Paleogeographic distribution of Lower Mississippian shallow-water, low-latitude heterozoan, biosiliceous and photozoan facies across continental U.S. and SW Canada: regional and local controls on deposition

Diana Ortega-Ariza[1] & Evan K. Franseen[1,2]
Kansas Geological Survey – University of Kansas
KICE3, Department of Geology – University of Kansas

Summary

Our study presents distribution patterns of Lower Mississippian carbonate-biosiliceous ramp facies across the United States (U.S.) and SW Canada. These carbonates form important reservoirs (e.g., Madison Group – Williston Basin; Mississippian Lime Play – U.S. Midcontinent) and are potential targets for CO_2 sequestration. Lower Mississippian carbonates developed in low-latitude (tropical) shallow-water areas with varying favorable and adverse photic-zone conditions that affected composition and distribution of heterozoan, biosiliceous, and photozoan facies. Our initial results show that areas bordering the Anadarko, Arkoma and Illinois basins, New Mexico and southern Appalachians are dominated by heterozoan components (± siliceous sponges). Photozoan components are lacking. Areas W, N, NW of the Transcontinental Arch (TA), including SW Canada, show significant abundances of photozoan components. Distribution patterns support documented basinal upwelling south of the TA as a major regional process delivering nutrients, silica, and cooler water to shallowest-water ramp environments, thereby creating conditions that hindered development of photozoans. Our ongoing study is further evaluating details of shallow-water facies distribution patterns to aid in determining local-to-regional controls on deposition and reservoir character.

Background

Compositions of shallow-water carbonates vary depending on factors that affect environmental conditions. Water temperature is a major factor, and most carbonate classification schemes are based on water temperature associated with latitude. A commonly used classification is that of James (1997) that defines a Photozoan Association and Heterozoan Association. The photozoan association includes organisms that are either photosynthetic or are zooxanthellates with symbiotic photosynthetic organisms; the association also is characterized by ooids, peloids, carbonate mud, and submarine cement. The heterozoan association is characterized by organisms that are non-photosynthetic and lack photosynthetic symbionts, so they are light independent; ooids, carbonate mud, and submarine cement are not common. Photozoans are typically dominant in low-latitude areas with warm and clear water conditions. However, if the photic zone is adversely affected, they can be greatly reduced or even absent, and heterozoans can dominate. A variety of processes can adversely affect the photic zone, with nutrient excess due to upwelling or land runoff being a common factor.

Our study is focused on Lower Mississippian strata in the U.S. and SW Canada, which were located in low latitudes (Fig. 1). A number of studies have provided information on paleogeography and -oceanographic conditions for Lower Mississippian strata in these areas (Lowe, 1975; Lane and DeKeyser, 1980; Parrish, 1982; Gutschick and Sandberg, 1983). Results from those studies provide a framework for examining shallow-water facies compositions and distributions across the region to aid in identifying regional-to-local processes that affected deposition. Our initial results combine data from our studies and from literature (Fig. 1).

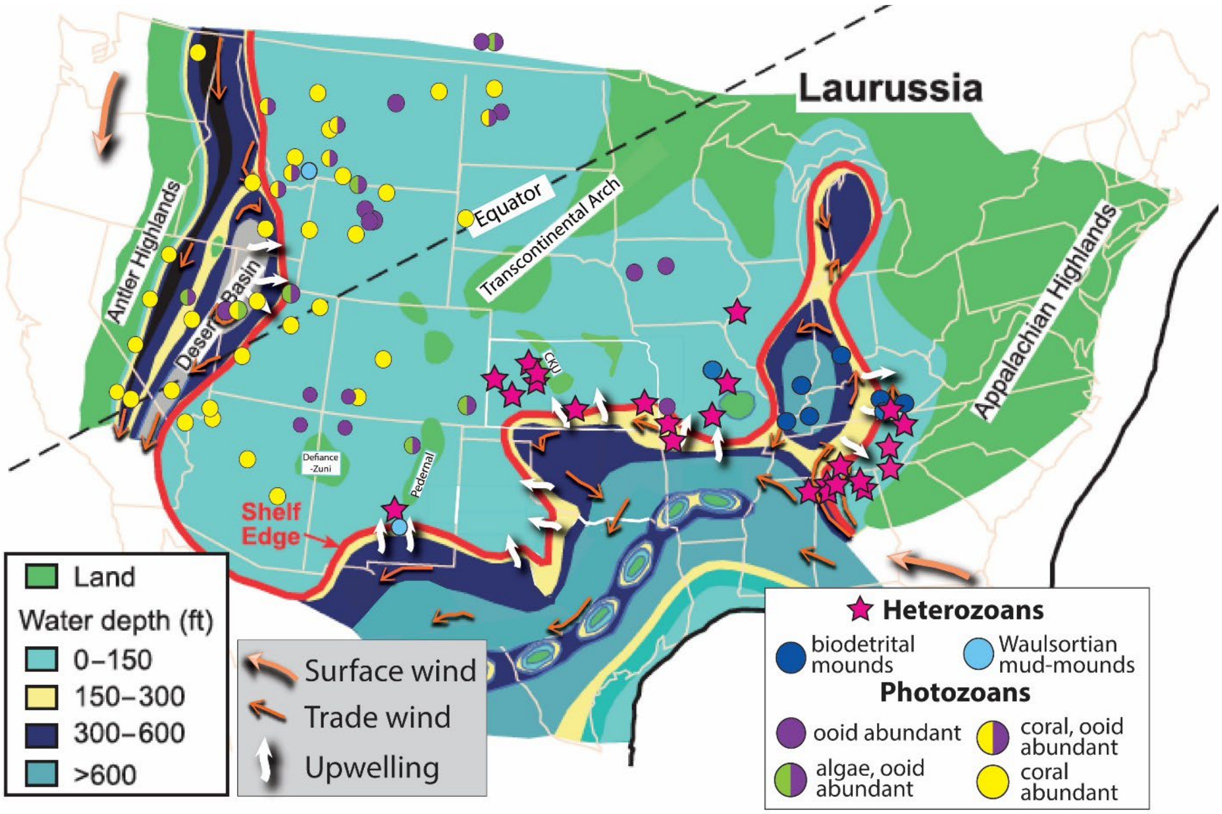

Figure 1. Paleogeographic map of the continental United States based on studies by Gutschick and Sandberg (1983) showing general distribution patterns of shallow-water heterozoan and photozoan carbonate facies (modified from Ortega-Ariza and Franseen, 2021).

Initial Results

Our initial results show distinct shallow-water facies patterns between two regions; one is defined as areas south and east of the Transcontinental Arch (TA) and the other is defined as areas west and north-northwest of the TA.

South and East of the TA – Heterozoan- and Biosiliceous-dominated facies

Deposition took place on shallow-water distally steepened ramps (Fig. 2). Inner-to-outer ramp facies in areas bordering basins south of the TA, southeast areas flanking the Appalachians, and New Mexico are dominated by heterozoans (mainly crinoids, bryozoans, and brachiopods) (e.g., Lasemi et al., 2003; Franseen, 2006; Kopaska-Merkel et al., 2013; Ortega-Ariza and

Franseen, 2021). Solitary rugose corals, siliceous sponges (including basin margin buildups; e.g., Kansas, Watney et al., 2001; Alabama, Kopaska-Merkel et al., 2013), and basin margin crinoid-bryozoan biodetrital and Waulsortian mounds (e.g., Kentucky, Lasemi et al., 2003; New Mexico, Kirkby and Hunt, 1996) are locally abundant. Evaporites are common in supratidal to intertidal settings (e.g., Kansas, Franseen, 2006). Notably, inner ramp areas lack abundant photozoans (minor occurrences of oolites locally).

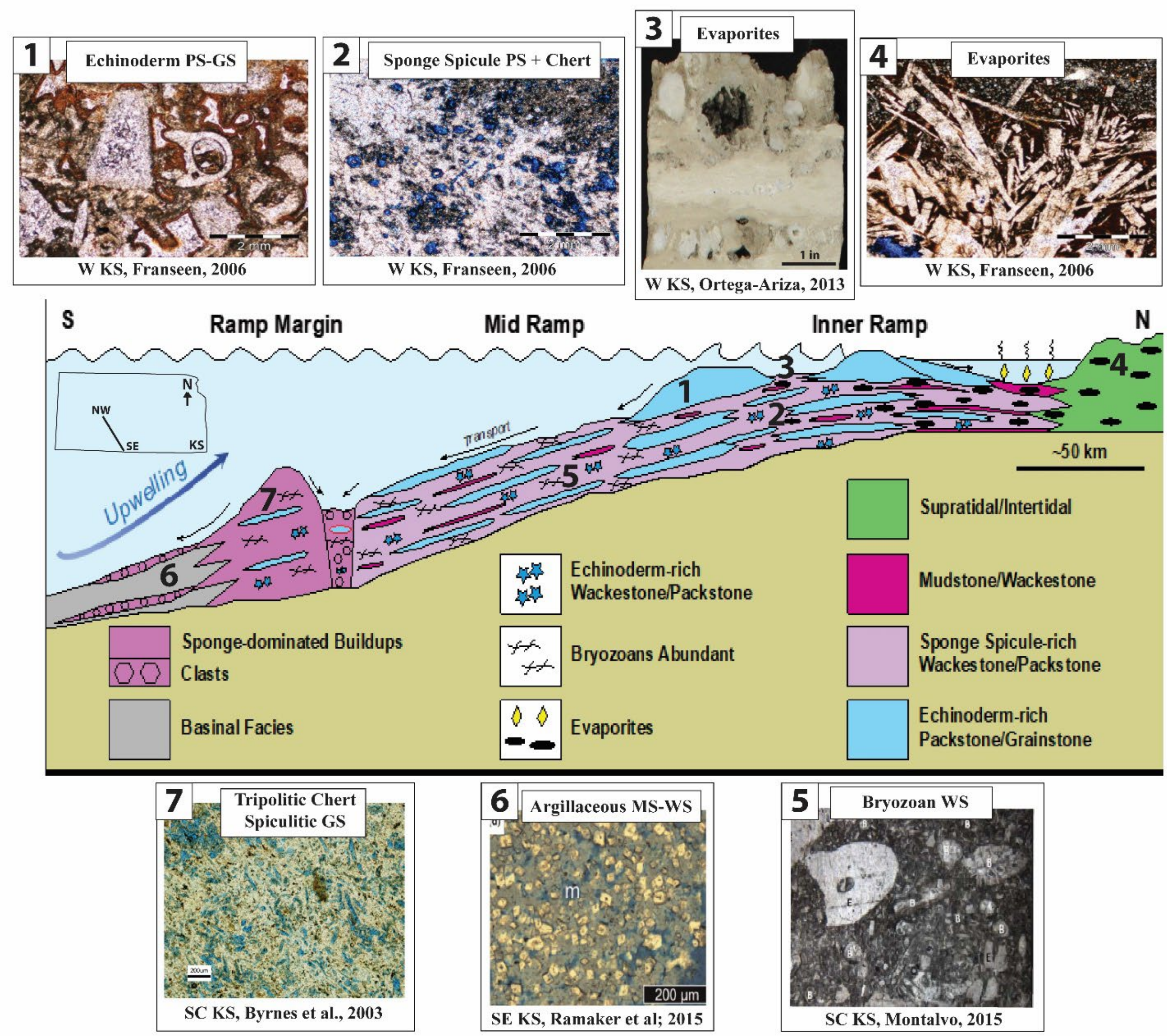

Figure 2. South of the TA – Heterozoan- and biosiliceous-dominated facies example. Kansas generalized ramp model showing facies distributions in inner ramp to ramp margin areas (modified from Byrnes et al., 2003 and Franseen, 2006). GS: grainstone, PS: packstone, WS: wackestone, MS: mudstone, W: west, SC: south central, SE: southeast.

West and North-Northwest of the TA – Photozoan-dominated facies

Heterozoan (especially crinoids and bryozoans), biosiliceous, and Waulsortian mound facies are found in shallow-water ramps west, north, and northwest of the TA. Those areas also show significant abundances of photozoan components including ooids, red, green, and blue-green calcareous algae (e.g., kamaenid), planar and hemispherical stromatolites, microbial laminites/mats, benthic foraminifera, and peloids (e.g., Sando, 1980; Elrick and Read, 1991; Figs. 3, 4). These photozoan-dominant facies characteristics are also observed in the Williston basin area in SE Saskatchewan, Canada (e.g., Rott and Qing, 2005; Qing and Nimegeers, 2008; Fig. 4) and the U.S. side of the basin (e.g., Lindsay and Kendall, 1980; Lindsay ad Roth, 1982). Colonial and solitary rugose corals and tabulate corals support shallow-water, tropical, and open marine conditions (Sando, 1980; Sando and Bamber, 1985; Waters and Sando, 1987).

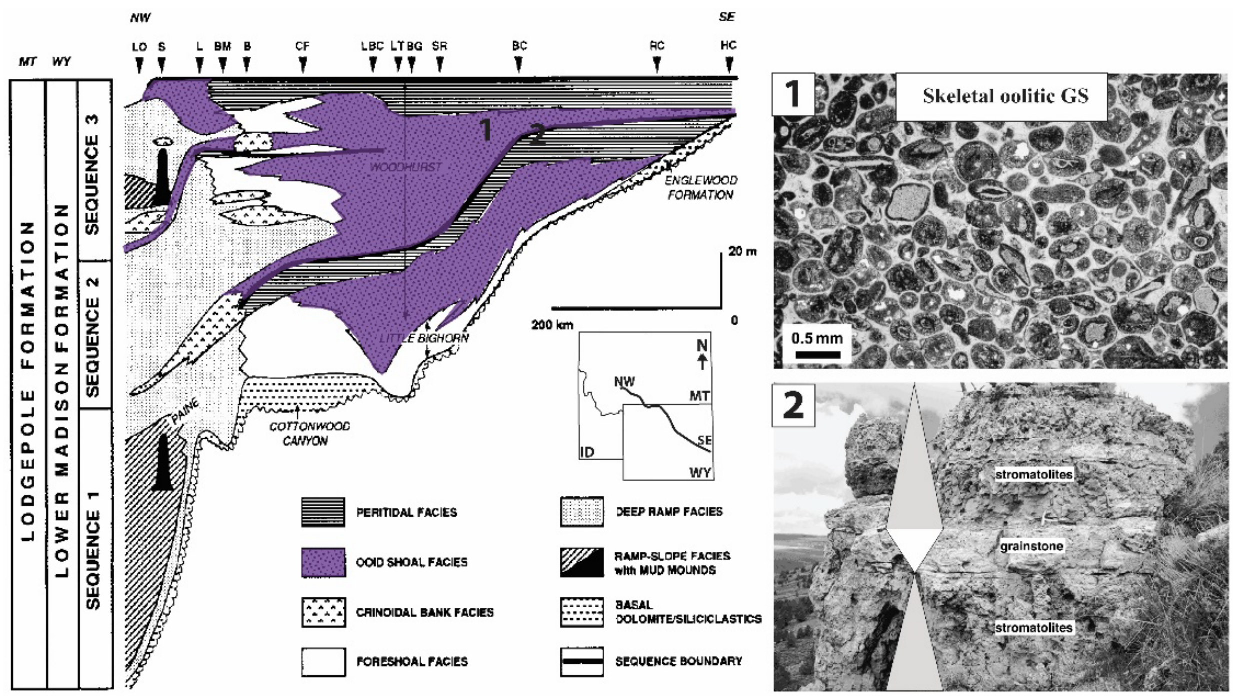

Figure 3. North-Northwest of the TA – Photozoan-dominated facies example. Wyoming-Montana schematic inner to deep ramp cross section highlighting photozoan facies components in shallow waters (modified from Elrick and Read, 1991 and Westphal et al., 2004).

Controls on Facies Distribution Patterns

The dominance of heterozoan and biosiliceous facies and relative absence of photozoans south and east of the TA suggest adverse photic zone conditions. These shallow-water areas are closest to basins where other workers have proposed upwelling to account for abundant biosiliceous facies in basin margin areas (e.g., Parrish, 1982). It is likely that nutrients from upwelling adversely affected shallow-water ramp areas as well resulting in the absence of photozoans (Franseen 2006; Ortega-Ariza and Franseen, 2021). In contrast many areas west and north-northwest of the TA were farther away from the basins to the south and land areas and therefore less affected by nutrients resulting in favorable photic zone conditions for photozoans. Some areas farthest west and north-northwest of the TA are located near the margin of a basin (Fig. 1). The presence of photozoans in those locations suggest upwelling was not a major factor. Within this overall heterozoan-photozoan pattern, there are finer scale distribution patterns and stratigraphic alternations of heterozoan and photozoan facies that could be tied to other processes such as sea-level fluctuations and climate changes. Our ongoing studies will continue adding details to the large- and fine-scale distribution patterns of heterozoan-biosiliceous and photozoan facies. Lower Mississippian strata are important petroleum reservoir systems. Understanding facies distribution patterns and controls on deposition can also provide a better understanding of reservoir character and predictive capabilities because heterozoan and photozoan systems can have different reservoir character due to mineralogic and diagenetic potential differences.

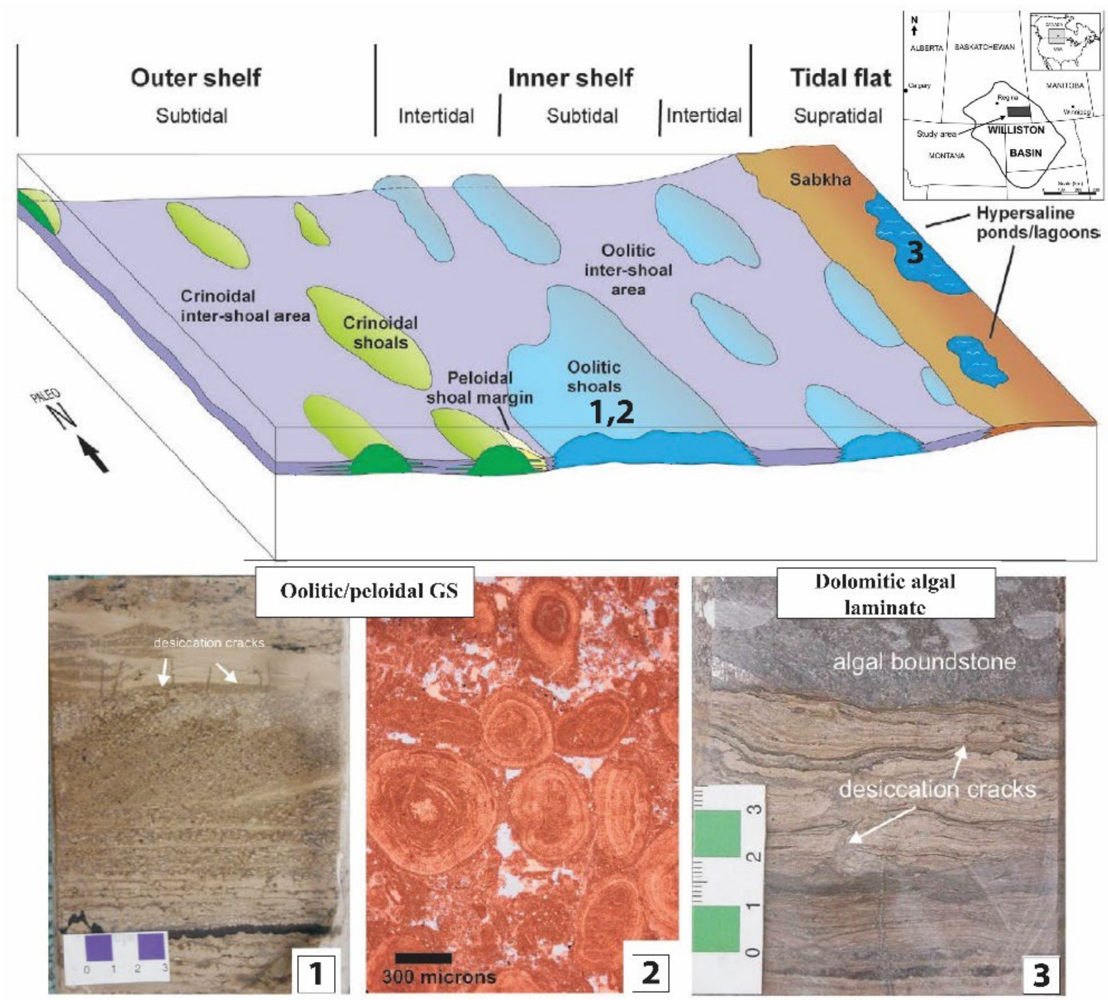

Figure 4. North of the TA – Photozoan-dominated facies example. Southeastern Saskatchewan - northern Williston Basin schematic model illustrating depositional environments and main facies within a shallow-marine shelf (modified from Qing and Nimegeers, 2005 and Rott and Qing, 2013). GS: Grainstone.

References

Byrnes, A. P., Franseen, E., Watney, W. L., & Dubois, M. K., 2003, The role of moldic porosity in Paleozoic Kansas reservoirs and the association of original depositional facies and early diagenesis with reservoir properties, Midcontinent Section Meeting Papers and Abstracts, Tulsa, OK.

Elrick, M., and Read, J. F., 1991, Cyclic ramp-to-basin carbonate deposits, Lower Mississippian, Wyoming and Montana; a combined field and computer modeling study: Journal of Sedimentary Research, v. 61, no. 7, p. 1,194–1,224.

Franseen, E. K., 2006, Mississippian (Osagean) shallow-water, mid-latitude siliceous sponge spicule and heterozoan carbonate facies: An example from Kansas with implications for regional controls and distribution of potential reservoir facies: Current Research in Earth Sciences, Bulletin 252.

Gutschick, R. C., and Sandberg, C. A., 1983, Mississippian continental margins of the conterminous United States; in The Shelf-break Margin—Critical Interface on Continental Margins, D. J. Stanley and G. T. Moore: Society of Economic Paleontologists and Mineralogists, Special Publication 33, p. 79–96.

James, N. P., 1997, The cool-water carbonate depositional realm; in Cool-Water Carbonates, N. P. James and J. A. D. Clarke, eds.: Society of Economic Paleontologists and Mineralogists, Special Publication 56, p. 1–22.

Kirkby, K. C., and Hunt, D., 1996, Episodic growth of a Waulsortian buildup: the Lower Carboniferous Muleshoe Mound, Sacramento Mountains, New Mexico, USA: Geological Society, London, Special Publications, v. 107, no. 1, p. 97–110.

Kopaska-Merkel, D. C., Mann, S. D., and Pashin, J. C., 2013, Sponge-microbial mound facies in Mississippian Tuscumbia Limestone, Walker County, Alabama: AAPG bulletin, v. 97, no. 11, p. 1,871– 1,893.

Lane, H. R., and DeKeyser, T. L., 1980, Paleogeography of the Late Early Mississippian (Tournaisian 3) in the central and southwestern United States; in, Paleozoic Paleogeography of West-central United States, T. D. Fouch and E. R. Magathan, eds.: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, p. 149-159.

Lasemi, Z., Norby, R. D., Utgaard, J. E., Ferry, W. R., Cuffey, R. J., and Dever, G. R., Jr., 2003, Mississippian carbonate buildups and development of cool-water-like carbonate platforms in the Illinois basin, midcontinent U.S.A.; *in* Permo- Carboniferous Carbonate Platforms and Reefs, W. M. Ahr, P. M. Harris, W. A. Morgan, I. D. Somerville, and R. J. Stanton, Jr., eds.: Society of Economic Paleontologists and Mineralogists, Special Publication 78 and AAPG, Memoir 83, p. 69–95.

Lindsay, R. F., and Roth, M. S., 1982, Carbonate and evaporite facies, dolomitization and reservoir distribution of the Mission Canyon Formation, Little Knife Field, North Dakota; *in* J. E. Christopher and J. Kaldi, eds., 4th International Williston Basin Symposium Volume: Saskatchewan Geological Survey Special Publication 6, p. 153–179, Regina, Saskatchewan, Canada.

Lindsay, R. F., & Kendall, C. G. S. C., 1980, Depositional facies, diagenesis and reservoir character of the Mission Canyon Formation (Mississippian) of the Williston basin at Little Knife field, North Dakota.

Lowe, D. R., 1975, Regional controls on silica sedimentation in the Ouachita System: Geological Society of America, Bulletin, v. 86, p. 1,123–1,127.

Montalvo, L. G., 2015, Petrography and paragenesis of diagenetic mineral phases in cherty and dolomitic spiculite strata, Mississippian, South-central Kansas, M.S. Thesis, University of Kansas, p. 173.

Ortega-Ariza, D. and Franseen, E. K., 2021, Distribution patterns of low-latitude, shallow-water heterozoan and photozoan facies during Mississippian (Osagean-Meramecian) in the continental US: in Midcontinent Carbonate Research Symposium Extended Abstracts, Kansas Geological Survey Technical Series 24, p. 38-41.

Ortega-Ariza, 2013, Dickman #4 core description, Ness County, KS, unpublished data, Kansas Geological Survey.

Parrish, J. T., 1982, Upwelling and petroleum source beds, with reference to Paleozoic: AAPG Bulletin, v. 66, no. 6, p. 750–774.

Qing, H. and Nimegeers, A. R., 2008, Lithofacies and depositional history of Midale carbonate–evaporite cycles in a Mississippian ramp setting, Steelman–Bienfait area, southeastern Saskatchewan, Canada, Bulletin of Canadian Petroleum Geology, v. 56, p. 209–234.

Ramaker, E. M., Goldstein, R. H., Franseen, E. K., and Watney, W. L., 2015, What controls porosity in cherty fine-grained carbonate reservoir rocks? Impact of stratigraphy, unconformities, structural setting and hydrothermal fluid flow: Mississippian, SE Kansas, Geological Society, London, Special Publications, 406 (1), p. 179-208.

Rott, C. M. and Qing, H., 2005, Sedimentology and facies description of Mississippian Alida Beds, Williston Basin, southeastern Saskatchewan, Summary of Investigations, v. 1, Saskatchewan Geological Survey, Industry Resources, Miscellaneous Report 2005-4.1, CD-ROM, Paper A-12, 10 p.

Sando, W. J., 1980, The paleoecology of Mississippian corals in the western conterminous United States: Acta Palaeontologica Polonica, v. 25, no. 3–4.

Sando, W. J., and Bamber, E. W., 1985, Coral zonation of the Mississippian system in the western interior province of North America: USGS Professional Paper 1334, 61 p.

Waters, D. L. and Sando, W. J., 1987, Corals from the Madison Group, Williston Basin, North Dakota, in Carlson, C.G., and Christopher, J.E., eds., Fifth International Williston Basin Symposium, Saskatchewan Geological Society, Special Publication 9, p. 83-97.

Watney, W. L., Guy, W. J., and Byrnes, A. P., 2001, Characterization of the Mississippian chat in south-central Kansas, American Association of Petroleum Geologists, Bulletin, v. 85, no. 1, p. 85-113.