GUIDEBOOK NO. 18

PENNSYLVANIAN SHARON FORMATION, PAST AND PRESENT: SEDIMENTOLOGY, HYDROGEOLOGY, AND HISTORICAL AND ENVIRONMENTAL SIGNIFICANCE

A field guide to Gorge Metro Park, Virginia Kendall Ledges in the Cuyahoga Valley National Park, and other sites in Northeast Ohio

Editor

Annabelle M. Foos

DIVISION OF GEOLOGICAL SURVEY
4383 FOUNTAIN SQUARE DRIVE
COLUMBUS, OHIO 43224-1362
(614) 265-6576
(614) 447-1918 (FAX)
e-mail: geo.survey@dnr.state.oh.us
World Wide Web: http://www.ohiodnr.com/geosurvey/

OHIO GEOLOGY ADVISORY COUNCIL

Ms. F. Lynn Kantner, *representing At-Large Citizens*
Mr. David A. Wilder, *representing Coal*
Mr. C. Robert Lennertz, *representing Environmental Geology*
Dr. Mark R. Boardman, *representing Higher Education*
Dr. Robert W. Ritzi, Jr., *representing Hydrogeology*
Mr. Garry L. Getz, *representing Industrial Minerals*
Mr. William M. Rike, *representing Oil and Gas*

SCIENTIFIC AND TECHNICAL STAFF OF THE DIVISION OF GEOLOGICAL SURVEY

ADMINISTRATION (614) 265-6988

Thomas M. Berg, MS, *State Geologist and Division Chief*
Dennis N. Hull, MS, *Assistant State Geologist and Assistant Division Chief*
Betty R. Lewis, *Fiscal Officer*
James M. Patterson, *Account Clerk*
Sharon L. Stone, AD, *Administrative Assistant*

GEOLOGIC MAPPING GROUP (614) 265-6473

Edward Mac Swinford, MS, *Geologist Supervisor*
Richard R. Pavey, MS, *Surficial Mapping Administrator*
C. Scott Brockman, MS, *Geologist*
Glenn E. Larsen, MS, *Geologist*
Gregory A. Schumacher, MS, *Geologist*
Douglas L. Shrake, MS, *Geologist*
Kim E. Vorbau, BS, *Geologist*

LAKE ERIE GEOLOGY GROUP (419) 626-4296, (419) 626-8767 (FAX)

Constance J. Livchak, MS, *Geologist Supervisor*
Jonathan A. Fuller, MS, *Geologist*
Donald E. Guy, Jr., MS, *Geologist*

CARTOGRAPHY & EDITING GROUP (614) 265-6593

Edward V. Kuehnle, BA, *Cartographer Supervisor*
Donovan M. Powers, BA, *GIMS Specialist*
Lisa Van Doren, BA, *Electronic Designer*

COAL & INDUSTRIAL MINERALS GROUP (614) 265-6594

Douglas L. Crowell, MS, *Geologist Supervisor*
Charles E. Banks, MS, *Geologist/GIS Specialist*
Ronald G. Rea, MS, *Geologist and Sample Repository Manager*
Mark E. Wolfe, BS, *Geologist*

PETROLEUM GEOLOGY GROUP (614) 265-6598

Lawrence H. Wickstrom, MS, *Geologist Supervisor*
Mark T. Baranoski, MS, *Geologist*
James McDonald, MS, *Geologist*
Ronald A. Riley, MS, *Geologist*
Ernie R. Slucher, MS, *Geologist*
Joseph G. Wells, MS, *Database Administrator*

GEOLOGIC RECORDS CENTER (614) 265-6585

Garry E. Yates, NZCS, *Supervisor*
Madge R. Fitak, BS, *Office Assistant*
Sharon E. Lundy, *Office Assistant*

An Equal Opportunity Employer - M/F/H

recycled paper

STATE OF OHIO
Bob Taft, Governor
DEPARTMENT OF NATURAL RESOURCES
Samuel W. Speck, Director
DIVISION OF GEOLOGICAL SURVEY
Thomas M. Berg, Chief

GUIDEBOOK NO. 18

PENNSYLVANIAN SHARON FORMATION, PAST AND PRESENT: SEDIMENTOLOGY, HYDROGEOLOGY, AND HISTORICAL AND ENVIRONMENTAL SIGNIFICANCE

A field guide to Gorge Metro Park, Virginia Kendall Ledges in the Cuyahoga Valley National Park, and other sites in Northeast Ohio

Editor

Annabelle M. Foos
Department of Geology, University of Akron

Authors

Annabelle M. Foos
Department of Geology, University of Akron

Neil A. Wells
Department of Geology, Kent State University

James E. Evans
Department of Geology, Bowling Green State University

Joseph T. Hannibal
Cleveland Museum of Natural History

David A. Waugh
Department of Geology, Kent State University

Prepared for the 2003 Annual Great Lakes Section-SEPM/Northern Ohio Geological Society Field Conference

Columbus
2003

This guidebook has been edited by the University of Akron and the Cleveland Museum of Natural History. The views, terminology, interpretations, and rock-unit terminology expressed are those of the authors. The Division of Geological Survey disclaims any responsibility for interpretations and conclusions.

Cover photo: The Cuyahoga Gorge at Cuyahoga Falls, Ohio, during the late 19th century. Photo courtesy of Taylor Memorial Public Library, Cuyahoga Falls Ohio.

CONTENTS

FIGURES

TABLES

PLATES

by David A. Waugh and Neil A. Wells

PENNSYLVANIAN SHARON FORMATION, PAST AND PRESENT: SEDIMENTOLOGY, HYDROGEOLOGY, AND HISTORICAL AND ENVIRONMENTAL SIGNIFICANCE

by Annabelle M. Foos,
Neil A. Wells,
James E. Evans,
Joseph T. Hannibal,
and David A. Waugh

CHAPTER 1, OVERVIEW AND ROAD LOGS

by Annabelle M. Foos

OVERVIEW

The focus of this field conference is the Pennsylvanian Sharon Formation, the basal unit of the Pottsville Group. We will visit classic exposures of the Sharon Formation at the Gorge Metro Park in Cuyahoga Falls and Virginia Kendall Ledges in the Cuyahoga Valley National Park. It has been over 25 years since a field guide has been written for these exposures (Heimlich and others, 1970; Rau, 1970; Coogan and others, 1974; Feldmann and others, 1977). The rocks have not changed much in the past 25 years, but how we view them has. One objective of this field guide is to update our understanding of the Sharon by summarizing some of the more recent works and to incorporate some newer concepts that have been developed since the seventies such as sequence stratigraphy and basin analysis. The practical application of our understanding of the Sharon has also changed during the past quarter century. Early studies focused on the use of the Sharon as a building stone or its relationship to the Pennsylvanian cyclothems and associated coal deposits. The Sharon was also used to develop models for braided stream deposits that could be used in the exploration of petroleum. Current applications of this knowledge are more focused on environmental issues. Therefore we will discuss the hydrogeology and fluid flow through the Sharon, in hopes of shedding light on the movement of contaminants through sandstones.

A second story we wish to convey with this field guide is one of how humans have affected their environment. Dams, associated mills, and industrialization are centered in areas where rivers flow over resistant layers such as the Sharon Formation. We will start by giving a historical perspective of the early settlers who first “improved” the Cuyahoga River by building a dam in 1812. We will then discuss the legacy of these dams and the issues involved in their removal. The effect of urbanization on the ground water quality of the Sharon aquifer will also be discussed.

Regional aspects of the sedimentology, stratigraphy and hydrogeology of the Sharon Formation are presented in chapters 2, 3 and 4. Chapters 5 and 6 describe outcrop to petrographic scale studies of the Sharon with a focus on what they tell us about fluid flow through the aquifer. Chapter 7 describes historical and cultural aspects of the Sharon and chapter 8 discusses the environmental issues associated with historic dams. The final chapter, 9, describes the outcrops and stops we will visit on this trip. Features discussed in chapters 6 and 9 are illustrated in the plates at the end of the guidebook.

DAY 1 ROAD LOG
(For maps refer to figures 1-1, 1-2 and 1-3.)

Total miles	Interval miles	
0		Country Inn, 222 Main Street, Cuyahoga Falls. Turn right (south) onto Main Street (Home Avenue)
0.2	0.2	At the first light, turn right (west) onto Howe Avenue. Stay in the right hand lane, pass under the bridge, and go straight ahead
0.9	0.7	At the traffic light, make a hard right turn (north) onto Gorge Parkway (Front Street)
1.2	0.3	At the first light, turn left (west) into the parking lot for the Gorge Metro Park

Stops 1 and 2: Hikes in Gorge Metro Park (see Chapter 9 for details)

Total miles	Interval miles	
1.2		From traffic light at entrance to Gorge Metro Park parking lot, turn left (north) onto Front Street
1.45	0.25	Stay on Front Street (bear slightly right at the next traffic light)
2.1	0.65	Turn right (east) on Prospect Street and park. You should be at latitude 41° 07’ 49.7” N and longitude 81° 28’ 58.0” W

Stop 3: View of the Cuyahoga River Gorge (see Chapter 9 for details)

Total miles	Interval miles	
2.1		Turn left (north) onto Front Street
2.3	0.2	Turn right (east) on Broad Street, and prepare for left turn immediately after passing under the Ohio Rte. 8 bridge
2.4	0.1	Turn left onto entrance ramp for Ohio Rte. 8 northbound, and enter Ohio Rte. 8

FIGURE 1-1.—Generalized map of northeast Ohio showing the location of field stops.

Total miles	Interval miles	
5.8	3.4	Take the Steels Corners exit, and turn left (west) on Steels Corners Road for 0.8 mile
6.6	0.8	Turn right (north) on Wyoga Lake Road
8.2	1.6	Cross Seasons Road and turn right (north) on Akron-Cleveland Road
9.3	1.1	Turn left (west) on Kendall Park Road (also called Truxell Road)
10.4	1.1	Turn right (north) into Virginia Kendall Ledges
10.7	0.3	Park in parking lot

Stop 4: Hike along Virginia Kendall Ledges (see Chapter 9 for details)

11.0	0.3	Turn left (east) onto Truxell Road
12.1	1.1	At the traffic light, turn right (south) onto Akron-Cleveland Road (State Road) (Going north takes you to Ohio Rte. 8 and I-80, the Ohio Turnpike)
15.1	3.0	Turn left (east) onto Steels Corners Road
16.6	1.5	Turn right onto Ohio Rte. 8 South
19.9	3.3	Take the Broad Boulevard exit
20.2	0.3	At the light, turn left (east) onto Broad Boulevard
20.4	0.2	At the second light, turn right (south) onto Newberry Street
21.1	0.7	Turn right into the Country Inn

End of road log for Day 1

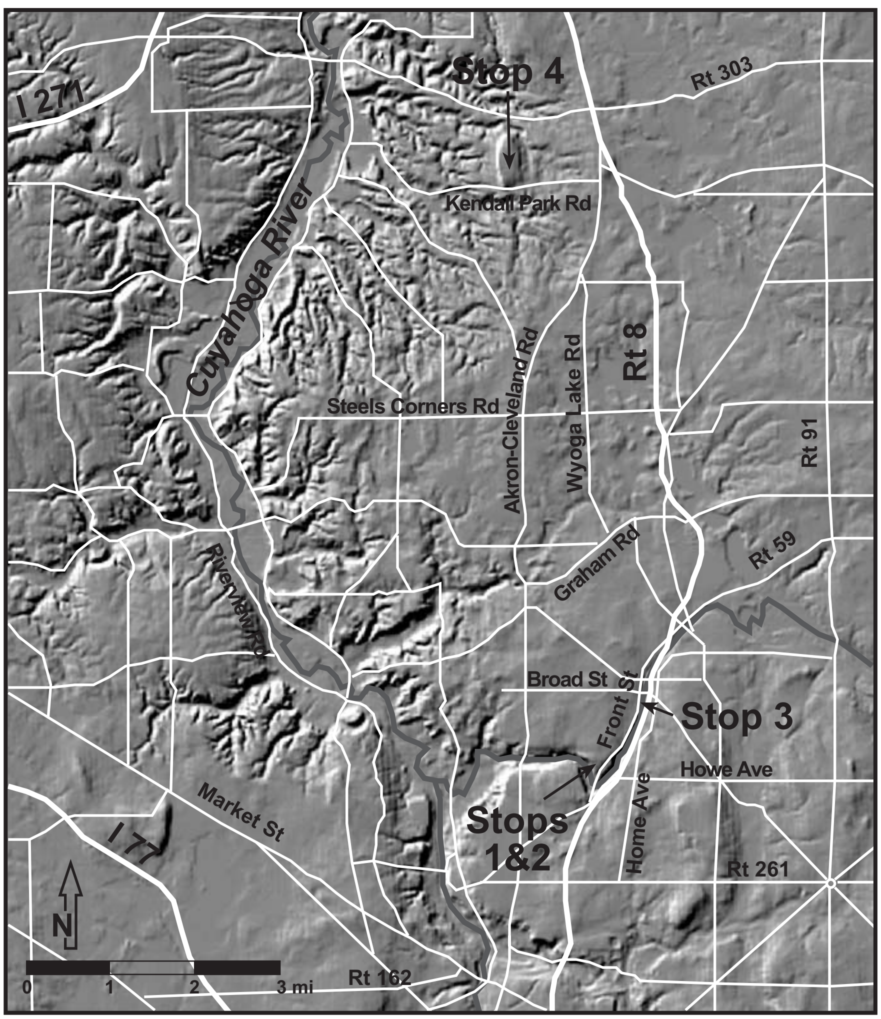


FIGURE 1-2.—Digital elevation map and roadmap showing the locations of Day 1 field stops. A comparison with the bedrock geology map (fig. 4.2) illustrates the relationship between the topography and underlying geology.

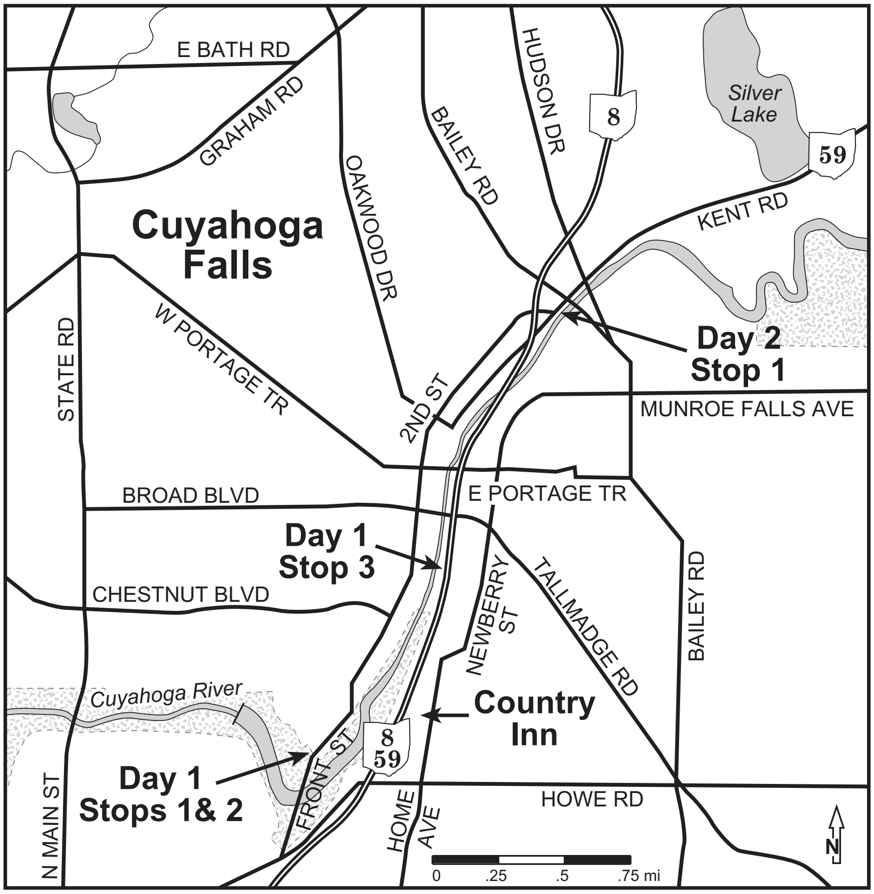


FIGURE 1-3.—Generalized map of downtown Cuyahoga Falls, Ohio, showing the location of field stops.

DAY 2 ROAD LOG
(For maps refer to figs. 1-1, 1-3, 1-4,and 1-5)

Total miles	Interval miles	
0		Country Inn, 1420 Main Street, Cuyahoga Falls, turn right (south) onto Main Street (Home Ave)
0.2	0.2	At the 1st traffic light turn right (west) onto Howe Ave. Stay in the right hand lane
0.4	0.2	Turn right onto Ohio Rte. 8 north
2.1	1.7	Take the Front Street Exit, turn right (east) onto Front Street (Ohio Rte. 59)
2.4	0.3	Pull into River Front park on the right

Stop 1: River Front Park (see Chapter 9 for details)

2.4	0	Turn right out of the parking lot onto Ohio Rte. 59 east
7.7	5.3	At the first light after Middlebury turn right onto Stow Road and make a quick left
8.0	0.3	Pull into Franklin Mills Riverside Park on your left or Tannery Park on your right

Stop 2: Kent Dam (see Chapter 9 for details)

8.0	0	Turn right out of Franklin Mills Park
8.3	0.3	At the stop sign turn right and make a quick left onto Rt. 59 west
12.3	4.0	Turn right (north) onto Ohio Rte. 91 (Darrow Road)
12.8	0.5	Turn left onto Graham Road
14.4	1.6	Turn right onto Ohio Rte. 8 north
24.4	10.0	Turn right onto Interstate 271 north
36.4	12.0	Exit 29 Chagrin Boulevard, turn right onto Ohio Rte. 87 (Chagrin Boulevard) east
42.3	5.9	Downtown Chagrin Falls, cross North Main and go straight onto Orange Street, Orange Street ends and the main road veers left as North Street
42.7	0.4	Turn right on High Street
43.3	0.6	Whitesburg Park, at the end of High Street

Stop 3: Former site of the IVEX Dam (see Chapter 9 for details)

Total miles	Interval miles	
43.9	0.6	At the stop sign turn left onto North Street
44.3	0.4	Cross North Main Street to West Orange Street which will eventually turn into Chagrin Boulevard (Rt. 87)
50.2	5.9	Turn left onto Interstate 271 south
62.2	12.0	Exit 18, Ohio Rte. 8 south
74.6	12.4	Take the Broad Boulevard exit
74.9	0.3	At the light turn left (east) onto Broad Boulevard
75.1	0.2	At the second light turn right (south) onto Newberry Street
75.8	0.7	Turn right into the Country Inn

End of Road Log for Day 2

REFERENCES CITED

Coogan, A. H., Feldmann, R. M., Szmuc, E. J., and Mrakovich, J. V., 1974, Sedimentary environments of the Lower Pennsylvanian Sharon Conglomerate near Akron, Ohio, *in* Heimlich, R. A., and Feldmann, R. M., eds., Selected field trips in northeastern Ohio: Ohio Division of Geological Survey Guidebook 2, p. 19-41.

Feldmann, R. M., Coogan, A. H., and Heimlich, R. A., 1977, Field guide: southern Great Lakes: Dubuque, Iowa, Kendall/Hunt, 241 p.

Heimlich, R. A., Mrakovich, J. V., and Frank, G. W., 1970, The Sharon Conglomerate, *in* Banks, P. O., and Feldmann, R. F., eds., Guide to the geology of northeastern Ohio: Cleveland, Northern Ohio Geological Society, p. 125-138.

Rau, J. L., 1970, Pennsylvanian system of northeast Ohio, *in* Banks, P. O., and Feldmann, R. F., eds., Guide to the geology of northeastern Ohio: Cleveland, Northern Ohio Geological Society, p. 69-124.

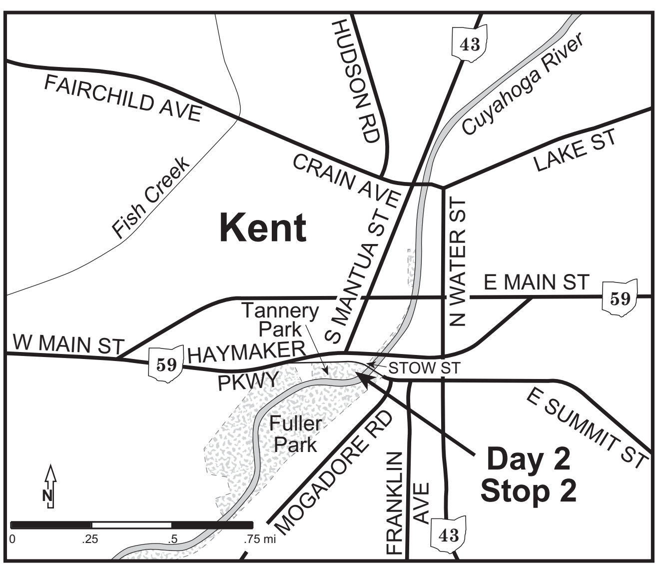


FIGURE 1-4.—Generalized map of downtown Kent, Ohio, showing the location of Day 2 field Stop 2.

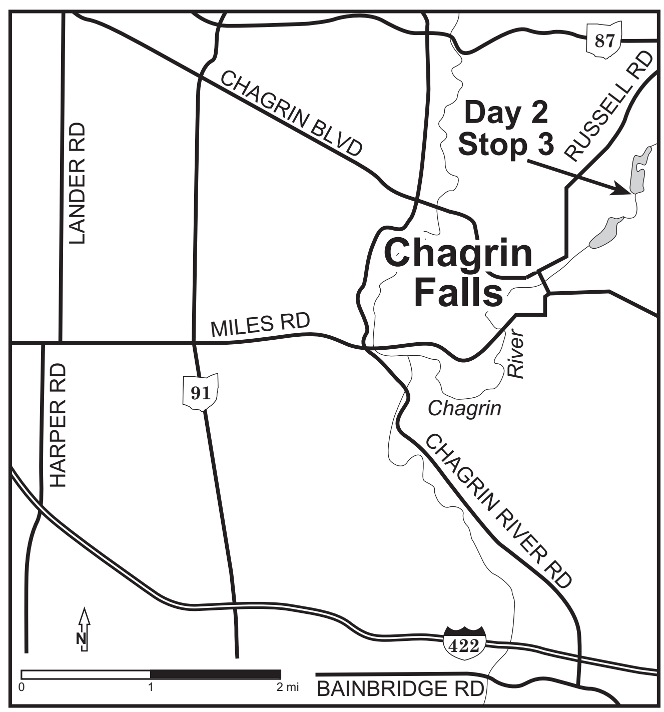


FIGURE 1-5.—Generalized map of downtown Chagrin Falls, Ohio, showing the location of Day 2 field Stop 3.

CHAPTER 2, THE EARLY PENNSYLVANIAN SHARON FORMATION OF NORTHEASTERN OHIO

by James E. Evans

...it [Sharon Conglomerate] *has been traced by Mr. Carll westward into Ohio and by Mr. White eastward as far as Warren* [Pennsylvania]. *It is undoubtedly part (or the whole) of the* Ohio Conglomerate.

Lesley (1879, p. xxxiv)

INTRODUCTION

In Ohio, the Sharon Formation is the basal unit of the Early Pennsylvanian Pottsville Group (fig. 2-1). In this region, the Sharon Formation unconformably overlies the Mississippian Cuyahoga Formation with paleotopographic relief on the unconformity of up to 80 m (Coogan and others, 1974; Krissek and others, 1986). The Sharon Formation represents deposition in a foreland basin affected by isostatic adjustment of the thrust sheet, foreland basin, and a peripheral bulge. In addition, the Sharon Formation was deposited during an interval of significant paleoclimatic change from arid to more humid, subtropical conditions.

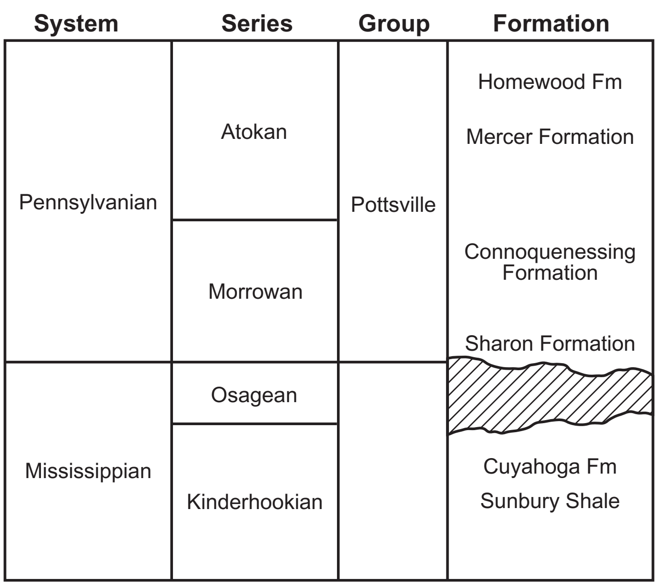


FIGURE 2-1.— Generalized column of bedrock units in the field trip area (after Berg and others, 1983).

AGE AND STRATIGRAPHIC NOMENCLATURE

Although the name "Sharon" has been consistently used to describe the rocks viewed on this field trip, there have been differences of opinion about nomenclature. Briefly, the history and issues are as follows: The Pottsville Formation of eastern Pennsylvania refers to the strata between the underlying Mississippian Mauch Chunk or Pocono formations and the overlying Llewellyn Formation in the Southern, Western Middle, Eastern Middle, and Northern Anthracite fields (Wood and others, 1956; Meckel, 1967). The Pottsville Formation of eastern Pennsylvania was subsequently split into three members, in ascending order, the Tumbling Run, Schuykill, and Sharp Mountain Members (Wood and others, 1956). In eastern Pennsylvania, the Pottsville Formation is up to 300 m thick, thinning westward, and forms a generally continuous NE-SW outcrop belt about 180 km long by 45 km wide (Meckel, 1967).

Further west, conglomerates and pebbly sandstones outcrop in paleotopographic lows above the Mississippian unconformity (Lamb, 1911). In western Pennsylvania and southwestern New York these were referred to as the Olean Conglomerate, while in northeastern and southern Ohio and adjacent western Pennsylvania they were referred to as the Sharon Conglomerate. Ashburner (1880) showed that the Olean and Sharon conglomerates were lithologically equivalent, and subsequent paleofloristic studies correlated the Olean and Sharon conglomerates to the Schuykill Member of the Pottsville Formation (Read, 1947). The rocks in question have thus been considered to be:

- The Sharon Formation of the Pottsville Group (e.g. Meckel, 1967; Berg and others, 1983; Ninke and Evans, 2002)
- The Sharon Conglomerate Member of the Pottsville Formation (e.g. Mrakovich and Coogan 1974; Mullett and others, 1990; Wells and others, 1993)
- The Sharon Sandstone of the Pottsville Group (e.g. Hansen, 1984)
- The Sharon Conglomerate of the Pottsville Group (e.g. Mrakovich, 1969)
- The Sharon Conglomerate (undesignated) (e.g. Fuller, 1955)

As in any disagreement about stratigraphic nomenclature, there are in fact significant underlying issues. In the Allegheny Plateau region, should the Pottsville be assigned formation or group rank? This depends in part on whether or not the overlying Connoquenessing, Mercer, and Homewood units meet the criteria for formation versus member rank. The question also depends on the independent consideration of whether or not the generally unfossiliferous Sharon unit should be considered part of the Pottsville, regardless of rank (although there is obviously a strong tradition to do so).

One final comment: It is misleading to link the lithology term "conglomerate" to the Sharon regardless of its stratigraphic rank. First, numerous studies have documented that the conglomeratic lower part of the Sharon is discontinuous even on outcrop scale (e.g. Meckel, 1967; Krissek and others, 1986; Ninke and Evans, 2002). Second, the "conglomerate" part of the Sharon typically changes from a lower conglomerate and pebble sandstone, to overlying sandstone. As noted by others (e.g. Mrakovich, 1969) sandstone is the predominant lithology in the Sharon "conglomerate." Third, the presence of shale intraclasts in the lower Sharon (and transition upward to an overlying shale and coal-bearing unit) indicates a mix of lithologies throughout the deposition of the Sharon. Accordingly "Sharon Formation" more accurately describes this unit.

TECTONIC AND CLIMATIC SETTING

During the Pennsylvanian (320-286 Ma), the collision of North America and Africa resulted in the Alleghenian Orogeny and final assemblage of Pangaea. Along its western boundary, the thin-skinned deformation created the Appalachian Mountains as a fold-and-thrust belt with an associated foreland basin (Hatcher, 1972; Allmendinger and others, 1987). The Appalachian foreland basin, found west of the deformed upper plate, was at least 650 km long (SW-NE) and 225 km wide (NW-SE).

Sediments of the Early Pennsylvanian Pottsville Group (including the Sharon Formation) were shed into the Appalachian foreland basin from the advancing thrust sheets to the east, and also from a landmass in Ontario and Quebec (Meckel, 1967; Krissek and others, 1986). This northern landmass has been interpreted as evidence of a peripheral bulge that formed west of the foreland basin due to isostatic effects (Slingerland and Beaumont, 1989). Previous workers have suggested that fairly subtle changes in sedimentation and erosion within the Pottsville Group can be attributed to the interplay of advancing thrust sheets and isostatic adjustment of the foreland basin and peripheral bulge (Robinson and Prave, 1995).

Significant changes were also occurring at this time with respect to eustatic sea level and paleoclimate. The disconformity on Mississippian marine rocks is generally interpreted as evidence for eustatic sea-level fall (Veevers and Powell, 1987; Ross and Ross, 1988). Glacio-eustatic sedimentary sequences ("cyclothems") are evident in the upper portions of the Pottsville Group (Algeo and Wilkinson, 1988), but are rare in southeastern Ohio (Nadon, 1998) and entirely absent in the Sharon Formation.

The rock record indicates progressive paleoclimatic change throughout the Appalachian Basin from arid to more humid conditions. Upper Mississippian rocks indicative of semi-arid conditions include a suite of marine carbonates, evaporites, eolianites, continental redbeds, and calcareous aridisols and vertisols. (Cecil, 1990; Cecil and others, 1997; Miller and Eriksson, 1999). Recent studies have shown increasing paleoclimatic variability (wet-dry cycles) that operated at Milankovitch frequencies at the Mississippian-Pennsylvanian transition (Miller and Eriksson, 1999). The overlying Lower Pennsylvanian rocks consist of quartz sandstones, aluminum-rich clays, and thick coals, indicative of humid subtropical conditions (Phillips and Peppers, 1984; Cecil, 1990; Miller and Eriksson, 1999). It has been suggested that Early to early Middle Pennsylvanian paleoclimate in this region fluctuated from ever-wet conditions during sea level lows, to wet but seasonally dry ("monsoonal") conditions during sea level highs (Cecil and Dulong, 1998).

SHARON FORMATION

Lithology and Stratigraphy in Northeastern Ohio

In eastern Pennsylvania the lower part of the Pottsville Formation (Tumbling Run and Schuylkill Members) have an overall wedge-shaped geometry, thinning from SE to NW from a maximum thickness of 300 m, with westerly paleocurrents. The upper part of the Pottsville Formation (Sharp Mountain Member) is sheet-like, with a maximum thickness of about 60 m, and has southerly paleocurrents (Meckel, 1967; Robinson and Prave, 1995).

The Sharon Formation of Ohio and western Pennsylvania is mostly sheet-like, averaging 15 m thick, with a planar upper contact and south-southwest paleocurrents. The lower contact is erosional into the underlying marine Mississippian rocks, creating highly variable local changes in thickness, to a maximum of about 80 m. This erosive lower contact and variable thickness has been interpreted as south-trending paleotopographic lows (paleovalleys) on the pre-Sharon surface (Butts, 1910; Lamb, 1911; Meckel, 1967; Williams and Bragonier, 1974; Wells and others, 1993; Ninke and Evans, 2002).

Stratigraphic sections from four accessible locations in northeast Ohio (Whipps Ledges, Kendall Ledges, Kennedy-Nelson Ledges, and Thompson Ledges) show the following general trends (fig. 2-2): The lowest part of the Sharon Formation consists of numerous cut-and-fill structures filled with massive, planar bedded, or cross-bedded pebbly sandstone and conglomerate. There is a general coarsening-upward sequence through this lower part of the Sharon Formation, leading to the development of gravel bar structures, particularly at Kennedy-Nelson Ledges and Thompson Ledges. The upper part of the Sharon Formation predominantly consists of cross-bedded sandstone, with occasional gravel stringers and some spectacular examples of over-turned cross bedding (Wells and others, 1993; Ninke and Evans, 2002).

Lithofacies and Lithofacies Assemblages

Ninke and Evans (2002) found eleven lithofacies in the Sharon Formation of northeastern Ohio (table 2-1). Markov chain analysis was used to demonstrate that certain lithofacies are associated with one another, and form characteristic sequences that are statistically significant (fig. 2-3). There are three main facies associations: longitudinal gravel bars, 2-D dunes (transverse bars), and 3-D dunes (linguoid bars).

Longitudinal gravel bars consist of massive to planar stratified (inclination $< 10°$) conglomerate that may be overlain by massive to planar stratified sandstone or siltstone drapes. The deposits commonly overlie a scoured surface. Small lenticular channels, herein called chute channels, are filled by cross-bedded sandstone, ripple-laminated sandstone, or siltstone. The gravel bars change laterally from massive conglomerate to planar stratified conglomerate, and occasionally to cross-bedded conglomerate. The 2-D dunes (transverse bars to some) consist of scoured surfaces overlain by planar-tabular cross-bedded sandstone. Occasionally ripple or climbing-ripple lamination is interstratified with the cross bedding (indicating bedform hierarchy). The 3-D dunes (linguoid bars to some) consist of scoured surfaces overlain by trough cross-bedded sandstone (Ninke and Evans, 2002).

Alluvial Architecture

Alluvial architecture is based upon describing the 3-D geometry of individual depositional units from: (1) recognition of bounding surfaces, (2) tracing lateral contacts in the field or by the use of photomosaics (this was facilitated by the exposure of isolated columns or blocks of rock at several of these stops), (3) describing the packages internally using lithofacies analysis, and (4) applying paleohydraulic analysis to each package (see below). The architectural elements (terminology of Miall, 1985) are shown in table 2-2. Note that while the 2-D and 3-D dunes are combined into a single category (sandy bedforms), the longitudinal gravel bars can be split (using the terminology of Bluck, 1979) into: (1) bar-platform deposits consisting of (1a) bar-head/bar-core deposits (lithofacies Gm), (1b) bar-tail deposits (lithofacies Gh), and (1c) bar-margin foreset deposits (lithofacies Gp), overlain by (2) supra-bar platform deposits consisting of (2a) tabular sheets of lithofacies Smc and Sh, and/or (2b) dissected during falling-stage by chute channels that can be infilled by lithofacies Sp, St, Sr, and/or Fm.

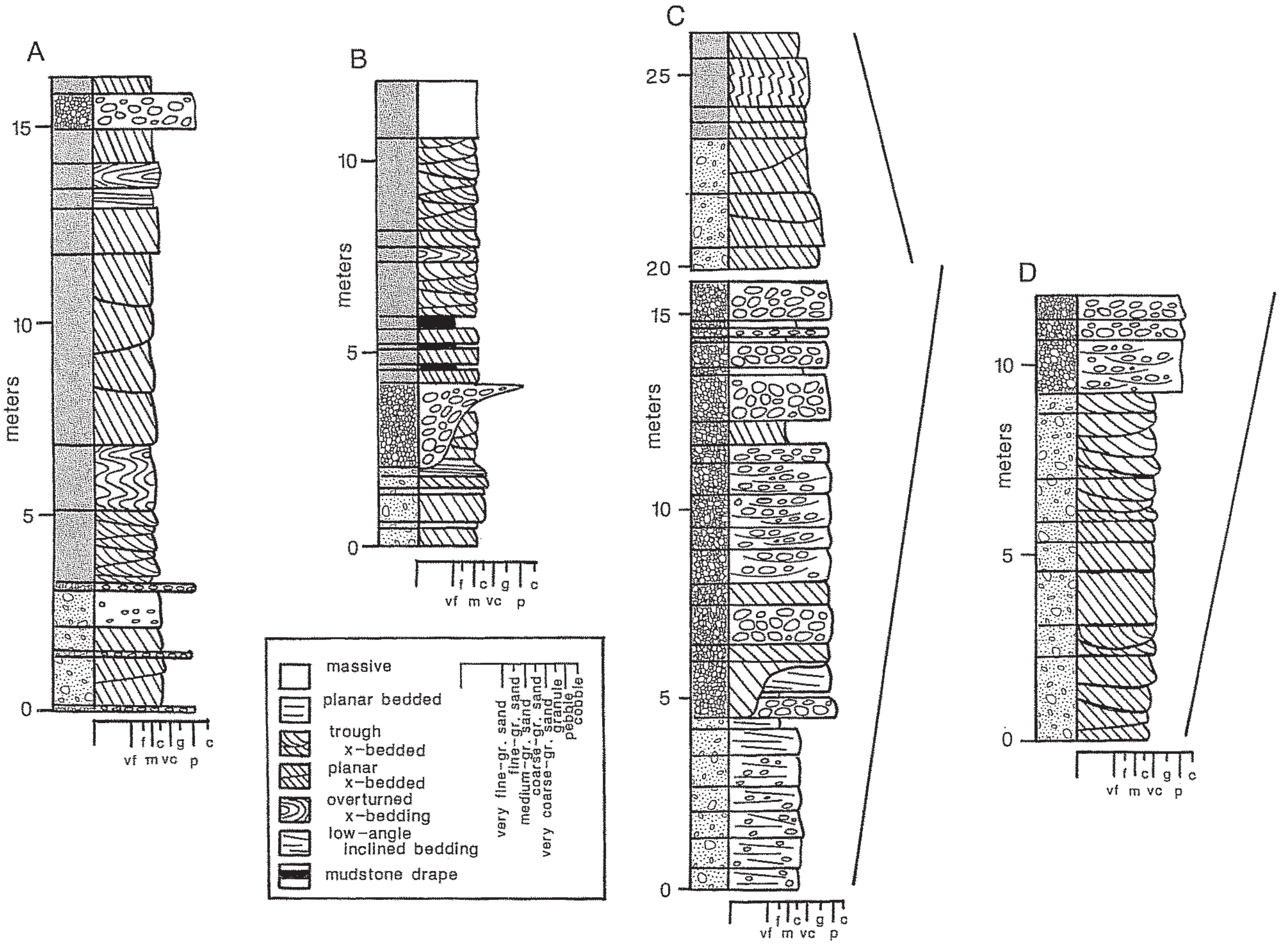


FIGURE 2-2.—Stratigraphic sections measured at: (A) Whipps Ledges, (B) Kendall Ledges, (C) Kennedy-Nelson Ledges, and (D) Thompson Ledges (from Ninke and Evans, 2002).

TABLE 2-1.—*Lithofacies in the Sharon Formation*

Lithofacies Code	Lithology	Sedimentary Structures	Environmental Interpretation
Gm	conglomerate	massive, imbrication	bar-head or bar-core
Gh	conglomerate	stratified, inclined < 10°	bar-tail
Gp	conglomerate	planar-tabular cross-beds	bar-margin foresets
Smc	sandstone	massive	bar-top deposit
Sh	sandstone	stratified	bar-top deposit
Sp	sandstone	planar-tabular cross-beds	2-D dune deposit
St	sandstone	trough cross-beds	3-D dune deposit
Sr	sandstone	ripple laminated	ripples
Se	sandstone with mud intraclasts	massive	scour fills
Ss	pebbly sandstone	scours	scour fills
Fm	siltstone	massive	mudstone drapes

Modified from Miall, 1977, 1978; Rust, 1978.

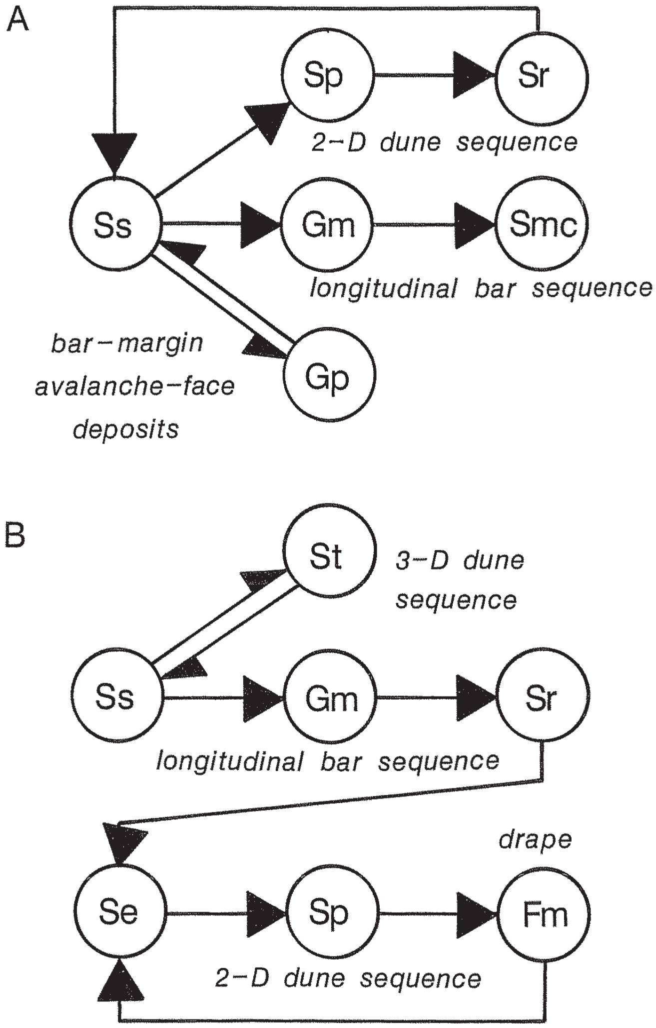


FIGURE 2-3.—Markov chain analyses for (A) gravel-bedload stream deposits and (B) sand-bedload stream deposits in the Sharon Formation. Lithofacies codes given in table 2-1 (from Ninke and Evans, 2002).

The advantage of this approach is an understanding of the sometimes-bewildering lateral complexity of fluvial deposits in the Sharon Formation. The environment is interpreted to have consisted of an alternate bar-and-pool topography. In modern equivalent environments, flow crosses the bars during high flow stage, but is topographically steered around the main channel bedforms during low flow stage. Pools are produced by flow-convergence downstream of the bars. When viewing the Sharon Formation, identify a set of bounding surfaces and observe how each gravel bar changes laterally (in the downstream or southerly direction) from an upstream pool into the bar head/bar core (massive conglomerate), to the bar tail (finer-grained, gently inclined, planar bedded conglomerate), and/or into bar-margin foreset deposits (cross-bedded conglomerate). Bar-margin foresets are analogous to a small delta building into the downstream pool. For the Sharon Formation one complication in these interpretations is the fact that clast fabrics (such as lineation and imbrication) are poorly developed because clasts in the Sharon Formation are typically spherical or subspherical shapes (Mullet and others, 1990; Ninke and Evans, 2002). Such clast fabrics can be useful tools for recognizing features in the massive conglomerates, such as differentiating the bar-head and bar-core regions.

Paleohydraulics

Flow conditions were reconstructed based upon the dimensions of channels, grain size data, and paleoslopes. Bankfull depth was obtained from the depth of scours, the maximum relief of bar platforms, the maximum height of bar-margin foresets, and dune heights. Channel widths were obtained from field measurement and photomosaics. Grids were used to measure clast dimensions in outcrop, estimating the median grain size (D_{50}) and largest size class moving through the reach (D_{95}). Paleoslopes were obtained from the relationship between the boundary shear stress (a property of the flow, and based upon channel depth and paleoslope) and the critical or entrainment shear stress (based upon grain size, grain shape, effective density, and sorting) using the method described elsewhere (Evans, 1991; Ninke and Evans, 2002).

Table 2-2.—*Architectural Elements in the Sharon Formation*

Element	Code	Typical Lithofacies	Geometry & Relationships
Channel-fill deposits			
Major channels	CH	any combination	broadly lenticular
Chute channels	CHc	Sp, St, Sr, Fm	lenticular
Bar-Platform deposits			
Bar-head deposit	GBh	Gm	tabular
Bar-core deposit	GBc	Gm	tabular
Bar-tail deposits	GBt	Gm, Gh	tabular
Bar-margin foreset deposits	GBf	Gp	wedge shaped
Sandy bedforms	SB	Sp, St	tabular and wedge shaped
Supra-bar platform deposits			
Bar-top deposits	SP	Smc, Sh, Sr	tabular
Chute channels-fills	CHc	Sp, St, Sr, Fm	lenticular

Modified from Miall (1985). Note that "foreset macroforms" of Miall (1985) are incorporated into bar-platform deposits as element GBf

The results are summarized in table 2-3. The interpretation of paleohydraulic data is fraught with uncertainties, including probable partial erosion of certain features. Much of the lower part of the Sharon Formation consists of gravel-bedload stream deposits. For these, the gravel bars were typically constructed to about 1-1.5 m tall, suggesting bankfull flow depths > 1.5 m to account for chute channels and other features cut into the bar platform during falling-stage. The accompanying sandy bedforms suggest bankfull flow conditions to 2-3 m water depth. Channel depth:width ratios were about 1:10 ($n = 8$, $r^2 = 0.69$) and paleohydraulic calculations show that paleoslopes ranged from 0.3-1.1 m/km.

Much of the upper part of the Sharon Formation consists of sand-bedload stream deposits. For these, the majority of paleo-depth indicators (dunes and scours) indicate bankfull flow depths of 1-1.5 m, somewhat shallower than the gravel bedload streams described above. In addition, the depth:width ratio was about 1:40 ($n = 14$, $r^2 = 0.89$), suggesting wider and shallower streams. Paleohydraulic calculations show that paleoslope ranged from 0.2-1.2 m/km, which are virtually identical slopes to those obtained from the gravel-bedload streams described above.

Depositional Environments

The earliest workers interpreted the Sharon Formation as marine (Butts, 1908; Stout, 1916), alluvial fan (Fettke, 1938; Bowen, 1953; Fuller, 1955), or deltaic (Lamb, 1911; Bowen, 1953; Fuller, 1955). More recently the environment has been interpreted as a “fluvial sheet gravel” (Meckel, 1967), meandering stream deposit (Mrakovich, 1969), or braided stream deposit (Mrakovich, 1969; Mrakovich and Coogan, 1974; Krissek and others, 1986; Mullett and others, 1990; Wells and others, 1993; Ninke and Evans, 2002). The lithofacies, sequences, architecture of the depositional units (gravel bar, 2-D dune, and 3-D dune), and paleohydrology are very consistent for gravel- and sand-bedload stream deposits. In contrast, there is a complete absence of point-bar sequences, fine-grained overbank deposits, chute or neck cutoff sequences, or other features associated with meandering streams. There is also a complete absence of features indicative of tides, waves, or other coastal features implicit in a deltaic environment.

Basin Analysis

In northeast Ohio, the thickest and most gravel-rich deposits of the Sharon Formation form N-S narrow belts that become thinner and finer-grained to the south (Lamb, 1911; Fuller, 1955; Meckel, 1967). Paleocurrents are generally southerly (Fuller, 1955; Meckel, 1967; Coogan and others, 1974; Mullett and others, 1990; Robinson and Prave, 1995; Ninke and Evans, 2002). Conglomerate clasts consist of vein quartz, quartzite, sandstone, slate, shale, silicified Devonian limestone, and rare plutonic or high-grade metamorphic clasts (Fuller, 1955; Meckel, 1967). The closest sources of clasts are between 80-120 km (sedimentary rock fragments) and 290-320 km (igneous and metamorphic rock fragments) to the northeast. The closest correlative marine rocks were located 160-200 km south of these outcrops. In sum, the trend of gravel-rich deposits, paleocurrents, and location of source areas is consistent with south-flowing fluvial systems (Meckel, 1967).

Within the Sharon Formation, the transition upward

Table 2-3.—*Paleohydraulic Summary of the Sharon Formation*

Criterion	Sand-bedload Streams	Gravel-bedload Streams
Scour depth		
Average	0.93 m	2.12 m
Maximum	2.25 m	3.70 m
(Observations)	(14)	(8)
Height of gravel-bar platform		
Average	0.59 m	0.85 m
Maximum	0.85 m	1.55 m
(Observations)	(11)	(15)
Flow depth from dune height		
Average	1.50 m	2.85 m
Maximum	4.50 m	3.55 m
(Observations)	(79)	(5)
Height of bar-margin foresets		
Average	—	0.80
Maximum	—	1.45
(Observations)	(0)	(3)
Range of grain size D_{95}	1.07-3.54 cm	1.92-4.68 cm
Range of sorting (D_{95} / D_{50})	2.14-3.01	2.13-2.74
Range of shields number (τ^*_{cr})	0.020-0.030	0.020-0.030
Range of paleoslope values	0.2-1.2 x 10^{-3}	0.3-1.1 x 10^{-3}

from conglomerate-rich to sandstone-rich noted by several authors (e.g., Mullett and others, 1990; Ninke and Evans, 2002) might be attributed to eustasy, tectonic subsidence, changes in sediment supply (source area or weathering rates), or some combination of effects. While there are many unknowns, several things are clear. The progressive changes in the Sharon depositional system were not accompanied by changes in provenance or paleocurrent directions. In addition, paleohydraulic calculations would indicate that there is no evident change in paleoslope throughout the unit (Ninke and Evans, 2002). Finally, it should be noted that although gravel can be found in the upper part of the Sharon Formation, it is more typical as thin lag deposits in scours rather than as organized bedforms (Mullett and others, 1990; Ninke and Evans, 2002).

An alternative explanation for the progressive changes in the Sharon fluvial system is linked to backfilling and overtopping bedrock paleovalleys. Modern bedrock-confined fluvial systems are characterized by high magnitude flows, higher flow stage, and gravel-rich deposits (e.g. Baker, 1984), in contrast modern sandy braidplain systems are characterized by numerous shallow, rapidly shifting channels. Once paleovalleys were infilled and overtopped by the deposition of the lower part of the Sharon Formation, flow might be expected to diverge into more numerous, wider, and shallower channels. Although in the case of the Sharon Formation these were temporal changes, such changes can be observed spatially today, where modern fluvial systems exit bedrock controlled valleys.

ACKNOWLEDGEMENTS

I would like to thank my former student Dave Ninke for our collaborative research on the Sharon Formation. In addition, I wish to thank Charles F. Kahle, Sheila J. Roberts, Brian Jones, Douglas Cant, and Neil Wells for suggestions and advice during my research on this unit, Larry Krissek for providing some of his data, and Neil Wells for providing computer software used in the analysis.

REFERENCES CITED

Algeo, T. J., and Wilkinson, B. H., 1988, Periodicity of mesoscale Phanerozoic sedimentary cycles and the role of Milankovitch orbital modulation: Journal of Geology, v. 96, p. 313-322.

Allmendinger, R. W., Nelson, K. D., Potter, C. J., Barazangi, M., Brown, L. D., and Oliver, J. E., 1987, Deep seismic reflection characteristics of the continental crust: Geology, v. 15, p. 304-310.

Ashburner, C. A., 1880, The geology of McKean County, and its connection with that of Cameron, Elk, and Forest: Pennsylvania Geological Survey, 2nd Series, v. R, 371 p.

Baker, V. R., 1984, Flood sedimentation in bedrock fluvial systems, *in* Koster, E. H., and Steel, R. J., eds., Sedimentology of gravels and conglomerates: Canadian Society of Petroleum Geologists Memoir 10, p. 87-98.

Berg, T. M., McInerney, M. K., Way, J. H., and MacLachlan, D. B., 1983, Stratigraphic correlation chart of Pennsylvania: Bureau of Topographic and Geologic Survey, 4th series, General Geology Report 75, third printing, one chart.

Bluck, B. J., 1979, Structure of coarse grained braided stream alluvium: Transactions of the Royal Society of Edinburgh, v. 70, p. 181-221.

Bowen, C. H., 1953, Petrology and economic geology of the Sharon Conglomerate in Geauga and Portage counties, Ohio: Ohio State University Engineering Experimental Station Bulletin, v. 153, p. 1-58.

Butts, C., 1908, The unconformity between the Mississippian and Pennsylvanian, and its bearing on questions of geologic correlation: Science, v. 27, p. 992-993.

Cecil, C. B., 1990, Paleoclimate controls on stratigraphic repetition of chemical and siliciclastic rocks: Geology, v. 18, p. 533-536.

Cecil, C. B., and Dulong, F. T., 1998, Pennsylvanian paleoclimates, sediment flux, and lithostratigraphy, Appalachian basin: Geological Society of America, Abstracts with Programs, v. 30, n. 2, p. 9.

Cecil, C. B., Dulong, F. T., Edgar, N. T., and West, R., 1997, Climatic controls on Carboniferous cyclic sedimentation, U.S.A.: American Association of Petroleum Geologists, Abstract from Annual Meeting, v. 6, p. 19.

Collins, H. R., 1979, The Mississippian and Pennsylvanian (Carboniferous) systems in the United States—Ohio: U.S. Geological Survey Professional Paper 1110-E, p. 1-26.

Coogan, A. H., Feldmann, R. M., Szmuc, E. J., and Mrakovich, J. V., 1974, Sedimentary environments of the Lower Pennsylvanian Sharon Conglomerate near Akron, Ohio, *in* Heimlich, R. A., and Feldman, R. M., eds., Selected field trips in northeastern Ohio: Ohio Division of Geological Survey Guidebook 2, p. 19-41.

Evans, J. E., 1991, Facies relationships, alluvial architecture, and paleohydrology of a Paleogene, humid-tropical alluvial-fan system: Chumstick Formation, Washington State, U.S.A.: Journal of Sedimentary Petrology, v. 61, p. 732-755.

Fettke, C. R., 1938, The Bradford Oil Field, Pennsylvania and New York: Pennsylvania Geological Survey 4th series, v. M21, p. 1-454.

Fuller, J. O., 1955, Source of the Sharon Conglomerate of northeastern Ohio: Geological Society of America Bulletin, v. 66, p. 59-176.

Hatcher, R. D., 1972, Developmental model for the southern Appalachians: Geological Society of America Bulletin, v. 83, p. 1735-1760.

Krissek, L. A., Ketring, C. L. Jr., and Kulikowski, D. L., 1986, Lower Pennsylvanian sandstones of southeastern Ohio: implications for sediment sources and depositional environments in the north-central Appalachian Basin, *in* Shumaker, R.C., ed., Appalachian Basin Industrial Associates, Program for Fall Meeting (October 16-17, 1986), v. 11, p. 109-141.

Lamb, G. F., 1911, The Mississippian-Pennsylvanian unconformity and the Sharon Conglomerate: Journal of Geology, v. 19, p. 104-109.

Lesley, J. P., 1879, Preface, in White, I. C., The geology of Lawrence County, to which is appended a special report on the correlation of the coal measures in western Pennsylvania and eastern Ohio: Pennsylvania Geological Survey Report of Progress in 1877, 2nd Series, v. QQ, p. ix-xxxvi.

Meckel, L. D., 1967, Origins of Pottsville conglomerates (Pennsylvanian) in the central Appalachians: Geological Society of America Bulletin, v. 78, p. 223-258.

Miall, A. D., 1985, Architectural-element analysis: a new method of facies analysis applied to fluvial deposits: Earth Science Reviews, v. 22, p. 261-308.

Miller, D. J., and Eriksson, K. A., 1999, Linked sequence development and global climate change: the Upper Mississippian record in the Appalachian basin: Geology, v. 27, p. 35-38.

Mrakovich, J. V., 1969, The Sharon Conglomerates of northeastern Ohio: The Compass, v. 46, p. 150-158.

Mrakovich, J. V., and Coogan, A. H., 1974, Depositional environment of the Sharon Conglomerate Member of the Pottsville Formation in northeastern Ohio: Journal of Sedimentary Petrology, v. 44, p. 1186-1199.

Mullett, D. J., Kurlich, R. A., Frech, K. R., and Wells, N. A., 1990, Paleocurrent analysis of the Sharon Conglomerate and sandstone lithosomes in the vicinity of Ice Box Cave at Kendall Ledges Park, Summit County, Ohio: The Compass, v. 68, p. 21-32.

Nadon, G. C., 1998, An allostratigraphic approach to the Pennsylvanian sediments of Athens County, southeastern Ohio: Geological Society of America, Abstracts with Programs, v. 30, n. 2, p. 63.

Ninke, D. J., and Evans, J. E., 2002, Alluvial architecture of the Early Pennsylvanian Sharon Formation in northeastern Ohio: Ohio Journal of Science, v. 102, p. 70-81.

Phillips, T. L., and Peppers, R. A., 1984, Changing patterns of Pennsylvanian coal-swamp vegetation and implications of climatic control on coal subsidence: International Journal of Coal Geology, v. 3, p. 205-255.

Read, C. B., 1947, Pennsylvanian floral zones and floral provinces: Journal of Geology, v. 55, p. 271-279.

Robinson, A. J., and Prave, A. R., 1995, Cratonal contributions to a classic molasse: the Carboniferous Pottsville Formation of eastern Pennsylvania revisited: Geology, v. 23, p. 369-372.

Ross, C. A., and Ross, J. R. P., 1988, Late Paleozoic transgressive-regressive deposition, *in* Wilgus, C. K., Hastings, B. S., Kendall, C.G.S.C., Posamentier, H. W., Ross C. A., and Wagoner, J. C., eds., Sea level changes—an integrated approach: SEPM Special Publication 42, p. 227-248.

Slingerland, R. L., and Beaumont, C., 1989, Tectonics and sedimentation of the upper Paleozoic foreland basin in the central Appalachians, *in* Sedimentology and thermal-mechanical history of basins in the Central Appalachian Orogeny: 28th International Geological Congress Field trip Guidebook, T152, p. 4-24.

Stout, Wilber, 1916, Geology of Muskingham County: Ohio Division of Geological Survey Bulletin 21, 351 p.

Veevers, J. J., and Powell, C. M., 1987, Late Paleozoic glacial episodes in Gondwanaland reflected in transgressive-regressive depositional sequences in Euramerica: Geological Society of America Bulletin, v. 98, p. 475-487.

Wells, N. A., Richards, S. S., Peng, S., Keattch, S. E., Hudson, J. A., and Copsey, C. J., 1993, Fluvial processes and recumbently folded crossbeds in the Pennsylvanian Sharon Conglomerate in Summit County, Ohio, USA: Sedimentary Geology, v. 85, p. 63-83.

Williams, E. G., and Bragonier, W. A., 1974, Controls on Early Pennsylvanian sedimentation in western Pennsylvania, *in* Briggs, G., ed., Carboniferous of the southeastern United States: Geological Society of America Special Paper 148, p. 135-152.

Wood, G. H. Jr., Trexler, J. P., Arndt, H. H., Yelenosky, A., and Soren, J., 1956, Subdivision of the Pottsville Formation in Southern Anthracite field, Pennsylvania: American Association of Petroleum Geologists Bulletin, v. 40, p. 2669-2688.

CHAPTER 3, REVIEW AND REGIONAL CONTEXT OF LATE DEVONIAN THROUGH EARLY PENNSYLVANIAN STRATIGRAPHY OF NORTH-CENTRAL OHIO

by Neil A. Wells

The Lower Carboniferous or Waverly Group is freely opened in the valley of the Cuyahoga and we here find some of the most satisfactory sections that can be seen in the State.
Geological Survey (*in* Perrin, 1881, p. 185)

INTRODUCTION

Following the nomenclature of Szmuc (1970), most strata to be seen on this trip belongs to the Meadville Member of the Cuyahoga Formation (locally the youngest preserved part of the Mississippian) and the overlying Sharon Formation (typically the first unit deposited in this area during the Pennsylvanian) (see fig. 2-1 of Evans, this volume). However, these units are part of two larger molasse sequences and comparisons and contrasts with the earlier cycle can shed some light on some of the geology to be seen on this trip.

LATE DEVONIAN CLASTIC WEDGE

During the Middle Devonian, sedimentation across Ohio changed from a fossiliferous, marine, carbonate platform (the Delaware and Columbus Limestones) to a less fossiliferous clastic wedge caused by the onset of the Acadian or Catskill Orogeny in the Appalachians north of New York City. This Catskill "delta" dominated the Ohio to New York area through the Late Devonian.

During this time, collision between eastern North America and Baltica (northwestern Europe) caused uplift in the Appalachians (the Acadian or Catskill orogeny) and correlative subsidence across the region consisting of western New York, Pennsylvania, and eastern Ohio, thereby forming the Appalachian foreland basin. Most of the molasse, consisting of coarser fluvial and proximal marine clastics, accumulated in the eastern part of the basin, nearest the mountains, due to preferential subsidence there. In general, sandstones and conglomerates accumulated east of the Ohio-Pennsylvania boundary. Farther west, the basin was effectively underfilled, and accumulated relatively distal muds (shales to fine sandstones of the Olentangy, Ohio, and Bedford Formations, with the Ohio Shale further subdivided into the Huron, Chagrin, and Cleveland Members). The peak of underfilling (and presumably of subsidence and thrusting) was marked by the accumulation of the black (euxinic) Cleveland Shale Member at the top of the Ohio Shale. Zagger (1995) shows that at least part of the Cleveland was dysaerobic and bioturbated, and deposited at storm-wave-base depths.

After the accumulation of thick mud deposits, the coarser clastics stepped out across the Ohio-Pennsylvania border and prograded westward, to Cleveland and beyond. This is the Berea Sandstone, and the nearly correlative Cussewego Sandstone and Euclid Siltstone. Because the Berea clastics prograded over a very thick (and very soupy) pile of saturated mud, its weight and rapid progradation caused extensive soft-sediment deformation, including diapiric mud lumps, giant slides, foundering of sandstones, and even local overthrusting and lystric overturning of beds, as discussed in Lewis (1976, 1986, 1988), Majoras and Wells (1988), Nesbitt and Wells (1990), Wells and others, (1991), and Duncan and Wells (1992) (fig. 3-1A). These deformations had previously been interpreted as large paleovalleys, supposedly representing a major disconformity prior to the Berea (Pepper and others, 1954). However, more recent workers have viewed the Berea and Bedford as having a closer and more continuous depositional relationship (Lewis, 1988; Pashin and Ettensohn, 1987, 1995; Pashin, 1990; Gutshick and Sandberg, 1991; Wells and others, 1991). The combination of the closer relationship and abundant soft-sediment deformation now makes it reasonable to view the Berea-Bedford contact as a continuous and gradational facies change. Following the logic suggested by Heller and others (1989a & b), massive westward progradation is likely to have occurred because a halt in collision halted subsidence of the foreland basin, without immediately halting erosion of the then still-youthful Appalachian Mountains.

Dating of the Berea has long been controversial, as different authors variously placed the Berea and/or the underlying Bedford partly or wholly in either the Late Devonian or the Early Mississippian (Zagger, 1995, p. 33). These scenarios involve inferring various disconformities, most notably between the Bedford and Berea (Pepper and others, 1954). More recently, Zagger's study of conodont biostratigraphy has settled the matter, by showing that the Cleveland, Bedford, and presumably also the Berea, formations all fit within the late Famennian, within the *expansa* and *praesulcata* zones, which correlates the Cleveland Shale to a significant late Famennian transgression. The Berea does not contain conodonts; however, it appears to be entirely Devonian. As explained by Gutschick and Sandberg (1991), the Devonian-Mississippian boundary in North America has been shifted to improve its alignment with the boundary in Europe. Eames (1974) reported some *Retisphora lepidophyta* pollen (formerly *Hymenozonotriletes lepidophyta*) from the Berea, placing at least that part of it firmly within the *praesulcata* conodont zone, which is now understood to be uppermost Devonian. Zagger recognized a hiatus, marked by a thin transgressive lag of reworked pyrite nodules and fish teeth and scales, at the base of the Cleveland Shale. This further suggests that the Cleveland accumulated in depressions with limited circulation, such as drowned estuaries or submarine valleys. Duncan and Wells (1992) recognized a later significant hiatus, a small angular unconformity, caused by soft-sediment deformation, representing a local boundary between delta lobe progradations, within the Berea. Zagger also inferred a brief hiatus, consisting of the last part of the *praesulcata* zone at the end of the Famennian, between the Berea and the overlying Sunbury Shale. He put the Devonian-Mississippian boundary within that break and dated the Sunbury Shale as Mississippian. However, Duncan and Wells noted that while the bulk of the Berea is progradational, the very top of the Berea frequently contains one or more thin and bioturbated sandstones that presumably represent condensed, reworked, post-abandonment, transgressive sheet sandstones. Cushing and others (1931), and Pepper and others (1954), made similar comments about a pyritic sandstone bed, possibly representing a basal Sunbury lag. Those beds presumably belong to the Early Mississippian Sunbury transgression. Aronson and Lewis (1994) showed that muscovite in the Berea gave bulk K-Ar ages of 387 ± 9, 387 ± 7, and 390 ± 8 m.y., and Lux and Wells (1994, unpublished) obtained four

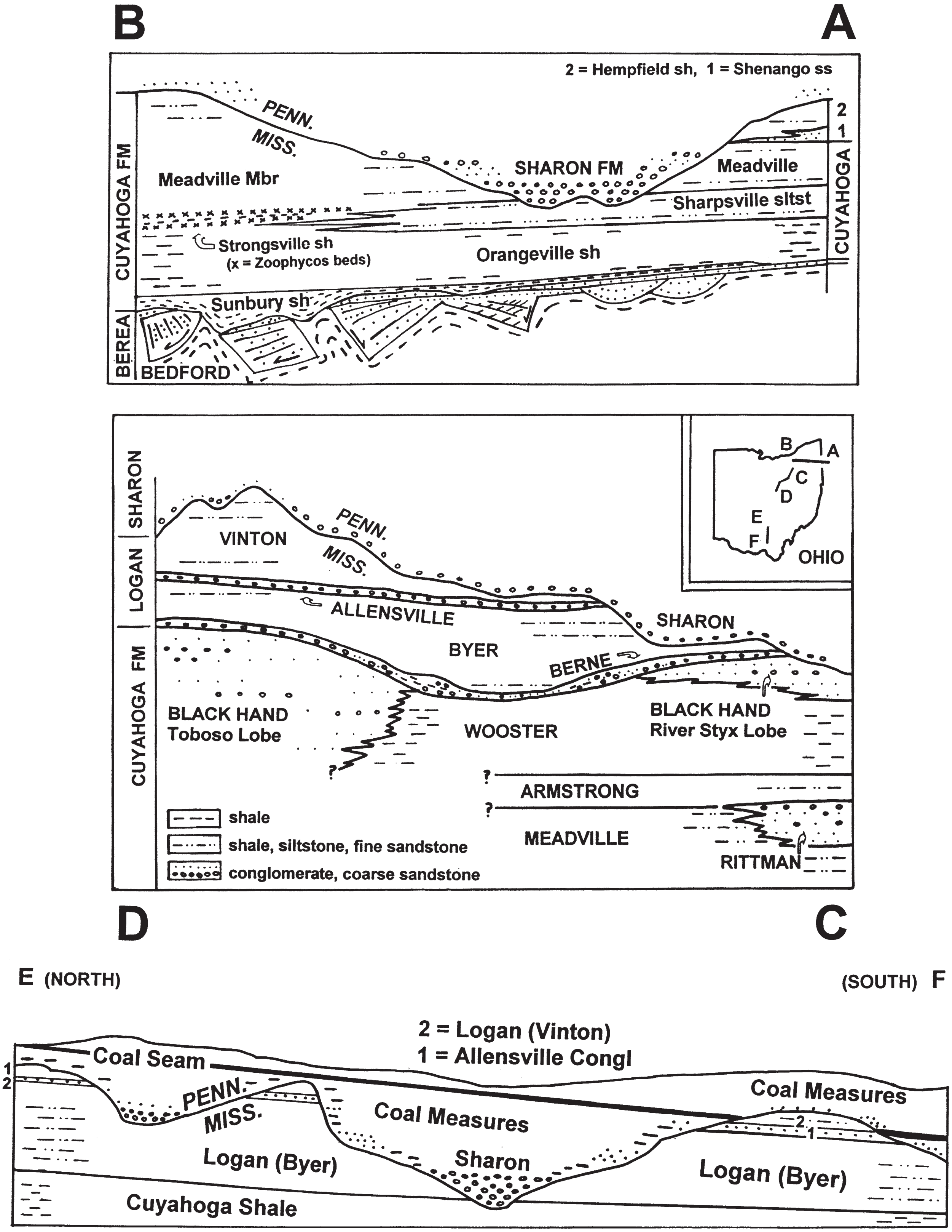


Figure 3-1.—Cross-sections illustrating Mississippian stratigraphy and the unconformity under the Pennsylvanian. Note that the Sharon conglomerates tend to fill paleovalleys. A-B and C-D are idealized and unscaled, and are modified from Szmuc (1970); E-F is modified from Hyde (1953), and covers almost 18 km N-S, just east of the Jackson County border with Ross and Pike counties, with a vertical exaggeration of 150 times.

$^{40}Ar/^{39}Ar$ total gas ages that averaged 385.9 ± 2.9 m.y. from muscovite, indicating the Berea appears to be eroded from Middle Devonian (Acadian) sources not much older than the formation itself.

MISSISSIPPIAN CLASTICS OF THE APPALACHIAN BASIN

In the area of this field trip, Mississippian strata consist of 41 m of Orangeville Shale, under 11-13.5 m of Sharpsville Member siltstones and under 32-36 m of the Meadville Member, all of which are part of the Cuyahoga Formation. The part of the Orangeville Shale in this vicinity is a uniform volume of medium to dark gray shales (2.5 YR 2.5-5/0), and is the finest-grained portion of our Mississippian section. The Sharpsville consists of subequal, alternating, cross-laminated, pale olive to gray siltstones and silty shales, and contains the thickest and coarsest beds of the Cuyahoga Formation in this area. The Meadville is intermediate between the other two in terms of facies character. It contains pale olive (5Y 6/2) siltstones and sandy siltstones that are much like the Sharpsville, except for being fewer and thinner, with more Orangeville-like shales.

Szmuc (1970) indicates that the Meadville is one of the most fossiliferous units in our area. It contains over 125 species of fossils, dominated by a fenestrate bryozoan and one genus each of spiriferid and productid brachiopod. Other fossils include sponges, gastropods, trilobites, corals, and cephalopods. All these shales, especially the lower Meadville, contain some impressive septarian nodules and concretions (some fossiliferous) that can incorporate calcite, sphalerite, galena, pyrite, marcasite, siderite, and fluorite.

In more comprehensive terms, the basal Mississippian unit might best be thought of as a ‘Cuyahoga group’, which would consist of the classic Cuyahoga Formation (which itself consists of a series of muddy to silty members with some sandy to conglomeratic lithofacies), plus two correlative facies equivalents, the Shenango Sandstone and the Hemphill Shale. Between the lithofacies stratigraphy of Hyde (1953) and the facies interpretations of Bork and Malcuit (1979), this complex group is now much better understood. Its stratigraphy is summarized in cross-sections A-B and C-D in fig. 3-1. The coarser units mostly coalesce and enlarge toward the south, but overall the intervening finer facies are dominant. All of that is locally overlain by a series of conglomerates and shales that belong to the Logan.

Some additional complications need to be considered. Although the Orangeville Shale at the base of the Cuyahoga ‘group’ consists primarily of the shales described above, it also contains the Sunbury Shale at its base and, locally and stratigraphicly higher, the Aurora and Chardon Siltstones.

The Sunbury Shale is a thin, but irregular, black shale that appears to represent euxinic conditions within shallow depressions that had formed on top of the Berea Formation, either in depressions formed by soft-sediment deformation in the Berea or between post-abandonment bedforms on top of it. According to Szmuc (1957), the Sunbury is marked locally by accumulations of inarticulate brachiopods, conulariids, fragmentary fish remains, conodonts, scolecodonts, foraminifera, and a few sponge spicules. The shale above (i.e., the Orangeville) is medium to dark gray (2.5 YR 2.5-5/0), but not quite as dark.

To the north and west of the area covered by this field trip, the Sharpsville is more or less replaced laterally by up to 5.5 m of shales that lie between a pair of distinctive and slightly thicker than usual siltstones with abundant *Zoophycos* burrows. This has been called the Strongsville Member.

According to Szmuc (1957 and 1970), the coarser members of the Cuyahoga in northern and central Ohio include the Rittman Member (12 m of micaceous pebbly sandstone in the middle of the Cuyahoga ‘group’ from northern Wayne County to Hinckley) and, just under the erosive top of the Cuyahoga “group,” the “River Styx” and “Toboso” lobes of the Black Hand Member, respectively in eastern Wayne County and in Ashland and Richland Counties (figs. 3-1 and 3-2). The lobes are quartz-rich sandstones with quartzose pebbles, and reach over 10 and 40 m thick, and the latter thickens southward in the subsurface. The pebbles are typically described as small, rarely > 1 cm, but some records cite rare pebbles up to 15 by 7.5 cm (Hicks as cited in Hyde,1953). At least parts of all three units contain marine fossils such as brachiopods and crinoids, with other parts containing logs and other plant material that may be brackish or non-marine. The Shenango Sandstone of NW Pennsylvania, clearly part of the Cuyahoga facies assemblage, reaches 12 m in thickness and contains siderite nodules and inarticulate brachiopods and fish remains. Additional facies, including the almost 200 m thick, NNW-SSE Hocking Valley conglomerate and sandstone trend, are present farther to the south (Hyde, 1953).

Facies interpretations for this part of the section are not entirely clear, in part because the exposures are so limited. It is evident that these beds represent continuation of nearshore-marine deposition in a clastic-dominated foreland basin. Szmuc (1970) refers to the strata as deltaic facies, building from the south, given the orientations and locations of the coarse facies, but he also labels them as “delta-bar-spit-

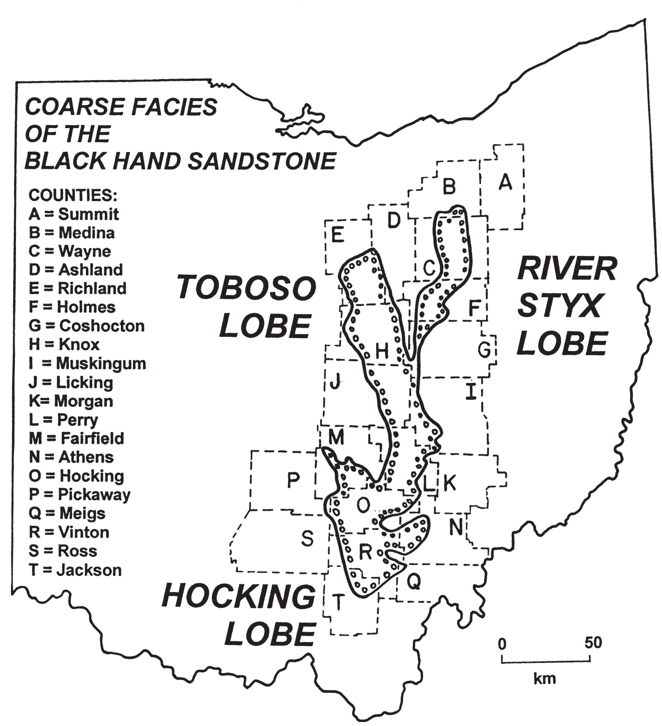


Figure 3-2.—Coarse facies of the Black Hand Sandstone, modified from Coogan and others (1981). The “Big Injun” lobe is present in the subsurface east of the River Styx lobe, approximately under the “River Styx” label (see figs. 22 and 29 in Szmuc, 1970).

beach" deposits. Coogan and others (1981), following Bork and Malcuit (1979), propose a limited number of large and generally northwardly prograding, pebbly sandstone, deltaic distributaries that serve to create and supply prodeltas, shelf sediments, enclosed bays, barrier bars, back-barrier lagoons, and the like. Most of the Sharpsville and Meadville siltstones suggest deposition around storm-wave base, but whether this is deep, or shallow but protected, is unclear. Some of the siltstones might be thin turbidites, as they contain many strongly directional, basal, groove marks, apparently from waterlogged vegetation, that are succeeded by massive to rippled fine sandstone and siltstone. However, continuity is hard to assess and they could more easily be tempestites. At least one bed shows two sets of nearly parallel and largely continuous grooves, with one set overriding the other, which would be difficult for turbidites. One overhanging ledge of thick Sharpsville Sandstone (since destroyed but the site will be seen at Stop 2.2 on Day 1), showed a set of discontinuous skip marks that apparently recorded surf beat combined with overall forward motion. Szmuc (1957) records strongly WSW orientations of grooves, cross-beds, and so forth for the Sharpsville and Meadville.

The Mississippian can be divided into the Kinderhookian, Osagean, Meramecian, and Chesterian (or alternatively the Tournaisian, Visean, and Namurian). The Cuyahoga "group" is most likely Tournaisian. Szmuc (1957) considered it to be of mostly Kinderhook age, possibly not starting at the beginning and entering the Osage stage halfway up through the Meadville Member. Appalachian uplift and yoked subsidence were apparently not significant at this time, thereby explaining the modest thickness of strata involved and the amount of sandstone reaching Ohio. However, it is unclear how much time is missing at the top and bottom of the Cuyahoga "group."

Later Mississippian strata are not preserved in north central Ohio. However, not far to the south are outcrops of the Logan Formation (Szmuc, 1970). These include the Vinton and Byer Members (yellowish laminated siltstones and gray shales, totaling about 85 m), that are respectively underlain by the thin but reportedly very continuous Berne and Allensville Conglomerates. Both conglomerates consist of well-sorted, and well-rounded, small (mostly 2-5 mm) quartz pebbles in medium-grained sandstone (Hyde, 1953; Szmuc, 1970). Thickness locally ranges up to 6 m, but are more typically 0.15-1.5 m thick. However, greater thickness and additional facies are present farther south (Hyde 1953). Both conglomerates sit on erosional surfaces (disconformities), with the Berne including blocks of the underlying lithology. Given the emphasis in the literature on the predominance of small quartz pebbles, it seems likely that the Bern and Allensville Conglomerates represent lag gravels derived by reworking pebbles from the underlying coarser facies.

Elsewhere in Ohio, discontinuous outcrops of the Maxville Limestone can be found locally between the Logan Formation and the overlying Pennsylvanian. Hyde (1953) reports that the Maxville sits on an eroded surface and initially constituted a broad sheet, with some hills poking up through it, but it has subsequently been removed from most areas by pre-Sharon erosion.

THE PENNSYLVANIAN: THE SECOND CLASTIC WEDGE

The Pennsylvanian begins with the Pottsville Group, and continues with the Allegheny. Except at their very base, these are classic, vast, flat, prograding alluvial plain/coal-swamp/delta/shallow-marine cyclothem sequences that are reset by episodic broad transgressions and delta-lobe switching. All of the Pennsylvanian and Permian strata in this region compose the clastic wedge for the last major Appalachian collision. This was the Hercynian or Alleghenian orogeny. The collision took place between the northern coasts of Africa and South America (joined as Gondwanaland) to the south, and the southern "Laurasian" coastline in the north (across the Gulf of Mexico, up the eastern seaboard to New York, and across central Europe). In Ohio, the Pottsville has been considered to consist of 12 cyclothems totaling about 80 m, although the whole section contains more cyclothems elsewhere (Stout 1931). Aronson and Lewis (1994) found that muscovite in the Sharon yielded a bulk K-Ar age of 371 ± 10 m.y., whereas Lux and Wells (1994 and unpublished) obtained a $^{40}Ar/^{39}Ar$, incremental release total gas age of 406.5 ± 7 m.y. from muscovite in the Sharon at Akron Gorge, so the Sharon has Acadian sources. Younger beds appear to contain somewhat older mica, in that Lux and Wells found detrital muscovite in subsequent Lower Pennsylvanian Freeport sandstone to be latest Silurian (416.2 ± 1.3 m.y.), and one sample from the Massillon Sandstone and another from the Homewood Sandstone gave ages of 435.8 ± 4.0 and 411.3 ± 2.9 m.y. respectively.

The base of the Pottsville consists locally of the "Harrison Ore" (described as a thin marcasite or pyrite bed) and the much more important Sharon Formation (Heimlich and others, 1970). The Sharon is a distinct exception to all the overlying Pennsylvanian deposits, as it is uniquely conglomeratic, and it sits on a major disconformity. The Sharon *sensu lato* consists of conglomerates and/or sandstones with overlying shale and coal (Rau, 1970). The Sharon has been interpreted as a valley-filling unit that buries perhaps 110 to 170 m of topographic relief that had been carved into Mississippian strata (Hyde, 1953; Denton and others, 1961; Mrakovich, 1969, fig. 3-3). Only after the old hills and valleys were buried was it possible to establish the broad alluvial plains, swamps and bays of the later Pennsylvanian. Today, the Sharon is commonly a cap rock on hills in this region, but detailed work (e.g., Mrakovich, 1969) makes it clear that many modern hilltop outcrops of conglomerate represent old valley-floor and hill-shoulder deposits. The Sharon has been interpreted as a braided-stream paleovalley complex that drained generally south (Mrakovich, 1969; Mrakovich and Coogan, 1974; and Beuthin, 1993, figs. 3-3 and 3-4). The Sharon does not begin to accumulate locally until approximately late Morrowan time (Meckel, 1967). The valleys eroded an uncertain but considerable distance down into the Mississippian: the Logan "group" was completely eroded away in our area, and the Cuyahoga Formation (where preserved below the Pennsylvanian) is locally eroded down from 190 m to less than 30 m thick. In southeastern Ohio, Hyde (1953) showed that Sharon conglomerates are restricted to paleovalleys that may be as deep as 100-120 m (cross-section E-F in fig. 3-1). However, estimating the total pre-Sharon erosion is complicated by uncertainty as to the thickness of the now eroded post-Cuyahoga strata, and as to exactly when the area rose above sea level.

REFERENCES CITED

Aronson, J. L., and Lewis, T. L., 1994, Ages of detrital white mica from Devonian-Pennsylvanian strata of the north-central Appalachian basin: dominance of the Acadian orogen as prov-

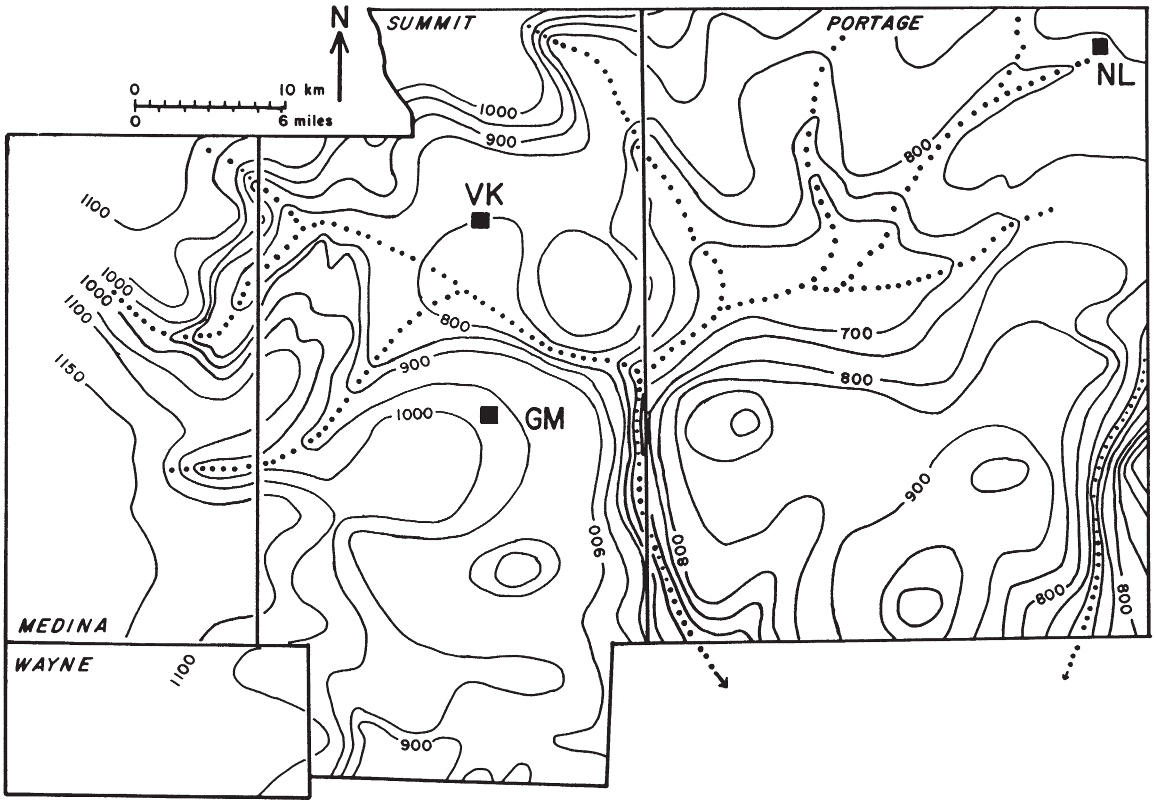


Figure 3-3.—Structure contour map on the base of the Sharon Formation, showing the paleotopography developed on the top of the Mississippian section in north-central Ohio (modified from Mrakovich, 1969). Units are in feet.

enance: Journal of Geology, v. 102, p. 685-696.

Beuthin, J., 1994, A sub-Pennsylvanian paleovalley system in the central Appalachian Basin and its implications for tectonic and eustatic controls on the regional Mississippian-Pennsylvanian unconformity: SEPM Concepts in Sedimentology and Paleontology, no. 4, p. 107-120.

Bork, K. B., and Malcuit, R. J., 1979, Paleoenvironments of the Cuyahoga and Logan Formations (Mississippian) of central Ohio: Geological Society of America Bulletin, part 1, v. 90, p. 1091-1094; part 2, v. 90, p. 1782-1838.

Coogan, A. H., Heimlich, R. A., Malcuit, R. J., Bork, K. B., and Lewis, T. L., 1981, Early Mississippian deltaic sedimentation in central and northeastern Ohio, *in* Roberts, T. G., ed., Geological Society of America Cincinnati '81 Field Trip Guidebooks, vol. 1: Stratigraphy, Sedimentology: American Geological Institute, Falls Church, Virginia, p. 113-152.

Cushing, H. P., Leverett, F., and Van Horn, F. R., 1931, Geology and mineral resources of the Cleveland district, Ohio: U.S. Geological Survey Bulletin 818, 138 p.

Denton, G. H., Collins, H. R., Delong, R. M., Smith, B. E., Sturgeon, M. T., and Brandt, R. A., 1961, Pennsylvanian geology of eastern Ohio, *in* Roberts, T. G., ed., GSA Cincinnati '81 Field Trip Guidebooks, vol. 1: Stratigraphy, Sedimentology: Falls Church, Virginia, American Geological Institute, p. 131-205.

Duncan, P. W., and Wells, N. A., 1992, The Mississippian Berea Sandstone at Bedford in northern Ohio: tidal cyclicity, syndepositional deformation, and major bounding surfaces: Northeastern Geology, v. 14, no. 1, p. 15-28.

Eames, L. E., 1974, Palynology of the Berea Sandstone and Cuyahoga Group of northeastern Ohio: Ph.D. diss. (unpub.), Michigan State University, 294 p.

Gutschick, R. C., and Sandberg, C. A., 1991, Upper Devonian biostratigraphy of history of Michigan Basin, *in* Catacosinos, P. A., and Daniels, P. A., Jr., eds., Early sedimentary evolution of the Michigan Basin: Geological Society of America Special Paper 256, p. 155-179.

Heller, P. L., Angevine, C. L., and Paola, C., 1989a, Comment and reply on "Thrusting and gravel progradation in foreland basins: a test of post-thrusting gravel dispersal": Geology, v. 17, p. 959-960.

__________ 1989b, Interpretation of pre-, syn-, and post-orogenic gravels in alluvial basins: Program and Abstracts, 4th International Conference on Fluvial Sedimentology, p.151.

Heimlich, R. A., Mrakovich, J. V., and Frank, G. W., 1970, The Sharon Conglomerate, *in* Banks, P. O., and Feldmann, R. F., eds., Guide to the geology of northeastern Ohio: Cleveland, Northern Ohio Geological Society, p.125-138.

Hyde, J. E., 1953, The Mississippian formations of central and southern Ohio: Ohio Division of Geological Survey Bulletin 51, 364 p.

Lewis, T. L., 1976, Late Devonian and Early Mississippian paleoenvironments, northern Ohio: Geological Society of America Abstracts with Programs, v. 8, p. 220.

__________ 1986, Dispersal systems and basin accommodation of Late Devonian and Early Mississippian clastic wedges, northern Ohio: Society of Economic Paleontologists and Mineralogists, Abstracts, v. 3, p. 67-68.

__________ 1988, Late Devonian and Early Mississippian distal basin-margin sedimentation of northern Ohio: Ohio Journal of Science, v. 88, p. 23-39.

Lux, D. R., and Wells, N. A., 1994, $^{40}Ar/^{39}Ar$ dating of coarse detrital muscovites from latest Devonian to Middle Pennsylvanian sandstones of northern Ohio: Geological Society of America Abstracts with Programs, v. 26, no. 3, p. 57-58.

Majoras, J. J., and Wells, N. A., 1988, Formation of Mississippian Berea Sandstone "channels" by soft-sediment deformation, at Elyria, Lorain County, Ohio: Geological Society of America Abstracts with Programs, v. 20, no. 4, p. 382.

Meckel, L. D., 1967, Origin of Pottsville Conglomerates (Pennsylvanian) in the central Appalachians: Geology Society of America Bulletin, v. 78, p. 223-258.

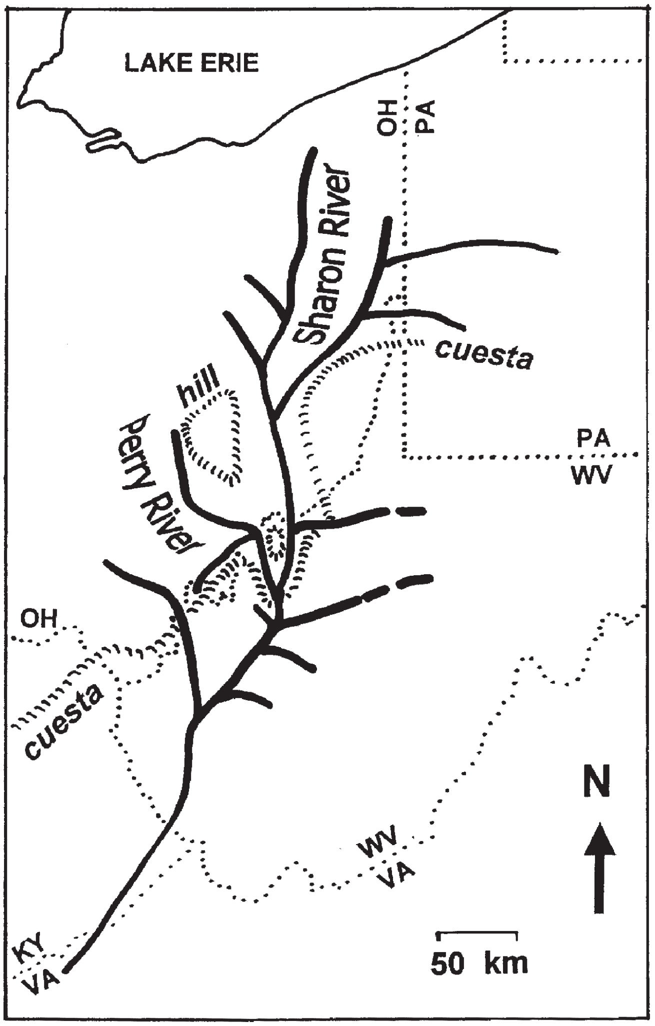


Figure 3-4.—The broader context of the Sharon paleovalley system, modified from Beuthin (1994).

Mrakovich, J. V., 1969, Fluvial deposits of the Sharon Conglomerate in Portage, Summit, eastern Medina, and northeastern Wayne Counties: M.S. thesis (unpub.), Kent State University, 92 p.

Mrakovich, J. V, and Coogan, A. H., 1974, Depositional environment of the Sharon Conglomerate Member of the Pottsville Formation in northeastern Ohio: Journal of Sedimentary Petrology, v. 44, no. 4, p. 1186-1189.

Nesbitt, K. L., and Wells, N. A., 1990, The Mississippian Berea Sandstone of the South Amherst Quarries, Lorain County, Ohio: deposition as valley-fills or oversized loadcasts?: Geological Society of America Abstracts with Programs, v. 22, no. 5, p. 40.

Pashin, J. C., 1990, Reevaluation of the Bedford-Berea sequence in Ohio and adjacent states: new perspectives on sedimentation and tectonics in foreland basins: Ph.D. diss. (unpub.), University of Kentucky, 412 p.

Pashin, J. C., and Ettensohn, F. R., 1987, An epeiric shelf to basin transition: Bedford-Berea sequence, northeastern Kentucky and southcentral Ohio: American Journal of Science, v. 287, p. 893-926.

__________ 1995, Reevaluation of the Bedford-Berea sequence in Ohio and adjacent states: forced regression in a foreland basin: Geological Society of America Special Paper 298, 68 p.

Pepper, J. F., Dewitt, W., and Demarest, D. F., 1954, Geology of the Bedford Shale and Berea Sandstone in the Appalachian Basin: U.S. Geological Survey Professional Paper 259, 111 p.

Perrin, W. H., ed., 1881, History of Summit County: Chicago, Baskin & Battey, p. 185.

Rau, J. L., 1970, Pennsylvanian system of northeast Ohio, *in* Banks, P. O., and Feldmann, R. F., eds., Guide to the geology of northeastern Ohio: Cleveland, Northern Ohio Geological Society, p. 69-124.

Stout, W. S., 1927, Geology of Vinton County. Ohio Division of Geological Survey Bulletin 31, 402 p.

__________ 1931, Pennsylvanian cycles in Ohio: Illinois Geological Survey Bulletin, v. 60, p. 195-216.

Szmuc, E. J., 1957, Stratigraphy and Paleontology of the Cuyahoga Formation of northern Ohio: Ph.D. diss. (unpub.), Ohio State University, 623 p.

__________ 1970, The Mississippian System, *in* Banks, P. O., and Feldmann, R. F., eds., Guide to the geology of northeastern Ohio: Cleveland, Ohio, Northern Ohio Geological Society, p. 23-68.

Wells, N. A., 1991, Synsedimentary fracturing in the Mississippian Berea Sandstone delta, at Elyria and Berea, Medina County, Northern Ohio: Geological Society of America Abstracts with Programs, v. 23, no 3, p. 65.

Wells, N. A., Coogan, A. H., and Majoras, J. J., 1991, Field guide to Berea Sandstone outcrops along the Black River in Elyria, Ohio: slumps, slides, mud diapirs, and associated fracturing in Mississippian delta deposits: Ohio Journal of Science, v. 91, no. 1, p. 35-48.

Zagger, G. W., 1995, Conodont biostratigraphy and stratigraphy of the latest Devonian of northeastern Ohio: M.S. thesis (unpub.), Case Western Reserve University, 112 p.

CHAPTER 4, REGIONAL HYDROGEOLOGY OF THE SHARON AQUIFER

by Annabelle M. Foos

Water of the purest quality is easily found anywhere in the sandstone rock which underlies the town at various depths.
Anonymous (1837 *in* Butterfield, 1881, p. 473)

INTRODUCTION

The Sharon Formation of the Pottsville Group is the most important bedrock aquifer in Northeast Ohio, particularly in Summit, Portage and Geauga counties. Aquifers from the Pottsville Group supply 38% of the groundwater in northeast Ohio and the Sharon Aquifer is the most productive of the Pottsville aquifers (Sedam, 1973). This summary of the hydrogeology of the Sharon aquifer is based on hydrological and hydrochemical data compiled from published reports (Eberts and others, 1990; Eberts, 1991; Sedam, 1973; Winslow and White, 1966), data available from the Ohio Department of Natural Resources, and a number of unpublished masters theses by students at The University of Akron (Brasaemle, 1978; Chowdhury, 1995; Eshler, 1988; Fyodorova, 1998; Jost, 1994; Garvey, 1988; Harper, 2000; Kesebir, 1986; Rizzo, 1993; Wilson, 1991) and Kent State University.(Butz, 1973; Heaton, 1982; Kammer, 1982; Krulik, 1982; Richards, 1981; Robertson, 1983; Stanley, 1973; Wells, 1970; Williams, 1983). These studies were based on water well log data available from the Ohio Department of Natural Resources, with the majority of the wells that tap the Sharon aquifer being domestic wells in relatively rural settings. Most studies on the hydrogeology of northeast Ohio treat the lower two sandstones of the Pottsville Group (Massillon and Sharon) as one hydrostatic unit, which will be referred to in this paper as the "Sharon Aquifer".

PHYSICAL SETTING

The distribution of the Sharon aquifer is shown in figure 4-1. The area lies within the glaciated portion of the Allegheny Plateau physiographic province. The topography is characterized by low, rounded hills, gentle slopes and broad valleys on the drift plains, cut by gorges of high relief and steep slopes. Bedrock units in northeast Ohio have a dip of approximately 20 ft/mi (3.8 m/km) toward the southeast (Smith and White, 1953). As a result bedrock units in this area of Ohio become progressively younger toward the southeast. The Sharon is the uppermost bedrock unit in most of Medina, Summit, Geauga, Portage and Trumbull counties. In southern Portage, Stark and Mahoning counties, younger Pennsylvanian units overlie the Sharon. The thickness of the Sharon aquifer is variable ranging from less than 6m (20 ft) to over 75 m (250 ft) (Sedam, 1973). The lower contact is defined by the unconformity with the Mississipian Cuyahoga Formation, which has up to 150 m (500 ft.) of relief (Mrakovich, 1969). The unconformity with Quaternary surficial deposits defines the upper extent of the Sharon. The preglacial topography of northeast Ohio was highly dissected and similar to the topography of the unglaciated Allegheny Plateau of southeastern Ohio. The Sharon, being resistant to erosion, caps the highlands of this preglacial topography (fig. 4-2). Pleistocene glaciation resulted in smoothing of the preglacial topography and blanketing the area with surficial sediments. The result was a number of rounded, isolated knobs and uplands of Sharon separated by bedrock valleys that have been infilled with glacial and proglacial deposits (fig. 4-3). In much of northeast Ohio

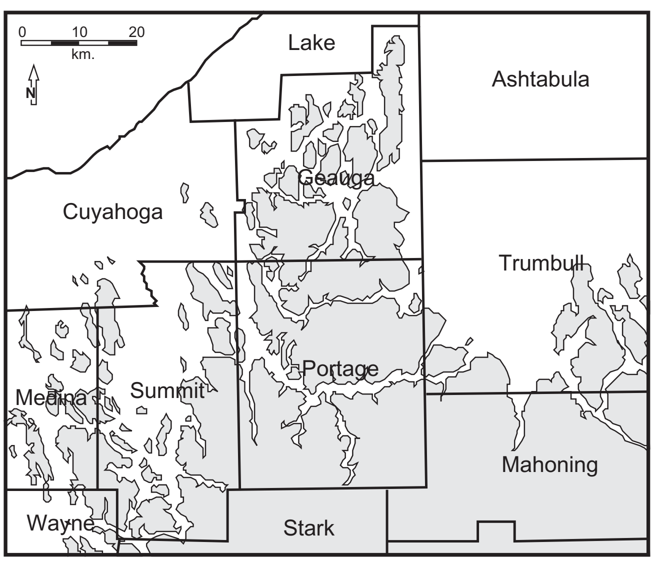


FIGURE 4-1.—Distribution of the Pennsylvanian Massillon through Sharon Formations, undivided aquifer in Northeast Ohio (shaded area). (Data from Ohio Division of Water, 2000)

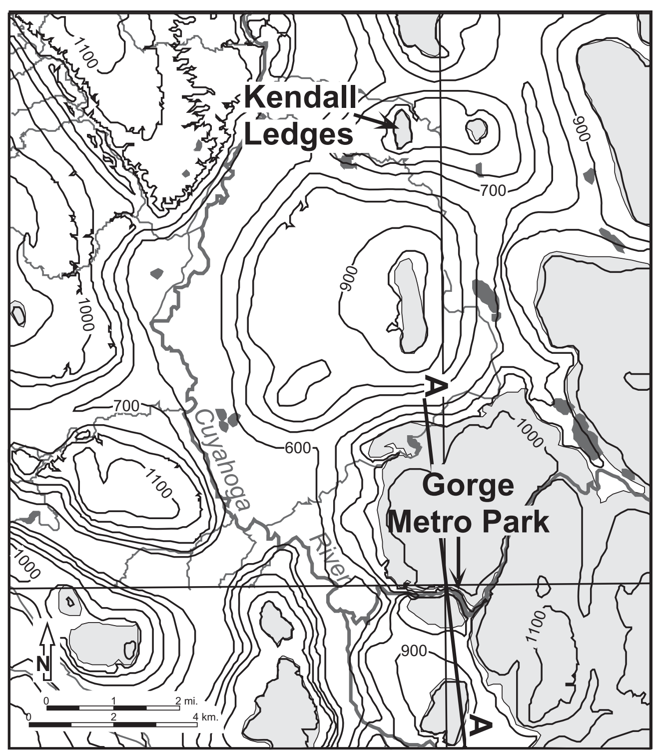


FIGURE 4-2.—Bedrock geology of the field trip area. Contour lines represent bedrock contours and shaded areas represent the Sharon aquifer. Contour interval equals 100 feet. A-A' represents the line of cross-section in fig. 4-3. (Data from Ohio Division of Geological Survey, 2003 and 1996)

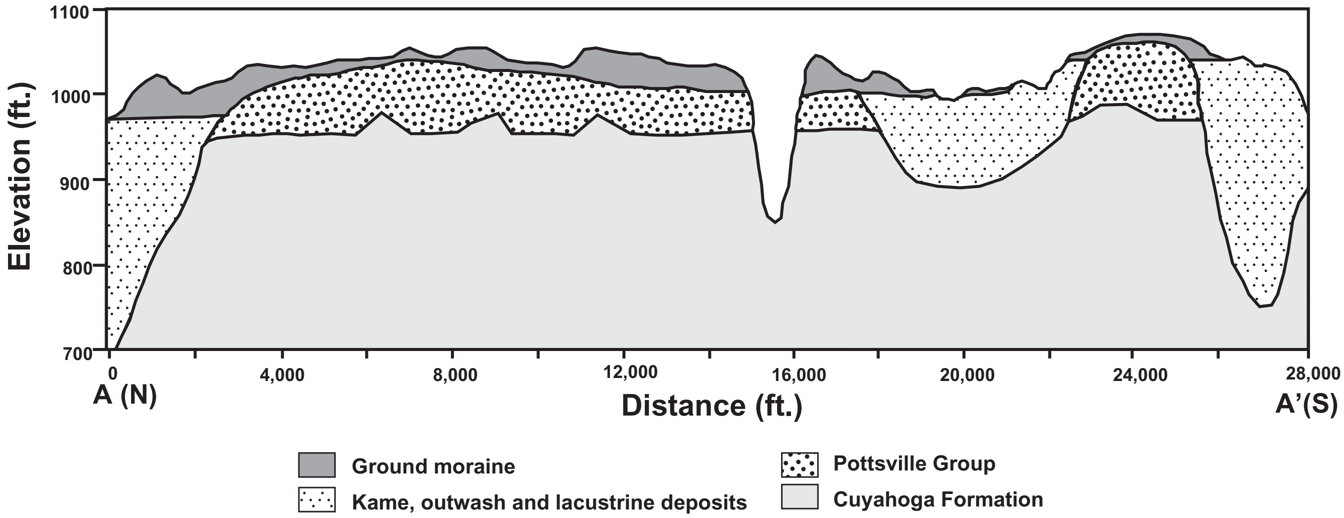


FIGURE 4-3.—Representative geologic cross-section of the field trip area showing isolated knobs of the Sharon Formation separated by bedrock valleys filled with glacial sediments.

the Sharon aquifer has been dissected into hydrologically isolated remnants bounded by the relatively impermeable Cuyahoga Formation below and clay-rich glacial tills above. The area of these isolated Sharon aquifers ranges from less than 1 km^2 to 375 km^2 (146 mi^2). The thickness of surficial deposits above the Sharon aquifer ranges from less than a meter to over 46 m (150 ft).

Joints and fractures are common in the Sharon aquifer. The major fractures run N45E and N45W, and are related to the regional fracture pattern of the Allegheny Plateau (Stanley, 1973). Fracturing has also been related to post-glacial stress release, and pre- and post-glacial valley stress release.

Annual precipitation in northeast Ohio ranges from 86 to 107 cm (34 to 42 in) (Woods and others, 1998). Most of the recharge to the Sharon is through direct infiltration. Induced infiltration from streams is minor, because most of the Sharon remnants are above the major streams (Sedam, 1973).

HYDRAULIC PROPERTIES

A database was compiled of 671 analyses of the hydraulic properties of the Sharon aquifer. Transmissivity and hydraulic conductivity were estimated from specific capacity analysis (Walton, 1962). A summary of the hydraulic properties is presented in table 4-1 and figure 4-4. The average hydraulic conductivity is 179 gpd/ft^2 (8.45×10^{-5} m/s), however it ranged over 4 orders of magnitude from 1.4 gpd/ft^2 (6.61×10^{-7} m/s), to 15,937 gpd/ft^2 (7.52×10^{-3} m/s). A similar average hydraulic conductivity and degree of variability is observed when the data is separated into counties (table 4-2), suggesting there is no geographic control on the hydraulic conductivity. When Williams (1983) compared the transmissivity to aquifer thickness, distance to subcrop contact, depth of penetration, and depth of burial, he found no relationships. Rizzo (1993) suggested that the heterogeneity in hydraulic properties of the Sharon is a function of the diverse sedimentology of the Sharon causing it to range from fine-grained sandstone to conglomerate. Others (Kammer, 1982; Richards, 1981; Sedam, 1973; Stanley, 1973) attributed the heterogeneity to the distribution of tectonic and stress release fractures. Stanely (1973) noted a relationship between the specific capacity and distance from major fractures, with the wells closest to the fractures having the highest specific capacity.

TABLE 4-1.—*Summary of the hydraulic properties of water wells from the Sharon aquifer (*n = *671)*

	Specific capacity gpm/ft	Transmissivity gpd/ft	Hydraulic conductivity gpd/ft^2
Average	5	9,061	179
Standard deviation	57	35,345	807
High	1,462	796,891	15,937
Low	0.11	121	1

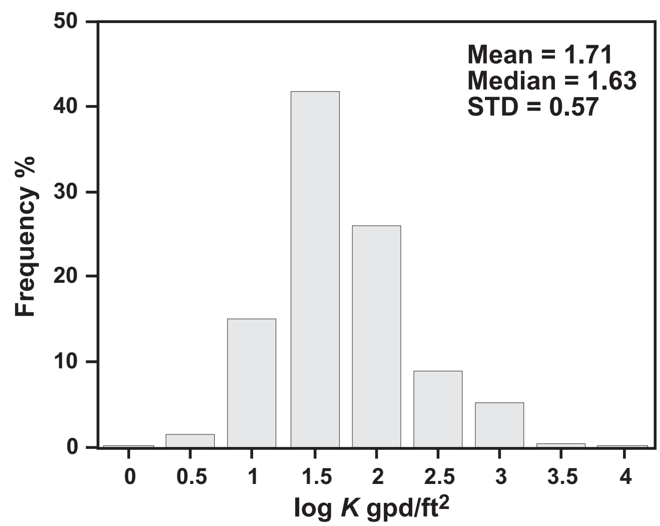


FIGURE 4-4.—Histogram showing the distribution of hydraulic conductivity (*K*) values for the Sharon aquifer of Northeast Ohio. (Data logarithmically transformed to more closely approximate a normal distribution.)

TABLE 4-2.—*Hydraulic conductivity (*K*) statistics of Sharon wells from different counties (data logarithmically transformed to more closely approximate a normal distribution)*

	log K gpd/ft^2				
	no. of wells	Average	Standard deviation	Low	High
All wells	671	1.71	0.57	0.15	4.20
Geauga	155	1.51	0.38	0.60	3.23
Medina	90	1.70	0.64	0.48	3.16
Portage	287	1.83	0.60	0.15	4.20
Summit	112	1.70	0.55	0.89	4.06
Wayne	27	1.75	0.56	0.65	2.72

The expected range of hydraulic conductivity of sandstones is from 10^{-3} to 10 gpd/ft^2 (Freeze and Cherry, 1979). The Sharon being a relatively clean, porous, sandstone should be in the upper part of this range. It is composed of 98% quartz and the median grain size ranges from 0.24 to 10.4 mm (fig. 4-5) with 76% of the samples having a grain size less than 2 mm (Bowen, 1953). Wells (1970) measured the porosity of the Sharon and found it ranged from 6 to 34% with an average of 21%. Jost (1994) determined the permeability of samples of Sharon sandstone using a constant head permeameter and found it to be 1.5×10^{-3} cm/sec (32 gpd/ft^2). The measured permeability is slightly higher than the range of sandstone permeability predicted by Freeze and Cherry (1979). However, the suggested range of sandstone permeability and measured permeability are significantly lower than the hydraulic conductivity determined by specific capacity analysis: 59% of the Sharon wells have a hydraulic conductivity greater than 32 gpd/ft^2. This suggests that factors other than matrix permeability are contributing to the hydraulic conductivity of the Sharon aquifer. Freeze and Cherry (1979) indicate that the expected hydraulic conductivity of karst limestones is between 10 and 10^5 gpd/ft^2. This range is similar to the range observed for the Sharon, suggesting that flow through the Sharon aquifer is similar to that of karst limestones and characterized by conduit flow. Outcrop evidence of springs and channelized voids, discussed elsewhere in this guidebook, supports this interpretation.

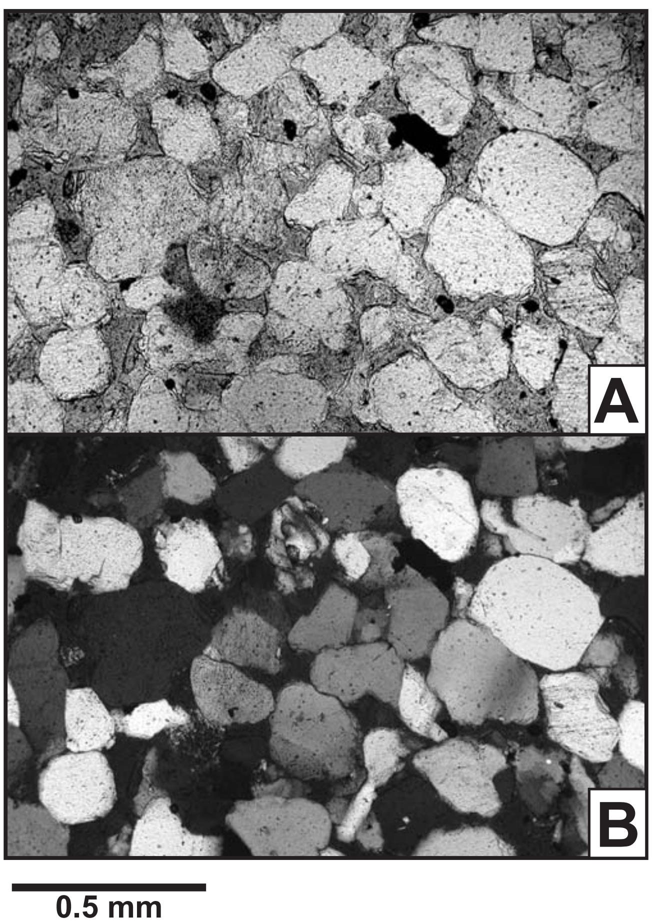


FIGURE 4-5.—Photomicrographs of Sharon sandstone. A) plane light, B) crossed nicols. Photos by D. Waugh.

HYDROCHEMISTRY

The average of 127 analyses of the ground-water chemistry from the Sharon aquifer is presented in table 4-3. In general the quality of water from the Sharon aquifer is good, with the exception of its hardness and iron content. The pH ranges from 5.1 to 8.2, however most of the waters are near neutral and the average pH is 7.0 (fig. 4-6). 88% of the waters were within the US EPA Secondary Drinking Water Standards (US EPA, 1992) range of 6.5 to 8.5. The concentration of total dissolved solids ranges from 28 to 2281 with an average of 436 mg/L. 72% are below the EPA secondary maximum contaminant levels (SMCL) of 500 mg/L. Water hardness is recognized by the quantity of soap required to produce a lather. It is either measured directly by titration or calculated from the Ca and Mg concentrations and is reported as mg/L of calcium carbonate. Hardness is an undesirable characteristic because it requires excessive use of soap and causes the formation of scale in boilers, water heaters, radiators and pipes. In most cases water hardness can be treated by use of a water softener. Water from the Sharon aquifer tends to be hard to very hard with an average hardness of 310 mg/L $CaCO_3$. 21%

TABLE 4-3.—*Average chemical composition of ground water from the Sharon aquifer (*n*=127; all concentrations in mg/L)*

	Average	Standard deviation	Range
pH	7.0	0.4	5.1 - 8.2
Total dissolved solids	436	333	28 - 2281
Hardness (as $CaCO_3$)	310	244	8 - 2088
Ca^{+2}	79	56	< 1 - 413
Mg^{+2}	27	28	< 1 - 257
Na^{+}	28	72	< 1 - 450
K^{+}	2.5	2.9	< 1 - 22.0
HCO_3^{-}	262	140	1 - 607
SO_4^{-2}	121	193	< 1 - 1350
Cl^{-}	36	87	< 1 - 780
NO_3^{-}	2.19	5.43	< 0.01 - 39.00
PO_4^{-3}	0.35	0.65	< 0.01 - 3.60
SiO_2	12.68	4.61	0.05 - 24.40
Total Fe	1.58	4.43	< 0.01 - 34.00
Mn^{+2}	0.28	0.62	< 0.01 - 3.10

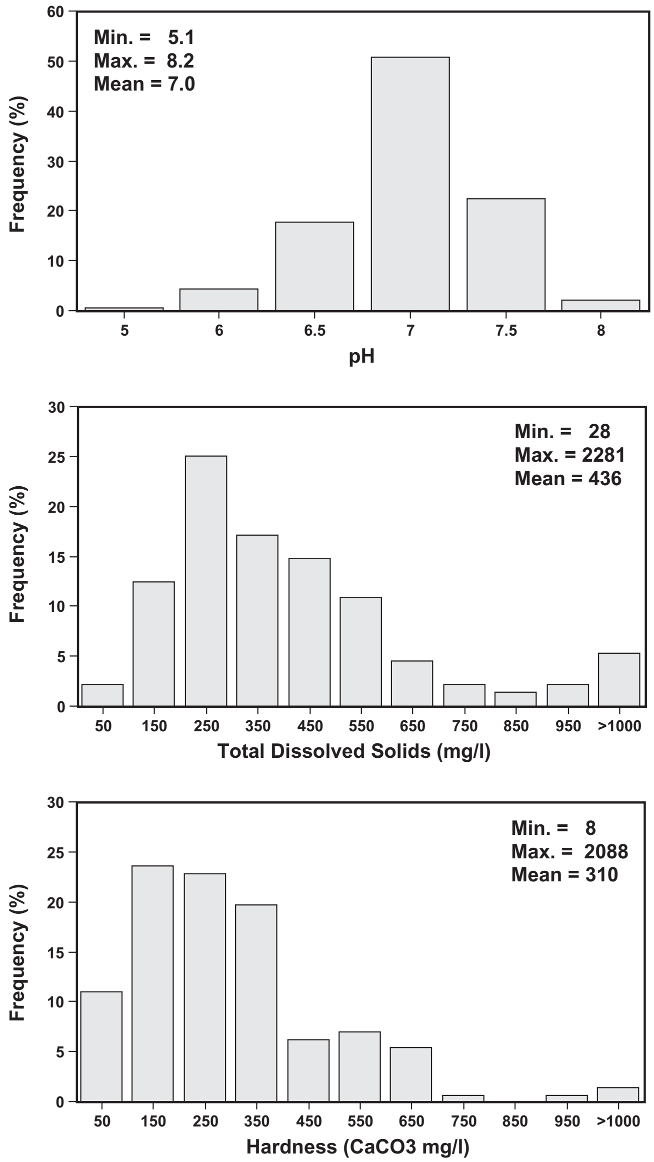


FIGURE 4-6.—Histograms showing the distribution of pH, total dissolved solids (TDS) and hardess of water from the Sharon aquifer (n = 129).

of the waters are classified as hard (121-180 mg/L $CaCO_3$) and 61% are classified as very hard (121-180 mg/L $CaCO_3$). The US EPA recommended SMCL for chloride (250 mg/L), sodium (20 mg/L), and sulfate (250 mg/L) were exceeded in only 2%, 4%, and 9% of the samples respectively. The US EPA recommends that iron concentration should be less than 0.3 mg/L for aesthetic reasons. Iron is objectionable at higher concentrations because it leaves reddish-brown stains on porcelain, enamelware and clothing. The iron SMCL (0.3 mg/L) was exceeded in 43% of the samples from the Sharon aquifer.

The ground-water chemistry of samples from the Sharon aquifer is illustrated on Piper diagrams in figure 4-7. Piper diagrams are commonly used by hydrologist as a convenient way to illustrate the relative proportions of the major chemical constituents of water and are used to classify water samples (Piper, 1944). The lower triangles are used to plot the relative proportions of the major cations (left) and anions (right) in meq/L. Information from the two triangles is projected onto the central quadrilateral with the total dissolved solids (TDS) illustrated by the circle diameter. The majority of the ground water from the Sharon Member is classified as calcium-bicarbonate type water with 86% of the waters dominated by calcium and 81% dominated by bicarbonate. A few of the sodium-chloride rich samples from Geauga County were believed to have been contaminated by road salt (Eberts, 1991). The Sharon ground water from Stark County is distinctly different from ground water in the more northern counties. Most of the water samples from Stark County are sodium-bicarbonate rich and the average TDS (764 mg/L) is significantly higher than other waters from the Sharon aquifer. In Stark County the Sharon aquifer is deeper and overlain by younger Pennsylvanian units. Recharge passes through the overlying sandstone and shale units and becomes enriched in sodium, potassium and chloride. Analysis of the Br/Cl ratio of Sharon ground water indicates it is also contaminated by formation brines (Harper, 2000). Because of its poorer water quality, relatively few water wells penetrate the Sharon aquifer in Stark County.

As the thickness of overlying Pleistocene glacial deposits increases there is a general increase in TDS and pH of water from the Sharon aquifer (fig. 4-8). The saturation with respect to calcite was calculated using the SOLMINEQ. GW program (Hitchon and others, 1999). The saturation index (SI) is the log IAP/K_T. Where IAP is the ion activity product and K_T is the equilibrium constant at the observed temperature. A saturation index of 0.0 indicates the waters are in equilibrium, a positive SI indicates oversaturation and a negative SI indicates undersaturation with respect to a specific mineral. The saturation index for calcite is plotted against the depth to bedrock or thickness of Pleistocene sediments in figure 4-8. The waters where the glacial deposits are over 50 ft thick are either close to equilibrium or oversaturated with respect to calcite. Most of the samples that are undersaturated with respect to calcite occur where the depth to bedrock is less than 50 ft. The glacial deposits of northeast Ohio contain significant amounts of fine-grained carbonate minerals (Szabo, 2004). As recharge waters pass through the glacial deposits they dissolve the carbonates until they reach a depth of approximately 50 ft where the water becomes saturated with respect to calcite. The result is an increase in pH and total dissolved solids with depth. This reaction of groundwater with carbonates in the glacial deposits is responsible for the dominance of calcium-bicarbonate type water and the hardness of water in the Sharon aquifer.

ACKNOWLEDGEMENTS

I would like to thank all the Masters students at the University of Akron and Kent State University who completed theses on the hydrogeology of Northeast Ohio. This study could not have been completed without the data provided in theses by J. Brasaemle, L. Eshler, J. Garvey, A. M. Harper, K. Heaton, D. Jost, H. Kammer, M. Kesebir, J. Krulik, S. Richards, J. Rizzo, W. Robertson, W. Wilson, and F. Williams. Arpita Nandi prepared the cross section in figure 4-3, and David Waugh provided the photomicrographs of the Sharon. In addition, I wish to thank John Szabo for reviewing an earlier draft of the manuscript.

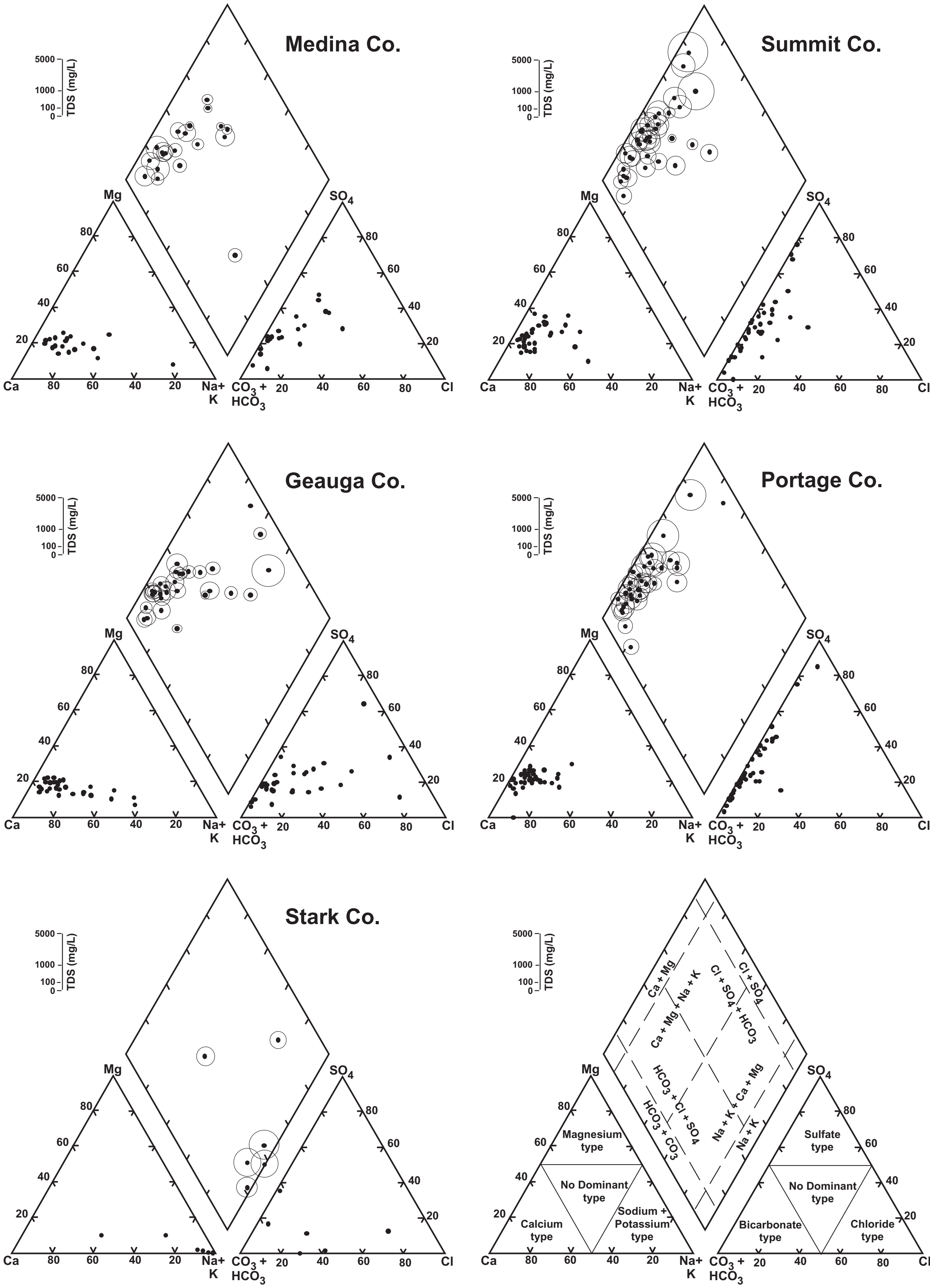


FIGURE 4-7.—Piper diagrams illustrating the chemical composition of water from the Sharon aquifer.

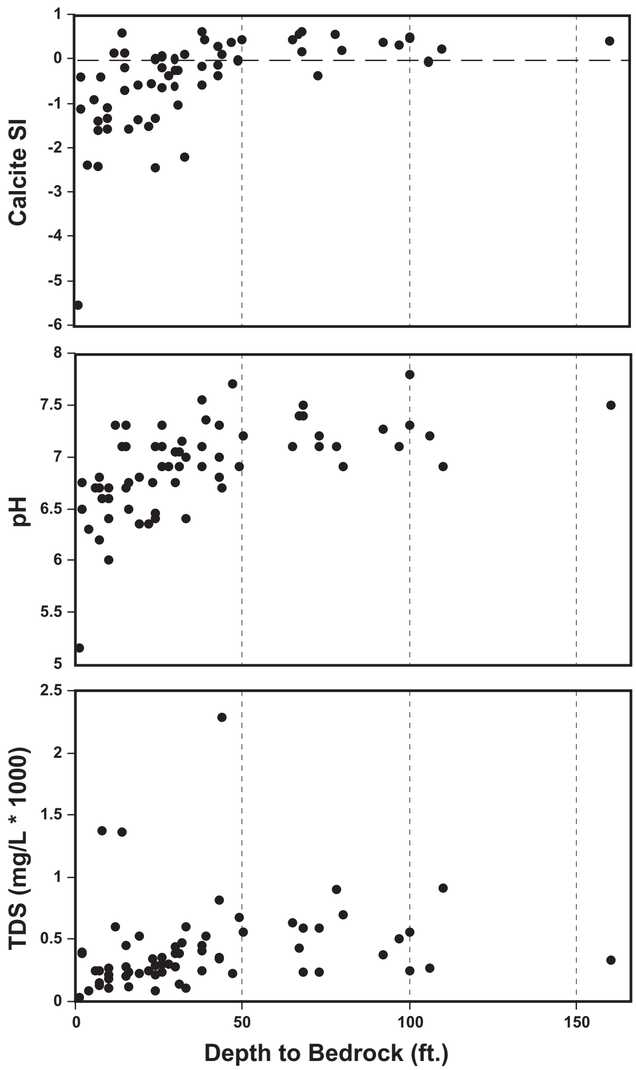


FIGURE 4-8.—The relationship between pH, total dissolved solids (TDS) and calcite saturation index (SI) with the depth to bedrock for water in the Sharon aquifer.

REFERENCES CITED

Brasaemle, J. E., 1978, Chemical character of ground water in and adjacent to the Cuyahoga Valley National Recreation Area, Ohio: M.S. thesis (unpub.), University of Akron, 164 p.

Bowen, C. H., 1953, Petrology and economic geology of the Sharon Conglomerate in Geauga and Portage Counties, Ohio: Ohio State University Engineering Experimental Station no. 153, iv, 58 p.

Butterfield, C. W., 1881, Chapter 16, in Perrin, W. H., ed., 1881, History of Summit County: Chicago, Baskin & Battey, p. 466-496.

Butz, T. R., 1973, The hydrogeology of a sandstone knob overlain by glacial till in Geauga County, Ohio: M.S. thesis (unpub.), Kent State University, 63 p.

Chowdhury, S. H., 1995, Hydrogeology and groundwater pollution potential of Chippewa Creek Basin, Wayne County, Ohio: M. S. thesis (unpub.), University of Akron, 121 p.

Eberts, S. M., Bair, E. S., and deRoche, J. T., 1990, Geohydrology, ground-water quality, and simulated ground-water flow, Geauga County, Ohio, U.S. Geological Survey, Water Resources Investigations Report 90-4026, Columbus Ohio, 93 p.

Eberts, S. M., 1991, Geohydrology and water quality in Northern Portage County, Ohio, in relation to deep-well brine injection. U.S. Geological Survey, Water Resources Investigations Report 91-4158, Columbus Ohio, 63 p.

Eshler, L. M., 1988, Hydrogeological analysis of Sharon Township, Medina County, Ohio: M.S. thesis (unpub.), University of Akron, 118 p.

Freeze, R. A. and Cherry, J. A., 1979, Groundwater: Englewood Cliffs NJ, Prentice Hall, 604 p.

Fyodorova, A. I, 1998, Hydrogeochemical study of cave systems in the Berea Sandstone and Sharon Sandstone/Conglomerate of north east Ohio: M.S. thesis (unpub.), University of Akron, 121 p.

Jost, D. J., 1994, Hydrogeology and pollution potential of aquifers, Doylestown, Wayne County, Ohio: M.S. thesis (unpub.), University of Akron, 142 p.

Garvey, J. T., 1988, The hydrogeology of eastern Franklin and western Green Townships, Summit County, Ohio: M.S. thesis (unpub.), University of Akron, 115 p.

Harper, A. M., 2000, Groundwater geology, hydraulic properties, and water quality of Pennsylvanian hydrostratigraphic units of southwestern Stark County, Ohio: M.S. thesis (unpub.), University of Akron, 123 p.

Heaton, K. P., 1982, The hydrogeology of Stow and Hudson Townships, Summit County, Ohio: M.S. thesis (unpub.), Kent State University, 251p.

Kammer, H. W., 1982, A hydrogeologic study of the Revenna Arsenal, eastern Portage and western Trumbull Counties: M.S. thesis (unpub.), Kent State University, 298 p.

Kesebir, M. M., 1986, Hydrogeology of Hinkley Township Medina County, Ohio: M.S. thesis (unpub.), University of Akron, 104 p.

Krulik, J. W., 1982, A hydrogeologic study of Franklin Township, Portage County, Ohio: M.S. thesis (unpub.), Kent State University, 175 p.

Mrakovich, J. V., 1969, Fluvial deposits of the Sharon Conglomerate in Portage, Summit, Eastern Medina and Northeastern Wayne Counties: M.S. thesis (unpub.), Kent State University, 92 p.

Ohio Division of Geological Survey, 1996, 1:24,000-scale Open-File Bedrock Geology Maps.

__________ 2003, Bedrock-topography data for Ohio: Ohio Geological Survey BG-2, GIS coverage.

Ohio Division of Water, 2000, Pennsylvanian Massillon through Sharon formations Undivided Aquifer: GIS coverage.

Piper, A. M., 1944, A graphic procedure in the geochemical interpretation of water analysis: American Geophysical Union Transactions, v. 25, 914-923.

Richards, S. S., 1981, A hydrogeologic study of South Russell and adjacent areas: M.S. thesis (unpub.), Kent State University, 202 p.

Rizzo, J. S., 1993, Hydrogeology of River Styx Basin, Medina and Wayne Counties, Ohio: M.S. thesis (unpub.), University of Akron, 198 p.

Robertson, W. L., 1983, The hydrogeology of Streetsboro, Portage County, Ohio: M.S. thesis (unpub.), Kent State University, 143 p.

Sedam, A. C., 1973, Hydrogeology of the Pottsville Formation in Northeastern Ohio: USGS Hydrologic Investigations Atlas HA-494, Washington DC.

Smith, R. C., and White, G. W., 1953, The groundwater resources of Summit County Ohio: Ohio Division of Water Bulletin 27, Columbus Ohio, 130 p.

Stanley, R. J., 1973, The relationship between groundwater transmissivity and fracture occurrence in the Sharon Conglomerate of portage County, Ohio: M.S. thesis (unpub.), Kent State University, 54 p.

Szabo, J. P. (2004) Textural and Mineralogical Characteristics of Tills of Northeastern and North-Central Ohio: Ohio Journal of Science (in Press)

US EPA (United States Environmental Protection Agency), 1992, Secondary Drinking Water Regulations: Guidance for Nuisance Chemicals. EPA 810/K-001, <http://www.epa.gov/safewater/consumer/2standards.html>

Walton, W. C., 1962, Selected analytical methods for well and aquifer evaluation: Illinois State Water Survey Bulletin 49, 81 p.
Wells, T. L., 1970, The hydrogeology of the Sharon Conglomerate in Geauga County, Ohio: M.S. thesis (unpub.), Kent State University, 45 p.
Williams, F. W., 1983, Hydrogeologic investigation of Boston and Northhampton Townships, Summit County, Ohio: M.S. thesis (unpub.), Kent State University, 350 p.
Wilson, W. E., 1991, Hydrogeologic analysis of the upper Tuscarawas River Basin, Summit and Stark Counties, Ohio: M.S. thesis (unpub.), University of Akron, 120 p.
Winslow, J. D. and G. W. White, 1966, Geology and ground-water resources of Portage County, Ohio, Ohio: U.S. Geological Survey Professional Paper 511, Washington D. C., 77 p.
Woods, A. J., Omernik, J. M., Brockman, C. S., Gerber, T. D., Hosteter, W. D., and Azevedo, S. H., 1998, Ecoregions of Indiana and Ohio: Reston VA, U.S. Geological Survey.

CHAPTER 5, HYDROGEOLOGY OF GORGE METRO PARK, CUYAHOGA FALLS, OHIO

by Annabelle M. Foos

You have to protect the seeps, because out of the seeps are the crops of the future.

(African expression)

INTRODUCTION

Gorge Metro Park is located on the glaciated Appalachian Plateau. The 200-foot deep Cuyahoga River gorge formed after the termination of the last glaciation, about 12,000 years ago, and cuts through Pennsylvanian and Mississippian aged sedimentary rocks. The gorge dissects the Sharon Formation, an important bedrock aquifer in northeast Ohio. An outcrop of the Sharon aquifer almost 3 km long is exposed on the walls of the Cuyahoga River gorge. By studying the distribution and chemistry of springs and seeps along this outcrop, we have gained an understanding of fluid flow through the aquifer.

The Sharon Formation is a quartz-rich sedimentary unit, consisting of interbedded conglomerate and medium to coarse-grained sandstones that were deposited in a braided stream environment. The Sharon Formation unconformably overlies the Mississippian Meadville Member of the Cuyahoga Formation, a marine unit composed of thinly bedded, fossiliferous, gray shales containing siderite concretions. The Sharon Formation is resistant to erosion and forms prominent ledges. Undercutting forms alcoves at the contact with the underlying Meadville Member. Along the length of the outcrop, seeps and natural springs emerge from fractures, thin conglomeratic beds within the formation, and at the contact with the underlying Meadville Member.

Wisconsin age glacial drift covers the Sharon aquifer in the recharge area. Its thickness ranges from 1 to 12 m, and averages 6 m. The Hiram Till occurs at the surface, but it is usually less than 1 m thick. It is a silty, clayey, till with 40% clay and 15% sand. Older Wisconsin age tills such as the Lavery and Magadore Tills occur below the Hiram Till. Proglacial outwash composed of interbedded and interlensing gravels, sands, and clays underlies the tills (White, 1984).

The study area has a humid microthermal climate with an annual temperature of 9.6° C and average rainfall of 94 cm per year. Precipitation is greatest during the months of April through July and lowest during December through March.

Gorge Metro Park is located in a predominantly residential and commercial, urban setting. A major highway, Ohio Rte. 8, runs parallel to the gorge to the southwest and a major city street, Front Street, runs parallel to the northeast side of the gorge. The Cuyahoga River is dammed within the Park; however the elevation of the dam is below the outcrop of the Sharon Formation.

METHODS

An inventory of all springs and seeps within the Gorge Metro Park was conducted between the fall of 1999 and 2001. Springs and seeps were located with a hand-held GPS unit. Field parameters were measured from 37 springs and seeps and 71 water samples were collected for chemical analysis. Three springs along the Glen trail were selected for bi-monthly measurement of the field parameters between September 1999 and September 2000. Monthly measurement of the field parameters of an additional 6 springs were made between August 2000 and September 2001. Standard methods described in Greenberg and others (1992), and Skougstad and others (1979) were used throughout the study: details are presented in Foos (2003). Field parameters were measured either *in situ* or on site and include temperature, conductivity, pH, and discharge. The anions analyzed included HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-, PO_4^{3-}, and Br^-. Major cations and metals analyzed included Na, K, Ca, Mg, Fe, Mn, Al, and Si. Stable isotopes ($\delta^{18}O$ and δD) were measured for three samples by a commercial laboratory.

RESULTS

Twenty-seven springs and seeps are located along the Glen Trail (GT) on the northeast side of the gorge (fig. 5-1). Five springs and seeps are located on the southeast side of the gorge (MS) that runs parallel to Ohio Rte. 8. Twelve springs and seeps are located along the Gorge Trail (GO) on the northwest side of the gorge and one spring was located on the High Bridge Trail (HB) on the southwest side of the gorge.

Discharge is a measure of the volume of flow discharged over a standard unit of time. The distinction between surface runoff, a local perched aquifer, and a regional aquifer can be determined by monitoring fluctuations in spring discharge (Shuster and White, 1971). Discharge from the springs and seeps ranged from less than 0.1 to 1000 mL/sec (table 5-1). Discharge from the seeps is diffuse, and occurs as numerous steady drips from the roofs of rock alcoves. Flow rate from individual drips ranges from less than 0.1 to 30 mL/sec. In some cases installation of drainage pipes by the park service made it possible to measure cumulative discharge of an alcove. There are four main springs with more concentrated discharges, ranging from 200 to 1000 mL/sec (fig. 5-2).

Discharge of six sites was monitored for a period of one year. A plot of discharge versus time for three sites is given in figure 5-3. All six sites had a relatively constant discharge with no significant seasonal variation. Spring discharge, cumulative discharge from an alcove, and the flow rate from individual drips within an alcove were constant with respect to time. The uniform discharge from these springs indicates they are fed by groundwater with a relatively constant head.

Bi-monthly temperature readings of one spring and two seeps are presented in fig. 5-4. The springs with significant discharge (HB-1, GT-13 and GO-8) had relatively constant temperatures throughout the year. The temperature of seeps with a lower discharge (GT-2, GT-9, GO-4, MS-1, MS-2, MS-3, MS-4a, MS-4b) was more variable. Spring GT-13, which has a high discharge, has a very uniform temperature throughout the year, averaging 13.7° C. Seep GT-2 has the lowest discharge and showed the greatest variation in temperature which mirrored the air temperature. This suggests that water from springs with a lower discharge is equilibrating with the atmosphere prior to sampling and does not reflect the true temperature of water as it emerges from the seep.

The pH ranged from 3.4 to 8.1; however the majority of

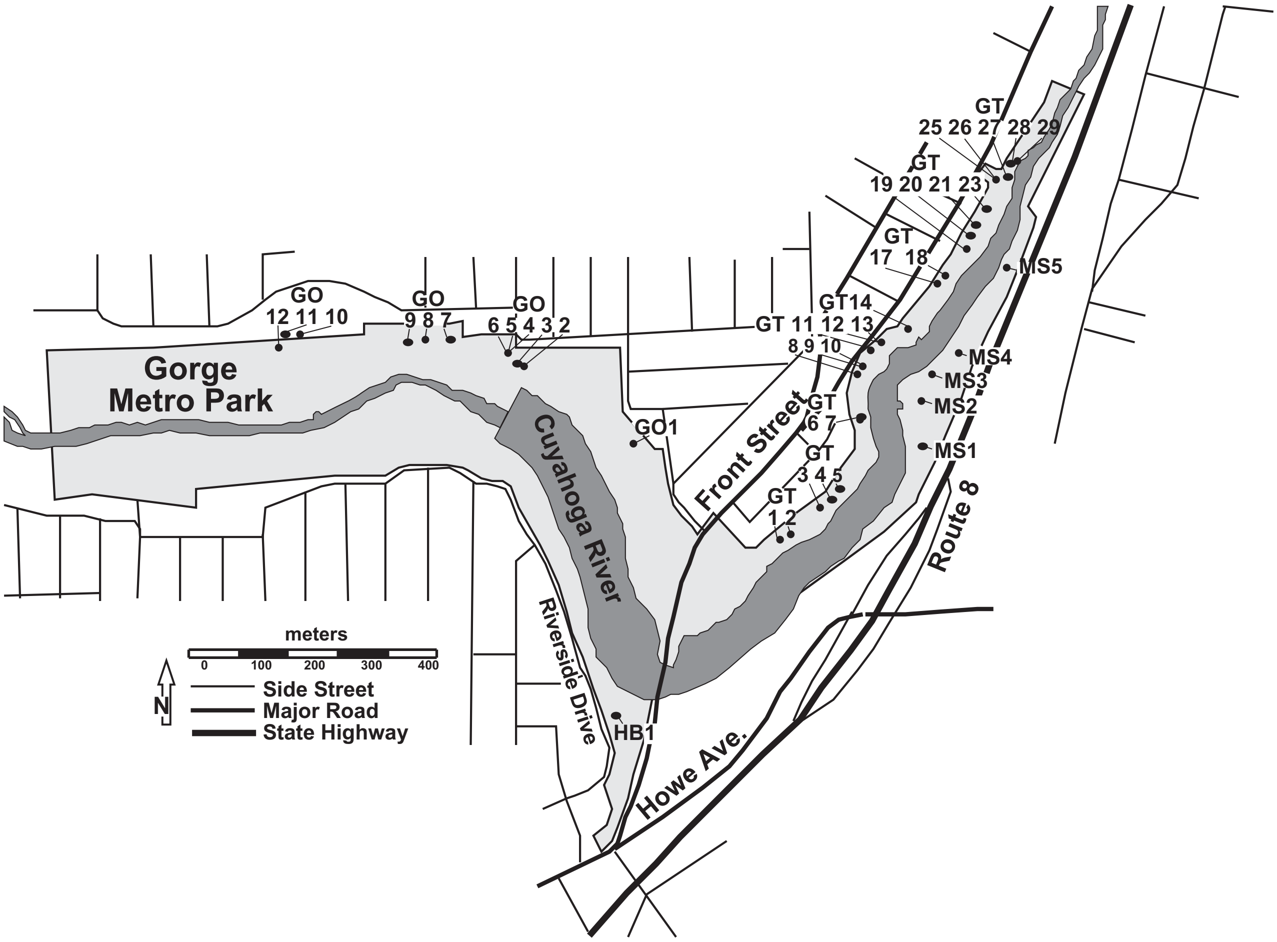


FIGURE 5-1.—Location of springs and seeps in Gorge Metro Park, Cuyahoga Falls, OH (modified from Foos, 2003). (GO-Gorge Trail; GT-Glen Trail; HB-High Bridge Trail; MS-Ohio Rte. 8 Sites)

the springs had a near neutral pH (average = 6.9). Conductivity is a rapid, inexpensive measure of total dissolved solids. The conductivity and chemical composition of the springs is highly variable with conductivity ranging from 392 to 8800 mS (table 5-1) and total dissolved solids (TDS) ranging from 250 to 4733 mg/L. There is a very good correlation between conductivity and TDS ($r^2 = 0.94$, fig. 5-5). Therefore, conductivity can be used to estimate TDS of springs and seeps at Gorge Metro Park. Geographic position played a role in the spring chemistry. Statistically significant differences exist between the average TDS of springs from the Gorge Trail (TDS = 605 mg/L), Glen Trail (TDS = 1266 mg/L), and Ohio Rte. 8 sites (TDS = 1989 mg/L). There was no relationship observed between conductivity and discharge.

Chemical analyses of representative springs are given in table 5-2. Most of the samples were classified as sodium-chloride-rich on a piper diagram (fig. 5-6). Two samples from the High Bridge Trail were classified as mixed-cation-bicarbonate-rich. Two of the samples from the Gorge Trail had no dominant cation, and four had no dominant anion, the remaining samples were sodium-chloride-rich. Along the Glen Trail, three samples were classified as mixed cation-sulfate-rich and the remaining samples were sodium-chloride-rich. All of the samples from the Ohio Rte. 8 sites were classified as sodium-chloride-rich. Water from the Sharon aquifer usually tends to be calcium-bicarbonate rich (see Chapter 4, this volume). However, most of the groundwater studies in northeast Ohio focus on relatively rural areas that are dependent on domestic water wells. The dominance of sodium-chloride rich waters at the Gorge reflects the urbanization of the recharge area for the aquifer. As will be discussed below, road salt is the most likely anthropogenic contaminant of these springs.

There was a high degree of variability among the chemistries of the springs, with the standard deviation being high for most variables measured. In some areas, springs that are closely spaced had widely different chemistries. Two springs, both flowing from thin conglomeratic beds, that were separated by 25 m horizontally and 2 m stratigraphically, differed by over 1,100 mg/L TDS. Within one rock alcove on the Glen Trail seeps that originated from different bedding planes showed conductivities ranging from 2,200 to 8,800 µS. By contrast, in some areas of the park the spring chemistry is more consistent. As an example, the conductivity for springs GO-2 through GO-6 along the Gorge Trail, ranges only from 960 to 1,167 µS. Those springs all appear to be emerging from the unconformity at the base of the Sharon Formation.

Bi-monthly measurements of select springs in 1999-2000 demonstrated that there was no seasonal variation in conductivity. Spring GT-13 had less than 3% variation in

Table 5-1.—*Discharge and conductivity of springs and seeps at Gorge Metro Park (from Foos, 2003)*

Spring	Discharge mL/sec	Conductivity µS
GT-2	0.2	808
GT-3		392
GT-4	0.1	416
GT-5		820
GT-6		644
GT-7	0.4	721
GT-8	1.2	3580
GT-9	12	2765
GT-9b		3300
GT-10		4900
GT-10b		8800
GT-11	5	3700
GT-12	12	1652
GT-13	530	1573
GT-14		1681
GT-17	53	2200
GT-18	13	2200
GT-19	13	1923
GT-20	120	1889
GT-21	200	1873
GT-23	20	1820
GT-25	0.5	1974
GT-27	50	1930
GT-28	100	1859
GT-29	8	2300
MS-1	15.5	6111
MS-2		1833
MS-3		5393
MS-4a	1.4	2362
MS-4b		1446
MS-5	1000	1523
HB-1	549	677
GO1		1664
GO-2	66	1229
GO-3	311	1131
GO-4	104	960
GO-5	0.5	1145
GO-6	0.9	1040
GO-7	167	1095
GO-8	201	893
GO-9	8	608
GO-10	0.3	1615
GO-11	20	1606
GO-12		900

FIGURE 5-2.—Photograph of spring GO-8 along the Gorge Trail. Photo by A. Foos.

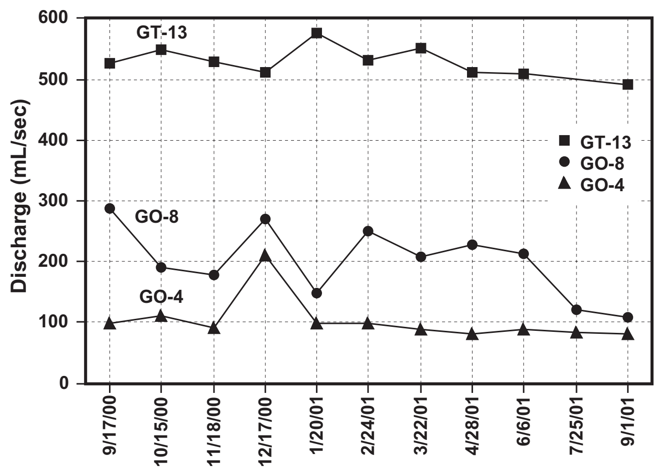


FIGURE 5-3.—Discharge of select springs at Gorge Metro Park between September 2000 and September 2001. GT-13 is the large spring along the Glen Trail. GO-4 and GO-8 are along the Gorge Trail. GO-4 represents a cumulative discharge from a number of seeps within Mary Campbell Cave

conductivity and springs GT-2 and GT-9 varied by less than 5% during 1999-2000 (fig. 5-7). Similar results were observed for the other six sites that were monitored monthly during 2000-2001. Complete chemical analyses of the monitored springs were conducted every three months. The results were similar to the conductivity results with no significant variation in the major constituents.

Stable isotopic composition was determined for three springs (GT2, GT9 and GT13; fig. 5-8). The local meteoric water line was calculated from IAEA-WMO (1996) data collected at Coshocton, Ohio, which is located approximately 100 km to the southwest. The equation for the meteoric water line in this region is $\delta^{18}O = 7.51\ \delta D + 8.81$. δD of precipitation at Coshocton, Ohio ranged from 3.6 to -125.7 ‰ and $\delta^{18}O$ ranged from 1.24 to -17.65 ‰. There is a seasonal variation in the isotopic composition of meteoric precipitation with values being lowest during the colder, winter months and highest during the warmer summer months. The weighted average δD and $\delta^{18}O$ of local meteoric precipitation are -46.56 and -7.39 ‰, respectively.

All three samples analyzed fell on the local meteoric water line. Water from spring GT-2, which flows from the unconformity, was slightly heavier than springs GT-9 and GT-13, which flow from within the Sharon Formation. This seep (GT-2) has a very low discharge, requiring one to two minutes for sampling. The heavier values could have resulted

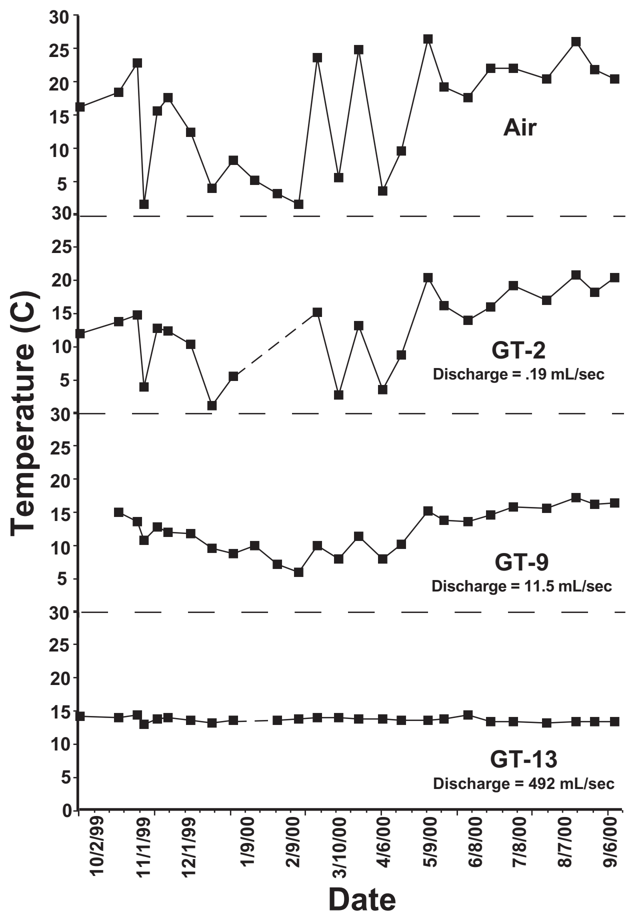


FIGURE 5-4.—Temperature of select springs and seeps along the Glen trail between October 1999 and September 2000. Note that spring GT-13 has the highest discharge and most constant temperature. Seeps GT-9 and GT-2 have lower discharge and equilibrated with the air temperature.

Table 5-2.—*Chemical analyses of select springs from Gorge Metro Park (discharge mL/sec.; conductivity µS; TDS - total dissolved solids; all other concentrations in mg/l) (modified from Foos, 2003)*

Spring	MS-3	GO-8	GT-13	HB-1
Discharge		194	522	439
Conductivity	5453	891	1580	708
pH	7.06	6.65	6.52	6.69
TDS	3368	517	924	451
HCO_3^-	206	101	105	149
Cl^-	1834	195	420	116
SO_4^{2-}	193	81	106	97
NO_3^-	4	13	18	18
PO_4^{3-}	0.1	0.1	0.2	0.3
Br^-	.35	.24	.34	.34
Ca	148	53	74	63
Mg	27	15	19	16
Na	1049	102	230	63
K	10	4	5	2
Fe	0.07	0.01	0.01	0.00
Mn	0.05	0.00	0.00	0.00
Al	0.01	0.01	0.01	0.01
Si	4	6	5	6

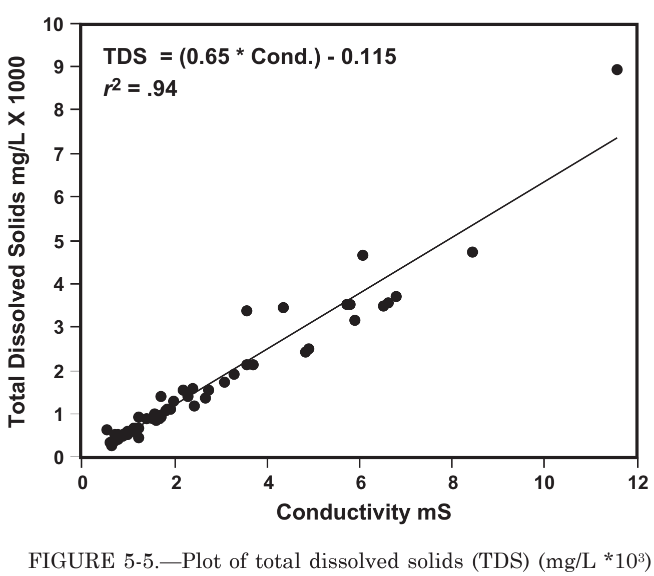


FIGURE 5-5.—Plot of total dissolved solids (TDS) (mg/L *10^3) against Conductivity (mS) for springs and seeps in Gorge Metro Park.

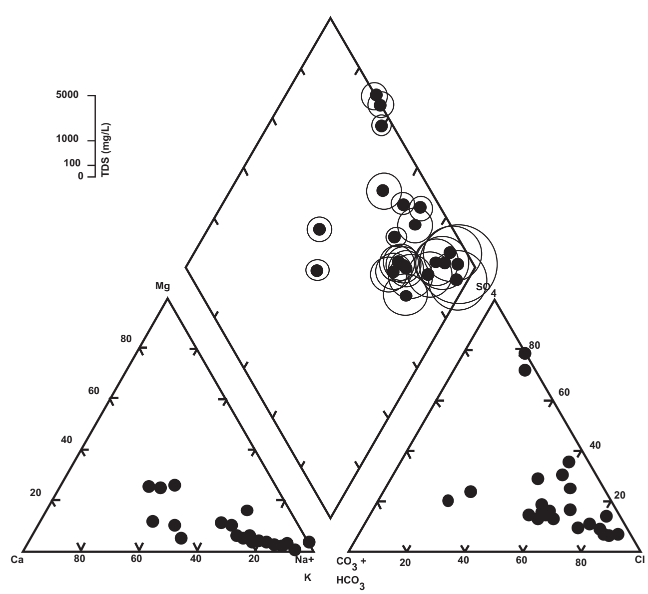


FIGURE 5-6.—Piper diagram showing the chemistry of springs and seeps in Gorge Metro Park (modified from Foos, 2003).

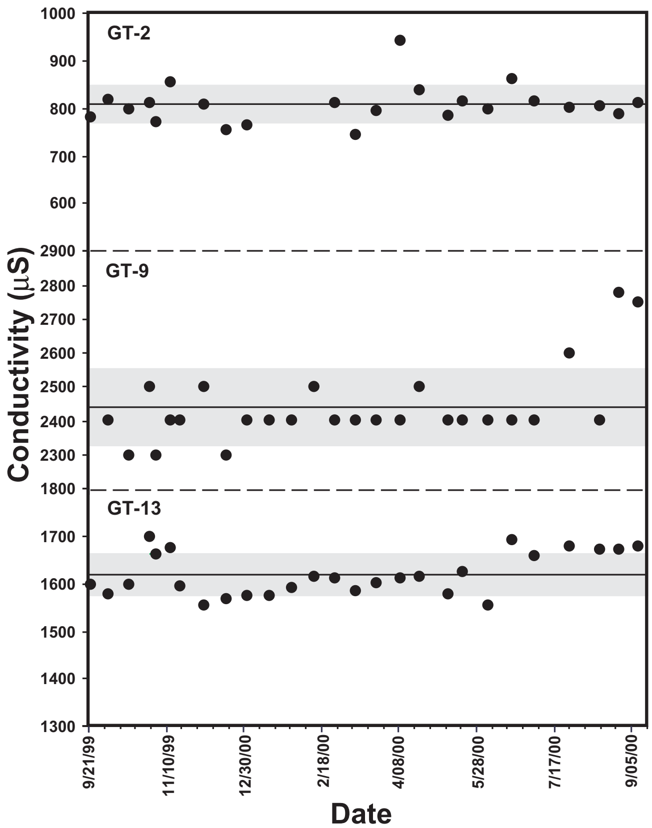


FIGURE 5-7.—Conductivity of three springs along the Glen Trail (GT-2, GT-9 and GT-13) between September 1999 and September 2000. Line represents the average and shaded area represents one standard deviation.

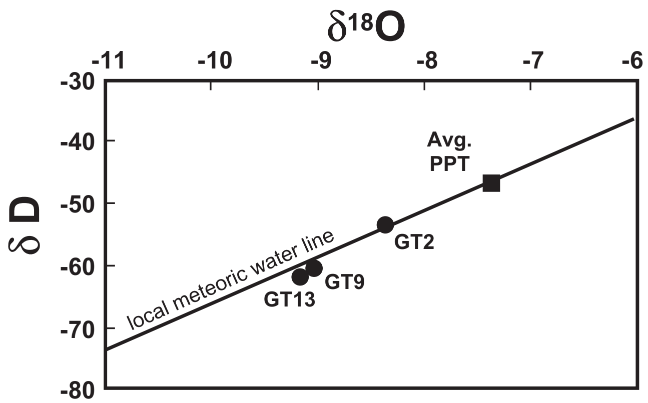


FIGURE 5-8.—Stable isotopes $\delta^{18}O$ and δD of springs from Gorge Metro Park.

from evaporation at the time of sampling. The isotopic composition of the springs is close to the average meteoric precipitation, but all three springs are lighter than the average. The isotopic composition of the springs represents a homogenization of the meteoric precipitation and the slightly lighter values indicate that more of the isotopically light, winter precipitation is recharging the aquifer.

DISCUSSION
Road Salt Contamination

Sodium and chloride are the most abundant ions in the waters at Gorge Metro Park. There is an excellent correlation between Na and Cl concentrations ($r^2 = 0.995$) and the molar Na/Cl ratio is close to one (fig. 5-9). There is also an excellent correlation between Cl and total dissolved solids ($r^2 = 0.997$; fig. 5-10)). These data indicate that the major constituent of these waters is dissolved halite.

Br/Cl ratios are useful in distinguishing the sources of salt contamination because both chlorine and bromine are conservative elements (Hitchon, 1999). For this study molar Br/Cl (*10^3) ranged from 0.04 to 3.66 with a mean of 0.63 (Table 5-3). This value is significantly lower than typical groundwater in northeast Ohio (2.44), and ground-water contaminated with locally derived, Clinton oil-field brines (1.35; Knuth 1987). Northeast Ohio groundwater, contaminated with road salt, has a Br/Cl (*10^3) ratio of 0.36 (Clabaugh 1987), which is very similar to the values obtained for the Gorge Metro Park springs. There is a decrease in the

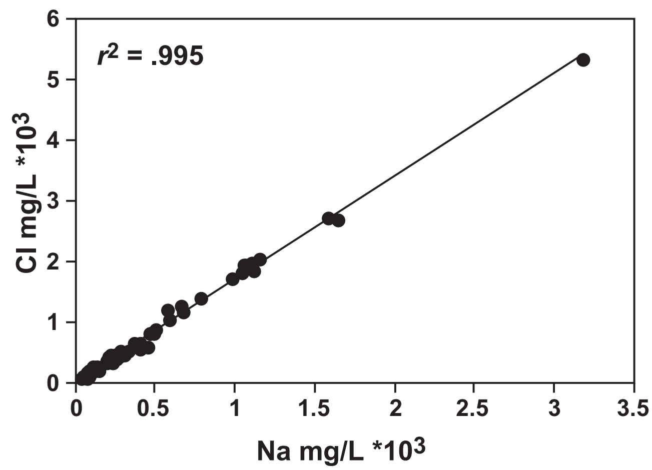


FIGURE 5-9.—Plot of Cl (mg/L *10^3) against Na (mg/L *10^3) for springs and seeps in Gorge Metro Park (modified from Foos, 2003).

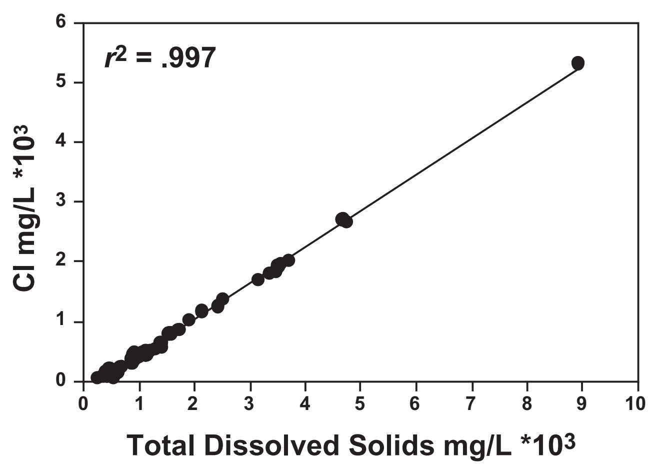


FIGURE 5-10.—Plot of Cl (mg/L *10^3) against total dissolved solids (mg/L *10^3) for springs and seeps in Gorge Metro Park (modified from Foos, 2003).

Table 5-3.—*Molar Br/Cl (*10³) of select water types and springs from Gorge Metro Park (modified from Foos, 2003) ([1]Knuth, 1987; [2]Clabaugh, 1987; [3]Hitchon and others, 1999)*

	Molar Br/Cl (*10³)
Clinton brine[1]	5.14
Road salt[1]	0.05
Sea Water[3]	1.52
NE Ohio ground water[3]	2.44
Brine contaminated ground water[2]	1.35
Road salt contaminated ground water[2]	0.36
Average Gorge Metro Park springs	0.63

Br/Cl ratio with an increase in Cl concentration (fig. 5-11). Uncontaminated springs with a Cl concentration less than 100 mg/L have an average molar Br/Cl (*10³) of 2.06, only slightly lower than typical ground water in Ohio. Whereas, road salt contaminated spring waters with greater than 250 mg/L Cl have an average molar Br/Cl (*10³) ratio of 0.28.

Snow removal and salting of all roads in the study area is the responsibility of the City of Cuyahoga Falls. The city classifies its roads into three categories for the purpose of prioritizing snow removal activity as main roads, secondary roads, and side streets. Front Street and Ohio Rte. 8 are classified as main roads and the remaining streets in the study area are classified as side streets. It is estimated that the main roads receive two to three times more salt than the side streets (J. Finan, Acting Street Commissioner, City of Cuyahoga Falls, personal commun., 2002). Although Ohio Rte. 8 has the same classification as Front Street, Finan estimated that it receives 50% more salt than the other main roads. Springs on the southwest side of the gorge are close to Ohio Rte. 8. A small residential area with side streets backs up against the gorge for the first half of the Glen trail and the second half of the Glen trail runs parallel to a major city street. Residential areas with side streets occur outside the park boundary near the Gorge and High Bridge Trail sites.

Conductivity was used to evaluate the magnitude of road salt contamination (table 5-4). The average conductivity of sites located closest to Ohio Rte. 8 was the highest, but

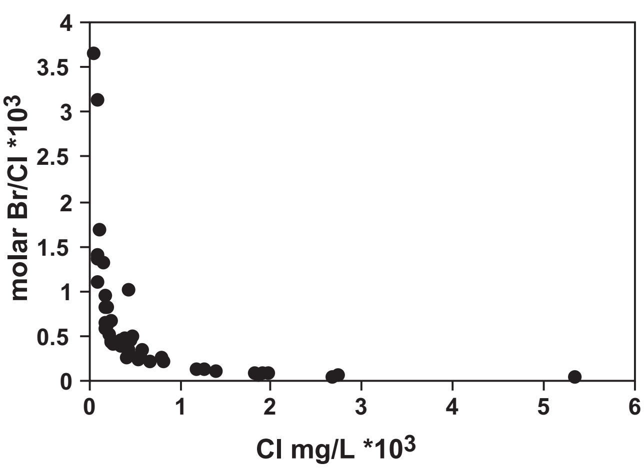


FIGURE 5-11.—Plot of molar Br/Cl (*10³) against Cl (mg/L *10³) for springs and seeps in Gorge Metro Park (modified from Foos, 2003).

Table 5-4.—*Conductivity statistics for springs and seeps associated with different road types (from Foos, 2003) (N-number of springs; STD-standard deviation)*

		Conductivity (μS)		
Road	Classification	*N*	Average	STD
Ohio Rte. 8	Main road	6	3036	1543
Front Street	Main road	14	2949	1795
	Side street	17	1105	504

they were not statistically different than sites located along Front Street. The average conductivity of springs and seeps located closest to major roads (2975 μS) was almost three times higher than the conductivity of sites located closest to side streets (1105 μS). These data indicate that the magnitude of road salt contamination can be directly related to the amount of road salt applied.

The road salt contamination is also highly localized. The average conductivity of residential sites along the Glen Trail (735 μS) is significantly lower than the Glen Trail sites closest to Front Street (2949 μS). The residential sites along the Glen Trail are located between 70 and 135 meters from Front Street, whereas the sites with the high conductivity are between 12 and 45 meters from Front Street. Evidently, the area most affected by road salt contamination is less than 70 meters from the source.

Hydrology of the Sharon Aquifer

The low temporal variability in discharge and chemical composition indicates this is a steady state flow system, characterized by diffuse recharge. It has been documented in karst systems that the coefficient of variability of conductivity and hardness is a function of the type of recharge to the aquifer (Worthington and others, 1992). Autogenic, percolation, recharge is characterized by low chemical variability and allogenic, sinking stream recharge, is characterized by high variability.

Recharge is greatest during the late winter/early spring when evapotranspiration is minimized. The water slowly percolates through the glacial till, where it is temporarily stored. Water movement through the tills is enhanced by the presence of fractures. The till acts as a buffer that regulates recharge to the Sharon. Butz (1973) calculated the storage capacity of a 3 m thickness of till above a knob of Sharon Sandstone in Geauga County and found the till was capable of storing approximately one third of the yearly discharge from the knob.

The road salt can be viewed as an "ambient" tracer, giving us clues as to the movement of fluids through the Sharon aquifer. The high spatial variability in chemical composition indicates that the springs and seeps are hydrologically isolated from each other. Flow within the Sharon Formation is channelized, and characterized by multiple high permeability pathways along bedding planes, fractures and joint networks. Sodium-chloride-rich waters are introduced into the system when water percolates through the tills immediately adjacent to the highways. When this water reaches the Sharon aquifer, it is distributed into a network of channels. Each channel has a unique hydraulic conductivity and degree of connectivity with the system as a whole. The regional ground water within the system mixes with the sodium-chloride-rich waters. The chemical composition is determined by the amount of dilution of the sodium-chloride-rich waters, which is a function of the hydraulic conductivity and degree of connectivity of the channels.

ACKNOWLEDGEMENTS

The University of Akron geochemistry classes (Fall 1999 and 2000) collected some of the data for this study. Metro Parks Serving Summit County provided financial support. Karla Elyard assisted with the field monitoring of the springs. In addition, I wish to thank Ira Sasowsky for reviewing an earlier draft of the manuscript.

REFERENCES CITED

Butz, T. R., 1973, The hydrogeology of a sandstone knob overlain by glacial till in Geauga County, Ohio: M.S. thesis (unpub.), Kent State University, 63 p.

Clabaugh, C. D. ,1987, Statistical identification of salinity sources in a sallow water-table aquifer: M.S. thesis (unpub.), University of Akron.

Foos, A., 2003, Spatial Distribution of Road Salt Contamination of Natural Springs and Seeps, Cuyahoga Falls, Ohio, USA. Environmental Geology, v. 44, p. 14-19.

Greenberg, A. E., Clescrel, L. S., and Eaton, A. D., 1992, Standard methods for the examination of water and wastewater. American Public Health Association, Washington DC.

Hitchon B., Perkins, E. H., and Gunter, W. D.,1999, Introduction to ground water geochemistry. Sherwood Park, Alberta Canada, Geoscience Publ. Ltd.

IAEA-WMO, 1996, IAEA-WMO Program on isotopic composition of precipitation: Global network for isotopes in precipitation (GNIP), Station 7252101, Coshocton, Ohio. <ftp://ftp.iaea.org/dist/gnip/uncompresse..._station/region7/Coshocton%2C%20ohio.asc> (5/23/00).

Knuth, M. C., 1987, Determination of the source of salt contamination in a private water well in Hudson, Ohio: M.S. thesis (unpub.), University of Akron.

Shuster, E. T., and White, W. B., 1971, Seasonal fluctuations in chemistry of limestone springs: a possible means for characterizing carbonate aquifers. Journal of Hydrology, v. 14, p. 93-128.

Skougstad, M. W., Fishman, M. J., Friedman, L.C., Erdmann, D. E, and Duncan, S. C., 1979, Methods for determination of inorganic substances in water and fluvial sediments. TWRI, Book 5, Chapter A1, U.S. Geological Survey, Washington DC.

White, G. W., 1984, Glacial geology of Summit County, Ohio. Ohio Division of Geological Survey, Report of Investigation 123.

Worthington, S. R. H., Davies, G. J., and Quinlan, J. F., 1992, Geochemistry of springs in temperate carbonate aquifers: recharge type explains most of the variation, *in* Chauve, P., and Zwahlen, F., eds., Annales scientifique, Memoire hs no 11(Actes du 5º Colloque Hydrologie en Pays Calcaire), Universitie Besancon: Geologie 2, p. 341-348.

CHAPTER 6, SOME NOTES AND HYPOTHESES CONCERNING IRON AND IRON REMOBILIZATION FEATURES IN THE SHARON FORMATION (SUMMIT COUNTY, OHIO)

by Neil A. Wells, David A. Waugh and Annabelle M. Foos

Such deposits [Harrison ore] *are apparently the remains of deposits of Maxwell limestone that were broken up by terrestrial and littoral forces, strewn over the eroded Mississippian plain by waves and currents, then covered by Pottsville sediments, and later cemented by iron compounds deposited from ground waters circulating along this contact zone.*

Stout (1927, p. 68)

ABSTRACT

The base of the Sharon Formation very locally contains extensive pyrite cement that is partly replacive of pre-existing quartz grains and epitaxial overgrowths. Destruction of previously more widespread pyrite cement may account for the abundant iron banding ("Liesegang banding") and Fe oxide-hydroxide (goethite, hematite, and amorphous phases) impregnations and coatings. However, the application of the term Liesegang banding seems inappropriate, because these bands do not constitute a series of parallel bands that relate to a single diffusion gradient. Instead, they demonstrate complex development over time, apparently involving fluctuating and migrating chemical interfaces, with dramatic Eh and pH boundaries and episodically reoriented gradients, presumably under complex and evolving hydraulic conditions. We are not yet able to offer a definitive scenario for iron remobilization, but can document evidence for a complex developmental history.

INTRODUCTION

This paper describes some of our observations of the distribution of iron minerals within the Sharon Formation at Gorge Metro Park, Cuyahoga Falls, Ohio (see Description of Field Stops, Day 1, Stops 1 and 2, this volume, for site locations). We are not presenting a single model for the migration of iron within the sandstone, but rather a series of working hypotheses meant to stimulate discussion of this topic. Like the Berea Sandstone down-section, this formation shows a considerable amount of iron dissolution and reprecipitation, which can be present as iron-coated surfaces, goethite-coated pebbles and vugs, honeycomb weathering, and, most picturesquely, as multiple sub-parallel color bands, which are commonly called Liesegang banding. The color banding is locally well enough developed to rise to the level of "scenic" or "picture" sandstone.

Previous authors have identified the Sharon as a mineralogically supermature orthoquartzite, consisting of > 96% SiO_2 with minor amounts of feldspar and limonite (Fuller, 1955). Fuller (1955) and Meckel (1967) both report quartz overgrowths, which they use to argue that the Sharon quartz pebbles and grains have experienced one or more cycles of reworking. Meckel (1967) reports that the Sharon contains > 95% quartz, mostly monocrystalline rather than polycrystalline, and further supports maturity by noting the nearly sole presence of zircon and tourmaline, which are very resistant, among the heavy minerals. Fuller (1950, 1955) also noted the presence of some fragmentary, reworked, and in some cases silicified fossils (Plate 12-I), including rugose and tabulate corals, plus bits of trilobites, brachiopods, and gastropods. He noted that the six corals, one brachiopod, and one gastropod that could be identified all pointed to a Middle Devonian age, thereby demonstrating erosion of sedimentary rocks of that age.

OBSERVATIONS

The base of the Sharon Conglomerate along the Glen Trail contains some conglomerate and sandstone that is massively cemented with pyrite, totaling around 10-20% of the rock mass. The mineral is silvery and massive, and thus strongly resembles marcasite. X-ray diffraction analysis indicates the sample contains quartz, pyrite, marcasite and minor amounts of kaolinite (fig. 6-1).

Thin section and polished slab analysis of the pyritic beds shows a series of interesting features (Plate 12). First, the pyrite is present as intergranular cement, with a slightly patchy distribution. Some of the quartz grains show well developed, partly euhedral, epitaxial overgrowths. Although the pyrite mostly fills pores, it has also slightly replaced the edges of the quartz grains. The pyrite seems to have precipitated after the quartz overgrowths. The rock also has what was assumed in the field to be a goethite weathering rind, although the presence of relict pyrite within the goethite suggests that it was formed much earlier, during pyritization. The pyrite is only very locally preserved at the base of the formation, but may have been more widespread.

XRD analysis was performed on a piece of coarse sandstone with heavy induration of black iron minerals (the lower sample in Plate 13A, from the "upper conglomerate" layer along Glen Trail). This resembled an extremely indurated and dark "Liesegang" band. The results showed the presence of quartz and goethite, possibly with a small amount of hematite, but no other identifiable iron minerals (fig. 6-1).

Thin-section and polished-slab analysis of the same rock shows significant quantities of iron cement (plate 13). The goethite is mostly dark and massive, but can show thin but well developed botryoidal rims. Hematite varies from thin stains to patches of cement that have been partly to wholly altered to hematite. As this rock contains a couple of patches of pyrite in the middle of otherwise goethite-filled pores, it is possible that the iron cement began as pyrite. The quartz has suffered significant dissolution and destruction, apparently even greater than in the basal pyrite, to the extent that in some areas the grains are no longer touching and their original outlines are scarcely if at all recognizable. This sample has fewer quartz overgrowths, that could simply be a result of the greater destruction of the exteriors of the grains in this bed.

A polished slab cut through one of the smaller goethite vugs (plate 8-A, B) showed much more complexity than expected. The grains surrounding the vug contained small patches of pore-filling goethite cement. The vug itself had a goethite lining almost 1 cm thick, which in turn showed a complex cement stratigraphy. The outermost cement, developed locally on the sides and the roof, and in fragments that had fallen to the floor of the vug, contained quartz silt and some hematite in what otherwise seemed to be parallel, fibrous, goethite crystals. The crystals are full of fluid inclusions, voids, or tiny new hematite crystals, because they scatter light so much that they appear pinkish white

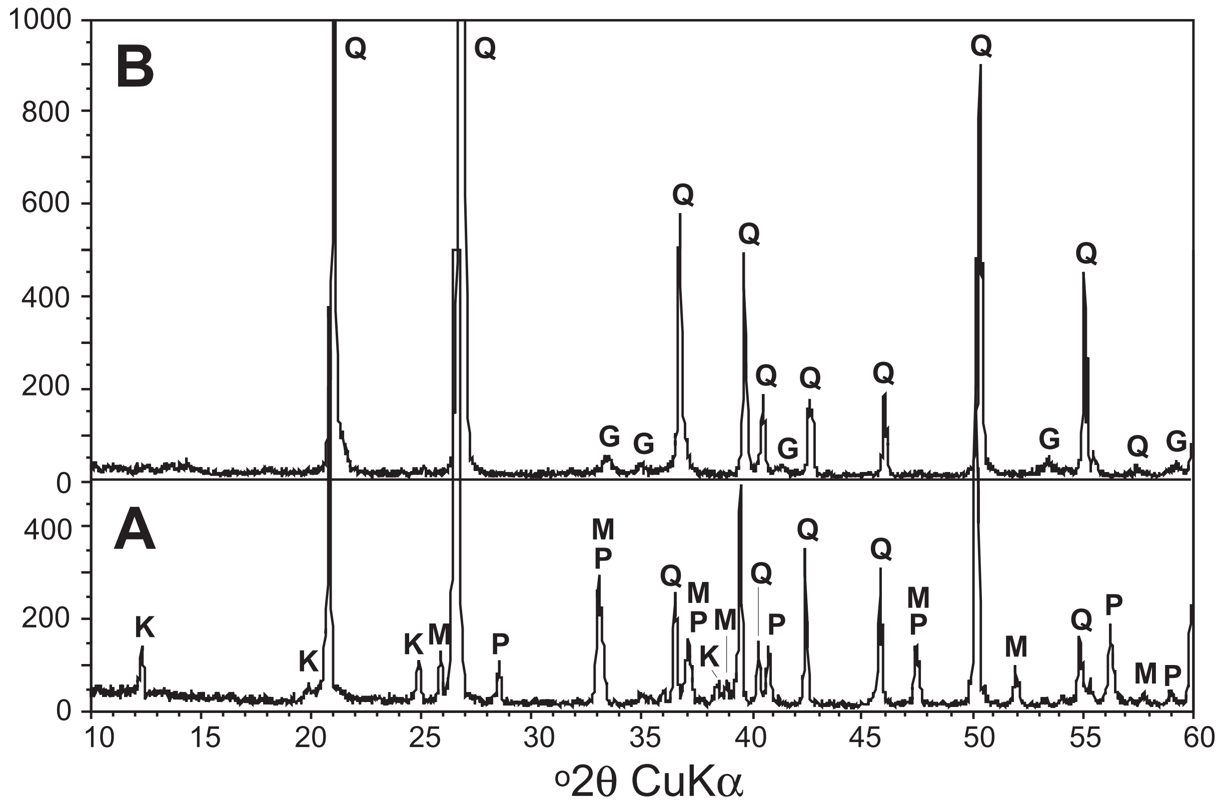


FIGURE 6-1.—X-ray diffraction spectra of iron rich samples from the Sharon Formation. A) The pyrite-rich bed at the base of the Sharon at Stop 1.3, Glen Trail. B) A goethite-impregnated band from next to the "upper conglomerate." (Q-quartz, P-pyrite, M-marcasite, G-goethite, K-kaolinite.)

under reflected light, and they will not take a polish. They have a mixed red and yellow streak. Next, followed three alternations of (a) thin, slightly reddened, radial acicular, botryoidal goethite, and (b) thicker layers of coarser, black, radial goethite crystals that were also capable of scattering a considerable quantity of light. It remains to be seen whether the cement stratigraphy can be followed from vug to vug.

The distribution of features that are related to iron remobilization is complex. The coarse pebble zones of the Sharon are associated with the most goethite, as linings in vugs (plate 8-A, D), as coatings around some of the quartz pebbles, and around possible clay pebbles, and as layers and impregnations. Sulfur efflorescence is restricted to the ceilings and rear walls of overhangs at the base of the formation, but would not survive for long elsewhere. Iron coatings occur along some joint faces, but not all. Both joints and coatings can extend from the bottom to the top of the cliffs. In some places, coatings are especially well developed along joint faces that are parallel to the gorge and/or which are relatively close to it. In contrast, they are only locally developed, if at all, on joint faces that are deeper into the rock mass. However, exceptions abound, so the story is not that simple. Some of the joints that intersect the modern gorge at a high angle have lots of ferruginous precipitate, but others that are nearby and parallel do not, implying that some of these joints opened later than others, after the phase of iron precipitation.

Liesegang-like iron banding can be present at any level within the Sharon, although it seems more abundant and intense toward the base. Close inspection shows that all of the banding occurs in successive sets in crosscutting relationships, much like architectural analysis of cross-cutting sets of trough cross-beds (plate 9). The banding in these outcrops almost unfailingly shows distinct crosscutting age relationships, even if the banding occurs in such complex swirls or splotches that it becomes quite difficult to determine the overall direction of younging. Very few of the bands are straight, as most consist of convex outward sections, creating out-pocketings that bulge outward from the younger direction to the older direction. Typically but not always, the front-most band in each set is the most strongly developed, being the thickest and the darkest. Subsequent bands show a less reliable but overall trend to becoming thinner and fainter. Most of the strongest bands are asymmetrical, with a sharp boundary against a leached rock mass on the older side and a gradational fading away on the younger side. With a few exceptions, when one set of bands crosscuts another, the original continuation of the older set is entirely destroyed behind the newer boundary. In other words, emplacement of the new set nearly always involves the complete obliteration of the earlier set behind the front, rather than an overprinting or preservation of the original bands as faint ghosts.

Just as cross-bedding can be viewed as occurring in a hierarchy of laminae (individual foresets), sets (bedforms), and cosets (individual compound bedforms or bars), and so on, so too these iron bands occur in hierarchies of individual bands, sets of bands (conformable series), compound sets, and disjunct groups. Compound sets are sets with modest disjunctions between them, indicative of a slight reorientation of chemical gradients rather than a complete reinstallation at an entirely different orientation. Disjunct groups are more severely disconformable sets. On the whole, banding in most Sharon beds shows either a single set or a fairly simple compound set. Some of the banding follows permeable zones along beds and cross-beds, but much cuts across those zones. Some banding is clearly controlled or influenced by bedding planes and fractures—for example, plate 9-B (Stop 1.1) shows two generations of iron banding in a triangular prism of sandstone that is bounded by two vertical fractures and a bedding plane. The earlier set parallels the bedding plane and one joint, whereas the second set parallels the other crack. Evidently, the second crack was not open when the iron banding began forming.

The most extreme remobilization of iron occurs locally near the base of the formation, in the lowest beds or just above them if they are unusually impermeable. These beds become riddled with thick iron bands and, where not indurated, typically become yellow and friable. In the case of concentric bands, old-to-young age progressions are seen both into the centers and out of them, although the latter are thought to be predominant. Otherwise, the lower beds in the formation typically show subhorizontal banding. Those bands typically become younger upward, toward the upper conglomerate. This is clearly the case nearly all the way along the Glen Trail, except where complex swirls are developed. In several places, bands above the conglomerate or above a coarse-grained bed become older upward, whereas bands underneath become younger upward, so the bands indicate an age recession toward the bed from both sides.

DISCUSSION

At present we can propose only very tentative hypotheses for the pyrite and iron banding. Pyrite clearly requires reducing conditions and a source of sulfur. Probably after deposition, the Sharon became buried under a thick clastic wedge that alternated between vast coal swamps and broad marine inundations. We suggest that the Sharon was an aquifer that principally carried coastal ground water down and out into the deeper basin under a modest hydraulic head that was developed in the proximal parts of the clastic wedge. During transgressions, the ground-water system became saline, with lots of sulfate. During progradation, the aquifer was invaded by highly reduced ground water from the coal swamps, thereby reducing the sulfate and precipitating iron sulfide.

Silica overgrowths preceded pyritization, and pyritization was accompanied by modest dissolution of quartz (especially of the overgrowths, as they are on the surfaces of the grains). It is possible that the invasion of reducing and ferrous water from coal swamps caused pyritization to progress downward from the shallower and up-flow regions of the aquifer. If the advance of the pyritization front generated the silica that caused the overgrowths, then one could speak of a silicification front that preceded a pyritization front.

The next events seem to involve oxidation of iron. Therefore, subsequent to the precipitation of pyrite, chemical and hydrological conditions may have been at or near equilibrium under moderately deep burial conditions and changed very little for a long time. This would have ended when uplift and erosion raised the Sharon back up toward the surface and opened fractures and bedding planes, thereby bringing it into the influence of oxidizing meteoric water.

The iron bands (the "Liesegang bands" and the joint coatings) seem likely to involve precipitation at a chemical interface between conditions that favor iron in solution versus conditions favoring its precipitation. This is likely to be a redox front, as Fe^{2+} is soluble whereas Fe^{3+} is quickly precipitated. However, it could also be a pH front, as increasing acidity favors dissolution of Fe^{3+} at increasingly positive Eh values (the boundary is at Eh = 0 at pH = 7, but rises to Eh = ca. 0.67 at about pH = 4.5). Solubility of iron is also favored by complexing with various organic chemicals (multifunctional carboxylic acids, aliphatic acids, phenolic acids, polyphenols, and others: Duchafour, 1977), so the degradation of organometal complexes might be involved, although that too could well simplify to simple redox and pH changes.

A source of iron is not a limiting factor in the formation of the iron banding. Ground water within the Sharon contains an average of 1.58 mg/L Fe, and has been observed to be as high as 34 mg/L. A back-of-the-envelope calculation indicates that at the current flow of springs and seeps at the gorge, sufficient amounts of iron to produce the banding and line the vugs could be supplied in a matter of days. It is the mobilization and precipitation of iron that controls its distribution and these processes are governed by redox and pH changes.

These bands appear to show an evolution of chemical and hydraulic conditions during the progressive drainage of the Sharon aquifer in the vicinity of modern exposures, from totally saturated to its present nearly dry state. For example, the diverse and variable interaction between joints and iron remobilization may well be because joints and fractures evolved during exhumation of the formation. Although some clear exceptions exist, we presume that for the most part the irregular, least planar, least vertical, and wedge-failure related fractures that do not cut through the entire Sharon were among the last to be formed. It seems logical that top-to-bottom joint coatings should represent a stage when the bulk of the aquifer was still saturated and when reduced iron was moving throughout, but when oxidation was possible in the joints. Thus, as soon as the joints could drain fairly quickly, iron precipitation was probably limited to the joint faces, as reducing ferruginous moisture seeped out of the interior of the rock or trickled over joint surfaces. As landscape relief and incision developed, some old joints opened widely as blocks slid out of the hillsides, and some new fractures were created (especially as valley stress-release joints and wedge failures). This would favor speedier drainage of the formation, and speedier ingress by oxidizing meteoric water. The frontmost blocks became dry as water drained around them rather than percolating through them, and leaching and reprecipitation would have shifted to other fractures.

Prior to that, there was probably a stage when the Sharon still had a large reserve of pyrite and reduced water, but when fresh oxidizing meteoric waters first started to episodically invade via the earliest joints and bedding planes. The inevitable shifting back and forth of reducing and oxidizing fronts within the fractures and surrounding rock masses might have promoted the faint, large-scale, swirling iron banding seen in the upper parts of the Sharon.

General principles would seem to suggest that as rainwater continues to invade more quickly and more pervasively along ever-increasing fractures, the redox front would be pushed farther back into the rock mass. It might re-expand during more stagnant times, but it would continue to fall back during successive flooding. This way, iron bands could progressively advance into the formation, become progressively better established as oxic conditions become more widespread and more permanent. Once a sufficient number of joints and bedding planes opened up, the aquifer should have drained (at least locally). We could then have had a situation where rainwaters flood in, move to the bottom of the formation, and puddle on whatever pyrite remains. That would make a late phase of flat-lying redox bands, which would probably gradually recede to the base of the formation, given that drainage should continue to improve.

Unfortunately for such a nice story, details seem to mandate almost the opposite scenario. Plate 10-A shows a recessional series of bands, retreating to a coarse and permeable unit from above and below. Evidently the redox front expands from the permeable bed, reaches some maximum extent and remains there long enough to precipitate an iron line, and then recedes or evolves, only to become reestablished later at a position less distant from the permeable bed. The problem is that the fluid that is expanding from the permeable bed would seem to be the reducing and/or anoxic fluid. If it were otherwise, the oldest iron band would end up soaking in the reducing/acidic water, and thus become dissolved, when the front shifted to make the next younger precipitation line. Specifically, in plate 9-D, the topmost set of bands is the youngest, so the other bands should have been largely wiped out (or are least turned into ghosts and mottles) if the reducing fluid had been on the lower side.

The source of the reducing water could be explained as follows: between rains, water stagnates at the base of the formation, in contact with pyritic beds, thereby becoming anoxic, acidic, and sulfurous. The first rush of rainwater into the formation might enter fractures, migrate downward, and flush the now-slightly-diluted acidic and reducing water at the base into superjacent fractures and permeable zones.

The recessional nature of the banding may seem to require an unrealistic diminishing progression of storms or wet periods, but, if precipitation is caused by the arrival of reducing acidic water and if banding is preserved, it has to be recessional. Precipitation lines presumably develop when a reducing front advances, precipitates some goethite, and then the water drains, dries, or oxidizes; subsequently, a new reflooding with reducing water expands in almost the same fashion, and creates a nearly coincident line. If the reflooding was larger, the older line is wiped out, but if it is smaller, the new line is deposited closer to the supply zone than the previous line. This is comparable to the way that back-beach deposits necessarily show a succession of decreasing storm deposits, decreasing from greatest at the back of the beach. Similarly, offshore bars necessarily show a succession that decreases shoreward from the largest storm in the deepest water farthest offshore. In addition, given that fractures are continually opening up during exhumation, it is likely that the joints will become better drained, so the soakings in any one place should become less extensive and shorter lived over time, thereby contributing to an overall decreasing trend in the thickness and extent of the bends. Given that the largest invasion of reducing waters should destroy any preexisting bands in the same rock volume, that front should scavenge all the previously precipitated iron and move it forward, thereby explaining why the frontmost line should also be the thickest and best developed.

A host of complications and uncertainties remain, especially concerning the subhorizontal, near-basal, upward younging bands. It is unclear whether each band represents a single storm or a long-term regime. The direction of fluid migration relative to the orientation of the bands is also unclear (i.e., whether any given precipitation line should be analogized with a terminal moraine or a lateral moraine). The bands might well represent reaction fronts where O_2 migrating one way meets Fe^{2+} diffusing the other way, but how can we avoid getting completely leached beds or completely reddened rock masses as the reducing water either drains down through the formation, or gradually becomes oxidized? Can the reducing front be overtaken by a second oxidizing front, as fresh water following the "first flush" mixes along permeable zones without going down through to the base of the formation and encountering pyrite, or can the reducing water quickly drain away after backing up during a flood? Could the rest of the formation be dry, so that the precipitation lines are more like evaporation fronts? That way, when the "first flush" loses its hydraulic head, the water might become stagnant, held in place by capillary draw. This could make the bands like many thin iron pans on top of reducing water tables in soils, albeit in many cases upside-down. Minor subsequent oxidation might then progress into the reducing water, accounting for the grading out of iron bands on their reducing sides.

The formation of the iron bands would seem to cause additional inevitable and intrinsic changes in the hydrology of the aquifer. They would seem likely to channelize flow, making it more constrained and less diffuse. This would potentially push reducing fluids farther along the aquifer, and could also concentrate the dissolution of quartz, which would in turn further concentrate flow. Such a process might explain how the upper conglomerate, which would initially have been a zone of preferential permeability, can become a zone of concentrated vug development, and how we can get progressively increasing iron precipitation nearer to it, culminating in thick goethite vug linings. Subsequently, the aquifer has drained below that level, so it has become almost totally inactive. The "rotten yellow sandstone" layer has also been largely but not totally abandoned (e.g., the dry spring at the SW end of Stop 1.9). Thus water collection and movement now principally occur at (or very locally below) the base of the formation or locally within or on top of its basal bed.

The formation of vugs (and also the friability and lack of cementation in some parts of the Sharon) might be explained by calling on extensive cementation, nodule growth, and replacement involving pyrite. The "rotten yellow sandstones" and some of the "upper conglomerate" vugs would be particularly good candidates for having been pyritized zones and patches of pyritic cement. Pyritization could have caused partial destruction of the original quartz sandstone, as seen elsewhere, and then the introduction of oxygen could permit considerable loss of volume by dissolution of the pyrite and removal of the iron and sulfur in solution. This might in turn permit the decemented region to collapse into silt that could easily be flushed out of the rock face. However, no hard evidence as yet supports this hypothesis.

Lastly, there is a problem with using the term "Liesegang banding". As described by Raphael Liesegang in 1896 and later (Liesegang, 1945), this happens when two coprecipitates diffuse towards each other through a gel, resulting in a decreasing series of parallel bands. However, the iron bands aren't parallel, but occur in disjunct sets, with an evidently complex history of reorientations of chemical gradients. We could easily call for the episodic reestablishment of different gradients under different hydraulic heads at later times; but the complex history of development and the active transport of fluids and components (i.e., advective flow rather than passive diffusion) contradict the one-gradient, simple-history sense implied by Liesegang banding.

We note that the Berea demonstrates a comparable history, with lots of surficial iron oxide reprecipitation, basal sulfurous seeps, and relict patches of replacive pyritic cement, mostly at the base of the formation, especially where protected by partial or total encasement in tight clays.

CONCLUSION

Although our understanding of iron remobilization in the Sharon is very preliminary, the iron clearly seems to reflect a complex evolution of the chemistry and hydrology of the formation, consistent with frequent reorientation and reorganization of flow paths, combined with the overall progressive drainage of the aquifer.

REFERENCES CITED

Duchafour, P., (trans. T. R. Paton), 1982, Pedology: London, George Allen & Unwin, 448 p.

Fuller, J. O., 1950, Northern Middle Devonian sedimentary source for the Sharon Conglomerate of northeastern Ohio: Geological Society of America Bulletin, v. 61, p. 1463-1464.

__________ 1955, Source of Sharon Conglomerate of northeastern Ohio: Geological Society of America Bulletin, v. 66, p. 159-176.

Liesegang, R. E., 1945, Geologische Baenderungen durch Diffusion und Kapillaritaet: Chemie der Erde, v. 15, no. 4, p. 420-423.

Meckel, L. D., 1967, Origin of Pottsville conglomerates (Pennsylvanian) in the central Appalachians: Geology Society of America Bulletin, v. 78, p. 223-258.

Stout, W. S., 1927, Geology of Vinton County: Ohio Division of Geological Survey, Fourth Series, Bulletin 31, 402 p.

CHAPTER 7, HISTORICAL SIGNIFICANCE OF THE SHARON FORMATION IN NORTHEAST OHIO.

by Joseph T. Hannibal and Annabelle M. Foos

The advantages resulting from the local history of cities and countries is no longer a matter of doubt.

Perrin (1881, p. 181)

INTRODUCTION

From the days of the first settlers to the present, the presence of the Sharon Formation has contributed to the economic development and quality of life in Northeast Ohio. New cities and towns were located where streams cut through resistant layers of the Sharon Formation, forming waterfalls and rapids needed for the generation of hydropower. The Sharon was an important building stone in the 1800's and continues to be quarried today for crushed stone and silica sand. Past and present-day parks and recreation areas centered around ledges of Sharon Formation have contributed to the quality of life in Northeast Ohio.

WATER POWER AND THE WESTERN RESERVE

There is probably no point in Ohio which offers more desirable manufacturing advantages.

Butterfield (1881, p. 466)

The Connecticut Western Reserve consists of the northeastern part of Ohio, so named because it was reserved from the western lands that Connecticut was ceding. Most early Euro-American settlements in the Connecticut Western Reserve were located along lakes and streams. Streams provided the most important means of inland transport as well as a source of power at the end of the eighteenth and first decades of the nineteenth centuries. The settlers moving into the Western Reserve were from New England (mainly Connecticut and Massachusetts), whose manufacturing centers were dependent upon waterpower (Doyle, 1908). The importance of water-powered mills was such that early historical sources invariably note the number and type of mills. Waterpower remained important for industrial uses until the widespread adoption of steam power during the second half of the nineteenth century.

Falls, cataracts, and rapids formed when streams cut through resistant layers of the Sharon Formation. These features impeded water transport, but provided potential power for mills. Perennial streams flowing over thick units of the Sharon were especially attractive: In such places, individual ledges of resistant rock within the unit would form individual falls. Thus a number of millwheels or turbines could be set up to exploit the potential power of the individual small falls in a series, and dams could be added to augment natural falls.

The Anglo-American settlers who came to the Western Reserve at the very end of the eighteenth century and during the first decades of the nineteenth century took special note of places with falls. Settlements tended to surround these locations. The Cuyahoga River, by virtue of its curved path, crossed a large outcrop area of the Sharon Formation. Settlers were attracted to places, such as Middlebury, a pre-canal town that was later to be part of Akron, by the potential waterpower of the Cuyahoga River (Doyle, 1908). Kent and Munroe Falls are other towns that grew up along falls of the Cuyahoga.

But it was the town of Cuyahoga Falls that was most closely associated with waterpower in northeastern Ohio. Here outcrops of the Sharon at the Great Falls of the Cuyahoga provided a number of sequential falls. The potential to harness the energy of these falls of the Cuyahoga was immediately recognized by the early settlers.

A series of canals built in the nineteenth century alleviated the impediments to transportation posed by the falls and rapids. And the canal waters were used for industrial purposes as well as transport.

At Cuyahoga Falls the falls extend for about two miles where the Cuyahoga River descends 220 feet. There were three main falls separated by rapids, yielding a continuous source of power. The sandstone cliffs that bordered the falls provided a stable foundation high above the river and a source of building stone. S. P. Hildreth (1837 p. 45), a Massachusetts native, noted, "The situation [at the Falls of the Cuyahoga] is one of the finest I have seen for a manufacturing town, and is destined, at no distant day, to become to the West what Lowell [Massachusetts] is to the East." Indeed, waterpower propelled the startlingly quick growth of Cuyahoga Falls. The town was originally called Manchester, but that name was too-often used, and the town was renamed for the falls of the Cuyahoga, which passed through the town. The site is said to have been called "Coppacaw" (translated as "Shedding tears") by the Native Americans (Howe, 1847).

The first dam, built in 1812 by Kelsey and Wilcox, was located in the upper reaches of the falls and powered a gristmill and sawmill. Stow and Wetmore constructed a second dam that flooded the earlier dam, in 1825. At the same time (1825), Henry Newberry was building a dam in the lower part of the village for a sawmill and an oil mill (Butterfield, 1881). Hildreth (1837) noted that the low stage discharge of the Cuyahoga at the falls was 4000 cubic ft per minute. In 1836 machinery propelled by water power included: "two large paper mills, one flouring mill, two saw-mills, one oil-mill, one pump-making establishment, one tilt-hammer, ax and scythe factory, woolen-mill, a stone saw-mill, one chair factory, one planing-mill, one furnace and foundry, one engine and machine shop, and other smaller works" (Butterfield, 1881, p. 474). By 1881, five dams crossed the Cuyahoga within the limits of the village and within a distance of about a quarter of a mile (Butterfield, 1881).

The Pennsylvania & Ohio Canal was constructed through Cuyahoga Falls during the second half of the 1830's. The entire length of the canal was completed in 1840. At first the canal was welcomed as it promised to, and indeed did, further stimulate the economy but later became problematical for manufacturers along the river because the need to keep it watered during dry times diminished the water power for other uses (Fairchild, 1876). The Pennsylvania & Ohio Canal was also a stimulus for the development of coal mines at nearby Coal Hill (Whittlesey, 1842).

In the early 1840's there was a plan to divert the water and use it to power a new "Summit City" that was destined to be one of the largest manufacturing cities in the world. The Portage Canal & Manufacturing Company's three-year project of building a dam and race to carry water to their new city was completed in 1844. (Presumably because of the large number of woodchucks in the area, the company was also known as the "Chuckery Company.") Samuel Lane

(1892) included a detailed commentary on the history of this project in his book *Fifty Years and Over of Akron and Summit County*. The construction of the millrace included both excavation of rock and erection of a cut stone wall, which can still be seen today (fig. 7-1). Engineering problems (excessive seepage along sandy parts of the millrace) and a series of lawsuits, led to the eventual abandonment of the project in 1850 (Fairchild, 1876). There was some hope of reviving the project, but, according to Lane (1892, p. 88), "The rapidly increasing use of steam, as a machinery propelling power, and the constantly diminishing volume of water in the Cuyahoga River, by reason of the wanton denudation of adjacent timber lands, rendering hydraulic privileges less desirable, the entire project was finally abandoned."

For five days in March 1913 eight inches of rain fell on already saturated ground of the Cuyahoga watershed, resulting in a devastating flood. Eight of the nine dams along the Cuyahoga Gorge were destroyed. The intense rainfall had a similar effect in other areas of Ohio; dynamite was used to blast apart canal-lock gates and release floodwaters in Akron (Gieck, 1992). The 1913 flood did irreparable damage to the Ohio & Erie Canal marking the end of the canal days in Ohio.

FIGURE 7-1.—Remnants of the Chuckery race along the valley of the Cuyahoga River as seen from the northeast end of the Glen Trail at Gorge Metro Park. Photo by A. Foos.

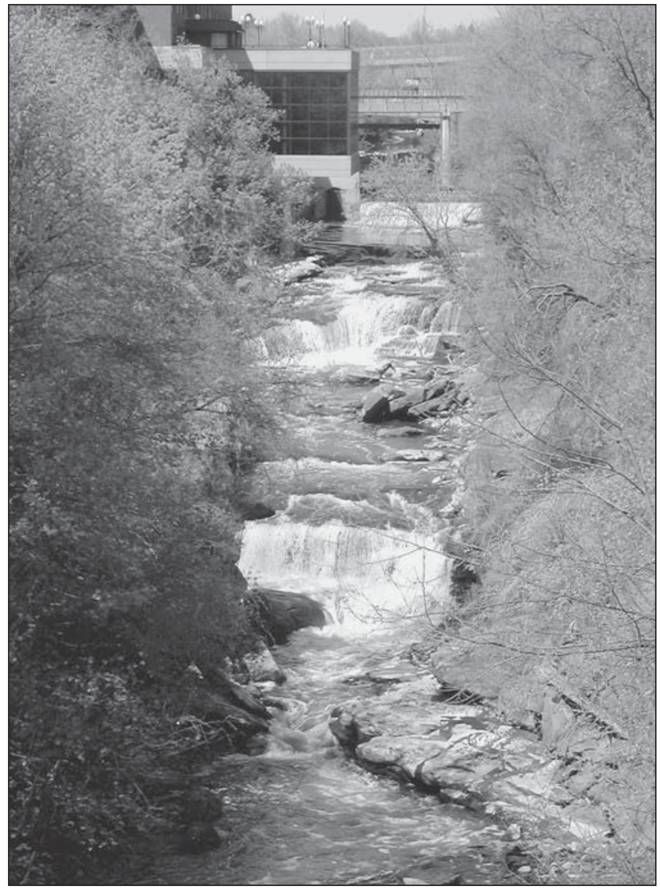


FIGURE 7-2.—Cuyahoga Gorge today, view looking upstream from the Prospect Street bridge. Note the rectangular, cantilevered dining room of the Sheraton Suites hotel projecting over the gorge in the upper left. Photo by A. Foos.

The 1880 census schedules record the use of the falls of the Cuyahoga at Cuyahoga Falls as power sources for flouring and grist mills, manufactures of sewer pipe, wire, light machinery and other products (U.S. Census, 1850-1880). The schedules note that the turbines for grist and manufactures were powered by falls that varied between 10 and 17 feet. A classic photo shows that the valley at Cuyahoga Falls was an incredible jumble of manufacturing plants (guidebook cover photo). Hildreth's (1837, p. 51) prediction of "a cordon of mills and machinery continuing without interruption, touching each other like the houses in a crowded street, for the distance of two miles on either side of the stream; the same water being used successively at the different dams, and taken along the sides of the river in plank raceways or penstocks," came to fruition, more or less. The position of the cantilevered dining room of the Sheraton Suites Hotel in Cuyahoga Falls, projecting over the cliff side along the Cuyahoga River (fig. 7-2), is reminiscent of the lost mills and plants that once lined the rapids and falls. The foundations of the old mills can still be seen from the hotel's observation deck. The hotel replaces the old Vaughn Machinery Company (known previously as Turner, Vaughn and Taylor), which occupied this site from 1856 until 1967. The dam of the Vaughn Machinery Company was the Henry Newberry dam (Lane, 1892). This dam is located along the river next to the hotel. The mechanisms used to open and close gates to allow water to run into the machine works to provide power are still evident. A similar dam and associated structure can be seen upstream at LaFever's Restaurant (fig. 7-3).

A 62 feet high, 450 feet long dam, owned by the Ohio Edison Company was built in 1913 at what is now Gorge Metro Park. The dam powered a 96-megawatt hydroelectric plant operated by the Northern Ohio Traction and Light Company from 1913 until 1958. A coal-fired plant that used water from the reservoir for cooling replaced the hydroelectric plant.

In 1999 an innovative type of generator was installed at the Ohio Edison Dam as a demonstration project by Universal Electric Power, an Akron-based company (fig. 7-4). Water is pumped over the dam and into a 36-inch diameter pipe where it drops 40 feet and is funneled into a turbine to produce electricity. The system cost approximately $400,000 to install and is capable of producing 100 kilowatts of electricity, enough to light up 100 to 150 homes. The environ-

FIGURE 7-3.— The gate mechanism at the inlet to machinery of the old powerhouse, built after the 1913 flood. Le Fever's River Grill in downtown Cuyahoga Falls (2291 Riverfront Pky.). Photo by A. Foos.

FIGURE 7-4.—Universal Electric Power's hydroelectric generator installed at the Ohio Edison Dam in Gorge Metro Park. Photo by A. Foos.

mental "fish friendly" design cost two thirds to one half less than conventional hydroelectric systems. There are 75,000 dams in the United States that are six feet or higher. UEP estimates that 8,000 could be outfitted with their power generating system. By retrofitting existing dams with this type of system, significant amounts of energy could be generated without generating additional greenhouse gasses or depleting fuel reserves. Environmentally friendly hydroelectric power could reduce our dependence on foreign oil without the hazards of nuclear power (UEP, 2003).

BUILDING STONE AND OTHER INDUSTRIAL USES OF THE SHARON FORMATION

Red sandstone—in many places of a deep red; structure, uniform; texture, compact and tolerably fine grained . . . It lies in beds of from four to eight feet in thickness, and can be split into blocks of any length desirable for architectural purposes, to which use it has already been extensively applied; several large, beautiful buildings having recently been erected of this material. It will probably afford the main building stone for a future city, as it is found in exhaustless quantities, and in very accessible situations, forming the upper portions of the cliffs of the Cuyahoga for several miles, —the whole length of the falls.

Samuel P. Hildreth (1873, p. 48)

Early evaluations of the Sharon Formation as a quarry stone ranged from the wildly optimistic view of Hildreth quoted above to the more somber view of Whittlesey (1838, p. 58) who wrote, "It does not, in general, quarry well, and undergoes great changes in its external characters, in short distances." On his visit to Cuyahoga Falls, Hildreth (1837, p. 48) did note differences between various layers now considered part of the Sharon. While he found the red layer to be quite suitable, he found one coarse pebble sandstone layer to be "seldom sufficiently compact for building stone" (yet it had been used for dimension stone). The stone is friable when first quarried and the pebbles cause some difficulties when the stone is cut. Hawes (1884, p. 280) noted that it could be a "very durable building stone," but that it did not hold up well under unequal pressure.

Despite the early opinion of Whittlesey, the Sharon Formation became a well-known building stone, and was quarried successfully at a number of sites in northeastern Ohio. Orton (1884) noted that the Sharon was quarried for local use in many localities, but was only extensively quarried in two: Akron and Twinsburg Township. The Akron quarries produced mainly foundation and bridge stone; the Twinsburg quarries produced stone for railroad bridges. Active quarries in Twinsburg Township are illustrated in the 1874 *Atlas of Summit County* (Tackabury, Mead & Moffett, 1874).

The south side of old Quarry Street (now Bowery Street), in downtown Akron, was once the site of a Sharon Formation quarry. Howe (1847) illustrated a view of Cuyahoga Falls taken from Joshua Stow's quarry at Cuyahoga Falls, and Fairchild (1876) noted the presence of a temporary stone-sawing mill at Cuyahoga Falls. Other quarries in Akron and elsewhere are noted by Prosser (1912). There are many small abandoned Sharon Formation quarries scattered about in northeastern Ohio including quarries in Thompson, Kirtland, and Twinsburg.

The Sharon from Akron and other quarries was used for buildings and foundations in Akron, Kent, Cuyahoga Falls, and elsewhere during the nineteenth century. Few buildings constructed primarily of the Sharon, however, still exist. Examples of existing buildings include the Old Stone Schoolhouse in downtown Akron, Perkins Mansion (constructed 1835-37) in Akron, and Akron's St. Vincent Church (figs. 7-5 and 7-6) (Hannibal, 1999). Stone houses in other parts of northeastern Ohio were made of locally quarried Sharon Formation. Blocks of red Sharon Formation were exported to Cleveland for some structures, despite the availability of Berea Sandstone from quarries in Berea and elsewhere nearer to Cleveland.

Many structures utilizing the Sharon Formation as a base,

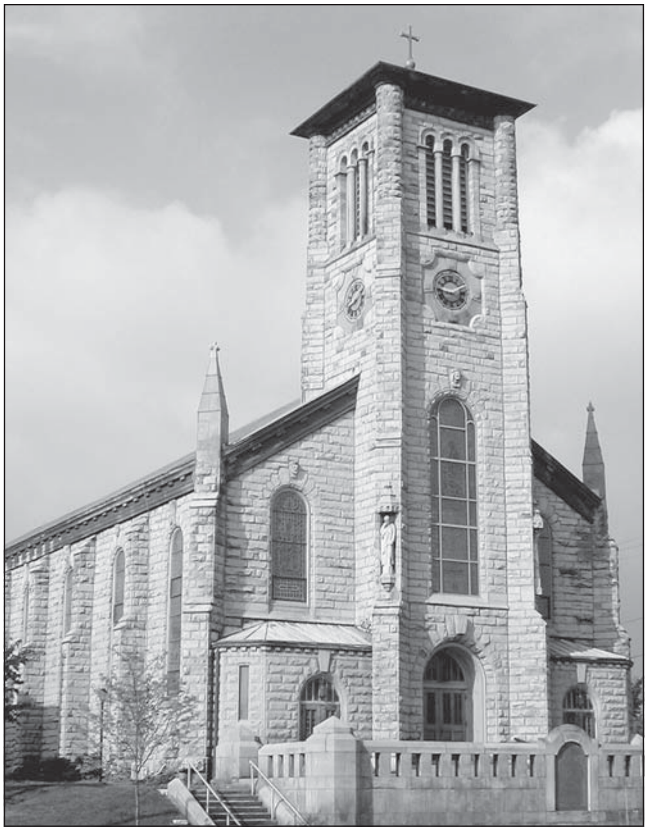


FIGURE 7-5.—St. Vincent Church, downtown Akron (164 W Market Street). Original stonework is made out of the Sharon conglomerate. Recent additions, including the front stairway, were made of Berea Sandstone. Photo by A. Foos.

FIGURE 7-6.—Close up of Sharon building stone at St. Vincent Church, downtown Akron. Photo by A. Foos.

however, still stand. These include the foundations of the Mustill Store (built in the 1850's) in Cascade Locks Park in Akron, the historic Tallmadge Church in Tallmadge, the Greek Revival Congregationalist Church located at the corner of Broad and Second in Cuyahoga Falls, and the adjacent Vaughn house, a stately Victorian brick house located at 122 Broad Street. The stone was also widely used for barn foundations. It was sometimes used for tombstone bases (examples can be seen in Ira Cemetery in the Cuyahoga Valley National Park and in Akron's Glendale Cemetery), and the Norris Monument (near the high point of Glendale Cemetery) is a Sharon boulder. The Sharon was also carved into hitching posts and water troughs, and bridge foundations made of Sharon can be seen in Summit and Lake counties.

The Sharon was probably used for a number of locks along the Ohio & Erie Canal and the Pennsylvania & Ohio Canal, a tributary canal. Many of these locks were replaced in great part with concrete in the early 1900's, but some Sharon can still be seen. The spillway adjacent to Lock 14 in the Cascade Locks in Akron (Hannibal, 1998) was made using Sharon, and pieces of Sharon Formation used for the original lock remain alongside the rebuilt Lock 2 in Clinton (south of Akron). The old canal structures at Kent are made of Sharon Formation stone.

Initial quarrying of the Sharon was done with hand tools. Old photographs and remains of ox shoes at a quarry in Kirtland along Ohio Rte. 306 show that oxen were used in transport. Horses or mules were used in the quarrying and transport of the Sharon Formation in the late 1800's. Illustrations of Twinsburg quarries show aspects of later 1800's quarrying technology, including the use of horse-powered derricks (Tackabury, Mead & Moffett, 1874). Census records (U.S. Census, 1850-1880) also note hand and horse-powered derricks.

The use of the Sharon Formation for dimension stone diminished as the use of other local stone, especially Berea Sandstone, expanded, and sandstones outside the area became available. The Berea's greater density and compressibility, as well as lesser friability recommended its use over the Sharon. Berea Sandstone was used instead of Sharon for canal lock repairs. Red sandstones such as *Hummelstown brownstone* and *Portage Entry Red sandstone* were used in Cleveland for mansions and other buildings (Hannibal and Schmidt, 1992). The Berea was used for buildings of importance in Akron, including the 1905 St. Bernard's Church. Indeed, the collective memory of the Sharon's use as a building stone in the Akron area faded.

Already by the 1830's, disaggregated Sharon was being utilized for flint glass and firebrick. Riddell (1836b, p. 165) noted that, "The brick makers of Cleveland have been in the habit of hauling large quantities of this sand in wagons from Little Mountain, not being aware that it might be obtained by canal from Akron, at one fourth the expense." John Newberry (1874) reported continued use of the Sharon for glass, and its pebbles as an element of firebrick in the 1870's.

Bownocker (1921) discussed the use of the Sharon as glass and molding sand and Stout (1944) reported the use of the Sharon for "the manufacture of silica brick, for reduction to the metal silicon, for pebble aggregate for nitrating plants, for paper, stucco work and sand blasting," as well as glass and foundry sand, and locally, for "road facing, concrete work, and railroad ballast."

In recent years the Sharon has been quarried (Wolfe, 2002) in several Ohio counties for use as crushed or broken stone. Best Sand, headquartered in Chardon, has quarried the stone in Manson Township, and R. W. Sidley Co. has quarried the stone in Hamden and Thompson townships in Geauga County. There has been some quarrying in Twinsburg (Weisgarber, 1994), and the unit has also been quarried in Pike County in recent years. In 2001 slightly over a million tons (1,058,998) of crushed stone, worth approximately 20 million dollars, were produced from Ohio quarries. The crushed stone is used primarily for glass sand, construction, aggregate, foundry sand, and silica flour (Best Sand Co., personal commun., 1999). Sharon pebbles are sold for use as ornamental stone, and have sometimes been used for exposed-aggregate concrete. Lucky-stone-laden concrete has been used, for example, on the campus of Kent State University and in part of downtown Cuyahoga Falls.

At Best Sand Corporation drilling rigs and chemicals are used for blasting. Workers pay attention to joint systems in the stone and work with them when preparing blasts. The blasted material is then scooped into trucks. The company uses a wet system for processing the sand quarried in Munson Township. Two types of crushers are used: A primary jaw crusher is used for initial crushing and secondary processing is done with a horizontal shaft impact crusher. Primary and secondary screens are used to sift the disaggregated material. The disaggregated Sharon has been used for abrasive blasting sands, casting for engine blocks, windshield glass, sand for sand traps of golf courses, concrete, and other uses. (Best Sand Co. personal commun., 1990's; web sites of Fairmont Minerals and Kohlberg-Pioneer). R. W. Sidley's quarries are in Thompson, not far from Thompson Ledges.

ROMANCE OF THE LEDGES: NINETEENTH-CENTURY PERSPECTIVES OF THE WILD AND PICTURESQUE

For the past twenty-five years, Cuyahoga Falls and vicinity has been one of the best known pleasure resorts in Northern Ohio. The river, with its deep gorges, its rumbling waterfalls, its leaping cascades, its over-hanging cliffs, its caves and grottos, its shady groves, its variegated shrubbery and picturesque views, has ever been a source of delight to lovers of the beautiful in nature, both savage and civilized.

Lane (1892, p. 746)

The Sharon is the most picturesque of the rock units found in northeastern Ohio. Ledges, grottos, shelter caves and other types of caverns, hills, waterfalls, ravines, gorges, rapids, and even a few natural bridges are composed of or developed in the Sharon. Many of the Sharon outcrops became picnic and tourist destinations during the second half of the nineteenth century, concomitant with the development of rail transportation, especially that of the steam and electric railways. Outcrops of the Sharon continue to be a destination for recreational hikers, nature lovers, and geologists.

Outstanding outcrops of the Sharon in northeastern Ohio have always been known as "ledges" and large isolated erosional remnants of the Sharon have been known as "knobs" or, when particularly prominent, "mountains." The highest summits in Lake and Geauga counties are Sharon hills, knobs, and "mountains." The better-known ledges include Whipp's and Worden's ledges in Medina County, Nelson-Kennedy Ledges in Portage County, Boston-Ritchie Ledges and Virginia Kendall ledges in the Cuyahoga Valley National Park, Thompson Ledges in Geauga County, Wolf's Ledges (now obscured) in Akron, and Newell's Ledges near Nelson. Using the criteria of Carll (1880), some of the Sharon outcrops could be considered "rock cities," but that term is seldom used in reference to northeastern Ohio outcrops.

Little Mountain, located on the Lake/Geauga county line, is the largest and best known of the "mountains" and knobs. Pierson's Knob, Gildersleve Knob (also known as Gildersleve Mountain, now in Chapin Woods, a Lake County Metro Park), and Lake County's eponymously named "The Knob," are others. Ledges Road runs through the outcrop area at Virginia Kendall Park in the Cuyahoga Valley National Park. This is not to be confused with Ledge Road along outcrops of the Sharon in Hinkley, Ohio.

The Sharon is also known for its "caves," including the Chesterland Caves located along Caves Road, Ansel's Cave, now in West Woods Reservation, and Ice Box Cave in Virginia Kendall Park. Other caves have been recorded, including a fairly large cave in Cuyahoga Falls (see Bierce *in* Butterfield, 1881). The largest cave-like feature is the large shelter cave known historically as Old Maid's Kitchen, now also known as Mary Campbell Cave. Although the Sharon is a siliceous clastic rock, Fyodorova and Sasowsky (1998, 1999) have identified "karst" features. The Sharon is one of the few rock units in Ohio to have natural bridges. The largest is along (actually under) Cat's Den Road in Lake County (Hannibal, 1991).

Smaller scenic features of the Sharon found at the ledges and other outcrops have been given colorful local names, some of which are no longer used. Features at Nelson's Ledges in Portage County include: Boulder Pass, Devil's Den, and Cascade Falls (Pettit, 1954; Ver Steeg, 1932) and there is "Fat Man's Squeeze" at Thompson Ledges.

Outcrops of Sharon Formation are notable for their flora. Riddell (1836a, p. 48) found the outcrops at Little Mountain to be "a most genial place for lichens, liverworts, and mosses," as well as an assortment of "rare and curious herbs." Other visitors (Hildreth, 1837) have elaborated on the plant assemblage. The outcrops provide a range of habitats for plants, including cliff-top habitats for the rockcap fern *Polypodium virginianum*, and well-watered sheltered areas for other ferns and rare wildflowers. The most obvious plants are the hemlocks and birches that root along and upon the outcrops. Ohio has three populations of Northern Monkshood (*Aconitum noveboracense*), a federally threatened species, that are found at the base of sandstone cliffs. Two of these populations are associated with the Sharon Formation at Gorge Metro Park in Summit County and Nelson Mills in Portage County (Windus and Cochrane, 2000).

Tales of the European settlers are associated with two Sharon features: Standing Rock, an isolated block of the Sharon in the middle of the Cuyahoga River in Kent, and Mary Campbell's Cave in Cuyahoga Gorge Park. Standing Rock is reputed to have been a landmark for both Native Americans and others traveling footpaths that passed this area. The monument, and the stretch of the Cuyahoga Gorge downstream of it in Kent, is associated with Captain Brady, a savage frontier figure, who supposedly jumped across the Cuyahoga Gorge at Kent about 200 yards above the present Main Street Bridge during a conflict with Native Americans (fig. 7-7). Mary Campbell's Cave (Day 1, Stop 2.6) is associated with Mary Campbell, a legendary captive of Native Americans during the time of Euro-American encroachment in the French and Indian War (McGovern, 1996). The Daughters of the American Revolution changed the name of the "Old Maids Kitchen" shelter cave at Gorge Metro Park to Mary Campbell's Cave (Grismer, 1952) in honor of this captive.

Sharon pebbles have long been known as "lucky stones" in northeastern Ohio. The appellation is recognized by "Lucky Stone Loop," a pebble-strewn hiking trail along the

FIGURE 7-7.— Rapids along the Cuyahoga at Kent in 1809 before this stretch of the river was modified as a slackwater for the Ohio & Erie Canal (from Howe, 1888, p. 441). The illustration was based on the memories of early settlers, and had the following caption: "The spot of Brady's Leap on the Cuyahoga River, a few hundred yards above the bridge at Kent."

Conglomerate outcrops in Chapin Forest Reservation of the Lake County Metro Parks. In the nineteenth century, their size range was traditionally referred to in terms of foods (McGovern, 1996). Riddell (1836, p. 47) found them to range in size "from the size of hens eggs to that of mere particles of sand." And Newberry (1873b, p. 213) noted that the pebbles ranged in size from that "of a hickory nut to that of an egg," while Carll (1880) found the pebbles at Nelson Ledges to range in size from that of a pea to a hazelnut.

As transportation techniques improved, Sharon ledges, knobs, gorges, and grottos became very popular as places to visit in the mid- to later 1900's, at least for those with the leisure time and money needed to do so. Visits to natural features melded with nineteenth century sensibilities regarding the natural world. Brown and other's (1885, p. 494) description of Nelson Ledges as always having "...been a noted place of resort for pleasure-seekers and curiosity-hunters..." can be extended to many other ledges. Little Mountain was another popular retreat, primarily for the upper class of the Cleveland area. Such destinations became well known because of advertisements as well as word-of-mouth. The romance of the ledges was echoed in *Ansel's Cave* a nineteenth century novel by the then well known author Albert G. Riddle (1893). His novel centered on a romantic gorge/shelter cave complex known then—and now—as Ansel's Cave (Goulder, 1949). This complex is the diamond of West Woods, a Geauga County park that opened in the fall of 2002.

The lure of the scenic outcrops along the gorge at Cuyahoga Falls (fig. 7-8) was recognized early in the nineteenth century. With the advent of the railroad, Cuyahoga Falls became a summer resort destination, complete with "natural scenery unequaled in Ohio" (Butterfield, 1881, p. 466). Butterfield (1881, p. 466) found it to be "a favorite resort for pleasure-seekers and excursionists during the summer months, where visitors can enjoy the beauties of natural scenery unequaled in Ohio." A full-page advertisement in the guidebook for the Valley Railway (Reese, 1880) listed the wonders of High Bridge Glens and Caves. A Grand Promenade extended one mile along the river adjacent to the Sharon Formation cliffs. High Bridge Glens was developed into a recreational area in the 1880's. Dancing halls,

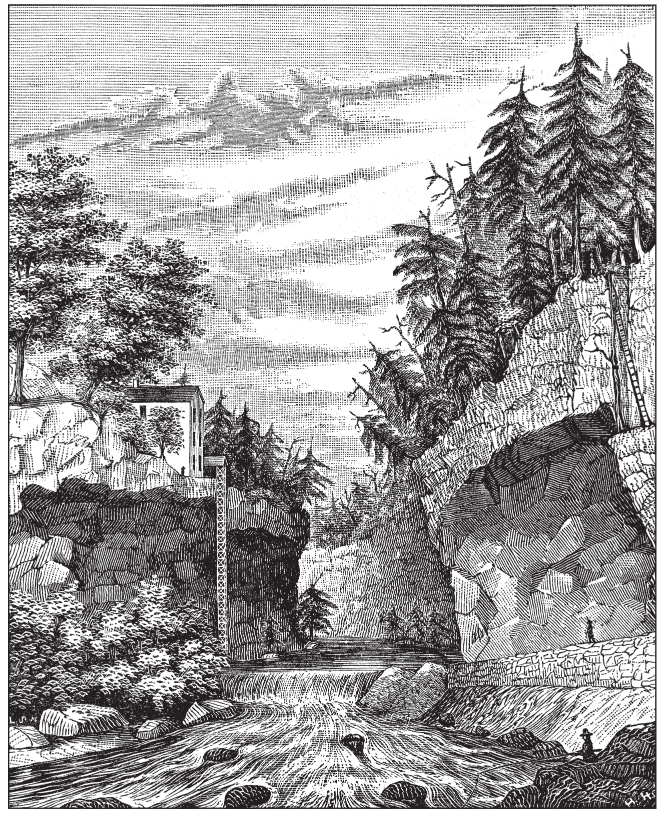


FIGURE 7-8.—Henry Howe's 1846 drawing of the ravine at Cuyahoga Falls (from Howe, 1888, p. 647).

a croquet field, skating rinks and even a roller coaster were added as commercial ventures (Lane, 1892). This was part of a trend; other natural features (gorges and lakes) were augmented with amusement parks, dance halls, and the like. Still, the natural wonders of the area are what caught the public imagination. Henry Howe reported (1888, p. 646) that:

Cuyahoga Falls has become a great place of resort for summer excursionists, and improved approaches, stairways, etc., have been constructed to make the romantic glens and nooks more accessible to the visiting multitudes. The High Bridge, Lovers' Retreat, Fern Cave, Observation Rock, Grand Promenade and Old Maid's Kitchen are some of the features that go to make up the romantic interest of this rock-bound gorge.

The scenic gorge was an attraction both in summer and in winter, when giant icicles festooned its sides. Visitors to the Glens arrived in "carriages and on regular and special trains, from Akron, Cleveland, Canal Fulton, and other points, even as far south as Columbus" (Lane, 1892, p. 748). Trolleys would later bring up to 60 carloads of visitors a day to the park (Seguin and Seguin, 2000). The great flood of 1913 had a destructive effect on the park along the river, and the park closed in the 1920's. The Glens were located just south of Prospect Avenue and the present Glens Trail in the Gorge Metro Park traverses most of the old Glens. Riverview Park, another park complex that took advantage of the scenic surroundings, was located downstream of the Glens, between the Ohio Edison Plant and the present dam. Today many of the scenic features that attracted visitors to these parks are under the water impounded by the Ohio Edison Dam.

TWENTIETH CENTURY DEVELOPMENT OF PUBLIC PARKS AT THE LEDGES

During the twentieth century, industry along the falls declined with the development of alternative power sources, especially that of steam power. Quarrying of the Sharon for dimension stone decreased with the increased of use of the Berea Sandstone and stone from outside the region. Many small amusement parks fell out of favor, and other parks came into being preserving the Sharon outcrops for the public. A range of government entities stepped in to purchase or receive donations of land containing some of the great outcrops of the Sharon.

The Cleveland Metroparks' "emerald necklace" of parks included Hinckley Reservation in Medina County. This reservation, added to the Cleveland Metropark system in the 1920's, is also famous for its "buzzards," turkey vultures, which are said to return each March 15. The ledges and other Sharon outcrops here and elsewhere (Shipman, 1927; Williams, 1950) are nesting sites for the turkey vultures, and air rising from the adjacent valleys provides thermals for these birds to ride in search of carrion.

A 1930 donation by the old Northern Ohio Traction and Light Company led to the formation of Gorge Park as part of the Akron Metropolitan Park System (now Metro Parks, serving Summit County). Hayward Kendall donated Virginia Kendall to the State of Ohio. The Akron Metropolitan Park System obtained Virginia Kendall Park from the State in 1933. The Akron Metropolitan Park System ran the park from 1933 to 1978 when it became a part of the Cuyahoga Valley National Recreational Area, now the Cuyahoga Valley National Park (McGovern, 1996).

The Industrial Silica Co. owned Nelson Ledges before the State of Ohio purchased it in 1920. The state purchased additional adjoining property in the 1940's. This land became Nelson-Kennedy Ledges State Park in 1949 (Holm and Dudley, 1957). Thompson township obtained Thompson Ledges Township Park, and Adel Durbin Park was obtained by the city of Stow.

Two newer parks preserving ledges are West Woods in Geauga County which includes Ansel's Cave, and Bennet-McDonald Ledges which preserves a beautiful set of ledges in Twinsburg, east of Liberty Road.

Riverfront Park in the Riverfront Center District off of Front Street in Cuyahoga Falls was an urban renewal project that created public space along the river in downtown Cuyahoga Falls. Riverfront Park extends the publicly accessible area of the gorge considerably north of Gorge Metro Park.

HISTORY OF GEOLOGICAL INVESTIGATIONS

The rock [in the valley of the Cuyahoga] *is about 100 feet in thickness; generally a coarse-grained, light drab sandstone, but in some localities, and especially near the base of the formation, becoming a mass of quartz pebbles, with just enough cement to hold them together.*

John Strong Newberry (1873a, p. 212)

Early geological reports and maps made note of the Sharon Formation as a conspicuous cliff-forming unit. The first reports were short notices. The Sharon was known in these reports and maps simply as "the Conglomerate," or as "the Carboniferous Conglomerate" (Whittlesey, 1869; Newberry, 1870).

S. P. Hildreth (1783-1863), a Marietta physician-naturalist, and first assistant geologist of the first Ohio Geological Survey (the Mather survey), made a number of geological observations, aided by Henry Newberry, during a visit to the Falls in May of 1835. Hildreth published a detailed account of his visit in the *American Journal of Science* in 1837. It included a measured section and detailed descriptions of what is now known as the Sharon Formation as well as associated rock layers.

Nineteenth century Ohio Geological Survey county reports for Summit and several other counties included information on the Sharon Formation. John Strong Newberry (1822-1892) authored the report (Newberry, 1873b) on the geology of Summit County (fig. 7-9). Newberry grew up in Cuyahoga Falls. He was the son of Henry Newberry (1783-1854) who came to the Western Reserve in 1824. Henry Newberry was a director of the Connecticut Land Company, a large

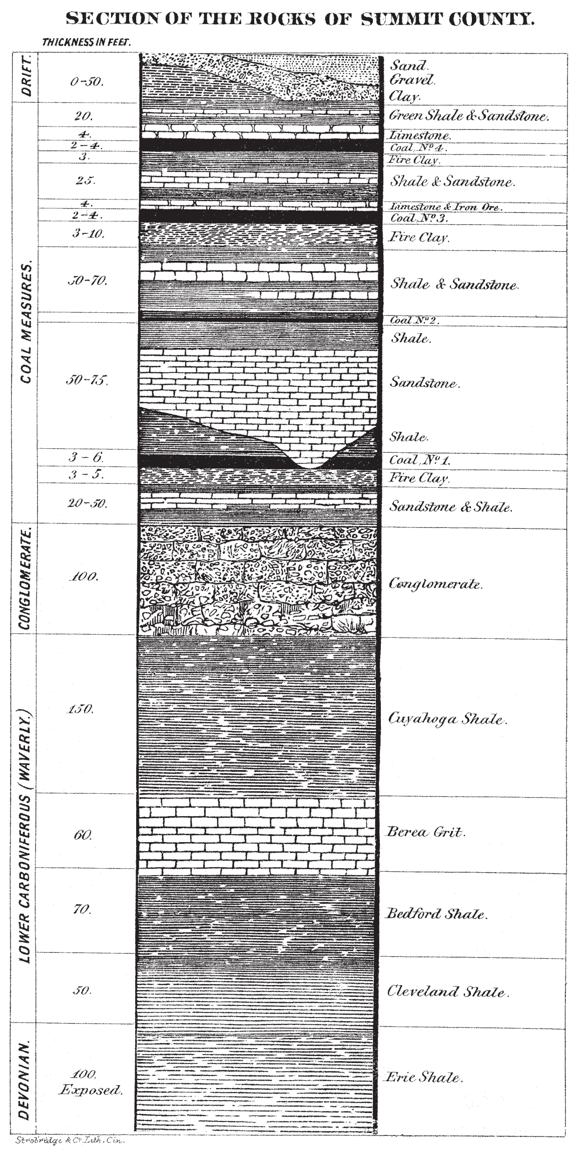


FIGURE 7-9.—Newberry's 1873 stratigraphic section of rocks in Summit County (from Newberry, 1873b).

landholder and developer in the Western Reserve, and first mayor of Cuyahoga Falls. Henry was the son of Roger Newberry, the owner of a 1000-acre share of the Western Reserve in the Cuyahoga Falls area. Henry inherited the property and moved there, becoming one of the founding fathers of Cuyahoga Falls. Henry Newberry mined coal at Coal Hill (now Chapel Hill) in nearby Tallmadge. John Newberry, therefore, was intimately acquainted with the Sharon. John Newberry eventually headed the second Geological Survey of Ohio. His report (Newberry, 1873a) on the Conglomerate touched on general aspects of the rock unit, composition, and fossil content of the pebbles, and hypothesized that the Conglomerate originated as glacial drift. Newberry later (1874) elaborated on his glacial theory. His glacial interpretation lived on in popular accounts, including that of Holm and Dudley (1957) who considered Nelson and Kennedy Ledges to be opposite banks of "a pre-historic river which carried the run-off from a melting glacier sheet which covered this section of the country."

This interpretation contrasted with the volcanic origin for ledges of the Conglomerate in an 1885 Portage County history by Brown and others (1885, p. 494), who described Nelson Ledges as follows:

The 'Ledges,' as they are called, in the northern part of the township, have always been a noted place of resort for pleasure-seekers and curiosity-hunters.... there is no doubt of their being the result of some terrific internal upheaval, when the fierce volcanic fires burst forth, and possibly shot out through the crevices that now appear in all directions, but which through the lapse of unnumbered ages have been mostly filled with rock and lava debris, pulverized in after ages to ordinary soil and sand.

Geologist M. C. Read (1891) favored a shoreline origin for the unit. Later geologists have interpreted the Sharon as marine (Butts, 1908; Stout, 1944); alluvial fans or plains; deltaic deposits, and braided streams (Mrakovich and Coogan, 1974; Wells and others, 1993; Ninke and Evans, 2002).

The prominent quartz pebbles of the Sharon figured in a contentious nineteenth-century battle over what is now known as peer review. By the time of the first formal geological surveys in Ohio in the 1830's, the formation of quartz pebbles in conglomerates was already understood (see, for example, Briggs, 1838) as being detrital. However, Jehu Brainerd (1807-1878), a Cleveland engraver, educator, amateur geologist, and faculty member of homeopathic medical colleges in Cleveland and St. Louis, presented what was to become a controversial paper on the origin of the Sharon pebbles to the 1853 Cleveland meeting of the American Association of the Advancement of Science (Brainerd and Hall, 1854). He argued against the detrital origin of the pebbles, advancing a theory of formation of the pebbles and accompanying stratified rocks out of solution in the sea. In his paper, he compared the formation of the pebbles to that of flint. This paper caused quite a stir (Holmfeld, 1970). James Hall, among others, criticized his interpretation (Brainerd and Hall, 1854). In fact, the initial publication of the proceedings of the conference was suppressed because of the inclusion of Brainerd's paper. Because his article was omitted from the final edition of the proceedings, Brainerd reprinted it, with an explanatory introduction (Brainerd, 1854). Newberry argued against a concretionary interpretation in his 1873 and 1874 reports.

Geologists of the Pennsylvania Survey applied the name "Sharon Conglomerate" to the Ohio rocks. The term Sharon Conglomerate was used in the chart of Ohio geological formations in MacFarlane's (1890) *Geological Railway Guide*. While formal status has been proposed in Ohio, the issue is complex (see Prosser, 1903; Slucher and Rice, 1994; Chapter 2 this volume) and the Ohio Division of Geological Survey currently refers to the unit as the Sharon conglomerate, an informal rock unit.

The fossils, which can sometimes be seen in outcrops of the Sharon (Heimlich and others, 1970) in Ohio, have never been comprehensively investigated. Impressions of large logs in cross section or top view can be found in the unit at Gorge Metro Park and elsewhere. The fossils recorded as occurring in the Sharon include the form genera *Lepidodendron, Sigilaria, Calamites*, and *Trigonocarpus* (Newberry, 1873a, p. 213). Newberry noted that the fossils were similar to those found in overlying Pennsylvanian deposits, and that they showed "evidence of transportation and accumulation in the same way that drift-wood is gathered by river currents or shore waves."

The methods by which the features seen at the Sharon Conglomerate ledges formed have been the subject of speculation over the years. Riddell (1836) observed that, "Many immense blocks of outliers of conglomerate have by some means, succeeded from the main mass, thus producing wide breaches or dark and narrow chasms...." Ver Steeg (1932, p. 191-192) noted the popular misconception that great earthquakes broke the large boulders from the outcrop, explaining that they formed through "a slow process of undermining by weathering and erosion." The usual explanation of the separation of blocks of the Sharon from cliffs is by separation at joints with concomitant slippage downslope on the underlying shales. In a somewhat similar context regarding a rock city in Illinois, Pius Weibel (*in* Tarr, 1998) has pointed out evidence of very long-term erosion.

There was once a "gold rush" of sorts at Nelson Ledges (Read, 1873a; Ver Steeg, 1937). Ohio Survey geologists took pains to dispel the notion of gold in deposits associated with Sharon outcrops at this site.

Glacial effects on the Sharon have been alluded to a number of times over the years. In a report on Geauga County, M. C. Read illustrated his measurements of glacial striae on a map of northeastern Ohio. In Summit County his measurements trend NW-SE (Read, 1873b). The Conglomerate, a resistant caprock, exhibits glacial rounding and glacial scratches.

Various twentieth-century publications provide information on Sharon outcrops: Prosser included numerous descriptions of Sharon Formation outcrops and illustrations of classic exposures of the rock unit in his work on Devonian and Mississippian (!) rocks of northeastern Ohio (1912). Banks and Feldmann's *Guide to the geology of northeastern Ohio* (1970) contains an appendix of measured sections that includes a number of Sharon outcrops and a list of the location of various places to observe the Sharon Formation in northeastern Ohio, including natural features, quarries and road cuts.

ACKNOWLEDGMENTS

Kathy Farago, Cleveland Heights-University Heights Public Library, aided with fieldwork and critiqued the manuscript.

REFERENCES CITED

Banks, P. O., and Feldmann, R. M., eds., 1970, Guide to the geology of northeastern Ohio: Cleveland, Northern Ohio Geological Society, 167 p.

Bownocker, J. A., 1921, Steel molding sand in Ohio: Ohio Journal of Science, v. 21, p. 249-266. [Reprinted in Glass Sands and Molding sands, Ohio Division of Geological Survey Reprint series no. 2.]

Brainerd, Jehu, and Hall, James, 1854, Origin of the quartz pebbles of the Sandstone Conglomerate, and the formation of the stratified sand-rocks: Cleveland, printed by Harris, Fairbanks, Cobb & Co., 16 p. [Another version was published in 1853 as Annals of Science, Cleveland, v. 1, p. 235-237.]

Briggs, Charles, Jr., 1838, Report of C. Briggs, Jr.: Ohio Division of Geological Survey First Annual Report, p. 71-98.

Brown, R. C, Norris, J. E., and others, 1885, History of Portage County, Ohio: containing a history of the county, its townships, towns, villages, schools, churches, industries, etc.; portraits of early settlers and prominent men; biographies; history of the Northwest Territory; history of Ohio; statistical and miscellaneous matter, etc., etc: Originally published: Chicago: Warner, Beers & Co., 1885. Facsimile reprint by Portage County Historical Society, 1972, 927 p. plus index.

Butterfield, C. W., 1881, Chapters 16 and 17, *in* Perrin, W. H., ed., 1881, History of Summit County: Chicago, Baskin & Battey, p. 466-496.

Butts, Charles, 1908, The unconformity between the Mississippian and Pennsylvanian, and its bearing on questions of geologic correlation: Science, n. s. (abs.): v. 27, p. 992-993.

Carll, J. F., 1880, The geology of the oil regions of Warren, Venango, Clarion, and Butler counties: Pennsylvania Geological Survey, Second Series, report of Progress III, 482 p.

Doyle, W. B., 1908, Centennial history of Summit County and representative citizens: Chicago, Biographical Publishing Co, 1186 p.

Fairchild, T. B., 1876, A history of the town of Cuyahoga Falls, Summit County, Ohio, an address delivered July 4th, 1876: Published by request of citizens: [Cleveland], Cleveland Herald Print., 39 p.

Feldmann, R. M., Coogan, A. H., and Heimlich, R. A., 1977, Field guide: Southern Great Lakes: Dubuque, Iowa, Kendall/Hunt, 241 p.

Fyodorova, A. I., and Sasowsky, I. D., 1998, Hydrogeologic study of cave development in the Sharon Sandstone, northeastern Ohio (abs.): Geological Society of America Abstracts with Programs v. 30, no. 2, p. 18.

__________ 1999, Silica dissolution and the development of sandstone caves: Geological Society of America Abstracts with Programs (abs.): v. 31, no. 7, p. 51.

Gieck, Jack, 1992, A photo album of Ohio's canal era, 1825-1913 (revised ed.): Kent, Ohio, Kent State University Press, 310 p.

Goulder, Grace, 1949, Ohio scenes and citizens: Ansel's Cave in Geauga County, scene of romantic novel of 100 year ago, still worth a visit today: Cleveland Plain Dealer Pictorial Magazine, December 18, p. 16-17.

Grismer, K. H., 1932, The history of Kent: historical and biographical: Kent, Courier-Tribune, 296 p.

__________ [1952?], Akron and Summit County: Akron, Summit County Historical Society, 834 p.

Hannibal, Joe, 1991, Ledges, caves & lucky stones: northeastern Ohio's Coal Age legacy: Explorer, v. 33, no. 2, p. 8–10.

Hannibal, J. T., 1998, Geology along the towpath: stones of the Ohio & Erie and Miami & Erie canals: Ohio Division of Geological Survey Guidebook no. 14, 60 p.

__________ 1999, Guide to stones used for houses of worship in Northeastern Ohio. Cleveland, Cleveland State University Urban Center Sacred Landmarks Monograph Series, 57 p.

Hannibal, J. T., and Schmidt, M. T., 1992, Guide to the building stones of downtown Cleveland: a walking tour: Ohio Division of Geological Survey Guidebook no. 5, 33 p.

Hawes, G. W., 1884, Report on the building stones of the United States and statistics of the quarry industry for 1880: United States Tenth Census, v. 10, 410 p.

Heimlich, R. A., Mrakovich, J. V., and Frank, G. W., 1970, The Sharon Conglomerate, *in* Banks, P. O., and Feldmann, R. M., eds., Guide to the geology of northeastern Ohio: Cleveland, Northern Ohio Geological Society, p. 125-133.

Heydinger, E. J., 1967, The Pennsylvania and Ohio Canal: Towpaths, vol. 5, p. 13-19, 25-31.

Hildreth, S. P., 1837, Miscellaneous observations made during a tour in May, 1835, to the Falls of the Cuyahoga, near Lake Erie: extracted from the diary of a naturalist: American Journal of Science, v. 31, no. 1, p. 1-84.

Holm, J. B., and Dudley, Lucille (eds.), 1957, Portage heritage: a history of Portage County, Ohio; its towns and townships and the men and women who have developed them; its life, institutions and biographies, facts and lore: Ravenna, Portage County Historical Society, 824 p.

Holmfeld, J. D., 1970, From amateurs to professionals: the controversy over the proceedings of an 1853 scientific meeting: Proceedings of the American Philosophical Society, v. 114, p. 22-36.

Howe, Henry, 1847, Historical collections of Ohio: Cincinnati, published for the author by Bradley & Anthony, 581 p. [There were numerous editions of this publication.]

__________ 1888, Historical collections of Ohio in two volumes, v. II: Cincinnati, published by the state of Ohio, 911 p.

Lane, S. A., 1892, Fifty years and over of Akron and Summit County: Akron, Beacon Job Departments, 1167 p.

Lesley, J. P., 1879, Preface, in White, I. C., The geology of Lawrence County, to which is appended a special report on the correlation of the coal measures in western Pennsylvania and eastern Ohio: Pennsylvania Geological Survey Report of Progress in 1877, 2nd Series, v. QQ, p.ix-xxxvi.

MacFarlane, James, 1890, An American Geological Railway Guide. Second Edition: New York, Appleton, 426 p.

McGovern, F., 1996, Written on the Hills: the making of the Akron Landscape: Akron, University of Akron Press, 241 p.

Mrakovich, J. V., and Coogan, A. H., 1974, Depositional environment of the Sharon Conglomerate Member of the Pottsville Formation in northeastern Ohio: Journal of Sedimentary Petrology, v, 44, p. 1186-1199.

Newberry, J. S., 1870, Report on the progress of the Geological Survey of Ohio in 1869. Ohio Division of Geological Survey, p. 3-51.

__________ 1873a, Report on the geology of Cuyahoga County. Report of the Geological Survey of Ohio, Vol. 1, Part 1, Geology, p. 171-200.

__________ 1873b, Report on the geology of Summit County. Ohio Division of Geological Survey, v. 1, part 1, Geology, p. 201-222.

__________ 1874, The Carboniferous System. Ohio Division of Geological Survey, v. 2, part 1, Geology, p. 81-180.

Ninke, D. J., and Evans, J. E., 2002, Alluvial architecture of the Early Pennsylvanian Sharon Formation in Northeastern Ohio: Ohio Journal of Science, v. 102, p. 70-81.

Orton, Edward, 1884, Sandstone: Ohio Division of Geological Survey, v. 5, p. 578-607.

Perrin, W. H., ed., 1881, History of Summit County: Chicago, Baskin & Battey, 1050 p.

Pettit, Lincoln, 1954, Nelson Ledges: a visitor's guide. Hiram, Hiram College, 15 p.

Prosser, C. S., 1903, The nomenclature of the Ohio geological formations: Journal of Geology, v. 11, p. 519-546.

__________ 1912, The Devonian and Mississippian formations of northeastern Ohio: Ohio Division of Geological Survey Bulletin 15, p. 323-882.

Read, M. C., 1873a, Geology of Geauga County. Ohio Division of Geological Survey, v. 1, part 1, Geology, p. 520–533.

__________ 1873b, Geology of Lake County. Ohio Division of Geological Survey, v. 1, part 1, Geology, p. 510–519.

__________ 1891. Geology of Summit County, Ohio, *in* Illustrated Summit County Ohio, representing her manufacturing interests, commercial houses, public institutions, farms, homes & people: Akron Map and Atlas Company, p. 29.

__________ 1892, Geology of Summit County, *in* S. A. Lane, Fifty years and over of Akron and Summit County. Akron, Beacon

Job Department, p. 614-620.
Reese, J. S., 1880, Guide book for the tourist and traveler over the Valley Railway: the short line between Cleveland, Akron, and Canton, containing a complete description of the scenery and objects of interest along the road, history of each station on the line, biographies of the officers of the road, etc.: Canton, Reese, 100 p.[Reprinted, 2002, by Kent State University Press.]
Riddell, J. L., 1836a, A geological ramble in the Western Reserve: Western Monthly Magazine, v. 5, p. 44-49.
__________ 1836b, Remarks on the geological features of Ohio, and some of the desiderata which might be supplied by a geological survey of the state: Western Monthly Magazine, v. 5, p. 160-172.
Riddle, A. G., 1893, Ansel's Cave: a story of early life in the Western Reserve: Cleveland, Burrows Brothers Company, 249 p.
Seguin, Marilyn, and Seguin, Scott, 2000, Images of Cuyahoga Falls, Ohio: Chicago, Arcadia Publishing, 128 p.
Shipman, C. M., 1927, Gildersleeve Mountain and the Sharon Conglomerate: Your Garden, v. 1, no. 3, p. 93, 116.
Slucher, E. R., and Rice, C. I., 1994, Key rock units and distribution of marine and brackish water strata in the Pottsville Group, northern Ohio. Geological Society of America Special Paper 294, p. 27-40.
Stout, Wilbur, 1944, Sandstones and conglomerates in Ohio: Ohio Journal of Science, v. 44, p. 75-88.
Tackabury, Mead & Moffett [sic], 1874, Combination atlas map of Summit County, Ohio, compiled, drawn and published from personal examinations and surveys: 139 p.
Tarr, Stuart, 1998, The streets of giant city: rewriting geological history: GeoNews (Illinois Geological Survey), v. 13, no. 2, p. 1, 3. [Report on observations of Pius Weibel.]
Universal Electric Power Corporation, 2003, www.uepholdings.com.
U.S. Census, 1850-1880, Federal nonpopulation census schedules, Ohio: In custody of State Library of Ohio, Products of Industry.
Ver Steeg, Karl, 1932, Nelson Ledge State Park. Ohio Journal of Science, v. 32, p. 177-193.
Weisgarber, S. L., 1994, 1993 report on Ohio mineral industries: Ohio Division of Geological Survey, 140 p.
Wells, N. A., Richards, S. S., Peng, Shengfeng, Keattch, S. E., Hudson, J. A., and Copsey, C. J.; 1993, Fluvial processes and recumbently folded crossbeds in the Pennsylvanian Sharon Conglomerate in Summit County, Ohio, U.S.A.: Sedimentary Geology. v. 85, p. 63-83.
Whittlesey, Charles, 1838, Mr. Whittlesey's report: Ohio Division of Geological Survey Second Annual Report, p. 41-71.
__________ 1842, A sketch of the settlement and progress of the Township of Tallmadge, (No. 2, Range 10): Summit Co., Ohio: Cleveland, Printed by Sanford & Co., 29 p.
__________ 1869, Contributions to the geology of Ohio: Cleveland, Fairbanks, Benedict & Co., printers. 48 p.
Williams, A. B., 1950, Birds of the Cleveland region: Cleveland, Cleveland Museum of Natural History, 215 p.
Windus, J. L, and Cochrane, K. E., 2000, Monitoring, research and restoration activities for Ohio populations of Northern Monkshood (*Aconitum noveboracense*): 1997-1999. Final report for the U.S. Fish and Wildlife Service, Reynoldsburg Office, FWS# 14-16-0003-90-967, Amendment No. 23, DCN# 1448-30181-97-J776, Reynoldsburg OH.
Wolfe, M. E., 2002, 2001 report on Ohio mineral industries: Ohio Division of Geological Survey, 155 p.

CHAPTER 8, THE ENVIRONMENTAL TRADE-OFFS OF DAMS, DAM REMOVALS, AND RIVER RESTORATION

by James E. Evans

As early as 1812, the water-power of the Cuyahoga River … [had] *been improved by Kelsey & Wilcox.*
Butterfield (1881, p. 466)

INTRODUCTION

The United States is the most hydrologically controlled nation in the world, with over 76,000 "large" dams (large dams are defined by the U.S. Army Corps of Engineers as structures > 2 m (6 ft) tall that impound > 61,700 m^3 (50 acre-ft) or > 7.6 m (25 ft) tall that impound > 18,500 m^3 (15 acre-ft)). In addition, there are an estimated 2 million smaller ("low-head") dams and structures in the United States (Graf, 1993). Dams and reservoirs in the United States store one full year of runoff over the conterminous lower 48 states (Graf, 1999), an extraordinary manipulation of the hydrologic cycle. Dams provide nearly 10% of the U.S. electricity supply as well as provide critical roles in navigation, flood control, water supply, and flat-water recreation (Heinz Center, 2002). At the present time, there are only approximately 42 rivers in the United States that still have free-flowing reaches of at least 200 km (e.g., Benke, 1990; American Rivers, 2002).

IMPACTS OF DAMS

Large dams represent one of the most fundamental human manipulations of earth-surface systems, impacting on climate, hydrologic regime, sediment budget, crustal subsidence, groundwater recharge or discharge, riparian and aquatic ecosystems, water quality, spread of disease or exotic species, and loss of human cultural assets. Dams both mitigate and create geologic hazards. Hydrologically and ecologically, dams fragment natural systems and disrupt the flow of water, sediments, nutrients, and species—with global implications, in some cases. For example, the sediment load of the Mississippi River to the Gulf of Mexico is one-half its pre-disturbance condition, mostly due to dams constructed since 1950 on the Missouri and Arkansas rivers (Meade 1995). Dams are uniquely long-lived structures— modern dams that are designed with adequate hydrologic information, carefully constructed, and adequately maintained, can last hundreds of years. Because of the combination of magnitude and longevity, dams and reservoirs have a philosophical effect on many people, becoming "natural" landscape elements in a manner different from bridges, buildings, and other constructed features.

The impact of any given dam is a complex subject best understood in the context of the interaction of drainage basin parameters (climate, hydrology, geology, biota, topography, and land-use) with the size of the dam and its mode of operation (e.g., Poff and Hart, 2002). One way to evaluate the impacts is to look at changes at three specific locations: within the dam-reservoir system, upstream of the reservoir, or downstream of the dam. The creation of a reservoir floods adjacent and upstream terrestrial habitat. In the United States, dams and reservoirs have drowned a total of over 97,600 linear km (60,000 linear miles) of stream valleys, resulting in extensive loss of riparian forests, riparian wetlands, and floodplains. Sedimentation in the reservoir, caused by the change in the river's longitudinal gradient, consists of deposition of the bedload as a delta at the upstream end of the reservoir, and deposition of the suspended load by settling in the downstream part of the reservoir. Aggradation upstream (due to the growth of the delta) can change channel morphology and can increase upstream flood hazards. Meanwhile, fallout from suspension will gradually infill the reservoir. How rapidly that occurs depends on the trapping efficiency of the structure, however the average dam in the United States loses about 0.5 to 1.0% of its storage capacity each year to sedimentation (Dendy, 1968). Other changes that occur within the reservoir include increased water depth, changes in temperature, possible development of density stratification, loss of light penetration due to turbidity, increased salinity due to evaporation, retention of nitrogen and phosphate, growth of plankton and algae, and changes in aquatic ecosystems from lentic to lotic species (Baxter, 1977; Petts, 1984; Poff and Hart, 2002). Finally, fine-grained sediments that accumulate in the reservoir may have adsorbed contaminants, vastly complicating efforts to maintain the reservoir by dredging or restore the river by dam removal (Evans and others, 2002).

Downstream of the dam the most immediate impact is degradation as the river re-establishes its sediment load by eroding bank and bed materials. Erosion downstream of the dam can cause incision and channel widening, preferential transport of fine-grained sediment, and resultant channel armoring, which can adversely impact on aquatic ecosystems (Petts, 1984). However the most pervasive long-term effect is aggradation downstream due to flow regulation. In other words, the controlled discharge through the dam typically results in eliminating the flood peaks that govern sediment transport in an unregulated river. The resulting deposition downstream affects channel morphology, substrate, and flood regime (Collier and others, 1996; Chin and others, 2002). Dams have other ecological impacts downstream, such as the effects of changes in a river's thermal structure due to release of water from below the thermocline of the reservoir (Muth and others, 2000), the effects of the dam as a barrier to the migration of anadromous fish and other species (Baxter, 1977), and the effects of altered flood regimes on riparian plant communities that depend on periodic inundation (Bayley, 1995; Wooton and others, 1996; Nislow and others, 2002).

IMPACT OF DAM REMOVALS

The United States is also the world leader in dam removals. Within the past two decades, more than 500 dams have been removed in the United States versus less than 10 in the rest of the world (WCD 2001), however only a few of these have been large dams. The removal of dams in the United States has accelerated from about 20 dams/year in the 1960's-70's, to about 100 dams/year during the 1980's, to about 160 dams/year in the 1990s, and during 2002 alone 63 dams were removed (Doyle and others, 2002; Poff and Hart, 2002; American Rivers, 2002).

The reasons for removing a dam can include economic obsolescence, structural obsolescence, safety considerations, legal and financial liability, dam site restoration, ecosystem and watershed restoration, restoration of habitat, development of unregulated flow recreation, or water quality issues (Heinz Center, 2002). Ecosystem restoration is probably the most controversial reason given because there is scientific uncertainty in the results (see below), and typically there are trade-offs inherent in dam removals (Evans and others, 2000a; Doyle and others, 2003a). The trade-offs include loss of qualities valued by some, such as flat-water recreation, wildlife habitat, and certain fisheries (Heinz Center, 2002). Many dam removals are driven by liability, financial, and safety issues inherent in the aging of the nation's dams. Most of the U.S. dams are approaching or have exceeded the 50-year life expectancy used as a rule-of-thumb by FEMA (1999). Owners of dams are thus faced with large expenses to dredge reservoirs or complete structural repairs, and are thus amenable to cost-benefit analysis (Johnson and Graber, 2002; Whitelaw and MacMullen, 2002). For example, cost-benefit analysis showed that one of the largest dams removed to date, Edwards Dam on the Kennebec River, Maine, would have cost 1.7 times more to repair than remove (AR/FE/TU 1999).

Dam removals are best understood by looking at short-term (up to several years) versus long-term (decade or longer) effects (e.g., Bushaw-Newton and others, 2002). The immediate short-term effects are loss of the reservoir and restoration of the fluvial channel. Concerns about reservoir dewatering include exposure of the reservoir sediments, dewatering processes, recolonization of riparian vegetation, and possible invasion of exotic plant species (Shafroth and others, 2002). Concerns about restoration of the fluvial channel include the rate and direction of incision, headward erosion, and channel widening, related mass wasting processes (slumping of water-saturated muds into the channel), erosion of fine-grained sediments and resulting problems with turbidity and siltation downstream, and remobilization of contaminants from the sediments (Evans and others, 2002; Pizzuto 2002; Doyle and others, 2002, 2003). Downstream siltation is probably the greatest concern. The effects of siltation might include fish kills, reduced volume of fluvial pools (which provide critical over-winter fish habitat), and clogging the pore spaces in spawning gravels, and such problems may occur many kilometers downstream (Wohl and Cenderelli, 2000). Remobilization of contaminated sediments has been a concern in some instances, such the release of PCB-laden sediments into the Hudson River following the removal of the Ft. Edwards Dam (Shuman, 1995).

Long-term effects include fundamental changes in flood regime and sediment budgets resulting from the transition from a regulated river to an unregulated river. Other changes might include reduction of ground-water recharge, reductions in riparian wetlands, and changes in temperature regime. Such changes could be accompanied by either positive or negative changes in water quality, riparian habitat and/or aquatic ecosystems. For example, dams and reservoirs may improve water quality by trapping particulate phosphate and providing sediment surfaces in an oxygen-poor environment, which facilitate denitrification of nitrate. Removing the dam may worsen these problems downstream (Stanley and Doyle, 2002). Although most dam removals to date have been justified by proposed improvements in aquatic ecosystems, there are instances where removal of a dam permits the spread of exotic species (e.g., the sea lamprey or flathead catfish) or the upstream access of hatchery-raised fish (Hart and others, 2002). Other concerns include decreased freshwater mussel populations due to siltation, shifts in macroinvertebrate populations due to substrate changes, loss of planktonic algae populations, and loss of lentic fish species (e.g., small-mouth bass or catfish).

Again, as a consequence of the longevity and magnitude of changes caused by dams, those advocating river restoration should understand it is typically impossible to fully return the fluvial system to its undisturbed (pre-dam) condition (e.g., Hart and others, 2002). Indeed, removing a dam in itself should be considered a form of major disturbance of the fluvial system and its ecosystems (e.g., Doyle and others, 2003b).

STATUS OF THE "SCIENCE" OF DAM REMOVALS

Despite the removal of over 500 dams in the United States, fewer than two dozen have been part of any systematic study on the effects of dam removals (Hart and others, 2002), and most of these have been too recent to draw final conclusions. Doyle and others, (2002) summarized the principal unresolved issues as follows: (1) the rate and mechanisms of sediment removal from the former reservoir, (2) how far and how quickly sediment will be transported downstream, and (3) the extent that transported sediment impacts channel morphology and biotic communities. In other words, although many of the impacts are biological, the controlling parameters are the sediments and their impacts on the hydrologic regime and channel morphology. In the absence of hard data about the long-term behavior of the sediment after a dam removal, predictive models are used. Four types of models have been utilized: (1) modeling the released sediment as a slug that translates downstream as a wave-form (Simons and Simons, 1991; Wohl and Cenderelli, 2000), (2) using geomorphic analogs which are called "conceptual channel evolution models" (Doyle and others, 2002, 2003a), (3) using mathematical dispersion models of the decay of the sediment pile in place (Lisle and others, 2001; Pizzuto, 2002), or (4) using sediment routing calculations which determine which respective grain size classes will be eroded, transported or deposited through each downstream channel reach (Evans and others, 2002).

Studies have shown that the most immediate impact of dam removal is the release of fine-grained reservoir sediment downstream, due to channel incision and channel widening by mass wasting (slumps). Suspended sediment concentrations might reach an order of magnitude higher than pre-dam removal (Doyle and others, 2002). One study of a sediment release showed that fine-grained sediment was deposited in pools up to 12 km downstream (Wohl and Cenderelli, 2000). However, much of this sediment is flushed through the fluvial system fairly rapidly by subsequent storms (Wohl and Cenderelli, 2000; Doyle and others, 2002). In addition, the effects of first sediment release were delayed several months, in one case, until major floods occurred (Hart and others, 2002).

In some cases channel widening by mass wasting has been appreciably less than anticipated, based upon the assumption that channel would restore its pre-dam cross-section. This apparently is due in part to the highly cohesive sediments in the former reservoir, aided by the lowering of the groundwater table as reservoir sediments dewatered, and by deposition around slump blocks that helped to stabilize them (Doyle and others, 2002). There is some evidence that controlled draw-down and partial breaching can help fine-grained sediments consolidate in place (Kanehl and others, 1997; Pizzuto, 2002). This can be combined with efforts to stabilize the channel banks using riprap and vegetative seeding (Shields and others, 1995). Finally, one additional effect of cohesive reservoir sediment is to limit or slow the extent of headward erosion of the restored channel (Doyle and others, 2002).

The major sediment impact of dam removals appears to be the fate of the coarser-grained sediment fraction from the upstream end of the reservoir. Depending upon the volume, grain size, and distance traveled by the coarse-grained sediment, its arrival downstream can reduce channel depth up to 20%, cause channel widening, fill pools, and change channel morphology (Doyle and others,. 2002). The sediment properties will determine whether the headward erosion of the channel proceeds as a headcut or as a nickpoint, and whether headward migration is continuous or episodic (Pizzuto 2002). One study found the downstream rate of sand transport was about 2 km/yr, and that complete flushing of the released sand fraction, following dam removal, through the fluvial system will be at least 50-80 years (Simons and Simons 1991). In other words, "restoring" the stream channel is on the same time scale as the length of time the river was dammed.

DAMS IN NORTHEASTERN OHIO

The Legacy of Dams in Northeastern Ohio

According to the U.S. Army Corps of Engineers (NID, 2003), there are 665 dams in northeastern Ohio (north of latitude 40.0° N and east of longitude 82.5° W). Table 8-1 summarizes their ownership, height, year completed, and hazard ranking of northeast Ohio dams.

As table 8-1 indicates, many of the dams in northeastern Ohio are relatively old (42% were completed before 1940). It is an interesting historical aspect that the major settlement of Ohio (1830's-1860's) corresponded to an important time interval prior to the Industrial Revolution (> 1860s) in which dams and hydropower played a major role. Northeast Ohio, at the edge of the Allegheny Plateau, was particularly affected by this convergence of geology, hydrology, and social development. Many of the cities in northeastern Ohio were settled during the 1830's-1860's specifically for their hydropower potential (e.g., Evans and others, 2000a).

The legacy of older dams in Ohio can be clarified as follows. In northeast Ohio 25% of the dams are ranked as "highly hazardous" versus 14% nationally, while 32% of the dams in northeast Ohio are ranked as "significantly hazardous" versus 18% nationally (NID, 2003). In other words, the proportion of hazardous dams in northeast Ohio is almost double the national average. One of the challenges that scientists in northeast Ohio face, is the difficulty of explaining to the public and to policy-makers how these significant assets have become dangerous liabilities that will require major expenditures to repair, replace, or remove.

Lessons from a Dam Failure

The following is an example of why this problem cannot be ignored, in hopes it will go away. The IVEX (or Upper Mill Pond) dam on the Chagrin River was constructed in 1842 and partially or completely failed five times (1842, 1877, 1913, 1985, and 1994) during its 152-year history. For most of its existence, the dam consisted of a masonry spillway 7.4 m tall, 1 m thick, and 33 m wide that was connected to an earth-fill dam 152 m long (fig. 8-1). The dam was originally constructed for hydropower for various mills, but was used for industrial water supply by a paper manufacturer starting in the early-1900's. The dam was classified as highly hazardous because the spillway design was inadequate, there was no emergency spillway, there was a history of failures, and there was downstream risk (the Lower Mill Pond dam and the Village of Chagrin Falls).

The IVEX dam failed catastrophically on 13 August 1994 after the upper Chagrin River watershed experienced a 70-year rainfall event (13.54 cm rain within 24 hours). Eyewitnesses observed that flows rose to 1.9 m above the spillway crest, impinging on the top of the dam (fig. 8-2) immediately prior to a seepage piping failure at the contact of the masonry spillway and earth-fill dam. The seepage piping

Table 8-1—*Summary of dams in northeastern Ohio*

	OWNERSHIP STATUS						
	Federal	State	Local	Public Utility	Private	Unknown	Total
HEIGHT							
> 100 feet	2	0	1	2	6	0	11
50-99 feet	12	5	7	4	17	2	47
25-49 feet	2	14	42	5	229	16	308
< 24 feet	0	13	39	3	241	3	299
(Total)	(16)	(32)	(89)	(14)	(493)	(21)	(665)
HAZARD							
High	16	12	37	7	90	3	165
Significant	0	6	30	2	171	3	212
Low	0	14	22	5	232	15	288
Undetermined	0	0	0	0	0	0	0
(Total)	(16)	(32)	(89)	(14)	(493)	(21)	(665)
CONSTRUCTED							
> 1980	0	0	9	1	32	0	42
1940-1980	3	17	38	5	278	1	342
< 1940	13	15	42	8	183	20	281
Undetermined	0	0	0	0	0	0	0
(Total)	(16)	(32)	(89)	(14)	(493)	(21)	(665)

Source: National Inventory of Dams (U.S. Army Corps of Engineers), 2003.

FIGURE 8-1.—Oldest available photograph of the IVEX Dam (circa 1870) showing the masonry spillway attached to bedrock on the west bank (left) and to an earth-fill dam on the east bank (right). The spillway was 7.4 m tall. Photo courtesy of the Chagrin Falls Historical Society.

FIGURE 8-2.—Photograph of the spillway of the IVEX Dam minutes before failure of the dam at the spillway–earth-fill dam contact (right). Photo courtesy of Y. Rausch, Chagrin Falls Historical Society.

failure was probably facilitated by poor maintenance of the structure, including allowing trees to grow on the earth-fill dam (Evans and others, 2000b). The collapse of the seepage pipe, under high hydraulic pressure, created a notch in the top of the earth-fill dam that downcut and expanded, within minutes, to a trapezoid shape approximately 20 m wide at the top, 12.4 m wide at the base, and 7.5 m tall (fig. 8-3). Paleohydraulic calculations suggest the peak discharge reached 466 m^3/sec, and the reservoir was dewatered within 2.7 minutes (Evans and others, 2000b). The breach released approximately 38,000 m^3 of impounded water and sediment (about 10 million gallons). From flood debris, it appears the initial wave was 1.5 m above bankfull, crossing a floodplain and point bar en route to the Lower Mill Pond reservoir and dam (a run-of-river structure), crossed these and continued downstream (Evans and others, 2000b). There was extensive downstream damage to culverts and stream banks, and the causeway of Ohio Rte. 87 was inundated about 7 km downstream. However, no lives were lost.

FIGURE 8-3.—Photograph of the breach in the dam taken several days after failure. The view upstream shows the approximately 4.5 m of sediment accumulated behind the dam. The lighter area on the spillway is a hydraulic cement patch from the 1985 partial seepage piping failure. Photo by J. Evans.

The dewatered reservoir provided a natural laboratory for researchers from Bowling Green State University, the University of Toledo, and the Ohio Geological Survey. Jointly, we collected nine vibracores to a maximum depth of 4.5 m, in addition to trenching, examination of stream cuts, and other sampling. Sedimentation rates were calculated using ^{137}Cs and ^{210}Pb geochronology, core stratigraphy, historical flood horizons, and other data (Evans and others, 2000c). The information permitted a reconstruction of the reservoir storage capacity loss over time (Evans and others, 2000b) and the sediment budget of the Chagrin River watershed over most of its history of post-Native American settlement (Evans and others, 2000c).

The data indicate that the IVEX Reservoir lost 86% of its storage capacity over its 152-year history (annual loss rates varied from 0.37% to 1.72% per year). This amounts to the deposition of 274,000 m^3 of compacted sediment (visualize a football stadium filled to about 49 m deep with sediment). The breach and subsequent incision mobilized between 9-13% of the accumulated sediment (23,700 to 31,300 m^3), of which most (61-86%) was deposited in the Lower Mill Pond and the remainder in the floodplain (Evans and others, 2000b).

Damage within the reservoir included large longitudinal scours (fig. 8-4), incision of the channel, and slumping of the stream banks (fig. 8-5). Incision exposed the bedrock cutbanks of the pre-reservoir channel, as well as the stumps of pre-reservoir trees, early settlement fence posts, the upstream deltaic foresets, flood rhythmite deposits, paleosols, and other interesting features (Evans and others, 2000b).

The site was remediated as a riparian wetland under an agreement between the village of Chagrin Falls and the dam's owner. The owner was faced with a repair cost of approximately $2.5 million. The owner was also faced with the need for water supply, and concerns about environmental remediation if the dam was not rebuilt. The situation was resolved by legal transfer of the dam and adjacent land to the Village of Chagrin Falls in exchange for the owner's access (at cost) to the municipal water supply and wastewater treatment facility. Financial adjustments were made to account for the fair market value of the land, less environmental remediation costs assumed by the Village. Through

FIGURE. 8-4.—Longitudinal scours in the reservoir sediment produced during the dam breach. Photo by J. Evans.

FIGURE 8-5.—Channel incision and slumping of reservoir sediments immediately following the dam failure, as the Chagrin River restores its channel shape and slope to the breaching of the dam. Photo by J. Evans.

an ODNR Natureworks grant and other funding, the Village initiated a plan to restore the site and develop it as a park. The work involved installing a temporary low-head dam constructed with rock-fill gabions to reduce sediment erosion until the former reservoir had fully dewatered. Subsequently the entire spillway was removed and replaced by rock rubble rapids (fig. 8-6). Portions of the former reservoir were contoured to create several wetlands ponds, and native vegetation was planted to stabilize the toes of slumps. Other costs included boardwalks, parking, interpretative signs and other features for visitors. The successful remediation of this site was primarily due to cooperation of the respective stakeholders, availability of funding, and cooperative research by various state and federal agencies and several universities (Evans and others, 2000a).

ACKNOWLEDGEMENTS

I would like to thank my co-workers on these projects, including Hans Gottgens, Scudder Mackey, and Bill Gill. We benefited from assistance and information from Larry

FIGURE 8-6.—View of the former dam site after removal of the spillway and conversion of the former reservoir to riparian wetlands. Photo by J. Evans.

Rohman (IVEX Corporation), Ben Himes and Robert McKay (Village of Chagrin Falls), Mark Ogden (ODNR), Harold Schindel (USGS), Randall James (OSU Agricultural Extension Service), Al Bonnis (USDA/NRCS), Phil Guss (Ohio Agricultural Statistics Service), Greg Taress (Geauga County Planning Commission), and Pat Zorba and Yolita Rausch (Chagrin Falls Historical Society).

REFERENCES CITED

American Rivers, 2002, Edwards Dam case study: available at <http://www.amrivers.org/damremovaltoolkit/edwardsdam.htm>. Accessed 28 July 2002.

[AR/FE/TU] American Rivers, Friends of the Earth, and Trout Unlimited, 1999, Dam removal success stories: restoring rivers through selective removals of dams that don't make sense: Washington D.C., American Rivers.

Baxter, R. M., 1977, Environmental effects of dams and impoundments: Annual Reviews of Ecological Systems, v. 8, p. 255-283.

Bayley, P. B., 1995, Understanding large river-floodplain ecosystems: Bioscience, v. 45, p. 153-158.

Benke, A. C., 1990, A perspective on America's vanishing streams: Journal of the North American Benthological Society, v. 9, p. 77-88.

Bushaw-Newton, K. L., Hart, D. D., Pizzuto, J. E., Thomson, J. R., Eagan, J., Ashley, J. T., Johnson, T. E., Horwitz, R. J., Keeley, M., Lawrence, J., Charles, D., Gatenby, C., Kreeger, D. A., Nightengale, T., Thomas, R. L., and Velisky, D. J., 2002, An integrative approach towards understanding ecological responses to dam removal: the Manatawny Creek study: Journal of the American Water Resources Association, v. 38, p. 1581-1599.

Butterfield, C. W., 1881, Chapter 16, *in* Perrin, W. H., ed., 1881, History of Summit County: Chicago, Baskin & Battey, p. 466-496.

Chin, A., Harris, D. L., Trice, T. H., and Given J. L., 2002, Adjustment of stream capacity following dam closure, Yegua Creek, Texas: Journal of the American Water Resources Association, v. 38, p. 1521-1531.

Collier, M., Webb, R. H., and Schmidt, J.C., 1996, A primer on downstream effects of dams: U.S. Geological Survey Circular 1126, 94 p.

Dendy, F. E., 1968, Sedimentation in the nation's reservoirs: Journal of Soil and Water Conservation, v. 23, p. 135-137.

Doyle, M. W., Stanley, E. H., and Harbor, J. M., 2002, Geomorphic analogies forassessing probable channel response to dam removal: Journal of the American Water Resources Association, v. 38, p. 1567-1579.

__________ 2003a, Channel adjustments following two dam removals in Wisconsin: Water Resources Research, v. 39, p. 1011, doi:10.1029/2002WR001714,2003.

Doyle, M. W., Stanley, E. H., Harbor, J. M., and Grant, G. S., 2003b, Dam removal in the United States: Emerging needs for science and policy: EOS, v. 84, p. 29, 32-33.

Evans, J. E., Mackey, S. D., Gottgens, J. F., and Gill, W. M., 2000a, From reservoir to wetland: the rise and fall of an Ohio dam, *in* Schneiderman, J. S., ed., The Earth around us: maintaining a livable planet, San Francisco, W. H. Freeman, p. 256-267.

__________ 2000b, Lessons from a dam failure: Ohio Journal of Science, v. 100, p. 121-131.

Evans, J. E., Gottgens, J. F., Gill, W. M., and Mackey, S. D., 2000c, Sediment yields controlled by intrabasinal storage and sediment conveyance over the interval 1842-1994: Chagrin River, northeast Ohio, U.S.A.: Journal of Soil and Water Conservation, v. 55, p. 263-269.

Evans, J. E., Levine, N. S, Roberts, S. J., Gottgens, J. F., and Newman, D. M., 2002, Assessment using GIS and sediment routing of the proposed removal of Ballville Dam, Sandusky River, Ohio: Journal of the American Water Resources Association, v. 38, p. 1549-1565.

[FEMA] Federal Emergency Management Agency, 1999, National Dam Safety Program: available at <http://www.fema.gov/mit/ndspweb.htm>. Accessed 3 November 1999.

Graf, W. L., 1993, Landscapes, commodities, and ecosystems: the relationship between policy and science for American rivers, *in* Sustaining our water resources: National Academy Press, Washington D.C., p. 11-42.

__________ 1999, Dam nation: a geographic census of American dams and their large-scale hydrologic impacts: Water Resources Research, v. 35, p. 1305-1311.

Hart, D. D., Johnson, T. E., Bushaw-Newton, K. L., Horwitz, R. J., Bednarek, A. T.,Charles, D. F., Kreeger, D. A., Velinsky, D. J., 2002, Dam removal: challenges and opportunities for ecological research and river restoration: Bioscience, v. 52, p. 669-681.

Heinz Center, 2002, Dam removal: science and decision making: H. John Heinz III Center for Science, Economics, and the Environment, Washington D.C., 221 p.

Johnson, S. E., and Graber, B. E., 2002, Enlisting the social sciences in decisions about dam removal: Bioscience, v. 52, p. 731-738.

Kanehl, P. D., Lyons, J., and Nelson, J. M., 1997, Changes in the habitat and fish community of the Milwaukee River, Wisconsin, following removal of the Woolen Mills Dam: North American Journal of Fisheries Management, v. 17, p. 387-400.

Lisle, T. E., Cui, Y., Parker, G., Pizzuto, J. E., and Dodd, A. M., 2001, The dominance of dispersion in the evolution of bed material waves in gravel-bedform rivers: Earth Surface processes and Landforms, v. 26, p. 1409-1420.

Meade, R. H., 1995, Contaminants in the Mississippi River, 1987-1992: U.S. Geological Survey Circular 1133, Reston, VA.

Muth, R. T., Crist, L. W., LaGory, K. E., Hayse, J. W., Bestgen, K. R., Ryan, T. P., Lyons, J. K., and Valdez, R. A., 2000, Flow and temperature recommendations for endangered fishes in the Green River downstream of the Flaming Gorge Dam: Upper Colorado River Endangered Fish Recovery Program, Final Report, Project FG-53.

[NID] National Inventory of Dams, 2003, U.S. Army Corps of Engineers. Available at: <http://crunch.tec.army.mil/nid/webpages>. Accessed 21 May 2003.

Nislow, K. H., Magilligan, F. J., Fassnacht, H., Bechtel, D., and Ruesink, A., 2002, Effects of dam impoundment on the flood regime of natural floodplain communities in the Upper Connecticut River: Journal of the American Water Resources Association, v. 38, p. 1533-1548.

Petts, G. E., 1984, Impounded Rivers, John Wiley, New York, 326 p.

Pizzuto, J. E., 2002, Effects of dam removal on river form and process: Bioscience, v. 52, p. 683-692.

Poff, N. L., and Hart, D. D., 2002, How dams vary and why it matters for the emerging science of dam removal: Bioscience, v. 52, p. 659-668.

Shafroth, P. B., Friedman, J. M., Auble, G. T., Scott, M. L., and Braatne, J. H., 2002, Potential responses of riparian vegetation to dam removal: Bioscience, v. 52, p. 703-712.

Shields, F. D., Bowie, A. J., and Cooper, C. M., 1995, Control of streambank erosion due to bed degradation with vegetation and structure: Water Resources Bulletin, v. 31, p. 475-489.

Shuman, J. R., 1995, Environmental considerations for assessing dam removal alternatives for river restoration: Regulated Rivers: Research and Management, v. 11, p. 249-261.

Simons, R. K., and Simons, D. B., 1991, Sediment problems associated with dam removal — Muskegon River, Michigan: Hydraulic Engineering, Proceedings of the 1991 National Conference of the American Society of Civil Engineers, New York, p. 680-685.

Stanley, E. H., and Doyle, M. W., 2002, A geomorphic perspective on nutrient retention following dam removal: Bioscience, v. 52, p. 693-702.

Whitelaw, E., and MacMullen, E., 2002, A framework for estimating the costs and benefits of dam removal: Bioscience, v. 52, p. 724-730.

[WCD] World Commission on Dams, 2000, Dams and Development: Earthscan Publications, London, 404 p.

Wohl, E. E., and Cenderelli, D. A., 2000, Sediment deposition and transport patterns following reservoir sediment release: Water Resources Research, v. 36, p. 319-333.

Wooton, J. T., Parker, M. S., and Power, M. E., 1996, Effects of disturbance on river food webs: Science, v. 273, p. 1558-1561.

CHAPTER 9: DESCRIPTION OF FIELD STOPS

For the convenience of visitors, Mr. Newberry has erected a strong and safe flight of steps, by which to descend to the foot of the cliffs, at a point which affords a fine view of the falls, and where the perpendicular walls are more than one hundred feet high.
Hildreth (1837, p. 53)

DAY 1

by Neil A. Wells, David A. Waugh, and Annabelle M. Foos

INTRODUCTION

This portion of the trip will feature the unconformity at the base of the Early Pennsylvanian Sharon Formation, the two-story architecture of much of the Sharon in this vicinity, its pebble concentrations, overturned cross-bedding, iron coatings and bandings, honeycomb weathering, iron (or "Liesegang") banding, pyritic cement, and vug development. We will also see some small exposures of the Early Mississippian fine clastics below the Sharon.

GPS measurements are given relative to the WGS84 datum, and represent averages taken on two different days. Differences during resurveying suggest that precision exceeds accuracy (mostly less than 1 second, but occasionally around 5 seconds). Distances along the trails are paced, but are thought to be slightly more accurate than GPS over short distances. Additionally, some GPS locations were measured slightly away from sites of interest to avoid cliffs and trees. Day one of the field trip will consist of four major stops:

Stop 1—a hike up the Cuyahoga River, along the Glen trail, from the Gorge Metro Park parking lot in Cuyahoga Falls, Ohio

Stop 2—a hike down-river, along the Gorge trail, from the same parking lot

Stop 3—a stop at the Prospect Street overlook, to see the youngest part of the Cuyahoga Gorge

Stop 4—a hike around the east side of Virginia Kendall Ledges, along the Ledges trail of the Cuyahoga Valley National Park, Peninsula, Ohio

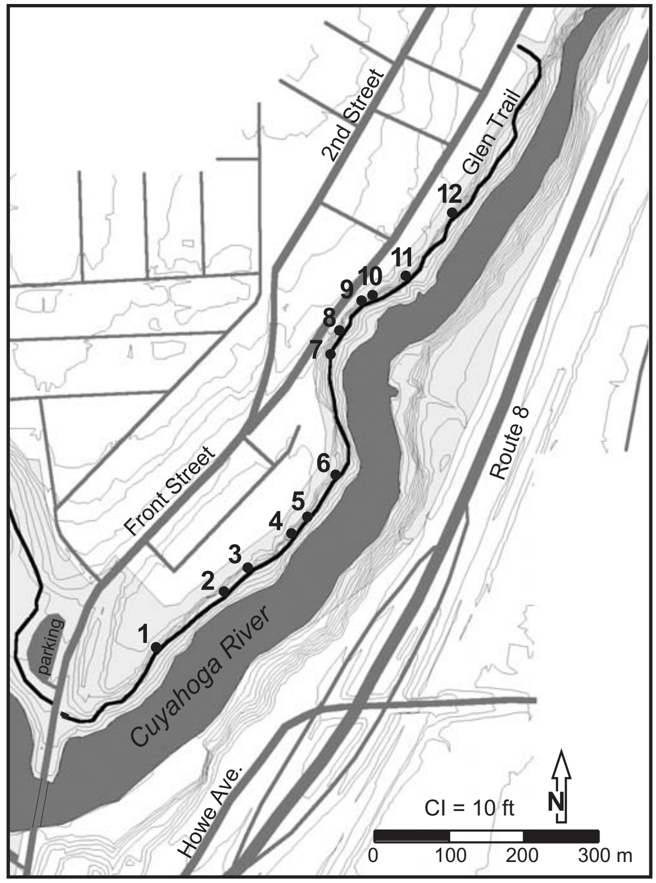


FIGURE 9-1.—Map of the Glen Trail, Gorge Metro Park (Stop 1) showing the stop locations.

STOP 1—GLEN TRAIL, GORGE METRO PARK, CUYAHOGA FALLS, OHIO

From the parking lot in Gorge Metro Park, cross Front Street to the head of the Glen Trail, just downhill from the traffic light at the parking lot entrance, at 41° 07' 09.9" N, 81° 29' 35.4" W (UTM: 17T 458598 4552130). The trail runs up the north side of the Cuyahoga River, upstream of the Front Street bridge, opposite the power station (fig. 9-1). Meter distances start from where the trail leaves the road.

After leaving Front Street, the trail passes the old Rte. 5 Northbound bridge abutments to the south and piles of debris including concrete to the north. By 75 m along the trail, note the abundance of well-rounded pebbles and boulders in the slopes above the trail, next to large broken blocks of Sharon sandstones.

Stop 1.1

Located at 164 m along the trail, at the first in situ bedrock outcrop immediately next to the trail, marginally downstream from the power station, starting at 41° 07' 11.75" N, 81° 29' 30.45" W (458714 4552187) (fig. 9-2).

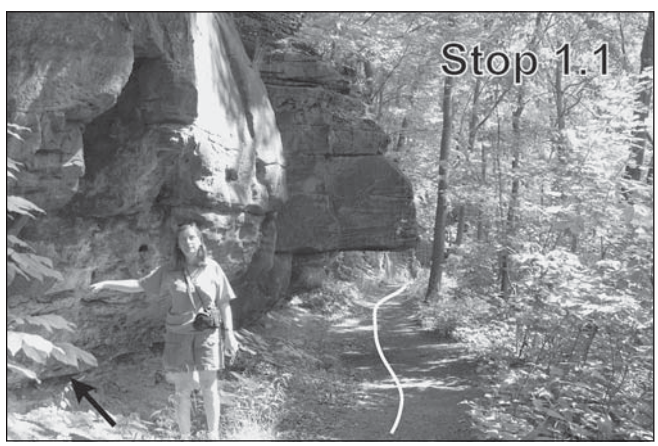


FIGURE 9-2.—Stop 1.1. The black arrow points to the unconformity between the Meadville and the Sharon. A. Foos is pointing to a log-like feature, and the upper conglomerate layer in the rock face at the far end of the white line contains some goethite-lined vugs (plate 8-C, D). Photo by D. Waugh.

Several features of interest can be seen and discussed at Stop 1-1. Starting at 0 m at the west end of the outcrop, note a possible "fossil log" at 7 m along the trail; wonderful complex "Liesegang banding" from 16 to 24 m; a variety of vertical joints (e.g., an open but debris-filled joint at 27 m); honeycomb weathering at 46 m; and some overturned cross-bedding near 55 m. The base of the Sharon is seen along much of this outcrop, and vugs are notable throughout, especially a series of narrow but very long vugs without iron-coating at around 10 m and extensive development of small iron-coated vugs along a thin conglomerate (the "upper conglomerate") a little above eye height, especially between 51 and 61 m.

In more detail, first, this exposure shows the unconformity at the base of the Sharon Formation, where it cuts into underlying shales, siltstones, and fine sandstones of the Mississippian Meadville Member (as discussed above). As is usually the case, the base of the Sharon is conglomeratic, consisting almost entirely of quartz and quartzite pebbles in a quartz-arenite matrix. As is also typical, the basal most conglomerate is thicker and is made of coarser pebbles relative to higher conglomeratic levels, with a few notable local exceptions. Here, as in most other localities, the base of the Sharon seems flat and conformable, but the Sharon is late Morrowan whereas the Meadville is probably Kinderhookian, so we are missing most or all of the Osagean stage, the Middle and Late Mississippian, and a bit of the Early Pennsylvanian, possibly amounting to somewhere around 24 m.y. Note the elevation of the unconformity relative to the lake level below, as its elevation will change slightly along the trail. The relief on the unconformity is typically only appreciated when examined over a large area.

Second, water tends to descend through the relatively porous Sharon (either along bedding planes and joints or through the rock itself), until it hits relatively impermeable Meadville shales underneath. At that point, the water tends to percolate laterally through the basal Sharon (especially through the coarser, conglomeratic, zones), until it seeps out along the unconformity. Therefore, outcrops of the unconformity tend to be damp, and tend to develop seeps and overhangs. However, this particular set of outcrops is unusually dry. A noteworthy vug, formerly a spring conduit but now dry, emerges just above the base of the formation, up-valley from the overhang.

Third, the Sharon here shows a two-story architecture. Both sequences start with a coarse layer (pebble conglomerate or pebbly sandstone) that is overlain by a couple of meters of megaripple-cross-bedded sandstone with rare pebbles. The upper story differs from the lower primarily in that its basal coarse unit, here two thin layers of conglomerate separated by a thin sandstone, is a much thinner and not as coarse as the base of the lower story. The higher conglomerate (plate 4-E) mostly varies from a layer one-pebble thick to a couple of thin layers, but it is locally thicker and is briefly interrupted in a couple of places. The breaks may separate different gravels at slightly different levels, but the outcrops could well represent only local interruptions in a single sheet that extends for a kilometer or so in both directions. The conglomerate mostly does not show cross-bedding, with some exceptions, whereas the sandstones tend to show tabular or trough cross-bedding.

Fourth, the outcrop shows some peculiar, elongate, iron-coated, conglomerate surfaces. One of these at 171 m, near the western end of the outcrop, looks very much like the impression of bark on a flattened log (similar to plate 4-D). This feature can be followed far enough along the outcrop that, if it were vegetal, it would have to be a tree trunk or a large log or root. This probably is not vegetal, in that it seems to continue too far into the exposure (making it too flat and broad), but its interpretation is certainly debatable. Features like this are common in the Sharon, and indeed along this trail we shall see some that are clearly not logs, and some that clearly are, so conclusions as to what this represents may change several times during the trip. Previous researchers have reported *Calamites* and *Lepidodendron* impressions and carbonization in the Sharon (e.g., Heimlich and others, 1970). Indisputable examples of *Lepidodendron* that occur as molds and are not associated with iron precipitation have been observed by Foos across the river from the Glen Trail.

Fifth, note the joints coming out of the rock face, many striking between 310 and 290°. These are quite variable. Some are quite wide open and have been packed with dirt and debris. One of the three most widely open joints, at 191 m, striking approximately 115-295°, is nearly perpendicular to the local 45-225° trend of the valley. It has opened to about 35 cm, and has filled with soil and rock debris. Another has only opened a few centimeters and remains empty. Toward the up-valley end of this outcrop, the rock faces on each side of one open joint are coated heavily with ferruginous precipitate, although most joints with similar orientations have remained uncoated. At 196 m, there is a cluster of parallel, NW-SE oriented joints in a narrow zone, and a little farther along a NW-SE joint has opened by 75 cm. Joints like these are common in the Sharon, but their origin is not always clear. In some places, such as on Ohio Rte. 303 in Hinckley and at Ice Box Cave at Kendall Ledges, the joints are very planar, seem fairly regularly spaced, and are parallel or orthogonal, so they appear to be tectonic. However, in other places they are more variable in orientation, and their orientations are not consistent from one location to another. Some are clearly parallel to adjacent valleys and gorges, but it is usually unclear whether the valleys follow the joints or vice versa (i.e., whether they are valley stress-release joints). The enigmatic SW-NE expansion of the joints here can be explained if the blocks of Sharon and the well rounded pebbles and cobbles to the SW of the outcrop represent a previously unfilled area toward which the blocks slid when it was still an open valley. More importantly, whatever the cause, the joints show sufficient variability in degrees of openness, infilling with debris, and mineral coating to demonstrate that they have a complex history, with different origins at different times.

Sixth, note several fine examples of multiple, more or less parallel bands of iron induration (plate 9-A, B), with various associated iron coatings and impregnations. Multiple bands of iron precipitates are typically referred to as Liesegang banding, after Raphael Liesegang, who in 1896 demonstrated self-ordered, rhythmic banding when coprecipitates diffuse toward each other through gels (Liesegang, 1945). Our thoughts on these are summarized in chapter 6, but for now we will just call them iron banding, because they may not involve either diffusion or gels. XRD analysis of a specimen with particularly dark and thick iron band indicated the sample contained quartz, goethite, and a minor amount of hematite. Iron banding in the Sharon can be subparallel to bedding, aligned along cross-beds, and/or parallel to fractures or joints. In rock masses that are bounded by bedding planes and joints, the banding can develop into subspherical or subcylindrical patterns. In those types of patterns, the iron banding is clearly forming impregnation haloes around zones of heightened permeability. However, the patterns can also cut across all such zones of permeability and may even be pervasive. Most iron banding in the Sharon appears to be of one generation, although multigenerational crosscutting sets can be seen on occasion. One such example occurs between two joints and a bedding plane at 198 m along the trail (plate 9-B). The banding has crosscutting relationships with a complex history of development (plate 9-A). The ceiling of the overhang above the trail at 193 m shows a series of iron bandings with the first band in each set is the most strongly developed. The rock face above the overhang shows the bands in full three-dimensional exposure. They compose a series of cauliflower-head-like curved surfaces or of out-pocketings. On freshly broken surfaces, iron bands show predominantly brown to reddish or yellowish brown colors, and relief is absent. In contrast, on old and weathered surfaces the iron-induration bands are dark and can stand out in slight relief, either emphasizing cross-bedding, obscuring it, or producing pseudo-cross-bedding.

At about 211 m, we can see a modestly developed example of honeycomb weathering (similar to plate 7-A), with distinctive complex pits and projections. This is well developed on many outcrop surfaces of the Sharon. Apparently, ground water seeps through to the surface of the rock and evaporates, precipitating iron at the surface or just under it. Induration with iron hardens the sandstone surface, making it more resistant. Where the iron coating is damaged or absent, the soft sandstone erodes back, developing pits between armored "noses." The projecting bits of sandstones can now act even more strongly as wicks, with evaporation on both sides pulling moisture out of the rock, and causing further impregnation and coating around the projections.

In the vicinity of the "log," note some small cylindrical vugs within the sandstone. Unlike most of the vugs that we will see on this trip, these are not marked by iron precipitate and can be surprisingly long relative to their diameter (some exceeding 0.5 m). More significantly, between 215 and 225 m (starting about 45 m east of the "log"), note the many small cavities in the upper conglomerate that are lined with thick dark coats of iron precipitate, presumably goethite. Some of these are coatings of quartz pebbles, where the pebble has fallen out, and some of the flatter ones may have been pebbles of shale or clay that have since disintegrated. However, on close inspection the majority turn out to be small vugs and discontinuous conduits that have been internally coated with iron, like plugged-up pipes (plate 4-E, 8-C, D). It is also common to see layers of goethite up to a centimeter thick, developed under, above, or within the conglomerate. Some are impregnations of pre-existing sandstones, but some are so pure in iron that they must have replaced or displaced the original rock or filled a preexisting void. It seems at minimum surprising to talk of macroscopic and largely isolated vugs forming by dissolution of quartzose sandstone and conglomerate. However, thin section inspection of one of the thicker iron-impregnated zones shows goethite between highly corroded quartz grains, and some fairly convincing dissolution vugs occur at the far end of this stop, at approximately latitude 41° 07' 12.8" N, longitude 81° 29' 28.6" W.

Two sets of cross-beds toward the far end of the outcrop (at about 220 m and 239 m) show minor recumbently overturned cross-beds, but we will see more and better examples later, especially at Kendall Ledges (Stop 4 of today's trip, as shown in plate 3).

Stop 1.2

Located at 263 m along the trail, 38 m beyond the aforementioned vugs, along the next set of outcrops, at latitude 41° 07' 13.8" N, longitude 81° 29' 28.2" W (458767 4552250) (fig. 9-3).

FIGURE 9-3.—Stops 1.2 and 1.3. A. Foos is pointing to iron banding superimposed on coarse-grained foresets (plate 10-C), and N. Wells is pointing to log-like iron-layering in the upper conglomerate. Photo by D. Waugh.

The section here consists of 0.90 m of basal granulestone, 1.40 m of sandstone, .05 m of conglomerate (small quartz pebbles), covered by 0.70 m of two to three sets of cross-beds, including some recumbent overturned cross-beds that change in character along a meter or so of outcrop. The upper conglomerate is associated with planar zones of induration with goethite (plate 12-A). There are also numerous small vugs, lined with goethite precipitate, which do not appear to be replacing bedrock (plate 4-E, 8-A-D). Plate 8-A, B (from near Stop 1.11) show that the goethite linings can show quite a complex history of infilling. Some of the individual iron layers here and in the "upper conglomerate" a little farther east (notably at 272 m, 9 m east) are quite similar to the putative "fossil log" in the first outcrop.

Note the alternating tabular foresets of granules and sands low in the section. Some of the cross-beds show coarsening down the cross-beds and either coarsening or fining perpendicularly across the cross-bed. However, subhorizontal iron bands (plate 10-C) significantly obscure the cross-beds. Crosscutting relationships in the iron banding, show that the bands form an age-series that consistently becomes younger upward toward the "upper conglomerate." With only a few exceptions where the banding is most complex and swirling, younging upward is the dominant pattern in the lower part of the Sharon (plate 11C-F).

Stop 1.3

Located at the next overhang, around 299 m, at latitude 41° 07' 14.7" N, longitude 81° 29' 25.6" W (458828 4552276) (fig. 9.3).

Some apparent "pseudo-wood" occurs in the roof of the ledge at 294 m (e.g., plate 7-B), but just left of the largest cleft (at 299 m) the ceiling and back wall of the overhang show some genuine if flattened imprints of large fossil logs or roots that locally enclose thin wisps of carbonized, plant remains. At one point near the large cleft, the matrix is rich in wisps of carbon at all orientations, which may represent a tangle of carbonized roots (plate 1-D). Depending on recent weather, some of the rock surface is marked by yellow sulfur efflorescence, often associated with bits of coal. The basal conglomerate contains large slabs of clayey fine sandstones and siltstones, representing little-traveled blocks of Mississippian bedrock (plate 1-B). A freshly broken fragment of basal rock here preserved pyrite cement (plate 12). There are some additional overturned cross-beds just beyond the upstream end of the overhang.

The chemical composition of the water from the seep at the east end of the outcrop (GT-2) is presented in table 9-1.

Table 9-1.—*Chemical composition of spring water from the alcove at Stop 1-3 (Concentrations are in mg/L)*

	Sample no. GT-2	Sample no. GT-2
Date	9/19/99	11/19/99
pH	3.36	3.64
Total dissolved solids	513	498
Ca^{+2}	54	49
Mg^{+2}	32	30
Na^{+}	37	41
K^{+}	3.3	1.3
HCO_3^{-}	0	0
SO_4^{-2}	283	280
Cl^{-}	80	76
NO_3^{-}	15	12
PO_4^{-3}	0.1	—
SiO_2	7.24	6.13
Total Fe	0.36	0.41
Mn^{+2}	1.44	1.44

(Details on the location and chemistry of the seeps and springs are found in Chapter 5) This water is extremely acidic, with high sulfate and moderate SiO_2. Iron is higher than the average spring composition along the trail but not exceedingly high, Mn is significantly higher than typical ground water. The acidity and the high SO_4 are consistent with the breakdown of pyrite and the generation of sulfuric acid, as seen in acid mine drainage, where:

$$4\ FeS_2 + 15\ O_2 + 8\ H_2O \Rightarrow 2\ Fe_2O_3 + 8\ H_2SO_4$$

This reaction can generate pH values of 3 and lower (Berner and Berner, 1996). The relatively low iron concentration of the seep reflects the removal of iron by precipitation following oxidation. This process removes iron preferentially over manganese. The ratio Fe:Mn of acid mine drainage from the Sharon Coal is approximately 3:1 (Foos, 1997). From the manganese concentration of this water it is possible to estimate that the iron concentration was between 3 to 7 mg/L prior to oxidation. The sulfur content and the acidity may be connected with the vugs and goethite. The acidity does not directly help dissolve silica, which is pH independent below a pH around 9, although it might help in the survival of some organic acids that could complex with silica.

After Stop 1.3 the next section of the trail, from 351 to 456 m, passes two pairs of long, smooth, parallel joint faces that run more or less parallel to the valley. The joints are oriented at 15-195° and 20-200°, and are thickly coated with goethite and/or amorphous iron oxides and hydroxides. The first rock face along this section of the trail shows large tabular cross-beds, and a small outcrop at trail height shows a bedding plane view of coated conglomerate. A little farther along, the second joint face shows some very well developed honeycomb weathering. Then the trail descends a series of steps (transversely placed logs) at 389 m, and the second pair of joint faces starts at 409 m. Upstream of the steps, some iron banding mimics overturned cross-bedding, and the upper pebble layer temporarily fades out. A small seep (GT-3) emerges at the base of the third joint face.

Stop 1.4

Located at 430 m, 41 m along the trail from the steps, at latitude 41° 07' 16.7" N, longitude 81° 29' 21.9" W (458914 4552338). (fig. 9-4)

FIGURE 9-4.—View down-valley from Stop 1.5 to Stop 1.4. Photo by D. Waugh.

This planar joint face (the fourth in the series) is oriented 005-185° and is coated in precipitated iron minerals that can be as thick as 1 cm. Cavernous excavation of the softer sandstone behind the coating can be seen wherever erosion has broken through the indurated surface. High up in the cliff above 430 m, there is a large vug with a notably massive iron coating (plate 7-D), testifying to the amount of dissolution of bedrock and to the quantity of iron moving through the Sharon back when it was a saturated aquifer. Seep GT-4 emerges at the base of the joint face, and another seep (GT-5) comes out of the basal Sharon conglomerate midway between this point and Stop 1.5.

Stop 1.5

Located at a significant recent wedge failure (fig. 9-4), at 456 m along the trail, at latitude 41° 07' 16.95" N, longitude 81° 29' 20.45" W (458948 4552346).

This site demonstrates several important features. First, note that the base of the formation has descended to a lower elevation. Second, the space formerly behind and under the wedge shows that a lot of soil had filled in behind the wedge, demonstrating increasing separation over a prolonged period prior to complete failure. Third, the rock formerly behind the wedge is very "rotten", and shows an iron-coated vug passing into the rock in both directions (plate 7-C). These cannot be interpreted as disintegrated clasts, so they must be considered to be large vugs. Adjacent homogenous sandstone shows tiny vugs (only a few with goethite linings), some thick goethite bands (plate 13-A), and some well-developed iron banding. Some of the reddest iron bands just NE of the wedge failure show a decreasing or recessional series of bands on either side of a porous bed of coarse sandstone (plate 10-A). The bands recede upward toward the porous bed from underneath, and downward to it from above, suggesting migration of reducing fluids through the permeable bed and expanding outward from it.

24 m farther along the trail (at 480 m), the upper conglomerate, now quite high up above the trail, locally becomes extremely thick. Note the thickness of the unit between the upper and lower conglomerate has increased.

Stop 1.6

Located at another wedge failure, 22 m farther along the trail, at 543 m, at latitude 41° 07' 19.65" N, longitude 81° 29' 19.25" W (458977 4552429).

The top of the failed block and the fresh surface behind it displays some small and shallow trough cross-bedding and some very lovely "scenic sandstone" iron banding (plate 10-D). The banding is very splotchy, although it is somewhat elongated along the cross-beds. Crosscutting relationships show that the banding developed over numerous episodes, mostly with the youngest generation in the middle of the "splotch".

At 103 m beyond Stop 1.6 (647 m along the trail), there is a huge and unsafe overhang that shows two conglomerates and some rippled bedding planes. Springs GT 6 and GT- 7 (now covered by slumping) emerge from Meadville shales a little below the Sharon unconformity. Apparently, the combination of a lower than usual line of outcrop and (presumably) appropriate fractures and lithologies here permit the water table to drain below the base of the Sharon and to emerge within the Meadville. Upon emergence, the water rapidly creates extensive ochreous iron precipitate, but it is nowhere as acidic and sulfurous as the spring at Stop 1.3. Its water has a pH of 6.6 and contains 2.36 mg/L total Fe, but only 69 mg/L of $SO_4^{=}$ and 419 mg/L of total dissolved solids. In comparison, GT-7 (at least back when it was more active) contained only 0.21 mg/L Fe.

The rocks involved in the overhang show a series of somewhat irregular joints that are oriented approximately N-S, which is parallel to the valley around the previous corner. These are presumed to be valley stress-release jointing.

Stop 1.7

Rounded outcrops starting at 702 m (55 m beyond the low spot where a drainage pipe crosses the trail), at latitude 41° 07' 19.75" N, longitude 81° 29' 19.65" W (458967 4552432) (fig. 9-5).

Here the Sharon outcrops are smoothed and scalloped, unlike nearly all the other outcrops. These are thought to be outcrops worn smooth by an earlier and higher phase of the Cuyahoga River or its precursor. In support of this hypothesis, note the large rounded boulders (one 40 cm long) wedged under and around these outcrops.

On both sides of this outcrop, the walls of the modern gorge above the trail are intersecting buried valleys. The valley on the east side (centered at 724 m along the trail) is more visible, being a large and smooth half-circle filled with unlithified pebble to boulder gravels. The significance of these valleys is as yet unclear. It is noteworthy that the base of the eastern valley appears to be higher than the scalloped exposures by the trail, which in turn seem to be higher than the base of the western valley. The block of rock beside the trail halfway back down to spring GT-6 shows iron-cemented upper conglomerate that appears to have been polished by stream abrasion or glaciers. The highest Sharon stratum up slope appears to be sandstone with the same iron band, which therefore appears to have been on the floor of this part of the ancient valley.

FIGURE 9-5.—Stops 1.7 and 1.8. A buried valley occurs behind the rocks in the foreground. Photo by D. Waugh.

Stop 1.8

Located at the next large overhang, at latitude 41° 07' 20.95" N, longitude 81° 29' 19.95" W (458961 4552469) (fig. 9-5).

After leaving Stop 1.7 and the buried valley, the trail passes a basal seep at 745 m (spring GT-8), followed shortly by a larger seep in the upper conglomerate, which is fairly thick and has developed a large seep cave. By 767 m, a form set on the ceiling of the overhang provides a three-dimensional exposure of an entire, 35 cm thick, mostly tabular-planar bedform whose foresets are slightly curved (i.e., sigmoidal) at top and bottom. Note that the ceiling of the alcove in the down-valley corner shows that the middle part of the Sharon outcrop has dropped a decimeter or two relative to the down-valley end. Separation along bedding planes above the up-valley end of the alcove likewise shows that the lower part of the outcrop is in the process of tearing off the main outcrop. Such a rockfall should eventually enlarge this alcove, but in the interim, cracks are presumably opening up deeper in the outcrop and no doubt as they evolve they are episodically redirecting water through and around the outcrop.

Water seeps into this alcove from a number of spots on the roof. Each individual seep has a unique chemical composition that is highly variable across the alcove, (table 9-2). Seep GT-9a emerges at the base of the Sharon in the southwest corner of the alcove, and GT-9b seeps out of the ceiling nearby. They have TDS concentrations of 1585 and 1896, respectively. Seeps GT-10a and GT-10b are from the northwest side of the alcove with GT-10a coming from the bottom of the lower bed and GT-10b from the bottom of the upper bed. Their TDS values are 2501 and 4733, respectively.

Table 9-2.—*Chemical composition of spring water from the alcove at Stop 1-8 (Concentrations are in mg/L)*

	Sample no. GT-9	Sample no. GT-9b	Sample no. GT-10	Sample no. GT-10b
Date	11/19/99	3/24/00	9/19/00	9/9/00
pH	6.93	7.08	7.11	8.45
Total dissolved solids	1585	1896	2501	4733
Ca^{+2}	68	71	114	108
Mg^{+2}	15	14	26	9
Na^{+}	490	590	780	1650
K^{+}	4.2	7.9	6.7	13.2
HCO_3^-	122	76	115	90
SO_4^{-2}	102	113	117	230
Cl^-	822	1036	1383	2662
NO_3^-	20.3	22.8	12.4	9.7
PO_4^{-3}	—	0.1	0.3	0.8
SiO_2	8.47	7.94	10.81	11.36
Total Fe	0.01	0.01	0.01	0.03
Mn^{+2}	0.00	0.00	0.00	0.00

Although the chemical composition varies across the alcove, the composition and discharge of individual seeps is fairly constant. Over the period of one year the conductivity of the larger seep in the southwest corner of the alcove (GT-9a) varied by less than 5% and the discharge varied by 12%. This attests to the very effective partitioning of ground-water flow within the Sharon.

At 767 m, the trail is just below Front Street and the cliff above the trail is capped by some masonry and one of the Front Street telephone poles. This explains the presence of salt efflorescence on the outcrop and the considerable salt in some of the seeps here (apparently increasing with proximity to the road), testifying to the fate of road runoff.

Stop 1.9

Starting at 797 m along the trail, just around the corner from Stop 1.8

From the local highpoint along the trail, we see a long rock face with some extensive iron banding and a strong-flowing spring (spring GT 13, at 839 m along the trail, at latitude 41° 07' 26.7" N, longitude 81° 29' 18.1" W [459051 4552647], as shown in plate 5-B). The section here consists of tight basal sandstone with some iron banding development, under rotten yellow sandstone, with extensive and very complex and contorted iron banding and goethite-coated vug development.

At the nearest part of the cliff, before the next low spot in the trail, there is a dead spring perched in a large dry alcove on top of the basal Sharon sandstone. The basal bed shows lovely and extensive iron banding, which shows a well-defined younging-upward pattern ending in some very thick iron beds just under the "rotten yellow sandstone" (plate 11-C, D).

Along the rock face, a basal seep (GT 11) comes out at the base of the Sharon at the low spot in the trail. A small seep and the stronger spring (respectively GT 12 and 13) flow out of the cliff along the bedding plane between the tighter basal sandstone and the overlying "rotten yellow sandstone" (plate 5-C). Thus the yellowing appears to relate to heavy flow through the more permeable layer. Above that is more typical sandstone, and the higher conglomerate, which has become quite thick and shows lots of thick iron coatings. Mid-cliff rock faces show considerable salt efflorescence.

These springs again show considerable differences in chemistry, notwithstanding their proximity (table 9-3). Note that GT-11 is extremely rich in road salt. GT-13 is in some ways similar to GT-11, but is twice as dilute. GT 11 is more similar to the springs at Stop 1-8 and happens to emerge from the same horizon as GT-9a, 9b and 10a.

Table 9-3.—*Chemical composition of springs from Stop 1-9 (see plate 5) (Concentrations are in mg/L)*

	Sample no. GT-13			Sample no. GT-11
	Avg. of 6	Std.	Range	3/25/00
pH	6.52	0.04	6.45 - 6.56	6.74
Total dissolved solids	924	31	890 - 941	2140
Ca^{+2}	74	3	71 - 80	55
Mg^{+2}	19	1	18 - 20	15
Na^{+}	230	22	210 - 270	580
K^{+}	4.7	1.0	3.4 - 6.4	7.0
HCO_3^-	105	4	97 - 109	44
SO_4^{-2}	106	4	100 - 112	215
Cl^-	420	16	386 - 437	1197
NO_3^-	18.12	3.49	13 - 23	43.09
PO_4^{-3}	0.22	0.17	0.06 - 0.55	0.04
SiO_2	10.56	0.67	9.82 - 11.56	12.41
Total Fe	0.01	0.02	0 - 0.04	0.03
Mn^{+2}	0.00	0.01	0 - 0.02	0.00

Stop 1.10

Centered at latitude 41° 07' 27.15" N, longitude 81° 29' 15.85" W (459057 4552660), at 857 m along the trail.

Starting above seep GT-12, the upper conglomerate splits into two, above and below a set of pebbly sandstones, although they once more merge at the NE end of the outcrop.

Two sets of well-developed cross-beds here show interesting lateral bedform evolution, with one bedform becoming gentler and thinner and gradually dying out downcurrent. Up to this point, the upper conglomerate has been quite level and relatively persistent. The best interpretation seems to be that it represents a laggravel formed during a temporary period of downcutting and removal of all but the coarsest available pebbles. A split of the unit suggests locally deep erosion, followed by accumulation of piled-up bedforms back up to the level of the main disconformity, at which point migrating lag gravels would be fed back over the top of the old scour site.

This outcrop shows a series of small conduits and alcoves that appear to have been former springs that have since been deactivated. This would be yet another example of ground-water flow switching from one route to another within the Sharon, presumably as old fractures drain and new ones start to open up.

Stop 1.11

Located 900 m along the trail, at latitude 41° 07' 28.1" N, longitude 81° 29' 12.5" W (459093 4552689) (fig. 9-6).

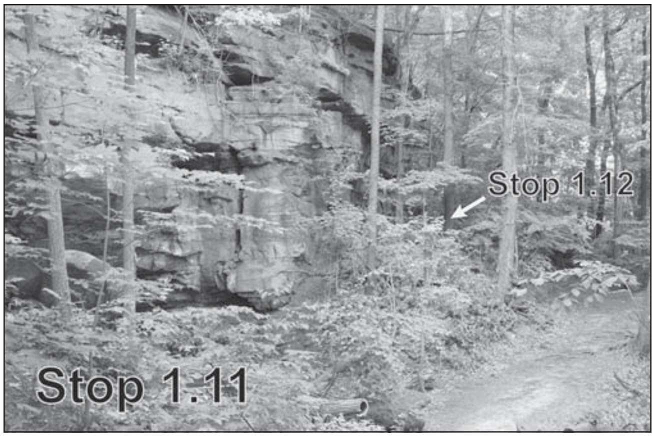


FIGURE 9-6.—Stops 1.11 and 1.12. Photo by D. Waugh.

Just around the next corner from Stop 1.10, facing one of the biggest of the overhangs, undercut by extensive seeping (spring GT 14). The rock face shows a huge but irregular joint with considerable separation, but without appreciable iron coating. The joint strikes 50-230°, as does the valley. This is thought to be a relatively recent valley stress release joint (plate 6-B).

The Sharon cliff shows cross-bedded cosets that descend generally westward, which suggests accumulation on the downstream end of a large bar. The base of the formation in the alcove appears to show about 1.5 m of relief here, although the contribution of construction around the drainpipe is unclear. Regardless, in situ rocks on the NE side of the alcove show a conglomeratic basal portion that is very heavily pyritized (plate 1-C).

Stop 1.12

Located from 30 to 64 m along the trail from the pyrite, at latitude 41° 07' 29.5" N, longitude 81° 29' 13.85" W (459104 4552732) (fig. 9-6).

A set of overturning and bedform development in the Sharon is visible mid-cliff-face (if it isn't just Liesegang banding). A series of megaripples are descending to the south, indicating downflow growth of the front of a large bar as megaripples migrated over its top and down its front. Subsequently developed above this and in front of it is a set of large cross-beds that also grow downstream. However, the tops of the cross-beds appear to be dramatically overturned, and show increasing overturning upward and downstream (plate 3-C, D). Insofar as one can tell with binoculars, the bed appears to become completely massive.

At the far end of this stop (between the trail sign and some steps), some additional extremely complex iron banding is present at the base of the exposure. The trail continues nearly another 300 m to the north parking lot of the American Legion post on Front Street, at latitude 41° 07' 37.5" N, longitude 81° 29' 8.2" W (459239 4552979), which is a good place to pick people up if logistics permit or time is critical. Remnants of the "Chuckery" race along the valley of the Cuyahoga River (fig. 7-1) are best viewed from the end of the trail. We will walk back to our parking lot along the trail.

STOP 2—GORGE TRAIL, GORGE METRO PARK, CUYAHOGA FALLS, OHIO

The Gorge trail runs up the north side of Cuyahoga River, downstream of the Front Street Bridge and the dam (fig. 9-7). From the parking lot take the lower trail down the gorge (posted "to the fishing deck"). Where the raised wooden staircase turns to descend to the foot of the dam, note the deep ravine beside the staircase. This comes from Mary Campbell Cave, which is formed by a modest seep at the base of the Sharon, toward the top of the gorge. We will see the cave at the end of this hike. For the moment, note that the ravine is several meters deep and is cut entirely in a thick mantle of colluvium, without showing any exposures of bedrock.

Stop 2.1

Located at the foot of the dam, at latitude 41° 07' 24.7" N, longitude 81° 29' 50.3" W.

Here, the Sharon crops out at the tops of the walls of the gorge, and the Meadville Member makes up most of the walls of the gorge, down to the level of the foot of the dam. The siltstones and shales from the foot of the dam to the bottom of the rapids below it compose the Sharpsville Member, and the dark shales barely seen at the base of the outcrops across the river belong to the Orangeville Member.

Universal Electric Power's demonstration power generating system can be seen from this stop. This environmental, "fish friendly" generator was designed to retrofit existing dams (see chapter 7, fig. 7-4).

From here the trail runs more or less horizontally along an artificial terrace that was cut to install a sewer pipe that we will see and smell from time to time. While walking along the next part of the trail, note the thick colluvium mantling the hillside, and extensive slumping into the gorge. Float gives us our best look at lithologies and bedding surfaces: coarse sandstones with quartzose pebbles are Sharon, big clasts of siltstone and fine sandstone are Sharpsville, turned up during installation of the pipes, and small pieces of siltstone are Meadville. Many of the siltstones and fine sandstones are isolated (lenticular) ripples, and fields of lunate ripples cap a couple of large blocks of siltstone. Basal tool marks are not uncommon. Fossils are very rare, but some of the fragments show a limited amount and variety of bioturbation. Nearly all the colluvium seems to be derived from adjacent bedrock, but it is possible to find a few glacial erratics (crystalline rocks from the Canadian shield). Gorges in the greater Cleveland area can have a very complex relationship with glaciation (with multiple generations of filling and reburial), but in this case it is difficult to point to anything along this trail that is clearly a till, outwash, or a glacially scoured bedrock trough. The occasional erratics could well have individually been washed in by the river or they could have rolled down or been let down from the till plain above the Sharon Formation. Slumping of the "pipeline terrace trail" at latitude 41° 07' 25.3" N, longitude 81° 29' 50.7" W has necessitated closing and detouring that part of the trail in the last decade, attesting to the continuing evolution of the gorge.

Stop 2.2

Located at the largest ravine crossed on this hike, at latitude 41° 07' 24.3" N, longitude 81° 30' 06.5" W.

This ravine comes from the largest side-valley to be

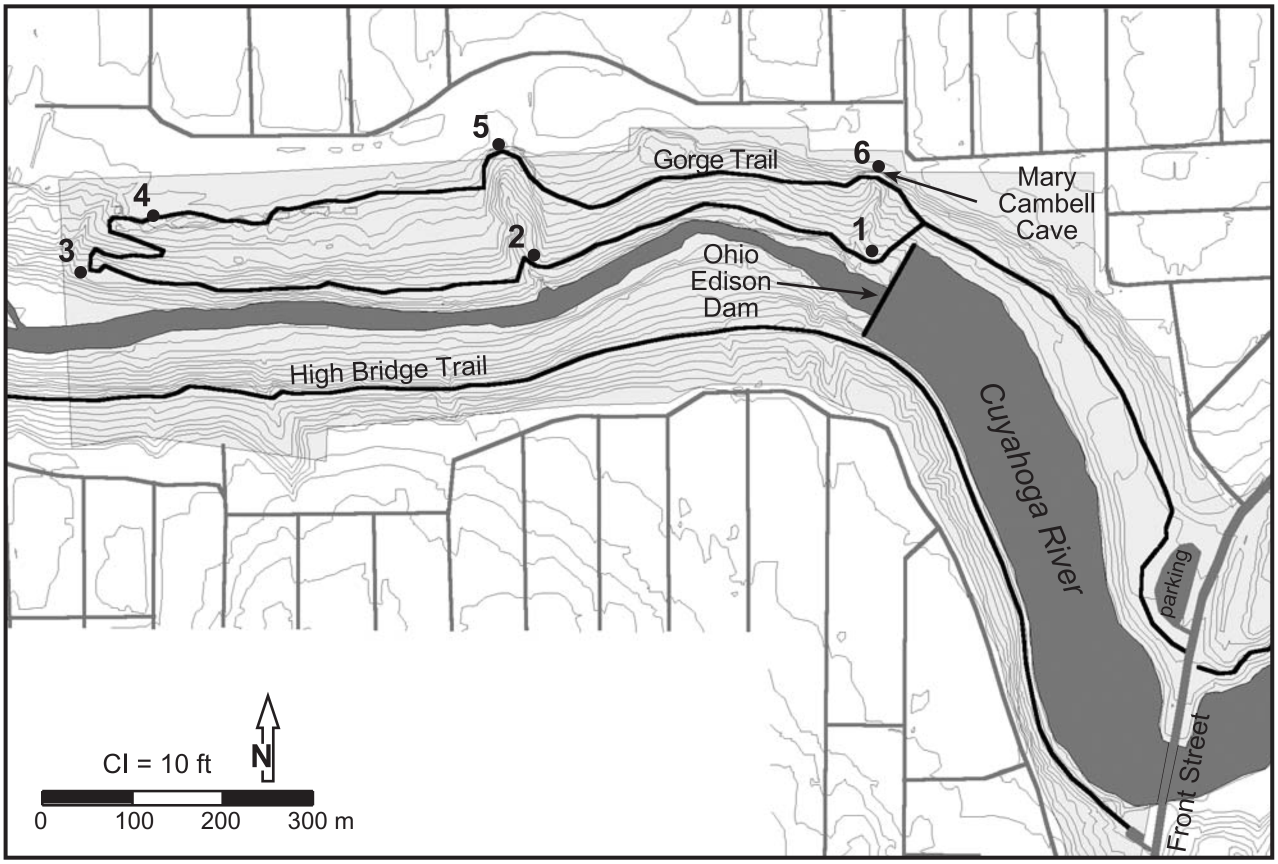


FIGURE 9-7.—Map of the Gorge Trail, Gorge Metro Park (Stop 2), showing Stop 2 locations.

crossed on this leg of the trip (we will see the waterfall over the Sharon during the hike back). Not surprisingly, this ravine offers the best exposures of the Cuyahoga Formation shales and siltstones. The shales by the river belong to the Orangeville Member. The waterfalls in the ravine, from the thick siltstone at the level of the footbridge down to the thick siltstone in the waterfall below the pipeline, constitute the Sharpsville Member, and the shales and siltstones higher up the ravine represent the Meadville.

The shales are predominantly laminated, unfossiliferous, and dark gray (2.5 YR 2.5-5/0), with siderite concretions and cementation. The siltstones can be much lighter (5Y 6/2), and contain abundant flakes of white mica. Most of the siltstones are plane-laminated to cross-laminated, and have little or no bioturbation, with the very notable exception of the bioturbated and nodular bed at the base of the Meadville just behind the footbridge, in which Szmuc (1970) identifies *Taonurus* traces. The bases of some of the siltstones show tool marks, probably from waterlogged wood given the absence of other, more obvious, tools and the presence of plant fragments in some of the shales up-section. At least one bed here shows two sets of nearly parallel and largely continuous grooves, with one set overriding the other (plate 1-A). Prior to a rockfall, the main overhanging ledge below the pipeline, of thick Sharpsville sandstone (since destroyed) showed a set of aligned, decimeter-long, grooves interrupted by equal lengths without grooves. Flute casts can be seen on the base of one of the overhangs just below the footbridge. The bedding plane surface at the lip of the falls contains large hummocky wave ripples. To the west of here, Szmuc (1970) records the Sharpsville interval as a series of shales between two thick siltstone beds that are totally reworked by *Zoophycos* bioturbation.

Stop 2.3

Proceed a few meters horizontally beyond the point where the trail turns uphill, to the edge of the third side-ravine, at latitude 41° 07' 23.7" N, longitude 81° 30' 28.7" W, almost under the State Road bridge.

The bed of the rivulet shows gray shales, passing up into thin lenticular siltstones (i.e., mostly laterally discontinuous, even across such a narrow outcrop). These seem to be the megaripple equivalents of barchan dunes, which is to say isolated, low, hummocky bedforms, moving across bare mud surfaces, unable to accumulate enough sand or silt to form a continuous sheet. Note that the transition to colluvium is mostly rapid, and the colluvium is quite thick. Once in a rare while, brachiopods can be found in siltstones in the float here and upslope, as we climb the hill beside the ravine.

Stop 2.4

Outcrops of the Sharon at the top of the slope, at latitude 41° 07' 26.3" N, longitude 81° 30' 26.7" W.

The Sharon in this area has been broken into a number of subrectangular blocks that are elongate parallel to the gorge (plate 6-C). The blocks in the outermost rank (the ones farthest into the gorge) have pulled out from the lip of the gorge. This allows us to walk completely around the blocks and see the cross-beds and bars from all orientations.

Features to see here include subhorizontal iron banding low on the face of one block. Behind one block, at latitude 41° 07' 26.8" N, longitude 81° 30' 23.3" W, one can see a widespread double-conglomerate layer (the "upper conglomerate" from the first leg), with a small and shallow, pebble-filled, channel, trending approximately to S5°W. The east-west orientation of the crack shows a lot of low-angle trough cross-bedding for trough megaripples heading southward (one set of tabular cross-beds dips 17° to 155°). By comparing the elevations of the pebble layers across the pathway, one can see that the outer block has been rotated outward into the gorge, so that its back has been raised slightly relative to its initial position.

When the path emerges from behind the block, the side face and the front face can be examined. The front face is another east-west joint face, but it has been thickly coated with iron precipitate. The side face shows southward-directed cross-bedding, although the cross-beds are almost obliterated by iron banding. Note that iron precipitate increases toward the front face, making for more extensive honeycomb weathering near the frontal joint face. The front of the next block to the west again shows a head-on view of trough cross-beds, and additionally shows wedge failures, massive iron banding, and rotten yellow pebbly sandstone.

The passage on the north side of the next sequence of detached blocks again shows southward cross-beds on the west- and east-facing sides and transverse cross-sections of troughs on the north- and south-facing sides. The passageway parallel to the gorge shows well-developed iron precipitation over the face, and there is one confusing spot where cross-bed-like iron banding and true cross-beds cross each other at identical but opposing angles.

Stop 2.5

King's Cave, near latitude 41° 07' 27.8" N and longitude 81° 30' 08.0" W

Here, a stream makes a waterfall over the Sharon and carves the largest of the ravines to be crossed on this hike. Seepage along the base of the Sharon contributes to making a long overhang. Relatively recent rockfalls along a fracture parallel to the gorge have removed most of the overhang and have left a rock face with very little iron staining. The rockfall debris is still plugging the head of the valley and has not yet been flushed farther downslope. Meadville shales can be seen in the lower sides of the ravine and along the trail at the east end of the wooden walkway. This is the upper end of the ravine seen at Stop 2.2.

The trail passes several small exposures of light olive gray (5Y 6/2) Meadville siltstones just below the Sharon at about latitude 41° 07' 26.8" N, longitude 81° 29' 56.9" W. The drainage from three springs emerging from the Sharon above (GO-7, 8 & 9) crosses the trail between Stops 2.5 and 2.6

Stop 2.6

Mary Campbell Cave, at latitude 41° 07' 27.1" N, longitude 81° 29' 51.4" W.

This is the upper end of the ravine seen near Stop 2.1. The "cave" is marked by a series of planar vertical fractures that trend approximately 105-285°. This is comparable to the development of the side-valley at the last stop, except that this is at the stage just before rockfalls destroy the overhang, rather than just after. Note that these fractures, like the rock face in the last side valley, are not heavily coated with iron.

The Sharon consists of a basal conglomerate that varies from nearly absent to 50 cm or so thick, and an upper "double layer" of pebbles. The lower conglomerate is carrying enough seepage to have washed out the topmost Meadville beds, which are very shaly here. Collapse of the conglomerate and removal of the shale contributed jointly to excavating this rock shelter.

On the eastern side of the mouth of the shelter, about a meter above eye height, is a feature that has been described as a fossil log. However, it seems more likely to be an iron-coated dissolution passage, as seen along the Glen Trail. One of the blocks on the west side of the alcove contains some more convincing plant fragments. Note that the plaque, which tells the story of Mary Campbell, is mounted on a large glacial erratic.

After viewing Mary Campbell Cave, proceed to the parking lot, and then follow the road log to Stops 3 and 4.

STOP 3—THE PROSPECT STREET OVERLOOK CUYAHOGA FALLS, OHIO

Located at latitude 41° 07' 49.7" N, longitude 81° 28' 58.0" W. Park on Prospect Street, on the east side of Front Street (ignore the offset of Prospect Street to the west). Walk out on the overlook for a view of the narrowest part of the Cuyahoga Gorge, where it cuts through the Sharon Formation. Note a series of natural rapids, enhanced by a weir next to the Sheraton Hotel.

The Cuyahoga River follows a very unusual V-shaped course through this region. It starts only 20 km south of Lake Erie, flows about 65 km SW to Akron, and then turns due north, to flow 45 km NNW to Lake Erie at Cleveland, less than 50 km west of where it started (these distances are given "as the crow flies"). The river flows across several bedrock highs, at which points it tends to develop narrow bedrock-lined gorges. This is the deepest and narrowest of those gorges.

Feldmann and others (1977) summarize that the part of the Cuyahoga River upstream of Cuyahoga Falls as originating as southward drainage from the glaciers. It initially continued south past Akron into the Tuscarawas River. The lower Cuyahoga Valley (the part north of Akron, downstream of Cuyahoga Falls, that flows north to Lake Erie) was a glacial trough that had briefly become a lake. Once the ice melted far enough back to allow northward drainage out of the lower Cuyahoga Valley, headward extension of a side-valley ravine up a former buried valley captured the upper Cuyahoga and diverted it through Cuyahoga Falls and into the lower Cuyahoga Valley. This section of the gorge is clearly very youthful and shows no evidence of formation prior to the last glaciation.

Where the gorge is cut into Sharon sandstones (upstream of the overlook), its sides are narrow and deep, and the scalloping and sculpting resemble the Sharon outcrop face seen at Stop 1.6. Where it cuts into the basal conglomeratic beds, more rapid erosion and disintegration of the conglomerate tends to undermine the sandstone cliffs and collapse them, as seen downstream of the overlook. Subsequently, when the river cuts down into the underlying shales, erosion becomes much more rapid and blocks of Sharon collapse or slide into the gorge, rapidly widening and deepening it.

The cover photo for this guidebook was taken just upstream of this spot. Close your eyes for a moment and imagine this spot as a nineteenth century, industrial center of the Western Reserve. The Sheraton Hotel has an observation area, where you can look across the river and see what remains of the foundations of the old mills. There is also an excellent bedding plane exposure of the Sharon, covered with ripples.

STOP 4—VIGINIA KENDALL LEDGES, CUYAHOGA VALLEY NATIONAL PARK, PENINSULA, OHIO

From the parking lot at latitude 41° 13' 24.6" N, longitude 81° 30' 37.1" W, walk north to the "trail crossroads". Take the eastern trail, toward Icebox Cave (fig. 9-8).

Above the Sharon cliffs, you are looking down on a series of rectilinear passageways formed when orthogonal joint blocks of Sharon Formation pulled away from the upland and slid outward over weak Mississippian shales into surrounding valleys

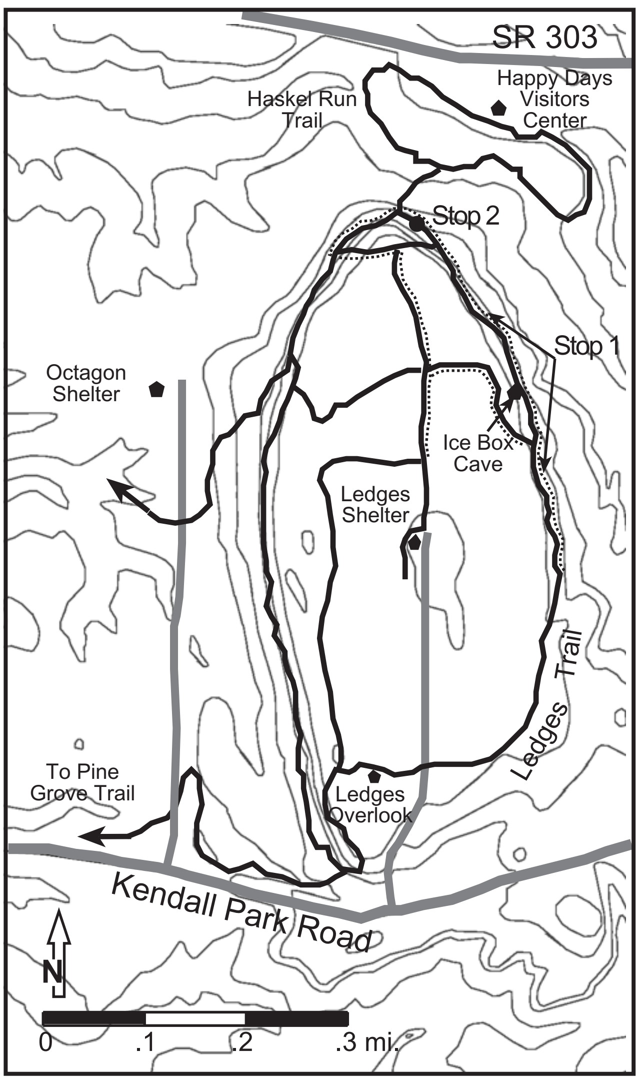


FIGURE 9-8.—Map of the Ledges Trail, Cuyahoga Valley National Park (Stop 4), showing Stop 4 locations.

Follow the trail southward down around the Sharon cliffs. Once we join the path along the base of the cliffs head south for a couple of hundred meters, prior to turning around and coming back.

While walking the southern loop, note a series of seeps along the base of the Sharon. Water from these seeps is very pure and slightly acidic, with a TDS of only 60 mg/L, hardness of 33 mg/L $CaCO_3$, and a pH of 5.3 (table 9-4). These springs are located very close to their recharge areas, in the forests and meadow above the ledges. The total recharge area (the top of the Kendall Ledges plateau) is very small (0.3 km^2) with a thin veneer of glacial deposits, so this water spends very little time in contact with carbonate rich glacial deposits. Because of the small recharge area and limited storage capacity of the Sharon aquifer in this area the flow from these springs varies throughout the year. Flow is greatest in the spring and some springs dry up completely during the late summer.

Table 9-4.—*Chemical composition of spring water from Ice Box Cave, Virginia Kendall Ledges (Concentrations are in mg/L)*

Date	9/18/99
pH	5.3
Total dissolved solids	60
Hardness (as $CaCO_3$)	33
Ca^{+2}	7
Mg^{+2}	4
Na^{+}	3
K^{+}	1.4
HCO_3^{-}	4
SO_4^{-2}	31
Cl^{-}	4
NO_3^{-}	3.55
PO_4^{-3}	0.48
SiO_2	7.90
Total Fe	0.03
Mn^{+2}	0.05

As we return, note the many apparent "channels" that are filled with pebble conglomerate and pebbly sandstone. Mullett and others (1991) showed that the "channels" are not quite at the same stratigraphic level. A couple of the outcrops (at latitude 41° 13' 29.5" N, longitude 81° 30' 28.6" W, and again at latitude 41° 13' 24.6" N, longitude 81° 30' 37.1" W) provide enough three-dimensional exposure to show that these are not channels so much as scoop-shaped scours, rising in all directions from a central low spot, with concentric infill (plate 2-A, B). The two largest scours are on the order of a few tens of meters long, perhaps as wide, and 2.5-4 m deep.

Stop 4.1

Ice Box Cave, at latitude 41° 13' 34.0" N, longitude 81° 30' 31.4" W, and the vicinity to the north.

The Sharon here seems distinctly bipartite, with a gravelly lower part under a rarely pebbly, planar and trough cross-bedded sandstone. The boundary between the upper and lower parts is planar and extensive, and it cuts across all but one of the conglomeratic "channels." The boundary is also marked by a pebble lag, which can be traced quite a distance along the ledges. Paleocurrents are generally to the SW (Ninke and Evans, 2002). Three categories of features will be discussed at this stop: 1) scours & compound bars; 2) springs, vugs, and iron banding; and 3) recumbently overturned cross-beds.

SCOURS & COMPOUND BARS: (fig. 9-9) Note that the conglomerate "channel" at Ice Box Cave does not make sense as a channel (plate 2-C). The south margin (at the cave) is gradational rather than being a crosscut surface. The pebbly beds are inclined southward "across" the channel. Most damning of all, the non-pebbly sandstone beds under the north "bank" of the channel are themselves inclined parallel to the channel, with cross-beds of smaller ripples descending the larger foresets. This is most easily interpreted not as a sandy point bar beside a meandering channel, but as a constructive bar front with a pebble filled scour out in front of it. Note that the top of the sandstone, below the pebble lag layer and upstream of the scour, is massive, suggesting a possible period of root bioturbation between establishment of the bar top and burial of the bar front by infilling of the scour.

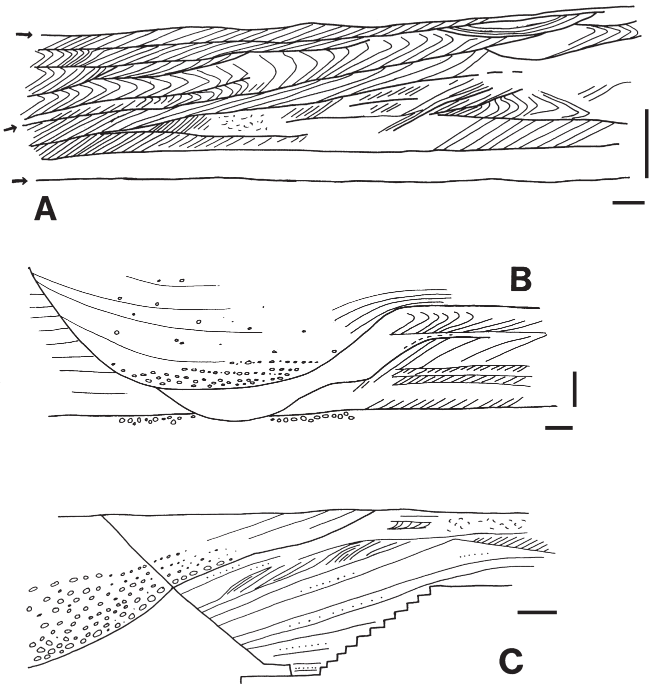


FIGURE 9-9.—Simplified diagrams of bars and giant scours in the Sharon Formation at Virginia Kendall Ledges (from Wells and others, 1993). Scale bars equal 1 m.

A) The downstream end of a large compound bar, with descending sets of cross-beds that show downstream and vertical accumulation. Several of the foresets show recumbent overturning (see plate 4-A, B for an illustration of their formation.)

B) This is the base of a 4 m deep scour that has been filled with pebbles and sand. Note that the upstream end of the scour is subparallel to the avalanche faces of the foresets that feed into it, and also note that the scour was established and filled, and was then reformed in almost the same position. This appears to be a scour pool developed at the foot of a bar, probably at the confluence of flows over and around the bar. A pothole-like swirling of currents has concentrated the coarsest clasts that were passing through the system, and has banked sands up against the downstream exit ramp.

C) The upstream end of the pebble-filled scour at Ice Box Cave (plate 2-C). Again note that the scour is almost coincident with a bar front that gradually built up prior to its formation.

Immediately to the north, over the next two blocks, is an even less evident scour, covered by the same broad lag. This scour consists of pebbly sandstone cut into pebbly sandstone. If you trace the boundary carefully enough it becomes clear that the "cut-bank" of the "channel" dips very steeply into the rock face and runs almost parallel to the rock face, rather than being a gentler slope that strikes at a high angle to the rock face.

Just above the pebble lag layer in the middle of the next block to the north, a series of beds are inclined gently and parallel to the south, with cross-beds that indicate a paleoflow in the same direction as the inclination of the beds. This clearly represents the downstream growth of the front of a compound bar that consisted of a pile of migrating megaripples and was a couple of meters high.

The top of the bed below the pebble lag layer once again seems massive. Above the bar and downstream of it, high on the NW corner of the previous block to the south, there is a narrow and very shallow pebble-filled scour, one of the few concentrations of pebbles above the pebble lag layer.

The southern corner of the next rock wall north (at latitude 41° 13' 39.1" N, longitude 81° 30' 31.5" W) is the "Rosetta stone" for interpreting the "channels". In this case, the scour is not one of the largest, nor does it have the coarsest conglomerate, and it sits atypically high in the section. It is unique (locally, anyway) in sitting above the lag gravel layer. Nonetheless, it is a well-formed double scour, with two episodes of formation and partial infilling. Its northern or upstream end is an avalanche face, and it is not erosional but depositional, as shown by coincident but preexisting megaripple sandstone foresets below the "channel surface". This built out at one level (low enough to cut through the previously noted pebble lag bounding surface), only to be cut back and reestablished at nearly the same site by later and higher flow. Cross-beds descend into the northern end of the scour, but they also descend northward from the south end. This is interpreted to represent flow over the top of a bar and around the sides (out of the plane of the exposure), merging just downstream of the bar to make an unusually deep scour pool. The northwardly inclined cross-beds are interpreted as the result of water swirling around the scour pool, banking a coarse lag against the downstream face of the scour, while flushing finer material downstream. These bars and scours are discussed more fully in Ninke and Evans (2002) and in Evans (Chapter 2, this volume).

SPRINGS, VUGS, AND IRON BANDING: Slightly north of the "Rosetta scour," but on the same cliff face, there are a series of interesting groundwater related facies. First, high in the cliff is an extinct spring (plate 5-D). This clearly dates to an older time when the water table was higher.

Secondly, the same cliff face shows the pebble lag-bounding surface between the upper and lower parts of the Sharon cliffs. Close inspection of this layer shows an impressive development of small vugs (plate 4-C), exactly as seen along Glen Trail in Gorge Metro Park. Some iron coating is present, but it is less developed than on Glen Trail.

Further along the cliff there is some very impressive development of honeycomb weathering, possibly reflecting a greater than usual age for the exposures. There are also many impressive and quite variable examples of iron banding. Banding high in the cliff tends to occur as faint but large swirls, whereas banding lower down tends to be more pervasive and more strongly developed.

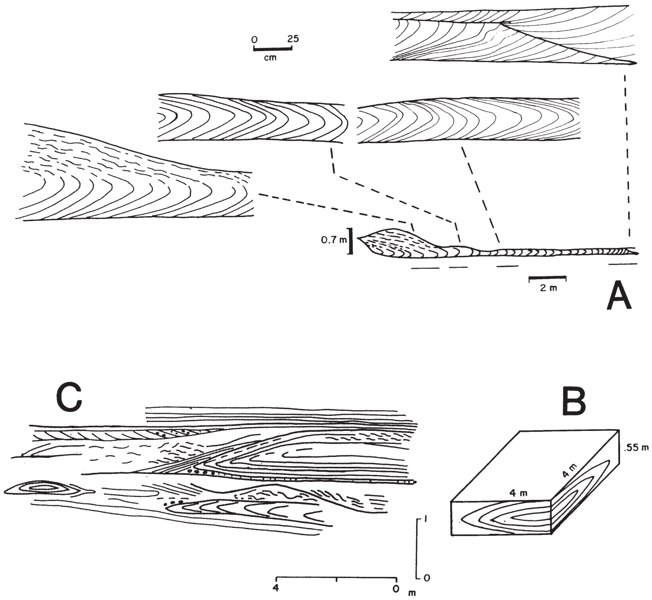


FIGURE 9-10.—Overturned cross-beds from Virginia Kendall Ledges (from Wells and others, 1993). A) Expanded views of parts of a 17 m long bed that shows extreme elongation downstream (at the south end of the westernmost alcove NW of Ice Box Cave). B) This cartoon shows how spoon-shaped trough cross-beds can form oval outlines when overturned (e.g., plate 3-B). C) An end-on view of recumbently overturned cross-beds, forming a concentric oval. At Stop 4.2 (plate 6-A).

RECUMBENTLY OVERTURNED CROSS-BEDS: (fig 9-10) As you follow passageways around to the back of this block, note the southerly cross-bedding in N-S rock faces and the transverse cuts through trough cross-beds on east-west faces. The rocks in this vicinity show an abundance of impressive recumbently overturned cross-beds, basically present as horizontal, nested, V's and U's. Most of these are relatively simple, with a simple, single, horizontal axial plane, and they can be interpreted as horizontal shearing (like offset of a pack of cards) under a downstream current, with offset decreasing downward. However, there are some interesting complications. One set of overturns is stretched out for several meters, until the bedding loses coherence and becomes massive. Several beds show more than one axial plane. In several beds, the axial plane of overturning climbs through the bed (as much as 9° above the horizontal), and in others, they descend, by as much as 12°. In one bed, two parallel axial planes descend downstream. Recumbent overturning occurs in 20-58% of the beds of the upper Sharon, in random succession. Wells and others (1993) presented statistics to show that deformed beds are thicker than undeformed beds (means of 36.0 cm vs. 7.56 cm), and thicker deformed beds show deeper deformation. This in turn suggests that more of the beds would have shown deformation, except that the beds have been eroded below the level of overturning. This is also supported by the observation that undeformed beds have much the same average thickness (13.2 cm) and range of thickness as shown by the undeformed bases of beds with deformed tops. As best as can be told, the directions of overturns are essentially coincident with the directions of flow that caused the original cross-beds.

Many of the variations in shape can be explained by variations in the initial shape of the cross-bed. For example, beds that are initially sigmoidal can develop a "mark of Zorro" outline where the topmost part of the bed fails to show overturning.

Wells and others (1993) used a computer model to confirm that sending a shock wave through the bed while regular currents were moving downstream over the tops of the bars could produce overturned cross-beds. This allowed the bed to shear under the current, with the amount of shearing decreasing upward, because the sand at the top of the bed took longer to settle back into a locked grain arrangement than did sand deeper in the bed. However, the apparent requirement for as much as one earthquake for every one to four bedforms seems unreasonable. However, none of the alternatives seems particularly reasonable either. Tree trunks banging into bars during floods might explain the ramping up of overturning at the upstream heads of bars. Flash floods funneled down narrow gorges might work, especially if the bars had been dry (due to low flow). Some of the complications of multiple or non-horizontal axial planes and thrusts might be explained if the flash flood was briefly preceded by rain that soaked (and thus lubricated) the tops of the bars but not their middles. However, we have not seen any mud drapes that might be indicative of great fluctuations in flow. It is not clear why the bedform tops sheared, rather than simply eroded away. Perhaps bursting of logjam dams in side-valleys during floods might send a pulse or wave of water down on top of a flood, rapidly increasing depth and velocity without increasing basal turbulence and erosion. Wells and others (1993) noted that the abundance of other reports of recumbent overturned cross-beds shows that overturning can be abundant (in the rare places that it occurs). At the same time, recumbent overturning is problematic in that some proposed explanations (like earthquakes) are inadequate to explain locally frequent occurrences, whereas others (e.g., shearing under flash floods) are so common that recumbently overturned cross-beds should be widespread in fluvial sediments. We would be happy to hear other suggestions.

After examining these exposures, follow the trail to the north end of the ledges.

Stop 4.2

Located at the NE corner of Kendall Ledges, at latitude 41° 13' 42.3" N, longitude 81° 30' 41.7" W.

The alcove shown in plate 6-A, has some cross-beds and overturning in transverse section (fig. 9-10 C). One of the beds even manages to approximate a sheath fold, where the cross-beds describe a complete oval in the exposure plane (similar to plate 3-D). However, this is merely the result of starting with spoon-shaped trough cross-beds (i.e., with an avalanche curved like the back of a spoon) and seeing the overturning in transverse section.

At latitude 41° 13' 39.2" N, longitude 81° 30' 43.1" W, a trail branches off to the south that will take us back onto the plateau, and back to the vehicles.

ACKNOWLEDGEMENTS

We would like to thank Lisiniaina Ramisaharimana Wells, Mialy Wells, and Sheila Wells for assistance with GPS, trail pacing, and road log work.

DAY 2

by Joseph T. Hannibal, James E. Evans, and Annabelle M. Foos

STOP 1—RIVER FRONT PARK, CUYAHOGA, FALLS, OHIO

River Front Park provides easy, safe access to the road cuts along Ohio Rte. 8, however it is not recommended that participants attempt to cross the highway. Samples of the Sharon Formation can be collected from the exit ramp road cut. The cuts show numerous bar forms, mostly bar-toe and bar-top accumulations, with some back-bar accumulations. Note mostly southward cross-bedding and concentrations of pebbles along scours, but no actual channels are visible. Also, note the absence of extensive iron banding.

Bedding plane surfaces of the Sharon containing ripple marks can be observed along the river.

STOP 2—KENT DAM, KENT, OHIO

Hike upstream on the Franklin Mills Riverside Park trail to view the Kent Dam. Kent, first known as Franklin, is also located at waterfalls where the Cuyahoga River plunges over the Sharon Formation. As in Akron and Cuyahoga Falls, the early Anglo-American settlers constructed a dam and mill early on to tap the power of the river. Settlers in the nearby hamlet of Carthage, located upstream, just to the north, also built a dam and mill. By 1827, both towns had small populations centered at the mill sites along the river. Additional mills and factories were added and the two adjacent villages were later merged into the new town of Franklin Mills (Brown and others, 1885).

The Pennsylvania & Ohio Canal (the same canal which passed through Cuyahoga Falls) was constructed through Franklin Mills in the 1830's. Surficial bedrock posed a problem for nineteenth-century canal builders. Most canal prisms were dug in alluvial or glacial deposits. It was extremely expensive using the technology of the time to cut through resistant bedrock to create canal prisms. Therefore, in places such as the Black Hand Gorge along the Ohio & Erie Canal, and in Kent along the Pennsylvania & Ohio Canal, sections of rivers were dammed to create slack waters, artificially raised sections of rivers.

The dam and accompanying stone lock at Franklin Mills (now Kent) were constructed in the 1830's utilizing blocks of Sharon Formation stone. The entire length of the Pennsylvania & Ohio Canal was completed in 1840. The lock allowed canal boats to pass from the lower side of the canal up into the higher, slackwater area, and vice versa. The slackwater area extended about one mile above the dam. The stone culvert that carried the canal across Plum Creek in the south of Kent was also constructed of Sharon Formation stone.

According to Gieck (1992), the canal towpath was blasted along the slackwater area on the eastern bank of the Cuyahoga River. Parts of the "Cuyahoga Rapids" (fig. 7-7) at this location were also removed by blasting to make slack-water travel easier (Weaver, 1999). Clearly the river has been somewhat straightened; drill holes in the stone along the side of the canal can still be seen today. A classic, frequently reproduced photograph (fig. 9-11) shows the lock and dam, along with the old covered bridge that crossed the Cuyahoga River. The dam and lock structure was damaged in the great flood of 1913 (Heydinger, 1967).

FIGURE 9-11.—Dam and associated (lower) lock along the Cuyahoga River, Kent, Ohio, circa 1870. The canal prism (ditch) is in the foreground, on the east side of the Cuyahoga River, and the lock is to the bottom right. The old (1837) stone-and-wood covered bridge over the Cuyahoga is seen in the middle right. The current Main Street Bridge replaced that bridge in 1877. Photograph courtesy of Archival Services, University of Akron.

The Pennsylvania & Ohio Canal brought a number of advantages to Franklin Mills. The Central Flouring Mill on the west bank of the Cuyahoga at Grant Street utilized water from the canal (Weaver, 1999). The mill purchased canal water that it then used to power its turbines. The water was returned after usage. The height of the canal usage was between 1843 and 1852 (Weaver, 1999). There was some feeling that the water of the Cuyahoga was being diverted for industries in Akron. The *History of Portage County* reported that "…the canal people, besides controlling the water at this point, were interested in the then rival town of Akron, they diverted nearly the entire volume of the Cuyahoga to their canal, ostensibly for navigation purposes, but really to furnish waterpower to Akron" (Brown and others, 1885, p. 440). The coming of the railroad in the 1850's was the death knell for the Pennsylvania & Ohio Canal.

Some of the present railway right-of-way at Kent runs along the old towpath. Cutting into and modifying the outcrop along the river also added additional space for trains. The contrast between the more modest canal modifications and the later, straighter cuts made for the railways can be seen by looking across the river from the portion of the path in Franklin Mills Riveredge Park just north of the Main Street Bridge in Kent.

Asymmetrical, half-cylindrical quarry marks can be seen in various places along the Sharon Conglomerate bluff just to the north of the Main Street Bridge, on the west side of the Cuyahoga River at Franklin Mills Riveredge Park. The marks are about 6 cm wide and are spaced 30 cm apart. The quarry marks have vertical grooves. These marks probably date back to the time of the canal era.

The old 1837 stone-and-wood bridge that crossed the Cuyahoga River at Main Street was considered inadequate for traffic flow a few decades after its construction. Construction of a "new," three-arched viaduct, made with blocks from the Sharon Formation, was begun in 1876 and completed in September 1877. Grismer (1932, p. 55) reported that most of the stone used was quarried on North Water Street, "near the foot of Columbus Street," in Kent. This quarry area is one block north of Main Street, along what is now the railway right-of-way.

The stone dam and lock at Kent are included in the Kent Industrial District on the National Register of Historical Places. The dam is said to be the oldest existing stone masonry dam west of New York State. Recent efforts by the Ohio EPA to bring the Cuyahoga River back to a more natural state have come into conflict with efforts by historic preservationists to maintain the dam and its waterfall (Kuehner, 2002a, 2002b). The dam at Kent impounds water, lowering its oxygen content. It also blocks movement of fish upstream. As part of the Middle Cuyahoga River Total Maximum Daily Load plan, a plan for improvement of the river in order to meet state water quality standards, the dam will be bypassed, in order to improve water quality and allow movement of fish (Keuhner, 2002a; Ohio EPA, personal commun., 2003). Additional plans call for destruction of most of the historic lock structure, leaving only a western wall in place, but preserving the curved dam adjacent to the lock. This plan was a compromise undertaken in part because of the greater expense of alternative plans to remediate the river quality. Comparison of historic photographs shows that the lock structure was modified previously. Lowering of the dam at Munroe Falls is another part of the Middle Cuyahoga plan (Downing, 2002a, 2002b). These are the first two dam alteration projects in Ohio to be ordered by the EPA (Downing, 2003).

STOP 3—FORMER SITE OF THE IVEX DAM, CHAGRIN FALLS, OHIO

A masonry spillway 7.4 m tall, 1 m thick, and 33 m wide, connected to an earthen dam 152 m long (which mostly still exists) used to be at this location. The dam was constructed in 1842, and failed partially or completely five times (1842, 1877, 1913, 1985, and 1994). The latter failure was catastrophic, following a 70-year rainfall event (13.54 cm rain within 24 hours) on August 13, 1994. The dam failed because of three factors: (1) the spillway was inadequate to handle flood flows, (2) there was no emergency spillway, and (3) the reservoir had lost 86% of its storage capacity due to sedimentation over the 152-year history of the dam. Accordingly, the water rose to the crest of the dam and (under the enhanced hydrostatic pressures) a seepage piping failure occurred at the masonry spillway-earthen dam contact. The failure released approximately 10 million gallons of water and sediment within approximately 2-3 minutes. The former owner decided not to rebuild the dam, and the site is now owned by the Village of Chagrin Falls while it is being restored as a riparian wetland and nature park. (See chapter 8 for photos and additional details.)

REFERENCES CITED

Berner, E.K., and Berner, R.A., 1996, Global environment: water, air, and geochemical cycles, Upper Saddle River, New Jersey, Prentice Hall, 376 p.

Brown, R. C, Norris, J. E., and others, 1885, History of Portage County, Ohio: containing a history of the county, its townships, towns, villages, schools, churches, industries, etc.; portraits of early settlers and prominent men; biographies; history of the Northwest Territory; history of Ohio; statistical and miscellaneous matter, etc., etc: Originally published: Chicago: Warner, Beers & Co., 1885. Facsimile reprint by Portage County Historical Society, 1972, 927 p. plus index.

Downing, Bob, 2002a, EPA cash flows to dam project: clean-water violations high in Ohio: Beacon Journal, October 18, p. B1, B6

__________ 2002b, EPA cash flows to dam project: Summit gets a $500,000 for work along the Cuyahoga: Beacon Journal, October 18, p. B1, B6.

__________ 2003, Dam changes tap river's possibilities: natural flow, habitats expected from Kent, Munroe Falls face-lifts: Beacon Journal, May 27, A1, A4.

Feldmann, R. A., Coogan, A. H., and Heimlich, R. A., 1977, Southern Great Lakes (K/H Geology Field Guide Series): Dubuque, Iowa, Kendall Hunt, 240 p.

Foos, A., 1997, Geochemical modeling of coal mine drainage, Summit Co. Ohio. Environmental Geology, v. 31, p. 205-210.

Gieck, Jack, 1992, A photo album of Ohio's canal era, 1825-1913 (revised ed.): Kent, Ohio, Kent State University Press, 310 p.

Grismer, K. H., 1932, The history of Kent: historical and biographical: Kent, Courier-Tribune, 296 p.

Heydinger, E. J., 1967, The Pennsylvania and Ohio Canal: Towpaths, vol. 5, p. 13-19, 25-31.

Heimlich, R. A., Mrakovich, J. V., and Frank, G. W., 1970, The Sharon Conglomerate, *in* Banks, P. O., and Feldmann, R. F., eds., Guide to the geology of northeastern Ohio: Cleveland, Northern Ohio Geological Society, p.125-138.

Hildreth, S. P., 1837, Miscellaneous observations made during a tour in May, 1835, to the Falls of the Cuyahoga, near Lake Erie: extracted from the diary of a naturalist: American Journal of Science, v. 31, no. 1, p. 1-84.

Kuehner, John, 2002a, To dam or not to dam, that is the question at the Cuyahoga. (Cleveland) Plain Dealer, September 6, p. B2.

__________ 2002b, Cuyahoga to get even more crooked: Kent plans to reroute river around dam to improve water quality. (Cleveland) Plain Dealer, September 16, p. B1, B3.

Liesegang, R. E., 1945, Geologische Baenderungen durch diffusion und kapillaritaet, Chemie der Erde, v. 15(4), p. 420-423.

Mullett, D. J., Kurlich, R. A., Frech, K. R., and Wells, N. A., 1990, Paleocurrent analysis of the Sharon Conglomerate and sandstone lithosomes in the vicinity of Ice Box Cave at Kendall Ledges Park, Summit County, Ohio: The Compass, v. 68(1), p. 21-32.

Ninke, D. J., and Evans, J. E., 2002, Alluvial architecture of the Early Pennsylvanian Sharon Formation in northeastern Ohio: Ohio Journal of Science, v. 102(4), p. 70-81.

Szmuc, E.J., 1970, The Mississippian System, *in* Banks, P. O., and Feldmann, R. F., eds., Guide to the geology of northeastern Ohio: Cleveland, Northern Ohio Geological Society, p. 23-68.

Weaver, Dudley, 1999, The Pennsylvania & Ohio Canal in Portage County, Ohio: Towpaths: v. 37, p. 61-79.

Wells, N. A., Richards, S. S., Peng, S., Keattch, S. E., Hudson, J. A., and Copsey, C. J., 1993, Fluvial processes and recumbently folded crossbeds in the Pennsylvanian Sharon Conglomerate in Summit County, Ohio, USA: Sedimentary Geology, v. 85, p. 63-83.

PLATES

by David A. Waugh and Neil A. Wells

PLATE 1
FACIES AT THE BASE OF THE SHARON FORMATION AND BELOW.

A) Tools marks (presumably from waterlogged wood fragments) on the base of a bed of fine sandstone from the Sharpsville Member, showing two episodes of current movement at slightly different directions. From float, at Stop 2.2, Gorge Trail.

B) Slightly rounded and somewhat imbricated blocks of Meadville Member siltstones redeposited in the quartz pebble conglomerate at the base of the Sharon. The larger blocks are 20-40 cm long. This conglomerate is locally pyritic. Stop 1.3, Glen Trail

C) Base of the Sharon Formation, locally consisting of sandstone and conglomerate heavily cemented with pyrite. The field of view is a little over 1 m high. Located at Stop 1.11, Glen Trail.

D) Plant material in the basal Sharon Formation. The black arrow points to a 35 cm wide mass of coal that is possibly a log or a large rhizome. The white arrows point in the general directions of a series of small rootlets. This surface also contains sulfurous efflorescences. Located at Stop 1.3, Glen Trail.

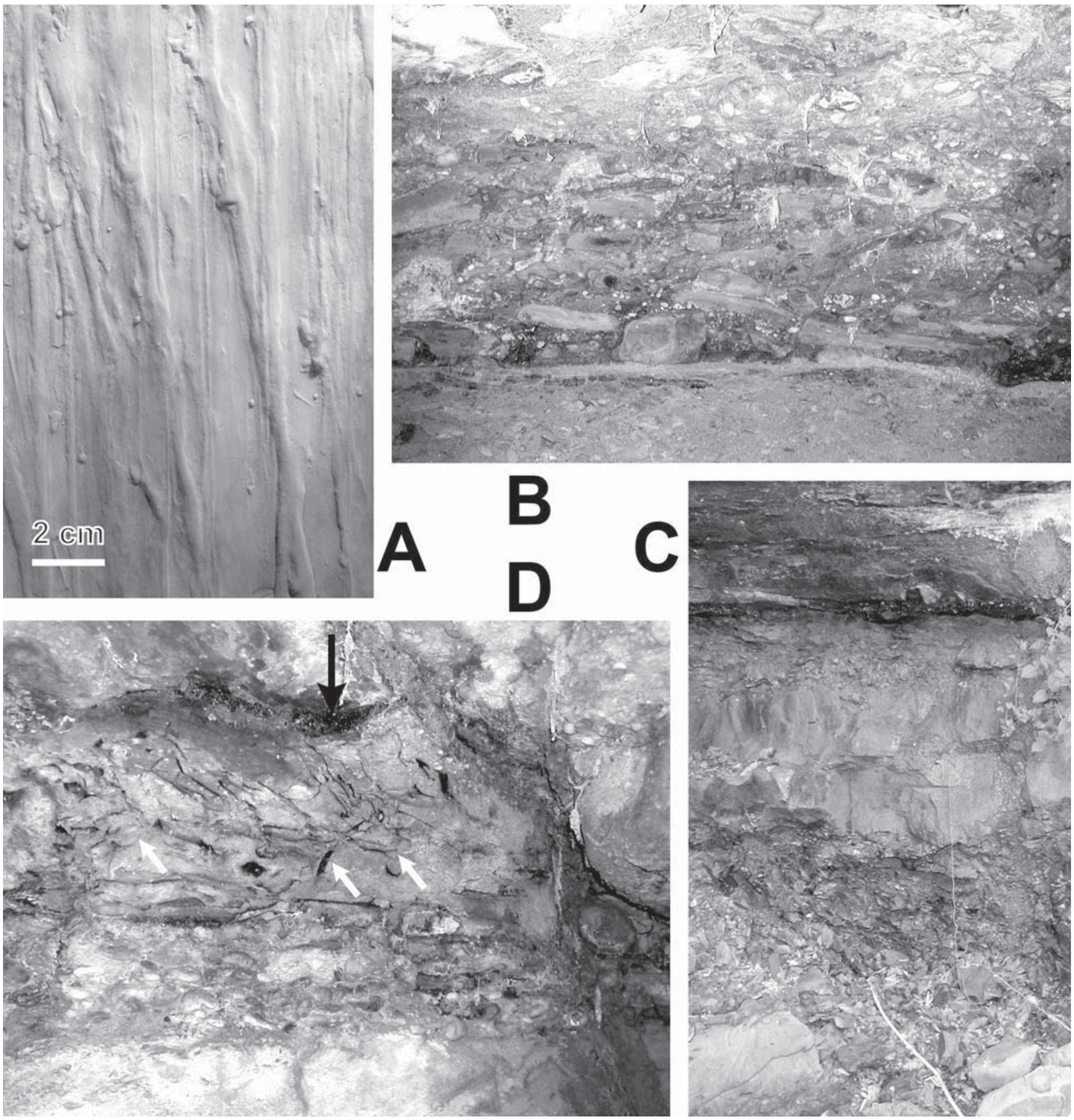

2 cm
A
B
C
D

PLATE 2
CONGLOMERATE-FILLED SCOURS, LOW IN THE SHARON,
AT KENDALL LEDGES.

These photos show various aspects of a series of scours with concentric draped infill that in the past have been interpreted as channels. Beds around the scours consist of sandstones and pebbly sandstones, but beds within the scours consist of pebble conglomerates and sandy conglomerates. A, B and C are located at Ice Box Cave and slightly but progressively farther to the north.

A) South is to the left, with essentially southward paleoflow in surrounding beds. The principal bounding surface here is at the south end of the scour, in effect the downstream exit ramp from a scour pool, with parallel, northward inclined conglomeratic infill.

B) This is a transverse view across one of the scours (flow presumed southward, to left), in the first clearing south of Ice Box Cave. This cut is oriented E-W.

C) North end of the Ice Box Cave scour (South is to the left; see fig. 9-9C). The base of the scour is shown by the arrow, and has parallel pebbly infill. Note that the base is almost but not quite conformable with the southward inclined bedding in the underlying sandstone, and that the angle of inclination, always too gentle for avalanche foresets, increases upward. The sandstone sets consists mostly of laminae that are parallel to the set boundaries, but a few sets are cross-bedded, indicating southward paleoflow. The sandstone indicates the southward and upward growth of the downstream end of a 1-2 m high bar, with a scour pool that formed almost conformably on the bar's downstream end. Note the last unit to be deposited prior to burial of the bar front by scour infill (i.e., the unit on top of the bar and under the bounding surface, right under arrow). It seems to be bioturbated, indicating prolonged exposure and nondeposition, presumably during some progradation and subsequent cutting back the front of the bar during formation of the scour pool. The arrow sits in the shadow of a ledge that separates the Sharon into two units, a basal unit with abundant conglomerate-filled scours, and an upper unit that has fewer scours and pebbles and much more trough and tabular cross-bedded sandstone, with abundant recumbent overturning.

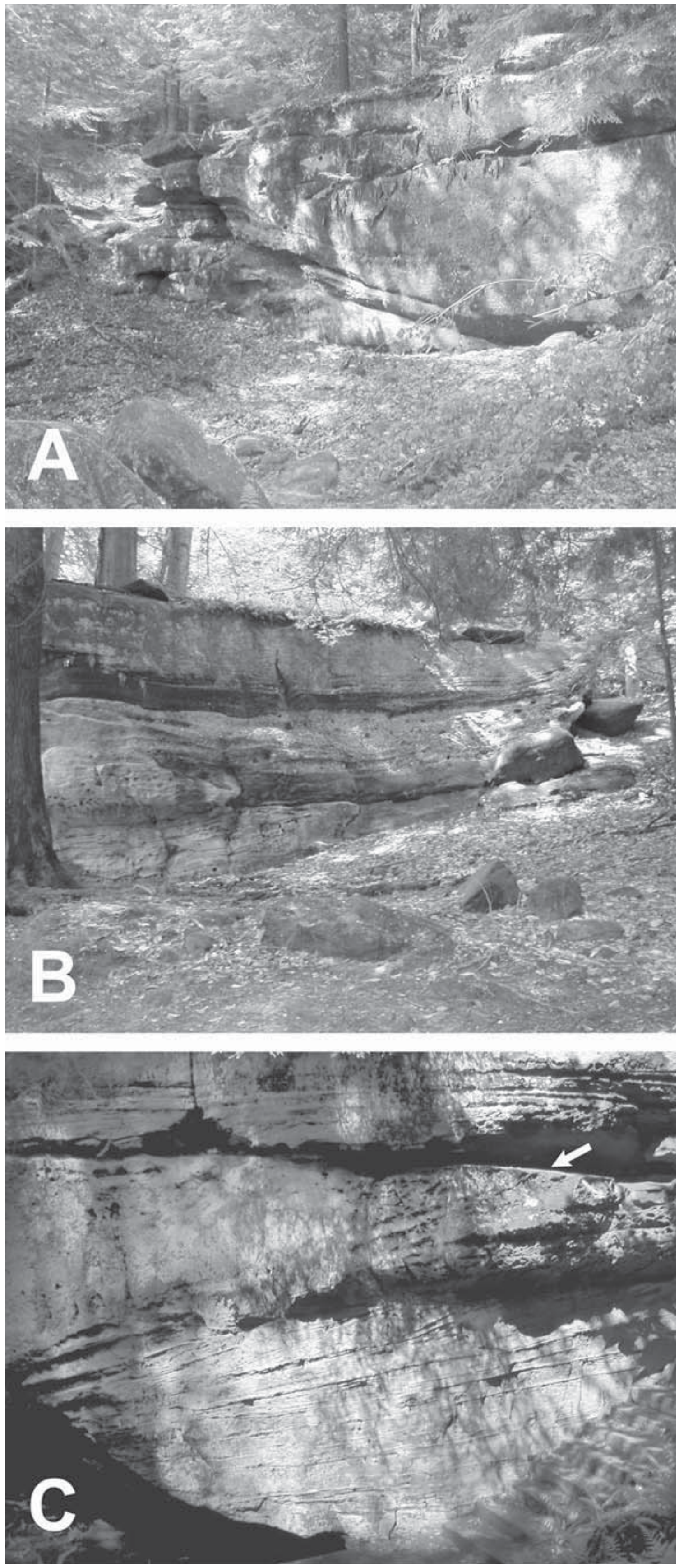

A
B
C

PLATE 3

RECUMBENTLY OVERTURNED CROSS-BEDS.

A) Multiple sets of cross-beds, with many showing overturning in a down-current direction. Note that curvature on the lowest set of cross-beds suggests that this set might have shown overturning as well, had it not been eroded so deeply prior to deposition of the next set. Recumbently overturned cross-beds are caused by shearing parallel to the top of the bed, under paleo-downstream currents, with the offset decreasing exponentially downward from the surface. Located at Kendall Ledges, NW of Ice Box Cave.

B) Spoon-shaped, trough-cross-beds, coming out of the outcrop, with an overturned top, that is creating the geometrical equivalent of a sheath fold. A similar feature can be seen in the SW face of a dead-end joint passage into the Sharon at the NE corner of Kendall Ledges, at latitude 41° 13' 42.3" N, longitude 81° 30' 41.7" W. Photo located under the north side of the State Street (Romig Road) bridge over I-76, SW of Akron.

C, D) Views respectively of the center and left end of a long exposure of downstream accumulation at the downstream end of a bar. Sets of cross-beds decline more or less southwestward, apparently along paleo-flow. Either the bed in the center of the photographs developed overturning, which becomes more extreme down-current, apparently eventually resulting in a massive bed, starting at the left of D, or bedding is completely obliterated by iron banding that strongly resembles overturned cross-bedding. Figure 9-10 C in the Day 1 guide shows a similar but smaller and less arguable example of overturned cross-bedding. Located at Stop 1.12, Glen Trail.

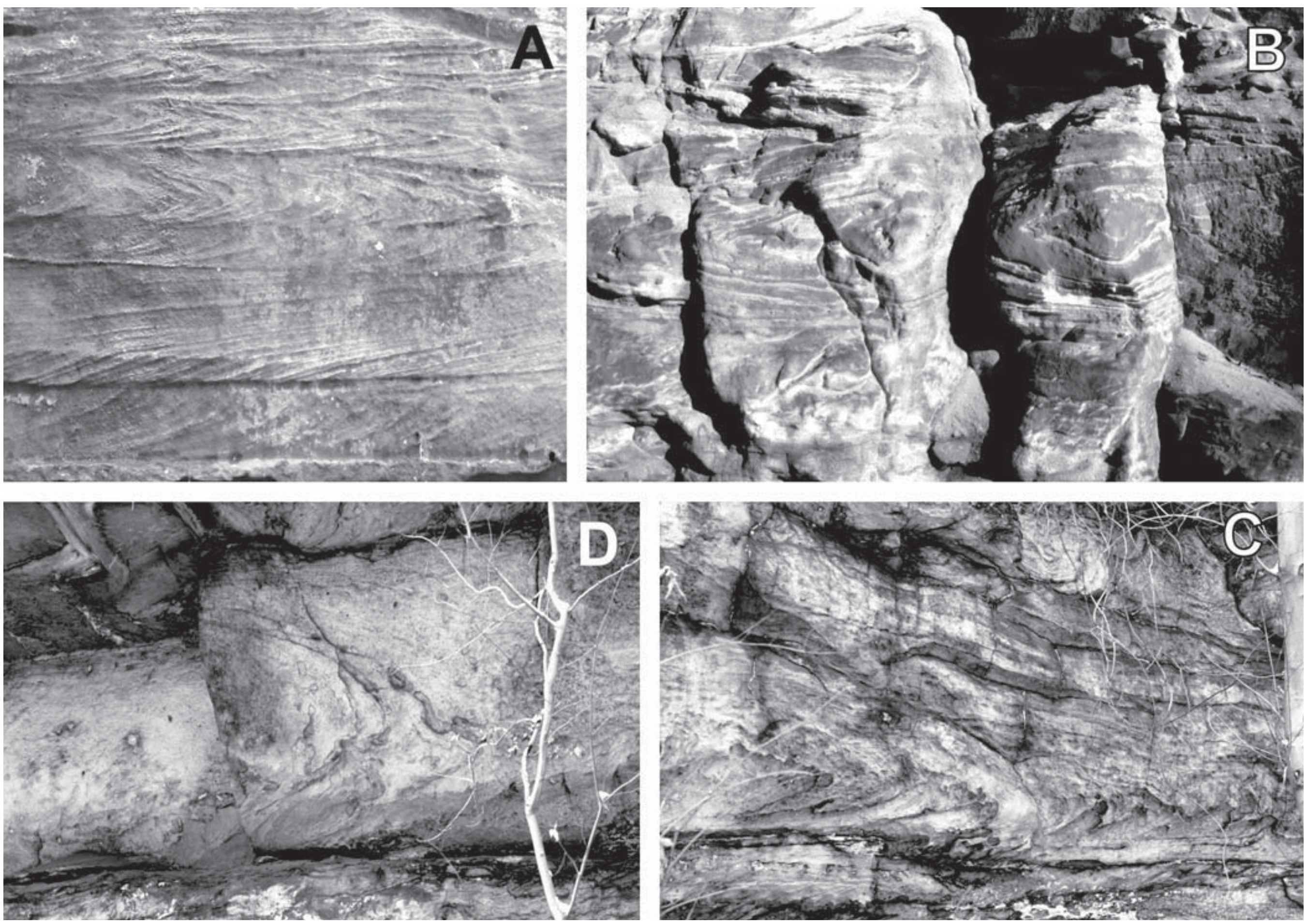

A
B
D
C

PLATE 4

RECUMBENTLY OVERTURNED CROSS-BEDS, MID-SHARON CONGLOMERATE LAYER(S) AND ASSOCIATED VUGS WITH GOETHITE LININGS AND INDURATIONS.

A & B) Illustration of formation of recumbently overturned cross-beds by pervasive shearing parallel to the top of the bed. The right side illustrates foresets of various shapes and angles.

C-E illustrates the distinctively coarse and permeable mid-Sharon conglomerate layer(s) and associated vugs, with goethite linings and indurations. All photos are about 15-20 cm high.

C) Extensive development of small vugs in the mid Sharon pebble lag layer at Kendall Ledges north of Ice Box Cave. This layer separates almost all the conglomeratic scours from most pebbly-free cross-bedded sands above. It might be correlative with the "upper conglomerate" layer in the Cuyahoga Gorge, if it represents a lag developed by a regional drop in base level.

D) Two thick goethite layers, formed on either side of the presumably preferentially permeable "upper conglomerate." Some of these iron coatings can look somewhat like fossil logs. Located near Stop 1.2 on Glen Trail.

E) Indurations and vug coatings, all of goethite, along the "upper conglomerate", near Stop 1.1, Glen Trail.

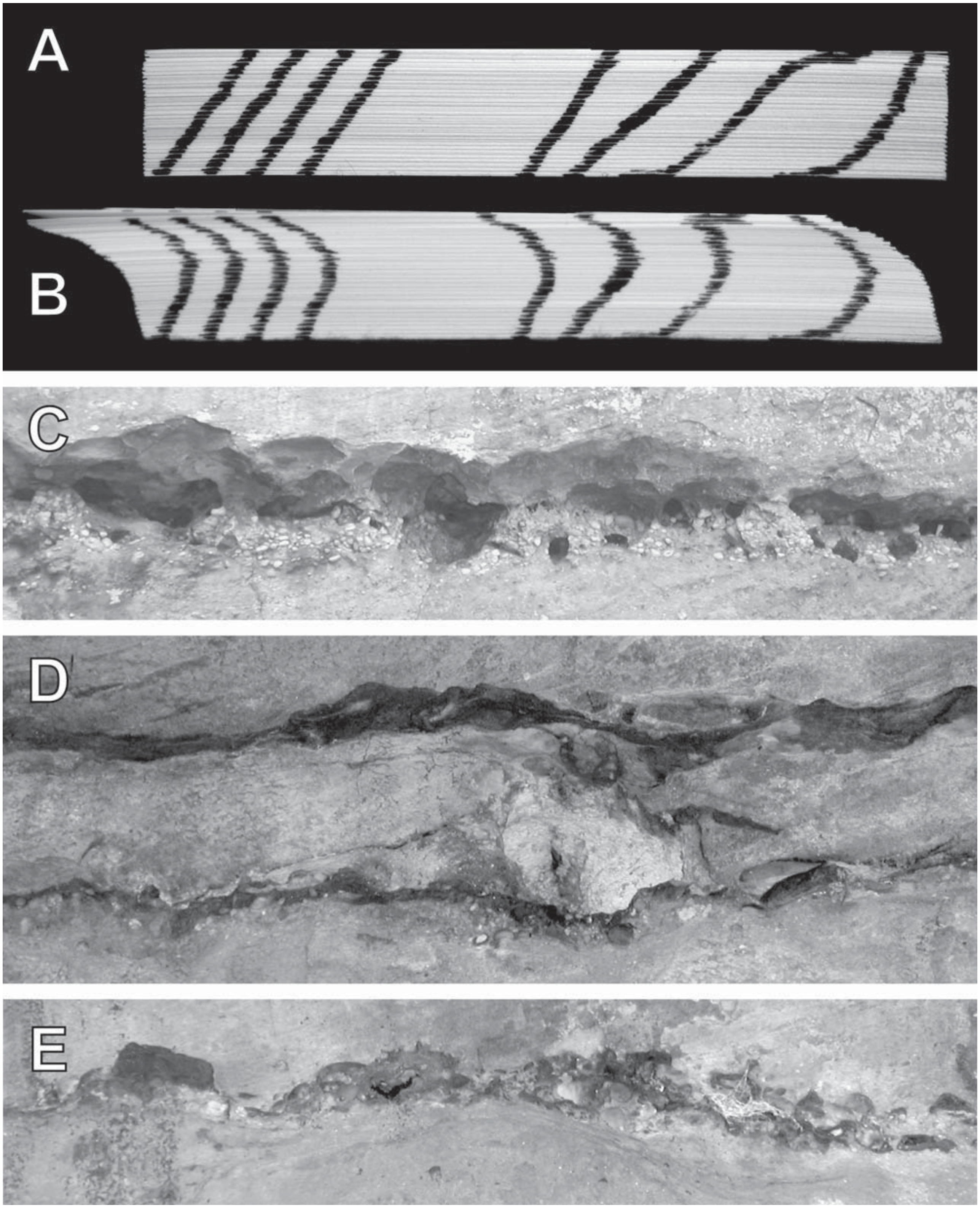

A
B
C
D
E

PLATE 5

SPRINGS IN THE SHARON FORMATION.

A) An ephemeral spring, flowing from a well-developed conduit, located on the west, side of the Kendall Ledges plateau. The rear opening is about 10 cm across.

B) Spring GT 13, a strongly flowing perennial spring at Stop 1.9, Glen Trail.

C) Perspective of spring GT 13 (at the hand of the person by the arrow in the background), and seep GT 11 (pointed to by N. Wells in the foreground). GT 11 comes out at the base of the Sharon, on top of impermeable Meadville shales, whereas GT 13 emerges on top of the relatively impermeable sandstone, at the base of the vuggy and iron-banded sandstone above, just above. Despite the proximity of the springs, their chemical compositions are very different (see table 9-3).

D) Extinct spring at Kendall Ledges. The position of this spring near the top of the cliffs testifies to an earlier period when the Sharon water table was at a higher elevation than today. The mouth of the conduit and "lower lip" erosion are comparable to the spring in A. The stained area is estimated to be 30-40 cm in diameter. Located approximately at latitude 41° 13' 39.1" N, longitude 81° 30' 31.4" W.

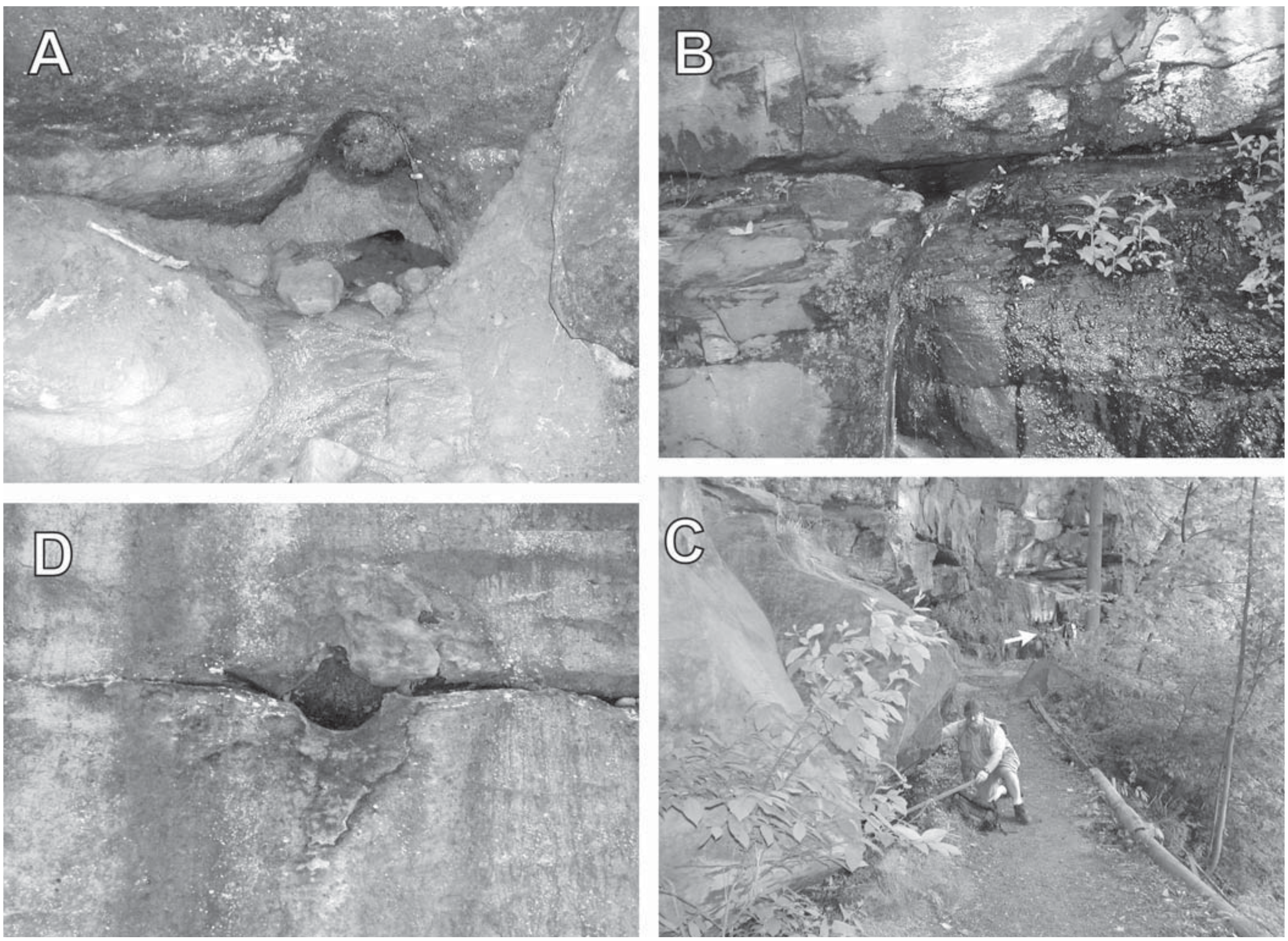

A
B
D
C

PLATE 6

JOINTS AND FRACTURES IN THE SHARON FORMATION.

A) A tall and planar joint, presumably early, where the outer block has slid outward into the valley on weak underlying Mississippian shales, causing a wide separation.

B) An irregular vertical fracture that trends parallel to the adjacent valley. Its irregularity and lack of iron coating suggest that this is a relatively recent valley-stress-release fracture. Stop 1.11, Glen Trail.

C) This joint face is planar and parallel to the valley, and has thick iron coating from top to bottom. The counterpart block that must have existed on the valley-ward side of this block has been completely removed. This block has itself more recently torn loose from the wall of the gorge and has moved about a meter out into the valley, as it is now possible to walk through a valley-parallel fracture behind this block. That second fracture has little or no iron precipitate, so the iron coating on the rock face in the picture argues for formation while the Sharon was still saturated throughout, before the valley-parallel fracture behind this rock mass had opened enough to disconnect the front face from groundwater supply. The second fracture presumably formed after the Sharon aquifer behind it had been substantially drained. Located at the west end of Gorge Trail, Stop 2.4.

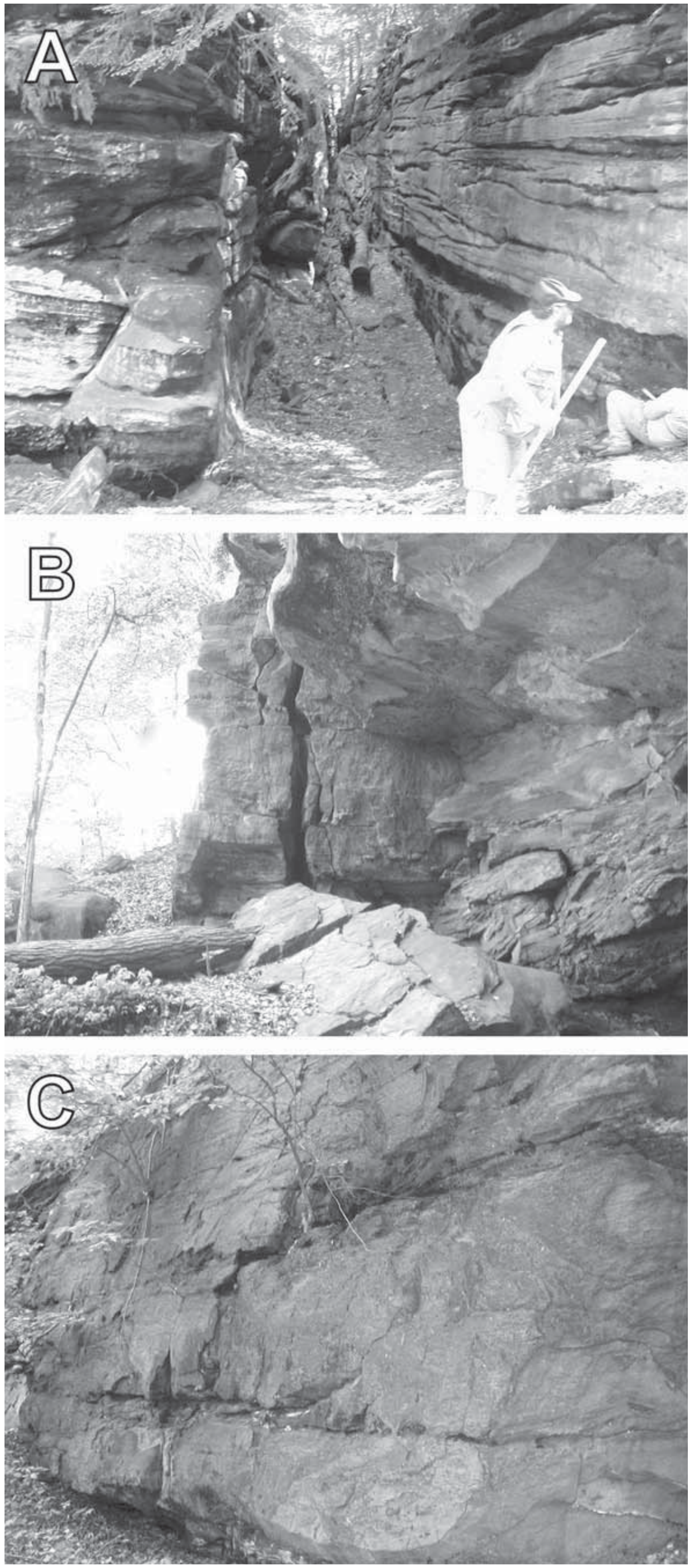

A
B
C

PLATE 7
FEATURES RELATING TO WEATHERING, IRON MOBILIZATION AND VUGS.

A) Honeycomb weathering. Weathering like this can be caused when erosion breaks through a platy indurated surface (as in Plate 6-C) and attacks the softer rock behind or by the creation of resistant projections by preferential impregnation with iron. Because the ridges or "noses" have larger surfaces relative to the volume of rock underneath them they experience more evaporation, which wicks moisture out of the interior of the rock mass, and thereby transports more iron to the ridge crests, whereupon oxidation and evaporation precipitate the iron. At the same time, recesses remain damp and moist and are therefore less cemented and more friable, and thus tend to become preferentially excavated. This view is about 75 cm high

B) A "logoid" that could be the imprint of a fossil log, or a diagenetic iron band. The Sharon contains some logs, proven by the presence of coal and/or additional carbonized rootlets or branches, but some diagenetic iron bands have very similar morphology. Pocket knife for scale. Located low in the Sharon at Stop 1.1.

C) A large but discontinuous vug, about 40 x 20 cm, that is believed to be related to the development of a natural equivalent to acid mine drainage. Located low in the Sharon at Stop 1.5 on Glen Trail.

D) A large vug, about 2 m long, coated with iron minerals. Located high in a joint face above Stop 1.4, Glen Trail.

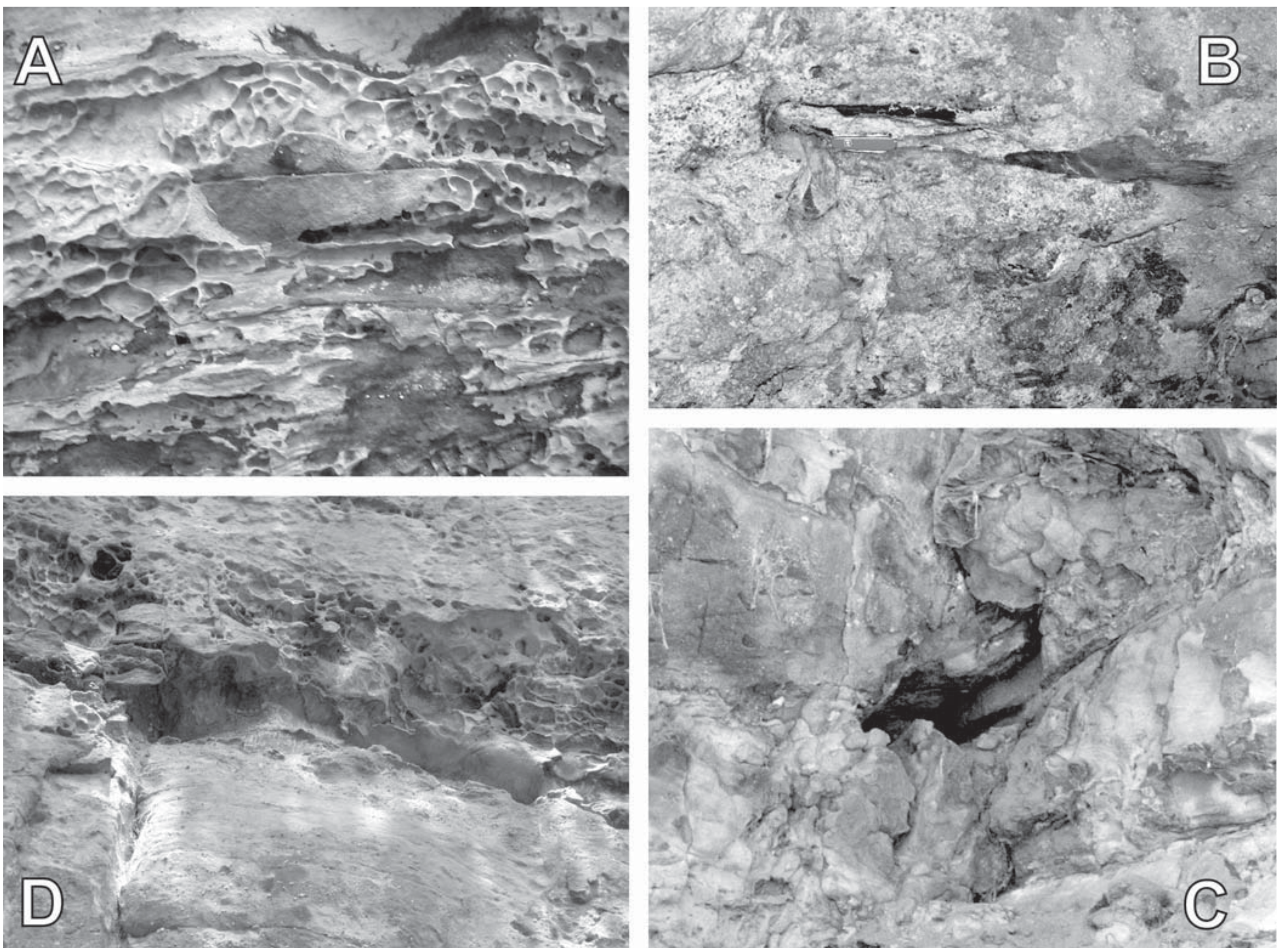

A
B
D
C

PLATE 8
GOETHITE VUG-LININGS AND BANDS.

A) Goethite-lined vug, approximately 4 cm in length, from the upper conglomerate. The base consists of quartz pebbles and sand coated and cemented with goethite, but the roof of the cavity is pure goethite in acicular botryoidal form, indicating growth into an open cavity. Located near Stop 1.11, Glen Trail.

B) Polished section from the end of the vug shown in 8A, illustrating multiple generations of void-filling cement. Note that the sample is tilted to maximize coverage (the scale bar and the text identify the correct horizontal), and some cement generations look different in different areas because of the incident light angles versus changing crystal orientations. The three thin, botryoidal, grayish layers, including the most recent generation that is lining the two vugs labeled V, are slightly reddish gray, radial acicular crystals, suggesting some hematite stain. The thick dark layers are actually the same as the thick glassy speckled layers, which are less well formed but larger radial crystals of very dark goethite, again with a yellow streak. The “white” block (actually pink) under the scale was acicular with lots of quartz silt but now contains hematite, with a red streak, and inclusions or cavities that scatter the light considerably and cause the apparent white color. That material is the same as the first phase of vug lining, “medium gray,” cement next to “B,” and in fact seems to have fallen from the roof of the vug.

C, D) Fairly large vugs, approximately 20 and 15 cm high respectively, lined with goethite, in the upper conglomerate layer. The vugs seem to have been voids prior to lining with goethite, and their sizes and shapes argue against simple removal of disintegrated pebbles. Located at the west end of Stop 1.1 on the Glen Trail.

E) A series of parallel joints has broken the rock into boxes and percolation of water from the joints and bedding planes into the cores of intact rock masses, leaving a succession of ferruginous bands. In these three cases, the bands are oldest in the interior and become younger outward. View is about 1.3 m wide. These are indurations within intact rock, whereas A, C, & D formed by lining pre-existing vugs. From Stop 1.12, Glen Trail.

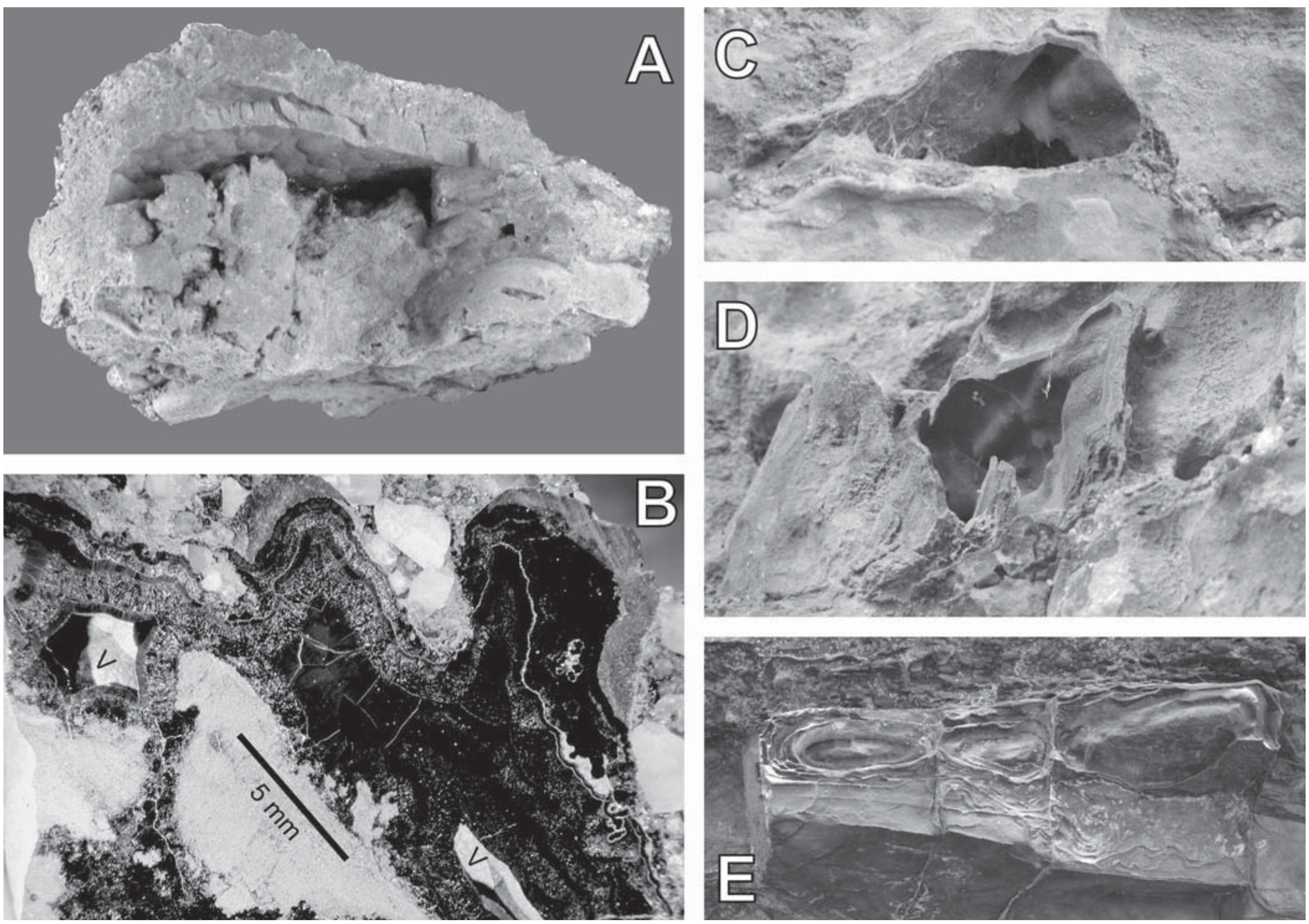

A
B
C
D
E
V
V
5 mm

PLATE 9
REPETITIVE FERRUGINOUS BANDING.

A) Well developed vertical banding, with the main set being oldest at lower left and become younger to the right. The bands seem to be leached on the older side, but grade out on the younger side. Glen Trail, Stop 1.1; view about 0.75 m across.

B) Multigenerational iron banding, with one set formed under the influence of cracks on the right and underneath. Then the crack on the left opened, causing iron banding that cut across the previous set. Stop 1.1, Glen Trail. View about 40 cm across

C, D) Multiple generations of iron banding. D is a close-up of the top right corner of C. Note that crosscutting relationships show that the lower layers are older. The older (or lower) sides tend to be more abrupt and more leached, and the upper or younger sides tend to be more gradational and diffuse. Bands tend to be completely destroyed after being crosscut by another set.

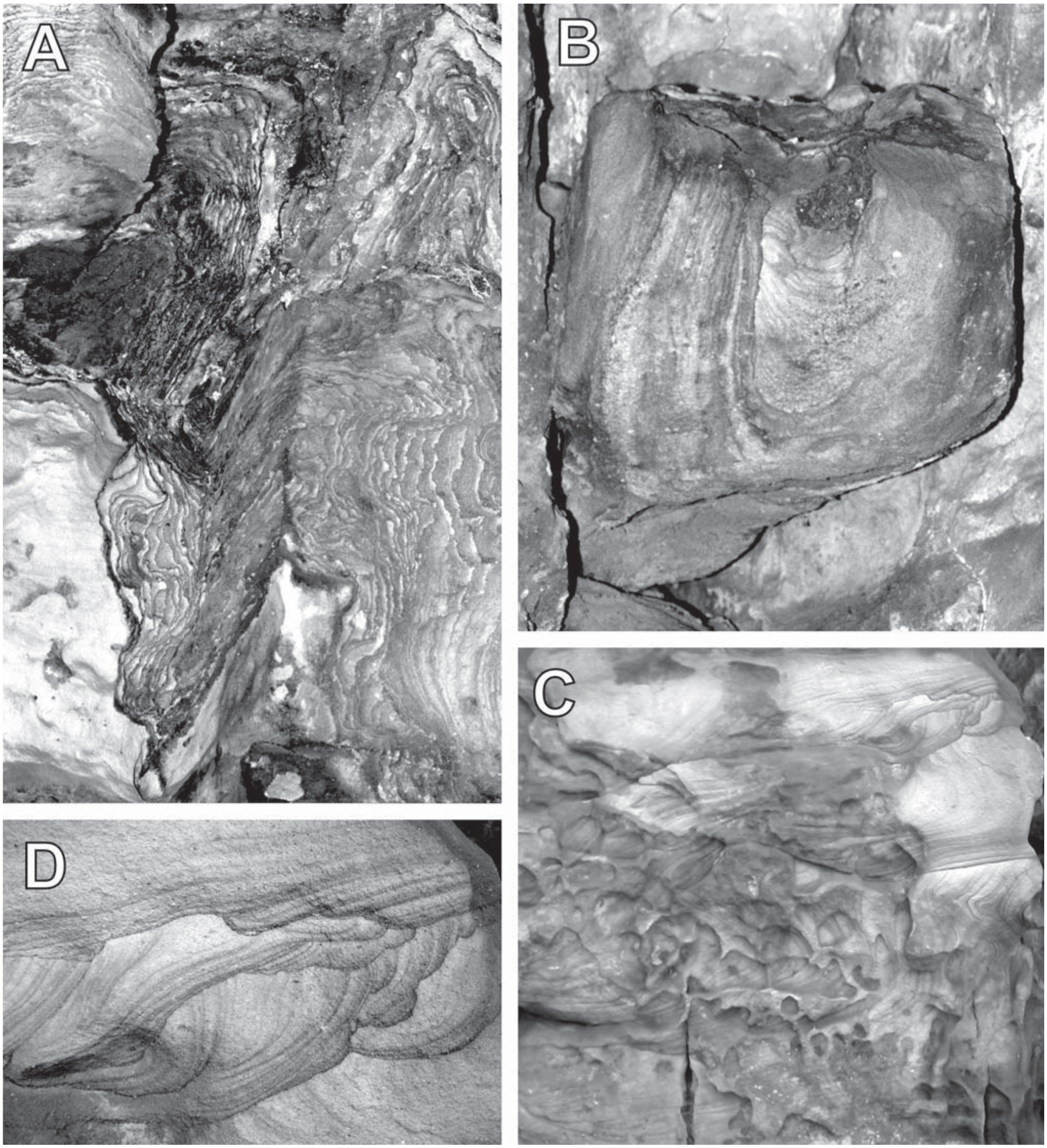

A
B
C
D

PLATE 10
VARIED RELATIONSHIPS BETWEEN BEDDING
AND REPETITIVE FERRUGINOUS BANDING.

Some iron bands follow beds or cross-beds, but many don't, and may furthermore mimic or obscure bedding, locally creating "pseudo-cross-beds."

A) Subhorizontal iron banding that obliterates bedding. The bands at top and bottom of the rock face are subparallel to the relatively coarse, permeable, and unstained sandstone between them. Note how crosscutting relationships show that the lower beds become younger upward, whereas the upper beds become older upward. In other words, band development receded toward the permeable bed over time. The rock face is 60 cm long. Located at Stop 1.5, Glen Trail

B) These foresets dip downward from left to right, whereas iron bands are inclined in the opposite direction. The largest pebble is about 2 cm in diameter. Kendall Ledges.

C) Alternating inclined foresets of granulestone and sandstone overprinted by almost horizontal iron banding. The view is about 50 cm wide. Stop 1.2, Glen Trail.

D) Splotchy iron bands in cross-bedded sandstone, bereft of easy interpretation. The splotches are somewhat elongated and inclined along cross-beds, but are evidently not constrained by them.

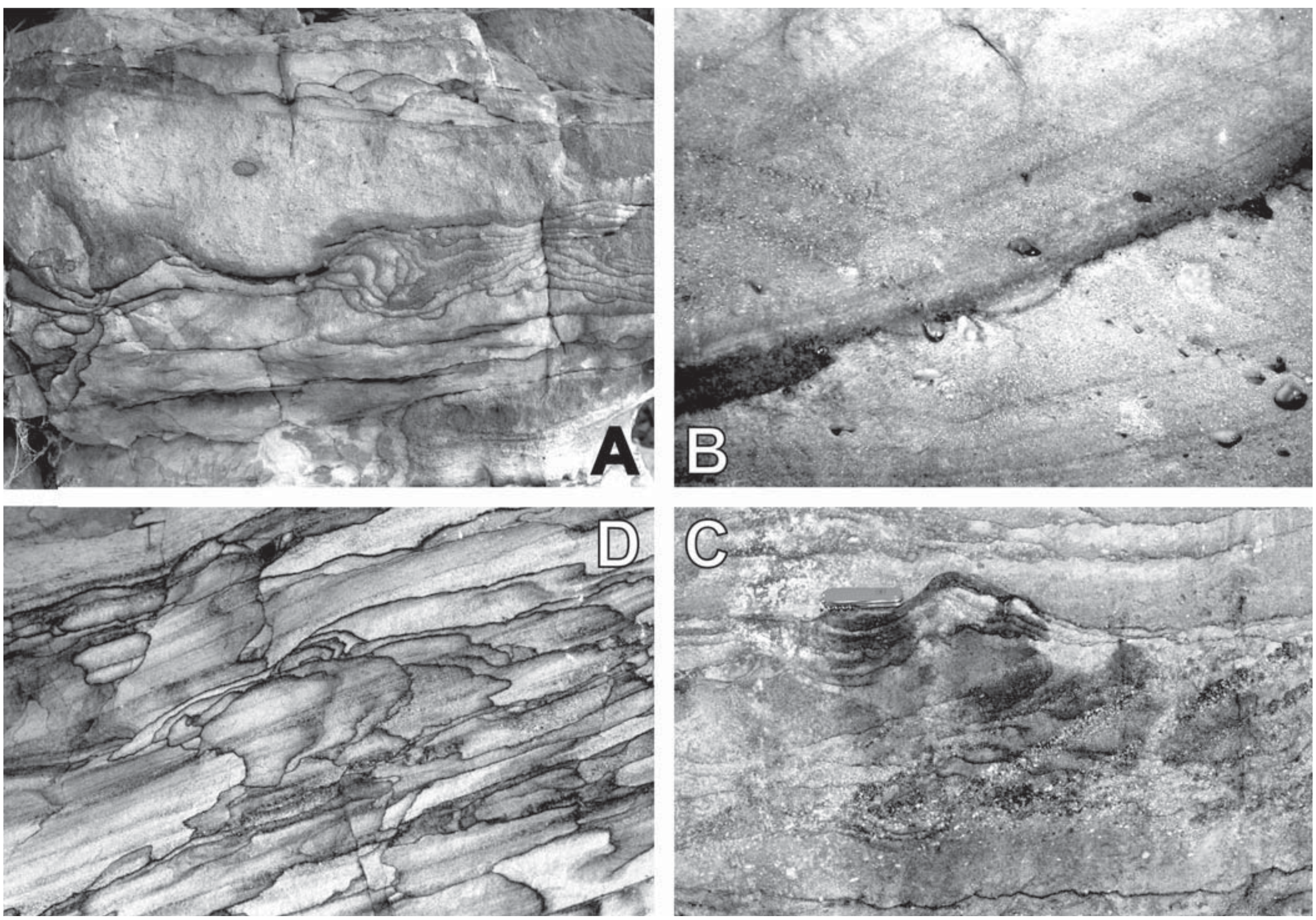

A
B
D
C

PLATE 11
GEOMETRICAL AND AGE RELATIONSHIPS BETWEEN IRON BANDS.

A & B) Front and underside views of compound sets of iron bands. Crosscutting age relationships can be seen in B, which also shows that the frontmost band in each set is thickest and tends to bulge outward. Erosion in A has removed all the softer sand so that several sets of crosscutting “outward bulges” make up the “cauliflower head” surfaces on the rock face. Stop 1.1, at the overhang, Glen Trail. Width of view is 1 m for A, 0.5 m for B.

C) Crosscutting relationships between bands near the base of the lowest bed in the Sharon show that the higher bands are younger (although an adjacent rock face shows the opposite trend). Located below a dry spring on the same bed as springs GT 12 and 13, just behind the photographer’s position in Plate 5C, just SW of seep GT 11, Glen Trail. View is 20 cm high.

D) The top of the same bed as plate 11-C, showing more extensive iron induration, again distinctively younging upward. Note the layer of small goethite lined vugs near the top. View is 30 cm high.

E & F) These bands show the distinct increase in goethite precipitation near the conglomerate, and crosscutting relationships in E show that the bands become younger closer to it. E is a close-up of the right end of F. The ledge in F is the lower split in the “upper conglomerate” at Stop 1.10 on the Glen Trail. Penknife for scale.

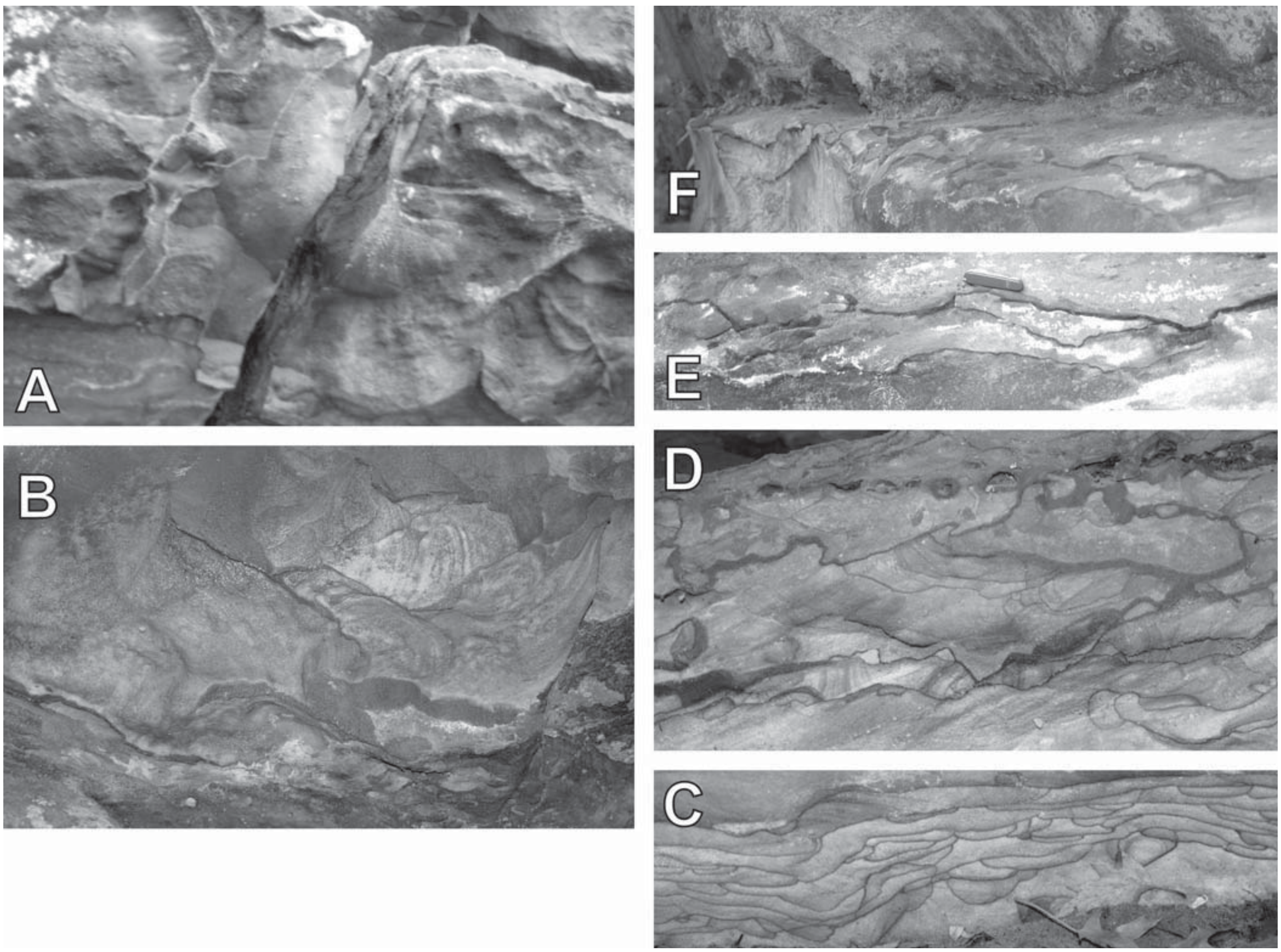

A
B
F
E
D
C

PLATE 12
PHOTOMICROGRAPHS OF PYRITIZATION AT
THE BASE OF THE SHARON FORMATION.

All photos except the last one (I) are from a sample collected at Stop 1.3.

A) Sandstone made of quartz grains, plus a siltstone pebble. The glassy areas are quartz grains in quartz cement, whereas the sparkling intergranular areas are pyrite cement. Bar scale = 5 mm.

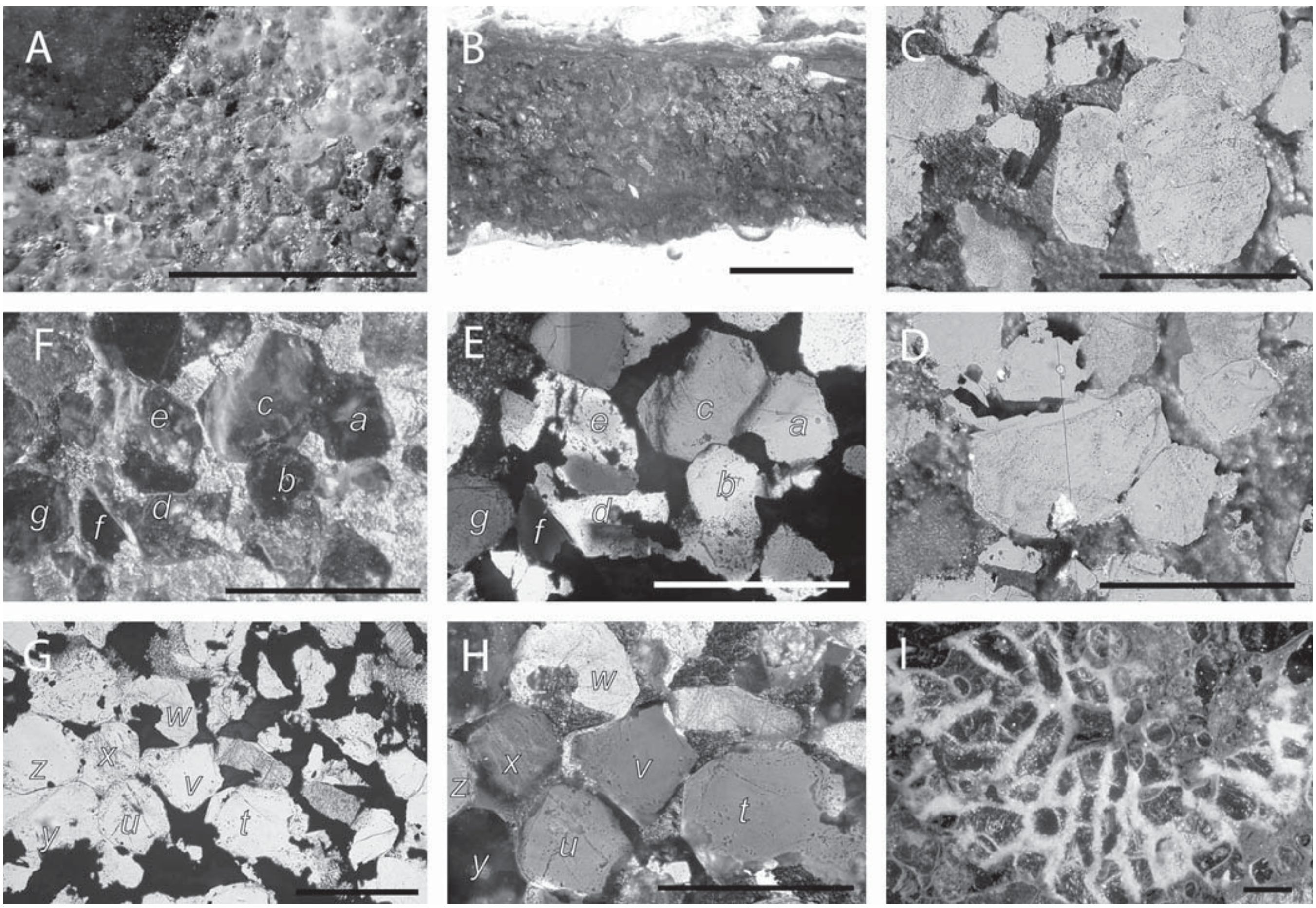
B) Iron rim above the same rock. Most of the rim is now goethite, but the brighter sparkling areas are remnant pyrite. Bar scale = 5 mm.

C, D) The grains are all quartz and show epitaxial and partly euhedral overgrowths plus minor corrosion from the pyrite cement, and the sparkling material between the grains is all pyrite. Quartz cementation seems to have preceded the precipitation of pyrite cement. Bar scales = 0.5 mm. Thin section in mixed reflected and transmitted light.

E, F) Quartz overgrowths and pyrite cement. Grains c, g, and e show euhedral edges due to well-developed overgrowths. The intergranular material that is opaque in E and sparkling in F is pyrite cement. Note how the pyrite embays grains e and d, and blocks light from parts of g and c. Bar scales = 0.5 mm. E is in transmitted light, F is in reflected light.

G, H) Quartz overgrowths, pyrite embayments and quartz cement. Grains t and x show well-developed euhedral overgrowths. Grains w and t show embayment by pyrite. Grains u, x, y and z show quartz cement that has escaped destruction by pyritization. Note how reflected light shows overgrowths that are not otherwise evident (e.g., grain x and especially in grain t, where the light is diffused into an euhedral overgrowth boundary that sits above pyrite deeper in the thin section). Bar scales = 0.5 mm. G is transmitted light, H is mixed reflected and transmitted light.

I) A clast consisting of a fragment of silicified colonial fossil. This is from the lower sample in Plate 13-A. Bar scale = 0.5 mm.



A
B
C
F
c
e
a
b
g
f
d
E
c
e
a
b
g
f
d
D
G
w
z
x
v
y
u
t
H
w
x
v
z
t
u
y
I

PLATE 13

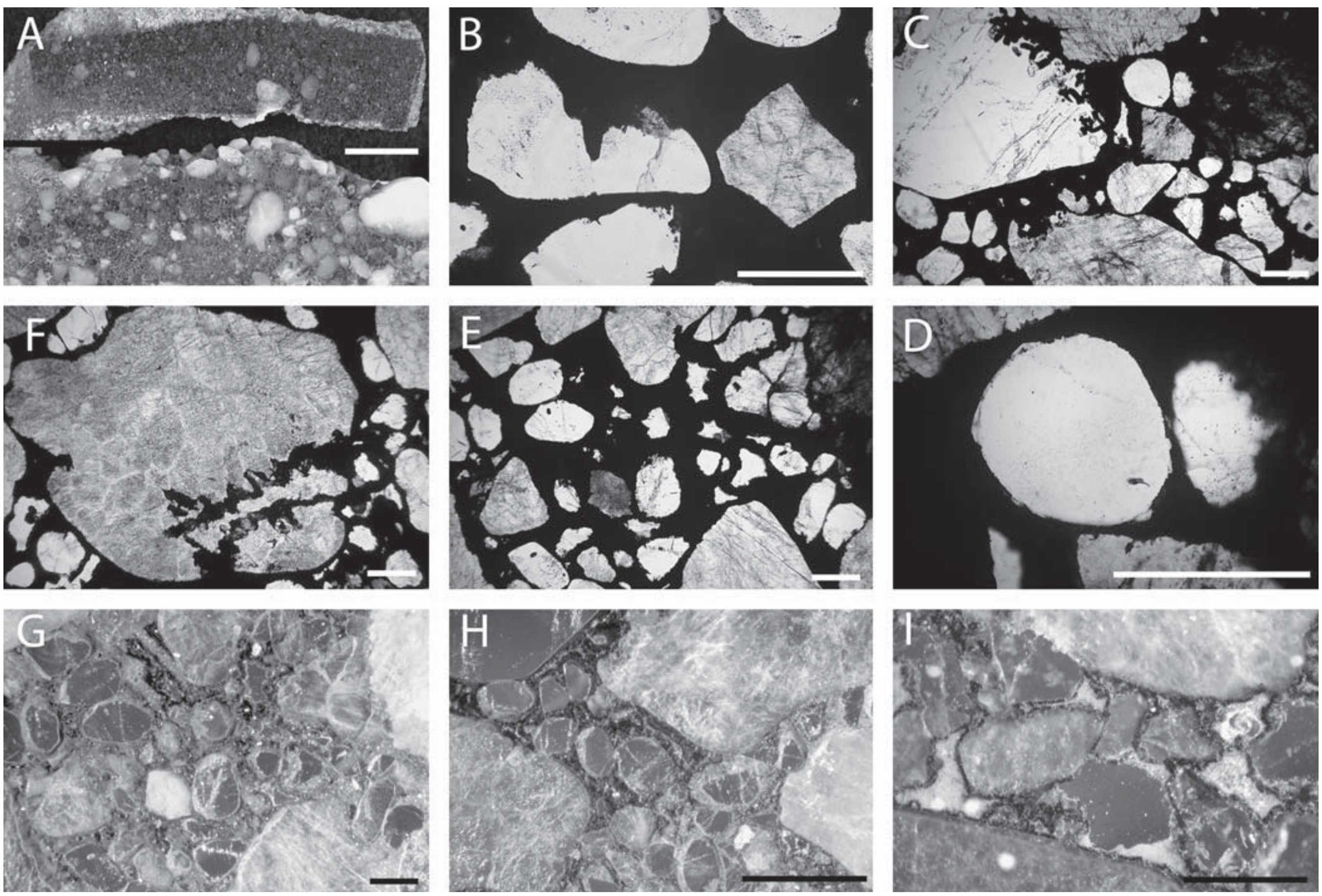
PHOTOMICROGRAPHS OF GOETHITE-CEMENTED AND REPLACED SANDSTONE WITHIN THE SHARON FORMATION.

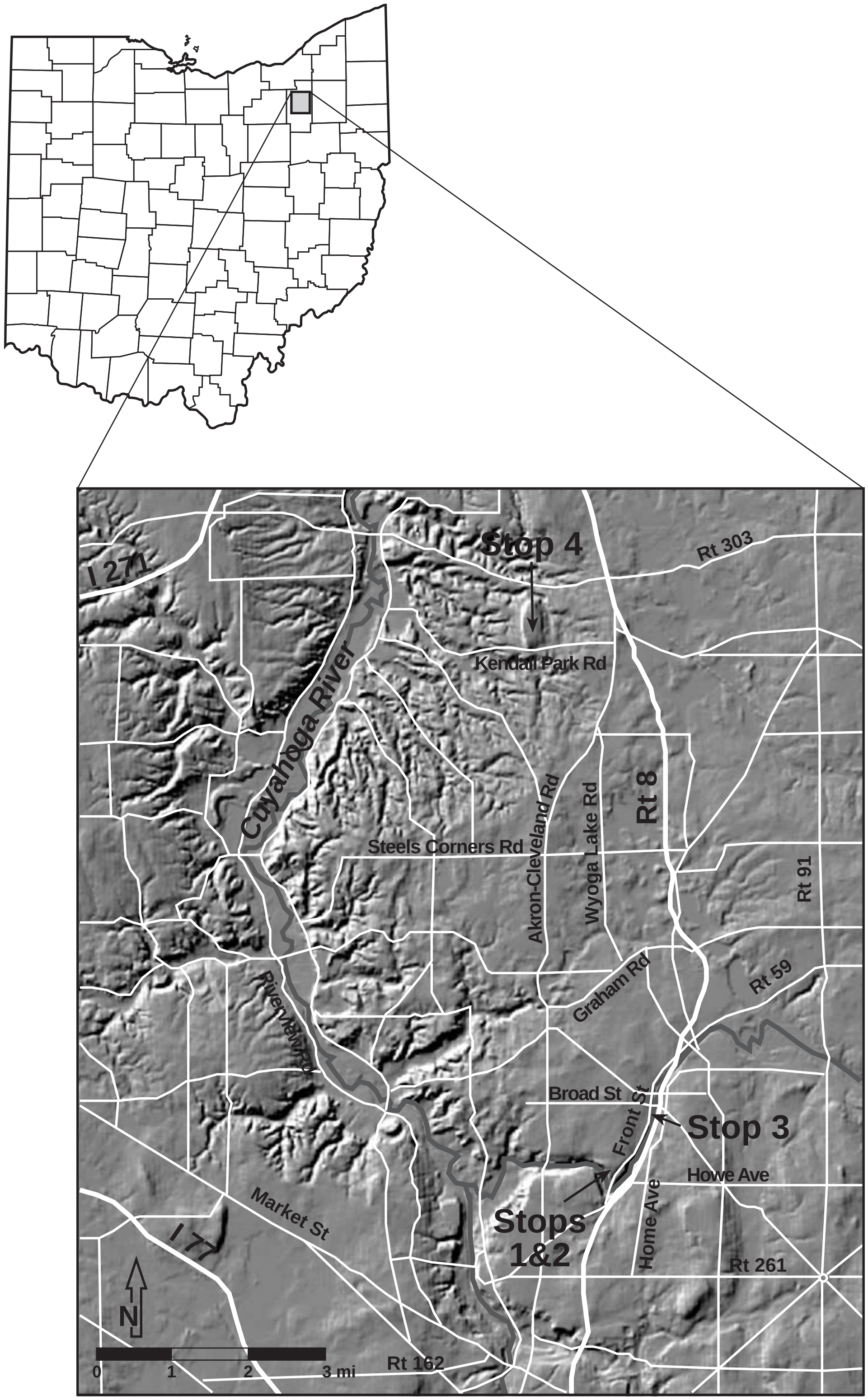
All the thin-section photos are from the lower sample in A.

A) The upper sample is from a goethite-impregnated band within sandstone at Stop 1.5, whereas the lower sample is a goethite-cemented band of conglomerate shown in plate 4D, from Stop 1.2. Bar scale = 5 mm.

B-F) The opaque areas are iron minerals, and the quartz grains have been heavily corroded and embayed. Note the very few surviving grain-grain contacts, especially in E. There are a few empty pores, distinguished by their incurved arcuate edges, such as the tiny clear area in the center of C. The quartz grain with arcuate edges in B is embayed by botryoidal goethite. The large grain in C was vermicular chlorite in quartz, prior to destruction by goethite, and the grain in D preserves some epitaxial overgrowths. Quartz overgrowths may have been more common prior to extensive destruction of grain surface by the pyrite. Bar scales = 0.5 mm. Transmitted light.

G-I) G shows rims of “limonite” or hematite (yellow to red in reflected light) around pores filled by goethite (extremely dark brown in reflected light). In H, the extremely dark intergranular cement in the upper right half of the grain is goethite, whereas the intergranular material in the lower left is “limonite” (orange in reflected light). In I, goethite rims (very locally botryoidal and radial fibrous) surround the grains, and “limonite” (the light-colored pore filling that is earthy yellow in reflected light) fills some of the pores. A few intergranular spaces, not shown here, preserve some pyrite. Bar scales = 0.5 mm. Reflected light.


A
B
C
F
E
D
G
H
I



DIGITAL ELEVATION MAP SHOWING THE LOCATIONS OF DAY 1 FIELD STOPS