SEQUENCE STRATIGRAPHIC SETTING OF RESERVOIR-QUALITY DOLOMITE, MADISON FORMATION, WYOMING AND MONTANA

Taury Smith, Gregor Eberli and Hildegard Westphal

Preliminary results of an ongoing regional study of the sequence stratigraphic setting of reservoir-quality dolomite in the Madison Formation suggest that most the dolomitization occurred during second-, third-, and fourth-order transgressions. Some intercrystalline porosity may have developed during dolomitization but most of the moldic porosity and at least some of the intercrystalline porosity formed when partially dolomitized strata were leached during subsequent periods of subaerial exposure.

The Madison is composed of a single, unconformity-bounded second-order supersequence. The majority of the dolomite and reservoir-quality dolomite in the Madison occurs within the basal, transgressive portion of the super-sequence.

The second-order supersequence is composed of six third-order disconformity-bounded sequences, and most of the reservoir-quality dolomite occurs in the lower three sequences (I-III) which are the focus of this study (Fig. 1). Third-order sequence boundaries are picked at the tops of grainstone units that underlie laterally extensive muddy carbonate horizons. With the exception of Sequence III, which is mud-dominated throughout most of the study area, the sequences typically have dolomitized mud-dominated transgressive systems tracts and grainstone-dominated highstand systems tracts. Carbon and oxygen stable isotopes typically get progressively lighter toward the sequence boundaries suggesting a meteoric signature in the precursor limestone that was preserved during dolomitization (Figure 2). Light carbon values in the overlying TSTs suggest that organic carbon was more common in the low energy transgressive facies than in the higher energy facies of the highstand systems tracts.

Sequences I through III are completely dolomitized updip (central and southeastern Wyoming). In some locations, there are thin, tan, porous intervals in tidal flat facies immediately overlying the sequence boundaries that are overlain by gray low porosity deeper water mudstone and wackestone deposited during the maximum flooding interval. These gray dolomites commonly have breccia beds within them which may have formed due to evaporite solution collapse. The best porosity occurs in the highstand
Figure 1. Distribution of porosity within sequence stratigraphic framework. Bold red lines denote 33rd-order sequence boundaries of Sonnenfeld (1996). Lighter red lines denote higher frequency 3rd-order or fourth order sequence boundaries. Additional measured sections will help constrain correlations. Gray dolomite is abundant downdip and occurs in the maximum flooding intervals in the mid-ramp sections. Note abundance of porous dolomitized grainstones in the mid ramp setting vs. the non-porous undolomitized grainstones at the tops of the sequences downdip. Porosity is best developed in the highstand portions of sequences whether they are composed of grain-dominated or mud-dominated strata.
systems tracts of the sequences whether they are composed of dolomitized grainstones (Sequences I and II) or mud-dominated facies (Sequence III). The high porosity values of both the grainstones and mudstones in the lower and middle portions of highstand systems tracts suggests that it is the position within the sequence rather than the rock type that controls porosity development and preservation.

In the downdip section (Benbow Mine Road), the transgressive portions of third- and fourth-order sequences are dolomitized while the highstand systems tracts are typically composed of limestone (Fig. 1). Few grainstones are dolomitized and the only reservoir-quality dolomite occurs in the muddy carbonates at the base of 4th-order sequences in 3rd-order Sequence III. Most of the dolomite in sequences I and II is the tight gray dolomite found in the maximum flooding intervals of the sequences in the updip locations. This facies likely marks the maximum flooding interval for the mid-ramp sequences.

The distribution of dolomite within the hierarchy of sequences suggests that most dolomitization of the Madison occurred during transgressions. The gray dolomite in the maximum flooding intervals is typically completely dolomitized with few molds and very little porosity suggesting that it was exposed to dolomitizing fluids for a longer period of time than the underlying, more porous dolomites. The underlying grainstones and muddy carbonates were probably only partially dolomitized by fluids percolating through them during the transgressions. There are numerous ways that seawater could have been cycled through the underlying strata including reflux, tidal pumping, cooling and sinking of surface waters due to cold fronts or Kohout convection. Whatever the mechanism for movement of seawater was, it appears to have been most active during transgressions.

It may also be the case that the microbacteria necessary to nucleate dolomite rhombs were more common in during transgressions when organic matter was more abundant. The presence of relatively light carbon in the TSTs of most of the sequences suggests that organic matter, and by association microbes, were more abundant on the ramp during transgressions. Some or all of these processes may have contributed to dolomitization of the Madison. Microbes may have filtered down into the underlying HST strata during transgressions and initiated dolomitization of grainstones as well.
Some porosity may have developed during dolomitization due to interparticle porosity in the precursor limestone or a higher rate of dissolution of CaCO$_3$ than precipitation of dolomite. However, most of the porosity in the dolomites probably formed during subaerial exposure and meteoric leaching of remaining CaCO$_3$ in the partially dolomitized strata (Fig. 3). There are well-preserved molds in almost all of the porous dolomite with the exception of a chalky dolomite unit near the top of sequence III. Additionally, some of the intercrystalline porosity may have developed due to partial dolomitization and leaching. Thin sections show dolomite growing within aragonite and high-Mg calcite grains. If the remaining CaCO$_3$ were leached, the resultant porosity would be indistinguishable from typical intercrystalline porosity. The same process may have occurred with the porous mudstones that occur in the study interval. Mudstones that were only partially dolomitized may have been subsequently leached, leaving intercrystalline porosity.

Thus, the dolomites with the highest porosity values in the Madison were probably only partially dolomitized and then subsequently leached (Fig. 3). This combination of processes appears to have been most common in the HSTs of 3$^{rd}$- and 4$^{th}$-
Fig. 2. Carbon and oxygen stable isotopes from Wind River Canyon Section. Generally heavy values of $\delta^{18}O$ suggest dolomitization by seawater. Both carbon and oxygen isotopes become lighter towards sequence boundaries suggesting that meteoric signature from exposure was maintained during dolomitization. Dolomite in TSTs commonly has lighter carbon values suggesting organic matter was bound in that facies. Higher frequency sequence within sequence III (of Sonnenfeld, 1996a) show similar trends. If these trends hold up at other locations, stable isotopes could be a powerful correlation tool and help better understand the depositional environments of the various facies.
order sequences in the middle and updip portions of the ramp. These strata were likely flushed with meteoric water during 3rd- and 4th-order sea-level falls while the strata in the downdip locations may only have been exposed to meteoric waters after deposition of sequence III.