J. Univ. Kuwait (Sci.) **7**, 1980

Microfacies and petrographic analyses of the Mauddud Formation in Kuwait and nearby regions

ALI A. AL-SHAMLAN

Department of Geology, University of Kuwait

ABSTRACT

The Albian Mauddud Formation is an important calcarenitic carbonate reservoir rock in Kuwait and north Arabian Gulf. It is widely spread in the Middle East, where it can be traced from Rub'el Khali in southern Saudi Arabia up to Iraq. In Kuwait, it ranges in thickness between a few metres and 98 m. Nine microfacies associations are recognised within the Mauddud Formation in Kuwait, namely: *Orbitolina–Trocholina* biomicrite, *Orbitolina–Trocholina* pelsparite, *Ovalveolina*–miliolid biomicrite, shelly biomicrite, argillaceous biomicrite, dolomitic biomicrite, dolomite, sandy dolomitic *Orbitolina* biomicrite and carbonaceous siltstone. The pronounced diagenetic alterations in the Mauddud Formation are mainly recrystallisation, rim cementation and dolomitisation. The porosity which could be identified is mainly leaching and intercrystalline whereas intergranular and intragranular porosities are of less magnitude.

The sediments constituting the Mauddud Formation are considered to have been deposited in a shallow marine environment with scattered shell banks. They formed during a regressive depositional phase which encountered an influx of detrital material from a nearby land mass in its early stages.

The pronounced thinning of the Mauddud Formation, as well as the smaller number of microfacies in southern Kuwait is either due to: (a) deposition over pre-existing structural highs or, (b) less subsidence during deposition in the south compared to more subsidence northward or, (c) erosion of the upper Mauddud in the south.

INTRODUCTION

The Early Cretaceous Mauddud Formation, one of the important petroleum reservoirs in Kuwait and the surrounding areas, has been thoroughly investigated by the writer to reveal its petrographic nature, microfacies aspects and environmental conditions of deposition. Cores and rock cuttings representing the formation were collected from five wells drilled by Kuwait Oil Company in Kuwait to furnish the base of this study. The wells, namely: Raudhatain No. 1(RA-1), Sabiriyah No. 1 (SA-1), Ahmadi No. 2 (AH-2), Magwa No. 26 (MG-26), and Burgan No. 129 (BG-129), were selected in order to form a line running from south to north through Kuwait (Fig. 1). The rock samples were described lithologically, then thin sectioned and scrutinised by using the petrographic microscope. Also, adequate staining procedures were used to verify the mineralogical composition of the rock types, and to aid in recognition of the environmental conditions which prevailed during the deposition of the formation.

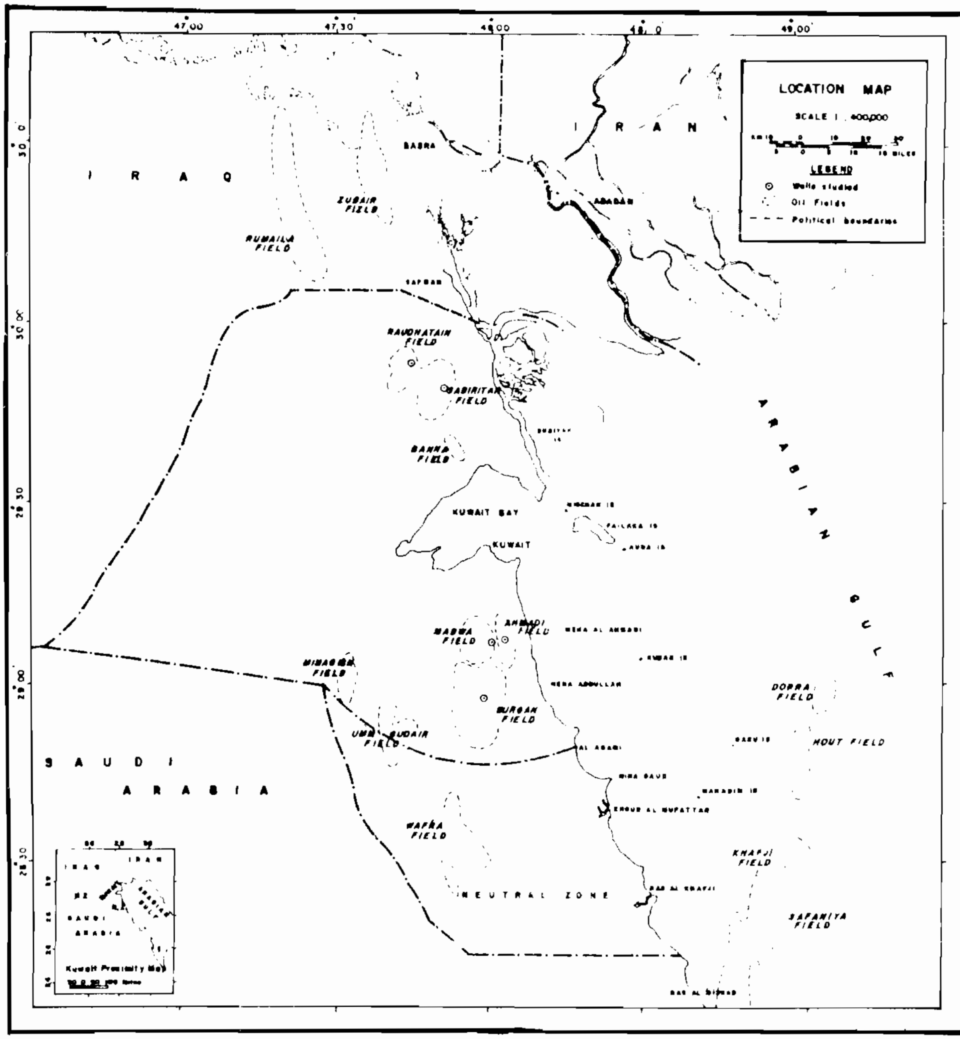

Fig. 1. Generalised map of Kuwait and nearby countries showing localities mentioned.

DEFINITION OF THE MAUDDUD FORMATION

The Mauddud Formation was defined by Henson (1940) in the subsurface section of Dukhan well no. 1 at the Dukhan Oilfield in Qatar. The definition was revised and amended by Sugden (1958), who described the formation in its type locality as a limestone, light grey, earthy, mostly of fairly high porosity except for the bottom few feet which are rather marly. Much of the limestone appears to be silty, due to the presence of fine calcareous detritus and the upper part contains beds with much fossil and pellet debris (Dunnington *et al.* 1959). The formation, in its type locality, contains *Orbitolina cf. concava* (Lamarck), *Orbitolina concava* (Lamarck) var. *quatarica* Henson, *Trocholina arabica* Henson, *T. lenticularis* Henson, and *Cyclammina whitei* Henson.

The Mauddud Formation in its type locality, conformably overlies the Albian Nahr Umr Formation, and is overlain conformably by the Khatiyah Formation which ranges in age from intra-Cenomanian at the top to Albian at the base. Therefore, the Mauddud Formation is considered by Sugden (1958) to be of Albian age.

REGIONAL DISTRIBUTION OF THE MAUDDUD FORMATION IN THE MIDDLE EAST

The Mauddud Formation can be traced laterally in subsurface sections penetrated by oil wells in different countries of the Middle East; it is also recognised in some outcrops in Iran (James & Wynd 1965).

In Saudi Arabia, this rock unit was lowered to member status and was included in the Wasï Formation (Powers *et al.* 1966). The Mauddud Member has been described by many authors since the time of early exploration for oil, specifically in subsurface sections of wells drilled in the eastern part of the country. However, Powers *et al.* (1966) and Powers (1968) discussed all the previous work and suggested the reference section of the Mauddud Member in Saudi Arabia to be at Safaniya well No. 17 between the drilled depths 1526 and 1531 m with a thickness of 5 m. It consists of marly dolomite. The member could be traced laterally in the country where it was found pinching out westward throughout the western Arabian Gulf area north and east of the famous Ghawar Oilfield. In the central and eastern Rub'el-Khali it attains a maximum thickness of about 60 m.

In the northern Arabian Gulf, the Mauddud Formation has been discussed by Loutfi & Jaber (1970) mainly in the Kuwait–Saudi Arabia offshore Neutral Zone area, and was found to consist of a limestone section ranging in thickness between an average of 30 m in Khafji Oilfield and an average of 97 m in Dorra Oilfield. The limestone is cream to tan and appears sandy due to the presence of abundant biogenic debris. Its upper part is highly vuggy and richly fossiliferous (Loutfi & Jaber 1970).

In Iran, James & Wynd (1965) subdivided the Middle Cretaceous Sarvak Formation into two members: the Mauddud Member at the base, succeeded by the Ahmadi Member, both of which are correlated with and named after formations of the same name in Kuwait and Iraq. The Mauddud Member was described by these authors as consisting of 'prominent weathering, thick-bedded, grey to brown, *Orbitolina*-rich limestone'. The unit ranges from 61 to 122 m in thickness.

In southern Iraq, the Mauddud Formation was described by Owen & Nasr (1958) to consist of 'organic, detrital, sometimes pseudo-oolitic, cream-coloured limestone with occasional green or bluish shale streaks'. It reaches a maximum thickness of about 150 m in parts of the Zubair Oilfield. In northern Iraq, the Mauddud Formation was recognised in several subsurface sections, with a thickness ranging between 37 m and about 110 m. In all sections the formation is composed of an organic, detrital limestone with a rather marly matrix and a persistent *Orbitolina-Trocholina* fauna (Dunnington *et al.* 1959).

THE MAUDDUD FORMATION IN KUWAIT

The formation is found to be mainly represented by marine calcarenitic limestones at its upper part; it grades downward to marly, dense, and partly fossil-bearing microcrystalline limestone. Its thickness ranges from only a few metres in the southern part

AGE	GROUP	FORMATION: BASRA AREA	FORMATION: KUWAIT	DESCRIPTION	
MIOCENE-PLEISTOCENE	KUWAIT	DIBDIBBA		Sands and Gravels, subordinate marls	
		LOWER FARS		Anhydrite, Gypsum, marls and shallow water limestones	
		GHAR		Sands and subordinate gravels occasional clays.	
EOCENE	HASA	DAMMAM		Recrystallized and dolomitized limestones of nummulitic facies. Capped by chert in Kuwait.	
		RUS		Anhydrite, thick bedded, with subsidiary limestone and marls	
		RADHUMA		Limestone, mostly marly with subsidiary recrystallized and dolomitized limestones, thin anhydrites	
UPPER CRETACEOUS	ARUMA	TAYARAT		Limestone, recrystallized, usually dolomitic, with few thin interbedded black shales	
		QURNA	BAHRAH	Globigerinal marly, sometimes dolomitic	Dense, cherty Ls. with detrital Ls &sh in the base
		HARTHA	GUDAIR	Limestones, organic, detrital, glauconitic with subsidiary dark shale	Dense, white detrital with some pseudo-oolitic marly limestone and black shales towards the base.
		SA'DI		White, chalky, marly, globigerinal limestones	
		TANUMA		Black shale with calcareous detritus	
		KHASIB		Fine grained marly limestone with interbedded shale.	
MIDDLE CRETACEOUS	WASIA	MISHRIF	MAGWA	Limestones, dense, organic and detrital with fresh water limonitic limestone bed at top	Grey dense marly pyritic limestone with green shales.
		RUMAILA		Limestones, fine grained, marly and chalky in parts	
		AHMADI		Shales, green, brown, grey, with prominent limestone member	Shales, green, brown and grey
		WARA		Sandstones and siltstones with interbedded dark grey shales.	
		MAUDDUD		Limestones, organic, detrital in parts.	
		NAHR UMR	BURGAN	Shale and limestone, with occasional limestone beds in upper part	Clean sandstone with only minor shale breaks.
LOWER CRETACEOUS	THAMAMA	SHU'AIBA		Limestone, fine grained, with dolomitized rudist bank developments.	
		ZUBAIR		Interbedded sandstones and shales	
		RATAWI		Greenish black shales with limestone streaks.	

Fig. 2. Stratigraphic nomenclature for Kuwait and southern Iraq (after Owen & Nasr 1958).

of the country to 98 m in the north. It is overlain by the Wara Formation, and underlain by the Burgan Formation (Fig. 2). The Mauddud Formation was assigned to Cenomanian age by Owen & Nasr (1958). However, this assignment has been amended by later authors and the formation is now accepted to be of an Albian age (Dunnington *et al.* 1959).

Based on the petrographic analysis, nine microfacies associations could be revealed within the Mauddud Formation. The nine microfacies are:

Microfacies 1: Orbitolina–Trocholina biomicrite (wackestone–packstone), Figs 3.1, 3.2 and 3.3
The dominant components of this microfacies are *Orbitolina* spp. and *Trocholina* sp. in a micrite matrix. Other elements associated with this microfacies are *Textularia* sp., dasyclad ocean algae, crinoids, echinoid spines, gastropods and pelecypod shell fragments, in addition to some intraclasts and pellets. This microfacies is highly porous with both intergranular and leached pore space. Recrystallisation affecting both fossils and matrix is common. The matrix was also partly dolomitised and contains fine dolomite rhombs.

Microfacies 2: Orbitolina–Trocholina pelsparite (grainstone), Figs 3.4, 3.5 and 3.6
Orbitolina spp. in a sparry calcite cement matrix is the most common allochem found in this microfacies. Less commonly found are: algae, crinoids, echinoid spines and some pelecypod shell fragments, in addition to pellets and a few intraclasts. Some fine, angular quartz and glauconite grains are occasionally encountered in this microfacies. Some fossils are obliterated due to recrystallization. Slight porosity and dolomitisation of the matrix occur in some samples.

Microfacies 3: Ovalveolina–miliolid biomicrite (wackestone), Fig. 3.7.
Ovalveolina sp. and miliolids in a micrite matrix are the dominant components of this microfacies. Other fossils occasionally found are *Nezzazata* sp., sponge spicules and other small foraminifera. Some patches of recrystallisation spar are present in the matrix.

Microfacies 4: Shelly biomicrite (packstone), Fig. 3.8.
The dominant components of this microfacies are pelecypod shell fragments in a micrite matrix. Some of the shell fragments are coated by blue–green algae. Other elements associated with this microfacies are *Trocholina* sp., gastropods, crinoids, echinoid spines and some *Orbitolina* sp., in addition to some intraclasts. Some quartz grains occur in the matrix. Partial recrystallisation of the fossil fragments is observed. The matrix is occasionally dolomitised, where dolomite rhombs are found scattered throughout.

Microfacies 5: Argillaceous biomicrite (wackestone), Figs 3.9 and 3.10
Orbitolina sp. and crinoids in a highly argillaceous micrite matrix dominate this microfacies. Other elements found are echinoid spines, *Solenopora* algae and pelecypod shell fragments, in addition to some pellets and intraclasts. Some quartz and glauconite grains are found in the matrix. The microfacies is poorly porous in general, but locally it is highly dissected by irregular empty cavities of different shapes and sizes which are most probably caused by leaching.

Microfacies 6: Dolomitic biomicrite (wackestone), Fig. 3.11.
This microfacies consists of relics of fossil remains, mainly *Orbitolina* spp., echinoids, crinoids and occasionally *Trocholina* sp. and miliolids, in a matrix formed mostly of fine to medium, rhombic to subrhombic dolomite crystals. Few fine, angular quartz

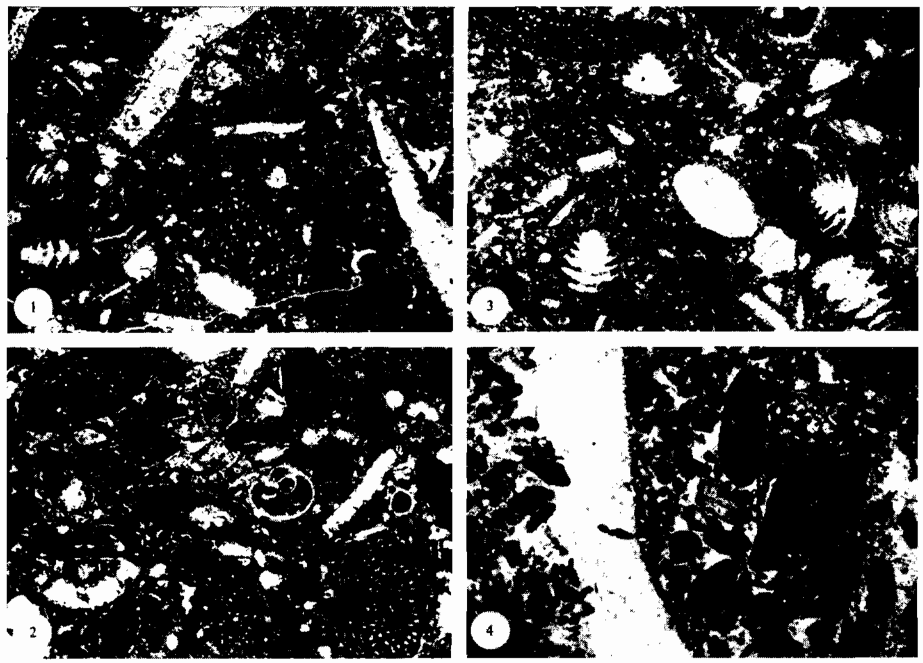

Fig. 3. Microfacies of the Mauddud Formation.

1, *Orbitolina–Trocholina* biomicrite: Fragments of *Orbitolina* sp., *Trocholina* sp., algae and recrystallised skeletal material, including pelecypod fragments, embedded in a micrite matrix. Pelecypod fragment in lower right corner exhibits blue–green algal coatings. Partial recrystallisation to microspar occurs in the matrix. Well SA-1, depth 2205 m (× 28), P.L.

2, *Orbitolina–Trocholina* biomicrite: Abundant, unsorted bioclasts, including fragments of *Orbitolina* spp., gastropods, dasyclad algae and other unidentified, reworked skeletal fragments, embedded in a slightly recrystallised micrite matrix. Some subangular to subrounded intraclasts are scattered throughout the matrix. Partial recrystallisation of both matrix and fossils is present. Well SA-1, depth 2268 m (× 24), P.L.

3, *Obitolina–Trocholina* biomicrite: Abundant bioclasts including *Trocholina* sp., *Orbitolina* sp., crinoids and other unidentified fragments, embedded in a partially recrystallised matrix. Some of the fossil remains are completely obliterated by recrystallisation. Well SA-1, depth 2212 m (× 28), P.L.

4, *Orbitolina–Trocholina* pelsparite: *Orbitolina* sp., pellets and intraclasts, in a sparry calcite cement matrix. Some fossils are partially obliterated due to recrystallisation. A thick vein of sparry calcite crystals is pronounced in the photo. Well RA-1, depth 2278 m (× 20), P.L.

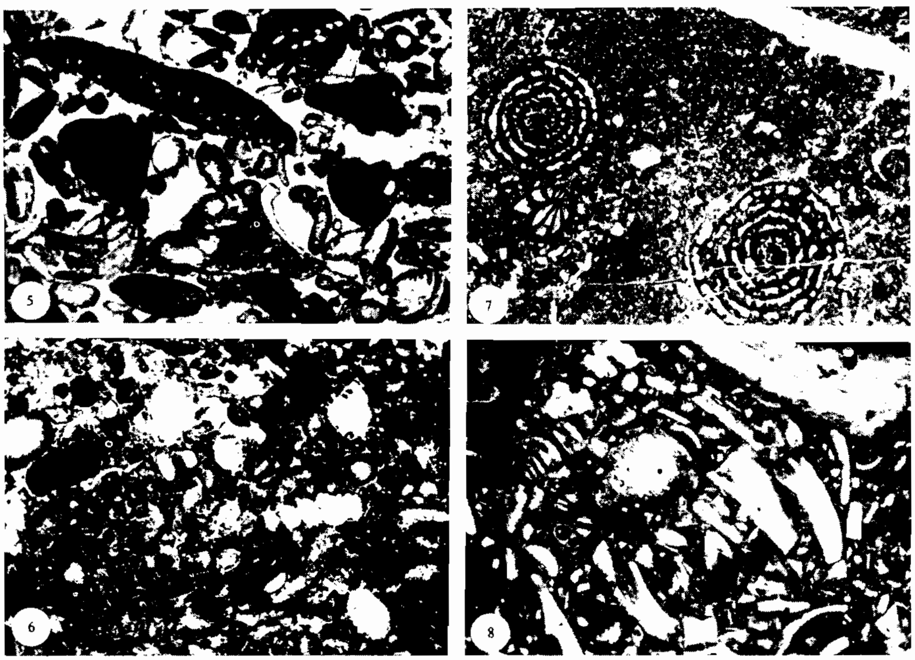

Fig. 3. Microfacies of the Mauddud Formation.

5, *Orbitolina–Trocholina* pelsparite: *Orbitolina* spp., *Trocholina* sp., crinoids, intraclasts and other unidentified fragments, in a sparry calcite cement matrix. Some fossil fragments are obliterated due to recrystallisation. Well SA-1, depth 2254 m (× 24), P.L.

6. *Orbitolina–Trocholina* pelsparite: Abundant, poorly sorted fragments including *Trocholina* sp., *Orbitolina* sp., algae, crinoids, pellets and other unidentified fragments, in a sparry calcite cement matrix. Some fossils are partially obliterated due to recrystallisation. Well SA-1, depth 2291 m (× 24), P.L.

7, *Ovalveolina* biomicrite: Abundant bioclasts including *Ovalveolina* sp., *Nezzazata* sp., miliolids and other small foraminifera, embedded in a micrite matrix. Fine fractures filled with sparry calcite are visible. Well SA-1, depth 2216 m (× 28), P.L.

8, Shelly biomicrite: Abundant, unsorted fossil fragments including pelecypods, crinoids, *Trocholina* sp. and other unidentified fragments, embedded in a micrite matrix. Partial recrystallisation of the fossil fragments is observed. Well RA-1, depth 2275 m (× 20), P.L.

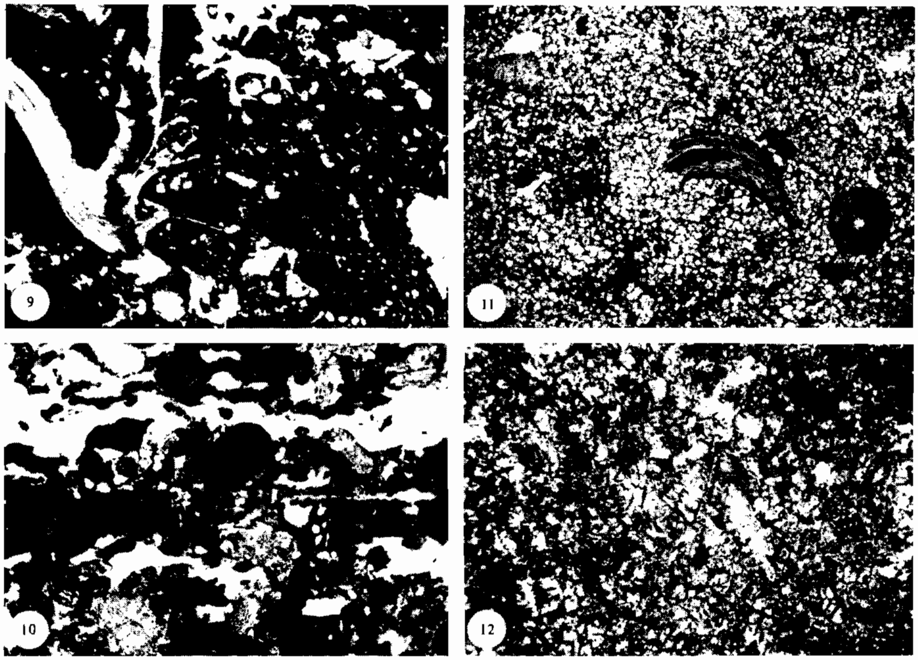

Fig. 3. Microfacies of the Mauddud Formation.

9, Argillaceous biomicrite: Fragments of *Orbitolina* sp., pelecypods and other fine skeletal fragments, embedded in an argillaceous, partly dolomitic, micrite matrix. Few quartz grains are present in the matrix. Solution porosity is observed as white patches. Well SA-1, depth 2271 m (× 28), P.L.

10, Argillaceous biomicrite: Crinoids, echinoid spines and *Orbitolina* sp., in an argillaceous matrix. Few quartz and glauconite grains are present in the matrix. Some of the white patches are caused by leaching porosity. Well SA-1, depth 2254 m (× 24), P.L.

11, Dolomitic biomicrite: A fragment of pelecypod and a crinoid embedded in a dolomite matrix formed of rhombic to subrhombic, fine dolomite crystals. Black patches associated with the dolomite are iron stains. White patches are the results of leaching porosity. Well RA-1, depth 2306 m (× 22), P.L.

12, Dolomite: Fine anhedral to subhedral, rhombic to subrhombic dolomite crystals forming an interlocking mosaic texture. Ghosts of dolomitised *Textularia* sp. can be recognised in the matrix. Traces of black oil stains occur in intercrystalline pore spaces. Well BG-129, depth 1203 m (× 30), P.L.

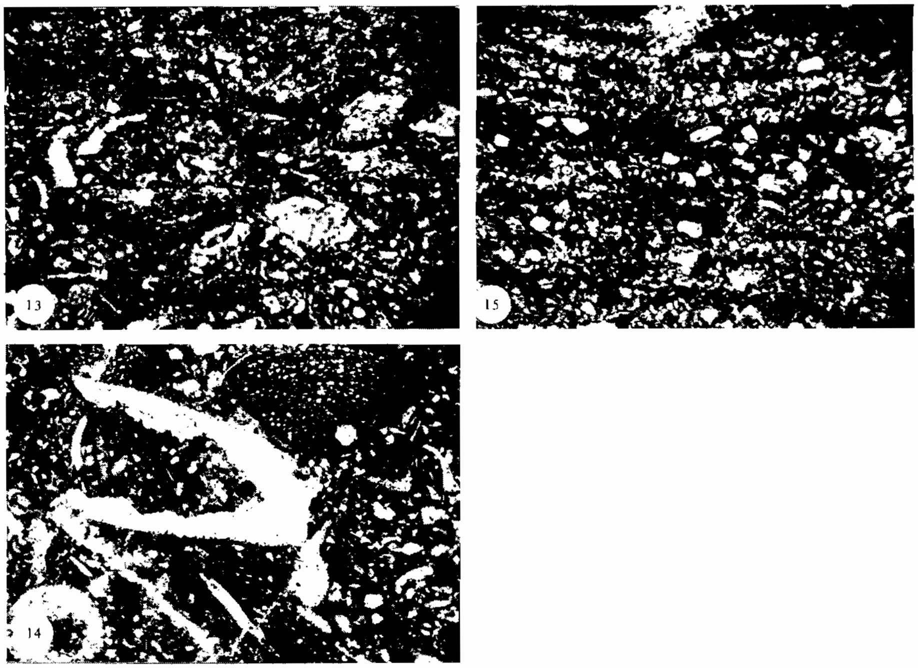

Fig. 3. Microfacies of the Mauddud Formation.

13, Sandy dolomitic *Orbitolina* biomicrite: *Orbitolina* sp. and crinoid fragments embedded in a partly dolomitic, micrite matrix. Abundant fine, subangular to subrounded, quartz and glauconite grains occur in the matrix. Solution of leaching secondary porosity is present. Dolomitisation affects both matrix and fossils. Well MG-26, depth 1291 m (× 19), P.L.

14, Sandy dolomitic *Orbitolina* biomicrite: Fragments of *Orbitolina* sp., dasyclad algae, crinoids and pelecypods, embedded in a partly dolomitised micrite matrix. Some fossils are completely obliterated due to recrystallisation. Abundant fine, angular, quartz grains with few glauconite grains occur in the matrix. Well SA-1, depth 2257 m (× 24), P.L.

15, Carbonaceous siltstone: Fine, subangular to subrounded, unsorted quartz grains, in a carbonaceous, argillaceous matrix. The quartz grains are inter-laminated with a carbonaceous matter giving the rock a successive string pattern. Well RA-1, depth 2312 m (× 22), P.L.

grains are occasionally present in this microfacies. Intercrystalline and leaching porosities are present in the matrix.

Microfacies 7: (Dolomite), Fig. 3.12.
The dolomite microfacies consists of homogeneous, fine to medium euhedral to anhedral, occasionally iron-stained dolomite crystals. Some of the fossils occasionally found in this microfacies are *Orbitolina* sp., *Textularia* sp., echinoids and crinoids. Few glauconite grains are associated with this microfacies. Intercrystalline porosity is present.

Microfacies 8: Sandy dolomitic *Orbitolina* biomicrite (packstone) Figs 3.13 and 3.14. *Orbitolina* sp. in a micrite matrix forms the dominant component of this microfacies. Other fossils occasionally found are dasyclad algae, crinoids, echinoid spines and pelecypod shell fragments. Abundant, fine, angular to subangular quartz grains and few glauconite grains are encountered in the matrix. Some fossils are partially to completely obliterated due to recrystallisation. Dolomitisation of the matrix is common. This microfacies is highly porous.

Microfacies 9: (Carbonaceous siltstone) Fig. 3.15.
This microfacies consists of very fine to fine, angular to subrounded, fairly sorted quartz grains in a slightly dolomitised, argillaceous matrix. Some carbonaceous material, arranged in successive laminae, is associated with this microfacies, giving the rock a striped pattern. A few fine glauconite grains occur in the matrix. The microfacies is rarely fossiliferous.

CHEMICAL ANALYSIS

The microfacies study of the different rock units in the area of study is complemented by the chemical analysis of some representative core samples to reveal the compositional variations among the carbonate rocks. This has direct bearing on their environmental conditions of formation. Moreover, the chemical analysis is found useful wherever staining techniques on fine grained micrite rocks failed to differentiate between calcite and dolomite.

The chemical analyses were carried out for the quantitative determination of the percentage of: SiO_2, Fe_2O_3, Al_2O_3, CaO, MgO, and CO_2. The percentages of $CaCO_3$, $MgCO_3$, Ca and Mg as well as the Ca/Mg ratio were calculated. The results are shown in Table 1.

DIAGENETIC ASPECTS

The diagenetic aspects which could be revealed in the microfacies association of the Mauddud Formation in Kuwait are mainly cementation, recrystallisation and dolomitisation.

A. Cementation

Cementation by sparry calcite is distinguished in two forms:
1. Calcite microspars having an interlocking mosaic texture. (Fig. 4.1).

2. Sparry calcite in the form of syntaxial overgrowth (Fig. 4.2).
This diagenetic aspect is pronounced in microfacies 2. The process greatly diminishes the porosity.

B. Recrystallisation

Partial to complete recrystallisation is widespread in most of the microfacies in the five sections studied. In some sections, only the matrix is altered; in others, the fossils are recrystallised or even completely obliterated.

Microcrystalline calcite (microspar). Lime mud might originate by several ways. It consists of calcite crystals which range in size from 1 to 4 μm. Recrystallisation of lime mud results in the formation of microspars (Fig. 4.3), which consist of crystals ranging from 4 to 30 μm (Folk 1965).

Coarse crystalline calcite (pseudospar). This type of recrystallisation differs from microcrystalline calcite and microspar in crystal size (larger than 30 μm). It is a recrystallisation product of micrite or microspar. In some cases, coarse crystalline calcite closely resembles the appearance of true pore-filling sparry calcite. For this reason it is termed pseudospar. The crystals are glassy clear, large and occur in many sizes (Fig. 4.4). Remnants of peloidal micrite appear within sparry areas between grains and offer evidence for recrystallisation of the micritic matrix.

Table 1. Chemical analysis of some core samples from the study area.

Microfacies Associations	Sample No.	Depth in Meters	Percentage of Oxides						Calculated Constituents				
			SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	CO_2	$CaCO_3$	$MgCO_3$	Ca	Mg	Ca/Mg Ratio
Orbitolina – Trocholina biomicrite	RA-1	2271	0.19	0.07	0.09	54.65	0.76	40.00	97.28	1.60	39.10	0.46	85.00
	SA-1	2250	0.75	0.18	0.31	52.00	1.60	41.90	92.58	3.36	37.20	0.96	38.75
Orbitolina – Trocholina pelsparite	RA-1	2278	0.22	0.07	0.08	54.35	0.62	43.80	96.74	1.30	38.86	0.37	105.03
	SA-1	2291	0.46	0.26	1.15	53.80	1.20	43.80	96.76	2.52	38.47	0.72	53.43
Ovalveolina – miliolid biomicrite	RA-1	2259	0.43	0.08	0.15	52.30	2.48	43.80	93.10	5.21	37.40	1.50	24.93
	SA-1	2216	0.25	0.14	0.12	54.05	1.20	43.90	96.20	2.52	38.65	0.72	53.68
Shelly biomicrite	RA-1	2316	0.40	1.73	0.12	46.10	5.90	42.30	82.06	12.40	32.96	3.56	9.26
	RA-1	2320	2.85	1.02	0.98	49.35	2.34	41.70	87.84	4.91	35.30	1.41	25.03
Argillaceous biomicrite	SA-1	2255	0.34	0.12	0.12	52.20	1.40	43.35	96.50	3.50	38.75	0.84	46.13
	SA-1	2271	1.15	0.41	0.45	53.00	1.40	42.60	94.34	2.94	37.89	0.84	45.11
Dolomitic biomicrite	RA-1	2329	5.50	3.70	2.40	39.85	6.11	37.95	70.93	12.83	28.50	3.70	7.70
	SA-1	2261	4.60	1.42	1.98	43.70	5.30	39.20	77.78	11.30	31.24	3.20	9.76
Dolomite	SA-1	2289	6.90	6.45	2.80	32.20	10.70	38.00	57.32	22.70	23.02	6.45	3.57
	BG-129	1291	2.65	7.60	0.62	31.30	13.80	43.90	55.71	29.00	22.38	8.32	2.70
Sandy Dolomitic Orbitolina biomicrite	SA-1	2276	15.20	1.02	1.24	40.60	40.60	35.90	72.26	9.66	29.03	2.77	10.48
	MG-26	1173	20.50	4.25	1.67	34.85	3.10	31.00	62.03	6.51	25.00	1.87	13.37
Carbonaceous siltstone	RA-1	2312	64.25	1.95	4.05	12.05	1.03	11.00	21.45	2.16	8.62	0.62	13.90
	RA-1	2322	55.60	3.42	7.70	13.05	1.35	12.20	23.23	2.84	9.33	0.81	11.52

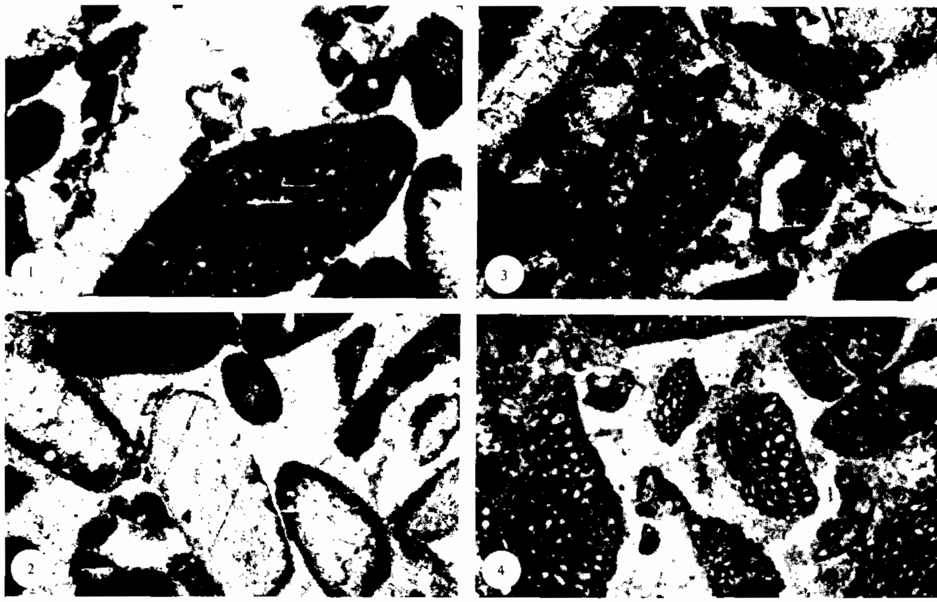

Fig. 4. Diagenetic aspects of the Mauddud Formation.

1, Photomicrograph of *Orbitolina* sp. and other unidentified fossil fragments, in a sparry calcite cement matrix (× 37).

2, Photomicrograph of crinoids and other unidentified fossil fragments, in a sparry calcite cement matrix (× 37).

3, Photomicrograph of *Orbitolina* sp. and other unidentified fossil fragments, in a micrite matrix recrystallised to produce microspar (× 37).

4, Photomicrograph of *Orbitolina* sp., in a micrite matrix recrystallised to pseudospar (× 37).

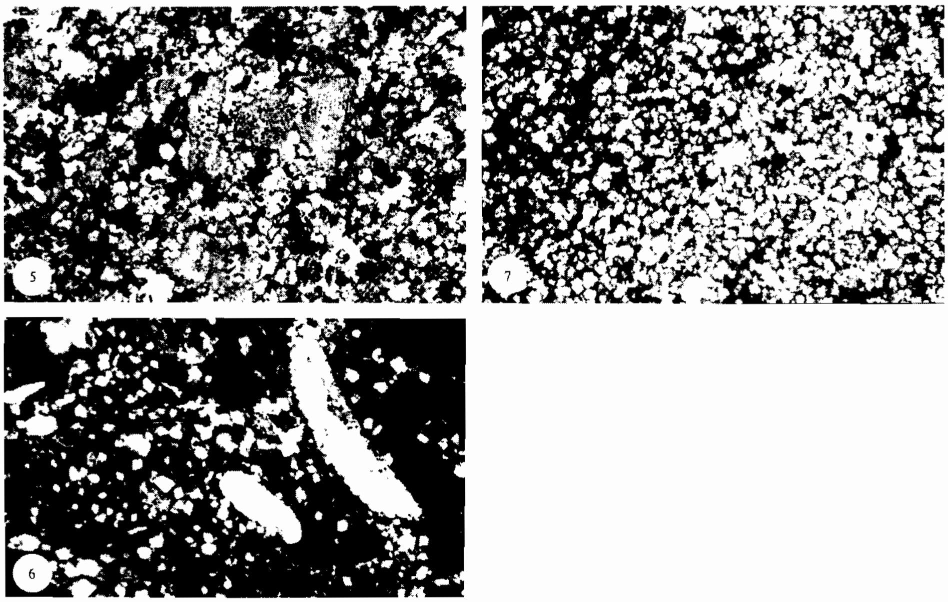

Fig. 4. Diagenetic aspects of the Mauddud Formation.

5, Photomicrograph of crinoid remains, in a dolomitised matrix (× 37).

6, Photomicrograph of crinoids, an echinoid spine and scattered dolomite rhombs, in a micrite matrix (× 37).

7, Photomicrograph of fine to very fine dolomite crystals (× 37).

C. Dolomitisation

The results of petrographic and chemical studies on the rocks of the Mauddud Formation show that the dolomites associated with the limestones are of diagenetic origin. The criteria for that are the following:

1. Presence of well-developed intergranular porosity.
2. Presence of fossil relics within the dolomitised horizons of the Mauddud Formation (Fig. 4.5).
3. Almost all dolomite rhombs are scattered within the micrite matrix (Fig. 4.6).
4. Presence of relics of original carbonate grains in the highly dolomitised horizons.
5. Zoned dolomite rhombs are less common and most of the dolomites are uniform in size.
6. Most of the dolomitised rocks in the formation are fine to very fine crystalline, rarely coarse crystalline (Fig. 4.7).

POROSITY IN THE MAUDDUD FORMATION

The porosity of the Mauddud Formation ranges from 12 to 30%. The main types of porosity which could be identified are, in order of decreasing abundance:

1. Leaching porosity

This type of porosity is pronounced in microfacies 1, 5 and 8, whereby abundant allochems have been leached out leaving void spaces. Also, leaching affects some parts of the matrix of some microfacies association (Figs 3.9 and 3.10), which could be termed channel solution porosity.

2. Intercrystalline porosity

This type of porosity is pronounced within the highly dolomitised parts of the formation, specifically, in microfacies 6, 7 and 8 (Figs 3.11 and 3.13).

3. Intergranular porosity

This type of porosity could be identified within microfacies 1 and 3 (Fig. 3.7).

4. Intragranular porosity

Although this type of porosity is less abundant in the formation, it could still be identified within microfacies 2 (Fig. 3.5).

DEPOSITIONAL ENVIRONMENT

The limestone of the Mauddud Formation represents deposition in a marine regressive period after deposition of the quartzose sand of the Burgan Formation. This limestone seems to have been deposited under shallow to very shallow marine water conditions within a shelf area and close to the basinal margin. At the early stages of accumulation of the limestone, a pronounced influx of detrital materials was brought to the basin from a nearby land mass (most probably during periods of heavy rainfall). This is followed by a period favourable for the flourishing and accumulation of a marine shelf

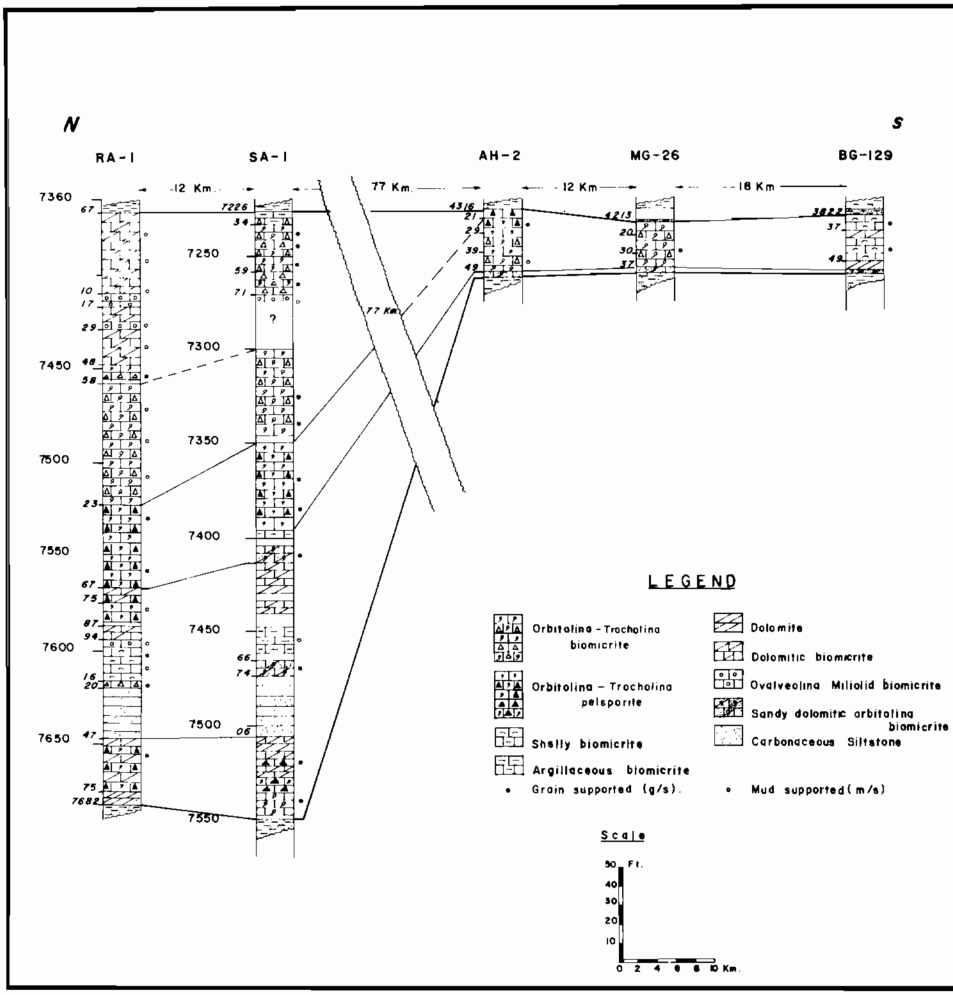

Fig. 5. Correlation section of the area studied.

biota of the genera: *Orbitolina*, *Trocholina*, *Textularia*, *Nezzazata*, miliolids, algae, as well as gastropods and pelecypods.

Turbulence and agitation of the sea prevailed during deposition of this formation, forming the cleanly washed biosparite limestone facies. However, at certain stages scattered shell banks were formed (shelly biomicrite microfacies). As a consequence, some parts of the shelf area were protected from the turbulence and water agitation, and conditions were favourable for the accumulation of the biomicrite limestone facies. At certain stages during the deposition of the limestone or perhaps soon after deposition, magnesium-rich brines in varying quantities were brought to the basin and dolomitisation occurred. It is worth mentioning that the pronounced thinning of the Mauddud Formation in southern Kuwait is either due to: (a) deposition over a pre-existing structural high or, (b) less subsidence during deposition in the south compared to more subsidence in the north or, (c) erosion of the upper Mauddud in the south (Fig. 5).

SUMMARY AND CONCLUSIONS

Analyses of thin sections resulted in the delineation of nine microfacies in this study, namely: *Orbitolina–Trocholina* biomicrite, *Orbitolina–Trocholina* pelsparite, *Ovalveolina*–miliolid biomicrite, shelly biomicrite, argillaceous biomicrite, dolomitic biomicrite, dolomite, sandy dolomitic *Orbitolina* biomicrite and carbonaceous siltstone. These microfacies are determined by microscopic examination of the distribution and abundance of fossils and other grains, sedimentary texture, matrix, diagenetic modifications of the original sedimentary features and chemical analysis.

The study of the microfacies of the Mauddud Formation revealed that samples from northern wells RA-1 and SA-1 contain a high number of different microfacies, 7 and 8, respectively. The southern wells contain relatively smaller numbers of microfacies, 4 in BG-129, 3 in MG-26 and only 2 in AH-2. This is attributed to the obvious thickening of the Mauddud Formation in northern Kuwait. The absence of some microfacies from the southern wells is attributed either to: (a) deposition over a pre-existing structural high or, (b) a smaller subsidence during deposition in the south relative to a greater subsidence in the north or, (c) erosion of the upper Mauddud in the south (Fig. 5).

Partial to complete recrystallisation is widespread in most of the microfacies in the five sections studied. In some samples, only the matrix is altered; in others, the fossils are recrystallised or even completely obliterated.

The results of petrographic and chemical studies show that the dolomite associated with the limestones is of diagenetic origin. It ranges from only few scattered dolomite rhombs to almost complete dolomitisation of the rock.

From the foregoing discussion of the various microfacies encountered in this study, it may be concluded that the Mauddud Formation was deposited within a shallow, warm marine environment in a gradually sinking zone marginal to the Arabian platform. This environment was interrupted by the influx of detrital material at early stages of deposition of the formation. Therefore, the Mauddud Formation represents facies belt 8 (of Wilson 1975, p. 359), i.e. facies of restricted circulation on marine platform, as well as standard microfacies 19 (Wilson 1975, p. 68), i.e. restricted marine shelf lagoons.

REFERENCES

Dunnington, H.V., Wetzel, R. & Morton, D.M. 1959. Lexique Stratigraphique International, vol. 3—Asie, facs. 10a—Iraq. Centre National de la Recherche Scientifique, Paris.

Folk, R.L. 1965. Some aspects of recrystallization in ancient limestone. Soc. Econ. Paleont. and Min., Special Pub. **13:** 14–48.

Henson, F.R.S. 1951. Cretaceous and Tertiary reef formations and associated sediments in Middle East. Am. Assoc. Petrol. Geol. Bull. **34:** 215–38.

James, G.A. & Wynd, J.G. 1965. Stratigraphic nomenclature of Iranian Oil Consortium Agreement Area: Am. Assoc. Petrol. Geol. Bull. **49:** 2182–245.

Loutfi, G. & Jaber, A.S. 1970. Geology of the Upper Albian–Campanian Succession in the Kuwait–Saudi Arabia Neutral Zone offshore area. 7th Arab Petrol. Congr., pp. 1–14.

Owen, R.M.S. & Nasr, S.N. 1958. Stratigraphy of the Kuwait–Basrah Area. In Habitat of Oil: Am. Assoc. Petrol. Geol.: 1252–78.

Powers, R.W. 1968. Lexique Stratigraphique International, vol. 3—Asie, facs. 10b—Arabie Saoudite. Centre National de la Recherche Scientifique, Paris.

Powers, R.W., Ramirez, L.F., Redmond, C.D. & Elberg, E.L. 1966. Geology of the Arabian Peninsula, Sedimentary Geology of Saudi Arabia. U.S. Geol. Survey, Prof. Paper 560-D: 1–147.

Wilson, J.L. 1975. Carbonate facies in geologic history. Springer-Verlag, Berlin, 471 pp.

(Received 4 May 1979)

التحليل السحني الدقيق والبتروغرافي لتكوين المودود في الكويت والمناطق المجاورة

علي عبد الله الشملان
قسم الجيولوجيا بجامعة الكويت

خلاصة

يعتبر تكوين المودود ذو العصر الألبي خزانا صخريا كربونيتيا مهما في الكويت ومنطقة شمال الخليج العربي ، وهو واسع الانتشار في الشرق الأوسط ، حيث يمكن متابعته من منطقة الربع الخالي في جنوب المملكة العربية السعودية إلى العراق . وفي الكويت يتراوح سمك التكوين من بضعة أمتار إلى ٩٨ مترا . وقد أمكن تقسيم تكوين المودود في الكويت إلى ٩ سحنات دقيقة وهي كما يلي : أوربيتولينا ـ تروكولينا بيوميكريت و أوربيتولينا ـ تروكولينا بلسباريت وأوفالفيولينا ـ ميليوليد بيوميكريت وبيوميكريت صدفي وبيوميكريت طفلي وبيوميكريت دولوميتي ودولوميت وأوربيتولينا بيوميكريت رملي دولوميتي وحجر غريني جيري . ان التغيرات الثانوية التي طرأت على تكوين المودود في الكويت عبارة عن إعادة التبلور واللحام والدلمتة ، أما أنواع المسامية فهي الاستخلاص وما بين البللورات وبدرجة أقل ما بين الحبيبات وداخل الحبيبات . ويعتبر تكوين المودود قد ترسب في بيئة بحرية ضحلة دافئة وقد تخلل هذه الظروف وصول مواد قارية منقولة خاصة في المراحل الأولى من الترسيب . وقد ترجع رقة تكوين المودود في جنوب الكويت ، وغياب بعض السحن الدقيقة منه إلى أي من الأسباب التالية :

ا ـ الترسيب على تركيبات عالية سابقة أو
ب ـ هبوط الجزء الشمالي بالنسبة للجزء الجنوبي أثناء الترسيب أو
جـ ـ حدوث تعرية في الجزء العلوي للتركيب في الجنوب .