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Devonian shelf-basin, Michigan Basin, Alpena, Michigan

Raymond C Gutschick, *Department of Earth Sciences, University of Notre Dame, Notre Dame, Indiana 46556-1020*

INTRODUCTION

This chapter cites two localities, Paxton Quarry and Partridge Point (Fig. 1), and combines field observations from both to illustrate important stratigraphic relations and principles. Focus is on litho- and biostratigraphy of Middle and Late Devonian rocks as they relate to the Michigan Basin (Fig. 2).

Black organic-rich shales deserve our attention due to their energy potential a source rocks and fracture reservoirs for petroleum and natural gas. The Paxton Quarry offers the opportunity to examine an exceptional exposure of black shale (large area in Fig. 3; thick section in Fig. 4) as part of the formational sheet that continues into the Michigan Basin subsurface. These special rocks offer a challenge to observe and test their physical, chemical, and organic composition and structure to decipher origin, paleoenvironments, diagenesis, history, and economic value. A spectacular display of numerous, large calcareous concretions, in situ and free of shale matrix, is present in the quarry. How were they formed?

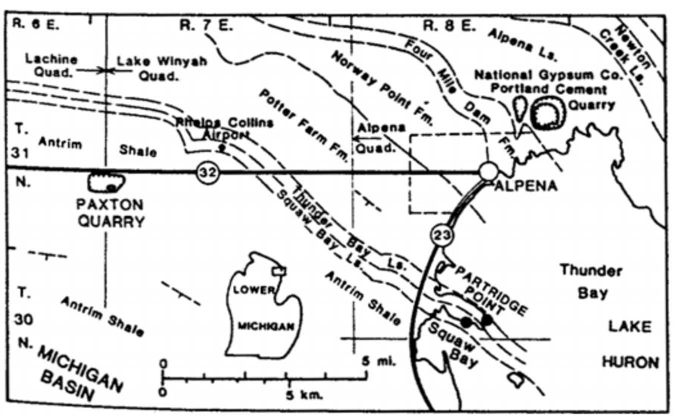

Figure 1. Geologic map of part of Alpena County, Michigan, northeast margin of Michigan Basin, showing the locations of the Paxton Quarry and Partridge Point area in relation to the geography and regional geology. Black dots show type localities. Adapted from Ehlers and Kesling (1970).

Partridge Point has an exposed limestone sequence that underlies Antrim black shales beneath Squaw Bay. Applying Walther's Law, one can go up section and down dip from fossiliferous shallow-water oxygenated Middle Devonian carbonate platform rocks at the shelf margin of the Michigan Basin into Upper Devonian transitional deeper water oxygen-deficient pelagic limestones followed by deep-water anaerobic black shales of a euxinic basin.

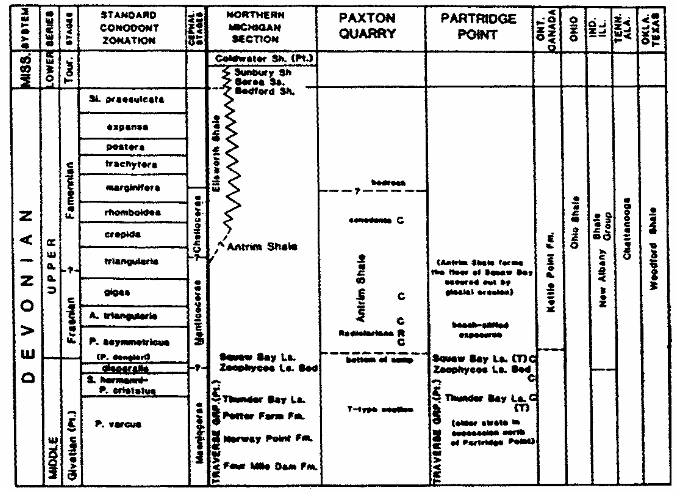

Figure 2. Chart to relate the chrono- and biostratigraphy of the rock sequence in the Paxton Quarry and Partridge Point area to standard accepted stratigraphic nomenclature. Chart shows relationship of the Antrim Shale to other widespread Late Devonian black shale units for parts of the United States and Canada. In the conodont zonation column, *Si* stands for *Siphonodella; P,, Polygnathus, A., Ancyrognathus*, and *S., Schmidtognathus;* other zones refer to species of *Palmatolepis*.

PAXTON QUARRY

Location and significance. The Paxton shale quarry is located in the N½Sec.30,T.31N.,R.7E., Lachine and Lake Winyah 7½-minute Quadrangles, Alpena County, along the south side of Michigan 32, about 9 mi (14.4 km) west of Alpena (Figs 1, 3). The quarry is owned by National Gypsum Company, Cement Division, with offices at the limestone quarry in Alpena. One part of black shale from the Paxton Quarry is mixed with four parts of limestone to make cement. Access to the Paxton Quarry can be arranged beforehand with the plant superintendent or directly with the quarry foreman at the site.

The following selected references are recommended for background study of the Late Devonian black shales: sedimentology of shales (Potter and others, 1980); world and United States paleogeography (Heckel and Witzke, 1979; Gutschick and Sandberg, 1983); Euramerican Devonian eustasy (Johnson and others, 1985); euxinic biofacies patterns (Byers, 1977); Antrim and correlative black shale studies (Ells, 1979; Winder, 1966; Russell, 1985; Cluff and others, 1981; Hazenmueller and Woodward, 1981).

The shale section in the Paxton Quarry represents the lower part of the Upper Devonian Antrim Shale (Figs. 2, 4), about 135 ft (41 m) thick. The Antrim Shale in the Alpena area, truncated northern margin of the Michigan Basin, ranges in thickness from an erosional cut-out (zero edge) to about 400 ft (122 m); however, it reaches more than 600 ft (183 m) in the basin depocenter to the southwest (Fisher, 1980). The oldest strata is exposed in the quarry sump (Figs. 3, 4). A greenish-gray shaly calcareous unit forms the bottom 5 ft (1.5 m) and this may be the upper beds of the Squaw Bay Limestone. Conodonts and radiolarians found in the sump section identify with the *Polygnathus asymmetricus* Zone. Another unit in the sump exposes at least 12 pairs of thin (few cm) alternating green-gray and black shale layers. The bottom contact of the lighter colored layers is very irregular where organisms burrowed into underlying black muds and backfilled with green-gray mud; whereas the top contact is sharp and planar with the overlying dark muds (Fig. 5, bottom left). Turbidite muds periodically washed into the euxinic basin from the platform margin and may represent distal prodeltaic tongues of sediment with entrained oxygen.

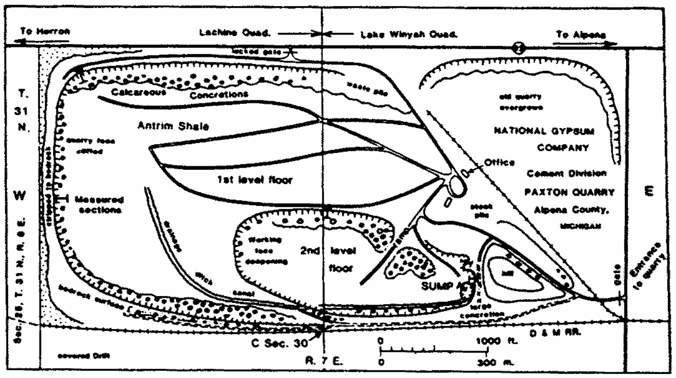

Figure 3. Geologic field sketch map of Paxton shale quarry (lower part of Antrim Shale). The second level is presently being quarried. Topographic quadrangles and oblique aerial views were used for the sketch.

Another seemingly anomalous interruption in black shale deposition is the light-colored calcareous unit that occurs between 33 and 50 ft (10 and 15 m) above the base of the section (Fig. 4). This unit sharply overlies black concretionary shale below, and in turn is overlain by thin layers of alternating green-gray and black shale (Fig. 5, bottom left). Fossils are present, including conodonts (Lower *gigas* Zone) and leiorhynchoid brachiopods, but this light-colored unit lacks a benthic community. How does one explain this abrupt change from anaerobic black mud conditions to oxygenated calcareous muds and return to anoxic conditions, assuming a deep-water basinal framework with a stratified water column?

Superficially, the black shales in the section look similar from bottom to top, although closer inspection reveals differences. Look for subtle changes of rock color (fresh or weathered), stratification—bedding fissility or the lack of it, sedimentary structures—current scour or cross-stratification, textural changes, jointing, concretionary zones, compaction, fossils (see Fig. 5)—hard and soft-bodied forms, burrows, minerals and crystals, and anything else the eyes can detect. Remember that all clues must fit the “frozen” pattern.

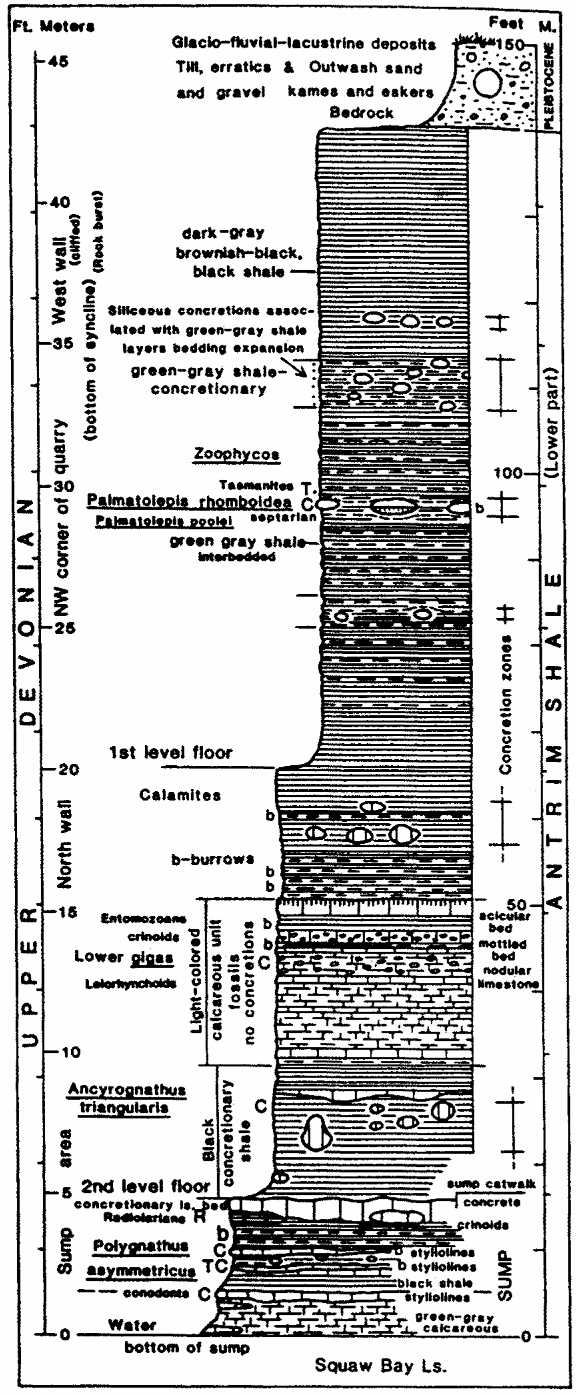

Figure 4. Detailed graphic columnar section of stratigraphy completely exposed in quarry showing current status of biostratigraphy. The rock column represents the lower part of Late Devonian Antrim Shale: C represents conodont occurrences; R, radiolarian concretionary limestone beds; T, *Tasmanites* occurrences; and b, burrowed and/or bioturbated beds.

The mineralogy and chemical composition of the Antrim Shale was studied by Ruotsala and others (1981). The Antrim is uniform in composition and contains about 30% Si, 8% Al, 4% Fe, 2% Mg, 3% Ca, 2% S, and 5% organic carbon. Its mineralogy consists of 50-60% quartz, 20-35% illite, 5-10% kaolinite, 0-5% chlorite, and up to 5% pyrite. When present, calcite and dolomite occur in limestone nodules, lenses, and interbeds as much as 5 ft

(1.5 m) thick in the lower half of the Antrim. Organic material, as measured by low-temperature ashing, is present up to 12.8%. Bitumen contents range from 0.2 to 0.8%. Average weights of bitumen components are 360 to 370. Deeper drill holes have higher bitumen contents. Kerogen, which makes up the remainder of organic material, is of low functionality, about 1 functional group per 25 carbon atoms. Hydroxyl (1 group/50 carbon atoms) and alkene bonds (1 group/50 carbon atoms) are the most common groups present.

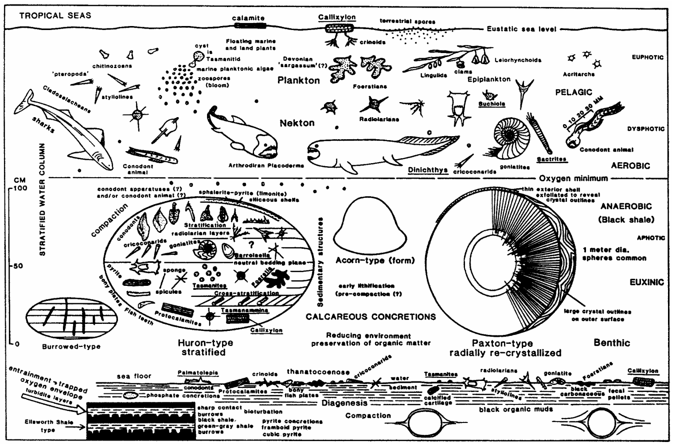

Figure 5. Paleoecological model for biota in Antrim-Kettle Point-Ohio (Huron)-New Albany black concretionary shales of midwestern United States and Canada (Michigan, Ontario, Indiana-Illinois-Kentucky). Size of organisms are not to scale, but scales are given for size of conodont animal and for range of most concretion sizes, except acorn-type, which is greatly reduced. Refer to Sandberg and Gutschick (1984, p. 149, Fig. 13) for Mississippian model.

Concretion biostratigraphy. Concretions may contain many important clues to the age, sedimentology, paleontology, paleoecology, paleogeography, origin, and history of the sediments that contain them (Gutschick and Wuellner, 1983; Sandberg and Gutschick, 1984). Calcareous concretions are present in many Phanerozoic black shales throughout the world. Often they are associated with deep-water, oxygen-deficient, ba-sinal fades where the benthos is very limited or absent, but the Pelagic plankton and nekton biota may have flourished (Fig. 5). Fossils, especially microforms, are often present in abundance and well-preserved in the concretions, whereas in matrix shales they may be crushed by compaction and difficult to recover or flagenetically altered beyond recognition.

Large calcareous concretions are common to the Antrim, Kettle Point, Ohio-Huron, New Albany, and other black shale formations. The Kettle Point Formation, Antrim correlative along the eastern shore of Lake Huron, Ontario, is named after the “kettles” (large calcareous concretions) conspicuous at this location. Huron Shale concretions, 13 ft (4 m) maximum diameter at Standardsburg, Ohio (Prosser, 1913), contain Late Devonian radiolarians documented by Foreman (1963), and their origin has been discussed by Clifton (1957). One is overwhelmed by the array of concretions of various sizes and shapes that lie loose on the Paxton Quarry floors and in place in the shale walls. The largest concretion seen in the quarry is 10 ft (3 m) in diameter. Several types—stratified Huron-type, radially crystallized Paxton-type, acorn-form, and burrowed-type (Fig. 5)—are recognized, based on size, shape, internal structure, and host rocks.

Paxton concretions have been studied by Wardlaw and Long (1982), who dealt with their origin. These authors wrote,

“The concretions are composed of ferroan dolomite, contain quartz, and are rimmed by 1-2 cm of pyrite. The weight percent of ferroan dolomite decreases from center to edge (90-50%). In thin section, the dolomite crystals are long, slender, feathery, with curved edges and sweeping extinction. There are no chemical trends from center to edge in the major elements (Ca, Mg, Fe), trace elements (Na, K, Sr, Mn, Zn), total organic carbon, or oxygen isotope values (-9.1%o PDB). The carbon isotope values range from -10 to -13°%$_0$ PDB and increase from center to edge. The data have been interpreted to indicate that the concretions grew below the seawater/sediment interface, within the top 33 ft (10 m) of the sediment surface, and in a system which was open to seawater. Growth occurred before major compaction.”

This information apparently applied to Paxton-type concretions.

PARTRIDGE POINT

Location and significance. Partridge Point is a small peninsula of land that is subparallel to the strike of the strata, projecting southeastward into Lake Huron (Figs. 1, 6). The type sections of two formations, the Thunder Bay and Squaw Bay Limestones, are exposed along the shoreline; the former in the W1/2SE1/4Sec.11, and the latter in the SW1/4SW1/4Sec.11, both in T.30N.,R.8E., 71/2-minute Alpena Quadrangle. Alpena County, Michigan. Both exposures are accessible along the beach at the water's edge and can be reached from the unmaintained boat-ramp launch roads (Fig. 6). Otherwise, private home owners should be consulted before crossing their lots to the beach.

The purpose of the Partridge Point study is to examine carefully the Thunder Bay and Squaw Bay Limestones (Fig. 7), reconstruct the sequence with the contrasting overlying Antrim Shale at Paxton Quarry (concealed under Squaw Bay), and interpret the history of the succession in relation to the Michigan Basin. Start at the type Thunder Bay Limestone location and follow the shoreline-beach up section and down dip, around to the Squaw Bay Limestone type section. Section descriptions of formations on Partridge Point with fossil lists and plates are given by Ehlers and Kesling (1970); conodonts are described and discussed in Muller and Clark (1967) and Bultynck (1976). Note that there are covered intervals and that the section is incomplete.

Fossiliferous limestone and shaly beds exposed along the shoreline buttressed by Thunder Bay Limestone are light-colored and replete with coralline and shelly faunas (Fig. 7). Sessile benthos animal skeletons abound with colonial corals, stromatoporoids, bryozoans, crinoids, and Mastoids, as well as other mobile benthic types of the reef-like community. This location is close to the shallow-water carbonate platform shelf margin of the Michigan Basin during the Middle Devonian. Note that the medium-gray, fine-grained limestone beds at the top of the section have few fossils. The upper sequence can also be seen south of Partridge Point.

The westernmost projection of land into Squaw Bay (Fig. 6) exposes a remarkably well-jointed limestone pavement covered with *Zoophycos* burrow swirl impressions followed by overlying thin irregular layers of brown-gray crystalline fossiliferous Squaw Bay Limestone. The rock with *Zoophycos* contains a fauna of agglutinated saccamminid foraminifera with some tests constructed of glauconite grains, conodonts (possibly pre-*P. asymmetricus*), scolecodonts, and water-worn phosphatic and glauconitic steinkerns of styliolines, ostracods, bryozoans, tiny snails, and pelmatozoans. This unit is discussed separately from the Squaw Bay Limestone, although some include it with the latter.

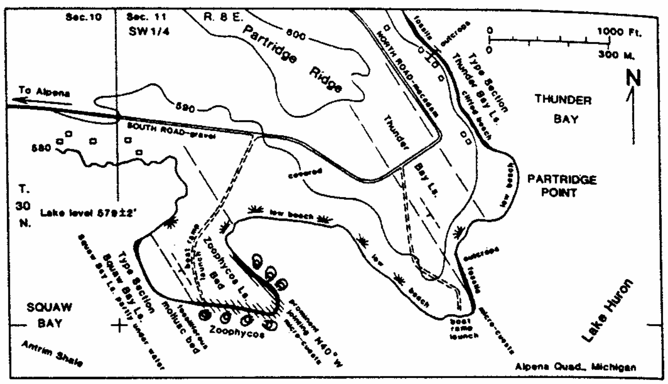

Figure 6. Geologic sketch map for Partridge Point, type localities of Thunder Bay and Squaw Bay Limestones, and for Squaw Bay floored by Antrim Shale bedrock.

The Squaw Bay Limestone makes a narrow rock platform along the shoreline at the type section. When the level of Lake Huron is high, or when winds from the southwest pile water onto the beach, most (if not all) of the Squaw Bay Limestone is barely awash. The best exposures are at times of low water levels of the lake. This pelagic limestone is a coquina of styliolines, cephalopods (goniatites), conodonts, few clams and snails, and poorly preserved wood fragments. Pyrite and sphalerite are also present. Details of the complete section are still forthcoming. Contact with the Antrim Shale is under water and not exposed at this location, but it may be observed in the quarry sump.

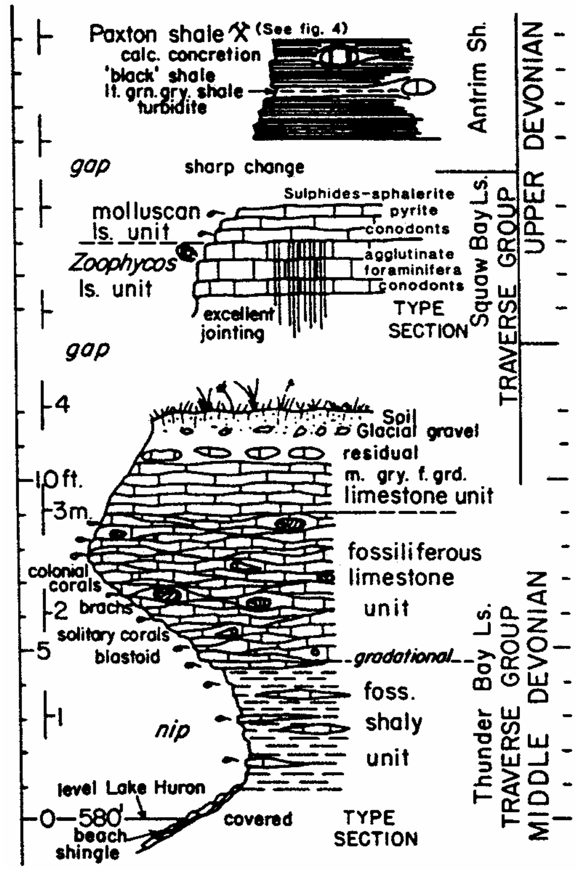

Figure 7. Stratigraphic section (composite) for type localities of Thunder Bay and Squaw Bay Limestones along Lake Huron shoreline, Alpena County and Quadrangle, Michigan. Sequence is interrupted by glacial drift or lacustrine sediment cover and underwater concealed intervals across formational boundaries.

Shelf-basin analysis. There are three formations (litho- and biofacies) in stratigraphic succession—Thunder Bay Limestone, Squaw Bay Limestone, and Antrim Shale—that are superimposed one on top of another in vertical succession.Walther's Law of Correlation (or Succession) of Facies states that only such fades that occur as contemporaneous deposits laterally adjacent to each other *can succeed one another in vertical sequence* (italics mine), provided there is no break in the succession (Middleton, 1973). The attributes of each formation have been singled out and plotted in a series of diagrams (Fig. 8,A-I); interpretation follows Walther's Law and the models of Gutschick and Sandberg (1983) and Sandberg and Gutschick (1984).

Lithofacies, rock colors, pelagic plankton and nekton faunas and floras, and benthos dictate the paleogeography and paleoecology. Thunder Bay Limestone rock colors are light colored as a result of the oxidation of the organic carbon, and sessile benthic framework builders dominate the biota. This combination represents a shallow-water carbonate platform community habitat. The *Zoophycos* limestone unit has deeper water benthic burrowing oganisms and an upper slope saccamminid foraminiferan biofades, but the presence of water-worn phosphate and glauconite steinkera fragments suggests traction transport downslope into deep water. The Squaw Bay Limestone is dominated by a pelagic molluscan and conodont nekton, the virtual absence of a benthos, and sulfides, which suggest an oxygen-defident stratified water column of a lower slope or basinal environment. The Antrim Shale is devoid of benthic forms, except for turbiditic green muds with bioturbation, but it has abundant plankton and nekton organisms, especially microforms. The black shale is interpreted as being deposited in deep water at depths of more than 165-330 ft (150-200 m) in an anaerobic basin where there was no oxygen to support bottom life and the organic carbon is in a reduced state.

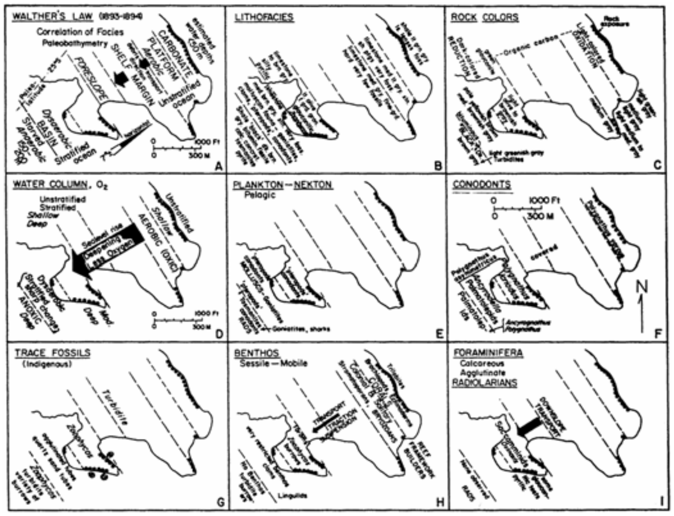

Figure 8. Graphic stratigraphic basin-platform analysis diagrams—framework, rock descriptions, water and biotic realms, important microbiota, and benthic traces (compare with Fig. 6; black dots refer to outcrop exposures). A, Paleoenvironmental framework down-dip across strike of beds from carbonate platform into basin to illustrate Walther's Law. Approximate paleolatitude after Heckel and Witzke (1979). B, Sequence of Thunder Bay and Squaw Bay lithofacies exposed across Partridge Point C, Distribution of rock colors (standard color chart) exposed across Partridge Point. Rock colors in large part reflect percentage and oxidation-reduction state of organic carbon and iron compounds related to their depositional history (Gutschick and Sandberg, 1983, p. 86, Fig. 7B; Sandberg and Gutschick, 1984, Fig. 15). D, Change in water column with time from shallow oxygenated unstratified conditions on the platform to deep basin stratified conditions of euxinic basin. E, Diagram to emphasize pelagic plankton-nekton aerobic stratification over basin (see Fig. 5). F, Conodont succession reflects zonal and paleoecological changes with time (Sandberg and Dreesen, 1984, Fig. 4, Late Devonian; Sandberg and Gutschick, 1984, Fig. 14, Early Mississippian). G, Map showing distribution of pavement *Zoophycos* traces on top surface of limestone unit. H, Map illustrates dramatic transition from flourishing sessile benthic communities on platform in aerobic zone to sterile benthos of anoxic waters in euxinic basin. I, Agglutinate foraminiferal fauna of the saccamminid biofacies (Gutschick and Sandberg, 1983, p. 87, Fig. 7E).

This chapter provides the reader with orientation, perspective, and focus for sharper resolution of the geology of the two localities described. It directs one's attention toward observational details, sampling for laboratory follow-through, and in-depth library research.

REFERENCES CITED

Bultynck, P. L., 1976, Comparative study of Middle Devonian conodonts from north Michigan (U.S.A.) and the Ardennes (Belgium-France): G eological Association of Canada Special Paper No. 15, p. 119-141.

Byers, C. W., 1977, Biofacies patterns in euxink basins; A general model: Society of Economic Paleontologists and Mineralogists Special Publication 25, p. 5-17.

Clifton, H. E, 1957, The carbonate concretions of the Ohio Shale: Ohio Journal of Science, v. 57, p. 114-124.

Cluff, R. M., Reinbold, M. J., and Lineback, J. A., 1981, The New Albany Shale Group of Illinois: Illinois State Geological Survey Circular 518, 83 p.

Ehlers, G. M., and Kesling, R. V., 1970, Devonian strata of Alpena and Presque Isle Counties, Michigan: Guidebook prepared for North Central Section Geological Society of America and Michigan Basin Geological Society, p. 1-130.

Ells, G. D., 1979, Stratigraphic cross sections extending from Devonian Antrim Shale to Mississippian Sunbury Shale in the Michigan Basin: Geological Survey Division, Michigan Department of Natural Resources, Report of Investigation 22, 186 p.

Fisher, J. H., 1980, Thickness of Ellsworth Shale, Plate 11, and thickness of Antrim Shale, Plate 12: Dow Chemical Co., U.S. Department of Energy Report No. FE2346-80, scale 1:1,000,000.

Foreman, H. P., 1963, Upper Devonian radiolaria from the Huron Member of the Ohio Shale: Micropaleontology, v. 9, p. 267-304.

Gutschick, K. C, and Sandberg, C. A., 1983, Mississippian continental margins of the conterminous United States, *in* Stanley, D. J., and Moore, G. T., eds. The shelfbreak; Critical interface on continental margins: Society of Paleontologists and Mineralogists Special Publication 33, p. 79-96.

Gutschick, R. C, and Wuellner, D., 1983, An unusual benthic agglutinated foraminiferan from Late Devonian anoxic basinal black shales of Ohio: Journal of Paleontology, v. 57, p. 308-320.

Hazenmueller, N. R., and Woodward, G. S., eds., 1981, Studies of the New Albany Shale (Devonian-Mississippian) and equivalent strata in Indiana: Indiana Geological Survey, U.S. Department of Energy Report, 100 p.

Heckel, P. H., and Witzke, B. J., 1979, Devonian world paleogeography determined from distribution of carbonates and related lithic paleoclimatic indicators: Palaeontological Association, Special Papers in Palaeontology 23, p. 99-123.

Johnson, J. G., Klapper, G., and Sandberg, C. A., 1985, Devonian ecstatic fluctuations in Euramerica: Geological Society of America Bulletin, v. 96, p. 567-587.

Middleton, G. V., 1973, Johannes Walther's Law of Correlation of Facies: Geological Society of America Bulletin, v. 84, p. 979-987.

Muller, K. J., and Clark, D. L, 1967, Early late Devonian conodonts from the Squaw Bay Limestone in Michigan: Journal of Paleontology, v. 41, p. 902-919.

Potter, P. E., Maynard, J. B., and Pryor, W. A., 1980, Sedimentology of Shale; Study Guide and Reference Source: New York, Springer-Verlag, 306 p.

Ruotsala, A. P., Sandell, V. R., and Leddy, D. G., 1981, Mineralogic and chemical composition of Antrim Shale, Michigan [abs.]: American Association of Petroleum Geologists Bulletin, v. 65, p. 983.

Russell, D. J., 1985, Depositional analysis of a black shale by using gamma-ray stratigraphy; The Upper Devonian Kettle Point Formation of Ontario: Canadian Petroleum Geology Bulletin, v. 33, p. 236-253.

Sandberg, C. A., and Dreesen, R., 1984, Late Devonian icriodontid biofacies models and alternate shallow-water conodont zonation, *in* Clark, D. L, ed, Conodont Biofacies and Provincialism: Geological Society of America Special Paper 196, p. 143-178.

Sandberg, C. A., and Gutschick, R. C, 1984, Distribution, microfauna, and source-rock potential of Mississippian Delle Phosphatic Member of Woodman Formation and equivalents, Utah and adjacent states, *in* Woodward, J., Meissner, F. F., and Clayton, J. L., eds., Hydrocarbon source rocks of the Greater Rocky Mountain region: Denver, Rocky Mountain Association of Geologists, p. 135-178.

Wardlaw, M. M., and Long, D. T., 1982, Mineralogy, chemistry, and physical setting of carbonate concretions in the Antrim Shale (Devonian, Michigan Basin); Clues to origin: Geological Society of America Abstracts with Programs, v. 14, no. 5, p. 291.

Winder, C. G., 1966, Conodont zones and stratigraphic variability in Upper Devonian rocks, Ontario: Journal of Paleontology, v. 40, p. 1275-1293.

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