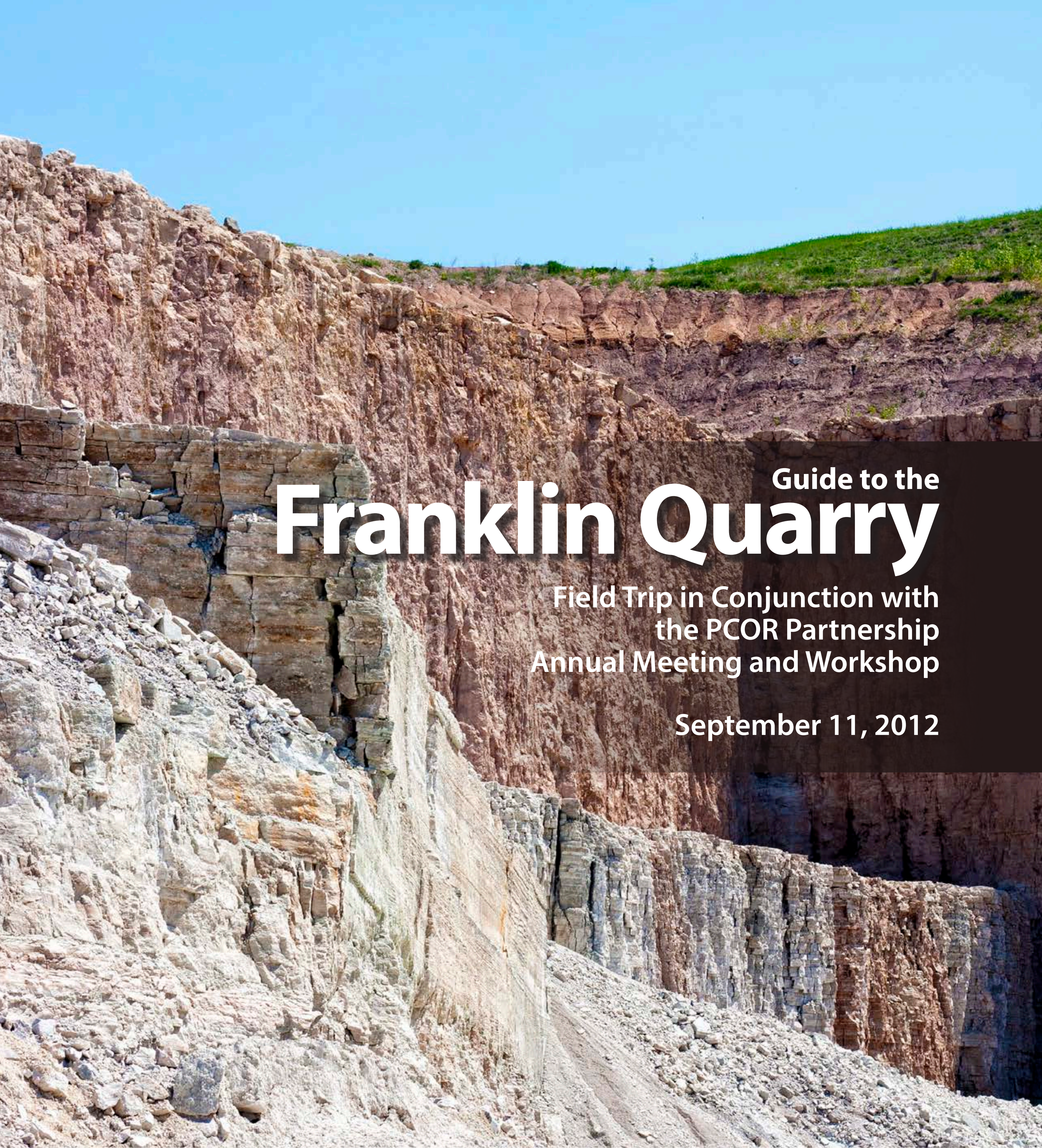

Guide to the

Franklin Quarry

Field Trip in Conjunction with
the PCOR Partnership
Annual Meeting and Workshop

September 11, 2012

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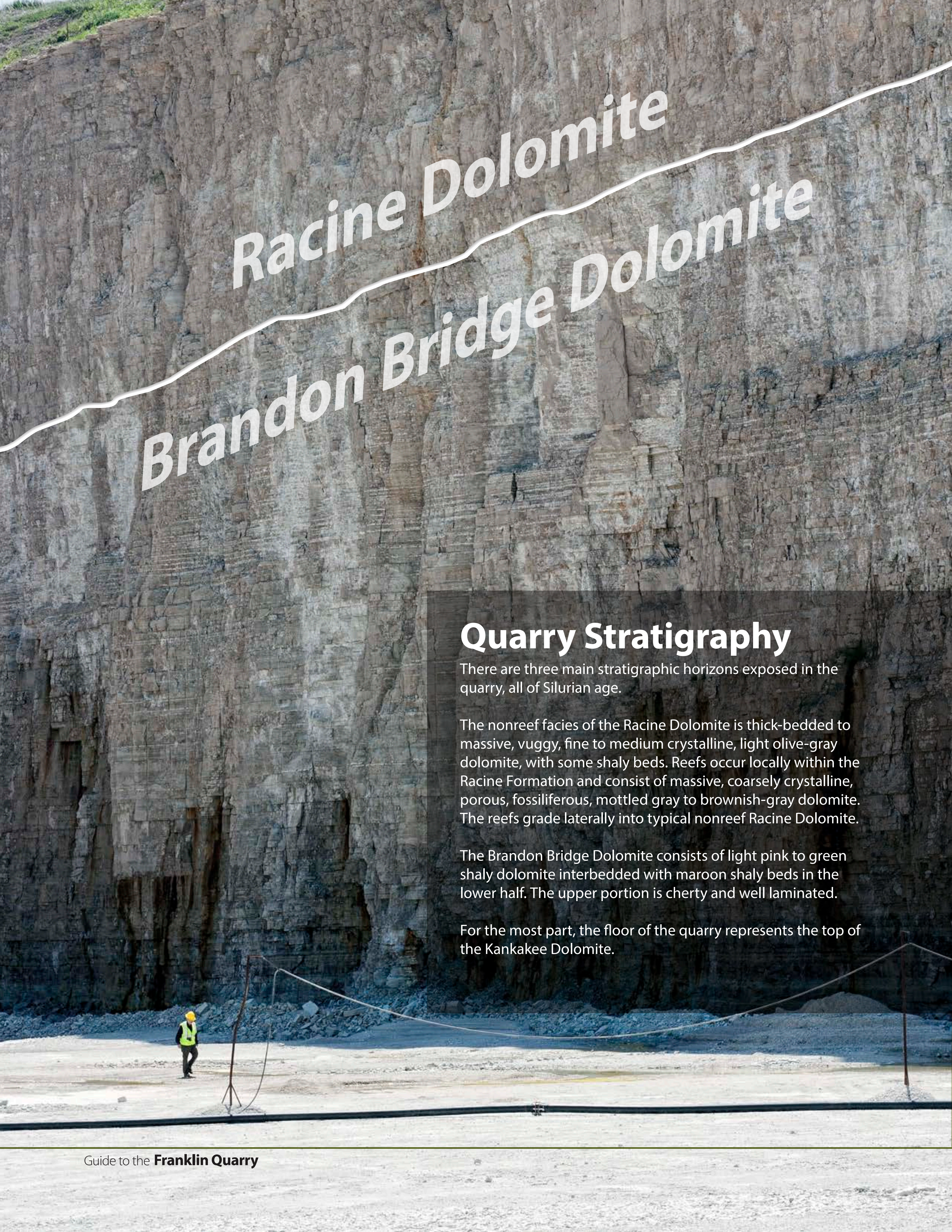

Quarry Stratigraphy

There are three main stratigraphic horizons exposed in the quarry, all of Silurian age.

The nonreef facies of the Racine Dolomite is thick-bedded to massive, vuggy, fine to medium crystalline, light olive-gray dolomite, with some shaly beds. Reefs occur locally within the Racine Formation and consist of massive, coarsely crystalline, porous, fossiliferous, mottled gray to brownish-gray dolomite. The reefs grade laterally into typical nonreef Racine Dolomite.

The Brandon Bridge Dolomite consists of light pink to green shaly dolomite interbedded with maroon shaly beds in the lower half. The upper portion is cherty and well laminated.

For the most part, the floor of the quarry represents the top of the Kankakee Dolomite.

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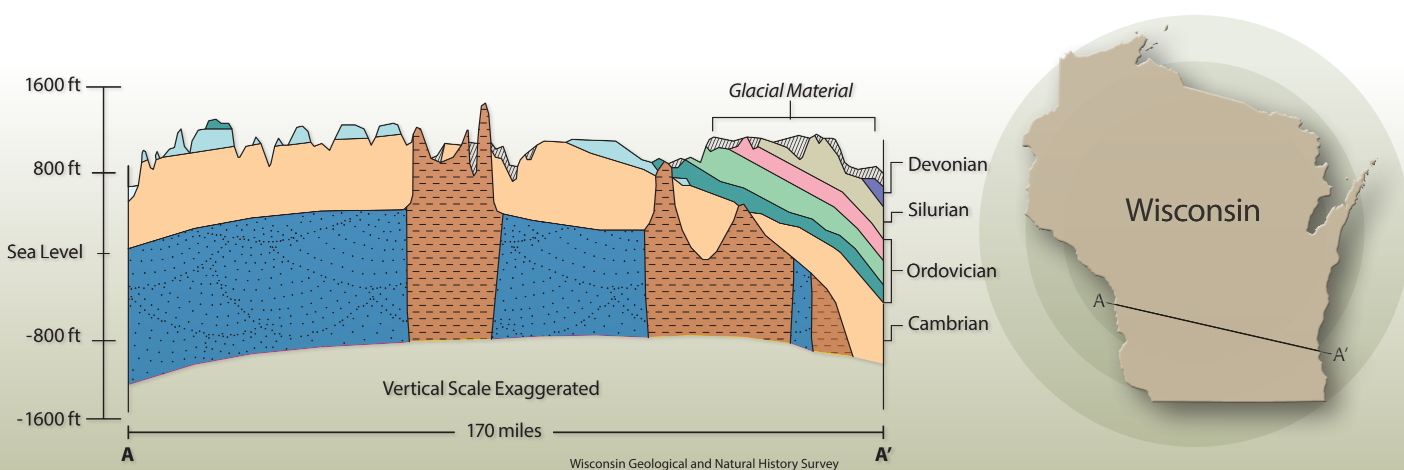
Today, Lake Michigan covers an impressive 22,350 mi^2 along the eastern "coast" of Wisconsin. However, approximately 420 million years ago, during the Silurian Period, this area was part of a large, shallow inland sea that was centered on what is now Michigan. Subsidence of the crust through a long period of geologic time allowed for the accumulation of sediments in what is known as the Michigan Basin. In the basin center, the entire sedimentary sequence comprises nearly 15,000 feet of rock representing the fluctuating shallow sea and marginal marine depositional environment that once existed here. Today, the Silurian rocks formed from the accumulation of sediment in the area of the sea that is now eastern Wisconsin consist mainly of carbonates (dolostone and limestone). Other portions of the basin also contain thick sequences of evaporates (rock salt, anhydrite), with lesser amounts of older shale and sandstone.

Paleogeographic map of North America during the Middle Silurian Period. Notable centers of deposition during this time were the Michigan and Williston Basins.

Except for some scattered thicker patches, most of Wisconsin's sedimentary bedrock layers are covered by an average of 100 feet of glacial drift. The carbonate rocks that peek through the glacial debris along the southeast edge of Wisconsin dip to the east where they are buried by nearly 5000 feet of additional sedimentary rock in the center of the Michigan Basin. Across the southern half of Wisconsin, erosion has removed nearly all of the sedimentary rock. In the northern portion, the ancient crystalline rock is at the surface or buried directly under glacial drift. The configuration of Wisconsin's geology has resulted in a relatively thin (shallow) layer of sedimentary rock and thus basically eliminates the possibility of finding CO_2 storage opportunities in the state. This geologic situation is basically the inverse of what is found in the Williston Basin and the neighboring Michigan Basin. The upside is that the rock deeply buried in the Michigan Basin can be found near the surface in southeastern Wisconsin, allowing it to be studied without extensive drilling programs.



Window into the Past

Geologists are constantly looking for ways to peer past, or infer beyond, the vegetation and soil layers that cover most of the rocks on the planet. An extensive stone industry that began in the late 19th century has provided scientists with numerous quarries that offer a unique opportunity to examine a multidimensional slice into the bedrock of the area. Although many of the older quarries have been filled, the few remaining newer and larger quarries provide spectacular windows into the geologic past.

The earliest reported quarry operation in the Franklin area dates to 1874. The Franklin quarry was started in 1943 and today is the only active quarry remaining in Milwaukee County. There are two companies operating out of the same "hole" – Payne & Dolan and Vulcan Materials. The primary product is crushed dolostone produced in various sizes to meet customer specifications and used in the construction industry (asphalt, concrete, road base, etc.).

The quarry excavation covers nearly 400 acres of land and has exposed nearly 245 feet of dolostone, all of Silurian age. The operations area where the processing plant (crusher) and stockpiles are is approximately 200 ft below the surface.

Payne & Dolan employs 18–20 people on-site as well as truck drivers, sales and parts distribution personnel, supervisors, clerical staff, inspectors, etc.

Although dependent on economic factors, the quarry is estimated to be active for the next 25–50 years. Production from the two operations in the quarry varies year to year but is estimated to be a combined output of 2–3 million tons per year. Once the quarry has reached its potential, the reclamation plan will include a +240-acre lake, with future development around the lake to be determined at the time of reclamation to suit the community.

Several pumps are used to move water from the quarry to keep it dry. Stormwater and groundwater are directed into sumps where fine particles are allowed to settle out before the water is pumped up and out to the Root River. This discharge process is monitored and regulated by the Wisconsin Department of Natural Resources. If the pumps were turned off, the quarry would fill to within 10–15 ft of the surface over a period of about 10 years.

Aggregates make up more than **95%** of asphalt and over **90%** of concrete.

Over **85,000 tons** of crushed stone is needed for the construction of 1 mile of four-lane interstate highway.

15,000 tons of aggregate is required to build an average school.

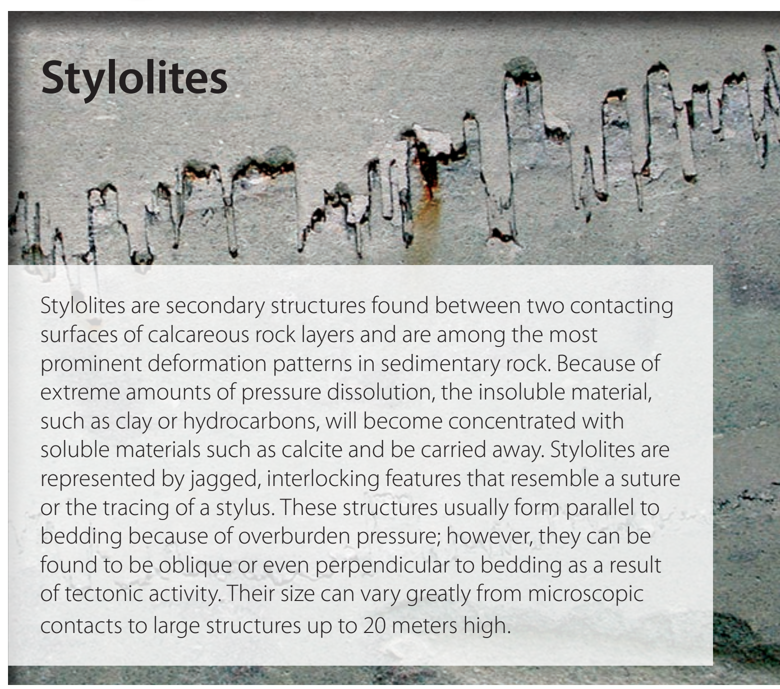
The Energy & Environmental Research Center (EERC) and the Plains CO_2 Reduction (PCOR) Partnership gratefully acknowledge support from Clint Weninger and Mike Saddy of Payne & Dolan for granting access to the Franklin Quarry. This guide has directly benefited from their knowledge and generosity as well as the quarry rock samples given freely. Our special thanks are extended to Dr. Donald Mikulic of the Illinois State Geological Survey for sharing his valuable time and extensive knowledge of the geology and history of the quarries in the greater Milwaukee area.

Carbonate Rocks

Most rock in the area of southeastern Wisconsin that was originally deposited as limestone (calcium carbonate [$CaCO_3$]) has been changed to dolostone ($CaMg[CO_3]_2$) by chemical replacement of calcium by waterborne magnesium. Although the rock is often referred to as dolomite, that term should be strictly used for the mineral dolomite. A quick way to distinguish limestone from dolostone is to drop a weak acid on the rock. Limestone will effervesce (fizz) readily, whereas dolostone may not fizz at all unless it is powdered.

In the classification of sedimentary rocks, the nature of carbonate rocks differs substantially from that of the sandstones, siltstones, and shales of the clastic realm. One major difference is that the vast majority of carbonate rock is biologic in origin and forms in narrowly restricted environments characterized by clear, warm, shallow waters. Also, whereas sand and silt can be transported hundreds of miles before deposition, the material that forms carbonate sediment is usually deposited very close to where it was created. The local deposition and the biologic origin each contribute significantly to the heterogeneity of resulting carbonate rock. Once carbonate rocks are formed, there are further changes that take place through a process called diagenesis, which involves a range of chemical and physical alterations that can increase the heterogenic complexity of the rock. It is this internal complexity that provides the biggest challenge when trying to understand and model the nature of fluid production from, or the storage of fluids in, a carbonate reservoir.

Reefs are solid, organic, wave-resistant sedimentary features built by the interaction of organisms (such as corals and calcareous algae) and their environment. They formed as positive features on the seafloor and now appear as sizable unlayered, fossiliferous masses within the horizontal layers of the main carbonate rock formations. As the first fossil reefs identified in North America and among the first recognized in the world, the Silurian reefs of southeastern Wisconsin became classic reference examples in the study of Silurian rocks and fossils. This significance has resulted in two exposures being raised to the status of National Historic Landmarks.



Stylolites

Stylolites are secondary structures found between two contacting surfaces of calcareous rock layers and are among the most prominent deformation patterns in sedimentary rock. Because of extreme amounts of pressure dissolution, the insoluble material, such as clay or hydrocarbons, will become concentrated with soluble materials such as calcite and be carried away. Stylolites are represented by jagged, interlocking features that resemble a suture or the tracing of a stylus. These structures usually form parallel to bedding because of overburden pressure; however, they can be found to be oblique or even perpendicular to bedding as a result of tectonic activity. Their size can vary greatly from microscopic contacts to large structures up to 20 meters high.

Photo courtesy of Michael C. Rygel

Carbonate Rocks and Carbon Capture and Storage

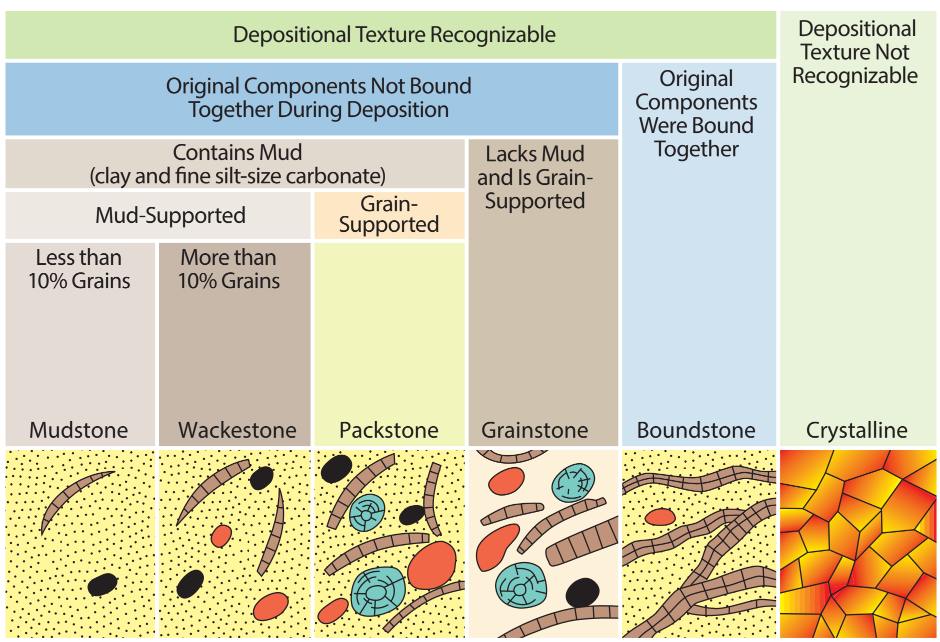
Although carbonate reservoirs are good candidates for CO_2 storage, they are not as well characterized as sandstone reservoirs. Diagenetic processes and fracturing play an important role in the distribution of porosity and permeability in carbonates and, consequently, may dramatically affect the CO_2 storage. Also, carbonate formations may become reactive when injected CO_2 mixes with formation fluids and thus require special attention for long-term storage assessment and for mineralogical and rock property changes during injection. The pursuit of CO_2 enhanced oil recovery (EOR) in carbonate formations such as those in the Permian Basin of Texas or the well-known Weyburn CO_2 EOR project in Saskatchewan are adding considerably to understanding the heterogenic nature of these rock types. This understanding will lead not only to more efficient and productive EOR projects but will improve confidence in determining CO_2 storage resource and behavior of all CO_2 storage projects in carbonate rocks.

Porosity

Unlike most sandstone reservoirs, which typically are relatively uniform single-porosity systems (interparticle pores), carbonate rock reservoirs commonly have multiple-porosity systems that include intraparticle, interparticle, and fracture porosity. Also, postdepositional or secondary porosity development can radically modify the original porosity distribution, size, and shape. Notable in this process is the development of vugs, which are macroscopic voids in the rock that formed from the dissolution of fossils and the coalescing of neighboring pore space.

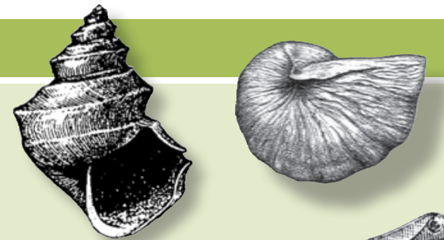
Two classification schemes are in common use by those who work on carbonate rocks. The Folk classification is based on a textural scale that incorporates grain size, roundness, sorting, and packing. Its complexity is more applicable to the microscopic examination of the rock. The Dunham classification is primarily textural in nature and is regarded as better-suited to the classification of hand samples.

Dunham Classification of Carbonate Rocks



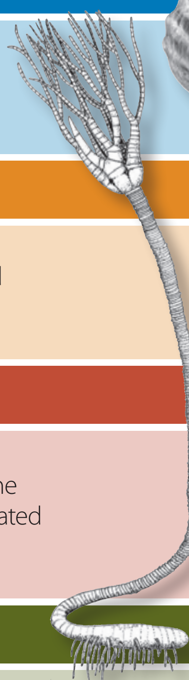
Ancient Silurian Marine Life

Gastropod



Gastropod, the largest group of mollusks, comprises snails and slugs with diverse calcareous shells. They live in a wide range of habitats, from land to the deepest ocean basins. Abundant fossil records from the Early Cambrian indicate periods of extinction and diversification.

Brachiopod

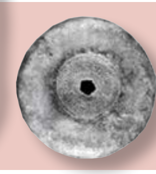


Brachiopods, often mistaken for clams or oysters, are diverse marine animals with common features. They were abundant primarily during the Paleozoic era but have been around since the Cambrian Period.

Trilobite

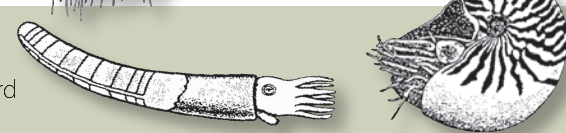
Trilobites are hard-shelled segmented extinct arthropods, similar in appearance to a wide, flat centipede or horseshoe crab. Their geologic and physical diversity make them a key marker for the Cambrian Period.

Crinoid



Crinoids primarily dominated the Paleozoic era in shallow marine environments. They superficially resembled flowers (sometimes called stone lilies) but are related to starfish and sea cucumbers. Specimens of disarticulated crinoid stems are among the most common fossils in Silurian reefs.

Cephalopod



Cephalopods, meaning "head-footed," are exclusively marine animals often known for their tentacles. Developing during the Cambrian, current representatives include octopi, squid, and nautiloids. Ancient forms had hard shells. Other than the nautiloid, modern cephalopods are soft-bodied.

Ichnofossils

Trace fossils, also called ichnofossils, are geologic records of biologic activity and represent indirect evidence of life. Trace fossils may be impressions made on the substrate by an organism and may represent burrows, borings, footprints, feeding marks, and root cavities.

The PCOR Partnership is a group of public and private sector stakeholders working together to better understand the technical and economic feasibility of sequestering CO_2 emissions from stationary sources in the central interior of North America. The PCOR Partnership is led by the EERC at the University of North Dakota and is one of seven regional partnerships under the U.S. Department of Energy's National Energy Technology Laboratory Regional Carbon Sequestration Partnership Initiative. To learn more, contact:

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Visit the PCOR Partnership Web site at www.undeerc.org/PCOR. New members are welcome.

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