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Modes of Occurrence of Dolomite in some Arabian Carbonate Rocks

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ABSTRACT. In Central Saudi Arabia, outcrops of the Upper Permian Khuff and Upper Jurassic Jubaila carbonate formations have been affected by widespread dolomitization and dedolomitization. The latter replacement process is frequently associated with the development of rhombohedral pores. Nine different modes of occurrence of dolomite were recognized in the examined rocks. They are: (1) ferroan dolomite and iron oxide rhombohedra; (2) calcitized dolomite; (3) leached dolomite rhombohedra; (4) zoned dolomite; (5) dark centered-clear rimmed dolomite; (6) sucrosic dolomite; (7) interlocking dolomite; (8) crypto- and microcrystalline dolomite; and (9) cement dolomite. These modes are likely to have resulted from paragenetic and epigenetic changes in the texture and composition of dolomite crystals during their growth stages and later weathering respectively. They possibly reflect as well differences between the physico-chemical environments of the penecontemporary and subsequent to burial dolomitization. The former produced extremely fine-textured, iron-free, dolomite replacing lime mud matrix and/or calcarenite, whilst the latter formed coarser and zoned dolomite crystals indiscriminately replacing depositional carbonate constituents and sparry calcite cement. Dolomite not only grew as replacement to calcium carbonate sediments and rocks, but also as pore-filling cement.

Introduction

The various modes of occurrence of dolomite are petrographically defined in the carbonate rocks of the Upper Permian Khuff and Upper Jurassic Jubaila Formations exposed in Central Saudi Arabia. The Khuff section was systematically sampled and measured at Buraydah (75 m), Smeghan (100 m) and Ar-Rayn (108 m) locations, whereas the Jubaila section and adjacent units at Wadi Huraymila (112 m), Wadi Hanifa (118.5), Wadi Nisah (174 m), Wadi Birk (122 m), Wadi Al-Haddar (125 m) and Widyan (Wadis) Al-Majami (140 m) locations (Fig. 1). The field work was carried out by Zeidan (1981); and Basyuni *et al.* (1992).

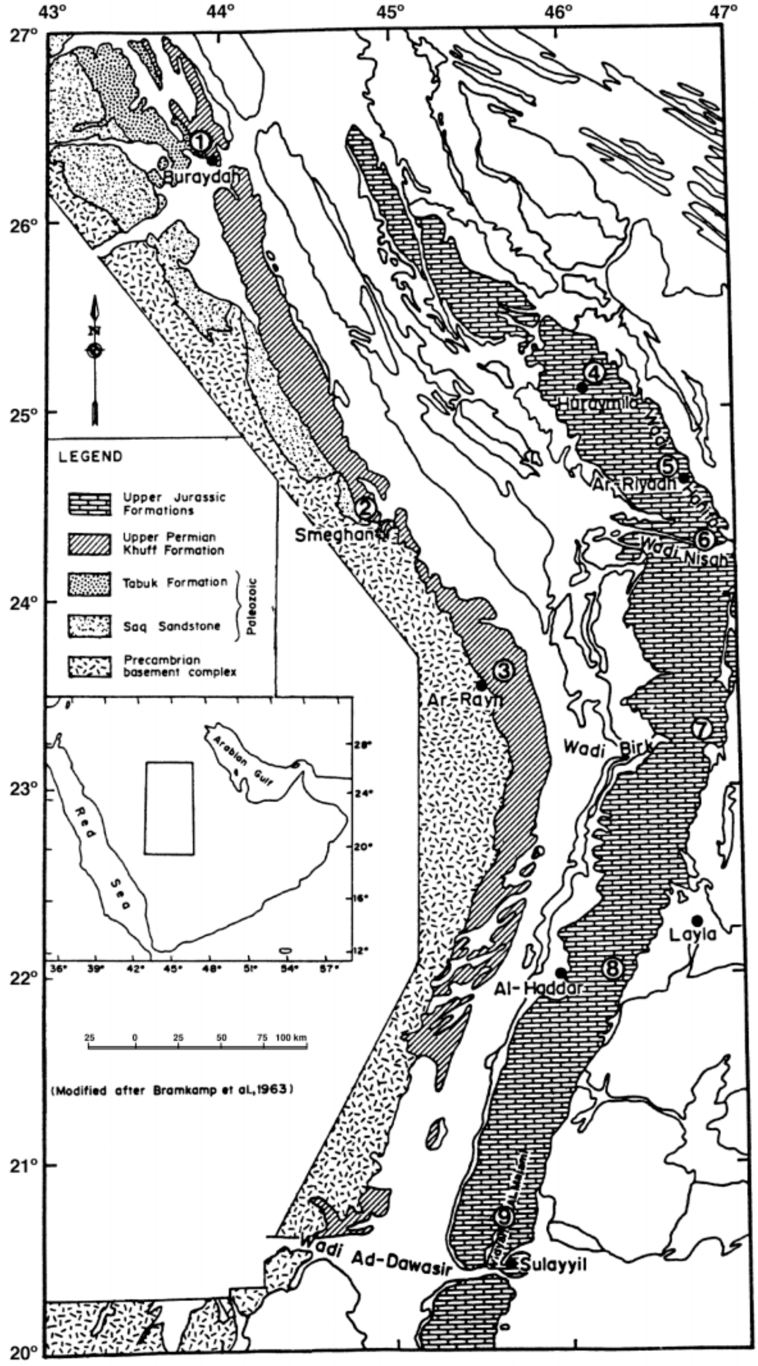

FIG. 1. Location map of the measured columnar sections in numbered circles.

In the Saudi Arabian stratigraphic nomenclature, the Upper Permian sequence is mostly assigned to the Khuff Formation, whilst the Upper Jurassic sequence is divided, from bottom to top, into Tuwaiq Mountain, Hanifa, Jubaila, Arab and Hith Anhydrite Formations (Powers, 1968). The Arab Formation is in turn, divided into 4 cyclic zones, each one consists of a lower carbonate and an upper evaporite member. The carbonate members, which follow the lower most one of the Arab zones, are poorly exposed because of their collapse following the surface dissolution of their cyclic evaporite members.

The stratigraphic sections of the Jubaila Formation and adjacent units are built up almost exclusively of carbonate rocks, though calcareous quartzose sandstone gradually replaces the lower Jubaila limestone southwards (Wadi Al-Haddar and Widyan Al-Majami locations). The Khuff sections include not only carbonate rocks, but also substantial units of fine siliciclastic sediments composed of marl and shale. The carbonate formations consist mainly of dolomite, dedolomite and bioturbated lime mudstone with occasional intercalations and persistent units of lime grainstone and rudstone rich in skeletal debris (mostly of foraminiferal, molluscan and echinodermal origin) and large intraclasts as well. Dolomite and dedolomite have much greater occurrence in the Khuff as compared to the Jubaila carbonates. Dolomite commonly replaced the original lime mud sediments with or without floating allochems (lime wackestone and mudstone) whose texture is generally preserved, at variable degrees, in the dolomite and dedolomite matrix.

The sedimentary record of the Khuff sections, in particular, provides an overwhelming evidence of shallow-water and recurring intertidal marine deposition of the carbonate sediments. This is revealed by the frequent presence of algal-coated bioclasts, coral heads (mostly silicified), stromatoporoids, algal stromatolites, desiccation mud cracks and widespread dolomitization associated, in some instances, with partial anhydrite replacement of original lime sediments. The shoaling conditions would have culminated in the cyclic development of supratidal sabkhas with anhydrite deposition throughout the Upper Permian Khuff and late Jurassic Arab-Hith Formations. This explains the abundant dolomitization and dedolomitization of the Khuff and upper Jubaila rocks where the latter directly underlie the Arab carbonate-evaporite sequence.

Petrographic examination is based on almost 600 thin sections prepared from carbonate rocks. Nearly half the surface of each thin section was stained by alizarin red-S and potassium ferricyanide according to Lindholm and Finkelman (1972). Calcite reacts with alizarin red-S to form a red stain, whereas ferroan calcite and ferroan dolomite react with pottasium ferricyanide to form a blue stain. All porous sections of the Khuff rocks were impregnated by blue resin. Rock nomenclature is made according to Dunham's (1962) classification of carbonate rocks and the terms micrite and allochems proposed by Folk (1962) are retained to denote the lithified lime mud and lime clasts (lime sand and gravel) respectively. The Wentworth (1922) size grade scale for the detrital and crystalline textures, and the crystal shape terminology by Friedman (1965) are also considered in this work.

Sibley and Gregg (1987) classified dolomite textures on the basis of nucleation and growth kinetics. In their scheme, dolomite can be classified according to crystal size distribution (unimodal or polymodal) and crystal boundary shape (planar or nonplanar). The many factors that may control the rates of nucleation and growth and hence affect the resultant dolomite texture include crystal size (surface area to volume ratio) and mineralogy of the $CaCO_3$ substrate, saturation state and temperature of the dolomitizing solution, as well as multiple periods of nucleation and variations in the local growth rate at different sites in the rock.

In the examined Arabian carbonate rocks, dolomite generally replaced micrite matrix in preference over allochem grains because of its originally aragonitic composition and/or its finer grain size i.e., larger surface area per unit volume (Zeidan, 1995). Dolomite is generally unimodal with planar crystal boundaries, and may contain allochem ghosts. The allochems are generally non-mimically replaced by unimodal, planar dolomite, or sometimes are leached to form mouldic pores. In fewer cases, the depositional micrite matrix is replaced by polymodal and non-planar dolomite (lobate and serrated crystals), whereas its embedded allochems are mostly mimically replaced by dolomite.

The mechanism of dolomitization could be simply induced by Mg-rich brines reacting with carbonate sediments and rocks so that Mg cations are substituted for nearly one half of the Ca cations in calcium carbonate minerals. Dolomitizing (Mg-rich) brines are generally created at sea margins (e.g., tidal flats) under arid climatic conditions (Iling *et al.,* 1965). Dolomite replacement may take place either early in recently deposited carbonate sediments or late in buried, but still permeable, carbonate sediments and rocks percolated by the downward flow (seepage reflux) of Mg-rich brines originating from overlying supersaline lagoons (Moore, 1989). The characterization of early versus late dolomitization in the examined rocks is out of the scope of this discussion.

Modes of Occurrence of Dolomite

Nine different modes of occurrence of dolomite have been recognized in the carbonate thin sections. Evidently, any particular rock may enclose more than one mode of occurrence of dolomite.

1. Ferroan Dolomite and Iron Oxide Rhombohedra

The petrographic examination has revealed the presence of some rare ferroan dolomite distinguished by its blue-stained crystals as a result of their reaction with potassium ferricyanide. This is very finely crystalline dolomite with tightly interlocked anhedral crystals (Fig. 2A). The ferrous iron content is almost uniformly distributed within the entire volume of dolomite crystals and was, most likely, partly substituted for Mg cations during dolomitization. This substitution is expected to have occurred in the subsurface reducing environment.

The rare occurrence of ferroan dolomite is apparently due to the oxidizing conditions of later subaerial exposure of dolomitic rocks. The exposure must have converted the earlier ferroan dolomite crystals into dark iron oxide rhombohedra. The latter occur scattered in a host micrite matrix and usually coexist with calcitized dolomite rhombohedra (Fig. 2B). Depending on the amount and occurrence of earlier ferrous iron content, oxidation may only yield little iron oxide aggregates with a particular distribution within individual dolomite crystals.

2. Calcitized Dolomite

Calcite replacement of the individual crystals of dolomite is common in both partially and completely dolomitized limestones. In the field, dedolomitized rocks are usually distinguished by their characteristic reddish stain on the weathered surfaces, whereas unaltered dolomites display dark grey or brown skin. As already pointed out by Shearman *et al.* (1961) and Evamy (1963, 1967) in their own descriptions, dedolomitization may partially or completely regenerate the original carbonate constituents of the pre-dolomitization limestone fabric. The former dolomite rhombs are usually replaced by polycrystalline granular calcite, thus producing the so-called composite calcite rhombohedra (Shearman *et al.,* 1961). The latter invariably occur in a host micrite material that forms the matrix or the allochems e.g., intraclasts and peloids of the original limestone (Fig. 2C).

This new generation of dedolomitic calcite generally develops in equant crystals that are slightly coarser than the host interstitial micrite particles. It usually ranges in crystal size, among individual rhombohedra in a given rock thin section, from 5 to 10 microns, thus forming distinct microsparry calcite crystals. The rhombohedral outlines of the former dolomite crystals are frequently emphasized by dark iron oxide rims enclosing granular calcite.

In many cases, the lime mudstones are found to consist of slightly recrystallized micrite matrix. The fine recrystallization is sometimes confined to isolated but uniformly-distributed patches in micrite, thus creating the so-called clotted or grumeleuse texture (Cayeux, 1935; Shearman *et al.,* 1961; and Evamy, 1967). This clotted micrite texture could have originated from neomorphic recrystallization but more likely from dedolomitization. The assumption for the latter origin is supported by the occasional presence of serrated contact between fine microspar patches and host micrite, and of isolated rhombohedra with faintly defined outlines but with comparatively coarser calcite aggregates inside than outside these rhombohedra. In some instances, the replacing calcite may, however, almost completely regenerate the original texture of micrite or sparry calcite cement. Hence, such calcite rhombohedra can only be recognized through the presence of relict rhombic rims of unaltered dolomite or iron oxide (Figs. 2D and 2E).

Pure dolomites may become completely calcitized wherein the original limestone fabric may be destroyed by dedolomitization. The latter usually generates coarsely crystalline calcite mosaic with diffuse crystal boundaries that poikilotopically enclose relict rhombic rims of iron oxide serving evidence of the former presence of dolomite (Fig. 2F). In other crystalline dedolomites, faintly defined and diffuse calcite crystals may enclose microsparry calcite or even micrite-textured calcite matrix (Fig. 3A).

The observed intimate association between dedolomitic calcite and iron oxide zones

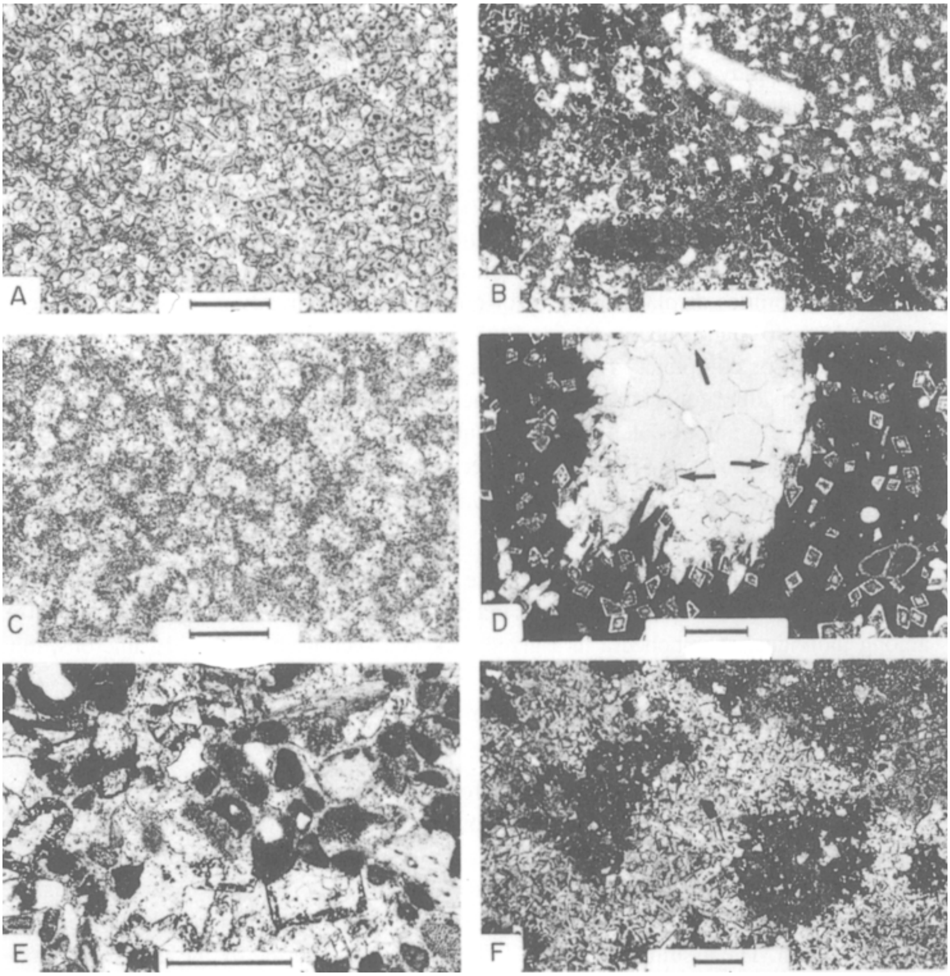

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FIG. 2A. Ferroan dolomite (blue-stained after reaction with potassium ferricyanide) in dark centered-clear rimmed, zoned, interlocking crystals. Jubaila Fmn., Widyan Al-Majami (Plane Polarized Light).

FIG. 2B. Dark iron oxide rhombohedra with thin clear calcite rims in association with composite calcite rhombohedra in bioturbated lime mudstone. Jubaila Fmn., Wadi Nisah (Plane Polarized Light).

FIG. 2C. Granular calcite replacing dolomite rhombs in a host of micrite matrix. Jubaila Fmn., Wadi Nisah (Plane Polarized Light).

FIG. 2D. Regenerated micrite in the rhombic cores and zones of dolomite crystals through dedolomitization as shown in the dark micrite matrix. The sparry calcite cement (light portion) delineates leached anhydrite that replaced both of the micrite matrix and earlier-formed dolomite rhombs recognizable by their rhombic rims of iron oxide and/or unaltered dolomite (arrows). Jubaila Fmn., Wadi Nisah (Plane Polarized Light).

FIG. 2E. Regenerated sparry calcite cement within completely calcitized dolomite crystals recognizable by their iron oxide rhombic rims. Upper Hanifa Fmn., Wadi Nisah (Plane Polarized Light).

FIG. 2F. Diffused-coarsely crystalline calcite poikilotopically enclosing rhombic iron oxide rims of calcitized dolomite crystals. Jubaila Fmn., Wadi Nisah (Crossed Polarized Light).

and rhombs most likely reflects their concomitant development during later subaerial exposure by the combined chemical weathering and oxidation effects (epigenetic changes). The regional dedolomitization of the examined carbonate rocks could have taken place as a result of the reaction between dolomite and calcium sulphate solutions from dissolved anhydrite. The latter, in fact, forms extensive cyclic evaporitic units within the Khuff and Arab-Hith Formations in equivalent subsurface strata (Powers, 1968). These anhydrite deposits have naturally been almost completely removed by dissolution following their later subaerial exposure where they cropped out in Central Arabia.

The assumption for the surface or near surface process of dedolomitization is indirectly conceived in the light of its inexistence in equivalent subsurface rocks examined and described in previous literature by Powers (1962) and Al-Jallal (1987). According to this concept, Schmidt (1965) considered the presence of dedolomite in the subsurface Gigas beds of Germany as an indication of an ancient erosional surface of stratigraphic unconformity.

3. Leached Dolomite Rhombohedra

The core or the entire volume of individual dolomite crystals may go into solution leaving behind rhombohedral pores. The dissolved dolomite crystals commonly occur scattered in a host micrite matrix and are often associated with unaltered and calcitized dolomite rhombohedra in partly dolomitized limestones (Fig. 3B). The rhombohedral pores are, in many instances, lined with relict granular calcite crystals serving evidence of the former calcitization of dolomite rhombs (Fig. 3C). Therefore, it can be assumed that leaching has preferentially affected calcitized dolomite rhombohedra.

This selective leaching might have occurred in initially formed aragonite or high-magnesian calcite that resulted from dedolomitization at normal atmospheric pressure and temperature (Evamy, 1967). Subsequently, the development of rhombohedral pores would be expected to take place shortly after dedolomitization, prior to the neomorphic transformation of aragonite or high-magnesian calcite into more stable low-magnesian calcite. These pores are consequently considered as the end product of the successive diagenetic changes of dolomitization, dedolomitization and selective leaching. They represent another mode of occurrence of dolomite in limestones and their origin is apparently linked with surface weathering effects.

Such pores are, occasionally, partially or completely filled with later precipitated calcite cement. This is distinguished from dedolomitic calcite replacement by its relative coarseness, clarity, freedom from iron oxide inclusions and above all by its characteristic drusy texture i.e., porewards increase of crystal size.

4. Zoned Dolomite

Zoned dolomite is common where rhombic cores, zones or rims are distinctly composed of either ferroan dolomite (stained in blue) or dark iron oxide aggregates (hematite) or composite calcite, or a combination of the latter two types of minerals in the same cores, zones, or rims. The zonal build-up must have been caused in the first place by paragenetic changes in composition at the growing stages of individual dolomite crystals (Shukla and Baker, 1988). Ferroan cores, zones and rims are rarely encountered in the dolomite crystals because of the oxidation of ferrous iron into ferric iron during the later subaerial exposure of dolomitic rocks (Fig. 3D).

Calcite cores and zones must have formed by calcitization of dolomite through dedolomitization (Figs. 3E and 3F). The intimate association of iron oxide inclusions with dedolomitic calcite implies that oxidation of pre-existing ferrous iron accompanied dedolomitization. This evidence supports the surface nature of the later dedolomitization process. In fact, this ferrous iron could have been a stimulating factor in the total or selective calcitization of dolomite crystals or their cores and zones respectively because of the destabilizing effect of Fe^{++} on the dolomite lattice structure.

However, Katz (1968, 1971) recognized a zonal distribution of calcian dolomite in that the ratio of calcium to magnesium is variable throughout the individual crystals of dolomite as revealed by electron micro-probe analysis. He pointed out that dedolomitization has affected, in preference, the calcian dolomite crystals, cores and zones containing more than 8 percent excess calcium as compared with the ideal composition of stoichiometric dolomite with molar ratio of Ca:Mg = 1:1. Accordingly, it is probable that excess calcium in former calcian dolomite has played as much role as ferrous iron in promoting total or selective dedolomitization in the examined rocks. This is because the presence of excess calcium would cause defects and hence destability in the dolomite lattice structure when calcium is partially substituted for magnesium due to their differing ionic sizes (Ca ion is larger than Mg ion).

Zoned dolomite has shown, in many instances, its concurrent growth in limestones. This is demonstrated by self-impinging dolomite crystals in cluster-like development where corresponding zones of iron oxide or calcite meet each other to form a continuous mutual boundary (Figs. 3E and 3F).

5. Dark Centered-Clear Rimmed Dolomite

Some finely crystalline dolomite with either idiotopic or xenotopic texture (Friedman, 1965) is found to consist of cloudy core-clear rim crystals. The cloudy core is variable in both size and shape. The size of the cloudy core grades, on the scale of a single thin section, from less than half to almost the entire volume of the individual crystals leaving a thin outer rim of clear dolomite (Fig. 4A). Equally, its shape varies from a perfect rhombohedron to nearly round core, but it is often irregular and more or less matches the anhedral outlines of the host crystal (Fig. 4B).

Examination by hand lens of this type of dolomite with cloudy core and clear rim crystals may mislead to the belief that it is peloidal grainstone because the cloudy cores appear as dense micritic peloids, while the clear rims appear as intergranular sparry calcite cement. Even under the microscope, it could be wrongly identified, at first sight, as dolomite replacing a former peloidal limestone. However, the straight sides and, above all, the rhombohedral outlines of these dark cloudy cores do not allow the misinterpretation of this dolomite texture as a replacement product of original carbonate peloids.

Murray (1964) explained the origin of this type of dolomite by the local source theory

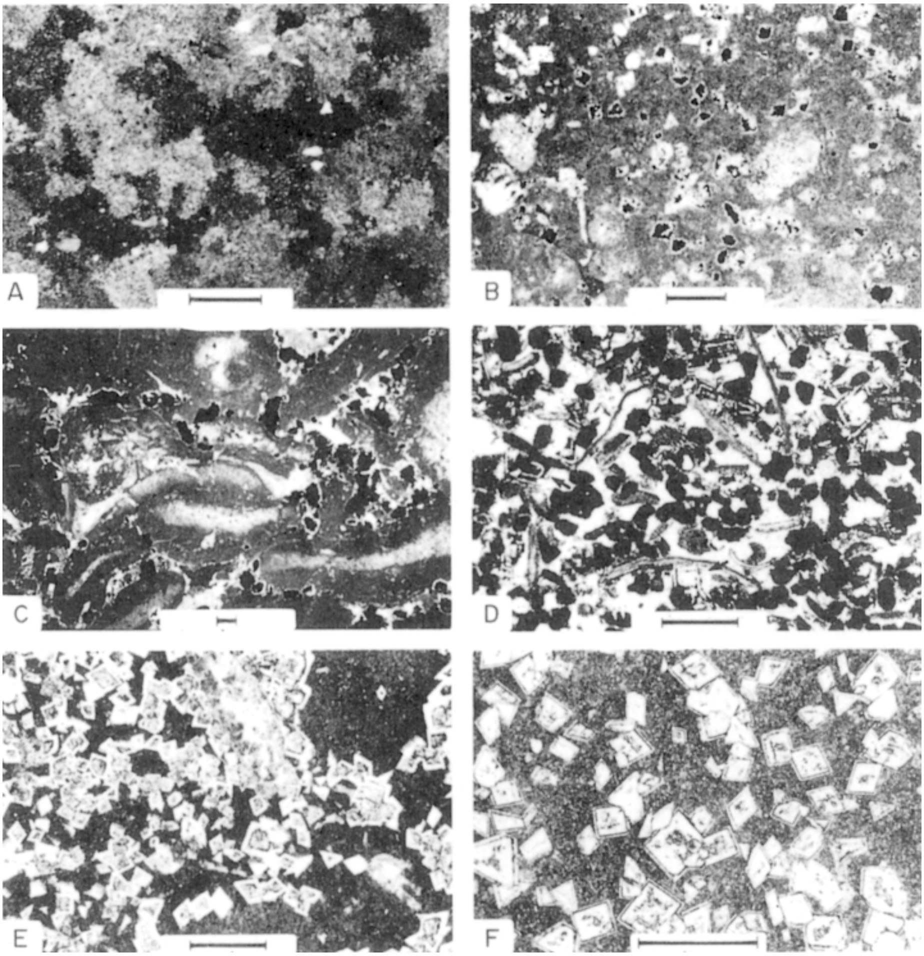

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FIG. 3A. Another coarse calcite texture with diffused crystal boundaries, consisting of finely microcrystalline calcite that apparently matches the replaced dolomite texture. Khuff Fmn., Ar-Rayn (Crossed Polarized Light).

FIG. 3B. Leached dolomite rhombs (in black) with relics of clear granular calcite lining the rhombohedral pores that are scattered in micrite matrix. Jubaila Fmn., Wadi Huraymila (Crossed Polarized Light).

FIG. 3C. Rhombohedral pores (in black) with clear dolomite rims. The preferential development of earlier dolomite rhombs across grains contact in tightly packed algal nodule lime rudstone indicates post-compaction dolomitization. Jubaila Fmn., Wadi Huraymila (Crossed Polarized Light).

FIG. 3D. Dolomite rhombs with multiple iron oxide zones (arrows) in peloidal-bioclastic lime grainstone. Hanifa Fmn., Wadi Huraymila (Plane Polarized Light).

FIG. 3E. Dolomite crystals with large rhombic cores of composite calcite (cloudy) and clear rims of unaltered dolomite in calcarenitic burrow-infill of lime mudstone. Concurrent dolomite growth is observed wherever dolomite rhombs mutually interfere. Jubaila Fmn., Wadi Nisah (Plane Polarized Light).

FIG. 3F. Clear dolomite crystals with dark thin rhombic zone of calcite and associated iron oxide in micrite matrix. Irregular calcitization also occurs within dolomite crystals. Concurrent growth of dolomite is shown by the mutually interfering zoned crystals. Jubaila Fmn., Wadi Hanifa, Jubaila type locality, 25 km north-west of Ar-Riyadh (Plane Polarized Light).

of dolomitization (Weyl, 1960; and Murray, 1960). This theory proposes that the additional carbonate ions needed for the volume per volume replacement of calcite or aragonite by dolomite are locally supplied by the limestone at the site or the immediate vicinity of the growing dolomite rhombs. According to Murray, the centre of dolomite crystals appears dark because it included relict material derived from locally replaced carbonate mud, while the outer rim of the rhomb is light because it grew almost as micro-void-filling cement and thus clear of inclusions.

Dedolomitization affecting this type of dolomite tended to regenerate the pre-dolomitization texture of the original limestone in the cloudy cores of dolomite crystals. Subsequently it could create dedolomitized limestone with a pseudo-peloidal grainstone fabric (Fig. 4D) as observed by Evamy (1967).

6. Sucrosic Dolomite

Very finely and finely crystalline (100-200 microns in crystal size) idiotopic dolomite with slightly or partially welded rhombic crystals is uncommon in the investigated rocks. This is usually described in literature as sucrosic dolomite (Fig. 4C). The significant intercrystalline porosity in this textural type of dolomite is thought to have been created through dolomitization to compensate for the decreased molar size of dolomite as compared with former aragonite or calcite in volume per volume replacement (Murray, 1960). However, the occasional presence of small remnants of depositional micrite matrix in the inter-rhomb spaces suggests selective leaching of the unreplaced lime material in the post-dolomitization stage. Such selective leaching can be promoted by meteoric waters that are undersaturated with respect to calcium carbonate minerals.

The impure nature of the individual crystals in sucrosic dolomite is due apparently to tiny inclusions which must have been inherited from an original micron-sized calcium carbonate material such as micrite (Murray, 1964). These crystals may show iron oxide zones and/or dark centres with clear rims, and appear to be poikilotopically enclosed within coarse sparry calcite cement possibly precipitated during later subaerial exposure of dolomitic rocks. Partial and complete dedolomitization of this dolomite texture may also take place. In dedolomitized sucrosic dolomite, the cloudy cores and clear rims of dolomite rhombohedra were partly replaced by micrite and clear calcite respectively (Fig. 4D). The inter-rhomb spaces are filled with clear calcite cement which is frequently in optical continuity with the calcite rims in earlier dolomite crystals. This optical continuity indicates that calcite cementation of the intercrystalline porosity in such idiotopic dolomite was concomitant with later dedolomitization. Sucrosic dolomites are occasionally encountered in the upper Jubaila rocks of Wadi Nisah and Widyan (Wadis) Al-Majami sections and the Khuff rocks of Buraydah section.

7. Interlocking Dolomite

This is a common mode of occurrence of dolomite whose individual crystals mutually interfere to form anhedral crystal boundaries in an interlocking xenotopic dolomite texture that may consist of cloudy core-clear rim crystals with scattered allochem ghosts (Fig. 4E). It is, consequently, almost completely devoid of secondary intercrystalline porosity. In some instances, the anhedral crystals of dolomite are zoned with perfect rhombic cores that are comparable in size to dolomite rhombs in sucrosic-textured dolomite (Fig. 2A). Therefore, it is apparent that optically continuous overgrowth of earlier-formed dolomite rhombs occurred, thus causing the occlusion of inter-rhomb spaces. In many instances, the dolomite matrix may contain relict allochem ghosts that are either dolomitized or leached to form scattered mouldic pores that may be cemented by sparry calcite or anhydrite (Fig. 4F). The dissolution of the unreplaced allochems (mostly skeletal in origin) at final stages of dolomitization could have locally released the additional carbonate ions needed for the volume per volume replacement of lime mud matrix and some floating allochem grains.

Xenotopic dolomite generally preserves the original limestone fabric in the dolomite matrix. The individual crystal aggregates of such dolomite range from micron-size to 200 microns at the scale of a single rock thin section. This variable dolomite crystal size often reflects the type of replaced calcium carbonate constituents of the original limestone. Fossil and other allochem ghosts may occur in either cloudy or clear interstitial dolomite matrix depending on the original limestone fabric (Fig. 5A and 5B). They are usually recognized by their dark impurities and relict inclusions that were apparently derived from the original allochems especially the organic-rich micrite envelopes produced by boring algae around skeletal grains as pointed out by Murray (1964). In some instances, the primary internal microstructure of depositional skeletal fragments, such as lamellar and prismatic microstructure of calcite bivalves and monocrystals of crinoidal ossicles and echinodermal plates, is preserved in full detail (mimic replacement) after a complete dolomitization of the limestone (Fig. 5A).

8. Crypto- and Microcrystalline Dolomite

This extremely fine-textured dolomite seems to have replaced, in preference, lime mudstones with or without floating allochem grains and mud-free calcarenite. It is free from both ferrous and ferric forms of iron, but could be affected by partial or complete dedolomitization. A large proportion of the Khuff rocks consists of the cryptocrystalline dolomite or dolomicrite which frequently encloses voids of leached anhydrite replacement (Fig. 5C). Dolomicrite is, however, rare in the Jubaila and absent in the adjacent Hanifa rocks, and only occasionally occurs in the uppermost Jubaila units. Microcrystalline dolomite (less than 15 microns in crystal size) is equally more common in the Khuff than in the Jubaila rocks (Fig. 5D). The crypto- and microcrystalline dolomite is texturally identical to recent dolomite that forms penecontemporaneously with calcium carbonate sedimentation within the tidal flats of the Arabian Gulf (Illing *et al.*, 1965).

In the preceding modes, the dolomite grew as a replacement to calcium carbonate sediments and rocks. Relict inclusions derived from the depositional lime material were generally born within the replacement dolomite. This had led to the common preservation of original limestone texture and structure in the dolomite.

9. Cement Dolomite

This dolomite is entirely different from the above-described dolomites, in that it orig-

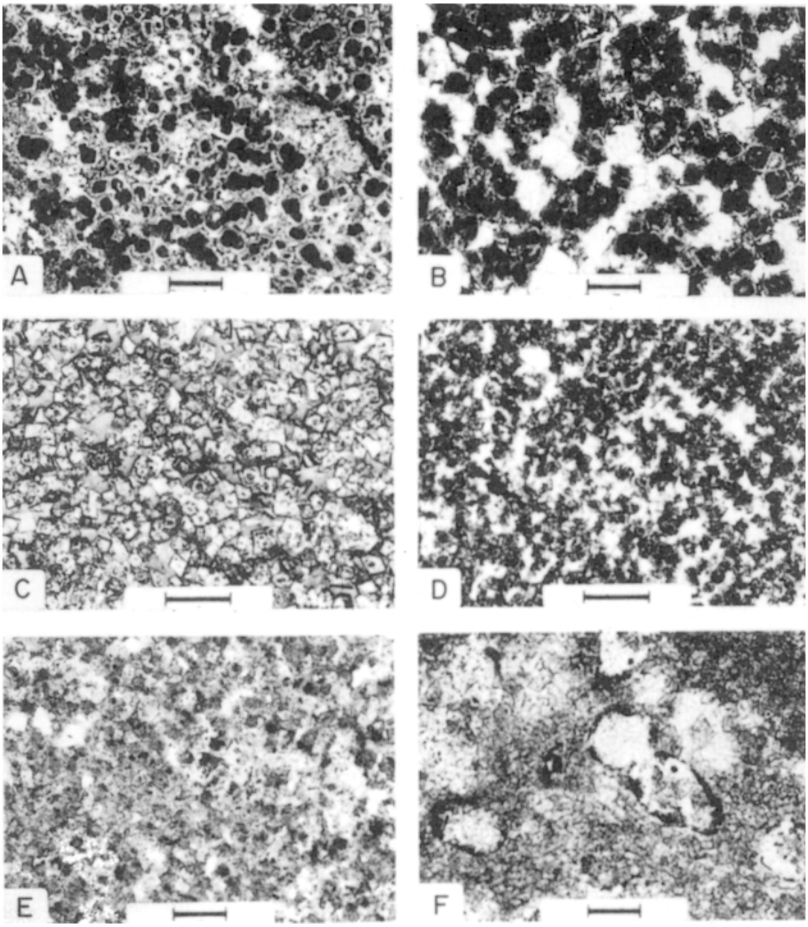

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FIG. 4A. Dark core-clear rim dolomite crystals with variable size of the dark core. Jubaila Fmn, Wadi, Nisah (Plane Polarized Light).

FIG. 4B. Another similar dolomite with variable shape of the dark core from perfect rhombohedron to irregular one, though, matching the outlines of the clear rim of hosting dolomite crystals. Jubaila Fmn., Wadi Nisah (Plane Polarized Light).

FIG. 4C. Sucrose dolomite, with impure dolomite rhombs, whose intercrystalline porosity is completely occluded by coarse sparry calcite cement (cloudy for being stained in red). Jubaila Fmn., Widyan Al-Majami (Plane Polarized Light).

FIG. 4D. Almost complete calcitization converted the earlier cloudy core and clear rim of individual dolomite rhombs in sucrose dolomite into micrite and clear calcite respectively. The dedolomitized limestone stimulates peloidal grainstone texture. Jubaila Fmn., Widyan Al-Majami (Plane Polarized Light).

FIG. 4E. Interlocking xenotopic dolomite. Allochem ghosts are scattered in cloudy interstitial dolomite that replaced the micrite matrix in former bioturbated lime mudstone. Jubaila Fmn., Wadi Nisah (Plane Polarized Light).

FIG. 4F. Similar to previous one, but with frequent mouldic pores of leached allochems plugged by anhydrite. The boundaries of former allochems, in bioturbated lime mudstone, are emphasized by dark impurities. Jubaila Fmn., Wadi Huraymila (Crossed Polarized Light).

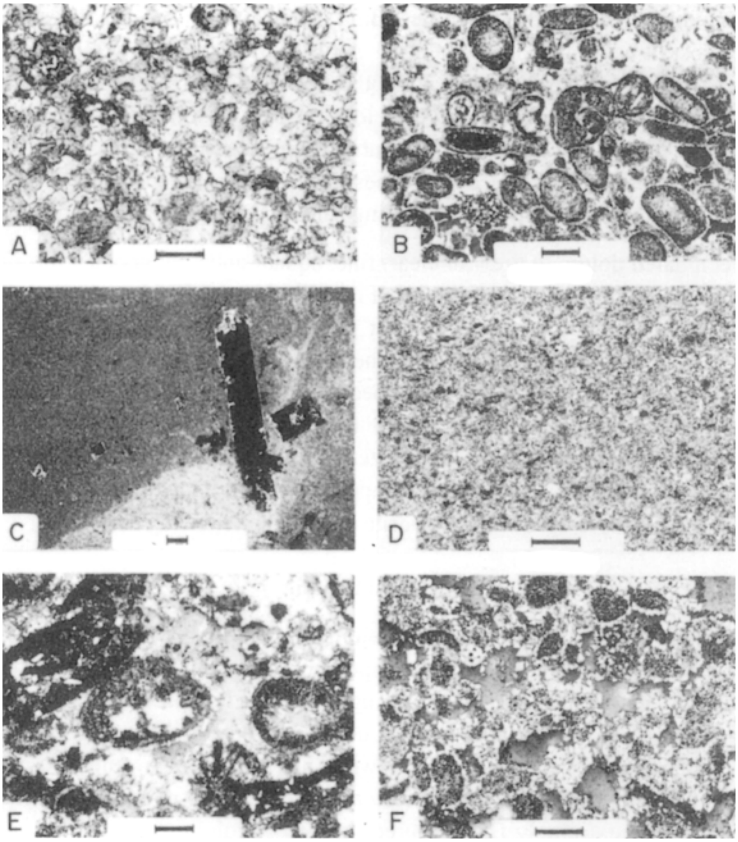
inated from direct precipitation as pore-filling cement. It is occasionally encountered in the uppermost Jubaila and adjacent basal Arab-D rock units as well as in some dolomitized grainstone facies collected from the uppermost Arab-A carbonate member in Dahl Hith sink hole (dissolution cavern) located 32 km south of Ar-Riyadh. Each of these carbonate units directly underlies anhydrite evaporites of the lowermost Arab-D zone and Hith Formation respectively. These laterally persistent late Jurassic evaporite deposits possibly originated from prograding sabkha plains (Leeder and Zeidan, 1977).

The precipitated dolomite grew in clear, fine, equant anhedral crystals forming uniform rinds around dolomitized allochem grains (Figs. 5B, 5E and 5F). It caused partial or complete occlusion of the primary intergranular pores of the grainstone facies. The allochem grains were apparently replaced by early penecontemporary dolomite prior to the emplacement of the dolomite cement. Less developed dolomite cement is also encountered in the Khuff rocks at Buraydah section. Here, it forms single rinds of clear, discrete microcrystalline rhombs that fringe the dolomitized peloids in grainstone facies. These peloids were equally replaced by early penecontemporary dolomite, and the bulk of intergranular porosity is completely occluded by anhydrite and calcite replacing anhydrite.

Conclusion

The various modes of occurrence of dolomite are possibly the result of paragenetic and epigenetic changes in texture and composition of dolomite crystals in the carbonate rocks. The paragenetic and epigenetic changes occurred respectively during the growth stages and later surface weathering of the dolomite crystals. Variations in the dolomite modes of occurrence possibly reflect as well differences in the physico-chemical environments between the penecontemporary and subsequent to burial dolomitization. The first one produced extremely fine-textured, iron-free, dolomite replacing lime mud matrix and/or calcarenite. Supersaturation of dolomitizing brines at or near sediment-water interface affecting finer-grained particles of micrite in the matrix or allochems with possibly aragonitic composition would produce densely populated nuclei of early dolomite. The second one usually formed coarser and zoned dolomite crystals (100-200 microns) indiscriminately replacing depositional carbonate constituents and sparry calcite cement. This later dolomite is expected to have occurred at prolonged but lower saturation of dolomitizing solutions resulting in more or less sparsely populated dolomite nuclei that freely grew at consecutive stages to form coarser, zoned crystals in the buried calcium carbonate sediments and rocks.

Ferrous iron substitution in the dolomite crystals, cores and zones as well as that in the sparry calcite cement is likely to take place in the subsurface reducing environment. Continued dolomite growth in this environment will cause the earlier-formed dolomite rhombs to mutually interfere with each other and ultimately produce compromise anhedral crystal boundaries in more or less interlocking dolomite matrix. Dedolomitization (calcite replacing dolomite) is likely to have resulted from the reaction between dolomite and calcium sulphate solutions derived from the dissolved anhydrite deposits under subaerial conditions. It is possibly promoted by excess calcium or ferrous iron substitution in the lattice structure of dolomite crystal cores, zones or entire



Scale bar = 0.5 mm

FIG. 5A. Clear interstitial dolomite possibly replacing sparry calcite cement in former lime grainstone texture. Its individual crystals grew uninterruptedly across the allochems boundary. Well preservation, in the dolomite mosaic, of original microstructure of many allochems e.g., foraminiferal (upper centre) and echinoderm grains (lower left). Upper Hanifa Fmn., Widyan Al-Majami (Plane Polarized Light).

FIG. 5B. Another clear interstitial dolomite apparently precipitated as cement, whereas the allochems, in grainstone facies, are replaced by cryptocrystalline and microcrystalline dolomite. Dolomite cement forms uniform rinds around allochems. Jubaila Fmn., Wadi Huraymila (Plane Polarized Light).

FIG. 5C. Cryptocrystalline and finely microcrystalline dolomite (lighter lower side), with small and large rectangular voids of leached anhydrite enclosing relicts of dolomite and/or calcitized anhydrite. Khuff Fmn., Ar-Rayn (Crossed Polarized Light).

FIG. 5D. Cloudy microcrystalline dolomite with faintly defined allochem ghosts. Khuff Fmn., Ar-Rayn(Plane Polarized Light).

FIG. 5E. Dolomite cement forming rinds around dolomitized calcarenite in grainstone facies. The bulk of primary intergranular and secondary intragranular pores are occluded with later sparry calcite cement that looks cloudy because of its red colour stain. Jubaila Fmn., Wadi Huraymila (Plane Polarized Light).

FIG. 5F. Another dolomite cement partially occluding the primary intergranular porosity in this dolomitized calcarenite. Later sparry calcite cement (in cloudy appearance) completely occludes the primary and secondary (mouldic) pores. Arab-A carbonate member, Dahl Hith sink (32 km south of Ar-Riyadh) (Plane Polarized Light).

volume. This calcitization process affects both penecontemporary and burial dolomites.

Dolomite may also grow as pore-filling cement in equant crystals that uniformly fringe dolomitized allochems with partial or complete occlusion of the primary intergranular porosity in grainstone facies. It is distinguished from the replacement dolomite by its clarity due to its freedom from relict micrite inclusions and impurities.

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أشكال تواجد الدولوميت في بعض الصخور الكربوناتية العربية

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المستــخلص . في المنطقـة الوسطى من المملكة العـربيــة السـعـودية ، تأثر منكشـفـات المتكونات الكربـوناتيـة (ألخُف والجبيـلة) للعصـرين البـرمي الأعلى والجوراوي الأعلى بدلمتة وإعادة كلستة واسعتين ، فالعـملية الإحلالية الأخيرة كثيراً مايصاحبها نشوء المسامات المعينيّة (موشورية سداسية) . هناك تسعة أشكال مختلفة لتواجد الدولوميت تم التعرف عليها في الصخور التي جرى فحصها ، وهذه الأشكال هي : (١) دولوميت حديدي ومعينيّات أكسيد الحديد ؛ (٢) دولوميت مكلست ؛ (٣) معينيّات دولوميت مذاب ؛ (٤) دولوميت ممنطق ؛ (٥) دولوميت ذو وسط غامق وحافة فاتحة ؛ (٦) دولوميت معيني البللورات ؛ (٧) دولوميت متشابك البللورات ؛ (٨) دولوميت بللوري دقيق ومتناهي الدقة ؛ (٩) دولوميت لحامي . هذه الأشكال قد نتجت على الأرجح من تغيرات في نسيج وتركيب بللوات الدولوميت خلال مراحل نموها (Paragenetic changes) وكذلك خلال التجوية السطحية المتأخرة (Epigenetic changes) ، ومن الممكن أيضًا أن تعكس هذه الأشكال اختلافات في الظروف الطبيعية والكيميائية بين بيئة الدلمتة المبكرة (المعاصرة) وتلك التي تلي دفن الرواسب ، فالبيئة الأولى أنتجت دولوميت ذو نسيج متناهي الدقة وخال من الحديد ليحل محل الأرضية الطينية الكلسية و/ أو الرمل الكلسي ، بينما أدت البيئة الأخيرة إلى تكوين بللورات دولوميت أكثر خشونة وممنطقة لتحل عشوائيا محل المكونات الكربوناتية الترسيبية ولحام الكلسيت البللوري . لم ينمو الدولوميت فقط كإحلال محل الرواسب والصخور الكربوناتية الكلسية بل أيضًا كلحام يملأ المسام .