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THE LOWER ORDOVICIAN MASCOT FORMATION, UPPER KNOX GROUP, IN NORTH CENTRAL TENNESSEE. PART I: PALEOENVIRONMENTAL HISTORY. PART II: DOLOMITIZATION AND PALEOHYDRAULIC HISTORY

Rice University PH.D. 1980

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THE LOWER ORDOVICIAN MASCOT FORMATION, UPPER KNOX GROUP,
IN NORTH CENTRAL TENNESSEE

Part I: Paleoenvironmental History

Part II: Dolomitization and Paleohydraulic History

by

Anthony Wagner Gorody

A THESIS SUBMITTED
IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE

DOCTOR OF PHILOSOPHY

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May 1980
ABSTRACT

THE LOWER ORDOVICIAN MASCOT FORMATION, UPPER KNOX GROUP, IN NORTH CENTRAL TENNESSEE

Part I. Paleoenvironmental History

Anthony Wagner Gorody

Petrographic examination of Lower Ordovician limestone and dolomite fabrics indicates that the sedimentary column in central Tennessee reflects multiple seaward progradation episodes of peritidal sediments across a broad, shallow shelf. The following sedimentary types were recognized: columnar, spheroidal, thrombolitic, domed, laminar and crinkled algal sediments; intramicrites, intrasparrites, pelmicrites, laminated micrites rich in clay and silt, algal-bound biolithites, oosparites with either tangential or smaller radial ooids, oomicrites and orthoquartzites. Vertical distribution of these sediment types within the stratigraphic column indicates that normal marine, transgressive waters were gradually displaced by progressively more saline waters originating from prograding evaporative tidal flats and restricted lagoons. The waning phases of such episodes are commonly marked by sheet-like deposits of coarse, unimodal sands derived from the distant craton. Because these sheets were deposited and reworked on tidal flat sediments during periods of maximum subaerial exposure, they are reliable lithostratigraphic markers.
An isopach map of the upper Mascot Formation and additional evidence of progressive shallowing throughout the depositional area suggest that the Nashville Dome may have become a positive feature during the early Ordovician. Continued uplift coincided with the development of the Sauk unconformity.
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"Illusions"

by Oliveve Johnstone, 1979

In the lightning of the Storm,
and the earthquake that alters form,
the hand of God moves,
and life goes on.

And when lives lay in shambles—
and people are asking why—
the Sun shines on,
till we can not deny—

though we stand and watch time move
as though death had stilled our hearts—
unmoving we are moved,
and somewhere deep inside,
Growth begins anew,
and our lives go on too.

For the Deaths that we live through
are our illusions too,
as is that greater Death,
we compare them to.

For painful is our Birth
but pain is joy unborn
for all these Deaths are Births
of growing spirit changing form.
THE LOWER ORDOVICIAN MASCOT FORMATION, UPPER KNOX GROUP,
IN NORTH CENTRAL TENNESSEE

Part I: Paleoenvironmental History
INTRODUCTION

Purpose of Investigation

To properly assess the diagenetic history of carbonate rocks in an area that has not been previously investigated, it is first necessary to reconstruct the history of carbonate deposition. Certain geologic conditions would be ideal for such an investigation. For example, because massive stratigraphic dolomite obliterates much petrographic information, any stratigraphic column in which both limestone and dolomite interdigitate would be ideal for deciphering both the paleoenvironmental and diagenetic history of a study area. Also, undeformed strata protected by burial from prolonged modern and ancient subaerial exposure would best preserve original sedimentary and diagenetic fabrics. The subsurface lower Ordovician carbonates in north central Tennessee are buried, structurally uncomplicated and include interdigitating limestone and dolomite; they are therefore ideal for such a study. This investigation provides a sedimentologic and paleoenvironmental framework for a larger study that evaluates the dolomitization history of the Mascot Formation in north central Tennessee.

Regional Setting

Since the discovery, in 1967, of the Elmwood Mississippi Valley type zinc ore deposit in Smith County, Tennessee, mining companies seeking additional potential mining areas have been actively drilling into the Upper Knox group in central Tennessee. As a result, numerous
cores of continuously-drilled sections donated to the Tennessee and Kentucky state geological surveys, have been made available for examination. Because most ore deposits in central Tennessee and south central Kentucky occur primarily in the Mascot Formation, drilling, as a rule, has not penetrated significant depths into the Kingsport Formation.

The study area is located on the northeast flank of the Nashville Dome and on a portion of the Cumberland Saddle that separates the Nashville Dome from the Jessamine Dome of central and northern Kentucky (Figure 1). Both domes constitute the southern and central portions of the Cincinnati Arch.

The Knox strata in central Tennessee are structurally uncomplicated. Regional dip away from the crest of the Nashville Dome is approximately 9.5 meters per kilometer; faults in the sedimentary sequence are minor and have little displacement (Kyle, 1976).

**Stratigraphy**

The Cambro-Ordovician Knox group is composed of four formations; the upper Cambrian Copper Ridge Dolomite and Chepultepec Dolomite, and the lower Ordovician Kingsport Formation and Mascot Dolomite (Harris, 1969). The upper Knox strata in central Tennessee are the product of predominantly carbonate sedimentation on an open marine and marginal marine shelf, similar in age to the Ellenburger group of Texas; to the Beekmantown Formation of New York, Pennsylvania, Maryland, West Virginia and Virginia; to the St. George Formation in Newfoundland; and possibly to the Newala Limestone of Alabama.

The Mascot Formation is characterized by the abundance of light to medium gray and olive, fine to medium-grained dolomite, interbedded
in some areas with limestone. The top of the formation is marked by the Sauk unconformity (Sloss, 1963), which represents the top of the Canadian Series in this area. The formation base has been defined by mining company geologists on the basis of two criteria: a distinctive black-green shale marker, sometimes absent, known as the TR marker; and a change in lithology below the TR marker to predominantly limestone and coarsely crystalline dolomite. Numerous thin sand beds are pervasive throughout the formation; two of these sand beds, M3 and a chert matrix sand (Figure 2) have been used to subdivide the Mascot Formation into upper, middle and lower members (Stagg and Fischer, 1970). Thickness of the formation varies over the study area from 180 meters to 260 meters and is controlled principally by the position of the unconformity (Staff and Fischer, 1970). Local relief on the Knox Surface is on the order of 38 meters (Gilbert and Hoagland, 1970).

The Wells Creek Formation overlies the Mascot Formation and fills the irregularities of the unconformity surface. Wells Creek is the lowermost formation of the middle Ordovician Stones River group. The basal contact is marked by shale, fine-grained dolomite and limestone, each of which commonly host chert, dolomite and limestone fragments derived from the underlying Mascot Formation. Chips of Knox material persist in distinct layers within a zone varying in thickness from .5 to 4 meters. Above this zone sedimentation is characterized by a normal, open marine limestone with locally abundant brachiopods, trilobites and crinoids.
FIGURE 1. Location of study area, north central Tennessee, and approximate location of dolomite-dolomite/limestone transition zone.
METHODS

Fifteen cores from 10 counties in Kentucky and Tennessee were selected for detailed examination in order to discriminate suspected facies trends. Of these, 8 cores were exclusively dolomite; 7 were comprised of dolomite interlayered with limestone. Approximately 130 meters of limestone and selected thicknesses of dolomite were slabbed. Three cores that contained the longest and most continuous sections of limestone provided all but 15 meters of the total cut; all of the limestone present in these cores was slabbed.

After etching the limestone with a 10 percent solution of hydrochloric acid, cut surfaces were examined and described macroscopically with the aid of a hand lens and binocular microscope. To represent adequately the observed varieties of limestone lithologies, 200 acetate peels and 20 thin sections were prepared from selected samples.

From 1400 dolomite samples, 250 thin sections were taken to represent the varieties of dolomite lithologies encountered. To determine approximate percentages of calcite in thin-sectioned dolomites, samples were powdered and subjected to X-ray diffraction analysis (Weber and Smith, 1961).

In order to further discriminate petrographic characteristics, all thin sections were examined and photographed under cathodoluminescence using a Nuclide Corporation ELM-2A Luminoscope. The use of 400-ASA
High-Speed Ektachrome film facilitated photography of slides by allowing maximum exposure times within a period averaging two to five minutes; resulting exposures were sharp and accurate in color rendition.

In an effort to understand the relationship between clastic and carbonate materials, shale laminae, insoluble residues and quartz sands were examined. X-ray diffractograms of shale laminae from 5 widely separated cores were compared and contrasted with those of insoluble residues of limestones. Samples were first crushed with a mortar and pestle. Included calcite was dissolved in a warm, buffered solution of sodium acetate with a pH of 5. To stabilize ion exchange sites in clays, insoluble residues were treated with a buffered ammonium oxylate solution, followed by a solution of magnesium chloride. Treated samples were decanted and the less than 10-micron fraction was collected in a settling tube, decanted and smeared on a glass slide. All samples were scanned using a Norelco Type 12046 X-ray diffraction unit at a rate of 1° of 2 theta per minute at 2000 cps scalar, and a time constant of one.

Six samples of quartz sand were chosen for settling tube analysis. Samples were obtained from various horizons in cores drilled from sites as far apart as 50 kilometers. Because quartz grains in dolomite tend to be less overgrown than grains in limestone, only dolomitized sections were sampled. Of the six samples analyzed, all but one contained slightly overgrown quartz grains. Many samples cemented by both chert and dolomite were discarded because the quartz grains could be not be disaggregated in sufficient quantities to perform the analyses. Large fragments of chert that could not be disaggregated
were picked out with a fine camel hair brush; smaller chert fragments were left undisturbed. Large dolomite chips were dissolved in a warm solution of 20 percent hydrochloric acid, and the insoluble residue was sieved through a 63-micron sieve. The resultant sand-sized fraction was processed through a large settling tube connected to an automated sediment analyzer (Anderson, 1979).

Extensive lateral brecciation, accompanied by solution thinning, collapse and dilation, is confined to the middle and lower members of the Mascot Formation. An isopach map of the entire formation, therefore, was too complicated for meaningful interpretation. Because the upper member of the Mascot is not brecciated, it was possible to construct an isopach map based on 112 cores, of which 46 were taken from the northeast corner of the Nashville Dome (Figure 3).
FIGURE 3. Isopach map of the upper Mascot Formation, M3 to the unconformity. Thinned areas are parallel to and on either side of the Nashville Dome axis.
RESULTS

Core surfaces of freshly drilled Mascot limestones commonly appear light gray in color and deceptively structureless and fine-grained. By contrast, slabbed limestones reveal a great variety of sedimentary fabrics and colors which recur as recognizable facies. The facies, described below, are named in terms of their most obvious descriptive characteristics. Where applicable, the algal form terminology of Logan and Rezak (1964) and the cement terminology of Folk (1974) are used.

Algal Forms and Related Fabrics

Five distinct types of algal-related textures recognized in Mascot Formation cores are illustrated in Figure 4. Because the 3.5 centimeter wide cores are much narrower than the structures they intersect, overall algal morphologies are inferred.

1. Small, stacked hemispheroidal algal stromatolites of constant (SH-C) and variable (SH-V) radius. - Digitate algal structures observed in cores commonly measure 2 to 3 centimeters in width and up to 20 centimeters in height. The small columns are composed of distinct laminae of pellets, microspar and silt. Laminae are separated by curvilinear birds-eyes, sometimes floored with micrite. Only one small SH-V stromatolite was found (Figure 4C), in association with an SH-C stromatolite of the type pictured in Figure 4B. The two columnal types possess several common features. Spaces between columns are filled with
large, well-washed intraclasts and fossils, reflecting growth in a fairly high energy environment. Intraclasts, clearly derived from ripped-up columns, average 2 to 4 millimeters in length, tend to be equidimensional and are commonly bound or partly to completely coated by large Girvanella-like tubules (Figure 5). Growth in a normal marine environment is suggested by the abundance of articulated and fragmented trilobite carapaces, calcisponge (?) spicules, pelmatozoan fragments, diverse gastropods, and Girvanella tubules.

Long-sinuous tubules, probably of algal origin, are also common to both column types and occur in many algal-derived limestones. These tubules, longer and thinner than those of Girvanella, are 20 to 30 microns wide and are filled with minute bladed crystals with irregular boundaries. Blades of crystals, perpendicular to the axis of a tubule, are arranged in a radial symmetry, suggesting that the cements were formerly high-magnesian calcite and grew from the edges to the centers of the tubes.

At least two generations of cement can be distinguished in both the digitate algal structures and their associated biointrasparites. Marine cementation is indicated by the bladed, isopachous, very finely crystalline cements in the algal tubules, and by the coarser, bladed, isopachous, medium crystalline cements surrounding the allochems; these larger cement crystals, however, are commonly not well developed. Phreatic cementation is suggested by the abundance of equant, fine to medium crystalline cements that fill interparticle voids and birds-eyes. A great number of grain to grain and microstylolitic contacts between allochems attest to the effects of burial compaction (Figure 6).
Absence of meniscus and microalactitic cements, and evidence of burial compaction of allochems not effectively cemented in the marine realm, indicate cementation in the phreatic rather than the vadose realm.

2. **Spheroideal (SS) algae; oncolites.** - Figure 4A illustrates the best-developed example of spheroidal algal textures found in the study area. Such algal forms are rare, occurring in the lowermost portion of only one core. The largest oncos, measuring 2 to 3 centimeters in diameter, display discontinuous concentric laminae composed of microspar and pellets; such oncos are commonly outlined by irregular and discontinuous stringers of chert. Disturbing the laminae are irregular birds-eyes filled with void-filling, bladed, very finely to medium crystalline cements. The larger bladed crystals display abundant microdolomite inclusions, indicating that they were originally high-magnesian calcite cements precipitated in the marine realm (Lohman and Meyers, 1977). Abundant sinuous tubules and sparse *Girvanella* tubules occur within laminae. Articulated and fragmented trilobite carapaces, pelmatozoans and sponge spicules occur in association with these oncolites.

Spheroideal algae are interpreted to have grown in a normal marine, shallow subtidal environment of moderate to high energy. The oncol depicted in Figure 4A, somewhat flattened at the base, serves as a sub- strate for a small column of algae, suggesting that it had become grounded and that continued algal growth and development occurred near the zone of columnar growth. Such coexistence further supports oncol algal growth and development in a moderate to high energy environment.
3. Massive, un laminated, mottled algae; thrombolites. - The predominant algal limestones in the study area are similar to thrombolites described by Aitken (1967) and by Mazzulo and Friedman (1977). These limestones appear clotted and burrow-mottled, and commonly display an internal, dark-colored, digitate arrangement of clots; they contain widely disseminated silt (Figure 4E). Examination of thin sections discloses abundant complex networks of algal tubules. Burrow mottles are commonly filled with abundant nested pellets and small intraclasts. The thrombolites host abundant predominantly small, lenticular birds-eyes, under 1 millimeter long, that are commonly floored by carbonate mud and cemented by void-filling, equant, very finely to coarsely crystalline cements. Also common are abundant irregular, vertical cracks ranging in length from 1 to 5 centimeters in width from 0.5 to 2 millimeters. These cracks, possibly resulting from tensional shrinkage, are filled with void-filling, equant, coarsely to very coarsely crystalline cements.

Algal thrombolites of the Mascot Formation are characterized by abundant scour surfaces, such as are illustrated in Figure 7. The earlier scour is cut into an extensively burrowed and silty thrombolite that contains abundant Girvanella tubules and sponge spicules. The scalloped surface is filled with abundant pelmatozoan and trilobite fragments and intraclasts derived from the algal colony. Rinds of Girvanella occur on several intraclasts. The grainstone fill was cemented with isopachous, bladed, very fine crystals, indicative of cementation in a marine environment. The second scour surface cuts directly across both the thrombolite and the cemented grainstone. The intrasparite that lies on the surface is cemented by void-filling, equant,
centripetally enlarging, medium to very coarse crystalline cements. Based on abundant grain boundaries occurring between allochems, cementation is believed to have taken place following a moderate degree of compaction. The composition and fabric of allochems occurring both above and below the second scour surface are identical; yet each allochem layer has been cemented by a different generation of cement. These relationships indicate the following sequence of events: cemented thrombolites were scoured and planed off following a high energy event; normal marine allochems filled depressions on the scoured surfaces and were cemented in marine water; a second high energy event caused planar erosion of the cemented grainstone and a new generation of allochems covered the planar surface; these new allochems were cemented only following burial in the phreatic zone. Similar relationships can be observed where contrasting grain size allows.

Thrombolite surfaces occasionally appear to have been bored by small organisms and colonized by substrate-loving alga such as *Girvanella*. Although the surfaces were hardgrounds, there is no evidence of ferroan or manganous mineralization. Grainstones overlying the scoured surfaces show no evidence of meteoric vadose cementation; thus it is unlikely that the surfaces were produced by karsting in a humid, intertidal environment (Read and Grover, 1977).

Normal marine fossils associated with the grainstones filling scours include trilobites, brachiopods, pelmatozoans, gastropods, sponge spicules and *Girvanella* tubules; such bioclasts, however, are rare. Pelmatozoan fragments appear rounded, and trilobites and brachiopods are commonly fragmented, reflecting transporation from a normal marine source.
Massive, mud-trapping, burrowed, thrombolite-producing algae grew in predominantly quiet, shallow and slightly restricted marine waters. A greater concentration of silt was trapped in these algal forms than in columnar and spheroidal algae. The bioherms were either located closer to shore, thus receiving a greater proportion of wind-blown silt, or their rate of growth was slower than that of other algal buildups. These bioherms also grew in an environment susceptible to rapid changes in energy; for example, storm waves that produced scour surfaces may have altered the environment sufficiently to result in development of temporary bars on planed surfaces. During such energetic episodes, a detrital normal marine fauna was introduced. Regeneration of algal bioherms ensued.

4. Large, dome-shaped, laterally linked hemispheroid (LLH) algal stromatolites. - Figure 4F illustrates a typical core intercept consisting of large, dome-shaped stromatolites. The average radius of curvature of laminae constructing the domes indicates that these stromatolites vary from 5 to 30 centimeters in width. Laminae are rarely continuous across the sample, tending to occur in pairs of alternating micrite and pelmicrite layers approximately 0.5 centimeters thick. Pellets are commonly preserved as micrite, whereas the enclosing matrix is microspar in the 10- to 15-micron range. Occasional laminar and circular birds-eyes occurring between laminae are filled with equant, void-filling, finely to medium crystalline cements. Laminae are commonly separated by low-amplitude, sharp-peaked stylolites (cf. Park and Schott, 1968), as well as by thin, discontinuous stringers of cryptocrystalline chert and dolomite. Silt, where it occurs in this facies, is restricted
to laminar surfaces. Fossils and larger than pellet-sized grains are absent; however, oosparites, laminated on a centimeter scale, and intramicrites with rounded intraclasts, are observed intercalated with the algal domes.

Algal (LLH) domes have been interpreted elsewhere to be growth morphologies of algae characteristic of a quiet and sheltered environment (Logan, et al., 1964). This interpretation is supported here by the absence of any coarse terrigenous or carbonate material. Algal domes of the Mascot Formation grew on partially-cemented ooid sands and intramicrite substrates such as would be expected in shallow, hypersaline waters.

5. **Laminated (Smooth and Crinkled) Algal Mats.** - Laminated algal mat morphologies, rarely preserved as limestone, have had their microfabrics obliterated by the growth of aggradational microspar; however, meagascopic textures are visible in both limestone and fine-grained dolomite (Figure 4G). Such textures are common to many tidal flat deposits of varying ages throughout the world. Recent analogs have been studied in such detail that it has been possible to develop both modern and ancient subaerial exposure indices on the basis of the following features: morphology and thickness of laminae; occurrence of prism and mud cracks; and size of mud cracks (Ginsburg et al., 1977; Park, 1976; Kinsman and Park, 1976; Hoffman, 1976; Monty and Hardie, 1976; Rhinehardt and Hardie, 1976). Because cores used in this study are small in diameter, many key features necessary to develop an exposure index in any one core may have been missed during drilling; careful examination of several cores, however, permits reconstruction of an
idealized sedimentation pattern which appears identical to that illustrated by Rhinehardt and Hardie (1976, p. 19). This pattern is consistently sequential from core to core and averages 2 to 3 meters in thickness; it contains the lightest colored sediments of any rocks in the area and is transitional with and overlies the pelmicrite facies.

Algal laminated units are commonly marked at the base by ripple cross-laminated sediments. Ripples may be cut by prism cracks, although neither burrows nor mud cracks are observed. The first laminae to occur upward in the sequence are occasionally intersected by narrow prism cracks but otherwise are undisturbed. Laminae appear thin, irregular, discontinuous, commonly horizontal, and occur as light and dark couplets ranging from .3 to 3 millimeters in thickness. The light laminae contain the highest concentrations of silt found in any Mascot Formation rocks.

The first mud cracks to appear in any unit are large and occur in association with prism cracks and folded laminae. Because these mud cracks intersect the core as planar features, they cannot be misinterpreted to be burrows. Laminae initially appear to be up to 1 centimeter thick, but closer inspection reveals them to be composed of smaller laminations of the same color. Each unit demonstrates an upward progressive decrease in thickness of coupled laminae, eventual loss of prism cracks, progressive decrease in width and depth of mud cracks, and increase in abundance of blistered and pustular algal mat forms. Ultimately the units lose all laminations and are replaced by structureless, tan and brown carbonates. There is little evidence of fenestral fabric.
Significant accumulations of medium-fine and coarse sand-sized quartz grains occur in association with the laminated carbonates. In most instances, sand grains appear to float in a dolomite, limestone or chert matrix; more rarely, they occur in orthoquartzitic layers, a few centimeters to a meter thick, that are cemented together either by dolomite, limestone or cryptocrystalline chert. To date, no trends to these sand bodies have been published. Petrographic and binocular microscope examination of individual sand grains dissolved from the matrix reveals the grains to be highly rounded and filled with scattered vacuoles distributed along planes; they commonly show straight, rarely undulatory, extinction. Many display well-developed percussion marks. These supermature sands appear to be derived from a plutonic source (Folk, 1974).

Results of settling tube analyses are shown in Figure 8A and in Tables 1A and 1B. Sands are well-sorted; in all samples they demonstrate the same narrow range in mean grain size. Five samples are unimodal in distribution; the sixth displays a bimodal distribution pattern. Similarities among samples from various stratigraphic levels over an area exceeding 1300 square kilometers offer strong evidence of an eolian mechanism of distribution, further supported by the percussion marks observed on sand grains lacking overgrowths. The thickest orthoquartzitic layers may represent coastal dunes or submarine bars composed of reworked sand grains. Because microtextural criteria are needed to distinguish between these two types of deposits, they cannot be differentiated in small diameter cores.
Laminated algae grew in an environment sufficiently hypersaline to exclude grazing fauna. The following factors, considered together, also tend to indicate a hypersaline environment of deposition:

a. Under cathodoluminescence, thin sections reveal bright blue luminescent silt-sized potassium feldspars with non-luminescent overgrowths (cf. Kastner, 1971). Similar authigenic overgrowths are thought by Buyce and Friedman (1975) to have developed in hypersaline interstitial fluids of tidal flats. With the exception of a few grains trapped in dolomitized algal domes, such overgrowths were not observed in other facies of the Mascot Formation. Fewer than 3 percent of feldspar silt grains per thin section display overgrowths; this percentage seems low in comparison to that of tidal flat sediments of similar age (Buyce and Friedman, 1975). However, such overgrowths are not, by themselves, reliable indicators by hypersalinity (Mazzullo, 1976).

b. Disruption of algal laminae into contorted, folded and, rarely, imbricated beds may have occurred when anhydrite, precipitated into pore spaces, was hydrated to gypsum (Figure 4H). Alternatively, contortion of laminae may have resulted from dewatering, or from action by storm waves that pushed bound mats inshore. There is no evidence favoring either mechanism.

c. A few dark olive brown, medium-grained dolomites enclose thumb-sized, light-colored nodules of irregular shape filled with dolomitized geopetal sediments, vug-filling pink and white baroque dolomite crystals that rarely enclose sphalerite, cryptocrystalline chert rich with fluid inclusions, fine-grained dolomite, length-fast chalcedony and megaquartz. Although evaporite minerals were not observed,
these may represent former evaporite nodules (Alberstadt, et al., 1978). Another explanation may be that the nodules represent lenses of limestone that were not dolomitized, became leached during the karsting episode related to the unconformity, and subsequently were filled with ore-related minerals. A third alternative is that the vugs represent large bubble spaces produced during the decay of organic matter.

d. Fish-tailed, twinned gypsum crystals, 2 and 3 centimeters long and 0.5 and 1.0 millimeters wide, were observed in samples from two small intervals within the upper member of the Mascot Formation, in a core retrieved 60 kilometers to the west of the present study area (Niel Olesen, personal communication). The gypsum crystals grew in sediments of the algal laminated facies. Partial calcitization of gypsum resulted in a mosaic of coarse calcite crystals interlocked by irregular, jig-saw like boundaries. Abundant idiotopic dolomite crystals are also scattered throughout the thin section. Palimpsests and inclusions of gypsum indicate that the crystals displaced the original sediment rather than growing as vug-filling gypsum related to mineralization. A greenish dolomite matrix adjacent to the calcitized zone is extremely porous and permeable. Selective dissolution of sulfates may have resulted in such porosity in addition to producing the thin bed of breccia overlying the gypsum. Direct evidence thus exists to indicate that pore waters in sediments to the west of the study area were sufficiently hypersaline to precipitate gypsum. An intensive search for similar features in cores studied here failed to yield similar evidence of evaporites; however, small relict anhydrite crystals were observed in medium-grained xenotopic dolomite rhombs in two samples
from two cores from the northern portion of the study area. Both samples represent dolomitized equivalents of the pelmicrite facies.

In summary, algal laminated facies show abundant direct and indirect evidence of repeated subaerial exposure of the lower Ordovician shelf in central Tennessee. Lack of grazing faunas, laminated smooth and crinkled algal mats, prism cracks, mud cracks, evidence of a progressive increase in the amount of subaerial exposure, and a suggestion of evaporites are all characteristics of a sabkha-like tidal flat environment. The coarsest sands of the Mascot are found in these sediments. Sand grains saltated 700 kilometers from their source during times of shelf-wide subaerial exposure. Winds acting over the shelf allowed only a restricted grain size to reach the study area; finer and coarser sand grains were winnowed out, suspended in the atmosphere or left behind. Sands reaching the area accumulated in coastal dunes and were periodically reworked in the aqueous environment. Resultant sand beds are therefore considered to be reliable lithostratigraphic markers.

**Pelmicrites**

One of the most persistent facies observed in any given sedimentary package of the Mascot Formation is that of dark olive-gray and tan pelmicrites. This facies, transitional at its base, commonly lies directly above normal marine algal facies. Grains include sparse spherulitic and radial ooids, equidimensional intraclasts with rounded edges, well-sorted pellets and occasional bioclasts; the latter decrease in number progressively toward the top of each unit. Complete delicate tests of trilobites, shells of gastropods and articulated but rare
FIGURE 4. Peels of algal textures in Mascot Formation limestones.

A. Spheroidal (SS) algae. Note flattened base and incipient columnar growth.
B. Digitate (SH-V) stromatolite. Note partially dolomitized calcarenite on either side of column.
C. Digitate (SH-C) stromatolite. Note calcirudite fill to right of column.
D. Thrombolitic and digitate algae. Arrow points to linear scour surface on thrombolite. Scour followed by deposition of grainstone, then by renewed growth of columnar algae, and finally by upward-fining cross bedded grainstone fill.
E. Typical mottled thrombolitic algae.
F. Large, laterally linked hemispheroid algae (LLH).
G. Smooth laminated algal mat. Note discontinuity of laminae and flat, imbricated, laminated intraclasts (arrow).
H. Severely contorted laminae. Evaporite or slump controlled? All bar scales 1 cm.
FIGURE 5. Girvanella-like tubules on the edge of an intraclast in photomicrograph of peel. Such tubules may also coat intraclasts. Bar scale 0.1 mm.

FIGURE 6. Limestone compaction features in photomicrograph of peel. Nearly reticulate pattern of microstylolitic seams are developed along grain to grain boundaries. Intraclasts in lower right hand of figure cemented by void-filling, equant, finely crystalline cement. Bar scale 0.4 mm.
FIGURE 7. Enlargement of peel showing multiple scour surfaces. Arrows point to two scour surfaces buried by calcirudite. Intraclasts above scour surface 1 are cemented by isopachous, bladed, fine-grained cement. Intraclasts above scour surface 2 are cemented with void filling, equant, coarse-grained cement. Bar scale 0.5 cm.
FIGURE 8.  A. Cumulative frequency curve for the sand sized fraction of six sandy units associated with smooth algal laminae.
B. Relative distances between cores from which sand samples were selected.
TABLE 1. RESULTS OF SETTLING TUBE ANALYSES

Table 1A

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<tr>
<th>Sample #</th>
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<th>Skewness</th>
<th>Kurtosis</th>
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Table 1B

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<th>WT.% of this phi range, in sample</th>
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ostracods indicate that these organisms were preserved in the same environment in which they lived, although pelmatozoan, trilobite and brachiopod fragments concentrated in layers 1 to 5 centimeters thick reflect transportation of some bioclasts.

The pelmicrite facies demonstrates a sequential and predictable pattern toward the top of each unit. The oldest pelmicrites were deposited in a reduced environment, as evidenced by the extremely dark color of the rocks, the abundance of finely disseminated frambooidal pyrite, and the absence of any benthonic biocenose assemblage. Heavy bioturbation of reduced mud resulted in a complex pattern of mottles outlined by large, irregular, pyrite-rich blebs. Examination of acetate peels and thin sections commonly shows concentrations of pyrite along burrow mottle edges. Homogeneous pelmicrites become replaced upward by small scour and fill fabrics; finely-laminated, clay-rich fabrics; rip-up breccias; and numerous thin trough and planar cross-laminae ranging in thickness from 1 to 3 centimeters and accentuated by subtle color changes. Attendant with this diversity in fabrics is a progressive lightening of color upward, indicating progressive oxidation of the environment. Although these micritic units are intersected by a few horizontal burrows, the majority of burrows within the lighter gray units are straight and vertical (Fig. 9C). By contrast, tan samples rarely show evidence of burrowing.

In gray pelmicrites, small scour and fill structures impart a distinctive texture of small, wispy, linear mottles. These discontinuous, lenticular mottles result from infilling of scoured depressions with darker-colored pyrite and clay.
Fine trough cross-laminated textures are easily visible in etched cores and in acetate peels. Etching of carbonate leaves behind a residue of clay that outlines delicate cross-laminations (Fig. 9D).

All pelmicrites of the study area contain a high clay, silt and fine sand fraction constituting up to 30 percent of the rock in weight. The highest concentrations of clay occur in the darker micrites. Fine quartz sand grains are locally concentrated, rarely form distinctive laminae, commonly appear to float in the matrix, and represent the coarsest detritus observed in this facies. The quartz grains are either the same size as or slightly larger than the carbonate pellets surrounding them. Because the quartz grains were denser than the organically-rich pellets, it is unlikely that pellets and larger sand grains were contemporaneously sorted and deposited by currents. Thus, fine sand coarser than pellets was introduced as a result of wind action.

Shale layers, up to 3 centimeters thick, commonly occur in pelmicrites. These are composed of anastemosing clay seams that accumulated along microstylolite swarms parallel to bedding (Fig. 9B). Furthermore, shale seams offset or partially digest vertical burrows, tension cracks filled with equant calcite cements, fossils and intraclasts. These observations suggest that thin shale layers result from the pervasive solution of limestones layers rich in clay, following limestone burial (cf. Wanless, 1979). Other minor inhomogeneities along limestone laminae, accentuated by such pervasive solution, produced color banding in pelmicrites.

Petrography shows that the shales are composed of well-oriented illite, a few small and shredded fragments of 1M muscovite, abundant
small framboids of pyrite, silt-sized feldspar grains, and silt and fine sand-sized quartz grains. Diffractograms of insoluble residues and shales from each core confirm the presence of potassium feldspar, quartz and illite. Mixed clay layers occur in small amounts and are interpreted to be diagenetic byproducts of illite degradation. No other clays, such as kaolinite, were recognized. Minor differences among diffractograms reflect changes in relative percentages of the various constituents.

The above evidence suggests that the pelmicrites were deposited in a quiet, subaqueous environment that was transitional to an intertidal environment. Absence of dessication features supports this interpretation. Tension cracks (Fig. 9C), a common feature, may represent either syneresis cracks or dewatering following regression. Because the pelmicrites overlie normal marine or slightly restricted marine algal-related textures, they are interpreted to have been deposited in protected embayments or lagoons; physiographic barriers or a seaward energy-baffling regime, such as the zone of columnar and thrombolitic stromatolites, may have provided sheltered environments. High concentrations of clay trapped in this quiet environment, as well as the high concentrations of fine, presumably wind-blown sand and silt, suggest deposition of pelmicrites in close proximity to shore lines.

_Intrasparudites and Intramicrudites_

Two distinct intraclast fabrics were observed in the limestones under study. The first is distinguished by the predominance of algal-derived intraclasts containing abundant algal tubules and sponge spicules (Fig. 9F). These intraclasts are stratigraphically associated with
digitate and thrombolitic stromatolites: they are either irregular or nearly equidimensional, and may have reduced cores and slightly oxidized rims. Such intrasparites commonly overlie distinct scour surfaces that truncate biolithites (Figs. 4D and 9F). Clasts tend to be bound, partially coated or bored by *Girvanella* tubules; they occur with normal marine faunas and become progressively finer upward. Infiltrated micrite, now microspar, is also common. Algal-derived intraclasts were probably deposited as a product of storm activity; the waning phases of each storm allowed infiltration of carbonate mud. Limestones of this type, transitional to the pelmicrite facies, accumulated in crevices between algal heads, in small channels and on the lee side of actively growing algal colonies.

The second type of coarse intraclast limestone is composed of elongate, silty and sandy, laminated chips derived from ripple cross-laminated textures as well as from smooth algal laminates of the tidal flat (Fig. 9E). Chips occur in either grain-supported or mud-supported fabrics, although the latter are rare. Intraclasts occurring in grain-supported fabrics are parallel to bedding or imbricated; those derived from cemented cross-bedded carbonates are upside-down, indicating that they have been flipped. Imbricated clasts are always associated with the algal laminated facies (Fig. 4G). Such clasts are interpreted to be the product of high energy events that deposited fragments of algal-bound or partially cemented tidal flat sediments at the storm strand line. Grain-supported fabrics in which intraclasts are parallel to bedding tend to occur in broadly defined laminae; gradually fine upward as laminations become finer and more distinct; and may grade into finely
laminated, sandy oosparites and oomicrites, or rare laminae of mud-supported clasts. When complete, units containing such intraclasts are on the order of 1 to 2 meters thick. A typical sequence contains a fragmented normal marine fauna at the base and a gastropod assemblage at the top.

In grain-supported laminae with horizontal intraclasts, voids sheltered from mud infiltration display poorly developed microstalactitic and meniscus cements (Fig. 10), incipient isopachous bladed cements, and void-filling, equant, finely to coarsely crystalline cements. Fragmented pelmatozoans and trilobites commonly exhibit monocrystalline and syntaxial overgrowths. Because one sample shows syntaxial cement on an echinoderm growing within free space provided after the shell of a gastropod had been dissolved, syntaxial cements were precipitated following meteoric diagenesis. Microstalactitic cements, although poorly developed, are characteristic of vadose cements; isopachous, bladed cements are typical of marine cements; and equant and syntaxial cements are characteristic of phreatic cements. The variety of cement types indicates that these sediments must have been subjected to periodic subaerial exposure.

The marked textural inversion of mud and large self-supported intraclasts, as well as evidence in the cement fabric of repeated subaerial exposure, suggest that such grain-supported fabrics may represent the infilling of tidal channels that had incised the tidal flat. Evidence of tidal channels is further substantiated by small "herring-bone" cross laminae found in several cores. At least one tidal channel sequence was identified in each core in which limestone was present near the middle
of the Mascot Formation; such sequences appear to be restricted to this horizon.

Algal-derived and tidal flat-derived intraclasts rarely occur together in a sample because each is characteristic of a different facies. This mutual exclusion indicates that each facies must have been geographically separated by a distance of at least several hundred meters, because plasticasts could not have survived excessive transport (Smith, 1972). Separation between facies is also implied by the restriction of complete normal marine tests to algal-derived intraclasts. Thus, a normal marine environment must have existed in the vicinity of a hypersaline tidal flat. Hypersaline and normal marine waters may have been separated by some physical barrier.

A third, less common intraclast fabric is characterized by pronounced linear scour surfaces upon which rest horizontal or imbricate, nearly equidimensional intraclasts both similar to and quite different from the underlying substrate. Layers containing such intraclasts are commonly succeeded by either a host of digitate and thrombolitic algal textures or grainstones and are interpreted to represent deposition following a transgressive episode.

Oosparites

Two distinct ooid assemblages are recognized in Mascot limestones, based on the classification developed by Kahle (1974). The first assemblage is characterized by the predominance of ooids of either concentric tangential and concentric unoriented structure (Fig. 11), or of combined concentric tangential and concentric radial structure (Fig. 12). Concentric laminae, commonly replaced by their stringers of cryptocrystalline
FIGURE 9. Typical pelmicrite and intraclast textures in peel enlargements.

A-D Textures typical of pelmicrite facies.

A. Finely laminated clay and silt rich pelmicrite.
B. Shale seams result when microstylolites coalesce during pervasive solution of limestone. Note how incipient dolomite rhombs are concentrated in shale seams.
C. Vertical burrows (arrow 2) disturb finely laminated pelmicrites. Tension crack (arrow 1) transects burrowed and laminated fabric. Note how crack is partially filled with sediment.
D. Delicate cross laminae in laminated pelmicrite. Note how anastomosing shale seams transect cross laminated fabric and burrows (arrows).

E-H Intraclast fabrics.

E. Tidal channel lag of laminated, silty, tidal flat derived intraclasts. Note the distinct textural inversion of fabric and the inverted cross laminated intraclast (arrow).
F. Algal derived intraclasts overlying a scoured surface. Many intraclasts have been derived from marine cemented pelsparites and cosparites.
G. Ooids and intraclasts within upward-fining centimeter scale laminae.
H. Cross bedded ooids and intraclasts. Arrow parallels direction of cross beds. All bar scales 1 cm.
chert, are clearly visible in peels. Ooid nucleii are predominantly unoriented and may have been either fecal in origin (Newell, et al., 1960) or abiotic (Davies, et al., 1978; Deelman, 1978). Bioclastic nucleii include pelmatozoan fragments, trilobite fragments and aragonitic fragments of molluscan origin. The largest ooids are 0.7 millimeters in diameter; among all samples, their average diameter is 0.5 millimeters. These ooids are associated with normal marine faunas and occur in all algal limestones except those of the smooth algal laminated facies; scattered algal-derived intraclasts are common. Ooids occur within well-sorted units, rarely thicker than a few tenths of a meter. A few cores contain oolitic beds cross-bedded at angles of 10 to 25 degrees.

Ooids of the first type exhibit either isopachous bladed or void-filling equant cements. Planar and scalloped scour surfaces cutting both allochems and bladed cements reflect early marine cementation; where phreatic cements occur, ooids commonly show evidence of close packing. Such oolites are interpreted to have grown on offshore bars generated in a normal marine environment.

Ooids within the second distinct assemblage commonly lack concentric tangential structure; instead, they are predominantly spheroids, with or without a nucleus (Fig. 13). They are circular with regular outlines, and may be concentrically radial. Nucleii are unoriented or detrital, consisting predominantly of pellets or fine quartz grains; sparse bioclastic nucleii are comprised of pelmatozoan fragments. The largest ooids of this type are 0.3 millimeters in diameter; their average diameter is 0.2 millimeters. Examination of acetate peels shows pointed terminations on radial and spherulitic rays, implying an original
calcite mineralogy, rather than aragonite (Fig. 14). Fallen steinkerns in gastropods occur in a few oolitic laminae, yet the ooids show no evidence of solution.

Ooids of the second type are associated with a sparse gastropod fauna of little diversity and commonly occur in centimeter scale, upward-fining laminations. The fine fraction of allochems in the laminae includes a fair percentage of peloids lacking internal structure. Radial ooids and pellets similarly occur in ripple cross-laminated fabrics common to the base of smooth algal laminites, wherein such pellets comprise 50 to 90 percent of allochems as estimated by observation. The combination of alternating brown pellets, rich in organic matter, and light-colored ooid microlaminae render the ripple cross-laminae clearly visible. Ooids that were not cemented by bladed, isopachous cements show evidence of close packing. No evidence exists of microstalactitic or meniscus cements.

Spherulitic and radial ooids are found today in the Great Salt Lake and the Persian Gulf (Loreau and Purser, 1973; Kahle, 1974; Halley, 1977). By analogy, similar ooids preserved in Mascot limestones are believed to have formed in a hypersaline environment. Absence of a normal marine environment is further suggested by the following factors: lack of a normal marine fauna, with the exception of detrital pelmatozoan fragments; the associated non-diversified gastropod fauna; and ooid nuclei composed of predominant quartz grains and pellets. Mascot ooids are more circular in outline than those illustrated by Kahle (1974), possibly reflect growth in a more agitated environment. Dilution of the ooids with pellets suggests that some mechanism may have dispersed the ooids from their site of growth.
Spherulitic and radial ooids may have originated in shoreward portions of tidal channels, on tidal channel bars, on the edges of tidal flat lagoons or on energetic, hypersaline shorelines, where they accumulated on levees and beaches, possibly following flooding that accompanied seasonal tides and storms. The further they were transported from their origin, the more mixed with pellets they became.

Oolitic limestones of the Mascot Formation would seem to be ideal subjects for additional study, particularly by means of scanning electron microscope, in order to shed light on the controversy surrounding the original mineralogy of ancient ooids. It is clear from their fabrics that the two distinct types of ooids had different primary mineralogies; alternatively, the differences may result from separate diagenetic histories. However, if primary mineralogy of ooid cortices is dependent on the magnesium/calcium ratio of the solution in which calcium carbonate precipitates, as suggested by Folk (1974) and Sandberg (1975), the observed fabrics may reflect differences in the Mg/Ca ratio of a normal marine versus a hypersaline lower Ordovician environment.
FIGURE 10. Vadose cement in photomicrograph of peel. Incipient, poorly developed gravitational cement on the underside of sandy intraclast (arrow). Note overgrowth on trilobite fragment (T) and monocrystalline overgrowth on pelmatozoans (P). Bar Scale 0.4 mm.

FIGURE 11. Concentric tangential ooids in photomicrograph of peel. Note cephalopod (C) and pelmatozoan fragment (P), suggesting deposition in normal marine environment.
FIGURE 12. Concentric radial ooids of normal marine affinity. Bar scale 0.4 mm.

FIGURE 13. Small spherulites of hypersaline affinity. Bar scale 0.2 mm.

FIGURE 14A. Terminations on radial rays of spherulite are pointed. Bar scale 0.1 mm.

FIGURE 14B. Close up of same.
FIGURE 15. Crystal terminations on radial ooid rays.

FIGURE 15A. Concentric radial rays on this ooid appear to have square-ended aragonite terminations. Preservation of terminations in the presence of equant phreatic cement indicates early neomorphism of aragonite to calcite. Bar scale 0.1 mm.

FIGURE 15B. Close up of square-ended terminations.
DISCUSSION

The Mascot Formation is a composite of sedimentary packages deposited between transgressive episodes. In each package, upper and lower boundaries are marked by rip-up breccias and by sharp changes in lithologies across scoured surfaces and clay seams. Each package consist of vertical succession of sedimentary fabrics that can be explained in terms of the following sedimentation model for the carbonates of central Tennessee.

Between transgressions, blue-green algae began colonizing relatively immobile, partially lithified substrates in quiet waters below wave base. Rapid growth brought these algae into wave base where their subsequent morphological development changed: in zones of highest energy, columnar and spheroidal growth ensued, while zones of lower energy promoted growth of thrombolites (cf. Ahr, 1971). Together, these differing algal forms became reefs and created a new energy-baffling regime (cf. Heckel, 1974).

Algal reef development may have been disrupted by severe storms. Partially cemented reefs, leveled by storm action, became stranded in an environment that was too turbulent to permit further growth. Temporary oolite bars formed on planed surfaces until reefal growth seaward could once again stabilize the environment for renewed algal colonization. This may explain why abundant scoured algal surfaces in the study area are commonly overlain by normal marine intrasparite and oosparite horizons rarely thicker than a few tenths of a meter. Similar reasoning explains
why normal marine oolite horizons and not algae commonly overlie scoured transgressed substrates. Oolite bars also developed within wave base in areas too turbulent for algal colonization.

Immediately shoreward of the algal reef zone was a narrow region in which algal-derived intraclasts accumulated, analogous to a modern back reef zone. This region marked the transition to a quiet lagoonal zone in which clays, carbonate muds, fecal pellets and wind-blown silts were deposited. Seaward edges of the lagoon, supporting local growth of pelmatozoans and an occasional invasion of trilobites, contained waters of near normal marine salinity; shoreward edges, lacking in normal marine faunas, were more restricted and hypersaline.

Where evidence of algal growth is absent in lagoonal sediments, only fecal pellets are preserved. Perhaps algal growth rates were retarded, permitting grazers to keep abreast with the production of food-stuffs. Alternatively the restricted environment may have encouraged the proliferation of more efficient grazers, resulting in creation of a dynamic equilibrium among grazers, burrowers and algal growth; such dynamic equilibria have been observed in modern environments of the Bahamas (Newmann, et al., 1970). Shoreward of the lagoons, where salinity tolerance levels for grazing faunas were exceeded, blue-green algae grew undisturbed. In sheltered, subaqueous, hypersaline environments, domed, laterally-linked algae grew; in environments subject to periodic subaerial exposure, laminar and crinkled algal mats grew. The latter sediments were incised by tidal channels filled by a gastropod fauna, tidal flat-derived intraclasts and spherulites generated on tidal channel bars and other high energy hypersaline environments. Spherulites,
small intraclasts and fecal pellets were distributed along centimeter-
scaled, upward-finining laminae during flooding that followed highest
tides and storms.

Distribution of clay, silt and sand reflects the considerable
geographic separation of distinct environments that were transitional
at their boundaries. Widely separated environments are suggested by
both a gradual seaward decrease in the concentration of clastic material,
and a more abrupt decrease in the size of clastic material; separation
over some distance is also supported by the mutual exclusion of algal-
derived intraclast and tidal flat-derived intraclast sediments, as well
as the occurrence of two distinct oolite assemblages. Lagoonal, hyper-
saline, shallow subtidal and intertidal sediments contained the highest
concentrations of detrital clastic material. Clays and silts were
deposited in lagoons; clays, silts and sands accumulated in hypersaline,
shallow, subtidal and intertidal environments. Sand-sized quartz grains,
transported by wind-blown saltation, were trapped in aqueous, low-
energy regimes behind shorelines connected to the mainland. Absence
of such coarse detritus elsewhere suggests that no transporting mechanism
existed to permit accumulation seaward of lagoons.

An overall concept of geographic separation is provided by incor-
porating the general model for epeiric seas proposed by Irwin (1965). He
divided a broad shelf by a slope of less than one foot per mile into
three zones: the X zone refers to that portion of the shelf, hundreds
of miles wide, where sediments were deposited below wave base; the Y
zone refers to that portion, tens of miles wide, where sediments were
deposited within wave base; and the Z zone alludes to that portion of
the shelf, hundreds of miles wide, where sediments were deposited in the innermost and shallowest shelf area, and where sedimentation was not appreciably affected by wave energy. In terms of Irwin's model his X zone corresponds here to the zone of incipient columnar algal growth; his Y zone corresponds here to the zone of columnar, spheroidal and thrombolic algal growth, as well as seaward portions of the lagoons; finally, his Z zone corresponds here to the zone of domed and smooth laminated algal growth incised by tidal channels. Similar relationships between facies and geography have been documented in recent carbonates (e.g. Hoffman, 1976; Kinsman and Park, 1976; Playford and Cockbain, 1976) and have been observed in other lower Paleozoic carbonates (e.g. Sando, 1957; Logan et al., 1964; Aitken, 1967; and Roehl, 1967).

The sedimentary package illustrated in Figure 16 is based on a composite of the vertical relationships observed among sedimentary fabrics in the Mascot Formation. The figure summarizes the following characteristics:

1. Both faunal and floral elements show a gradual upward displacement of diversified normal marine species by non-diversified hypersaline representatives;

2. Toward the top of each package depositional fabrics reflect sedimentation regimes of progressive shallowing waters;

3. Based on an "exposure index" developed by Ginsburg, et al. (1977) and others, upper portions commonly show evidence of a progressive increase in degree of subaerial exposure; and

4. Both amount and size of clastic detrital material increase upward.
The above characteristics all confirm a seaward progradation of peritidal sediments. Between 28 and 40 such packages are recognized in Mascot cores, representing successive progradational and transgressive episodes. Many episodes can be correlated between cores. The most reliable correlations are obtained using the distinctive and well-developed sand beds that blanketed the early Ordovician shelf during repeated periods of wide-spread subaerial exposure. Other markers are defined by abrupt changes in color and texture.

The sequence of sediments upward in each core is also indicative of gradual and progressive shallowing of facies throughout the study area. Digitate, spheroidal and thrombolitic algae are abundant in the lower Mascot and become increasingly rare upward in both limestone and dolomitized equivalents; domed algal, grainstone bar and tidal channel sequences are predominant in the middle Mascot; and domed algal, algal laminated, scour and fill and ripple cross-laminated units dominate the upper Mascot.

The isopach map illustrated in Figure 3 shows the upper Mascot to be thinnest parallel to and on either side of the present axis of the Nashville Dome, indicating that the axis may have been the locus of maximum uplift during the lower Ordovician. Added to the sedimentologic evidence derived in this study, this observation suggests that elements of the Nashville Dome were active during Mascot deposition; continued uplift eventually coincided with expression of the more regional Sauk unconformity. In order to validate this interpretation, however, additional cores should be studied to confirm both an expected thickening of the upper Mascot eastward of the 50-meter contour line, and more restricted and hypersaline conditions west of the dome's axis.
Because evidence points to periodic emergence of sabkha-like tidal flat environments throughout the study area, rates of evaporation must have been fairly high. However, the dominant mineral preserved in tidal flat sediments was fine-grained dolomite, not gypsum. Vadose cements in grainstones are not common indicating either that shorelines were of relatively low energy, that rainfall may have been minimal, or both. Such evidence suggests that the climate may have been arid or that precipitation was sporadic. Sedimentary features typical of strongly arid climates, however, are absent. For example, there is no evidence of either vadose pisolites, abundant, large birdseyes or sedimentary features suggestive of tepee structures. Also absent are caliche crusts that, according to James (1972), are indicative of repeated periods of heavy rainfall followed by intense evaporation. Therefore, it appears that the Early Ordovician climatic environment in central Tennessee was similar to that of the Bahamas today in that sediments reflect deposition in an oceanic and not a continental carbonate environment. Rainfall may have been quite sporadic. Thus there was a net loss of water in the hydrologic system by evaporation.

Limestones constitute only a few percent of the total section examined in the study area. The majority of cores consisting predominantly of dolomite and thin layers of nodular, bedded chert contain no limestone. An idealized pattern of limestone distribution, shown in Figure 17 illustrates a jagged transition zone separating an entirely dolomitized section to the north and northwest, from a partially dolomitized section to the south and southeast. The number of limestone beds increases southward; to the southeast, the number of beds remains
approximately the same but their thickness increases. Beds of limestone above the TR marker range between a minimum thickness of 10 centimeters, a maximum thickness of 15 meters, averaging 1 to 3 meters. As shown in Figure 17, limestone beds commonly occur at or shortly below the unconformity surface, directly above and below the Mds marker, and directly above and below the TR marker.

Although dolomitization has obscured most primary microscopic fabrics, most dolomitized equivalents of limestone facies may be recognized. Colors and megascopic textures observed in limestone, such as mudcracks, ripple marks, algal domes and columns, thrombolites, and scour and fill structures have been preserved in dolomite. Chert nodules embedded in dolomite have also preserved original fabrics at the microscopic level. With the aid of a light diffuser (Delgado, 1977), it is possible to recognize relict allochems including pellets, ooids, pelmatozoan fragments, trilobites and gastropods. The similarity between macroscopic and microscopic textures in both limestone and dolomite provides evidence that the bulk of the dolomite grew by replacement. The same repetitive sequences observed in limestone can be identified in the dolomite. Thus, dolomitization must have followed deposition of at least the normal marine phase of each progradational episode. Complications in the diagenetic history of the Mascot Formation arise from repeated mobilization of silica, dedolomitization, burial compaction and solution of limestone, and karst-related solution of limestone.
FIGURE 16. Idealized sequence of sedimentary structures within limestones of the Mascot Formation.
FIGURE 17. Schematic representation of dolomite-dolomite/limestone transition zone occurring in study area.
CONCLUSIONS

1. The Mascot is distinguished by recurring sequences of sediments that reflect peritidal sediment progradation across a broad, shallow shelf. As many as 40 sequences are recognized. Textural fabrics in each sequence indicate upward shoaling sedimentation, increasing salinity, and a gradual increase in both grain size and abundance of terrigenous detrital material.

2. Sediments deposited in the shallowest environments preserve evidence of subaerial exposure and are characterized by sands. Such sands are aeolian in origin, were deposited as sheets during regional subareal exposure, and are reliable lithostratigraphic markers.

3. Shallowest sediments are commonly dolomitized by fine-grained dolomite. This is the dominant evaporite mineral of the tidal flat. Evidence for other evaporite minerals is circumstantial.

4. Coarsest carbonate sediments were deposited close to the base and middle of each sedimentary sequence; such sediments may or may not have been cemented before burial.

5. Cements are predominantly of marine or phreatic origin; evidence for vadose cementation is not common.

6. The Mascot Formation is characterized by progressive shallowing throughout deposition. Shallowing culminated and coincided with development of the Lower Ordovician Sauk unconformity.

7. The locus of shallowing is the Nashville Dome axis.
BIBLIOGRAPHY


Larsen, K.G., 1977, Sedimentology of the Bonneterre Formation, Econ. Geol., v. 72, pp. 408-419.


THE LOWER ORDOVICIAN MASCOT FORMATION, UPPER KNOX GROUP,
IN NORTH CENTRAL TENNESSEE

Part II: Dolomitization and Paleohydraulic History
ABSTRACT

THE LOWER ORDOVICIAN MASCOT FORMATION, UPPER KNOX GROUP,
IN NORTH CENTRAL TENNESSEE

Part II. Dolomitization and Paleo hydraulic History

Anthony Wagner Gorody

Mascot Formation dolomite is made up of several genetically
distinct dolomite types that are recognized by their combined petro-
graphic, cathodoluminescent, and geochemical characteristics.
Cathodoluminescence, however, is the key investigative tool used to
distinguish and classify dolomite types into 2 basic categories and
5 subcategories: \underline{NZh}, and \underline{NZc} dolomite are subcategories of \underline{NZ} dolomite
rhombs exhibiting \underline{Non Zoned} luminescence; \underline{Z₁}, \underline{Z₂}, and \underline{Z₃} dolomite are
subcategories of \underline{Z} dolomite exhibiting \underline{Zoned} luminescence and three or
more concentric luminescent zones.

Based on macrotextural and petrographic relationships observed
among dolomite categories, most \underline{NZh}, \underline{NZc} and, \underline{Z₁} dolomite grew penecontemporaneously on evaporative tidal flats and following deposition of
prograding peritidal sediments, within shallow, schizohaline, subsurface
sediment environments.

Recognizable recurrent sequences of abundant luminescent
zones occurring in \underline{Z₂} dolomite can be correlated in subsurface samples
throughout a geographic area exceeding 1300 km² and a stratigraphic
thickness exceeding 250 meters. Additional evidence obtained using an established microstratigraphic sequence of these luminescent zones records the southward movement of regional dolomitizing solutions both laterally and upward through karsted carbonate sediments. These, other petrographic, and geochemical data, indicate that regional dolomitization occurred within subsurface marine-meteoric water mixing zones that formed during the marine inundation of an incipient, subareally exposed, Nashville dome. As southward-transgressing middle Ordovician seas drowned topographically high meteoric recharge zones, dolomitization ceased.

Following at least one additional karsting episode, Mississippi Valley-type mineralizing solutions invaded the study area. These transported zinc, iron, and sufficient magnesium to precipitate $\text{Z}_3$ dolomite before and immediately following sphalerite precipitation.

The common occurrence of multiple dolomite overgrowths exhibiting several luminescent characteristics, and other petrographic evidence, indicate that maximum permeability pathways for subsurface fluids were generated during the earliest karsting episode following collapse of multiple, thin and permeable grainstone horizons. These pathways channeled subsurface fluid flow from the end of early Ordovician time to at least Mississippian and possibly Pennsylvanian time.
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INTRODUCTION

One of the most challenging problems facing the carbonate geologist and geochemist today continues to be discovering an adequate mechanism that accounts for thick, laterally continuous dolomite in the stratigraphic record. Because thermodynamics and solution equilibrium calculations in natural water systems predict precipitation of dolomite, failure to synthesize dolomite in the laboratory under near-surface geological conditions has been frustrating. Recent dolomite appears to be quite dissimilar to the bulk of ancient dolomite, thus compounding the problem.

Most of the information obtained about ancient dolomite has been developed from careful field and laboratory observation and stable isotope and trace element geochemistry. Any effort to determine areal dolomitization history must use more than one technique before a valid interpretation can be made. However, there are several problems inherent with each technique.

Results of geochemical measurements have been so diverse that they have raised many more questions than they have answered (Land, 1979). Interpretation of trace element data from dolomite is complicated for the following reasons: 1. most dolomite replaces limestone and therefore the initial trace element content of the limestone largely determines the trace element composition of the dolomite; 2. The original trace element composition of limestone is determined by its original mineralogy, its environment of deposition, the amount of organic
material in the sediments, the temperature and salinity of the waters in which the carbonates are deposited, and the trace element composition of aquifers in which metastable carbonates reequilibrate; and 3. the trace element composition of the dolomite depends on the trace element composition of the fluid medium in which dolomite grows. The interpretation of stable carbon and oxygen isotope data is also complicated for several reasons. The following factors directly affect the final stable isotope composition of dolomite: isotopes in the precursor carbonate; the rate of dolomite growth; the temperature of the medium in which dolomite grows; and the isotopic composition of fluids in which dolomite grows. Clearly, finding a mechanism of dolomitization based on geochemical data alone would be impossible.

Petrographic approaches to the dolomite problem have focused on textural differences among dolomites. As a result, a wealth of descriptive terms designed to differentiate generations and/or mechanisms of dolomite growth have proliferated (Friedman and Sanders, 1967, and Katz, 1972). However, because no one yet understands the factors that control textural differences in dolomite, petrography has not provided an adequate solution to the dolomitization problem.

As a technique for studying dolomite, cathodoluminescence is still in its infancy, and most investigations explain the occurrence or absence of luminescence in dolomite (Pierson, 1977; Glover, 1977; and Oglesby, 1976). One study of "gangue" dolomite (Ebers and Kopp, 1976) has used dolomite luminescent zones as a tool to show that dolomitizing fluids precipitating dolomite-zinc mineralization of a carbonate environment may move upwards and laterally through the sedimentary column.
Studies that assess the geographic and stratigraphic distribution of dolomite and limestone attempt to discover why there is dolomite in one area and not in another. On a regional scale, explanations of its distribution is not straightforward and is locally even more complicated. As a rule, dolomite replaces shallow water and shelf facies, grows in areas that are most permeable to dolomitizing fluids, is commonly most conspicuous and abundant beneath unconformities and other evidence of subaerial exposure, and is closely associated with evaporite deposits. However, the exceptions to these generalizations are numerous.

Regardless of the approach to the problem interpreting the origin of dolomite in ancient rocks is complicated by ambiguities arising from the complicated nature of dolomitization processes. Nevertheless, a synthesis of available field, petrographic and geochemical data suggests that the following conditions are necessary for dolomite growth: 1. there must be a continuous supply of magnesium ions to the site of dolomitization; 2. the minimum ratio of magnesium ions to calcium ions in solution must be 1:1; 3. there must be sufficient time to overcome the slow kinetics of nucleation and crystallization; 4. sufficient thermodynamic drive must be developed for the dolomitization reaction to proceed. These conditions imply that dolomitization can be accomplished through the interaction of host rock with Mg-bearing fluids. Because dolomite is a diagenetic mineral, its petrography and geochemistry should reflect the geochemistry of fluids that precipitated it (Land et al., 1975). Furthermore, if multiple generations of dolomite can be recognized within ancient, thick and laterally continuous dolomite beds, then each generation should contain information reflecting the geochemistry
and paleohydrology of dolomitizing fluids.

To date, five geologically reasonable mechanisms have been proposed to account for the formation of dolomite. A description of each mechanism in terms of the source of magnesium ions can be summarized as follows: 1. Reflux (Adams and Rhodes, 1960); dolomitization can be promoted by the refluxion of Mg-rich, hypersaline brines generated in a partially barred, evaporating basin. 2. Solution cannibalization (Goodell and Garman, 1967); dolomitization takes place in a closed aquifer system whereby magnesium is derived from dissolution of Mg-rich allochems during an episode of uplift and/or erosion. 3. Evaporative pumping (Hsu et al., 1969 and 1973; Mckenzie et al., 1979); dolomitization occurs close to the surface of tidal flats as water lost by capillary evaporation is replaced from below by a mixture of upward-moving hypersaline and meteoric fluids. 4. Schizohaline replacement (Badizamani, 1973; Folk and Siedlecka, 1974; Folk and Land, 1975); dolomitization results when Mg-rich sea water and meteoric waters mix in the phreatic zone. The Mg/Ca ratio of the resulting solution is high, but the kinetically inhibiting effect of concentrated ions is minimized by dilution. 5. Pressure solution (Manless, 1979); dolomitization occurs when magnesium is released in a closed system as magnesium-rich allochems are consumed by pressure solution along micro and macrostylolites.

If each mechanism discussed above can be responsible for producing dolomite, then conceivably each mechanism generates dolomite with its own unique petrographic and geochemical properties. For example, all dolomite known to have grown on an evaporative tidal flat tends to
be very fine grained and obtains a geochemical signature indicative of evaporative conditions. This study, therefore, proposes new applications for established petrographic and geochemical techniques to demonstrate that dolomite textures can be differentiated in space and time and that multiple dolomitization episodes can be recognized.
LOCATION, STRUCTURE, AND STRATIGRAPHY
OF STUDY AREA

Since the discovery in 1967 of the Elmwood lead-zinc ore deposit in Smith County, Tennessee, mining companies seeking additional potential mining areas have been actively drilling into the Lower Ordovician Knox group in central Tennessee. Numerous cores of continuously-drilled sections have been recovered by one of these mining companies during their exploration efforts in central Tennessee from 1977 to 1979. Several of their cores and others available from local state surveys were examined for this investigation.

The study area is located on the northeast flank of the Nashville Dome and on a portion of the Cumberland Saddle that separates the Nashville Dome from the Jessamine Dome of central and northern Kentucky (Figure 1). Both domes constitute the southern and central portions of the Cincinnati Arch.

Knox strata in central Tennessee are structurally uncomplicated. The regional dip away from the crest of the Nashville Dome is approximately 9.5 meters per kilometer; faults in the sedimentary sequence are minor and have little displacement (Kyle, 1976).

The Cambro-Ordovician Knox group is composed of four formations: the upper Cambrian Copper Ridge Dolomite and the Chepultepec Dolomite; and the lower Ordovician Kingsport Formation and Mascot Dolomite (Figure 2). Because most of the Mississippi Valley-type ore deposits in central
Tennessee and south central Kentucky predominate in the Mascot Formation, drilling, as a rule, has not penetrated significant depths into the Kingsport Formation. This study will therefore focus on the dolomitization history of the Mascot Formation.

A fairly thin sequence of Middle Ordovician, Devonian and Mississippian rocks cover the Knox strata, thus the Knox has been protected from modern subareal exposure. Consequently, limestone and dolomite fabrics have been preserved in relatively pristine condition, rendering the study area ideal for reconstruction of paleoenvironmental and diagenetic events.
FIGURE 1. Location of study area, north central Tennessee.
FIGURE 2. Stratigraphy of Knox Group and subdivision of the Mascot Formation (adapted from Kyle, 1976).
METHODS

To determine the relationship between megascopic and microscopic characteristics of the Mascot Formation dolomite, 250 samples were taken from 8 cores in the study area. Samples representing the variety of macroscopic textures were selected following a preliminary hand lens and binocular microscope examination of 1400 samples from 15 cores. Samples were thin sectioned and polished, and half of each thin section was immersed for approximately one minute in a 2% HCl solution in which Alizarin Red S and Potassium Ferricyanide were dissolved (Evamy, 1963; Lindholm and Finkelman, 1972). This staining mixture provides a simple way to petrographically differentiate between calcite, dolomite, iron-rich calcite and iron-rich dolomite. Each thin section was examined under diffuse light, under plane and cross polarized light, and photographed under cathodoluminescence. Diffuse light was provided by a thin sheet of translucent white plastic placed under the slide (cf. Delgado, 1978; Zenger, 1979). Luminescent characteristics were examined with an ELM-2A Luminoscope\textsuperscript{R}; operating conditions during examination were 12.5 to 13.5 kilovolts accelerating voltage and .7 to .8 milliamps beam current. Excellent photographic results were obtained with 400 ASA Ektachrome film; exposure times varied from 2 to 5 minutes, photographs were sharp and yielded accurate color rendition. Photographs were taken at magnifications of either x20, x32, or x80. 450 photographs were studied using two screen projectors to compare and contrast differences between samples and varying fields of view. Because the
cathodoluminescence technique commonly burns the epoxy in pore spaces, photographed areas were easily found when scanning thin sections under transmitted light; in this way it was possible to study a field of view in a slide while a luminescent photograph of the identical field of view was being projected on a screen.

An estimate of dolomite size ranges was based on an inspection of 10 rhombs per sample in 60 measured samples. For each sample, occurrence of grains within 40 micron size intervals were counted and results plotted on a histogram. For example, grains in a sample within the 40 to 80, 240 to 280 and 440-480 micron ranges were tabulated once for each size interval recognized.

Porosity and permeability measurements were made on 30 randomly selected dolomite samples from one core by a commercial core laboratory. Plugs were drilled perpendicular to the core, and were approximately one inch wide and one inch long.

A random selection from the suite of samples for which limestone peels and dolomite thin-sections were prepared, was selected for atomic absorption analyses by throwing dice. Duplicate samples were chosen in the same way. Samples were crushed by hand in a mortar and pestle under acetone; one to two grams of powdered material was carefully weighted. Solution was carried out on a shaker table with a heating element in 80 ml of a 2% HCl solution. Samples were permitted to react for at least 24 hours. The resulting solution was filtered through a medium speed filter paper that had been previously labeled and weighed. After washing with a 10% solution of nitric acid, the filter paper and insoluble residue were dried in an oven at 90°C to
avoid dehydration of clays, and reweighted. The filtrate was transferred to a volumetric flask, diluted to 100 ml, transferred to a 200 ml polyethylene bottle and refrigerated. The pH of the solution was measured and found to be less than 1.5. Solutions were stored for less than three weeks prior to analyses; standards of varying concentrations were prepared with commercial dispensing micropipettes immediately preceding analysis. The analyses were accomplished with a Perkin Elmer 560 atomic absorption unit.

Thirty samples of dolomite and 27 samples of limestone were analyzed for their bulk Fe, Mn, Sr, and Zn content. To assess the accuracy of the results, 4 duplicate dolomites and 4 duplicate limestones were also analyzed.

Recent studies of carbonate luminescence have demonstrated that luminescence is activated by trace amounts of Mn$^{+2}$, whereas luminescence is quenched by iron (Sommer, 1972). Medlin (1959) and Glover (1977) have suggested that Fe$^{+3}$ is responsible for quenching; other workers (Sommer, 1972; Meyers, 1974; and Pierson, 1977) believe that Fe$^{+2}$ is the quenching ion. Luminescent intensity is affected by Fe concentrations of at least 1000 ppm in calcite (Meyers, 1974) and 100 ppm in dolomite (Pierson, 1977); iron in excess of 1% by weight, or $10^4$ ppm quenches all luminescence in both calcite and dolomite regardless of the amount of Mn$^{+2}$ present (Pierson, 1977; J.R. Frank, personal communication 1979). As long as the concentration of iron falls below the limiting value, these investigators have demonstrated that the intensity of luminescence depends on the ratio of FeCO$_3$ to MnCO$_3$ in the sample; the greater the ratio, the duller the intensity of luminescence.
Because the ratio of Fe and Mn control luminescent intensity in carbonates, analyses of these elements were made to assess the relationship between bulk geochemistry and luminescent characteristics. To measure the influence of zinc mineralization on carbonate diagenesis, zinc was determined. Sr was examined to indicate diagenetic history (Kinsman, 1969; Veizer and Demovic, 1974; Land et al., 1975).

Eleven dolomite samples and 4 limestone samples were analyzed for their stable carbon and oxygen isotope content. To determine the range in values among samples that did not exhibit a mixture of dolomite or limestone types, but that best represented the variety of dolomite and limestone types observed, samples were selected from the entire suite following completion of petrographic examination. Samples were ground under acetone with mortar and pestle. Powders were sent to a commercial stable isotope laboratory for analysis. There, a small amount of sample was reacted in phosphoric acid in a water bath at 25.0 ± 0.1°C. Replicate analyses and checks against their laboratory standard were used for internal quality control and the values reported were believed valid to better than 0.2 per mil.

X-ray diffraction analyses revealed that two of the 11 dolomite samples contained enough calcite to affect the results of the analyses for dolomite. These samples were reacted for 12 hours and carbon dioxide removed before reaction with phosphoric acid was continued. After all remaining dolomite reacted, carbon dioxide was extracted a second time for analysis. This method has been shown to be an effective way of removing calcite from a sample of dolomite (Walters et al., 1976).
RESULTS

A. Descriptive Classification of Grain Types

Dolomite textures in the Mascot Formation can be distinguished on the basis of grain size, intercrystalline fabric, diffuse and transmitted light characteristics and cathodoluminescent properties. The histogram in Figure 3 shows that there are five crystal range size categories. Ranges in grain size have been arbitrarily classified as follows: very fine -- ranging in size from 15 to 150 microns with a mode of 50 microns; fine -- ranging in size from 150 to 375 microns with a mode at 250 microns; medium -- ranging widely in size from 375 to 800 microns with a mode at 500 microns; coarse -- ranging in size from 800 to 1100 microns with a mode at one millimeter; very coarse -- anything larger than 1100 microns.

Xenotopic, hypidiotopic and idiotopic textures occur throughout the formation; nomenclature for these intercrystalline fabrics is that proposed by Friedman (1965 and 1967). Dolomite textures also exhibit a wide variety of transmitted and diffuse light characteristics; terminology for these characteristics come from several sources, notably, Beales (1953), Folk (1959), Murray (1964), Friedman (1965 and 1967) and Folk and Siedlecka (1975).

Cathodoluminescent characteristics yield photographable distinctions that cannot be observed with standard petrographic criteria alone. These characteristics facilitate recognition and grouping of recurrent petrographic associations and therefore form the basis for classification of
grain types in this study. This classification is especially useful to link both petrographic characteristics and chemical environments in which dolomite growth occurred. Luminescent properties of Mascot Formation dolomite can be classified as follows:

1. Rhombs of non-zoned luminescence: (NZ)
   a. Rhombs of homogeneous luminescence: (NZh)
   b. Rhombs of homogeneous luminescence with relatively bright luminescent, regular and irregular circular to rhombohedral cores: (NZc)

2. Rhombs of zoned luminescence (Three or more concentric zones) (Z)
   a. Type I Luminescent zoned dolomite: (Z1)
   b. Type II Luminescent zoned dolomite: (Z2)
   c. Type III Luminescent zoned dolomite: (Z3)

1. Rhombs of non-zoned luminescence: (NZ)
   a. Rhombs of homogeneous luminescence: (NZh)

All very fine grained dolomite samples and several that are fine and medium grained, exhibit homogeneous luminescence (Fig. 4A,B & 5A,B). Commonly, petrographic fabrics of homogeneous luminescent dolomite are xenotopic: such crystals appear homogeneously cloudy or vaguely sector zoned (Folk, 1959) under diffuse transmitted light. However, more hypidiotopic fabrics are developed for samples with a high weight percentage of both clay and silt (Fig. 6). For example, variable contents of silt and clay within laminae can result in alternating xenotopic and hypidiotopic dolomite fabrics across laminae in a sample (Fig. 7). This suggests that high insoluble residue content can prevent dolomite
rhombic from coalescing during growth. An enlargement in crystal size across siltier laminae is also commonly observed, suggesting a somewhat slower rate of growth. When examined in cross-polarized light with the aid of a gypsum plate, clays within rhomb interstices in these samples are oriented. Silt is rarely trapped within rhombs, but instead is concentrated around them (Fig. 6). Coarser mosaics of homogeneous luminescing dolomite can have one or two crystals of dolomite that enclose minute, irregular blebs of brighter-luminescing dolomite not necessarily centrally located within the crystal (Fig. 5A).

b. Rhombs of homogeneous luminescence with relatively bright luminescent, regular and irregular circular to rhombohedral cores: (NZc)

The majority of fine-grained and medium-grained dolomite rhombs with xenotopic and hypidiotopic textures show homogeneous luminescence and contain bright circular to rhombohedral cores. The distribution of these luminescent areas, however, varies from sample to sample. Rhombs commonly have nearly circular to nearly rhombohedral luminescent cores of medium intensity with irregular and diffuse outlines (Figs. 8A & 9). These brighter cores correspond to those areas within the center of a crystal that are cloudy under diffuse transmitted light and are also more susceptible to etching by weak acid (Fig. 8B). The cores are surrounded by dolomite of relatively dull luminescent intensity.

Other rhombs contain bright blebs that are not necessarily centrally located (Fig. 10). Other bright spots are distributed within the crystals as if they were remnants of once homogeneously bright luminescent rhombohedral cores (Fig. 9). The brighter luminescent blebs also occasionally correspond to vague and irregular outlines of relict
FIGURE 3. Histogram of range in dolomite crystal size used to arbitrarily classify grain size in Mascot Formation dolomite.
HISTOGRAM OF RANGE IN CRYSTAL SIZE

MODE 50\(\mu\)  MODE 250\(\mu\)  MODE 500\(\mu\)  MODE Imm

NO. OF SAMPLES

10  8  6  4  2

VERYL FINE  FINE  MEDIUM  COARSE  VERY COARSE

INCREMENT 40  MICRONS
FIGURE 4. Luminescent-transmitted light photo pair of very fine grained NZh dolomite.

4A. Luminescent photograph of very fine grained, dull, homogeneous, luminescent dolomite: (NZh). Bright luminescent rhombohedra visible because they are raised surfaces on an etched slide.

4B. Transmitted light photograph of same field of view. Rhombs in xenotopic mosaic of very fine grained cloudy dolomite are smaller than relatively clear idiotopes.
FIGURE 5. Luminescent-transmitted light photo pair of fine grained NZh dolomite.

5A. Luminescent photograph of predominantly homogeneous luminescent fine grained dolomite: (NZh). Note occurrence of brighter luminescent blebs in left hand side of photo. Mn, 56 ppm, Fe, 451 ppm, Sr, 38 ppm.

5B. Transmitted light photograph of same field of view. Xenotopic crystals are cloudy. Area of relatively clear dolomite in left and lower left hand portion of photograph corresponds to those areas in luminescent photograph exhibiting remnant blebs.
FIGURE 6. Luminescent photograph of medium grained, hypidiotopic NZh dolomite. Abundant detrital, silt-sized, potassium feldspar grains luminesce as bright specs between rhomb interstices.

FIGURE 7. Transmitted light photograph showing change in dolomite texture across fine sedimentary laminae. Coarser, more hypidiotopic rhombs occur in lamina, rich in clay and pyrite framboids.
FIGURE 8. Luminescent-transmitted light photo pair of NZc dolomite.

8A. Luminescent photograph of fine grained, xenotopic to hypidiotopic mosaic of dolomite: (NZc). Irregular and embayed circular central areas exhibit relatively bright luminescence.

8B. Transmitted light photograph of same field of view. Central rhombic and circular cloudy zones are accentuated by acid etching on left hand portion of photograph.
FIGURE 9. Luminescent photograph of medium grained, hypidiotopic NZc dolomite exhibiting centrally located remnant blebs of bright luminescent dolomite. Blebs appear to have originally been euhedral in outline (arrow).

FIGURE 10. Luminescent photograph of fine grained hypidiotopic NZc dolomite exhibiting bright luminescent blebs scattered throughout rhombs.
FIGURE 11. Ooid and intraclast ghosts occurring in medium grained xenotopic dolomite. Relict allochems transect crystal boundaries.
allochems visible in transmitted light. Allochems tend to be more
visible in xenotopic mosaics than in hypidiotopic mosaics (Fig. 11).

2. Rhombs of Zoned Luminescence (Three or more concentric zones): (Z)

Three types of crystals that exhibit concentric zoning of variable
luminescent intensity are observed in Mascot Formation dolomite. These
three types of luminescent dolomite crystals will be referred to as
Type I, Type II, and Type III based on their descriptive characteristics.

a. Type I Luminescent-zoned dolomite: (Z₁)

This type of luminescent zonation is uncommon in Mascot rocks
and is restricted to hypidiotopic fine-grained dolomite mosaics. Zones
tend to be of equal thickness and have only slight differences in
luminescent intensity. Alternate laminae have approximately equal
luminescent intensity, whereas the greatest contrast is observed
between adjacent laminae (Fig. 12A). The contact between luminescent
zones is diffuse and crystal cores tend to be small, euhedral, and
bright. In diffuse transmitted light, crystals exhibit nearly circu-
lar and nearly rhombic cloudy outlines but are predominantly sector
zoned (Fig. 12B). Relict allochems were not observed in these mosaics.
Because significant variation in luminescence intensity among zones is
lacking, it is not possible to determine whether or not similar rhomb
mosaics in several samples are genetically related.

b. Type II Luminescent-zoned dolomite: (Z₂)

Type II dolomite exhibits abundant narrow luminescent zones
forming euhedral whose boundaries are sharp and abrupt, and have a wide
range of intensities. Such dolomite grows by replacement of both
oolites (Fig. 13A and B) and micrite (Fig. 14A and B). Type II
FIGURE 12. Luminescent-transmitted light photo pair of Z

12A. Luminescent photograph of fine grained, hypidiotopic and xenotopic Type I dolomite. Luminescent zones are faint and appear to decrease in brightness from the center to the edge of rhombs.

12B. Transmitted light photograph of same field of view. Note occurrence of sector zoning as well as cloudy cores and relatively clear rims.
dolomite also grows within free space occurring in vugs (Fig. 15A and B), fractures (Fig. 16A and B), and pore spaces. A characteristic of this type of dolomite is that central portions of rhombs are cloudy and full of inclusions, whether they grow as overgrowths on other dolomite mosaics, or whether they grow as idiotopics in limestone (Figs. 14A and B; 18A and B).

Another zonation pattern characteristic of Type II dolomite replacing limestone is illustrated in Figure 17A and B. Here, zones are not developed concentrically around an euhedral crystal. Instead, zones are concentric around highly irregular crystal clusters that tend to become progressively euhedral away from cluster centers. Perhaps this zonal configuration reflects the response of a pelleted carbonate mud to compaction and consolidation. Continual compaction of pellets may have prevented growth of euhedral crystals until the limestone was sufficiently consolidated to allow relatively undisturbed rhomb growth.

Fabrics resulting from replacement are characteristically either hypidiotopic or idiotopic. Relict allochems occur within cloudy centers and around the edges of coarse, luminescent-zoned dolomite (Fig. 19A and B). Where such dolomite contains relict allochems of ooids and intraclasts, the crystal fabric is very open and porous. Intercrystalline spaces are commonly euhedral and are especially large in those samples where no original limestone or chertified limestone is preserved.

A micro-stratigraphy based on the numerous luminescent zones found in Type II rhombs can be constructed. This technique is similar
FIGURE 13. Luminescent-transmitted light photo pair of Z₂ dolomite replacing oolite.

13A. Luminescent zones are abundant and well developed; rhombs are coarse.

13B. Mirror-imaged transmitted light photograph of same field of view. Limpid rims correspond to those areas in the photograph above exhibiting sharply defined luminescent zones. Cloudy areas correspond to those areas in the photograph above exhibiting broader, more diffuse luminescent zones.
FIGURE 14. Luminescent-transmitted light photo pair of Z₂ limestone replacing micrite.

14A. Note poorly defined and irregular development of luminescent zones at centers of crystals, and sharper more euhedral development of zones away from centers. Rhombs are coarse.

14B. Mirror-imaged transmitted light photograph of same field of view. Cloudy centers correspond to areas in the photograph above exhibiting poorly developed luminescent zones. Limpid rims correspond to well developed luminescent zonation.
FIGURE 15. Luminescent-transmitted light photo pair of $Z_2$ dolomite lining vug.

15A. Vug within xenotopic NZc dolomite. Luminescent blebs are abundant and irregularly distributed throughout rhombs.

15B. Mirror-imaged, transmitted light photograph of same field of view. Thin, euhedral cloudy zones occur within Type II dolomite. Xenotopic mosaic is characterized by irregularly-shaped cloudy interiors and relatively clear rims. Cloudy zones correspond to areas exhibiting blebs of bright luminescence.
FIGURE 16. Luminescent-transmitted light photo pair of $Z_2$ dolomite lining fracture.

16A. Type II dolomite partially occluding fracture. Bright luminescent blebs occur throughout the interior of host xenotopic dolomite rhombs.

16B. Transmitted light photograph of same sample, different field of view. Note small patch of coarser crystals occurring diagonally across the field of view from upper right hand corner to center of photograph (arrows). Such textures produce some of the mottling observed in these rocks. Note also that fracture transects relatively coarse crystal patch. Type II dolomite occurring in fracture is partly cloudy with limpid outer edges.
FIGURE 17. Luminescent-transmitted light photo pair of $Z_2$ dolomite replacing intrapelmicrite.

17A. Note that concentric zones are initially highly irregular but become more euhedral away from crystal centers.

17B. Magnified, transmitted light photograph of same sample. Ghosts of allochems occur in central portions of the dolomite mosaic and correspond to the area of irregularly developed zonation in luminescent photograph above. Crystal edges on these mosaics are limpid and correspond to those areas exhibiting more euhedrally developed luminescent zonation.
FIGURE 18. Luminescent-transmitted light photo pair of $Z_2$ over-growths on $Z_1$ dolomite.

18A. Bright blebs due to detrital feldspar occurring between rhomb interstices. Silt appears to be more concentrated in dolomite than in limestone.

18B. Mirror-imaged transmitted light photograph of same field of view. Type 1 dolomite is hypidiotopic and sector zoned. Type II dolomite exhibits both Sector zoning and concentric cloudy zonation in crystal interiors. Outer edge of Type II crystal is limpid and corresponds to areas above exhibiting most pronounced luminescent zonation.
FIGURE 19. Luminescent-transmitted light photo pair of $Z_2$ dolomite enclosing ooid and intraclast ghosts.

19A. Transmitted light photograph. This sample taken from collapsed grainstone horizon. Note how pyrite-rich insoluble residue fills space between rhombs. Note also that relict allochems are preserved at centers and around edges of idiotopes.

19B. Magnified, luminescent photograph of same sample, different field of view. Relict allochems are outlined by irregular zone of bright luminescence at left hand portion of photograph (arrow). Note irregular development of luminescent zones within the interior of rhomb in upper right hand corner of photograph.
to that used in dendrochronology to determine relative tree ages in forests. This approach has been successfully applied to calcite cements in limestones (Meyers, 1974) and to fracture and vug-filling dolomites (Ebers and Kopp, 1979). A useful approach to cathodoluminescent microstratigraphy and a discussion of the assumptions that must be made was presented by Ebers and Kopp (1979). In summary, Ebers and Kopp suggest the following: 1. cathodoluminescent zoning reflects crystal growth zoning; 2. variations in luminescent color and intensity are due to varying amounts of Fe$^{+2}$ and Mn$^{+2}$ in growth zones; 3. correlation of zones should only be attempted when three or more zones occur or when distinct zones are recognized; 4. measurements made across a given crystal cross-section should record relative luminescent color hue, intensity and width of zones and for any sequence of zones, measurements should be made on the same slide; 5. instrumental operating conditions should be recorded and should remain as constant as possible.

Luminescent zones have been correlated in rhombs throughout the study area. Two narrow zones of quenched luminescence occurring within the luminescent zone sequence facilitate correlation. Figure 20 was constructed using one of these quenched zones as a reference marker. Luminescent Ektachrome photographs of five samples from four cores were projected on a piece of paper, thicknesses of luminescent zones traced, and relative luminescent intensities of zones were recorded. Three of the photographs used to erect this portion of the microstratigraphy are illustrated in Figures 21A, B and C. Core locations in which these rhombs occur are plotted on Figure 22.
Figure 23 shows how a microstratigraphy can be erected using the sequence of relative zonal intensities. Each zone was assigned a relative intensity value between 1 (dead zone) and 8 (very bright zone). The sequence of relative intensities among selected dolomite rhombs was compared; recognizable groups of zones were labeled.

Although most zones can be matched from sample to sample, certain zones occurring in some samples are absent in others (Fig. 23). For example, zones B'' and D'' are missing in (rhomb) 6.679.8B, but occur in (rhomb) 6-679.9A. Rhombs A and B are adjacent to each other in sample 6-679.8, but rhomb A is larger and better developed than rhomb B. This therefore is an example where certain zones could not be recognized because of differences in crystal size. As a rule, the smaller the crystal, the more zonal compression is recognized. Zone IIIE occurs in all rhombs except 18-656.7. Similarly, zone IID occurs in all rhombs except in 5-514.5 and 18-656.7. In this example, rhombs were isolated from fluids generating growth of brightly luminescent dolomite, implying that either the input of dolomitizing fluids throughout the aquifer system is episodic and diachronous or that permeability of these sediments was opened and closed to fluids at different times.

Rhombs selected to demonstrate regional correlation of zones in the previous figures show only a portion of the total number of luminescent zones found throughout the area. The most complete sequence of zones comes from one sample in core 136 and is illustrated in Figure 24. Two extinct zones are markers used to arbitrarily divide the sequence into three major zones, I, II, and III and 15 subzones from the center to the edge of a rhomb. Figure 25 defines
this arbitrary microstratigraphy in terms of relative width and zonal intensity occurring in this sample. The sequence of luminescent zones that occurs in rhombs at depth in a core (Fig. 26), was plotted using this arbitrary microstratigraphy. M3, a quartz sand bed that occurs throughout the area, was used as a lithostratigraphic marker bed to relate one core to another. This bed marks the lower boundary of the upper member of the Mascot Formation as defined by Stagg and Fischer (1970) and is shown to be a reliable lithostratigraphic marker (Gorody, Part 1).

Figure 26 illustrates the following: 1. The event that produced luminescent zoned dolomite was regional in extent. In fact, distances over which correlation can be made are the longest reported for crystal zone stratigraphy. 2. Identifiable zones occur throughout the Mascot as well as in the upper Kingsport Formation, thus late dolomitization affected at least 250 meters of the sedimentary column. 3. Type II zoned dolomite ceased to grow throughout the area after growth of zone IIIH. This zone marks the end of this episode of regional dolomitization. 4. All samples plotted exhibit intervals of luminescent zones; range and position of these intervals relative to the established microstratigraphic sequence show no systematic change with depth in the stratigraphic column. Most complete zonal sequences are commonly found in open fractures and vugs. The pattern of zoned intervals with depth suggests that earliest luminescent zones grow within sediments of greatest initial permeability; dolomite growth ceases as soon as permeability is occluded. In other words, these variations provide a tool with which to determine progressive alteration of the
FIGURE 20. Partial microstratigraphy of Type II luminescent zones identified in samples 6-679.8 A & B, 6-669.9, 136-618.3, 136-643.8, 5-514.5 & 18-656.7. Relative intensity and thickness of luminescent zones traced from selected Ektachrome slides. Large letters and Roman numerals refer to arbitrary microstratigraphy proposed for luminescent zones. Stars next to samples indicate these are illustrated in next figure. Quenched luminescent zone III A serves as reference marker.
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**CODE FOR LUMINESCENT INTENSITY**

- DEAD = D = 1
- VERY DARK = VDK = 2
- DARK = DK = 3
- MEDIUM DARK = M.DK = 4
- MEDIUM = M = 1
- MEDIUM BRIGHT = V.B = 2
- BRIGHT = V.DK = 3
- VERY BRIGHT = V.V = 4
FIGURE 21. Luminescent photographs for 3 of 6 samples illustrated in Figure 20.

21A. Luminescent photograph showing enlargement of Type II luminescent zones in sample D5-514.55. Refer to previous figure showing luminescent stratigraphy of these zones.

21B. Luminescent photograph showing enlargement of Type II luminescent zones in sample 136-618.3. Refer to previous figure showing luminescent microstratigraphy of these zones. Note initial offset of luminescent zones occurring near boundary between zone III B and III C. Offset zones occur from this boundary to edge of crystal (arrow).

21C. Luminescent photograph showing enlargement of Type II luminescent zones in sample D6-669.9. Refer to previous figure showing luminescent microstratigraphy of these zones.
FIGURE 22. Location of sampled cores in which Type II luminescent microstratigraphy was examined. Position of cores 136, 18, 137, 6 and 5, plotted on isopach map of the Upper Member of Mascot Formation. Present axis of Nashville dome plunges northeastward into the Cumberland Saddle in Cumberland County, Ky.
FIGURE 23. Partial microstratigraphy of Type II luminescent zones. Luminescent stratigraphy based entirely on relative intensity and sequence of luminescent zones for samples plotted in Figure 20 and illustrated in Figure 21. Squiggly lines indicate a "hiatus" in the luminescent stratigraphy; shaded luminescent zones occur in some samples, not in others.
FIGURE 24. Luminescent photograph of key sample (136-636.8) used to establish complete Type II luminescent, zonal microstratigraphy. Note excellent definition and abundance of luminescent zones in these crystals. Dolomite growing in pore space within pelmicrite.
FIGURE 25. Complete microstratigraphy of Type II luminescent zones. Arbitrary nomenclature of Type II luminescent zonal microstratigraphy based on sample 136-636.8 illustrated in previous figure.
ARBITRARY NOMENCLATURE OF TYPE II LUMINESCENT ZONAL MICROSTRATIGRAPHY

SAMPLE 136-636.8

CENTER OF CRYSTAL

ZONES

I
A B A B
II
3 5
III
4 1

RELATIVE WIDTH OF ZONES

EDGE OF CRYSTAL

SUBZONES

RELATIVE INTENSITY VALUES

15 mm (APPROX.)

CODE FOR LUMINESCENT INTENSITY

1 = DEAD
2 = VERY DARK
3 = DARK
4 = MEDIUM DARK

5 = MEDIUM
6 = MEDIUM BRIGHT
7 = BRIGHT
8 = VERY BRIGHT
FIGURE 26. Luminescent microstratigraphy of 48 samples as plotted with depth in cores 136, 137, 18, 6 and 5. Symbol for compaction next to core indicates limestone exhibits evidence of pre-cementation burial compaction. TR marker separates the lower Ordovician Mascot and Kingsport Formations. The Middle Ordovician Wells Creek Formation buries the unconformity surface.
PET STRATIGRAPHY FOR 48 SAMPLES FROM 5 CORES

PLOTTED WITH DEPTH-METERS
FROM 5 CORES
rock column as it is subjected to the influence of diagenetic fluids.
5. Earliest luminescent zones are absent in both southern cores but
occur in all three northern cores. Therefore, the dolomitization
episode must have begun with fluids originating to the north and
working their way to the south. This comprises evidence for diachron-
ous movement of dolomitizing fluids on a regional scale.

Because the same luminescent zones occur throughout the Mascot
and into the Kingsport Formations, the dolomitization episode followed
deposition of at least 250 meters of sediment. However, as the follow-
ing examples demonstrate, rhomb growth preceded development of petro-
graphic features characteristic of limestone compaction such as
stylolites. 1. Rhomb growth begins in mudstones during initial
compaction. Ghosts of delicate mudstone laminae preserved in dolomite
show that laminae were being compressed during the growth of rhombs
and that the process continued after growth terminated (Fig. 27).
Irregularities on surfaces of microlaminae preserved within dolomite
rhombs correspond to boundaries between thin, concentric, limpid and
cloudy zones. Such a pattern could arise if compaction of microlaminae
was continuous relative to growth of dolomite zones or if both or
either process were discontinuous. This provides additional evidence
that growth of zoned dolomite is episodic. It should be emphasized
that such evidence of compaction is limited to the lowermost portions
of cores and is not observed at shallow depths within the Mascot.
Thus, although dolomite growth is synchronous throughout the formation,
growth of rhombs concurrent with compaction is only observed at depth
in cores. This demonstrates that luminescent zoned dolomite can be
used to decipher the compaction history of limestone. 2. Rhomb growth ceased before microstylolite development. Figure 28 shows a transmitted light photograph wherein limpid rims on dolomite are being consumed by microstylolites. Under cathodoluminescence, this sample reveals that the limpid rims are composed of Type II luminescent-zoned dolomite, and that the outermost luminescent zones have been partially to completely digested by microstylolites. It is also common to see clay residues hugging the sides of crystals in a limestone matrix rich in clay. This supports compaction following dolomitization. 3. Rhombs are consumed by large amplitude stylolites (Fig. 29). These observations indicate that burial of at least 250 meters of Ordovician limestone is not sufficient for the development of microstylolites or high amplitude stylolites and that dolomite grew throughout the region as petrographic evidence of limestone compaction developed, but before compaction ended.

In Type II rhombs replacing limestone, zoned laminations are concentric around the crystal nucleus, but luminescent laminae are commonly displaced midway between the center and the edge of rhombs. Figure 21B shows laminae that are jagged and form a displaced rectangular pattern of concentric zones. The width of luminescent zones varies proportionately within each group of offset zones. This difference in zonal width appears to have resulted following rotation of crystal segments along cleavage planes. Zonal displacement does not occur at the same sites relative to the luminescent microstratigraphy in all Mascot Formation samples. In fact, distribution of this phenomenon within several cores suggests a systematic change in dislocation sites
with depth. Dislocations occur in later luminescent zones in rhombs replacing limestone close to the top of the Mascot Formation; dislocations occur in earlier luminescent zones at lower stratigraphic horizons. Dislocations of luminescent zones may reflect changes in the response of limestone to stress. Regular concentric zones may develop when limestone is relatively unconsolidated and unable to transmit shear across the surface of a growing dolomite crystal; irregular zones may develop once limestone is able to transmit shear. Because dolomite crystals are relatively brittle in comparison to limestone, they may react to shear in limestone along crystallographic planes. Absence of similar dislocations in zoned dolomite rhombs that fill pore spaces supports this interpretation: shear cannot be transmitted in fluid filled pore spaces. Because it provides an explanation of the way undulatory extinction is produced in dolomite, a more thorough investigation of this phenomenon is necessary. Nevertheless, the evidence suggests that Type II dolomite grows in limestone before it is sufficiently consolidated to transmit stress. Furthermore, the evidence suggests that such stress is transmitted first closer to the base of the formation, implying that limestone consolidation works its way up the stratigraphic column.

c. Type III Luminescent-zoned dolomite: \(Z_3\)

Type III luminescence is characteristic of very coarse white and pink saddle-shaped rhombs that partially or totally occlude large vugs and fractures. Dolomite of this type, the common mineral growing in unrotated fragment and mineral matrix breccias, does not appear to replace limestone and is characterized by sweeping extinction and
FIGURE 27. Transmitted light photograph showing compacted laminae in micritic limestone and ghosts of compacted laminae within coarse, faint concentrically zoned, Type II dolomite crystals. Laminae are biconvex across dolomite crystal indicating that compaction was continual throughout growth history of rhomb. Also, perturbation in compaction laminae occur adjacent to cloudy concentric zones indicating that dolomite growth was episodic.
FIGURE 28. Transmitted light photograph of coarse $Z_2$ rhombs being consumed by microstylolite swarms in a micrite matrix.

FIGURE 29. Luminescent photograph of coarse, idiotopic, $Z_2$ dolomite being consumed at stylolite. Note that central zones are diffuse and irregular, becoming sharper and progressively euhedral away from center.
minute two-phase fluid inclusions. Type III rhombs are also the only ones with zones that stain blue with Potassium Ferricyanide; stained zones correspond to zones of dullest luminescence.

Luminescent zones in Type III dolomite are broad, have dull orange hue and have a weaker overall intensity than Type II dolomite (Figs. 30A and B).

Because a few samples of this dolomite type were collected, it was not possible to erect a microstratigraphy of these luminescent zones. However, the limited samples collected suggest that it is possible to correlate these zones with both depth and distance. It is the luminescence of this type of "gangue" dolomite that Ebers and Kopp (1979) were able to correlate throughout the Mascot-Jefferson City mining district in East Tennessee.

B. Relative Growth Sequence of Dolomite Grain Types

1. Type III Luminescent zoned dolomite \((Z_3)\)

Rhombs exhibiting Type III zoned luminescence occur in fractures or vugs as overgrowths on dolomite of all types of luminescence. Fractures occurring in limestone or shale are devoid of Type III dolomite unless grains or grain mosaics of earlier dolomite also occur. Thus Type III dolomite did not grow on substrates other than dolomite. The petrographic relationship between this dolomite and its substrate exhibit one or more of the following characteristics: 1. Type III dolomite commonly grows in optical continuity with dolomite that has been fractured and always grows in optical continuity with dolomite that lines fractures and vugs. 2. Type III dolomite cements blocks of
FIGURE 30. Paired luminescent photos of $Z_3$ dolomite.

30A. Coarse $Z_2$ dolomite occluding vug. Note remnants of Type II luminescent zones in overgrown rhombs. Overgrown rhombs surfaces appear rough whereas overgrowths are smooth.

30B. $Z_2$ dolomite overgrowth on $Z_3$ dolomite. Note remnants of original Type II luminescent zones and large solution pits occurring within interiors of overgrown rhombs.
FIGURE 31. Transmitted light photograph, larger field of view of sample illustrated in Figure 30B. Note occurrence of three types of dolomite: fine grained xenotopic dolomite rich in pyrite framboids; cloudy zoned \( Z_2 \) dolomite; clear \( Z_3 \) dolomite. This sample occurs one meter above collapsed grainstone horizon. Fractures caused by collapse are partially occluded with \( Z_2 \) dolomite overgrown with \( Z_3 \) dolomite. Both \( Z_2 \) and \( Z_3 \) dolomite are optically continuous.

FIGURE 32. Transmitted light photograph showing three types of dolomite in this sample. The first generation of dolomite is lenticular, medium grained and exhibits sector zoning. Cloudy and zoned \( Z_2 \) idiotopes grew as overgrowths on the small lens of xenotopic dolomite and preserve evidence or relict allochems in the lower left hand corner of the photograph. Both earlier generations of dolomite were fractured and fractures are filled with clear \( Z_3 \) dolomite.
FIGURE 33. Luminescent-transmitted light photo pair of $Z_3$ dolomite cementing fracture.

33A. Luminescent photograph of $Z_3$ dolomite growing in fractured xenotopic dolomite exhibiting homogeneous luminescence. Note irregular narrow zone of relatively bright luminescent blebs at boundary between dolomite types. Also note curved crystal faces within fracture.

33B. Transmitted light photograph of same field of view. $Z_3$ dolomite in optical continuity with NZh dolomite.
FIGURE 34. Luminescent photograph of Z₂ dolomite overgrowths on Z₂ dolomite lining vug. Note faint remnants of Z₂ luminescent zones in upper right hand portion of photograph. Overgrowths of Z₃ dolomite do not occur where geopetal silt covers dolomite rhombs at the bottom of vug. Remaining space occluded by coarse, irregular concentrically zoned, faintly luminescent calcite.
FIGURE 35. Luminescent photo pair of Z₃ dolomite and its association with sphalerite.

35A. Luminescent photograph shows clearly that growth of Z₃ dolomite was interrupted by growth of sphalerite (Sp). Note remnants of Type II luminescent zones in overgrown rhomb upper right hand corner of photograph, and rhomb covered by geopetal silt in bottom right hand corner of photograph.

35B. Luminescent photograph of sphalerite growing within dolomite exhibiting Type III luminescence. Z₃ dolomite partially cements detrital dolomite in brecciated zone. Note that bright Type III luminescent dolomite zone grew immediately following sphalerite mineralization in both Figures A and B. These samples were obtained from 2 cores 10 miles apart.
dolomite and grows on detrital dolomite occurring within brecciated and collapsed stratigraphic intervals (Fig. 31). 3. There may be a narrow zone, invisible in transmitted light, containing blebs of bright luminescence separating dolomite types. 4. Figure 30A and B shows that Type III overgrowths on void-filling dolomite appear polished and free of any evidence of corrosion, whereas overgrown rhombs appear pitted and corroded. This suggests a temporal discontinuity between growth of pitted and non-pitted dolomite. In addition, Figures 30A and 30B show that, luminescent zones of overgrown rhombs are discontinuous and embayed. Such zones are remnants of Type II dolomite zonation. The most common and easily recognized zones are zones 111E and 111C because they were originally the brightest zones; remnants of both can be seen in Figures 30A and B. Thus iron and manganese in overgrown rhombs has been mobilized. Mobilization of these elements may have taken place along paths of maximum permeability in the crystal, such as cleavage or dislocation fractures. Commonly, overgrown rhombs exhibiting the greatest degree of pitting are devoid of relict zones. This suggests that rhombs had varying susceptibilities to attack by solutions and that some homogeneously luminescing dolomite may at one time have exhibited zoned luminescence. 5. Figure 34 shows that Type III zoned overgrowths occur on homogeneous luminescent rhombs not covered by geopetal clay lining a large vug. There, infiltration of clay into vugs preceeded growth of zoned rhombs and followed growth of vug-lining, homogeneous luminescent dolomite. Also, rhombs covered with detrital clay exhibit remnant luminescent zonation. These relationships suggest that solutions causing partial corrosion and re-mobilization of iron and manganese in originally zoned luminescent rhombs were the same as
those causing solution, corrosion, collapse and brecciation of the stratigraphic column. 6. Type III rhombs are the only rhombs that partially enclose and surround crystals of sphalerite (Figs. 35A and B). Both figures clearly illustrate that growth of Type III dolomite was interrupted by the growth of sphalerite. A similar relationship between sphalerite and dolomite with similar zonation has been described by Ebers and Kopp (1979) from mineralized carbonates of equivalent age in East Tennessee. Furthermore, Figures 35A and B show that the first luminescent dolomite zone precipitated following mineralization exhibits bright luminescence. A similar relationship has been observed in other areas of the country that have undergone Mississippi-Valley type mineralization (e.g. Ebers and Kopp, 1979). Perhaps this indicates effective removal of ferrous iron from mineralizing fluids following mineralization. However, because successive zones always exhibit some degree of quenched luminescence, ferrous iron must have been transported into these mineralized terrains.

Because it texturally cuts across or overgrows all other types of dolomite, Type III dolomite was the last type of dolomite to grow in the study area. Its growth was preceded by at least one episode of fracturing, brecciation, collapse and infiltration of clay into vugs and pore spaces. Mineralization accompanied growth of this dolomite.

2. Type II Luminescent zoned dolomite: (Z₂)

Type II zoned dolomite grows within collapse breccias that occur throughout the Mascot (Figure 36A and B). Breccias of this type have the following characteristics: A. collapsed beds are rarely thicker than 2 meters; B. megascopically these beds are strongly color mottled
with brown and white or gray and white dolomite. Breccia units are commonly filled with clay, silt and collapse debris at their base. Clay surrounding collapsed debris is brown under condensed plane polarized light and strongly oriented under cross polarized light; orientation of clays tend to follow contours of zoned dolomite overgrowths. Upper portions of collapse zones are free of debris and commonly fractured (Fig. 31). Fractures occur in fine to medium grained NZc and NZh xenotopic dolomite and are commonly small, narrow, and cemented with Type II and Type III dolomite. Small breccia blocks, commonly less than 5 centimeters wide, are composed of angular chert fragments, fragments of fine to coarse grained xenotopic and hpidiotopic dolomite mosaics and rarely, fragments of limestone.

Grains of detrital dolomite in collapse zones are overgrown with Type II dolomite and are made up of irregular shaped patches of xenotopic and hpidiotopic dolomite exhibiting NZh and NZc and Z, luminescence. The contact between dolomite types is commonly marked by a zone of bright luminescent dolomite blebs. Occasionally, detrital dolomite grains are pitted and appear corroded whereas zoned Type II overgrowths are free of pits or evidence of corrosion (Fig. 36A). These petrographic characteristics are strongly reminiscent of similar features observed between dolomite and Type III overgrowths. Furthermore, it is common to find both Type II and Type III overgrowths on detrital dolomite. Wherever this association is observed both the detrital dolomite and the Type II overgrowths appear pitted and corroded.

Coarse Type II dolomite mosaics and rhombs in collapse zones commonly preserve relict allochems composed of ooids and intraclasts.
(Figs. 19A and B, 37A and B). Allochems occur around edges and within centers of coarse rhombs and exhibit abundant evidence of solution and collapse prior to replacement by dolomite (Figures 37A and B). This distribution of allochems within Type II dolomite rhombs is quite different from that observed in xenotopic mosaics of non-zoned luminescent dolomite (compare Figs. 11, 19 and 37). Reasons for such dolomitization style differences are not understood, but may reflect differences resulting from dolomitization of unconsolidated, partially dissolved allochems versus dolomitization of cemented allochem fabrics wherein allochems are uniformly distributed throughout dolomite.

Type II zoned dolomite partially cements breccia blocks, partially or totally replaces limestone, cements fractures in earliest dolomite, grows as overgrowths on detrital dolomite, and preserves relict allochems characteristic of ooid grainstones. These observations indicate that corrosive waters attacked relatively permeable grainstone units and caused collapse of overlying sediments. Breccia columns, supported by sedimentary fragments and floored with clay and silt, became highly permeable conduits. Subsequent dolomitizing fluids invaded highly permeable zones; dolomite grew both as luminescent zoned overgrowths and as zoned cement on detrital and fractured dolomite. Later compaction served to orient clays around overgrown dolomite blocks.

Mining company geologists who have worked in the study area have recognized that argillaceous matrix breccias are common near the top of the Mascot Formation in those areas where the formation is overlain by the Low Green shale member of the middle Ordovician Wells Creek Formation. Such breccias resulted when clay from the overlying unit invaded fractured sediments near the top of the Mascot. Microscopic
examination of these breccias reveal that zoned Type II luminescent dolomite lines fractures in breccia columns and that green clay rests geoptically on these crystals (Fig. 38A and B). Therefore, fracturing and growth of Type II dolomite occurred before infiltration of clay from sediments of the overlying formation. Subsequent growth of faintly luminescent zoned calcite cemented fractures. The Wells Creek Formation is not dolomitized with Type II dolomite. The few patches of dolomite occurring at the base of the formation are thin and composed of fine grained iron-rich, xenotopic crystals.

In summary, Type II luminescent zoned dolomite crystals grew throughout the Mascot Formation following at least one episode of solution, collapse and fracturing of limestone and earlier dolomite. However, Type II dolomite crystals grew before the final middle Ordovician transgression across the study area. At least one other episode of collapse and brecciation temporally separates Type II from Type III luminescent zoned dolomite growth (Fig. 39). These observations support Kyle's (1976) interpretation of two distinct episodes of brecciation and collapse.

3. Type I Luminescent zoned dolomite ($Z_1$)

Type I dolomite rarely occurs in the Mascot Formation, and therefore it is difficult to interpret the timing of its growth relative to all other recognizable dolomitization events. However, because Type II dolomite overgrows Type I dolomite (Fig. 18A) and also cements Type I dolomite in collapse breccias, Type I dolomite must have grown prior to Type II dolomite.
FIGURE 36. Luminescent-transmitted light photo pair of $Z_2$ overgrowth on brecciated detrital NZ dolomite.

36A. Luminescent photograph of $Z_2$ dolomite overgrowths occurring on corroded and pitted grains of NZ detrital dolomite in breccia (lower right hand corner of photograph). Bright specs in dark matrix are detrital feldspar grains.

36B. Slightly enlarged transmitted light photograph of same sample, different field of view. Note occurrence of relict ooids within large rhomb, and solution pits. Oriented clays wrap around dolomite rhomb at top central portion of photograph. Mn, 80 ppm, Fe, 806 ppm, Sr, 79 ppm.
FIGURE 37. Transmitted light photo pair of Z₂ dolomite replacing allochems in collapsed grainstone.

37A. Ooid ghosts occurring within coarse mosaic of Z₂ dolomite. Allochems exhibit evidence of overcompaction due to solution. Note euhedral terminations of dolomite rhombs occurring within central relatively clear portions of grains.

37B. Same sample. Trilobite fragment, resistant to solution, bridges pore space and prevented infiltration of collapsed debris into pore space. Pore space in lower left hand edge of photograph is filled with a large single crystal of Z₃ dolomite.
FIGURE 38. Luminescent-transmitted light photo pair illustrating relationship between fracture, $Z_2$ dolomite and Wells Creek clay infiltrated into fracture.

38A. Luminescent photograph of $Z_2$ dolomite lining and growing within fracture near top of Mascot Formation where overlain by Low Green Shale member of the Wells Creek Formation. Dark areas correspond to clay, light green in transmitted light, that rests geopetally on $Z_2$ rhombs. Remaining areas of fracture occluded by faintly zoned, luminescent calcite.

38B. Transmitted light close up of clay resting both within interstices and upon $Z_2$ dolomite rhombs. Clay also rests directly on calcite in lower right hand corner of photograph suggesting that calcite growth and final occlusion of fracture was interrupted by clay infiltration. These relationships suggest dolomite grew before infiltration of Wells Creek clays. Calcite cementation and clay infiltration appear to be contemporaneous; both processes accompanied the final transgression of the Knox unconformity surface.
FIGURE 39. Luminescent photograph of brecciated $Z_2$ dolomite surrounded by insoluble residue.
4. Non-zoned, homogeneous luminescent dolomite: (NZh)

Paleoenvironmental reconstruction of the Mascot Formation shows it to be comprised of multiple sequences of regressive sedimentary packages (Gorody, Part I of this dissertation). Each regressive package, ranging in thickness from 3 to 8 meters, represents gradual shoaling and progradation of shallow subtidal and peritidal environments. The base of each shoaling sequence is marked by algal and grainstone facies indicative of a high energy shallow subtidal environment. The middle of each package is distinguished by algal, pelleted, laminated and intraclast sediments indicative of lagoonal and tidal channel facies. Ripple marked, laminated, and algal bound sediments indicative of intertidal environments that occasionally exhibit evidence of subaerial exposure characterize the top of each sequence. Although petrographic criteria used to establish these facies and their relationships are based on examination of limestone in the study area, the facies relationships are partially or completely preserved in dolomite. Both macroscopic and microscopic observations support facies equivalence between limestone and dolomite.

Dolomite exhibits an area-wide tendency to become finer grained towards the top of each sedimentary sequence. For example, dolomite occurring in all textures exhibiting evidence of subaerial exposure as well as in those produced by smooth and crinkled intertidal algae is very fine grained with predominantly homogeneous luminescence (NZh). This overall upward fining pattern in dolomite textures is characteristic of dolomitized regressive packages even if the section contains interbedded limestone as it does off the present axis of the Nashville
Dome in the north-central, eastern and southern portions of the study area. This suggests that distribution of early, fine grained, homogeneous luminescent (NZh) dolomite may have been dependent on the relative position and distribution of facies occurring during each episode of regression; sediments proximal to areas subject to high rates of evaporation may have been more susceptible to early dolomitization. Furthermore, this pattern of alternating limestone and dolomite suggests that early (NZh) dolomite may have grown predominantly during or shortly after each regressive package was laid down.

C. Dolomite Fabrics and the Occurrence of NZc Luminescent Dolomite Grains

1. Fabrics in partially dolomitized limestone samples

Burrows, laminae, changes in algal morphology, ripples, differences in insoluble residue content, and fenestral fabric all provide minor inhomogeneities in limestone (Gorody, Part I). Such inhomogeneities necessarily have differing responses to both burial compaction and diagenetic fluid flow and tend to be accentuated by these different processes. The distribution and petrographic characteristics of light colored dolomite patches in limestone appears to be related to such inhomogeneities. For example, burrows can be preferentially dolomitized. Figure 40A and B shows a burrow that was affected by at least two generations of dolomitizing fluids. An earlier generation of dolomite yielded a permeable, fine grained xenotopic mosaic of homogeneous bright luminescent dolomite; later, dolomitizing solutions permeated the dolomitized burrow and precipitated dull Type II luminescent zoned dolomite that replaced limestone immediately adjacent to the burrow.
FIGURE 40. Luminescent-transmitted light photo pair of NZc and Z\textsubscript{2} dolomite associated with burrow in limestone.

40A. Transmitted light photograph showing Z\textsubscript{2} dolomite growing at the boundary between a burrow, dolomitized by fine grained xenotopic dolomite, and pelsparite. Z\textsubscript{2} dolomite grows into a fracture at the lower left hand corner of photograph, indicating that the limestone was fairly consolidated at the time of dolomitization.

40B. Luminescent photograph of same sample, at higher magnification. Note that relatively bright luminescent rhombs in the xenotopic mosaic have been embayed and partially replaced by dull luminescent dolomite leaving relict blebs of bright luminescent dolomite. This relationship suggests that the xenotopic dolomite mosaic within the burrow was permeable to subsequent dolomitizing solutions.
FIGURE 41. Luminescent photo of dolomite in limestone. Note scoured surface on a marine cemented oolitic grainstone. Marine cement exhibits no luminescence. Overlying scoured surface is another grainstone with similar allochems cemented by phreatic luminescent zoned calcite. Dolomite grows in pore space not occluded by calcite cement.

FIGURE 42. Luminescent photo of dolomite in limestone. Fenestral fabric occurring in this pelmicrite is partially occluded by luminescent zoned calcite. Remaining pore space is occluded by coarse, homogeneous luminescent dolomite.
FIGURE 43. Luminescent photo of $Z_2$ dolomite in limestone. Fenestral pore space occurring in this intrapelmicrite was occluded by geopetal vadose silt and luminescent zoned calcite. Remaining pore space is occluded by Type II luminescent zoned dolomite.

FIGURE 44. $Z_2$ overgrowths on medium grained, sector zoned, xenotopic dolomite, enclose a small lens of limestone. Vuggy porosity would result if limestone were to be dissolved. Transmitted light photograph.
As a result, remnants of the originally homogeneous bright luminescent dolomite are centrally located within xenotopic rhombs that are now characterized by their NZc type luminescence.

Larger than burrow sized irregularly shaped lenses of xenotopic dolomite occurring in limestone appear to have grown within inhomogeneities produced during early compaction. As shown in Figure 32, these pockets were also susceptible to one or several generations of dolomitizing fluids.

Dolomite distribution may also be controlled by differences in limestone permeability produced by an earlier episode of vadose or phreatic diagenesis. Figures 41 and 42 show that dolomite grew in pore spaces not occluded by luminescent zoned calcite that grew in a phreatic environment (cf. Meyers, 1974). Figure 43 shows such open pores in fenestral fabric floored with vadose silt and occurring in a pelleted limestone that host Type II luminescent dolomite.

Small limestone lenses surrounded by dolomite, occurring across transitional boundaries between dolomite beds and limestone beds yield another commonly observed mottled texture. Dolomite in these rocks can exhibit one or more luminescent types. When more than one type occurs, Type II zoned dolomite lines the entire limestone lens (Fig. 44).

2. Fabrics in predominantly dolomite and purely dolomite samples

Pervasively dolomitized bedded, laminated, and burrowed lagoonal sediments are typically color mottled and composed of fine and medium grained NZh and NZc dolomite. Ripple marked and laminated sediments
characteristic of intertidal environments are predominantly replaced by fine grained NZh and NZc dolomite and are also occasionally color mottled. Such color mottled rocks commonly consist of dolomite exhibiting patchy bimodal grain size distribution. In these samples, small pockets of lighter colored dolomite enclosed by darker colored xenotopic and hypidiotopic dolomite, contain fewer and larger crystals per unit area than the surrounding dolomite. Boundaries between smaller rhombs and patches of larger rhombs are commonly sharp, so that a gradual increase in crystal size across the boundary is rarely seen (Fig. 168). These observations suggest that minor inhomogeneities in pervasively dolomitized carbonates yielded fewer dolomite nucleation sites. Larger crystal sizes, therefore, may be due to two factors: faster growth rates or longer growth periods. Cathodoluminescent examination of rhombs within and rhombs surrounding lighter colored mottles show that their central zones, often exhibiting circular to rhombohedral shapes of relatively bright luminescence (NZc) are of approximately the same size. This suggests that dolomite growth rates were equivalent. Because a greater number of nucleation sites occurs outside mottles, those areas became occluded first and thus became relatively impermeable. Consequently, dolomitization continued within relatively permeable mottled zones that continued to be accessible to dolomitizing solutions. Type II and Type III luminescent zoned dolomite overgrowths on larger crystals within mottles is frequently observed, therefore these areas must have remained relatively permeable throughout the dolomitization history of Mascot rocks.
Mottling may also be produced when inclusions originally occurring in dolomite are digested or redistributed during multiple dolomitization episodes. Minute inclusions of undigested limestone, clay and organic matter, are predominantly responsible for cloudiness observed in dolomite rhombs. These inclusions may have homogeneous or patchy distribution throughout rhombs, or they may outline the shape of ooids, pellets, intraclasts and other relict allochems. Redistribution or loss of inclusions in originally cloudy dolomite is herein referred to as bleaching.

Patterns of clear and cloudy dolomite in Figure 45A and B suggests that xenotopic dolomite here originally contained abundant inclusions homogeneously distributed throughout each crystal. However, several grains are surrounded by halos of inclusion-free, optically clear dolomite. Removal of inclusions appears to be related to the growth of Type II dolomite rhombs. Figure 45B shows that the bleached rinds surrounding xenotopes correspond to halos of dulled luminescence and pore spaces filled with Type II luminescent dolomite. Detailed examination of Figure 45A shows that original xenotopic NZc crystals are broadly zoned with a wide, relatively bright zone at their centers, and a dull zone at their edges. Central zones appear euhedral in outline but are embayed and interrupted by duller luminescing dolomite. Type II overgrowths occur on these crystal within pore spaces and around crystals adjacent to limestone; luminescent zones are sharp and continuous around the edges of overgrown crystals. Thus, prior to or during Type II dolomite precipitation, iron and manganese were being remobilized in earlier crystals of dolomite, thus producing one type
of NZc crystals. Because these crystals were rich in inclusions, they may also have been rich in crystal defects that allowed solutions internal access. Thus, solutions travelling through this permeable rock matrix mobilized iron and manganese across the network of defects, so that only remnants of original brighter luminescent cores remain. It also appears that the outermost edges of earlier dolomite crystals reequilibrated with subsequent dolomitizing solutions; overgrowths may have efficiently consumed and excluded all inclusions from the crystal lattice. Such a process produced optically clear dolomite. Patches of dolomite susceptible to this process are lighter in color than dolomite not affected, and thus color mottling was produced.

Many samples of xenotopic and hypidiotopic NZc dolomite in the Mascot Formation show similar evidence indicating mobilization of iron and manganese previously locked in crystals even though they do not co-occur with Type II dolomite. These NZc crystals commonly retain irregular blebs of bright homogeneous luminescence (Figs. 8A, 9 and 10). Blebs appear to be embayed and partially consumed by dolomite of greater optical clarity and dulled luminescence. When viewed in diffuse transmitted light, such blebs originate from central portions of rhombs that are sector zoned (Folk, 1959), or have cloudy rhombohedral and circular cores. Occasionally, these central zones, when viewed under cathodoluminescence, appear pitted with minute holes filled with either calcite or dull-luminescent dolomite.

Figure 46 shows a sample in which bleaching has removed evidence of relict allochems. Small euhedral pore spaces are surrounded by clear dolomite free of ooid ghosts. Under cathodoluminescence, areas of clear
dolomite are luminescent zoned Type II dolomite; luminescent zones are best developed within euhedral pores. Because these bleached areas do not appear to be distributed along fractures, later Type II dolomitizing solutions must have travelled between grains in earlier inclusion-rich dolomite. Efficient consumption and/or exclusion of inclusions during reequilibration may have produced small pore spaces if molar rather than volume replacement of limestone inclusions occurred.

In summary, these observations suggest that earliest, non-luminescent zoned dolomite rhombs in permeable mosaics can have their original luminescent character partially or totally obliterated by solutions related to subsequent dolomitization episodes. Such subsequent episodes often bleach earlier, inclusion-rich rhombs. Multiple episodes of non-luminescent zoned dolomite growth can not be identified if luminescent and petrographic characteristics of later rhombs are similar to the original dolomite. On the other hand, NZc equisized dolomite grains result from two or more episodes of dolomitization. Multiple generations of dolomite can also be positively identified when zoned and non-zoned luminescent dolomite occur together in a sample. Color mottling of dolomite in hand specimens may be used as a preliminary indication that multiple dolomitization episodes affected the rock column. Therefore, such samples should be examined first under cathodoluminescence.
FIGURE 45. Luminescent-transmitted light photo pair of $Z_2$ dolomite overgrowths on NZc dolomite exhibiting bleached crystal boundaries.

45A. Luminescent photograph of $Z_2$ dolomite growing at the boundary between medium grained xenotopic dolomite and micritic limestone. Note that relatively bright rhombohedral cores within xenotopic dolomite have been partially embayed and replaced with dull luminescent dolomite. This relationship suggests that dolomitizing solutions travelled through the xenotopic mosaic of dolomite crystal before $Z_2$ dolomite replaced limestone.

45B. Transmitted light photograph of same field of view. Note that optically clear dolomite corresponds to those areas exhibiting dulled luminescence in the photograph above.
FIGURE 46. Transmitted light photograph showing bleached patches in medium grained xenotopic mosaic dolomite replacing ooid grainstone. Patches of clear dolomite result from infiltration of subsequent dolomitizing solutions that removed cloudy inclusions and thus removed traces of grains (arrows).
D. Petrography of Dolomite Grain Types with Respect to Solution Episodes in the Mascot Formation

Because Type II dolomite replaced limestone blocks and cemented NZh, NZc, and Z₁ dolomite blocks that filled collapsed grainstone units, these dolomite types must have grown prior to solution, collapse and Type II dolomitization. Type III dolomite, as established earlier, grew following brecciation and solution pitting of Type II dolomite, as well as before and during the mineralization episode. These petrographic relationships therefore indicate that there were at least two episodes of limestone solution followed by collapse and dolomitization.

In those cores that show abundant evidence of limestone solution and brecciation, limestone lenses originally surrounded by dolomite are commonly dissolved. Vugs created by solution of such small limestone lenses can be floored with geopetal silt, presumably insoluble residue, and carbonate debris. Vugs formed during the first solution episode are lined with and totally to partially occluded with Type II dolomite, lined or partially occluded with either Type II and Type III dolomite, or they are unlined and open. Those vugs formed during the second solution episode are partially to totally occluded with Type III dolomite or they are also empty. When vugs produced during this second solution episode are lined with Type II dolomite they have geopetal silt resting on top of and filling pore spaces between Type II dolomite rhombs. Type III dolomite occurring in all vugs may enclose small grains of sphalerite.

Zones of vuggy porosity are ideal passageways for mineralizing and dolomitizing solutions, especially if fractures produced during collapse connect vugs. Furthermore, petrographic examination reveals
that interconnected vuggy networks are extremely resistant to collapse and compaction because remnant dolomite behaves as archways with enough strength to support overburden. Such zones therefore remained highly permeable as evidenced by the infilling of these vugs with minerals and mineral-related dolomite. This may provide one reason why economically important minerals are more likely to accumulate in areas where limestone and dolomite interfinger (mining co. exploration manager, pers. comm.).

E. Geochemistry

Both oxygen isotopic analyses and atomic absorption analyses show similar trends in values between limestone and dolomite samples; values for limestone samples are shifted away from those for dolomite samples (Figures 47, 48, 49, 50, 51, and 52). This indicates that dolomite values result from continued diagenesis of Mascot Formation sediments. Most significantly all elemental values in dolomite, with the exception of zinc, show several modes. Strontium values exhibit three modes at 140, 80 and 60 ppm, manganese values exhibit two modes at 75 and 45 ppm and iron values exhibit at least three modes at 350, 1050, and 1450 ppm. Zinc values for dolomite exhibit only one mode at 12 ppm that is close within experimental error to that of limestone values at 20 ppm.

Figures 47 and 48 show that the analytical results for zinc among dolomite samples exhibit the smallest range of concentrations, followed by manganese, then strontium, and finally iron, which exhibits the largest range in values.
Modes in the analytical results suggest a relationship between geochemical signatures and geochemistry of possible dolomite generations. The relationship becomes apparent when elemental values are plotted against each other. For example both iron and manganese values increase as strontium values decrease. More importantly, plots of iron against manganese (Fig. 49), manganese against strontium (Fig. 50), and iron against strontium (Fig. 51), demonstrate that differences in elemental values for dolomite are closely related to cathodoluminescent properties of the samples.

Based on the temporal relationships established for dolomite with differing luminescent characteristics, successive generations of dolomite yield a progressive increase of iron and manganese concentrations as well as a progressive decrease in the concentration of strontium. For example, dolomite samples exhibiting homogeneous luminescence have the highest strontium and the lowest iron and manganese values; Type III dolomite samples have the highest iron and manganese and the lowest strontium contents; Type II dolomite rhombs have intermediate values. The same relationships are indicated by the few samples for which stable isotope measurements are available. Very fine grained dolomite exhibiting homogeneous luminescence has the heaviest oxygen isotope values, Type III dolomite has the lightest oxygen isotope values and all other samples have intermediate values (Fig. 52 and Table 5). These results suggest that the hydrologic system throughout diagenesis was open, resulting in continual reequilibration of samples with waters flushed through the system.
Analytical results show that isotopic fractionation between dolomite and limestone samples is smaller than the fractionation expected if dolomite grew in isotopic equilibrium with calcite. For example, based on extrapolation from high temperature experiments (Hanza and Broecker, 1974; Northrop and Clayton, 1966; O'Neil and Epstein, 1966), values of coexisting mineral pairs precipitated in equilibrium within hydrothermal and metamorphic terraines (Clayton and Epstein, 1958; Engel et al., 1958; Sheppard and Schwarz, 1970), and low temperature experiments with magnesium calcite and protodolomite (Fritz and Smith, 1970, Tarutani et al., 1969), dolomite coprecipitated in isotopic equilibrium with calcite at temperatures between 20 - 25°C will be heavier in δ^{18}O/^{16}O by +4 to +7 per mil and will be heavier in δ^{13}C/^{12}C by +3 to +4 per mil relative to calcite. However, maximum enrichment here is +3.6 for oxygen and +1 for carbon isotopes. Such values are consistent with numerous fractionation values obtained by Degens and Epstein (1964) from coexisting limestone and dolomite samples throughout the world.

Excepting the value obtained for Type III dolomite, dolomites are both enriched in O^{18} and have a wider range of values than those of limestones. Wider oxygen isotope range indicates that dolomitization occurred under the influence of formation fluids with variable chemical composition. This also explains why fractionation values between limestone and dolomite samples are smaller than expected; successive dolomite overgrowths on previous rhombs and partial reequilibration of early rhombs with successive dolomitizing solutions shifted isotopic values towards limestone values. These observations are consistent with
petrographic evidence. The shift towards increasingly negative oxygen isotope values suggests that either successive dolomitization episodes occurred at progressively higher temperatures, or that dolomite grew under the influence of meteoric waters. Because petrographic evidence suggests that the bulk of the dolomite grew prior to significant burial of the sediments, it is unlikely that the fractionation was due to dolomitization at increased temperatures. Thus, meteoric influence is indicated, especially for those samples exhibiting Type II luminescence. Similar interpretations have been suggested for other dolomitized terrains (Land, 1970, 1973; Supko, 1977).

Both limestone and dolomite samples show similar values and a similar range of carbon isotope values. These values fall within the range derived from normal marine carbonates (Craig, 1953; Hoefs, 1973). They also suggest that carbon isotopic values were derived from lower Ordovician carbonates and were not influenced by soil-derived bicarbonate that would have produced more negative carbon isotopic values (Hoefs, 1973).
FIGURE 47. Histograms of atomic absorption analyses for Mn and Fe in both dolomite (shaded) and limestone samples.
FIGURE 48. Histograms of atomic absorption analyses for Sr and Zn in both dolomite (shaded) and limestone samples.
FIGURE 49. Plot of atomic absorption results for Mn and Fe in both limestone and dolomite samples. Values for iron as plotted are X.1 of actual values.
FIGURE 50. Plot of atomic absorption results for Mn and Sr in both limestone and dolomite samples.
FIGURE 51. Plot of atomic absorption results for Sr and Fe in both limestone and dolomite samples. Values for iron as plotted are X.1 of actual values.
FIGURE 52. Stable carbon and oxygen isotope results for selected dolomite and limestone samples. Refer to Table 5 for description of samples.
DISCUSSION

Because modern dolomite examined throughout the world is micron sized, carbonate geologists have been unable to provide a satisfactory mechanism explaining the absence of micron-sized dolomite in ancient rocks. The results of this investigation suggest that multiple episodes of dolomitization occurring over time resulted in the fine and medium grained textures observed in Mascot Formation dolomite. The occurrence of decimicron-sized, cloudy, xenotopic dolomite crystals with the highest strontium values and heaviest oxygen isotope values in the Mascot Formation suggest that such dolomite grew from solutions produced in an evaporative environment. This interpretation is consistent with the sedimentologic textures observed; the finest rhombs occur at or near the top of each prograded package of sediments (Gorody, Part I). However, this dolomite represents only a limited percentage of the rock column. The majority of the section is comprised of predominantly xenotopic, centimicron sized dolomite exhibiting variable strontium and oxygen isotope values.

Finest grained dolomite samples exhibit predominantly dull homogeneous luminescence. Coarser rhombs, exhibiting predominantly dull homogeneous luminescence, either have blebs of relatively brighter luminescent dolomite that may or may not be centrally located within rhombs, or they exhibit brighter luminescent circular to rhombic cores. This suggests that coarser dolomite textures may have been produced by
episodic and/or progressive dolomite growth under changing geochemical conditions relatively early in the diagenetic history of these sediments. For instance, one set of geochemical conditions can produce relatively bright luminescent dolomite, whereas subsequent or progressive dolomitization in a different geochemical environment can produce relatively dull luminescent dolomite. Provided partial reequilibration of dolomite with subsequent dolomitizing solutions takes place, it is possible to produce relatively dull luminescent dolomite overgrowths surrounding either remnants of brighter luminescing dolomite or circular cores of brighter luminescing dolomite. On the other hand, if the geochemical environment changed gradually as dolomite growth continued, then rhombohedral would retain rhombic or zoned cores of relatively bright luminescence.

Whether or not initial or subsequent dolomitizing solutions produce luminescent dolomite depends on both the oxidation state of the dolomitizing fluids and the availability of ferrous ions that when incorporated in the dolomite lattice act to quench luminescence. Only manganese +2 ions occurring in reduced environments activate luminescence when incorporated in the dolomite lattice. Thus, dolomite growing in an oxidizing environment will not luminesce and explains why supratidal dolomite from Florida and the Bahamas does not luminesce (Glover, 1977). However, reduced environments in which both Mn+2 and ferrous ions occur are common at relatively shallow depths within tidal flat sediments. Therefore, were dolomite to grow in such environment, it would luminesce only if ferrous ions could be prevented from entering the dolomite lattice. Thus, there must have been some ubiquitous mechanism operating in Mascot sediments to account for commonly occurring NZc dolomite.
Recent studies have shown that ionic iron is strongly complexed and chelated by dissolved organic matter whereas ionic manganese is not (Krom and Sholkovitz, 1978; Moore et al., 1979; Sass and Starinsky, 1979). It is known that pore waters on algal tidal flats are rich in dissolved organic matter. Therefore, dolomite growing in a reduced organic-rich environment could incorporate Mn+2 and luminesce provided ferrous iron remains complexed and ionic manganese uncomplexed. It is also well known that organic matter degrades with burial, and that the molecular integrity of dissolved organic matter can be easily destroyed by *Desulfovibrio* bacteria. Lyons and Gaudette (1979) have shown that *Desulfovibrio* content increases with depth in modern estuarine environments, and that these bacteria degrade algal organic remains much faster and more effectively than organic remains of vascular plants. Assuming *Desulfovibrio* or equivalent bacteria lived in reduced, algal-rich early Ordovician tidal flat sediments, and that their numbers increased with depth, degraded organic matter in sediments would have increased with depth and time. As degrading organic matter released chelated ferrous iron into the pore water system, ferrous ion content available for incorporation into the dolomite lattice also increased with depth and time. Consequently, dolomitization subsequent to initial dolomitization of near-surface sediments may have produced dolomite with quenched luminescence. Furthermore, degradation of algal derived organic matter during diagenesis also releases Mg which may serve as a Mg source for later dolomitizing solutions (Gebelein and Hoffman, 1971). This sequence of events explains why relatively bright luminescing dolomite is commonly surrounded by dull luminescing dolomite.
Centimicron sized, NZc luminescent dolomite rhombs began growing in a reducing environment before sufficient iron was released into the pore water system to quench luminescence. Discontinuous and episodic growth of these rhombs necessitated reequilibration with subsequent dolomitizing solutions in which unchelated and uncomplexed ferrous irons became increasingly concentrated. As a result, portions of earlier micron-sized brighter luminescing rhombs, were partially digested and enlarged by reprecipitated, relatively dull luminescent dolomite. If on the other hand, growth was continuous and dolomite rhombs began growth while iron was complexed and growth continued as iron was released into the pore water system, then rhombs with relatively bright luminescing rhombic cores were produced.

This mechanism can also explain the occurrence of Type I dolomite. If dolomite growth was uninterrupted and rates of ferrous iron incorporation into the dolomite lattice approached dynamic equilibrium with the rate of ferrous iron release into the pore water system, then zoned dolomite would have been formed. For example, slightly accelerated dolomite growth rates would result in removal of ferrous iron within the aqueous system and a bright luminescent zone would be produced. Alternatively, a slightly higher rate of ferrous iron release would produce a quenched zone. Because Type I dolomite rarely occurs in the Mascot Formation, such a dynamic equilibrium mechanism may have been a rare event.

Atomic absorption analyses of dolomite samples in the study area reveal that very fine grained dolomite samples exhibiting dull homogeneous luminescence have relatively low iron concentrations, whereas coarser
grained dull luminescent dolomite with bright central zones or blebs have highly variable iron concentrations. A plot of iron versus manganese (Fig. 49) shows not only that there is a direct relationship between iron and manganese content in dolomite samples but also that the range in iron values is nearly four times the range of manganese values. This suggests that manganese concentration was relatively constant with respect to iron throughout dolomitization and supports a mechanism that obtains a gradual increase in iron content throughout dolomitization history of the sediments. Also, a plot of strontium versus iron content in dolomite samples (Fig. 51) shows that in general, higher strontium values are associated with lower iron contents. These data support multiple dolomite growth episodes; each episode is accompanied by a progressive increase in dolomite grain size, a large increase in iron content, a small increase in manganese content, and a decrease in strontium content.

The narrow range of stable carbon isotope values for all dolomite samples suggests that degradation of organic matter was not complete enough to release organic derived carbon to be incorporated into the carbonate equilibrium system. Had that been the case, more negative carbon isotope values might be expected. These data support the idea that only chelated and complexed ferrous ions were released, and that the environment was not strongly reducing.

The tendency for dolomite to be progressively finer grained when associated with macrotextures and sedimentary structures indicative of progressive shallowing and subareal exposure suggests a model to explain the progressive dolomitization of Mascot Formation sediments, on modern evaporative
tidal flats, dolomite growth is more pervasive within surficial sediments, and the abundance of dolomite rhombs decreases with depth. This gradual transition of dolomite content with depth is observed in modern carbonates from Bonaire (Deffeyes et al., 1965), Andros Island, (Shinn et al., 1965 and 1969), and the Persian Gulf (Butler, 1971). A progressive change in dolomite rhomb abundance can also take place if dolomitizing fluids travel through supratidal and intertidal sediments along sedimentologically controlled permeability pathways leading away from the source of dolomitizing fluids. In this instance, the further the sediments are from the source of dolomitizing solutions, the sparser the dolomite rhombs. An example of this type of transitional boundary has been documented in the Persian Gulf by Bush (1973). One way to produce an overall increase in size of dolomite rhombs with depth is to subject transitional boundaries described above to repeated influxes of dolomitizing solutions over a period of time. Under these conditions, originally pervasively dolomitized sediments would necessarily remain very fine grained because there would be limited space between rhombs for overgrowths of later dolomite. However, later dolomite could easily precipitate as overgrowths on seed crystals within dolomite in transitional zones, thus increasing the overall size of crystals.

The mechanism for early dolomitization may have been similar to the evaporative pumping mechanism occurring on Persian Gulf sabkhas (Hsu and Siegenthaler, 1969; Hsu and Schneider, 1973; and McKenzie et al., 1979). An increase in the Mg/Ca ratio of interstitial solutions necessary for initial dolomitization (Folk and Land, 1975) accompanied gypsum precipitation on Ordovician evaporative tidal flats. Because
gypsum was not observed in tidal flat sediments of the Mascot Formation, it is probable that gypsum dissolved following tidal, storm derived and eustatic transgressive incursions of sea water (Gorody, Part I). Such incursions drowned evaporate pumping and introduced carbonate sediments that buried dolomite crusts and transitional boundaries of the type described above. At least two significant prerequisites would have been necessary for continued dolomitization once the initial evaporative pumping mechanism ceased: there would have to be a source for magnesium; magnesium-bearing brines would have to have access to pathways of permeability so that magnesium could be distributed throughout each prograded sedimentary package.

Magnesium necessary for subsequent dolomitization could have been derived from conversion of high magnesium calcite to low magnesium calcite or, decomposition of algal-derived organic matter that served to complex magnesium ions or, seepage refluxion of brines derived from a relatively distant source or, from an overlying package of sediments or, introduction of fresh water into the pore water system serving to decomplex strongly hydrated Mg ions. Geochemical data gathered here indicate that dolomitized sediments were open to different kinds of fluids. For example, strontium values decrease as oxygen isotopes delta values become lighter and as dolomite rhombs become larger. These data indicate that introduction of fresh water into the pore water system may have been an important dolomitizing mechanism. Such a mechanism is consistent with modern hypotheses of "schizohaline" dolomitization. These essentially propose that introduction of fresh water into a pore water system filled with Mg-rich brines promotes dolomitization because
it serves to increase activity of Mg ions; ions become dehydrated while the Mg/Ca ratio in solution remains relatively constant (Folk and Land, 1975).

The vertical distribution of Mascot sediment types was ideally suited for the distribution of magnesium-bearing solutions. In general, each prograded wedge of sediments was characterized by an upward decrease in grain size. Enos (1979) has shown that mean permeabilities in grainstones and packstones from Holocene carbonate sediments are four to nine times greater than permeabilities in wackestones, and 100 to 200 times greater than permeabilities in very fine wackestones. Therefore, relative permeabilities of sediments in upward-fining Mascot sediments must have decreased significantly upward. Even if the uppermost fine grained sediments in any package had their permeabilities sealed with xenotopic mosaics of dolomite, subsequent "schizohaline" dolomitizing solutions could travel through coarser, more permeable sediments below. These were deposited in normal marine high energy environments, in restricted marine strand line or beach sediments, and in tidal channel environments (Gorody, Part I). Such a mechanism may explain why xenotopic dolomite exhibiting ghosts of ooids and intraclasts have relatively light oxygen isotopic values.

The dolomitization mechanism that produced Type II luminescent zoned rhombs was very different than that which produced non-zoned luminescent and Type I luminescent dolomite. This can be explained by differences in scale and mineralogy of carbonates being replaced, growth rates, permeability pathways through which dolomitizing solutions
travelled, and differences in geochemical conditions under which dolomite grew.

Solutions that produced Type II dolomite rhombs affected the entire Mascot Formation and upper portions of the Kingsport Formation throughout the study area whereas earlier dolomitization affected portions of one or a few local sedimentary packages at a time. It is therefore likely that Type II luminescent zoned rhombs grew in carbonate sediments that had undergone vadose and phreatic diagenesis and had been transformed from a polymineralic carbonate assemblage to a bimineralic assemblage of calcite and dolomite. This idea, supported by textural relationships established earlier between limestone and Type II dolomite, may provide a reason for Type II dolomite exhibiting coarse-grained hypidiotopic and idiotopic dolomite textures. Under experimental conditions of one atmosphere pressure, at 252 to 295° C (Katz and Matthews, 1977) and at 100° C (Gaines, A., pers. comm., 1979) reaction rates for dolomitization differ if the reactants are Mg calcite, aragonite, or calcite. Gaines found that at 100° C aragonite is dolomitized faster than Mg-calcite, which in turn reacts faster than calcite. This may provide one reason that xenotopic dolomite is predominantly cloudy and zoned dolomite is predominantly limpid. Xenotopic non-luminescent zoned dolomite may have grown quickly and trapped inclusions before they could be digested or excluded from the crystal lattice. Coarser, zoned dolomite, on the other hand, is limpid whenever delicate luminescent zonation can be recognized. Furthermore, had Type II dolomite grown faster than the rate at which the interstitial water chemistry responsible for producing zonation changed, no zones would be
visible or zones would be wider and less numerous. Because Type II dolomite is idiotopic and hypidiotopic and exhibits delicate luminescent zonation, this textural evidence supports experimental evidence that dolomite replacing a polymineralic assemblage grew faster than dolomite replacing calcite.

The following observations indicate that initial access of regional dolomitizing solutions into the sedimentary column was provided primarily by solution and collapse of grainstone units and that these processes were contemporaneous with the evolution of the Lower Ordovician Sauk unconformity:

1. Textural relationships between detrital dolomite blocks with Type II overgrowths occurring in brecciated sediments indicate that collapse preceeded regional dolomitization.

2. Type II dolomite occurring in collapsed units commonly enclose ghosts of ooids and intraclasts.

3. Fractures and vugs are commonly lined with Type II dolomite exhibiting abundant luminescent zones.

4. Samples of xenotopic NZc dolomite and those showing evidence of bleached boundaries related to the invasion of regional dolomitizing solutions have Type II dolomite growing in pore spaces, but the number of luminescent zones are few. Zones are far more abundant in fractures.

5. Porosity and permeability values for dolomite plugs taken from core D6 show that those plugs with fine and medium grained xenotopic mosaics have permeabilities lower than an average for 26 or 30 samples of .06 millidarcies (Table 1). These extremely low values suggest that xenotopic dolomite mosaics must have been relatively
impermeable to regional dolomitizing solutions when compared to permeabilities produced by fracturing.

The relative position of the earliest recognizeable luminescent zones in Type II dolomite with respect to the complete luminescent microstratigraphic sequence appears to be randomly distributed with depth in the sedimentary column (Fig. 26). This indicates that different portions of the sedimentary column became accessible to regional dolomitizing solutions at different times. Furthermore, because the relative position of the latest recognizable luminescent zones are also randomly distributed with depth, portions of the sedimentary column became sealed to regional dolomitizing solutions at different times. Lastly, all of the zones occurring near the top of the Mascot Formation, also occur near its base (cores 137, D6, and D5 in Fig. 26). These observations together indicate that dolomitizing solutions travelled laterally through the Mascot Formation. In fact, because the earliest zones occur in all three northern cores, 136, 137 and 18 and are absent in the two southern cores D5 and D6, regional dolomitizing solutions appear to have travelled from north to south. Also, the very earliest luminescent zones occur at the base of core 18 (subzone AA), thus dolomitizing solutions are shown to have worked their way upward as well as laterally through the sedimentary column. Although additional evidence is needed to substantiate this last observation, there is absolutely no evidence indicating the downward movement of dolomitizing solutions.

Gorody (Part I), has demonstrated that the sedimentary sequence in the Mascot Formation indicates progressive shallowing of the study
area throughout deposition. On the basis of an isopach map of the
upper member of this formation (Fig. 22), he also suggests that the
Nashville Dome had become a positive feature by the time the regional
unconformity was developed on the Mascot. This investigation demon-
strates that Type II luminescent zoned dolomite grew after a regional
episode of limestone solution and collapse, presumably related to the
invasion of corrosive vadose solutions through the sedimentary column
occurring during initial subareal exposure and throughout the evolution
of the Sauk unconformity, but before the final phase of the middle
Ordovician transgression. Therefore, Type II luminescent zoned dolomite
must have grown during the transgression of middle Ordovician seas.

The sum of all the evidence can only mean that Type II lumines-
cent zoned dolomite grew throughout the study area in response to
regional mixing between transgressive marine waters and meteoric waters
recharged on topographic highs. Thus, the following sequence of events
is indicated.

The middle Ordovician transgression began after maximum subareal
exposure of the incipient but topographically positive Nashville Dome.
Seas must have invaded topographic lows first, and therefore mixing
first began close to those areas. This explains why Type II dolomite
in the three northern cores exhibited earlier luminescent zones than the two
southern cores. Cores 136, 137, and 18 are located near the northern
plunging axis of the present Nashville Dome, and at the edge of the
Cumberland Saddle; cores D5 and D6 are located closer to the interior
and horizontal axis of the Dome (Fig. 22). Assuming that the axis of the
incipient Ordovician Nashville dome corresponded closely to the present
axis (Gorody, Part I), then the three northern cores occupied a position
that was closer to the topographically low Cumberland Saddle than the
two southern cores. This is supported by the northward thickening of
isopachs in Fig. 22. Therefore, mixing and subsequent dolomitization
would have occurred earlier to the north, nearer the topographic low of
the Cumberland Saddle. As the middle Ordovician seas continued trans-
gressing, the mixing zone was being progressively shifted upward through
the sedimentary column. This is substantiated by early luminescent
zones in the three northern cores and the observation that the very
earliest luminescent zones anywhere occur at the very base of core 18.

Runnels (1969), Badiozamani (1973), and Plummer (1975), have
shown that when calcium carbonate saturated groundwaters initially mix
with sea water, the resultant fluids are commonly undersaturated with
respect to calcite. Thus, initial mixing during the middle
Ordovician transgression could have caused continued collapse of already
highly permeable, cavernous and vuggy limestones. Such a process
explains the random distribution of early luminescent zones with depth.
Certain stratigraphic horizons were impermeable to regional dolomitiz-
ing solutions until solution and additional collapse following initial
mixing provided new avenues of permeability into those horizons.
Dolomitization ceased as the transgression over the incipient Nashville
Dome covered all areas of meteoric recharge and mixing stopped.

The mechanism proposed above can also be used to help predict
the geographic and depth distribution of remnant limestone beds in a
regionally dolomitized terrain. For example, pervasively dolomitized
rocks might be expected directly below and surrounding paleotopographic
highs. Because these areas must have been recharged zones for the longest period of time relative to topographic lows, mixing, collapse, and dolomitization accompanying regional transgression would have been most thorough below topographic highs.

Other factors, however, also determine the distribution of limestone in regionally dolomitized terrains. In light of facies distribution in the lower Ordovician peritidal environment in central Tennessee (Gorody, Part I), it is easy to visualize how lenses of limestone can be protected from invading solutions. Relatively permeable sediments were surrounded by relatively impermeable lagoonal and algal bound sediments and were capped by relatively impermeable xenotopic supratidal and later dolomite. Such lenses of limestone, mainly shoals or bars or channel fills, could have remained protected from regional dolomitizing solutions unless fracturing allowed solutions access to these permeable horizons. Gorody (Part I) has shown that several unaltered grainstone beds in the study area exhibit evidence of burial compaction in the form of abundant microstylolitic contacts between grains and an absence of vadose silt or collapse. Samples exhibiting such compaction textures have been plotted next to the cores in Figure 26. These observations indicate that several grainstone units, especially those in core D6, must have been uncemented at the time of burial, and therefore, must have been highly permeable. However, these grainstone units survived dolomitization as well as several solution episodes. Evidence presented earlier indicates that solutions producing Type II dolomite rhombs pervaded micritic limestone beds during but before final compaction of the sediments. Assuming that compaction of micrite
and compaction of uncedmented grainstones was essentially contemporaneous, then uncedmented grainstones survived solution and regional dolomitization because they were sealed off. These observations further support regional dolomitizing solutions travelling preferentially through avenues of fracture, cavern, and vug related permeability.

The mechanism of emplacement of Type III luminescent zoned dolomite rhombs in the study area is also quite different than others already discussed. Because Type III dolomite occurs exclusively in open pore spaces, vugs and fractures, dolomitizing solutions must have travelled predominantly through highly permeable avenues of fractured and collapsed sediments. It is significant that a large number of samples exhibit Type III dolomite overgrowths on Type II dolomite. This suggests that there were common avenues of maximum permeability for both generations of dolomitizing solutions producing Type III and Type II rhombs. These observations indicate that the most permeable avenues occurring in the original sediments exerted control on the permeability of the rocks during subsequent diagenesis. As several generations of dolomite grew in vugs and fractures produced by the solution and collapse of grainstone units. The results of this investigation also show that at least one additional episode of solution and collapse occurred prior to the emplacement of Type III dolomite but after the growth of Type II dolomite rhombs. Petrographic examination of these collapse zones indicate that there was no preference for limestone types involved in the solution process; wackestones, packstones and grainstones were all
dissolved during the latter solution episode. These observations suggest that the latest corrosive solutions attacked limestones irrespective of their original permeabilities. By that time, multiple episodes of diagenesis probably had served to occlude most original permeabilities in limestones, and access to these limestones must have been provided through fractures. Furthermore, closely spaced drill holes commonly have irregularly distributed collapse zones. Cores devoid of limestone are replete with major collapse zones (e.g. core D5 in Fig. 26), whereas cores drilled a few tenths of kilometers away exhibit no evidence of major collapse and limestone beds remain intact. These observations indicate that zones of maximum permeability had limited geographic distribution and support the concept of fracture and joint-controlled permeabilities.

Oxygen isotope analyses for both a dolomite sample exhibiting Type I zoned luminescence and Type III dolomite growing within a fracture transecting the same sample shows that the isotopic signatures are distinctly different. The sample of Type III dolomite is strongly depleted in $^{18}O$ relative to its host (Table 5, sample 137 - 560.4), indicating that there was little reequilibration between solutions producing Type III rhombs and the host dolomite. This is also substantiated by luminescent petrography showing no remnant blebs within nor overgrowths of Type III dolomite on host Type I dolomite rhombs. Therefore, access of dolomitizing solutions through the host Type I dolomite was made available entirely through fracturing and not through rock matrix.
In summary, access of latest dolomitizing solutions through limestone and dolomite was provided by fractures. These originated following solution and collapse of thin originally permeable limestone facies occurring throughout the stratigraphic column. Fractures were propagated by subsequent episodes of limestone solution and collapse of fractures as well as by jointing and later faulting.

The strongly negative oxygen isotope signature of the single Type III dolomite sample analyzed indicates that crystallization occurred at relatively high temperatures. This is substantiated by two-phase fluid inclusions occurring in Type III dolomite and is supported by homogenization temperatures obtained for 2 phase fluid inclusions in sphalerite (Roedder, 1971). Thus, this style of dolomitization was associated with elevated temperatures.

This investigation also demonstrates that the precipitation of sphalerite interrupted growth of Type III dolomite. The results of geochemical analyses indicate that values for zinc in dolomite samples show no systematic variation with any other element analyzed. Also, Zn concentrations are extremely low among all samples and are lower for dolomite than limestone. Concentrations for manganese, however, are greater for most dolomite samples than for limestone samples. The atomic radius for Zn$^{+2}$ in six-fold coordination is .71 Å and the atomic radius for Mn$^{+2}$ in six-fold coordination is .80 Å. These values indicate that Zn$^{+2}$ would fit more easily in the dolomite lattice than Mn$^{+2}$. However, there are no systematic differences in zinc content with successive dolomitization episodes whereas systematic differences in manganese content are observed. Therefore, it is unlikely that zinc was
significantly concentrated during successive dolomitization episodes. These observations indicate that zinc must have been introduced into the study area at the time of mineralization. Because some fractures in Mississippian sediments have been mineralized, Type III dolomite precipitated and zinc was introduced during or after the deposition of Mississippian sediments.

A summary chart of this discussion are presented in Figures 53 and 54.
FIGURE 53. Summary diagram of dolomite types as defined in this study.
TRANSMITTED LIGHT CATHODOLUMINESCENCE

XENOTOPIC

XENOTOPIC-HYPIDIOTOPIC

HYPIDIOTOPIC

IDIOTOPIC-HYPIDIOTOPIC

IDIOTOPIC
FIGURE 54. Summary diagram of relationship between dolomite types as defined in this study.
<table>
<thead>
<tr>
<th>Sequence of Events</th>
<th>Qualifying Conditions</th>
<th>Resulting Dolomite Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deposition of Peritidal Sediment</td>
<td>Oxidizing Environment</td>
<td>VF, X, dull, Nzh</td>
</tr>
<tr>
<td></td>
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<td>VF, X, dull and bright Nzh</td>
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<td>F-H, H, with rhombohedral cores</td>
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<td>F-H, X-H, N-Z with circular cores and irregular blebs</td>
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<td>Rhombs in Contact with Corrosive Solutions</td>
<td>Corrosion, pitting and Fe^{2+}, Mn^{2+} mobilization in all dolomite types</td>
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<td>Rhombs Not in Contact with Corrosive Solutions</td>
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<td>Solutions Travelling through Dolomite Rock Matrix</td>
<td>Zn in N-Z and N-Zh interstices: bleached dolomite</td>
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**Legend**

- VF = Very Fine Grained
- F = Fine Grained
- M = Medium Grained
- H = Hypidiotopic
- C = Coarse Grained
- VC = Very Coarse Grained
- I = Idiotopic
- X = Xenotopic
- O = Overgrowths
APPLICATIONS

Cathodoluminescent petrography in this investigation establishes that regional dolomitization was contemporaneous throughout a triangular area of at least 1300 km$^2$ and affected at least 250 meters of the sedimentary column. This indicates that formation fluids across these distances reacted contemporaneously to aqueous chemical changes that were regional in extent. It has also been demonstrated that dolomitizing solutions travelled from northern to southern portions of this study area and that these solutions worked their way laterally and upward into the sedimentary column through a complex network of joints, fractures, solution caverns, and collapsed, breccia-supported columns. Therefore, although subsurface fluid movement was primarily channeled through pathways of maximum permeability, this vast aqueous system was chemically and physically linked in space and time. Of key importance is the observation that the same permeability pathways remain open for millions of years. For example, based on the recognition of multiple luminescent dolomite overgrowths in vugs and fractures, it has been established that pathways of maximum permeability in this study area were open to subsurface fluids from the early Ordovician through at least Mississippian time.

All of the above observations suggest cathodoluminescence is a valuable tool that can be applied to study the evolution of regional formation fluid flow patterns in the subsurface. This is of significance
in evaluating the nature and distribution of economic minerals and hydrocarbons in a carbonate terrain. For instance, little is known about the migration history of oils in any terrain. However, existing data indicates oil migration follows pathways similar to those of subsurface fluids. Therefore, if it can be established that a buried carbonate terrain evolved permeability pathways that channel fluids in specific directions and through specific stratigraphic levels, then it can be assumed that hydrocarbons travelling through such a terrain migrated through similar pathways and in similar directions. Going one step further, cathodoluminescence can help predict the regional and stratigraphic distribution of dolomite, a rock type long known as an ideal oil and gas reservoir. For example, the results of this investigation suggest it is possible to outline the paleotopography of an incipient Nashville dome by examining the regional occurrence of earliest luminescent zones within an established Type II luminescent microstratigraphic sequence. The data further suggest that dolomite is stratigraphically most abundant directly below topographic highs and that interfingered limestone beds susceptible to vadose solution and collapse are distributed near the periphery of such paleotopographic highs. Thus, reconstruction of subtle differences in paleotopography with cathodoluminescence could aid geologists to find diagenetic closures in buried carbonate terranes that are transparent to conventional geophysical prospecting tools.

Knowledge, in any region, gained of hydrocarbon or mineral-bearing fluid migration with knowledge gained of reservoir rock distribution and power exploration guidelines emerge to direct the quest for oil in
diagenetic traps. Such information could be obtained with limited expenditure, few numbers of cores and in relatively short periods of time.

Because cathodoluminescent examination of dolomite can aid to evaluate the relative timing of dolomitization events, it may provide the geologist a framework with which to examine the timing of other diagenetic events. For instance, one sample from this study area revealed that a pore space in chert replacing homogeneous luminescent dolomite was filled with Type II dolomite. Therefore, chert grew after the growth of early dolomite and before the growth of Type II dolomite. Another sample showed chert replacing Type II dolomite. Hence, at least two generations of chert growth occurred in the study area. Only two samples showed these relationships between chert and dolomite; further investigation could not be pursued.

Recognition of distinct dolomite generations under cathodoluminescence could greatly amplify the significance of a geochemical study of the diagenetic minerals in an area. Samples could be isolated with this technique and the geochemistry of genetically distinct diagenetic minerals could be more properly evaluated. This technique could also help easily establish paleogeochemical gradients on a regional scale. For example, microprobe analysis of a readily identifiable zone in Type II and Type III luminescent microstratigraphy of dolomite across the Nashville dome, might yield values that could be contoured both vertically throughout the sedimentary column and horizontally across the study area. This also could be of great value in evaluating the
paleohydrography in this and other areas containing dolomite exhibiting zoned luminescence.

Finally, based on the evidence gathered, it appears that regional dolomite may be a transgressive mineral. This would explain the upward and lateral movement of dolomitizing fluids that are being sourced by transgressive sea water and the common occurrence of dolomite below unconformities. If this is the case, it would be expected that concentric Type II luminescent zones in $Z_2$ dolomite would yield heavier oxygen isotopic signatures towards crystal edges and lighter oxygen isotopic signatures towards crystal interiors. These trends should be checked when the technology to study isotopic signatures at the microscopic scale becomes available. Provided the assumption can be validated, geologists would have a new tool with which to evaluate sea level changes through geologic history.
CONCLUSIONS

1. Genetically different dolomite of the Mascot Formation in north central Tennessee is recognizable on the basis of combined petrographic, cathodoluminescent, and geochemical characteristics.

2. Dolomite is classified as follows:

A. Rhombs of non-zoned luminescence: \((NZ)\)
   1. Rhombs of homogeneous luminescence: \((NZh)\)
   2. Rhombs of homogeneous luminescence with relatively bright luminescent, regular and irregular circular to rhombohedral cores: \((NZc)\)

B. Rhombs of zoned luminescence (Three or more concentric zones): \((Z_3)\)
   1. Type I luminescent zoned dolomite: \((Z_1)\)
   2. Type II luminescent zoned dolomite: \((Z_2)\)
   3. Type III luminescent zoned dolomite: \((Z_3)\)

3. Very fine NZh rhombs grew on evaporative tidal flats contemporaneously with deposition.

4. Fine and medium grained NZh and NZc dolomite grew in schizohaline environments within shallow subsurface sediments both during and after deposition of prograded, peritidal, sediment packages.

5. Medium and coarse grained NZh and NZc dolomite results from mobilization of \(Fe^{+2}\) and \(Mn^{+2}\) in the crystal lattice during late diagenesis.

6. \(Z_1\) dolomite is rare and its indistinct zonation results from slow fabric evolution of rhombs in the shallow subsurface.

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7. Type II luminescent zones are abundant, well developed, and can be correlated in \( Z_2 \) dolomite throughout an area exceeding 1300 km\(^2\) and a thickness exceeding 250 meters of Mascot Formation and Kingsport Formation carbonates.

8. Growth of \( Z_2 \) dolomite followed maximum uplift and karsting of the study area at the end of early Ordovician time, but preceded the final transgression of middle Ordovician seas.

9. \( Z_2 \) dolomite grew in a meteoric-sea water mixing zone below and adjacent to topographic highs on an incipient Nashville dome; transgressing seas provided a continual source of magnesium. Dolomitization ceased as meteoric recharge zones were covered by transgressive seas.

10. Dolomitizing solutions that produced Type II luminescent zones travelled north to south, laterally, and upwards, through the sedimentary column. These solutions travelled preferentially through highly permeable avenues generated by karst related-solution and collapse of grainstone horizons intercalated throughout the formation. Solutions also travelled through permeable rock matrix.

11. \( Z_2 \) dolomite grew during burial compaction of limestone but before compaction ceased.

12. At least one other episode of karsting separates \( Z_2 \) and \( Z_3 \) dolomite growth.

13. \( Z_3 \) dolomite grew at elevated temperatures before, and immediately after Mississippi-Valley Type mineralization of the Mascot Formation. Mineralization post dates deposition of Mississippian sediments.
14. Dolomitizing solutions that produced Type III zonation travelled through both the same highly permeable pathways as solutions that produced Type II zonation and through new pathways generated during subsequent karsting. However, they did not travel through rock matrix.

15. Formation fluids become enriched in manganese and iron, and depleted in strontium through time. Both iron and zinc were introduced into the study area during mineralization.
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TOTAL 25 samples and 4 duplicate analyses.
*Indicates mean value for duplicate samples.
## TABLE 3

**ATOMIC ABSORPTION RESULTS FOR DOLOMITE SAMPLES (PPM)**

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*Indicates mean value for duplicate samples.
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<td>45</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>89</td>
<td>1076</td>
<td></td>
<td>53</td>
</tr>
<tr>
<td>D6</td>
<td>-549.8</td>
<td>8</td>
<td>76</td>
<td>1067</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>77</td>
<td>983</td>
<td></td>
<td>67</td>
</tr>
<tr>
<td>D6</td>
<td>-595.0</td>
<td>14</td>
<td>46</td>
<td>370</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>45</td>
<td>352</td>
<td></td>
<td>59</td>
</tr>
</tbody>
</table>
TABLE 5
STABLE CARBON AND OXYGEN ISOTOPE RESULTS*

<table>
<thead>
<tr>
<th></th>
<th>$\delta^{18}O/^{16}O$</th>
<th>$\delta^{13}C/^{12}C$</th>
<th>General Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limestone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18-765</td>
<td>-7.84,-7.96</td>
<td>-2.21,-2.17</td>
<td>Laminated lagoonal mud, rich in clay</td>
</tr>
<tr>
<td>10-755.9</td>
<td>-8.0</td>
<td>-2.2</td>
<td>Thrombolite</td>
</tr>
<tr>
<td>18-629.4</td>
<td>-7.6</td>
<td>-2.8</td>
<td>Oosparite with upward fining centimeter-scale laminations</td>
</tr>
<tr>
<td>6-570.7</td>
<td>-7.8</td>
<td>-2.5</td>
<td>Normal marine grainstone with intraclasts and ooids</td>
</tr>
<tr>
<td>Dolomite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6-488.1</td>
<td>-4.38</td>
<td>-2.44</td>
<td>Very fine grained xenotopic NZh dolomite</td>
</tr>
<tr>
<td>6-535</td>
<td>-4.6</td>
<td>-2.3</td>
<td>Very fine grained xenotopic NZh dolomite</td>
</tr>
<tr>
<td>137-560.4</td>
<td>-4.75</td>
<td>-3.14</td>
<td>Hypidiotopic to idiotopic medium grained mosaic of $Z_1$ dolomite overgrowths</td>
</tr>
<tr>
<td>137-560.4</td>
<td>-8.75</td>
<td>-2.32</td>
<td>Baroque, $Z_3$ dolomite filling fracture</td>
</tr>
<tr>
<td>-6-491.5</td>
<td>-4.96</td>
<td>-3.24</td>
<td>Hypidiotopic fine grained $Z_1$ dolomite</td>
</tr>
<tr>
<td>6-653</td>
<td>-5.36</td>
<td>-1.83</td>
<td>Sandy hypidiotopic medium grained NZc dolomite</td>
</tr>
<tr>
<td>100-377.7</td>
<td>-5.92</td>
<td>-2.78</td>
<td>Predominantly hypidiotopic idiotopic medium grained $Z_2$ dolomite with xenotopic NZc dolomite</td>
</tr>
<tr>
<td>6-526.6</td>
<td>-6.99</td>
<td>-2.22</td>
<td>Coarse grained $Z_2$ dolomite in collapsed grainstone unit</td>
</tr>
<tr>
<td>6-531</td>
<td>-7.00</td>
<td>-2.13</td>
<td>Coarse grained idiotopic $Z_2$ dolomite replacing oolite</td>
</tr>
<tr>
<td>6-603.7</td>
<td>-7.43</td>
<td>-1.97</td>
<td>Fine grained xenotopic NZc dolomite with relict ooids</td>
</tr>
<tr>
<td>6-588.6</td>
<td>-7.50</td>
<td>-2.24,-2.35</td>
<td>Medium grained xenotopic to idiotopic NZh and NZc dolomite with ghosts of intraclasts and ooids</td>
</tr>
</tbody>
</table>

*All values relative to PDB standard.
BIBLIOGRAPHY


Beales, F.W., and Hardy, J.I., 1979, Criteria for recognition of diverse dolostone types from Mississippi Valley-Type Ore deposits: AAPG-SEPM Annual program of meetings with abstracts for 1979, pp. 52.


Dunham, J.B., and Olson, E.R., 1979, Shallow subsurface dolomitization of subtidally deposited carbonate sediments in Hanson Creek Formation (Ordovician-Silurian) of central Nevada -- Evidence for groundwater mixing: AAPG-SEPM Annual program of meetings with abstracts for 1979, p. 78.

Ebers, M.L., and Kopp, O.C., 1979, Cathodoluminescent microstratigraphy in gangue dolomite, the Mascot-Jefferson City district, Tennessee: Econ. Geol., v. 74, pp. 908-918.


Gross, M.G., 1964, Variations in the $\delta^{18}O/\delta^{16}O$ and $\delta^{13}C/\delta^{12}C$ ratios of diagenetically altered limestones in the Bermuda Islands: Jour. Geol., v. 72, No. 2, pp. 170-194.


Hsu, K.J., and Siegenthaler, C., 1969, Preliminary experiments on hydrodynamic movement induced by evaporation and their bearings on the dolomite problem: Sedimentol., v. 12, pp. 11-25.


Mansfield, C.F., 1979, Possible biogenic origin for some sedimentary dolomite: AAPG-SEPM program of meetings with abstracts for 1979, pp. 1.


Mountjoy, E.W., 1979, Late-Stage subsurface dolomites -- problems of origin: AAPG-SEPM Annual program of meetings with Abstracts for 1979, pp. 135.


Ross, C.A., and Gana, S., 1961, Late Pennsylvanian and Early Permian limestone petrology and carbon isotope distribution, Glass Mountains, Texas: Jour. Sed. Pet., v. 31, #2, pp. 231-244.


Sommer, S.E., 1972, Cathodoluminescence of carbonates; Geological applications: Chem. Geol., v. 9, pp. 275-284.


