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DIAGENETIC MODEL OF A REEF COMPLEX, AQRA-BEKHME FORMATION (LATE CRETACEOUS), NORTHEASTERN IRAQ

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ABSTRACT

The extensive reef complex of Aqra-Bakhme Formation on northeastern Iraq consists of massive rudist-dominated limestone which characterizes the central part, and a periferial, medium to thick-bedded limestone and dolostone representing the detrital part of complex. Petrographic examination of rock samples of six esposed section from different localities reveal a variety of diagenetic products that results from long and complicated diagenetic history. The significant diagenetic processes were: micritization, cementation, recrystallization, leaching, silification, dolomitization and oil dissipation.

The diagenetic history of these processes are reviewed in term of changes in diagenetic environments and tectonic setting of the area. A diagenetic model is suggested to classify these processes into two stages. (A) The early diagenetic model (prior to final burial) which includes micritization, cementation, recrystallization, leaching, selective dolomitization and bitumene seepage. (B) The late diagenetic model (post final burial) which includes intensive dolomization, dolomite cementation, leaching as well as interstitial oil impregnation.

INTRODUCTION

The Aqra-Bekhme Formation of northeast Iraq represents an elongated, bank-type reef complex. It extends in a northwest-southeast direction parallel to the tectonic strike of northeast Iraq *(Fig. 1)*. The huge carbonate body is more than 75 km. long and about 20 km. wide. The age of its rocks range between Upper Campanian to Maastrichtian. The reef body is rudistdominated limestone which is commonly surrounded by detrital limestone and massive dolostone. Outcrops of the complex exposed throughout the high folded zone of north Iraq, displaying its estensive distribution as well as variable lithologic association. The complex is remarkably associated with hydrocarbon which shows either in the form of oil impregnation (Aqra, Bekhme Shaqlawa and Harir localities or bituminous fragments or seeps (Aqra, Bekhme localities). Because of this and due to its stratigraphic position within the Upper Cretaceous cycle which is developed during the tectonic climax of the Zagros orogenic belt, the formation earn considerable attention of geologists and sedimentologists, respectively.

Early investigations of these rocks goes back to the fifties when HENSON (1950) examined their stratigraphic and paleontological aspects. DUNNINGTON (1958) discussed their stratigraphic relation to hydrocarbon accumulation of north Iraq. The stratigraphic status is defined formally by BELLEN *et al.* (1959). Detailed sedimentological studies which include microfacies analysis were given by SADIK and AL-OMARI (1977), AL-RAWI and a AL-HAMADANI (1985), and AL-AMERI and LAWA (1986). However, most of these works are confined to the Aqra area. Recently Al-

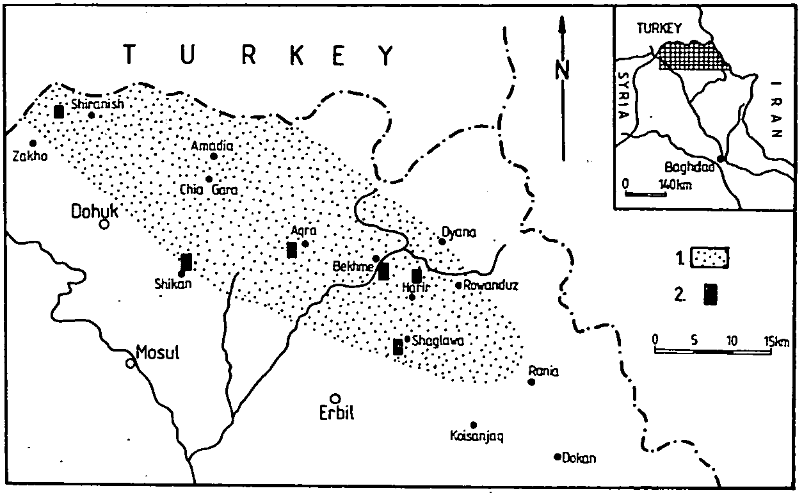

Fig. 1. Index map of studied area and examined localities.
1 = Areal extent of the reef complex, 2 = studied localities

Quayim and SAADALAH (1989) had given regional account to the sedimentary facies type and distribution of the complex compiling data from several localities. Little attention is given to the diagenetic characters of these rocks. This study deals with examination of the diagenetic aspects and its role in the development of the lithologic characters of the reef complex. Various diagenetic processes had influenced these rocks including micritization, cementation, leaching, recrystallization, silicification, and dolomitization. The nature, distribution, and possible origin of these processes is reviewed here to understand better their relations to the reef complex.

About 150 rock samples were collected from exposures of six localities. These localities are Aqra, Bekhme, Harir, Shiranish, Sheikhan, and Shaqlawa areas *(Fig. 1)*. Polished slabs and thin sections were prepared from the studied samples for detailed petrographic examination. Alizarinred staining solution is used to differentiate the dolomite from the calcite, and X.R.D analysis were conducted for further mineralogical differentiation specially for some sampless insoluble residue's.

STRATIGRAPHY AND FACIES

The Aqra-Bekhme Formation is defined by BELLEN *et al.* (1959) as two different stratigraphic units. The Aqra Formation represents a massive reef limestone mass of the complex, and the Bekhme Formation consists of dolomitic detrital limestone which is closely associated with the former. Due to their mutula origin and complex lithologic interrelation BUDAY (1980) had unified then into one single unit, namely the Aqra-Bekhme Formation. The formation represents the extensive carbonate body of the Upper Campanian-Maastrichtian cycle of north Iraq. It has been interfingering with the flysch sediments of Tanjero Formation northeastward and with the basin-origined marl of Shiranish Formation southward *(Fig. 2)*. The Aqra-Bekhme Formation is usually underlies unconformably the middle Cretaceous Qamchuqa Formation, and conformably and transgressively is overlain by the Shiranish Formation. However, in certain areas i.e. Aqra and Sheikhan, the

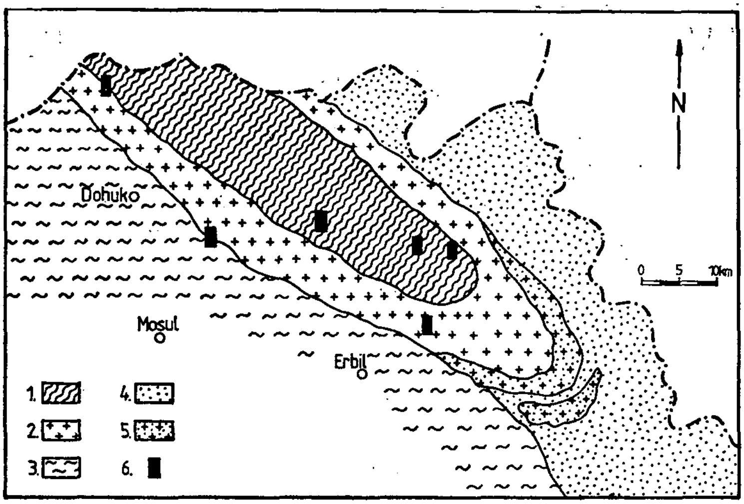

Fig. 2. Facies map of Upper Cretaceous Sedimentary Cycle of Northeastern Iraq showing regional facies belts of Aqra-Bekhme Formation (from AL-QAYIM and SAADALAH, 1989).
1 = Reef body, 2 = Reef apron, 3 = Shiranish basinal limestone, 4 = Tanjero flysch, 5 = Reef apron within Tanjero Sediments, 6 = Studied localities

upper contact of the formation is unconformable and erosinal, whereby the Paleocene-Lower Eocene marine clastics of the Kolosh Formation is succeeded.

According to AL-QAYIM and SAADALAH (1989), the Aqra-Bekhme reef complex consists of two closely associated but regionally distinctive parts. The central reef body, and the periferial detrital shade which surrounds it, is known as a reef apron facies *(Fig. 3A)*. The reef body is a massive limestone buildup which constitutes the core of the complex *(Fig. 2)*. Three distinctive facies have been recognized within the reef body, as follows: reef core, interior lagoon, and fore-reef facies *(Fig. 3B)* Below there is a brief description of the reef complex facies.

a) Reef core facies

It is characterized by massive rudist-dominated limestone. Other skeleta constituents, such as algae, bryozoa, and echinoderms. are also occured. These rocks are variably oil impregnated and recrystallized and selectively domomitized and/or leached.

b) Interior lagoon facies

This facies is represented by peloidal-miliolid rich gray limestone. It shows patchy distribution within the reef core facies *(Fig. 3B)*. It is strongly influenced by recrystallization and cementation with occasional occurrence of selective dolomitization.

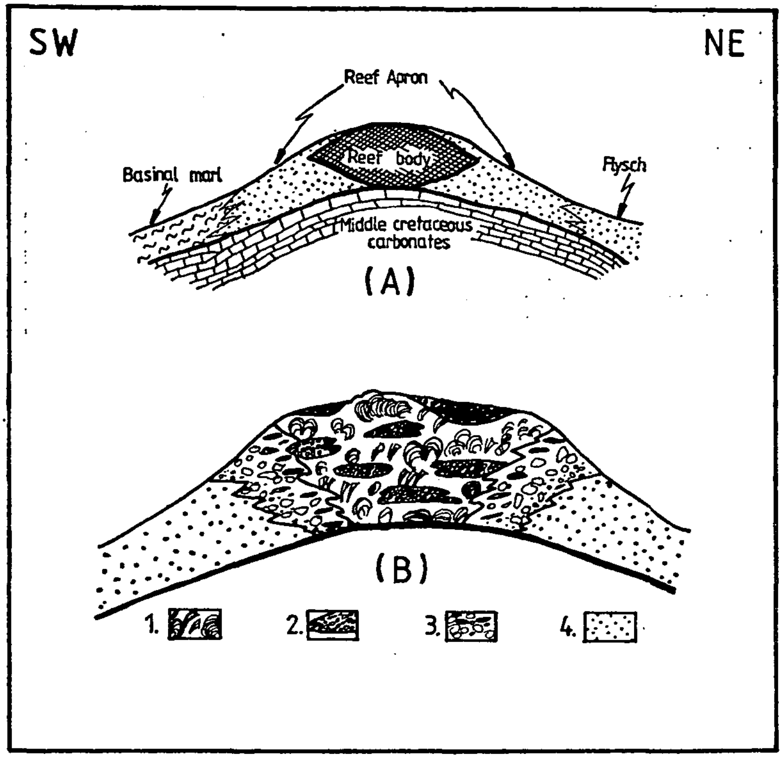

Fig. 3. Schematic cross section illustrating the Aqra-Bekhme Facies types. (A) regional belts, (B) facies types in detail (from AL-QAYIM and SAADALAH, 1988).
A = Reef core, 2 = interior lagoon, 3 = Fore reef, 4 = Reef apron

c) Fore-reef facies

This facies is used here to designate the reef talus sediments which represent a narrow belt developed around the reef core and characterized by massive to thick bedded bituminous limestone. Fragments are reef-derived with characteristic fauna includes Laftosia, Acteonella, and Orbitolina. Recrystallization, dolomitization and to less extent silicification are characteristic diagenetic processes in this facies.

d) Reef apron facies

The sediments of this facies is characterized by medium to thick bedded reef-derived calcarenite type detrital limestone. This facies is deposited in a relatively deep water and spreads distantly from the reef body into the surrounding deep marine basin sediments. Intensive dolomitization had commonly altered these rocks into a massive and thick sequence of sucrosic dolostone which is often impregnated with oil. Other diagenetic processes including silicification, dolomite cementation and leaching are also recognized.

DIAGENETIC PROCESSES

Several diagenetic processes have had influenced the Aqra-Bekhme rocks. Among these processes micritization, leaching, recrystallization, silicification, cementation, dolomitization, fracturing and oil impregnation are noticed. Below is the discussion of the most important ones.

Cementation

Several type of cement have been recognized. These types are as follows: (1) *Syntaxial cement* is developed as thin clear rim surrounding the echinodermal bioclasts *(Fig. 4a)*. It is recognized within the detrital limestone of fore-reef facies and adjacent part of the reef apron facies. Such an early diagenetic cementation is probably took place during the shallowing periods and upon the meteoric influences (LONGMAN 1980). (2) *Intragranular cement* is the spary calcite which fills foram chambers and other skeletal cavities. Miliolids of the interior lagoon facies are often contain such cements *(Fig. 4b)*, as well as cavities of reef-derived macrofossils. However the succeeding leaching couldreduce the amount of this cement by the dissolution. (3) *Intergranular cement* represents the sparite, microsparite subhedral calcite mosaic which fills mainly the intergranular spaces of the skeletal limestone of interior lagoon and reef core facies *(Fig. 4f, 5a)*. The close association of this cement to these two facies implies marine vadose to meteoric conditions (LONGMAN, 1980) which could prevealed during or shortly after the deposition, i.e. early diagenetic stage.

Recrystallization

This process affects both skeletal grains and micrite of the reef body facies. The reef core and the interior lagoon facies are most affected *(Fig. 4d, e)*. The extent of this process is hard to be evaluated because products of the cementation might be incorporated in the groundmass.

Inversion of skeletal fragments into coarse crystalline calcite are common especially within parts which are rich in unstable (high Mg calcite) skeletal grains i.e. the reef core, fore reef facies *(Fig. 4f, 5a)*. Neomorphism of these shallow marine sediments could have been occurred within a meteoric phreatic environment during the early stages of diagenesis (LONGMAN, 1980).

Micritization

It is recognized as thin dark film surrounding reefderived skeletal fragments *(Fig. 5a)*. The extent of this process is limited to certain parts and often associated with samples from fore reef facies.

Micritization is believed to have been developed during postdepositional algal and bacterial activities (BATHURST, 1977 and REIJERS and HSU, 1986).

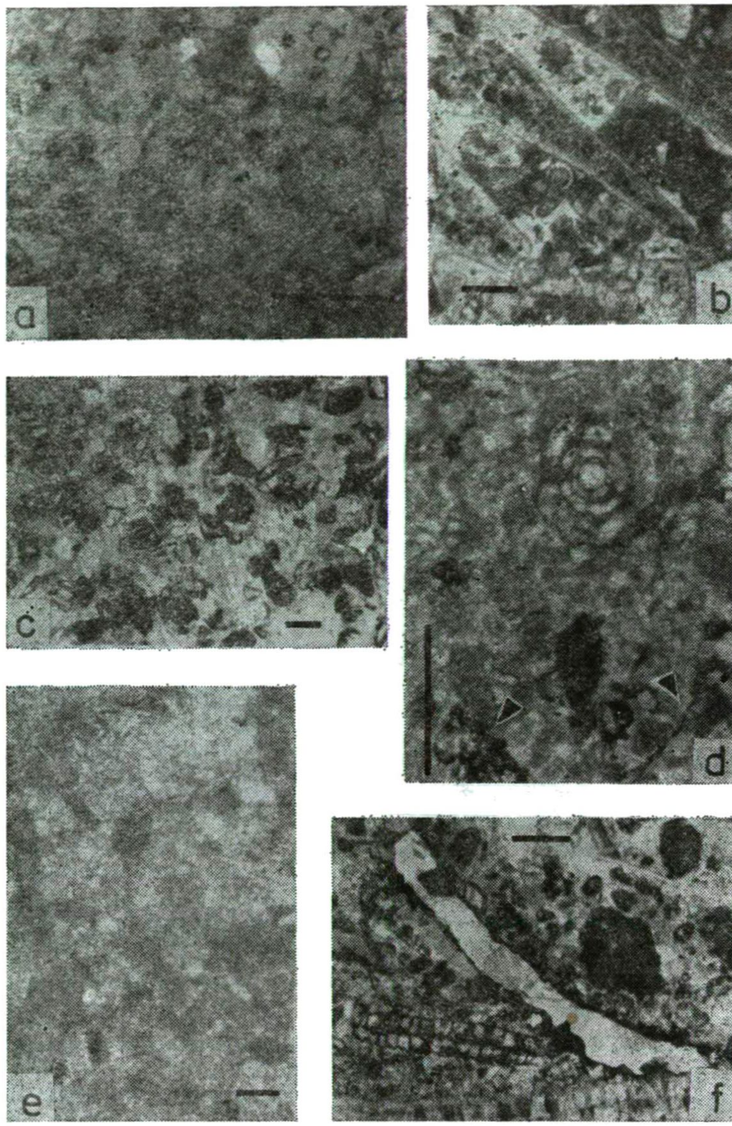

Fig. 4. (a) Photomicrograph of nondolomitized detrital limestone of the reef apron facies. Grains are dominated by fine sand size echinodermal bioclasts showing syntaxial rim cement (arrows). (XN) Fore reef rudstone with spary intergranular calcite cement filling skeletal cavities. (XN) (c) Miliolid pelcidal packstone of reef interior facies showing intergrabular spary calcite cement. (d) Miliolid peloidal packstone which shows cementation and recrystallization of both grains and matrix. Note microcracks and vugs filled with oil (arrows). (e) Intensive recrystallization of peloidal wackestone of the interior lagoon facies. (XN). (f) Gastropod fragments which is totally inverted into spary calcite mosaic. Note oil impregnation in leached out micritic envelope of the fragment. (Bar is 0.5 mm)

Leaching

Influence of this process have been recognized on samples from different facies. It is noticed in samples from reef core and interior lagoon facies producing moldic or vugs porosity which is frequently replaced by oil impregnation *(Fig. 4d, 5b)*. Other samples from dolostone of the reef apron facies show large (2—10 cm. wide) irregular vugs which are partially filled by white dolomite cement *(Fig. 5f)*.

Paragenesis of leached material and replaced substances suggest two mode of leaching occurred during successive subearial conditions and consequent meteoric vadose environment which is the most favourable for leaching phenomena (HECKEL, 1983).

Silicification

Silica replacement is observed in a limited distribution. It is recognized in the field as elongated, up to 10 cm. wide, dark brown chert nodules. In these cases no evidences of the precursor limestone is preserved. In other cases where partial replacement occur the original detrital limestone fabric is recognized *(Fig. 5e)*. However, both cases the silicification seems to have been associated with the reef apron facies and in particular near its upper part. The deep water environment of these sediments and its transgressive upbulding (AL-QAYIM *et al.* 1986) rule out the mixing zone origin. Silicification of these sediments seem to have been developed during late diagenesis and probably in association with intensive dolomitization.

Dolomitization

Dolomitization affect the different facies of the Aqra-Bekhme reef complex in different ways suggesting different mode of origin. Three distinctive type of dolomite is recognized: (1) *Selective floating dolomite* occurs as dissiminated, euhedral silt size dolomite rhombs within specific skeletal grains or rarely within the matrix. It is generally associated with the grains of reef core and interior lagoon facies and matrix of reef apron facies. The fabric of this dolomite suggests early stage of dolomitization (RANDAZZO and ZACHUS, 1984) and could be generated by concentration of Mg^{++} ion within sediment particles (MATHEWS, 1974). (2) *Intensive sucrosic dolomite* is the most common and extensive type of dolomite and it is strongly associated with the detrital limestone of the reef apron facies and often obliterate its original fabric. The resulting dolomite is sucrosic in type and consists of silt size, euhedral and interlocking *(Fig. 5e)*, or subhedral sutured *(Fig. 5d)* mosaic. The resulting intercrystalline prosity is often impregnated with oil *(Fig. 5e)*. The pervasive nature, subrosic fabric and association w th relatively deep marine facies suggest a late diagenetic and deep burial origin (MATTES and MOUNTJOY, 1980, and RANDAZZO and ZACKUS 1984). (3) *White dolomite cement* is locally developed as white euhedral coarse crystalline dolomitic patches or pods especially associated with intensively dolomitizized rocks *(Fig. 5f)*. It is often line vugs and cavity walls that have been developed within the sucrosic dolostone. Dolomite of such characters is believed to represents a late diagenetic phenomena which post dates the sucrosic dolomite (MATTES and MOUNTJOY, 1980).

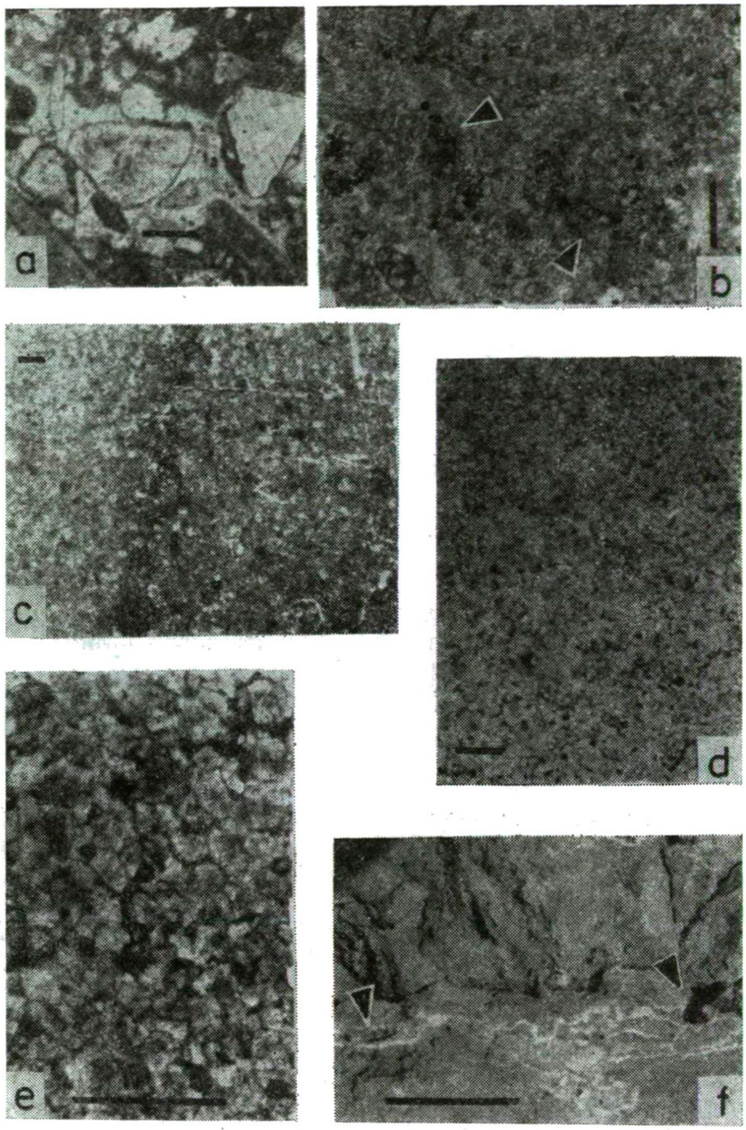

Fig. 5. (a) Fore reef bioclastic calcarenite showing neomorphosed skeletal grains with micritic envelope. Intergranular spaces partially filled by spary calcite (XN). (b) Interior lagoon packstone which is selectively leached into small irregular vugs. Both vugs and micro-cracks (arrows) filled with oil (c) Detrital limestone of the reef apron facies showing partial silicification of matrix (XN). (d) Subhedral silt size sutured mosaic dolomite of the reef apron facies. (e) Silt size, euhedral, and interlocking dolomite mosaic of the reef apron facies with intercrystalline porosity filled with oil. (f) White irregular pod of coarse crystalline dolomite cement within the sucrosic dolomite of the reef apron facies. Note secondary vugs that associated with these pods (arrows). (Bar is 0.5 mm except for f is 15 cm.).

DIAGENETIC MODEL

From the preceding description of the diagenetic products and processes that had affect the Aqra-Bekhme reef complex and its distribution and relation to the different facies, and based on their paragenetic relationships, a diagenetic model which depicts the evolution and sequence of these processes is attempted. The suggested model is schematically presented in *Figure 6A, B* and discussed below in term of changes in diagenetic environment and tectonic setting.

The sediment of the Aqra-Bekhme Formation is deposited under marine water of various environmental condition. The reef core and interior lagoon facies represent a shallow marine environment which could be interupted by subaerial conditions. This situation would conceivably provide an alternating marine phreatic — marine vadose and even meteoric environments. Development of such conditions obviously would intiate early diagenetic processes such as micritization, inversion, leaching, cementation (intragranular, intergranular & syntaxila) as well as early stage of oil seepage and butumine fragmentation. The sequence and distribution of these processes would depends on local water chemistry and circulation as well as type and composition of specific sediments particle *(Fig. 6A)*. Simultaneously, the fore-reef and reef apron facieses show little or no response to most of these processes. This is probably due to deposition under relatively deep water, whereby inactive water circulation would yield passive marine phreatic reactions (LONGMAN, 1980). As accumulation of sediments continue and probably prior to lithification partial dolomitization might be generated selectively depending on grain type and matrix mineralogy.

Prior to significant burial and after early lithification stage the whole reef body is believed to be uplifted forming an emerging ridge (DUNNINGTON, 1958). Such a tectonic event is believed to cause the early cracking phase which characterizes the already lithified parts of the complex. The whole complex is drown again upon the transgression of the paleocene which causes its burial under the paleogene marine sequence.

The burial history of the area is not the subject of this paper, however, it semingly contribute to the late diagenetic history and possible hydrocarbon disspiation within the complex. The intensive dolomitization which is associated with the reef apron facies could have been developed by reactions of compaction fluids which might be expelled from surrounding marl and shale basins *(Fig. 2)*. These fluids which could be enriched with Mg ion required for dolomitization (ILLING, 1959 and JODRY, 1969) might migrate laterally towards the reef body through the detrital limestone the reef apron facies causing its dolomitization *(Fig. 6B)*. Similar mechanism for the development of the intensive dolostone which is associated with the Miette buildup of Alberta is suggested by MATTES and MOUNJOY (1980). Oil migration and dissipation could have occured along with migration of these fluids or later on. The oil impregnation which fills this dolomite intercrystalline porosity *(Fig. 5e)* as well as microcracks *(Fig. 4d, 5b)* suggests post-dolomitization emplacement.

Successive deep burial changes in chemical environment would conceivably cause the leaching and vugs as well as the white dolomite cementation of reef apron facies *(Fig. 6b.)*.

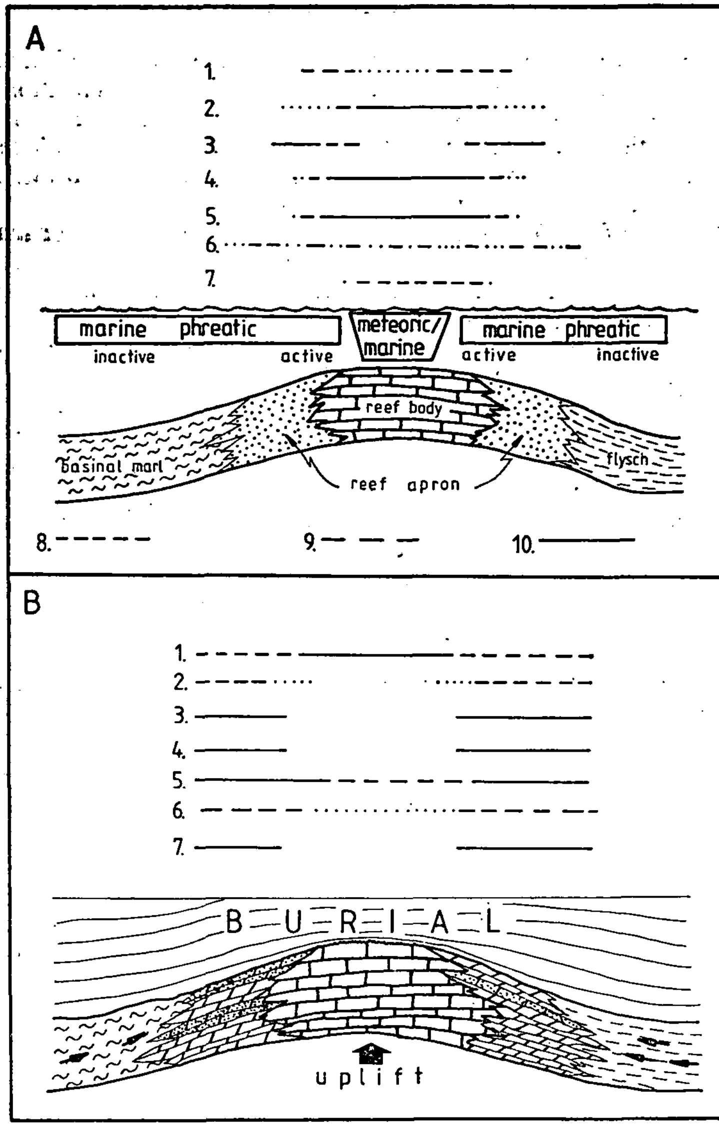

Fig. 6. Diagenetic model for the Aqra-Bekhme reef complex showing type and distribution of diagenetic products interm of sedimentary facies and diagenetic environments. (A) Early diagenetic sequence. 1 = micritization, 2 = cementation, 3 = syntaxial rim, 4 = recrystallization, 5 = oil seepage, 6 = selective dolomitization, 7 = leaching, 8 = weak, 9 = moderate, 10 = strong. (B) Late diagenetic sequence. 1 = cracking, 2 = silification, 3 = intensive dolomitization, 4 = intercryst porosity, 5 = oil impregnation, 6 = leaching and vugs, 7 = dolomite cement

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