Bed and Facies Scale Selectivity During Late-Stage Dolomitization: Lower Ordovician El Paso Group, Franklin Mountains, West Texas

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The origin of dolomite and the process of dolomitization has long been an inconclusive struggle for geologists. Many different aspects of dolomitization have been applied to try and decipher this dilemma, including geochemistry, sequence stratigraphy, petrography, fluid dynamics, etc. This study uses petrography to systematically determine a textural and allochem specific order of dolomitization using shallow subtidal carbonate rocks from the Lower Ordovician of North America.

In west Texas, Lower Ordovician carbonates outcrop within the southern Franklin Mountains (figure 1). These rocks display very localized dolomitization of limestone surrounding collapse breccia that at the boundary of a large-scale (roughly 33 my) unconformity of Middle Ordovician age. The breccia bodies are roughly 20-50 meters wide along the outcrop used for this study. They extend from below outcrop exposure at the bottom of the canyon, to the top of the Lower Ordovician rocks along the wall of the canyon. The individual beds/facies range from 10 centimeters to 5 meters in thickness. Generally, the finer-grained facies are thicker than the coarser-grained facies.

Surrounding most of the collapse breccia in the southern Franklin Mountains are very distinguishable brown destructive dolomite halos. These brown halos finger out into the wall rock of the breccia up to about 5 meters. The dolomite alteration cross-cuts various facies vertically and dissipates into the unaltered rock. These features are scale invariant and have been documented at the meter scale to the hundred-meter scale. Figure 2 is a photograph taken from the north wall of Transition Canyon showing one of these dolomite fingers "frozen-in-time" during migration of dolomitization fluids from within the collapse breccia. Sampling was concentrated around the boundaries from brown dolomite to gray limestone.

Sub-facies Lithology
The lithologic descriptions of the sub-facies present in the outcrop analyzed are all shallow sub-tidal rocks. In their unaltered form, they are:

(A) Peloidal packstone-grainstone
Composed of peloids and intraclasts of sponge-wackestone. Also present in small quantities are trilobite, brachiopod, gastropod, and nuia (algae) fragments; hardgrounds are preserved.

(B) Crinoid-intraclast packstone-grainstone
Abundant crinoid fragments, intraclasts, some trilobite and brachiopod fragments and peloids. Because rocks are currently altered and recrystallized, it is difficult to assess either grainstone or packstone classification to this, and the following subfacies.

(C) Sponge-spicule wackestone with wispy seams
Contains a muddy matrix with microscopic sponge-spicules abundant within the muddy/micritic areas. Round imprints and mottled textures are evidence of burrowing and intense bioturbation. These areas are lighter and the sponge-spicules align concentrically around the burrows. This rock may occasionally contain large sponge fragments. Brown sediment laden 'wispy' layers are present. These wavy (thicken and thin throughout rock), brown silty seams are discontinuous. These seams are the sites of early dolomite crystallization. The dolomite forms an idiotopic mosaic of equant rhombohedrals that are confined early on, to the brown sediment seams. Tension gashes filled with calcite are visible within these wackestone beds, corresponding to early lithification.
(D) **Sponge wackestone-packstone with wispy seams**
Composed of sponge spicules, and a peloidal micritic matrix containing fossils of ostracods and other skeletal hash. Bioturbation is present. Brown dolomitic ‘wispy’ seams are present; this is very similar to the description of the previous subfacies, in geometry, size, and texture. This facies differs in that more skeletal and non-skeletal grains are present within the matrix.

(E) **Flat-pebble conglomerate**
Elongate and rounded intraclasts composed of peloidal to skeletal packstones to wackestones. The matrix is grainier, with crinoids, brachiopod, trilobite fragments, and peloids.

(F) **Breccia**
All of the breccia clasts observed are of variable textures composed of coeval Lower Ordovician carbonates and Upper Ordovician carbonates. Cements and matrix are also variable, ranging from brownish-yellow silty sediment to white saddle/baroque dolomite crystals. Clasts are angular to sub-rounded ranging in size from <1mm to 10 meters in diameter.

**Alteration Grades**
One hundred thirty thin-sections were analyzed petrographically from this canyon. To systematically distinguish different transitional phases of alteration and dolomitization a systematic grouping of these rocks must be implemented. Looking through previous work, there was no precise methodology for this type of categorization. Six distinct grades of alteration were defined and are described below and visually displayed in figure 3. These have been devised and applied to all of the samples analyzed for the study. The descriptions take into account the percent of dolomitization, the amount of allochemical replacement, and the shape of the crystals based on Sibley and Gregg (1997).

**Stage 1**: No alteration. Original grain and cement compositions are present.
**Stage 2**: Little alteration. Can distinguish most allochems and their original mineralogy. Penecontemporaneous dolomitization is determined.
**Stage 3**: Grains are becoming micritized. The onset of late-stage alteration/dolomitization begins to occur. Secondary cements appear. Matrix is completely recrystallized. Up to 15% of the rock is dolomitized.
**Stage 4**: Secondary minerals (mostly dolomite, and silica) are selectively replacing allochems. Less than 50% of the rock is undistinguishable from the original rock and composed of dolomite. Early dolomite is being neomorphosed (more ordered dolomite forms along with larger crystal sizes and different crystal shapes).
**Stage 5**: Secondary minerals (mostly dolomite, and occasionally calcite) are continually disrupting rock. Ghosts of allochems are prevalent. No original fossils are preserved in rock. Over 50% of rock is undistinguishable from the original rock and composed of dolomite.
**Stage 6**: Complete fabric destructive recrystalization (predominantly dolomite). May see some ghosts, but not likely.

All analyses were performed using standard transmitted-light microscopy. Figure 4 displays photomicrographs of sub-facies B (crinoid-intraclast packstone-grainstone). The images are a lateral progression from least-altered rock (100% limestone) to most-altered rock (100% dolomite).

**Alteration Mapping**
After each sample was assigned an alteration number from one to six, those values were transferred to the photomosaic of the north wall of the canyon at their sample collection location. These values were coded to easily visualize alteration differences and the front geometry on the canyon wall.

It is plainly visible that there is a distinct pattern in the grades of alteration, or the dolomitization front geometry. The most altered rocks (6,5) are concentrated within and immediately surrounding the collapse breccias. There are some regions in which the alteration transitions from 6 to 2 very abruptly. Samples were taken within six-inches from either side of the dolomite-limestone front, so, this alteration front has been very well defined. The individual dolomite fingers seem to move laterally through the rock, regardless of the size and orientation of the fractures.
present. There are other regions in which the transition from completely altered rock to least altered rock occurs over several meters. This is visible from the transition of alteration designations of 6, 5, 4, 3. Within these beds, the dolomitization front may not be as distinct.

When specific facies were correlated to the corresponding beds associated with the transitional-abrupt alteration front geometry, a very distinct pattern was recognizable. The abrupt transition from most altered to least altered rock occurs within the wackestone facies (muddiest facies). The gradational transition occurred within the grainier facies (packstone to grainstone). These distinct patterns, repeated vertically along the canyon wall, conclude that there are textural variations of the original host rock controlling the alteration and dolomitization of the rocks surrounding the collapse breccia. This pattern represents a macroscopic facies control of dolomitization based on the original porosity and permeability of the individual facies present.

Textural Controls
All of the thin-sections described for this thesis appear to have similar trends regarding the textural controls on dolomitization within and between facies. There is also an allochem/fossil specific pattern to the dolomitization along with the unique facies specific trend. The microscopic repeatable trend encompasses the order in which fossils, allochems, and cements become dolomitized.

Order of Dolomitization
There is a distinct order that the fossil assemblage follows during alteration. The first allochems to become dolomitized are the micrite lumps, peloids, intraclasts, as well as interparticle micrite matrix. These allochems are the finest-grained sediments with the originally highest amounts of microporosity and permeability. This amount of grain-to-fluid contact permits the dolomitization fluid to have the most affect on these allochems.

The next groups of fossils to be altered are the crinoids and mollusks. These fossils are chiefly composed of high-magnesium calcite, which is less stable than low-magnesium calcite (the predominant composition of the other allochems and cements). Mollusks and crinoids also have porous skeletons. This again increases the surface area of the individual fossils, which allows the dolomitizing fluids to attack a larger percentage of the allochem.

Trilobites and ostracods are mainly composed of low-magnesium calcite, with non-porous skeletons. These two features help to withstand the dolomitizing fluids until all other allochems have been altered. At this time, there are an abundant number of nucleation sites for dolomitization, and the transformation is inevitable.

The last aspect of these rocks to become dolomitized is the cement or crystalline matrix. This low-magnesium calcite cement is very stable. Because there are no transitional phases in which the calcite cement is being dolomitized, it must have happened relatively quickly and completely.

Conclusions
The main microscopic textural control on the dolomitization of each individual facies is the amount of surface area present while the dolomitizing fluids where introduced into the rock, the greater the surface area of the individual allochems (microporosity and permeability), the more intense the dolomitization. The composition of the allochems and cements also play a significant role in the timing and order of dolomitization. Because these rocks formed during a greenhouse period, there was no precipitation of aragonite, so compositions did not vary as much as they would today.

The overriding macroscopic textural control on the pattern of the dolomitization front is the overall classification of the rocks present. Finer-grained rocks (wackestone) display an abrupt change from limestone to dolomite. Coarser-grained rocks (grainstone) follow a transitional change from limestone to dolostone. This transition occurs at the tens-of-meters scale. This pattern was obviously visible when the amount and grade of alteration was displayed for each sample on the photomosaic from Transition Canyon.
Fracture analyses were also performed on the outcrop. They show that there is not a deterministic, or ordered pattern to the distribution of fractures as one moves from the collapse breccia, through the dolomite, into the surrounding limestone. The results provided conclude that the fractures within the collapse breccia are the main conduit to bring the dolomitizing fluids into the Lower Ordovician carbonates. As the fluid leaves the main collapse breccia, and enters the surrounding wall rock, the texture and composition of the individual facies controls the flow and distribution of the dolomitizing fluid.

Figure 1: Franklin Mountains are located at the asterick, at the far western edge of Texas.
Figure 2: Photography of the dolomitization front along the outcrop.
Figure 3: Schematic diagram of the classification used to categorize each sample analyzed under the microscope. The solid lines in the matrix are calcite; the dashed lines in the matrix represent dolomite; the diagonal pattern represents syntaxial overgrowth; and the background for stage 1 represents original cement (calcite or aragonite).

Figure 4: Alteration of sub-facies B, bed #6 (crinoid-intraclast pack-grainstone). A) 98% LS, AG3; B) 95% LS, AG4; C) 42% LS, AG5; D) 100% DS, AG6.
Figure 5: Photomosaic of north wall of Transition Canyon, with alteration grade designation super-imposed on canyon wall. Notice the concentration of the most altered grade (yellow and orange) surrounding and encompassing the collapse breccia (green dashed line), while the less altered rock (warmer colors) are present with lateral continuity between outside of the breccia bodies. The layers that move from yellow to purple (6 to 2) form an abrupt boundary and occur in the wackestone facies, while the layers that transgress from yellow to orange to green to blue (2-3-4-5) occur in the grainier facies.