°C due to loss of moisture from the clays. All samples confirm the presence of kaolinite. Typical differential curves of the Qarain clay are presented in Fig. 6. In one sample (QR-387), the illite is present in considerable amounts as indicated by the endothermic peak at 825°C (Gaudette *et al.* 1964). The presence of quartz in these samples could not be confirmed in the presence of illite and kaolinite due to overlapping of endothermic peaks around 570°C. Brownish red colour of the samples indicates the presence of iron oxide. In DTA, hematite fails to show any thermal transformation up to 1000°C. However, its presence has been confirmed by X-ray diffraction.

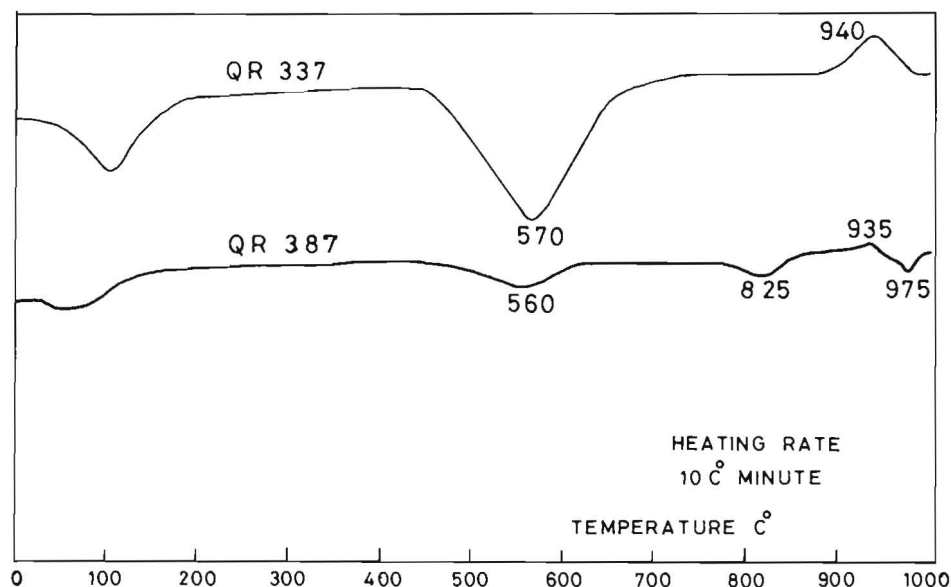


Fig. 6. Typical differential thermal curve for the Qarain clay samples.

Discussion

The dominant amount of kaolinite in the Qarain area may have formed from all source sediments when weathering solutions were acidic to neutral in flowing water. Kaolinite requires an open environment, with low pH and fairly intensive leaching of alkali and alkaline earth metals and to some extent silica.

However, illite was probably produced from volcanic or igneous rocks, when the solutions were basic or slightly acidic (Millot 1970).

Red beds from different parts of the world have been studied extensively. Several workers have put forward different hypotheses to explain the origin of red colour. The voluminous literature on the subject, including numerous reviews (Dunber and Rodger 1957, Van Houten 1968 and 1972, Glennie 1970, Blatt *et al.* 1972, Turner 1974, Friedman and Sanders 1978, and many others) have led to the conclusion that red beds may form under a wide variety of conditions, and cannot be used as a specific palaeoenvironment indicator. Krynine (1949) and Van Houten (1968) envisaged that the red beds are formed by the erosion of brown to tan amorphous iron hydroxide or ferric oxide material in humid upland regions and their aging to hematite in the deposited sediments. Thus, it is concluded that the red colour of the Qarain clays indicates the presence of iron oxides, especially hematite.

Various clay mineral assemblages have been reported in red beds of different geologic ages, and formed in different environmental conditions. Dominant kaolinite has been reported in some of the red beds, especially in highly sorted siltstones, mudstones and sandstones (Walker 1974). Hematite is formed by diagenesis of hydroxides (Berner 1971).

It is suggested that the clay minerals of the Qarain area have been formed from the weathered products of the igneous and metamorphic rocks of the Arabian shield.

The red colour of the Qarain clay desopits is due to hematite which has been confirmed from X-ray analysis. Most of the hematite occurs as fine particle evenly disseminated in the clay and in lesser amount as irregular coating on sand grains.

It is suggested that partial laterization of the source rocks, mainly acid igneous rocks of the Arabian shield, is the process through which the clay minerals in the Qarain area were formed. Partial laterization of the source rocks was probably operated under humid tropical conditions. The weathered products were transported to the present area and deposited in a shallow and near shore environment in and around the Toarcian sea.

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دراسة معدنية لرسوبيات الصلصال بمنطقة القرائن بالمملكة العربية السعودية

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- المملكة العربية السعودية

تقع رسوبيات صلصال القرائن بمنطقة القرائن إلى الغرب من مدينة الرياض بحوالي ٢٣٠ كيلومتراً. وتقع هذه الرسوبيات ضمن متكون مرات (الجوراسي السفلي). وتثبت الدراسة المعدنية والكيميائية لهذه الرسوبيات سيطرة معدن الكاولينيات كمعدن رئيسي مع كمية قليلة من معدن الإليت في الجزء الصلصالي ويوجد معدن الكوارتز كمعدن غير صلصالي في هذه الرسوبيات. إن اللون الاحمر الذي يميز هذه الرسوبيات يعود إلى معدن الهيماتيت والذي أمكن التعرف عليه من رسومات الأشعة السينية.

ويقترح البحث أن اللترتة الجزئية لصخور الدرع العربي وخاصة النارية ربما تكون هي العملية التي كونت معادن الصلصال بتلك المنطقة. ولعل هذه اللترتة الجزئية قد حدثت تحت ظروف مدارية رطبة حيث نقلت مكونات الصخور المجوأة الى هذه المنطقة في بيئة بحرية قريبة من الشاطئ حول وداخل البحر التوارس في العصر الجوراسي.