COMPLEX BRECCIATION HISTORY ASSOCIATED WITH EVAPORITE AND CARBONATE DISSOLUTION IN THE LOWER ORDOVICIAN ONEOTA FORMATION (PRAIRIE DU CHIEN GROUP) NEAR SPRING GREEN, WISCONSIN

George L. Smith[1]

ABSTRACT

Evaporite-dissolution brecciation focused subsequent porosity development and brecciation within carbonates of the Lower Ordovician Oneota Formation (Prairie du Chien Group) near Spring Green, Wisconsin. Stratiform breccia was formed first by the dissolution of bedded anhydrite. Younger, discordant carbonate breccia and existing caverns are superimposed on stratiform evaporite-dissolution breccia. The breccia and caverns continue to be zones of relatively high permeability and porosity.

INTRODUCTION

Studies of Lower Ordovician carbonate in North America generally emphasize the extensive paleokarst developed beneath the Lower-Middle Ordovician Sauk-Tippecanoe unconformity (for example, Kyle, 1976; Mussman and Read, 1986; Kerans, 1988; Mazzullo, 1989; Knight and others, 1991). The extent of buried paleokarst beneath this unconformity in Wisconsin is well documented (summarized by Mai and Dott, 1985). Paleokarst developed beneath the less well-known mid-Lower Ordovician unconformity is also recognized (Smith, 1989; Smith and others, 1993, 1996).

Breccia formed during evaporite dissolution is known to be an important source of porosity (for example, Middleton, 1961; Warren and Kendall, 1985), and is also known to promote the later dissolution and brecciation of interbedded carbonate strata (for example, Beales and Oldershaw, 1969; Park and Jones, 1985). This paper examines the role of evaporite dissolution in localizing subsequent karstification of shallow-marine carbonate of the Lower Ordovician Prairie du Chien Group in Wisconsin. Improved understanding of the relationship between former bedded evaporite and subsequent patterns of brecciation may result in improved prediction of zones of high permeability and porosity in carbonates of economic importance, such as hydrocarbon reservoirs and freshwater aquifers.

GEOLOGIC SETTING

Quarrying operations south of Spring Green, Wisconsin (fig. 1; SE1/4 sec. 3, T. 7 N., R. 3 E.), have exposed a 21 m-thick section of the Lower Ordovician Oneota Formation, which is unconformably overlain by a 1m-thick section of silicified oolitic grainstone and quartz arenite. Regional stratigraphic relationships determined from outcrops and water-well logs and a late-Early Ordovician-age conodont fauna (Smith, 1991) suggest that the grainstone and quartz arenite are part of the basal Shakopee Formation (figs. 2 and 3).

The Oneota Formation at this quarry displays an unusual degree of brecciation and cavern development (fig. 3), but is otherwise representative of the Oneota Formation in the outcrop area (Smith and others, 1993, 1996). The Oneota Formation is dominated by 10- to 30-cm thick laterally continuous beds of stromatolites, wavy-laminated peloidal boundstone, oolitic-peloidal grainstone and packstone, and other peritidal carbonate (fig. 2; Smith, 1991). Quartz sand and silt are abundant within the basal Oneota Formation and decrease in abundance up-section (fig. 2). Evidence for syndepositional subaerial exposure consists of desiccation cracks, and silicified and moldic anhydrite (Smith, 1991; Smith and others, 1993, 1996). Sediment of the Oneota Formation is interpreted as having been deposited in a shallow, tropical, epeiric sea, in shallow-subtidal to peritidal settings (Adams, 1978; Davis, 1970, 1971).

[1]Department of Geology, Lawrence University, Appleton, Wisconsin 54912-0599; currently at Department of Earth Sciences, SUNY College at Brockport, Brockport, New York 14420-2936

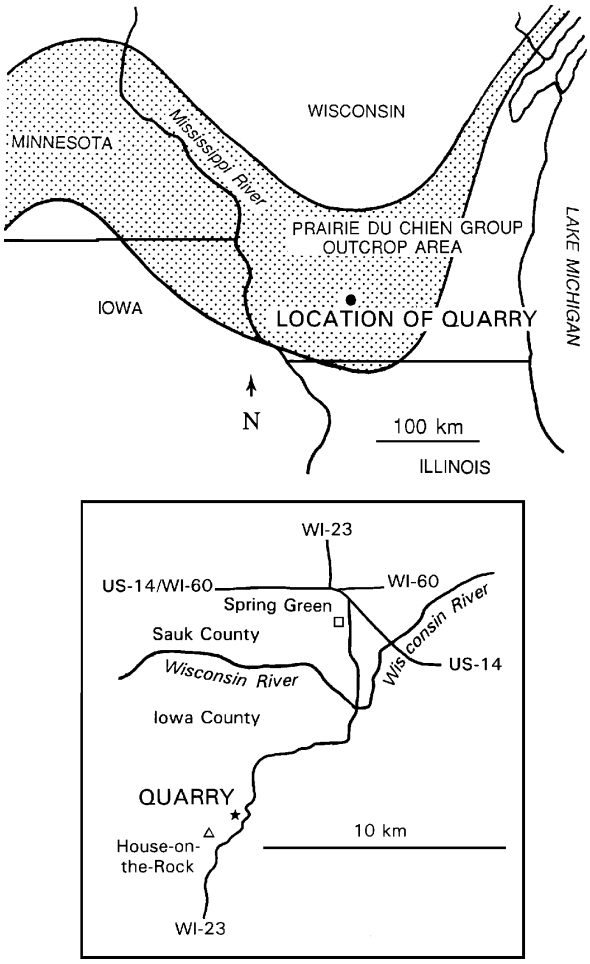

Figure 1. *Location of quarry within Prairie du Chien outcrop area (stippled). Inset map at bottom shows location of quarry relative to nearby cultural features (after U.S. Geological Survey, 1960; S.E. 1/4, S. 3, T. 7 N., R. 3 E.).*

RESULTS AND DISCUSSION

Stratiform breccia

Quarrying operations have exposed caverns and both stratiform and discordant breccia. Stratiform breccia is cross-cut by all other breccia and thus is the oldest breccia fabric in the quarry. Stratiform breccia is 10 to 25 cm thick, laterally-continuous over 200 m of quarry wall, and follow gentle undulations in bedding. The lower one- to two-thirds (5 to 20 cm) of most stratiform breccia have been silicified and consist of chalky-appearing chert (fig. 4). In thin section, the chalky chert contains abundant anhydrite crystal ghosts (fig. 5), suggesting that silicification accompanied anhydrite dissolution, a common phenomenon in shallow-burial diagenetic settings (Milliken, 1979).

Carbonate strata underlying stratiform breccia are relatively undisturbed, whereas the 3 to 5 m of overlying strata typically display gentle folding and minor fracturing (fig. 6), indicating lithification prior to deformation. Brecciation and fracturing occurred as overlying carbonate strata collapsed into stratiform voids produced by the gradual dissolution of anhydrite beds. The lateral continuity of stratiform breccia suggests that dissolution and collapse took place gradually over a broad area, as suggested for analogous settings by Middleton (1961) and Warren and others (1990). Cross-cutting relationships indicate that stratiform breccia formed during subaerial exposure associated with development of the Oneota-Shakopee unconformity.

Discordant breccia

Discordant breccia is superimposed upon stratiform breccia (fig. 7). The timing of development of the discordant breccia is bracketed by the end of Oneota deposition and the inception of marine conditions during Shakopee deposition (approximately 495-490 Ma based on time scales summarized in Smith and others, 1993, 1996). Discordant breccia formed as Oneota carbonate beds collapsed into underlying caverns (fig. 7). Breccia consists of carbonate and/or chert clasts with carbonate and/or quartz-arenite matrix (fig. 8). Tilted beds were truncated prior to the deposition of the overlying Shakopee Formation (fig. 7).

Existing caverns

Existing caverns are largely localized within older discordant breccia and cavern fill, all of which are centered on and partially localized within stratiform breccia. As a consequence, caves line the walls of this quarry at levels corresponding to the positions of stratiform breccia (figs. 4 and 7). Caverns contain aragonitic and calcitic speleothems, aragonite-cemented breccia, and unlithified reddish-brown clay-rich sediment interstratified with fragments of speleothems (fig. 9).

SUMMARY

Stratiform breccia was formed by the dissolution of bedded anhydrite. Discordant breccia produced by later carbonate dissolution cross-cut stratiform breccias. Existing caverns cross-cut both stratiform and discordant breccia, but are localized along stratigraphic horizons containing stratiform breccia. In general, evaporite-dissolution brecciation has focused all major subsequent porosity development, empha-

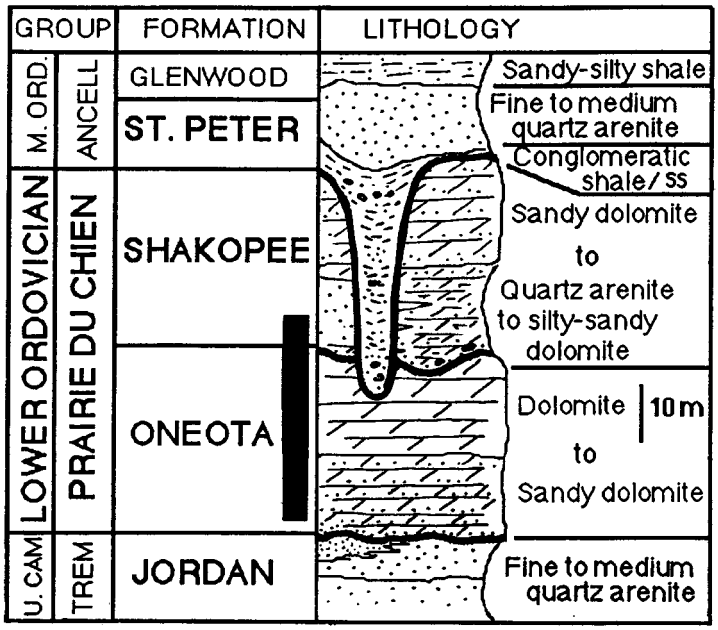

Figure 2. *Generalized stratigraphic column for southwestern Wisconsin. Dark vertical bar indicates stratigraphic interval examined in this study. After Smith and others (1993).*

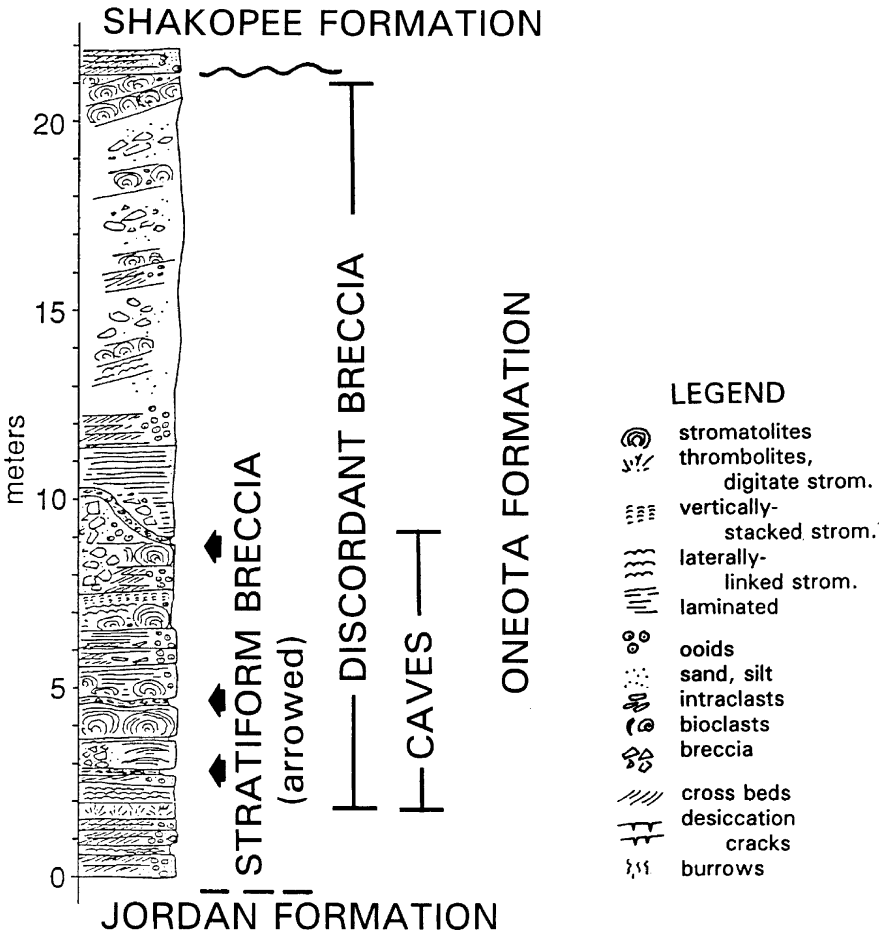

Figure 3. *Composite measured section in quarry showing positions of stratiform breccia, discordant breccia, and caves.*

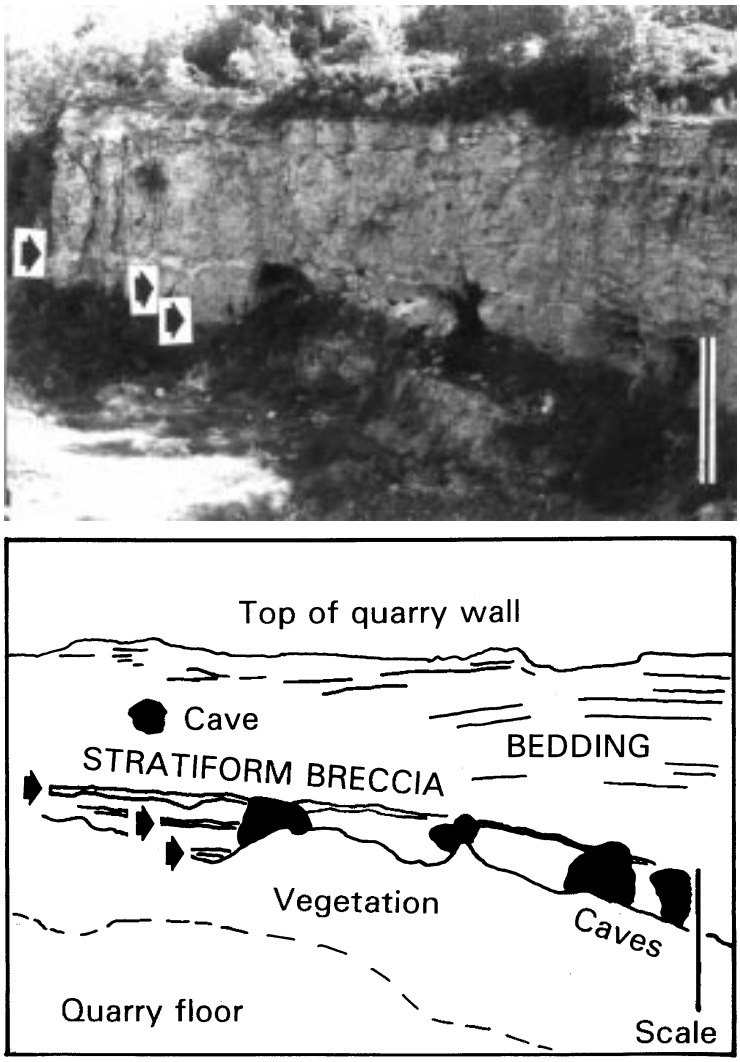

Figure 4. *Photograph of east quarry face showing positions of stratiform breccia (arrows). Note preferential position caverns within the zone containing the three stratiform breccia. Scale bar is 10 m tall.*

sizing the influence of bedded anhydrite on the pattern of porosity evolution.

ACKNOWLEDGMENTS

This research was partially supported by grants from the American Association of Petroleum Geologists, ARCO Oil and Gas Company, the Gas Research Institute, Sigma Xi—The Scientific Research Society, and the University of Wisconsin Graduate School. C.W. Byers and R.H. Dott, Jr., provided invaluable insights and assistance. This manuscript benefitted from thorough reviews by B.A. Brown, M.T. Harris, R.M. Peters, and M.G. Mudrey, Jr.

REFERENCES

Adams, R.L., 1978, Stratigraphy and petrology of the lower Oneota dolomite (Ordovician), south-central Wisconsin, *in* Lithostratigraphy, petrology, and sedimentology of Late Cambrian-Early Ordovician rocks near Madison, Wisconsin: Wisconsin Geological and Natural History Survey Field Trip Guide Book 3, p. 82-90.

Beales, F.W., and Oldershaw, A.E., 1969, Evaporite solution brecciation and Devonian carbonate reservoir porosity in western Canada: *American Association of Petroleum Geologists Bulletin,* v. 53, p. 503-512.

Davis, R.A., Jr., 1970, Prairie du Chien Group in the upper Mississippi Valley, *in* Field trip guidebook for Cambrian-Ordovician geology of western Wisconsin: Wisconsin Geological and Natural History Survey Information Circular, p. 35-44.

Davis, R.A., Jr., 1971, Prairie du Chien Group (L. Ord.) in the upper Mississippi Valley: Wisconsin Geological and Natural History Survey Open-File Report 71-2, 71 p.

Kerans, C., 1988, Karst-controlled reservoir heterogeneity in Ellenburger Group carbonates of west Texas: *American Association of Petroleum Geologists Bulletin,* v. 72, p. 1160-1183.

Knight, I., James, N.P., and Lane, T.E., 1991, The Ordovician St. George unconformity, northern Appalachians: the relationship of plate convergence at the St. Lawrence promontory to the Sauk/Tippecanoe sequence boundary: *Geological Society of America Bulletin,* v. 103, p. 1200-1225.

Kyle, J.R., 1976, Brecciation, alteration, and mineralization in the central Tennessee zinc district: *Economic Geology,* v. 71, p. 892-903.

Mai, H., and Dott, R.H., Jr., 1985, A subsurface study of the St. Peter sandstone in southern and eastern

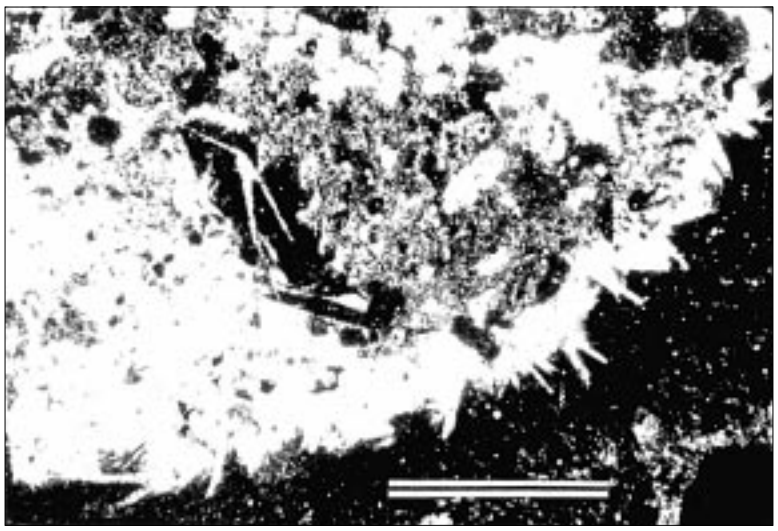

Figure 5. *Thin section photomicrograph of anhydrite crystal ghosts. Sample is from silicified base of uppermost of three stratiform breccias identified in figures 3 and 4. Partial dissolution of anhydrite and some compaction preceded silicification. Crossed nicols. Scale bar is 2 mm long.*

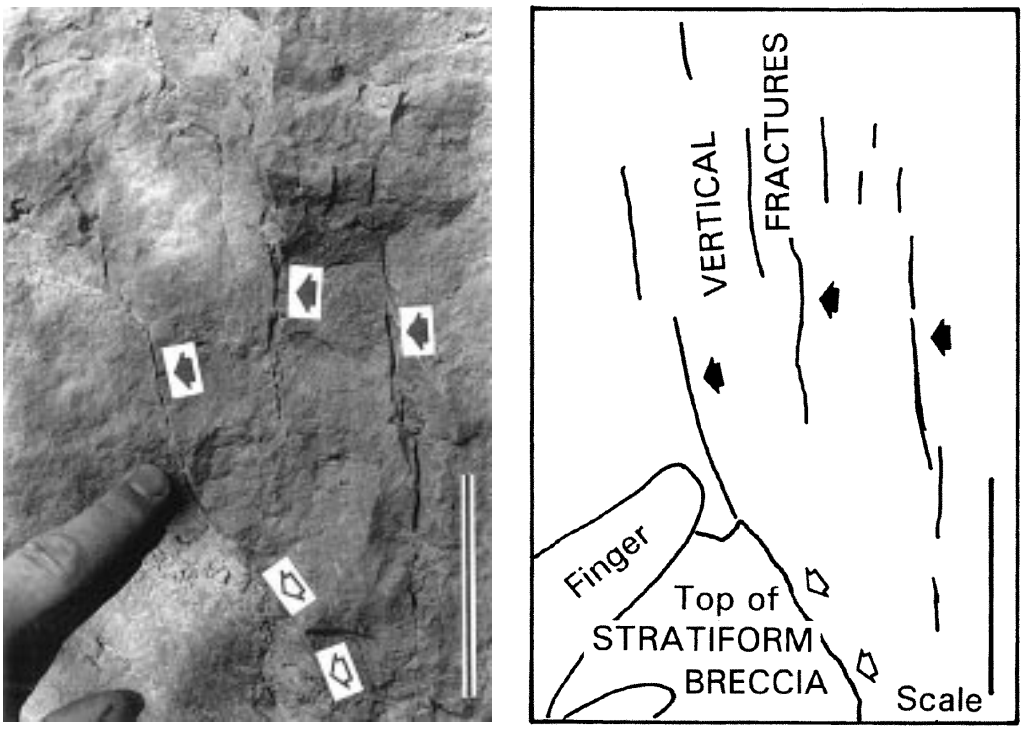

Figure 6. *Field photograph of top of uppermost stratiform breccia shown in figures 3 and 4. Open arrows indicate contact between dolomitized carbonate breccia and overlying fractured dolostone. Black arrows indicate fractures extending upward from top of breccia through fractured dolostone. Scale bar is 10 cm tall.*

Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 47, 26 p.

Mazzullo, S.J., 1989, Formational and zonal subdivisions of the Ellenburger Group (Lower Ordovician), southern Midland basin, Texas, *in* Cunningham, B.K., and Romwell, D.W., eds., The Lower Paleozoic of West Texas and Southern New Mexico—Modern Exploration Concepts: Permian Basin Section-SEPM Publication 89-31, p. 113-122.

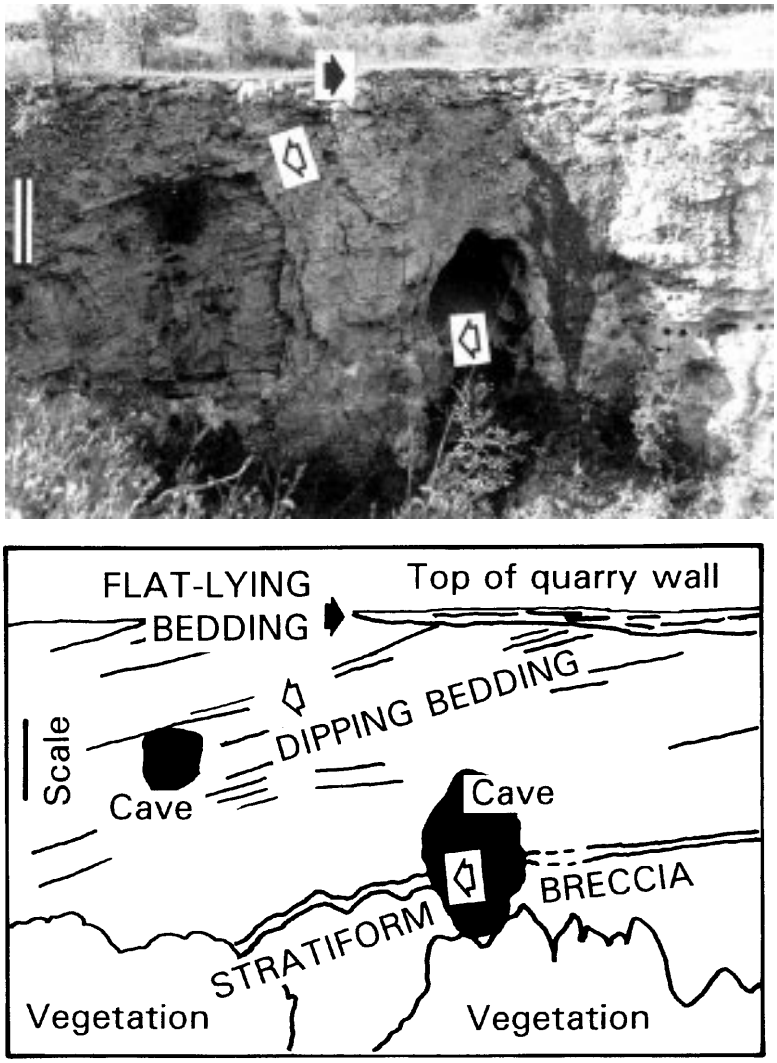

Figure 7. *Photograph of west quarry face showing collapse feature within Oneota Formation. Part of quarry wall shown corresponds to zone of discordant breccia in figure 3. Black arrow indicates 1 m-thick section of flat-lying silicified oolitic grainstones and quartz arenites of the basal Shakopee Formation overlying truncated beds of the Oneota Formation. Upper open arrow indicates truncated, left-dipping Oneota strata. Lower open arrow indicates position of uppermost stratiform breccia. The large (2.8 m-tall) cavern opening, developed within discordant breccia, is centered on the highest stratiform breccia. Cavern opening in quarry wall connects to extensive (> 500 m-long) cavern system within hilltop. Scale bar is 2 m tall.*

Middleton, G.V., 1961, Evaporite solution breccias from the Mississippian of southwest Montana: *Journal of Sedimentary Petrology,* v. 31, p. 189-195.

Milliken, K.L., 1979, The silicified evaporite syndrome — two aspects of silicification history of former evaporite nodules from southern Kentucky and northern Tennessee: *Journal of Sedimentary Petrology,* v. 49, p. 245-256.

Mussman, W.J., and Read, J.F., 1986, Sedimentology and development of a passive-to-convergent margin unconformity—Middle Ordovician Knox unconformity, Virginia Appalachians: *Geological Society of America Bulletin,* v. 97, p. 282-295.

Park, D.G., and B. Jones, 1985, Nature and genesis of breccia bodies in Devonian strata, Peace Point area, Wood Buffalo Park, northeast Alberta: *Bulletin of Canadian Petroleum Geology,* v. 33, p. 275-294.

Smith, G.L., 1989, Karsting and eolian deposition during a pre-New Richmond (Early Ordovician) sea level drawdown, Prairie du Chien Group, upper Mississippi Valley: *Geological Society of America Abstracts with Programs,* v. 21, p. A80.

Smith, G.L., 1991, Sequence stratigraphy and diagenesis of the Lower Ordovician Prairie du Chien Group on the Wisconsin arch and in the Michigan basin: unpublished Ph.D. dissertation,

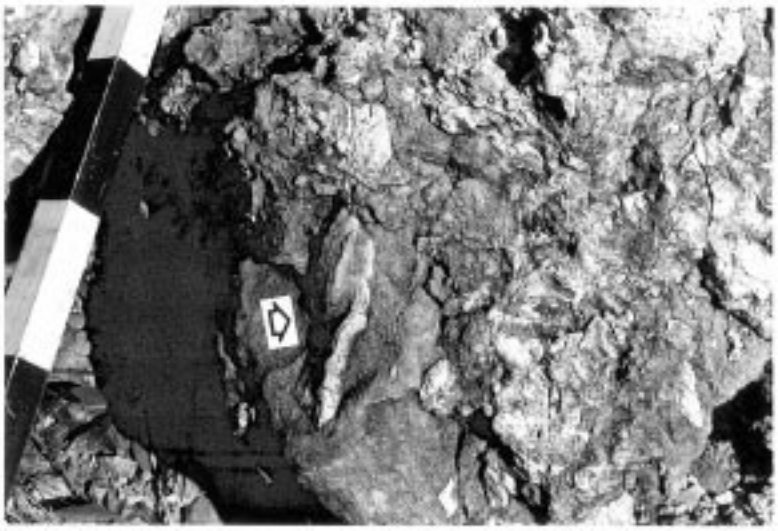

Figure 8. *A quarried block of discordant breccia with quartz-arenite matrix containing chert (arrow) and dolomite fragments. Stripes on scale bar are 10 cm in length.*

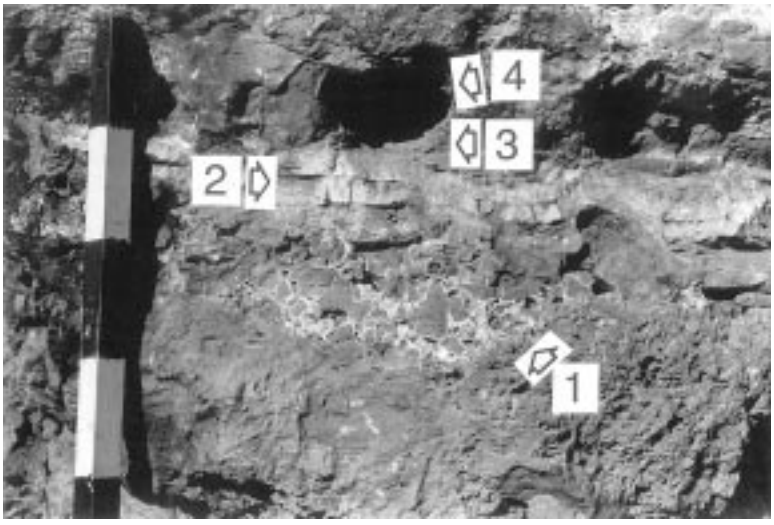

Figure 9. *Field photograph of cavern exposed on north face of quarry: 1. aragonite-cemented dolomite breccia, 2. two generations of aragonitic flowstone, 3. unlithified reddish-brown clay, and 4. remaining cavernous porosity. Stripes on scale bar are 10 cm in length.*

University of Wisconsin-Madison, Madison, Wisconsin, 265 p.

Smith, G.L., Byers, C.W., and Dott, R.H., Jr., 1993, Sequence stratigraphy of the Lower Ordovician Prairie du Chien Group on the Wisconsin arch and in the Michigan basin: *American Association of Petroleum Geologists Bulletin,* v. 77, p. 49-67.

Smith, G.L., Byers, C.W., and Dott, R.H., Jr., 1996, Sequence stratigraphy of the Prairie du Chien Group, Lower Ordovician, Midcontinent, U.S.A., *in* Witzke, B.J., Ludvigson, G.A., and Day, J., eds., Paleozoic Sequence Stratigraphy: Views from the North American Craton: Geological Society of America Special Paper 306, p. 23-33.

U.S. Geological Survey, 1960, Spring Green Quadrangle, Wisconsin, 15 Minute Series (topographic).

Warren, J.K., and Kendall, G.C.St.C., 1985, Comparison of marine sabkha (subaerial) and salina (subaqueous) evaporites: modern and ancient: *American Association of Petroleum Geologists Bulletin,* v. 69, p. 1013-1023.

Warren, J.K., Havholm, K.G., Rosen, M.R., and Parsley, M.J., 1990, Evolution of gypsum karst in the Kirschberg Evaporite Member near Fredericksburg, Texas: *Journal of Sedimentary Petrology,* v. 60, p. 721-734.