Dolomitization of the Brassfield Formation (Lower Silurian) in Adams County, Ohio

Lisa L. Varga
Western Michigan University

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DOLOMITIZATION OF THE BRASSFIELD FORMATION (LOWER SILURIAN) IN ADAMS COUNTY, OHIO

Lisa L. Varga, M.S.
Western Michigan University, 1981

The Lower Silurian Brassfield Formation which outcrops in the Tri-state area of Ohio, Indiana and Kentucky is a transgressive sequence consisting of a series of interbedded shales, limestones and dolostones. Evidence from depositional environments, petrography and spatial relationships of dolomitized and undolomitized rock suggests dolomitization in southwestern Ohio was a two-stage process. Initial dolomitization was restricted to the basal Belfast Member and probably occurred penecontemporaneously on small supratidal islands in a manner analogous to that which occurs in the modern sabkha environment of the Persian Gulf. Regional dolomitization was a later diagenetic event related to the formation of a fresh-seawater mixing zone beneath a landmass created by upwarping of the Cincinnati Arch at the close of the Silurian. Intensity of dolomitization in the outcrop belt is controlled by the proximity of the original carbonate to the source of dolomitizing fluids in the mixing zone.
ACKNOWLEDGEMENTS

The writer would very much like to thank Dr. William B. Harrison III for his advice and assistance on this project. Dr. Harrison was most generous with his time and his unfailing good humor was greatly appreciated. Acknowledgement is made to Dr. Thomas Straw and Dr. John Grace who kindly read an early draft and made helpful suggestions.

Finally, I am grateful for the encouragement and moral support provided by my family and friends. I thank you all.

The research for this study was partially funded by a grant from the Graduate College of Western Michigan University.

Lisa L. Varga
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INTRODUCTION

The principal aim of this study was to investigate the occurrence, and propose a process for the genesis of dolomite in the Brassfield Formation (Lower Silurian) of Adams County, Ohio. The Brassfield rocks are a series of interbedded shales, limestones and dolostones which outcrop in the Tri-State area of Ohio, Indiana and Kentucky (Fig. 1). They are unique in the study area because the rocks are not uniformly dolomitized. This irregularity in the dolomite distribution is a major concern.

The enigmatic nature of ancient dolomite formation has been considerably discussed within the geologic community in recent years, and several models concerning the environments of dolomitization have been advanced; for instance, seepage refluxion (Adams and Rhodes, 1960), evaporative pumping (Hsu and Siegenthaler, 1969) and mixed water (Land and Epstein, 1970). The dolomitizing mechanism of the Brassfield Formation will be considered in view of the existing models.

Geologic Setting

The shales, limestones and dolostones of the Brassfield Formation form an arcuate outcrop belt on the flanks of the Cincinnati Arch and overlie Upper Ordovician rocks in a regional disconformity. The Brassfield is thinner and less shaley on the western side of the arch than on the eastern side, and the section
Fig. 1 - Brassfield outcrop in the Cincinnati Arch area.

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thins southwestward from the study area to a pinchout near Stanford, Kentucky.

The Brassfield rocks were deposited in an epeiric sea during the Early to Middle Llandoveryan (Berry and Boucot, 1970), (Fig. 2). Carbonate deposition at this time was widespread and relatively continuous although local evidence for short periods of subareal exposure is present on the eastern side of the arch. According to recent reconstructions of paleogeographic positions, the study area was situated between 10-20° south latitude (Dott and Batten, 1976; Irving, 1979), within a climate and setting which exists in many modern carbonate producing areas, such as the Gulf of Mexico and the Caribbean. Islands in the Appalachian belt known as Taconian land shed sand and fine mud that was carried westward influencing Brassfield sedimentation in Ohio and Kentucky. Local tectonism in the vicinity of the Cincinnati Arch was subtle although gentle uplifts may have influenced Brassfield deposition and diagenesis (McDowell and Peterson, 1980).

Stratigraphic Nomenclature

August Foerste (1885, 1896, 1904) was the pioneer worker who formally named the Brassfield Limestone for rocks exposed at the type section in Madison County, Kentucky. Previously these rocks had been miscorrelated with the Clinton group (Middle Silurian) of New York by Orton (1890). Foerste recognized that although the Ohio "Clinton" represented similar facies, it was not
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Fig. 2- Generalized regional distribution of Lower Silurian rocks in the Cincinnati Arch area (modified from Berry and Boucot, 1970).

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time equivalent with the New York Clinton. Above the Brassfield Limestone, Foerste combined two formations, the Indian Fields and Alger Formations, to form the Crab Orchard Group.

The term Brassfield Limestone was used as originally proposed until Rexroad, et al. (1965) made several changes in the classification (Fig. 3). Additionally O'Donnell (1967) further amended the Brassfield Formation to include four general lithologic units including the Noland Member.

This study recognizes three of O'Donnell's proposed units; 1. Belfast Member, 2. lower massively bedded Brassfield, 3. upper thinly bedded Brassfield. In Adams County additional thin bedded and massively bedded units can be found between O'Donnell's "lower massively bedded Brassfield" and "upper thinly bedded Brassfield". Since these units may not be widely persistent or recognizable, they will be treated informally within the scope of this study (Fig. 3).

The Noland Member, designated as a formation by Rexroad, et al. (1965), is difficult to trace or correlate north of Bath County, Kentucky and is not recognized in Ohio (Harrison, personal comm.). Furthermore, the joint U.S. Geological Survey and Kentucky Geological Survey did not include the Noland in their mapping program (Peck, 1967). Therefore, the Noland is disregarded by this study in favor of the Crab Orchard Formation for rocks which overlie the Brassfield Formation.
<table>
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<th>FOERSTE (1966)</th>
<th>REXROAD et. al. (1965)</th>
<th>O'DONNELEL (1967)</th>
<th>THIS STUDY</th>
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<td>INDIAN FIELDS</td>
<td>Plum Creek</td>
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Fig. 3- Stratigraphic nomenclature for the Brassfield Fm. in the Ohio valley area.
METHODOLOGY

Field and Laboratory Methods

Three outcrop sections of the Brassfield Formation were measured and described in detail from Adams County, Ohio on the eastern flank of the Cincinnati Arch (Fig. 4). Several additional outcrops were examined and these observations were used to supplement data from the three major sections. Sections were measured with a jacob's staff and a Stratex surveying micro-altimeter was used to crosscheck elevations. Samples were collected from every major carbonate bed, while shales were described in situ. One hundred polished slabs were made and representative thin sections from each measured section were examined. Both slabs and thin sections were etched and stained with Alizarin Red S (Dickson, 1965) to more easily distinguish calcite from dolomite. Selected slabs were stained with a solution of potassium ferricyanide (Dickson, 1965) so the type and amount of ferroan dolomite could be assessed. A modified Wentworth grain-size scale (Folk, 1962) was used for all grain measurements.

Terminology

Dolomitic rocks of the Brassfield Formation retain much of their original depositional texture despite diagenesis. This is particularly true in Ohio where the rocks are not as strongly altered as they are in Kentucky. Textural properties and compositional data are prerequisites for interpretation of depositional
Fig. 4- Study area and location of sample sections.
environments, therefore, the terminology of Dunham (1962) is used in this study (Fig. 5). Following the suggestion of Gordon (1980), Dunham's terms will be followed by a Roman numeral which indicates the corresponding "Energy Index" as proposed by Plumley et al. (1962) and modified by Catalov (1972), (Fig. 5). The energy index provides a genetic classification based on the energy that existed in the depositional environment. Textural data of important consideration are size, sorting, roundness of the allochems, and the degree of winnowing. The four textural levels of the energy index are related to the degree of water agitation.

The combination of Dunham's textural classification and the energy index concept provide a more detailed description of the physical environment of deposition. For example, packstone (III) indicates the original sediment was grain-supported, and deposited in moderately agitated water.

Where dolomitic rocks are discussed Dunham's terminology (along with the corresponding energy index) will be prefixed by terms that indicate the degree of dolomitic alteration. Powers (1962) offered the terms, "partially dolomitized" for rocks which display 10-75% discrete dolomite rhombs and "strongly dolomitized" where 25-75% of the rock is interlocking dolomite (Figs. 6 and 7). Dolomite with "relic original texture" is more than 75% interlocking dolomite where original texture is still recognizable (Fig. 8). Usually only ghosts of original texture remain. "Crystalline dolomite" has no recognizable original texture and consequently

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### Classification of Carbonate Rocks

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<td>IV</td>
<td>Deposited in strongly agitated water</td>
<td>Grain-supported</td>
<td>10-75% discrete dolomite rhombs</td>
</tr>
<tr>
<td>III</td>
<td>Deposited in moderately agitated water</td>
<td>Mud-supported</td>
<td>25-75% interlocking dolomite</td>
</tr>
<tr>
<td>II</td>
<td>Deposited in slightly agitated water</td>
<td>Wackestone</td>
<td>More than 75% interlocking dolomite</td>
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<tr>
<td>I</td>
<td>Deposited in quiet water</td>
<td>Mudstone</td>
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**Fig. 5:** Classification of carbonate rocks according to their original texture and their altered texture.
Fig. 6- Photomicrograph of sample WU- 24 showing partial dolomitization of matrix (x 11.2).

Fig. 7- Photomicrograph of sample WU- 12 displaying strong dolomitic alteration (x 11.2).
Fig. 8- Photomicrograph of sample WU- 5 showing strong dolomitization. Note the relict original texture preserved by the dark laminae (x 11.2).
cannot be classified on the basis of depositional fabric although
some generalizations can usually be made based on crystal size or
relict structures.
STRATIGRAPHY

General Statement

The Brassfield Formation as defined by this study, in Adams County, Ohio consists of five lithologic units, only one of which is formally recognized as a member (Figure 3). The Brassfield Formation at the West Union location is the thickest exposure of Brassfield strata (16 meters) in the entire outcrop belt. South-westward along strike, the rocks thin to a point near Stanford, Kentucky where the formation is truncated by pre-Devonian erosion. To the north near Dayton, Ohio and on the western side of the Cincinnati Arch in Indiana, the formation thins to average thicknesses of 10 meters and 3 meters, respectively. Consequently, in most sections outside Adams County some of the component stratigraphic units recognized in this study are missing or unrecognizable. For example, the Belfast Member attains its maximum thickness at the West Union section and pinches out near the Ohio River at the Manchester section. At the Manchester section the lower massive Brassfield directly overlies Ordovician rocks. Therefore, the composite stratigraphic section (Fig. 9) illustrating Brassfield stratigraphy in the study area cannot be strictly applied to other Brassfield outcrops outside southwestern Ohio.

In general, the Brassfield is disconformable with the underlying Cincinnatian Formations of the Richmond Group in the Ohio valley region. Contacts are sharp and well-defined. However, in
Fig. 9- Generalized stratigraphic column of the Brassfield Formation in southwestern Ohio.
Adams County, notably at the West Union and Belfast sections of this study, the contact between the Ordovician Preachersville Member of the Drakes Formation and the Belfast Member of the Brassfield Formation is more subtle. The shales and siltstones of the two formations were deposited in similar environments without any pronounced physical evidence for a break in sedimentation. This apparent paraconformity and the evidence about water depth it provides has been discussed by Gray and Boucot (1972). Data based on acritarchs and spore tetrads indicates water depths no deeper than intertidal, or possibly even nonmarine environments at the top of the Ordovician and in the lower portion of the Belfast. Water depth increases higher into the Belfast. Depth zonation for higher Brassfield beds which contain megafossils can be assigned by criteria proposed by Ziegler (1965) and Ziegler and Boucot (1970).

In the study area the top of the Brassfield is defined by a prominent, biostratigraphic marker bed, in the upper shales of the upper thinly bedded Brassfield. The "bead bed", as it is commonly known (Rexroad et al., 1965), is a distinct megarippled bed containing large crinoid columnals. Geographically the beds are found on the east side of the Cincinnati Arch from Dayton, Ohio to Birmingham, Alabama (O'Donnell, 1967). The contact with the Brassfield and the overlying limestones and shales of the Crab Orchard Formation is gradational.
Description of Stratigraphic Units

Belfast Member

The Belfast Member consists of a series of thinly-bedded dolomitic, light gray siltstones and shales (Fig. 10). It is 1-2 meters thick and rests paraconformably on Ordovician shales (Gray and Boucot, 1972). There is a slight lithologic and color change marking the contact (Fig. 11). Siltstone beds are flat or slightly undulate and are usually finely (less than 1cm) laminated. The laminations have a thin (organic?) film separating each pair. Quartz silt is common in some beds. A distinctive 4-8 cm thick siltstone has flute or load casts on its base which trend to the northwest. Since this bed was only observed at two nearby locations, it must have been a very localized pulse of energy. Fossils other than very sparse vertical burrows are rare. Petrographically the dolomitized Belfast Member displays only relict original texture but represents former argillaceous mudstones (I).

Lower Massively Bedded Brassfield

The lower massive Brassfield is a widely persistent, blocky, relatively homogeneous, ledge-former above the Belfast Member (Fig. 12). It sometimes appears as a single massive bed 1.5-2 meters thick, although near the top of the unit very thin shale partings separate irregular bedding surfaces. The unit is extremely bioturbated (Fig. 13). Megafossils, including
Fig. 10- Interbedded shales and siltstones of the upper Belfast Member exposed at the West Union section. Note the gently undulating bedding.

Fig. 11- Paraconformable contact between the Ordovician Drakes Fm. and the Belfast Member of the Brassfield Fm. Hammer pick rests on the contact.
Fig. 12- Lower massively bedded Brassfield at the Manchester section. Hammer rests on sandy lens.

Fig. 13- Horizontal branching burrows characteristic of the lower massively bedded Brassfield.
disarticulated crinoid columns and solitary rugose coral, occur within the shale partings. The contact between the lower massive Brassfield and the thin bedded unit is gradational, but a zone of glauconite and manganese oxide (black staining) is characteristic of the uppermost lower massive Brassfield. Petrographically, the strongly dolomitized lower massive Brassfield is also a former mudstone (I).

**Thin Bedded Unit**

The thin bedded unit is a sequence of alternating gray, splintery shales and partially dolomitized limestone beds (2-10 cm thick), which is approximately 1.5 meters in total thickness (Fig. 14). Many limestone beds appear lumpy or nodular due to bioturbation by large organisms (Fig. 15). Other limestones are finely laminated (less than 1 cm) and appear to be deposited by interruptive bursts of higher energy. Fossils other than traces, become more common and assemblages, more diverse upward. Crinoids, solitary rugose coral, brachiopods and bryozoa are plentiful in certain layers. Higher in the section discontinuous chert stringers within the nodular beds may be related to burrowing (Fig. 16). Petrographically these rocks are mainly wackestones (II) and packstones (III) and are among the least dolomitized rocks in the study sections.
Fig. 14- Thin bedded unit exposed at the West Union section.
Fig. 15- Close-up of a portion of the thin bedded unit at the West Union section showing lumpy or nodular bedding.
Fig. 16- Large burrow in the thin bedded unit preferentially replaced by chert.
Upper Massive Unit

The upper massive unit is a distinct chert-bearing unit which is 1.2-1.6 meters thick in the study area (Fig. 17). Although the unit appears massively-bedded, thin shale partings occur at 30 to 40 cm intervals. Bioturbation is very localized. Surfaces of fallen slabs appear nobby and mounds of diverse fauna represent isolated well-developed communities. Occasionally these mounds are wholly or partially replaced by chert.

Generally, the white chert is globose, associated with glau­conite, and often richly fossiliferous. Some nodules contain pyrite. O'Donnell (1967) found that, going from north to south, the chert is found progressively lower in the section. The unit is strongly dolomitized and probably represents former wackestones (II), packstones (III) and grainstones (IV).

Upper Thinly Bedded Brassfield

The interbedded shales and dolomitic limestones above the upper massive unit are known as the upper thinly bedded Brassfield (Fig. 18). Limestones rarely exceed thicknesses of 30 cm. Some display high-energy features including large-scale ripples (wave-lengths reaching 100 cm) (Fig. 19), cross-bedding and scour and fill structures. Shale interbeds are much thicker (up to 100 cm) than shales in lower Brassfield units. Bioturbation is restricted to a few muddy horizons. This unit contains the most
Fig. 17- Upper massive unit exposed at the West Union section. Note the large globose masses of white chert.
Fig. 18- Upper thinly bedded Brassfield exposed at the West Union section. Note the thick shale beds and the megarippled horizon at the meter stick.
Fig. 19- Megarippled bed characteristic of the upper thinly bedded Brassfield. Wave-length is approximately 100 cm.
fossiliferous strata, including the "bead bed", the conventional marker for the top of the Brassfield, which is a megarippled horizon composed of a variety of quite large (0.5-2.5 cm in diameter) crinoid columnals (Fig. 20). Beds of hematite coated bioclasts and intraclasts occur near the top of the section and were once mined locally as an iron ore. The limestones are partially to strongly dolomitized. They represent wackestones (II) through grainstones (IV), with packstones (III) being most predominant.
Fig. 20- Surface of the megarippled "bead bed" exposed at the West Union section. Note the variety of crinoid columnals.
DEPOSITIONAL ENVIRONMENTS

Introduction

Different lithostratigraphic units often represent different environments of deposition or facies. Each may undergo different diagenetic histories producing different textures and mineralologies. Original sedimentary texture is indicative of the energy which existed in the depositional environment while diagenetically altered textures reflect post-depositional environments. Altered textures of the Brassfield units show a relationship between original sedimentary texture and the type and extent of dolomitization. Therefore study of the Brassfield depositional environments provides clues which help to clarify many of the complexities of diagenetic alteration.

Tectonic Setting and Regional Paleogeography

The Brassfield rocks were deposited in a shallow, northwestwardly transgressing sea across a gently sloping, slightly irregular shelf. A world-wide Llandoverian (Early Silurian) transgression due to melting of Late Ordovician-Early Silurian glaciers in the southern hemisphere has been documented by Berry and Boucot (1973) and McKerrow (1979). In addition, minor eustatic fluctuations in sea level continued throughout the Silurian resulting in several short pulses of sea level change (Sheehan, 1975).

The platform on which the Brassfield was deposited in the
Ohio valley region was generally of low relief although locally several high areas may have existed and influenced sedimentation. Foerste (1904) and Rexroad (1967) discussed the Ripley Island or Ripley positive area in southwestern Indiana where Brassfield strata are missing apparently due to nondeposition. Gordon (1980) also postulated a high area in east-central Kentucky where the absence of the Belfast Member may be evidence of subareal exposure during initial Brassfield deposition. The Cincinnati Arch must have affected sedimentation although scattered outliers across the crest suggest inundation of this area during at least part of Brassfield deposition (Foerste, 1906). Thinning of section westwardly across the arch and the absence of clastics on the western flank suggest the arch must have acted as some sort of barrier to sedimentation. In southwestern Ohio this influence is negligible, but in Kentucky, flexure of the insipient arch had a pronounced effect on Brassfield sedimentation (Gordon, 1980). Basal conglomerates, stromatolites, mudcracks and the dominance of high-energy very near-shore environments suggest synsedimentary uplift south of Bath County, Kentucky which did not exist to the north along depositional strike. This implies a shallow-water to deep-water facies change, south to north, controlled by flexure of the insipient arch which may have similarly affected Upper Ordovician formations in the area (Weir & Peck, 1968). The facies change along strike northeastward into Ohio. Individual units become thicker, more shaley and less dominated by high-energy regimes.
Overall Brassfield sedimentation in the study area was continuous in a steadily transgressing sea that was only slightly affected by the gentle upwarping to the southwest.

Stratigraphic Units and Facies Interpretations

The vertical sequence of facies in the Brassfield represent transgressing environments which migrated laterally over each other through time. In ascending order the Belfast Member, lower massively bedded Brassfield, thin bedded unit, upper massive unit and upper thinly bedded Brassfield display depositional textures, structures and fossils that suggest these units were deposited as three major facies representing deepening marine environments. These facies are 1.) supratidal to intertidal and lagoonal, 2.) subtidal shoal and, 3.) subtidal open marine (Fig. 21).

Supratidal to Intertidal and Lagoonal Facies

The laminated, non-fossiliferous mudstones (I) of the Belfast Member are indicative of deposition in a very quiet low-energy environment (Fig. 21). In fact the presence of gypsum casts (Fig. 22) in the basal Belfast combined with evidence of land-derived spore tetrads (Gray and Boucot, 1972) suggests an initial phase of supratidal conditions. The supratidal environment was however, short-lived as the bulk of the Belfast rocks represent intertidal to very shallow subtidal environments. Dolomitic mudstones (I) with brown algal (?) films between thin (0.2 cm) laminae and bird's eye structures are interpreted to record middle to upper
Fig. 21- Lateral distribution of Brassfield facies equivalents.
Fig. 22- Gypsum casts preserved in the lower Belfast Member.

Fig. 23- Laminae (A) and bird's eye structures (B) in the lower Belfast Member.
intertidal environments where algal mats developed on carbonate muds (Fig. 23). Although no desiccation cracks were observed in the field some irregularly shaped bird's eye structures, obvious in polished slabs, may be internal or "healed mudcracks". These are believed to originate from internal shrinkage of the muds resulting from their dehydration during subareal exposure (Laporte, 1967).

Often fine-grained layers in the lower Brassfield mudstones are selectively dolomitized. This preferential dolomitization of fine-grained laminae may be the result of evaporation at the algal mat surface bringing magnesium-rich sea water upward through the sediment by capillary action. This process suggested by Shinn et al. (1965), results in dolomite being precipitated at the mat surface as a fine-grained layer. This initial stage of dolomitization produced distinct dolomitic laminae in the algal sediments of the lower Brassfield and supports the shallow intertidal interpretation.

Oscillatory ripple marks and increased infaunal activity characterize the lower intertidal zone and marks the gradational contact between the Belfast Member and lower massively bedded Brassfield. The lower massively bedded Brassfield represents lower intertidal to shallow subtidal facies (Fig. 21). It is intensely burrowed and bioturbated (Fig. 13). Murray (1975) in his study of trace fossils in the Brassfield attributed the prolific browsing and burrowing activity in this unit to deposit
feeding worms. These organisms exploit nutrient-rich layers. Their horizontal, branching burrows form tiers in the sediment and consequently erase any additional intertidal imprint.

Occasionally the mottled mudstones (I) of the lower massively bedded Brassfield are interrupted by liminated, grainy, lensoid beds (not more than 25 cm thick). These beds may represent intertidal channels which form wedges of sandy sediment brought onto the intertidal zone by storms rather than tides (James, 1979). The result is a layer of coarser, sandy debris left behind as a lag deposit.

Small (1-2 cm) solitary rugose coral, scattered crinoid columnals and higher-energy rock textures suggest subtidal environments in the upper lower massively bedded Brassfield. The unit grades into wackestone (II) and packstones (III) of the thin bedded unit.

Since the intertidal rocks of the lower Brassfield exemplify a muddy low-energy system, it follows that deposition must have occurred in a protected location; that is protected from waves and swells which would produce a high-energy beach zone. A protective barrier such as a shoal (Fig. 21) dissipates wave energy and in the lee of this barrier, provides a protected environment, a lagoon. The Belfast and lower massively bedded Brassfield were deposited in a muddy intertidal to lagoonal environment protected from wave processes by a seaward shoal. The limited areal extent of the units in southwestern Ohio and northern east-central Kentucky also suggests
a restricted depositional environment. Supratidal flats were not extensive and were only developed locally in southwestern Ohio.

**Subtidal Shoal Facies**

The depositional textures and sedimentary structures of the upper massive unit are suggestive of a high-energy or shoaling environment above wave base. The packstones (III) and grainstones (IV) of this unit are highly fossiliferous. In fact, mounds of diverse invertebrate fauna often in life position which are dominated by crinoids, solitary rugose coral, and associated bryozoan assemblages may represent bioherms which could flourish in the agitated environment. Wilson (1975) discussed the baffling action produced by thickets of crinoids. The organic activity usually begins below wave base. Binding, trapping and encrusting of organic debris and sediment by these organisms eventually builds mounds which are colonized by successive generations of crinoids and bryozoans. Continued baffling and building results in a mound which intersects wave base and dissipates open-ocean energy. The large masses of chert which characterize this unit seem to be a replacement type preferentially altering all or portions of these fossiliferous buildups. Sheltered areas between the mounds, and sediment deposited on the lee side of the shoal (represented by rocks of the thin bedded unit) are muddier wackestones (II). Infaunal activity was minimal. A few large burrows, probably produced by trilobites or other arthropods (Murray, 1975), penetrated the muddier sediments of the back shoal.
These rocks are interrupted by several stratified grainstone (IV) beds (10 cm thick). The beds are often graded and contain well-rounded quartz silt. The sedimentologic character of these rocks suggests rapid deposition, probably during storms.

The thin bedded unit and upper massive unit represent a shoaling bank which was dissected with channels of well-winnowed skeletal sands deposited during storms. The fossil communities which thrived on these banks were necessarily capable of withstanding high-energy conditions.

**Subtidal Open Marine Facies**

A change in regime is indicated where rocks of the upper massive unit grade into the upper thinly bedded Brassfield. Interbedded dolomitic limestone beds are separated by thick (up to 100 cm) fissile shale sequences. The shales indicate a return to quieter energy conditions. Original wackestone (II) and packstone (III) textures suggest that this environment was only occasionally agitated. Sedimentary structures such as crossbedding, graded bedding and scours are best developed in the lower portion of the unit. Thicknesses of shale interbeds and the abundance of burrowers greatly increase toward the top. This suggests a gradual deepening of the Brassfield subtidal environment resulting in a transition from shallow to deeper open marine facies (Fig. 21). Fossil diversity is moderate to high and again, crinoids dominate. Several megarippled horizons contain fossil allochems which are well-rounded and abraded. These beds may represent transported and
mixed assemblages which were deposited as major storms lowered wave base and disrupted the quieter energy conditions which prevailed on the shelf. The fossiliferous "bead bed" is a megarippled packstone (III) formed during such a high-energy event. The "bead bed" interrupts a thick shale sequence in the uppermost Brassfield that was deposited as the Brassfield sea reached its maximum level of inundation.

The depositional environment represented by the upper thinly bedded Brassfield was a steadily deepening, open marine, shallow shelf environment where quiet energy conditions were predominant as water depth increased.

Summary of Depositional Environments

The Brassfield Formation represents a transgressive sequence of carbonate rocks. Facies existed contemporaneously and migrated northwestward across the Ohio valley region (for a detailed description of depositional environments in east-central Kentucky, see Gordon, 1980). In southwestern Ohio small islands of low relief, lying just above normal high tide level were covered by algal mats. Primitive vascular plants may have colonized these supratidal flats as algal growth stabilized the sediment. The supratidal zone sloped gently, eventually becoming alternately inundated and drained by tides. Browsing and burrowing organisms exploited the rich organic layers of the intertidal flats. Tidal waters flooding these flats cut channels or creeks which during
storms would deposit coarser-grained sediment, as a lag deposit on the fine-grained muds. The adjacent subtidal (lagoonal) areas were sites of slow, low-energy deposition suggesting the existence of a barrier shoal. The lagoon which existed in the lee of this barrier was protected from the full force of ocean waves and swells. The shoal was formed by a belt of crinoid gardens, supporting a diverse fauna which could thrive in the high-energy environment. The crinoid bars were not continuous, but were breached by channels that may have migrated laterally through time. The shelf on which these bars existed gradually deepened seaward, and quiet, low-energy conditions were established below normal wave-base. Deposition of thick shale sequences was periodically interrupted by storms which lowered wave base and deposited mega-rippled bodies of abraded skeletal sands. When the storms passed quiet, deeper water sedimentation resumed.
DOLOMITIZATION

Introduction

Dolomite is a complex carbonate mineral which seems to form under a variety of natural conditions, where the dolomitizing solution is oversaturated with respect to dolomite. Many chemical environments should be conducive for dolomite formation. However, no one has yet synthesized dolomite under temperature and pressure conditions typical of modern sedimentary environments. Synthesis of dolomite at elevated temperatures (greater than 100°C) has been accomplished and is relatively uncomplicated (Gaines, 1980). The most significant advances made on the problem of dolomite genesis have come from the studies of natural modern dolomites and their ancient analogs.

It is generally agreed that most dolomite is a replacement product. This "secondary" dolomite is formed during early or late stages of diagenesis by replacement of some calcium carbonate sediment precursor. The small amount of dolomite considered "primary" is formed by direct precipitation usually in hypersaline lakes. Knowledge of the depositional setting is useful in distinguishing primary and secondary dolomites as well as the timing of the secondary event.

Evidence for the multiple origins of large bodies of dolomitized rock is extensive and several models have been proposed to account for the variety of geologic settings and formative processes.
which yield dolomite (Fig. 24). Discovery of "Recent" dolomite in the Persian Gulf (Illing et al., 1965) and on Andros Island (Shinn et al., 1965) helped reconcile the discrepancy between the large amounts of Proterozoic and lower Paleozoic dolomite and the lack of any significant amounts of late Cenozoic dolomite. In addition, the Holocene discoveries helped fuel the popular concept of the necessity of hypersaline solutions for dolomitizing processes.

Hypersaline Models of Dolomitization

Dolomite formed by brines with a high Mg/Ca ratio are associated with evaporite deposits. Original evaporite minerals may be preserved, but often these minerals are removed or obscured by later dissolution or diagenetic change. However, evidence of vanished evaporitic minerals has been found and has been discussed in detail by Friedman (1980).

Two methods for the formation of dolomite by hypersaline brines have been favored in the literature. Both involve the transportation of brines through carbonate sediment. Adams and Rhodes (1960) proposed the seepage refluxion model in which reflux of brines through the sediment by gravitational forces caused dolomitization along porous zones where the brines seeped through the underlying sediment. Development of a restricted lagoon or tidal flat where evaporation concentrated the brine and caused evaporites to form is a prerequisite for the model. Sears and Lucia (1980) have also suggested a refluxing mechanism for one phase of dolomitization in the pinnacle reefs of Northern Michigan. The seepage reflux model has also been applied by other authors.
Fig. 24- Classification of dolomite types, environments and mechanisms of formation.
Evaporation at the sediment-air interface in arid supratidal zones concentrates pore fluids into hypersaline brines. These fluids subsequently rise from the shallow water table by capillary forces causing the precipitation of gypsum (and other evaporites) and the replacement of aragonitic sediment by dolomite. The "sabkha" or evaporative pumping model has been suggested for the penecontemporaneous, modern dolomites of the Persian Gulf region and has been investigated by many workers (Illing et al., 1965; Kinsman, 1969; McKenzie, et al. 1980). A sabkha is a salt flat, and the broad supratidal flats of the Persian Gulf are areas of arid, evaporitic conditions where periodic marine flooding augments the water supply lost to evaporation. In contrast, the Coorong district of southern Australia is a humid region where evaporitic dolomite is formed in ephemeral, alkaline lakes situated behind a modern coastal dune barrier or on the inner portion of a broad coastal plain (von der Borch, 1965; Muir et al., 1980).

The Coorong model of dolomitization is an example of penecontemporaneous evaporitic dolomitization in a humid climate rather than an arid sabkha environment and expands the premise preferred by Friedman (1980) that most dolomites form under conditions of hypersalinity. Although it is clear that many dolomite formations in the recent and ancient geologic record owe their origin to reaction of calcium carbonate sediment with hypersaline brines, this model needs to be reconciled with widespread dolomitic facies which represent shallow marine, subtidal environments and are in
no way associated with evaporitic minerals or their traces. Although subtidal deposition does not necessarily preclude later dolomitization by hypersaline waters, where there is no evidence of later hypersaline conditions in the rock record other dolomitizing mechanisms must be considered.

**Nonhypersaline Models of Dolomitization**

Studies by Runnels (1969), Land and Epstein (1970), Badiozamani (1973) and Folk and Land (1975) have shown that dolomite can form in fresh or brackish waters with Mg/Ca ratios as low as 1:1 provided a slow rate of crystallization. This "dorag" or mixed water model for dolomitization has been applied by Hanshaw et al., (1971) for Florida and Yucatan, Badiozamani (1973) for the Ordovician of Wisconsin, Land (1973a) for the Pleistocene of Jamaica, and others for nonhypersaline dolomites associated with shallow epicontinental shelves or structural highs. The mechanism involves the creation of a zone of brackish water saturated with dolomite (undersaturated with calcite) due to mixing of fresh meteoric and sea waters. Folk and Land (1975) suggest that dolomite can form readily under these conditions, but as salinity and crystallization rates increase the Mg/Ca ratio at which dolomite can first form rises until values of 5:1 or 10:1 are reached in hypersaline environments. Therefore, the lower the salinity, the easier dolomite forms, since the concentration of competing ions is reduced.

Work on Andros Island by Gebelein et al., (1980) has verified
the existence of disordered "protodolomite" in peritidal sediments below palm hammocks that are underlain by fresh water lenses. The dolomitic sediment does not strictly coincide with the fresh or mixed water zones but may be related to burrows, desiccation cracks or organic material that allow the migration of dolomitizing waters. Other work by Gebelein and Hoffman (1973) indicates that dolomitic laminae in ancient carbonates may also be related to an organic origin. Algal mats may act as a source of magnesium for penecontemporaneous or secondary dolomitization along algal-rich layers. This mechanism has been suggested for recent dolomitic laminae in the Bahamas (Shinn et al., 1965) and for ancient rocks by Gebelein and Hoffman (1973).

Other aspects of dolomitization include cannibalization of pre-existing Mg-rich sediment. This process produces small amounts of dolomite and has been reported in the Bahamas by Goodell and Garman (1969).

Deep burial, late diagenetic dolomitization can occur on a local scale as long as there is a source of magnesium-bearing fluids such as a shale basin (Mattes and Mountjoy, 1980). This latter type of dolomite grades into hydrothermal, essentially metamorphic dolomite, often associated with base metal ore deposits (Engle et al., 1958).

It is clear from the preceding discussion that dolomite is known to form in a variety of environments and at varying stages in the history of a sediment body. It seems no one model or solution can be applied universally to the many types and occurrences
of dolomite. Even within the various models, sediment or fabric selectivity can affect the degree of dolomitization.
Brassfield Dolomite

The carbonate rocks of the Brassfield Formation are not uniformly dolomitized. Dolomitization ranges from 100% near the southern-most exposure of the outcrop belt to less than 5% in some beds of the northern portion (Fig. 25). Dolomitization is most pronounced in east-central Kentucky. Rocks in the study area are partially dolomitized and seem to represent a transition between a dolomite suite to the south and a limestone suite to the north. It is likely that the rocks in southwestern Ohio lie on some sort of boundary between where dolomitizing fluids had a profound effect in Kentucky and where rocks were minimally or unaffected in Ohio and Indiana.

Distribution

The distribution of dolomite in the Brassfield Formation may be controlled by the physical chemical nature of the original texture of the individual rock units or by the availability of dolomitizing solutions. In as much as the Brassfield rocks studied in Adams Co., Ohio occur along the boundary between dolomitized and undolomitized rocks it could be assumed that the sediment had limited access to the dolomitizing waters. In addition preferential dolomitization of the Brassfield carbonates was apparently a fabric selective process.

The most striking correlation between dolomitization and depositional fabric is the strong preference for dolomite to replace
Fig. 25- Median percentage of dolomite (carbonate fraction) in the Brassfield Fm. (modified from O'Donnell, 1967).
rocks which were originally deposited as lime muds. Murray and Lucia (1967) noted the susceptibility of fine-grained sediments to preferential dolomitization in Mississippian rocks in Alberta, Canada. They suggested a number of interactive physical factors to explain this selectivity. Such factors as permeability, and particle size, reflective of the surface area available to react with fluids, are important aspects. Since coarser-grained units of the Brassfield must have had greater initial permeabilities than the muddy sediments, early calcitic cementation or lithification of the coarser-textured rocks must have occurred prior to, or in greater amounts than, cementation of the mudstones. Another approach would be to consider the combined effects of a larger particle surface area and the presence of a more soluble carbonate in the muds. Recent carbonate muds are aragonitic which tends to be more soluble than calcite. Murray and Lucia (1967) suggest this solubility difference may be enough to cause dolomite selectivity.

In addition to the strong dolomitization of mudstone beds, fine-grained matrix in wackestones and packstones is also dolomitized, usually when the allochemical grains are not (Fig. 26). Burrow-fillings and geopetal muds are dolomitized as well (Fig. 27). Bioturbation may have aided dolomitization in two ways. Infaunal organisms tend to increase the porosity of the sediment by their activities and, the organic matter left behind is rich in magnesium which could react with dolomitizing pore waters during diagenesis, much like the dolomitization of algal mats.
Fig. 26- Photomicrograph of sample WU-12 showing the preferential dolomitization of fine-grained matrix surrounding the mollusk fragment (x 11.2).

Fig. 27- Etched and stained slab (sample M-1) showing the preferential dolomitization of geopetal mud within the rugose coral (A) and fine-grained burrow muds (B).
described by Gebelein and Hoffman (1973). Dolomite which preferentially replaces organic-rich algal laminae in the intertidal facies of the Belfast Member has been previously mentioned.

Facies of the Brassfield which were deposited in low-energy, quiet regimes where abundant fine-grained sediments were deposited, are the most intensely dolomitized. This corresponds with the Belfast Member, the lower massively bedded Brassfield and quiet water facies of the upper thinly bedded Brassfield (Fig. 28). Intertropical muds and burrow-fillings were preferentially dolomitiz ed in the coarser-textured, higher-energy environments of the thin bedded unit, upper massive unit and the upper thinly bedded Brassfield. Organic activity by infaunal organisms and blue-green algae aided this process by acting as additional sources of magnesium.

Another fabric selective aspect of Brassfield dolomitization involves the preferential replacement of fossil allochems that have high-magnesium hard parts. Dolomitization of crinoid debris and mollusks is actually rather minor, but is worthwhile to note. This type of dolomitization is most common in the higher-energy textures of the wackestone (II), packstone (III), and grainstone (IV) facies where fossil grains are most abundant and dolomite is scarce.

An association exists between dolomite and stylolites and fractures in the Brassfield. Typically stylolites are dolomitiz ed (Fig. 29). Alteration concentrated around these seams in relatively undolomitized rocks indicates that compaction and styolitization occurred prior to dolomitization. The stylolites acted as avenues
Fig. 28- Photomicrograph of sample WU-1 showing the fine-grained dolomite typical of the Belfast Member, deposited in a low-energy environment. Note the dark algal laminae (x 3.2).

Fig. 29- Photomicrograph of sample WU-31 showing the preferential dolomitization of styolites (x 11.2).
for dolomitizing fluids and consequently selective alteration occurred along these accesses.

To summarize, the most volumetrically important amounts of dolomite in the Brassfield Formation are associated with carbonate muds. Whether the fine-grained sediment comprises an entire unit or facies, or on a petrographic scale is only a bit grain sheltered sediment, preferential dolomitization is favored. Biological activity, usually related to the muddy facies, enhances the process. Selective alteration of high-magnesium fossil grains and dolomitization along styolites occurs to a lesser extent.

Petrography

Dolomite in the Brassfield Formation occurs as two distinct crystal sizes ranging from 0.01-0.04mm and 0.06-0.4mm in long diagonal size approximating the intermediate axis.

The finer-grained dolomite is restricted to the siltstones of the Belfast Member of the basal Brassfield (Fig. 30). This group of crystals has an average diameter between 0.01mm and 0.04mm. The crystals are anhedral, irregularly-meshed and usually only relict original textures are discernable. The centers of the crystals are cloudy, probably due to abundant inclusions.

The second group of crystals is found throughout the Brassfield section. These crystals are relatively large, 0.06-0.4mm, well-ordered, euhedral rhombs (Fig. 31). The centers appear clear and limpid and a few crystals seem to be zoned. These coarser
Fig. 30- Photomicrograph of sample WU-5 showing the fine-grained anhedral dolomite characteristic of the basal Brassfield produced in hypersaline brines (x 32).

Fig. 31- Photomicrograph of sample WU-41 showing solitary rhombs of euhedral dolomite replacing allochems surrounded by blocky calcite cement (x 32).
crystals partially to strongly replace the original carbonate sediment with original textures well-preserved. The crystals appear as solitary rhombs (Fig. 31) or as loosely intergrown mosaics (Fig. 32) replacing calcitic cements, carbonate mud matrix or fossils, sometimes selectively. For instance, grain sheltered muds are sometimes preferentially replaced.

Staining with potassium ferricyanide reveals the abundance of ferroan dolomite. The presence of ferroan dolomite is noteworthy, because as Choquette (1971) suggests, it is characteristic of later epigenetic dolomitization. The source of iron for Brassfield ferroan dolomites may be beds of iron-coated bioclasts within the Brassfield and the overlying Crab Orchard Formation, or iron-rich clays.

Cementation of the original Brassfield sediments occurred prior to dolomitization. Equant calcite is the most common initial pore filling cement and is indicative of freshwater phreatic diagenesis (Longman, 1980). Cement is distributed evenly around the grains. Sometimes the grains are not in contact, suggesting the former presence of now recrystallized mud. The secondary dolomite crystals partially or wholly replace portions of this cement (Fig. 31).

**Suggested Origin of Dolomite**

Evidence from depositional environments, petrography and regional relationships of dolomitized rock in the Brassfield suggests multi-stage dolomitization in southwestern Ohio.
Fig. 32- Photomicrograph of sample WU-27 showing loosely intergrown mosiac euhedral dolomite (x 11.2).
The dolomite limited to basal Brassfield (Belfast Member) is the typically fine-grained, dirty dolomite produced by hypersaline brines. The crystal form is anhedral, irregularly-meshed, and micritic. Dolomite replaces 100% of the original carbonate sediment.

Analyses of depositional environments suggests an initial phase of supratidal conditions at the onset of Brassfield deposition. Small islands, probably lying just above normal high tide level, existed on a very localized basis. Evidence of these supratidal flats is not known to exist outside the study area. The presence of gypsum casts suggests this environment was suitable for the formation of evaporites and was therefore hypersaline. Since the gypsum casts are preserved, the environment must have also been subject to protracted periods of drying. Dissolution of the gypsum would likely have occurred in a more humid setting.

The Brassfield supratidal environment must have been similar to the classic sabhka of the Persian Gulf and it can be assumed that dolomitization was a penecontemporaneous process not unlike the modern sabkha (Fig. 33). Flood waters from storm tides infiltrated the flats, as evaporation commenced the precipitation of gypsum and anhydrite depleted the ground-water brine of Ca resulting in an enrichment of Mg. The Ca/Mg ratio of the residual brine would be >7 allowing the formation of dolomite (McKenzie, et al., 1980). As the hydrologic cycle continued, dolomitization could proceed as "evaporative pumping" of the ground-water artesians brought fresh solutions upward into the evaporitic zone. This
Fig. 33- Diagramatic representation of the sabkha or "evaporative pumping" model for dolomitization. Diagram illustrates the circulation pattern during times of evaporation and dolomite formation (modified from McKenzie et al., 1980).
process was enhanced by blue-green mat-forming algae that provided an additional source of magnesium.

As transgression deepened the Brassfield seas the supratidal environment required for sabkha-style dolomitization was replaced by intertidal and finally open marine subtidal environments. Evaporitive dolomitization was halted as the bulk of the Brassfield rocks were deposited. No other hypersaline environments existed during deposition of the Brassfield Formation or the overlying Crab Orchard Formation which could provide brines for further dolomitic alteration. Additionally, the most strongly dolomitized portion of the Brassfield outcrop belt in east-central Kentucky (Fig. 25), exhibits none of the restricted hypersaline characteristics of an evaporitic environment (Gordon, 1980). The Brassfield paleoenvironments in Kentucky were exclusively shallow marine (Gordon, 1980). The intense dolomitization of these rocks was due to their proximity to a structural high which was subareally exposed following Silurian deposition.

Several authors have suggested that a major regression at the onset of the Devonian restricted marine deposition to a few basins and along marginal mobile belts. Much of the continental interior was exposed as a lowland for several million years (Dott and Batten, 1971). Evidence of this major Devonian unconformity exists in east-central Kentucky where Silurian strata are truncated by Devonian erosion. McDowell and Peterson (1980) suggest upwarping of the Cincinnati Arch, was initiated during the Early Silurian and became fully developed before Middle Devonian time.
The exposure of a relatively high area along the axis of the Cincinnati Arch would have caught meteoric water and provided a site for the formation of a paleoaquifer in the Brassfield limestones. Underlying this fresh water lens, mixing with magnesium-bearing marine pore water could produce a chemical environment conducive for the formation of regionally extensive dolomite by fresh-seawater mixing. Consequently, regional dolomitization of the Brassfield rocks was probably an eogenetic secondary process resulting from the admixture of marine interstitial waters and meteoric water that occurred in a brackish mixing zone below an exposed landmass (Fig. 34).

Dolomitization by fresh-seawater mixing has been suggested by several authors. Badiozamani (1973) proposed the mixing zone model for the dolomitization of Ordovician limestones in Wisconsin. Badiozamani suggested that uplift of the Wisconsin Arch provided a structurally high, subareally exposed element that absorbed meteoric water establishing a fresh water phreatic lens in a manner seemingly analogous to the dolomitization of the Brassfield. Dolomitization occurred where this fresh water lens intersected marine-saturated carbonates (Fig. 34). The dolostone-limestone boundary followed the lower margin of the ground-water lens. Where dolomitic rocks are present, mixing occurred, whereas limestones suggest mixing did not occur. Any shifts in this boundary are due to sea-level fluctuations caused by transgressions and regressions, or tectonic flexures. Dunham and Olson (1978, 1980) in their studies of the mixed water dolomitization of the Hanson Creek Formation in Nevada point...
Fig. 34 - Diagramatic representation of the mixing zone process for dolomitization. Arrows show generalized flow paths. Dolomitization occurs in the brackish mixing zone (modified from Hanshaw et al., 1971).
out the importance of paleogeographic control in the formation of
dolomite. Like the Brassfield, the Hanson Creek Formation includes
dolomitized and undolomitized rocks. Portions of the formation
which were dolomitized had access to meteoric-derived groundwater
with interstitial sea water acting as the magnesium source. The
sections that remained limestone were distal to the area of fresh
water recharge.

The degree of dolomitization of the Brassfield Formation
reflects the proximity of the original carbonate sediment to a
zone of fresh-seawater mixing. It has been mentioned that the
most strongly dolomitized rocks occur in east-central Kentucky,
coincident with the axis of the Cincinnati Arch and the area of
fresh water recharge. The Kentucky dolostones grade into limestones
in the northern portion of the outcrop belt (Fig. 25). This trend
reflects the position of the paleoaquifer and the zone of mixing.
Apparently the mixing zone did not extend far into Ohio or Indiana
since these Brassfield rocks remain basically unaltered. The
partial dolomitization of the rocks in the study area may indicate
the lower margin of the ground-water lens where effective dolomit-
ization was limited.

Rock selectivity may have had a greater bearing on the extent
of dolomitization in southwestern Ohio, where the dolomitizing
fluids were contaminated with excessive marine waters. Periodic
minor fluctuations in sea level may have aided the dolomitization
process along this interface by lowering or extending the influ-
ence of the ground-water lens.
Dolomite crystals of the Brassfield Formation not associated with hypersaline brines, are euhedral, loosely intergrown rhombs usually larger than 0.1mm. The dolomite is typically limpid and is sometimes zoned. The significance of limpid dolomite produced at slow crystallization rates in dilute solutions has been discussed by Folk and Land (1975). These well-ordered crystals are the signatures of mixing zone dolomitization.

Trace elements such as strontium and sodium and stable isotope composition also provide clues to the nature of dolomitizing waters. Attention has been focused on the elements Sr and Na because Sr is an important precursor of the original carbonate sediment and Na, being the most abundant cation in marine water, should roughly indicate the salinity of the marine-derived solutions (Land, 1980). Although laboratory analysis of the trace element and isotopic geochemistry of the Brassfield dolomite was not possible in this study, some general comments can be made. Sr and Na substitute for Ca in carbonate minerals more readily in hypersaline solutions or by rapid crystallization. Consequently evaporitic sabkha dolomite is enriched in Sr and Na relative to dolomite formed from dilute fluids. However, this simple relationship is complicated by several factors, including nonhomogeneous crystallization rates, later neomorphism of the initial dolomite, and contamination by new fluids injected during burial (Land, 1980).

Oxygen isotope composition shows a similar relationship to that of Sr. $\delta^{18}O$ values are higher in hypersaline dolomites because evaporation preferentially depletes the CaCO$_3$ sediment of
the lighter isotopes. Although dolomite formed in hypersaline conditions is enriched in $^{18}O$ the $\delta^{18}O$ of dolomite depends in part on the $\delta^{18}O$ of the water, the temperature at which dolomite formed, and $\delta^{18}O$ of the precursor sediment (Land, 1980).

Interpretation of absolute values for trace elements or isotopes is difficult because of the variables that affect natural systems. However prudent application of the relative values of these factors can be useful in the systematic study of dolomite.

**Timing of Dolomitization**

Dolomitization of the Brassfield Formation in southwestern Ohio was a two-stage process. Initial dolomitization of the basal Brassfield supratidal islands was a penecontemporaneous event. As the supratidal environment was replaced by shallow open marine conditions as the Brassfield seas transgressed however, this phase of dolomitization was halted. Large-scale dolomitization of the formation took place sometime later, and hypersaline brine was likely not the agent of dolomitization.

Although evidence for the timing of major dolomitizing events is often equivocal (Choquette and Steinen, 1980), it is possible to bracket the timing of the event by the relationship of dolomite to other diagenetic features, and in the case of the Brassfield, to tectonic activity.

Equant calcite is the most common non-dolomitic Brassfield cement. Large blocky crystals will fill the pore spaces between grains. However, where dolomite is present, calcitic cement is
replaced by single euhedral, or mosaics of dolomite crystals. Dolomite formation is clearly secondary to calcite cementation (Fig. 31).

Apparently the Brassfield sediments underwent physical compaction which produced stylolites before dolomitization, as seen by the preferential dolomitization along stylolites and fractures (Fig. 29). The stylolites acted as conduits for dolomitizing fluids which formed crystals and replaced the original carbonate.

Silicification of the original carbonate sediment also occurred prior to dolomitization. Preservation of undolomitized high magnesium bioclastic debris in chert nodules precludes dolomitization of the original sediment before silicification since altered bioclasts occur in the surrounding dolomitized sediment. The silicified sediments preserve the original textures sometimes obscured by later dolomitization.

It appears that regional dolomitization of the Brassfield Formation occurred post-depositionally after calcite cementation, compaction and silicification of the carbonate sediment. The proposed mixing zone model for Brassfield dolomitization is based on the existence of a subareally exposed landmass that contained fresh water in a paleoaquifer available to react with marine pore waters. It has been suggested that this landmass existed along the axis of the Cincinnati Arch in east-central Kentucky, and that subareal exposure, resulting in a major unconformity, was developed before Middle Devonian time (McDowell and Peterson, 1980). Sedimentation resumed by the Upper Devonian resulting in the deposition
of the Ohio Shale. Therefore, dolomitization of the Brassfield which was controlled by the position of the paleoaquifer in the landmass along the Cincinnati Arch must have occurred sometime within the Middle Silurian and Upper Devonian hiatus represented by the regional unconformity. Dolomitization by the mixing zone process can only take place at depths shallow enough to be influenced by a fresh groundwater lens. This constraint coupled with the spatial trend in dolomitic alteration related the proximity of Brassfield sediments to the paleoaquifer suggests dolomitization was associated with flexure of the Cincinnati arch probably at the onset of the Devonian.
SUMMARY AND CONCLUSIONS

Evidence from depositional environments, petrography and regional relationships of dolomitized and undolomitized rock in the Brassfield Formation suggests two stages dolomitization in Adams County, Ohio. Initial dolomitization of the basal Brassfield took place penecontemporaneously on supratidal islands that existed in what is now southwestern Ohio. Dolomitization probably occurred in a manner analogous to that which occurs in the modern sabkha environment of the Persian Gulf. Dolomite crystals in the basal Brassfield are small, 0.01-0.04mm, anhedral, dirty rhombs typical of hypersaline environments.

Since the Brassfield rocks are representative of an Early Silurian transgression the supratidal environment was replaced by shallow open marine conditions. Regional dolomitization of the Brassfield Formation can best be explained as a later epigenetic event that occurred in a brackish mixing zone of fresh and sea waters associated with the creation of a landmass due to upwarping of the Cincinnati Arch at the close of the Silurian. The dolomite crystals formed by this process are large (up to 0.4mm), euhedral, limpid rhombs characteristic of dilute dolomitizing solutions. Intensity of dolomitization is directly related to the proximity of the original carbonate to the source of dolomitizing fluids in the mixing zone.
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