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Depositional Sequence Trends Resulting from Differential Loading on Pennsylvanian Salt in the Paradox Basin, U.S.A.

Donald L. Rasmussen, Paradox Basin Data, Denver, Colorado, and
Dalton L. Rasmussen, Platte River Associates, Boulder, Colorado

In the Blanding Sub-Basin portion (10,000 sq. km) of the Paradox Basin in southeastern Utah and southwestern Colorado, the five oldest fourth-order sequences in the Missourian and the seven youngest fourth-order sequences in the Desmoinesian were examined in detail for evidence of stratigraphic trends resulting from differential loading on the underlying Desmoinesian salt intervals. Each sequence was subdivided into specific entities of the respective systems tracts or portions of systems tracts utilizing well logs, sample and core data, etc. from over 2500 well locations. Each sequence has two or more of the following entities starting at the base of the transgressive systems tract marked by distinct organic-rich shales and/or dolostones: 1) transgressive systems tract shales and dolostones lacking a bottom-dwelling fauna and grading upward into transgressive-highstand systems tract silty and calcareous mudstones with a restricted marine fauna; 2) highstand systems tract carbonates with a normal marine fauna and an overlying sequence boundary; 3) lowstand systems tract evaporites; and 4) lowstand-transgressive systems tract siliciclastics, sabkha, and/or playa deposits lacking faunas or with thin intervals having a restricted marine fauna. Entity 3 (evaporite) was further subdivided based on the presence of anhydrite, halite, or halite with potash. Entity 4 was subdivided based on the absence or presence of siliciclastics. Of the twelve sequences, the two oldest include the lower and upper Desert Creek intervals, followed by the lower and upper Ismay intervals, followed by eight sequences in the basal Honaker Trail portion of the Pennsylvanian Hermosa Group. These twelve sequences overlie five salt-bearing sequences in the Akah, nine salt-bearing sequences in the Barker Creek, and twelve anhydrite- and salt-bearing sequences in the Alkali Gulch (the latter having the Desmoinesian and Atokan boundary). The top of the highest salt to the base of the lowest salt averages 300 meters with a range of 30 to 600 meters. Salt is absent in this area for the even older sequences in the Atokan and Morrowan Pinkerton Trail unconformably overlying the Mississippian Leadville Formation.

An innovative spatial mapping program has allowed detailed quick analyses of all of the interval data for the twelve sequences and all of the underlying salt-bearing intervals where penetrated by the existing well control. Most of the wells in the Blanding Sub-Basin did not fully penetrate the youngest salt- and potash-bearing sequence of the Akah at the top of the underlying salt section, but scattered and clustered wells provide the critical deeper control that can be utilized by the spatial program. The spatial program allows a rapid review of the broad Blanding Sub-Basin, with its complex stratigraphy, by providing almost instant surface generation and contouring of any selected surface or interval, dynamic diagrammatic cross sections that can be moved about in the spatial data cube and instantaneously flattened on any selected horizon, full access to the mapping database for data checking or correcting, and the ability to plot any and all illustrations as prepared.

Deposition of the anhydrite-, salt- and potash-bearing intervals, starting in the Atokan Alkali Gulch and ending in the Desmoinesian Akah, was basically uniform over the entire Blanding Sub-Basin with almost no surface or sea floor topography present by the end of Akah deposition. The overlying organic-rich Chimney Rock Shale (transgressive systems tract, 1 to 16 meters thick) at the base of the Desert Creek was likewise uniformly deposited throughout the area but was subsequently modified by sub-aqueous erosion prior to deposition of the highstand systems tract carbonates of the lower Desert Creek, thereby resulting in a subtle sea floor topography with distinct trends where the interval was partially or totally eroded away (by strong currents during the maximum flooding event). In numerous locations, phylloid algal bioherms (mounds) in the lower Desert Creek (up to 57 meters thick at Aneth Field and up to 34 meters thick outside of Aneth Field) developed on the least eroded remnants (slight topographic highs) of the Chimney Rock Shale, with some exceptions on paleo-structures or where phylloid algae filled lows possibly related to underlying salt dissolution in the uppermost Akah along an eroded eastern margin of the Chimney Rock Shale in Colorado (Matheny and Longman, 1996). Lower Desert Creek carbonate islands and carbonate banks left distinct trends of northwest-southeast trending calcarenites across the Blanding area (Chidsey, Eby, and Wray, 2001), but these trends are thinner than the contemporaneous bioherms. Lower Desert Creek bioherms (and possibly the thickest calcarenite trends) locally overloaded the underlying Akah salt (top of salt 9 to 21 meters below the base of the bioherms) resulting in the progressive "sinking" of the bioherms while the underlying Akah salt flowed laterally away from the area (through differential loading). Initial "sinking" may have started during early growth of the biohermal mounds on areas of thicker Chimney Rock Shale. Even while mounds continued "sinking" after they stopped growing, many of the lower Desert Creek carbonate mounds remained as positive features during the beginning of the lowstand systems tract phase of the sequence and were sub-aerially exposed, eroded and chemically altered (dolomitized). During the evaporite phase of the lowstand systems tract, the mounds sank below the surface of the accumulating evaporites and were covered or partially covered by anhydrite, eventually sometimes becoming the site of renewed carbonate deposition (stacking of bioherms and/or calcarenites) during the highstand systems tract of the upper Desert Creek. Noticeably thicker deposits of anhydrite directly above one or both of the Desert Creek carbonate intervals within the mounds and in the off-mound areas directly adjacent to the mounds implies that "sinking" of the carbonate mounds created local areas with greater accommodation for evaporite deposition compared to more distant "off-mound" areas. Since anhydrite is denser than carbonate, the local additional weight of the overlying anhydrite perpetuated the "sinking" of the mounds and the creation of additional accommodation space at the surface. During the "sinking" of the lower and upper carbonate buildups at Aneth Field in the southwest corner of Utah there was thicker deposition of Desert Creek anhydrites in the "moat" (circular depression) surrounding the buildup than across the top of buildup, resulting is an area larger than the actual Aneth carbonate buildup that was slowly sinking into the underlying Akah salt. Lateral flowage of the Akah salt from the Aneth area appears to have been mainly toward the east, creating subtle sea floor bulges ("highs") during Ismay time along the present Utah-Colorado border. These "highs" may have promoted the growth of the large stacked lower and upper Ismay phylloid algal mounds in that area.

During Ismay time in the central Blanding Sub-Basin there were local areas of biohermal development during the lower Ismay and numerous areas of biohermal development in the upper Ismay. Deposition of the organic-rich Gothic Shale at the base of the lower Ismay filled several topographic lows and provided an almost level surface for deposition of the lower Ismay carbonates. During lower Ismay deposition, the entire sequence was basically conformable to the underlying Gothic Shale with notable exceptions where highstand systems tract bioherms formed on “salt highs” east of Aneth Field, where lowstand systems tract anhydrite covered much of the Desert Creek carbonate buildups at Aneth Field that were slowly “sinking” into the underlying Akah salt, and where anhydrite and halite were deposited in unfilled accommodation space from the underlying Desert Creek evaporites (possibly the result of local dissolution of salt in the upper Desert Creek). Deposition of the organic-rich Hovenweep Shale on the top of the lower Ismay was originally much thicker prior to extensive erosion during the maximum flooding event in the early highstand systems tract for the upper Ismay. Erosional remnants (“mud” mounds and ridges) of the Hovenweep Shale in the central Blanding Sub-Basin became the starting areas for several phylloid algal mounds in the upper Ismay, although some nearby upper Ismay mounds were stacked on top of lower Ismay mounds or were localized on paleo-highs (some structural and some from possible salt movement). Upper Ismay algal mounds are up to 55 meters thick and may be elongated, oval-shaped, or pinnacle-like. All show “sinking” through displacement of the underlying Akah salt and in some cases of both the underlying Desert Creek salt and Akah salt (in Colorado), and most show associated thicker deposition of overlying or adjacent anhydrite during the evaporite phase of the lowstand systems tract for the upper Ismay. In the Blanding Sub-Basin the upper Ismay algal mounds were the last mounds deposited during the Pennsylvanian. However, the upper Ismay mounds, the stacked upper and lower Ismay mounds, the stacked upper and lower Desert Creek mounds and calcarenites, and the lower Desert Creek mounds continued to “sink” into the underlying Desmoinesian salt as seen by the localization of siliciclastic trends in the eight Honaker Trail sequences overlying the Ismay. Siliciclastic trends, in particular, are the most obvious trends filling the accommodation space created in the eight Honaker Trail sequences above the slowly “sinking” Ismay and Desert Creek carbonate buildups and their associated adjacent anhydrites. By the end of deposition of the last of the eight sequences in the Honaker Trail, the gross interval thickness above the upper Ismay carbonate mounds (79 to 149 meters) is slightly less than for the same interval in the off-mound areas (89 to 153 meters), therefore limiting the use of gross isopach maps to identify underlying bioherms. Later Honaker Trail sequences shows no evidence of available accommodation space nor localization of siliciclastic trends above the mounds and it is assumed that equilibrium had been reached with the strata overlying the Akah and deeper salts.