From: Beggs, Tauren R - DNR
Sent: Wednesday, January 31, 2018 10:29 AM
To: Bradbury, Ken
Subject: Re: Manitowoc County info - Follow up

Hi Ken,

No problem, I have been out sick most of this week so I totally understand. Thanks for getting back to me on this!

From: Bradbury, Ken <ken.bradbury@wgnhs.uwex.edu>
Sent: Monday, January 29, 2018 3:57 PM
To: Beggs, Tauren R - DNR
Cc: Deith, Linda
Subject: RE: Manitowoc County info - Follow up

Tauren-

I apologize for the long delay in getting back to you. I was traveling, and we had some other staff out with the flu, and we're now catching up. Attached is Pat McLaughlin's last report on Manitowoc County. Pat now works for the Indiana Geological Survey, so specific questions about this report should be directed to him there at pimclaug@iu.edu.

Best, Ken Bradbury

Kenneth R. Bradbury
Director and State Geologist
Wisconsin Geological and Natural History Survey
University of Wisconsin - Extension
3817 Mineral Point Road
Madison, WI 53705

Phone: 608 263 7921

Email: Ken.Bradbury@wgnhs.uwex.edu
http://wgnhs.uwex.edu/about/people/ken-bradbury/

From: Beggs, Tauren R - DNR [mailto:Tauren.Beggs@wisconsin.gov]
Sent: Wednesday, January 10, 2018 4:27 PM

To: Bradbury, Ken <ken.bradbury@wgnhs.uwex.edu>
Subject: RE: Manitowoc County info - Follow up

Hi Ken,

How have you been? I am looking to follow up on the bedrock mapping research/publication about Manitowoc County that was prepared by Patrick McLaughlin. You provided the bedrock map in March 2016. The report that goes with the map, was that completed? And if so, is there a way I can access it?

Hope you are doing well!

Regards,

We are committed to service excellence.
Visit our survey at http://dnr.wi.gov/customersurvey to evaluate how I did.

Tauren R. Beggs
Phone: (920) 662-5178
Tauren.Beggs@wisconsin.gov

From: Henderson, Dave [mailto:Dave.Henderson@aecom.com]
Sent: Monday, March 28, 2016 5:00 PM
To: Beggs, Tauren R - DNR <Tauren.Beggs@wisconsin.gov>; Heinen, Elizabeth M - DNR <Elizabeth.Heinen@wisconsin.gov>; Johnson, Dave M - DNR <Dave.Johnson@wisconsin.gov>
Cc: GravelPit (GravelPit@manitowoc.org) <GravelPit@manitowoc.org>
Subject: FW: Manitowoc County info - Follow up

Team,

FYI see the attached.

dsh

David Henderson, P.E.
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From: Bradbury, Ken [mailto:ken.bradbury@wgnhs.uwex.edu]
Sent: Monday, March 28, 2016 4:52 PM
To: Henderson, Dave
Cc: Maletzke, Jeff; Dan Koski (dkoski@manitowoc.org); Pat McLaughlin pimclaug@iu.edu
Subject: RE: Manitowoc County info - Follow up

Hi Dave-

Yes, Dr. McLaughlin has completed the map in draft form, and I have attached a copy. Pat is currently working on a report to go with it.

Please let me know if you have other questions.

Best wishes,

Ken Bradbury

Kenneth R. Bradbury
Director and State Geologist
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Madison, WI 53705

Phone: 608 263 7921

Email: Ken.Bradbury@wgnhs.uwex.edu
http://wgnhs.uwex.edu/about/people/ken-bradbury/

From: Henderson, Dave [mailto:Dave.Henderson@aecom.com]
Sent: Saturday, March 26, 2016 10:34 AM
To: Bradbury, Ken <ken.bradbury@wgnhs.uwex.edu>
Cc: Maletzke, Jeff <Jeff.Maletzke@aecom.com>; Dan Koski (dkoski@manitowoc.org) <dkoski@manitowoc.org>
Subject: Manitowoc County info - Follow up

Ken,

About a year ago members of our Team (WDNR & AECOM) met with you concerning an environmental impact site in Manitowoc County. The site name is the Former Newton Pit.

At the time I understood that, if I recall correctly, Patrick McLaughlin was completing a bedrock mapping research/publication about Manitowoc County.

Could you please provide me an update on that publication and, if its available (even in draft form) where I might find a copy of it.

Thanks
dsh

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FINAL REPORT

Bedrock geology of Manitowoc County, Wisconsin

Project status and explanation of deliverables
Year 3 of 3

P.I. McLaughlin, W.G. Batten, K.C. Roushar, P.R. Schoephoester, E.K. Stewart, and K.R. Bradbury

Core drilling at the Eden Stone quarry in Valders, Wisconsin. The worked interval is a thick flank bed on one of the many fossil reefs that characterize the Silurian in eastern Wisconsin. Core from this site helped us assess the composition and age of the reef interval.

This work was supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program, under assistance award no. G14AC00142.

UW Extension
University of Wisconsin-Extension
Wisconsin Geological & Natural History Survey

Project background

For the past 3 years, the Wisconsin Geological and Natural History Survey (WGNHS) has been mapping the bedrock geology as part of a 3-year STATEMAP project. This report describes the work performed over the course of the project and summarizes the major conclusions and implications of this mapping.

Manitowoc County lies on the shores of Lake Michigan in east-central Wisconsin. The county was chosen for bedrock mapping to address pressing societal issues and broader scientific questions. For example, a major resource issue involving the bedrock geology of the county is the dwindling availability of dolomite for construction aggregate, ornamental/decorative stone, and high-quality lime used in steel production. Most quarries are more than a century old and are running out of reserves on their permitted properties. A general lack of knowledge about the concealed bedrock and its contained groundwater has created a barrier to the issuing of new mining permits. Our work mapping the bedrock geology is helping the county identify and plan for the development challenges related to these natural resources.

The new bedrock map also provides the necessary geologic framework for groundwater quantity, quality, and migration studies. Scientific questions that can now begin to be addressed with the completion of this map include the following: How does the lithologic character of the bedrock influence fracturing and regional groundwater flow patterns? How do high concentrations of arsenic in sulfides associated with late-stage alteration of the bedrock affect groundwater quality? What other geologic factors, such as the distribution of brine in the subsurface, should be considered together with the hydrostratigraphy in water use planning?

Wisconsin's mapping strategy

The Manitowoc County project is one of three STATEMAP projects undertaken by the WGNHS during FY2014. We are also mapping the bedrock geology of Columbia County and the Quaternary geology of the Driftless Area. Each of these projects follows our long-range Geologic Mapping Plan for the state and address scientific and societal needs. The projects were chosen in consultation with our geologic mapping advisory committee and reflect the ongoing discussion, evaluation, and prioritization of the changing needs of the citizens of Wisconsin. Our mapping advisory committee continues to endorse our mapping at the regional- and county-level scale (1:100,000). The geologic problems addressed, as well as the relative lack of pre-existing high-quality data, determine the appropriate scale at which an area is mapped. Therefore, the WGNHS mapping plan consists of multi-year projects producing interim maps that will form the basis for the final geologic maps prepared at the 1:100,000 scale.

Summary of deliverables and mapping procedure

The ultimate goal of this 3-year project was to create a 1:100,000-scale digital bedrock geologic map and cross sections of Manitowoc County. For year 3 of 3, we are submitting the following five quadrangle maps prepared at 1:24,000 scale (locations shown in fig. 1), the 1:100,000 compilation county map with two cross sections, and this document describing project status. Each zip file contains a PDF of the map and a copy of this report.

Year 3 deliverables submitted for FY2014:

1. Brillion Quadrangle
2. Denmark Quadrangle
3. Morrison Quadrangle
4. Reedsville Quadrangle
5. Whitelaw Quadrangle
6. Manitowoc County compilation map (1:100,000) with two cross sections

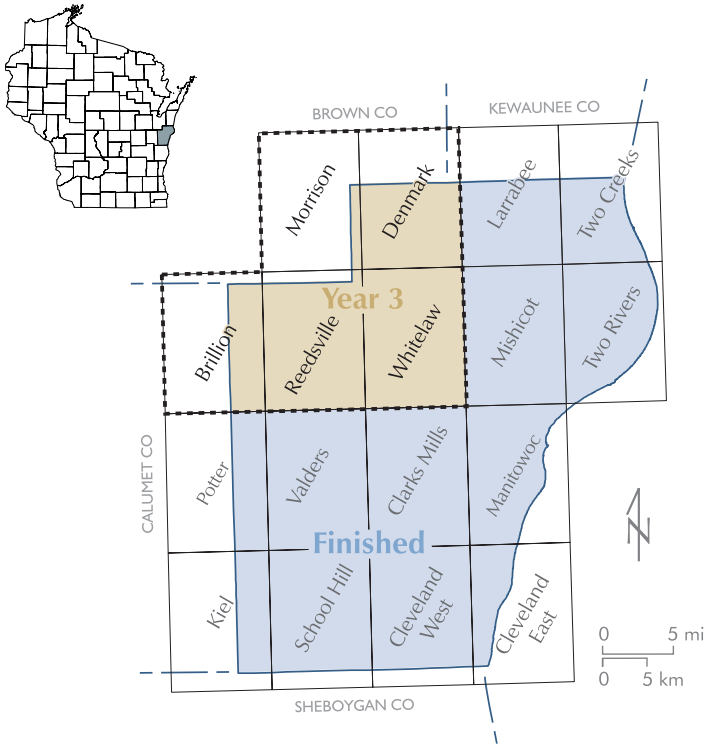

Figure 1. Manitowoc County showing completed and current year mapping.

The mapping procedure was an iterative process, as outlined in figure 2. First, the WGNHS used a geographic information system (GIS) database to compile drill cuttings from municipal wells and well construction reports from private wells into "working version" base maps of the bedrock surface for the current map area. The base maps are used to identify regions where collecting drill core and borehole geophysical data would provide the best understanding of the bedrock geology. The ultimate location of drill core is controlled by a variety of factors:

1. How thick is the glacial overburden? *At least 95 percent of Manitowoc County's bedrock is concealed below glacial deposits. Our drill rig can penetrate a maximum of about 50 ft (15 m) of unconsolidated material; however, nearly half of the county's bedrock is below more than 100 ft (30 m) of glacial till.*
2. How many formation contacts are we likely to encounter? *Our drill rig is able to core up to 600 ft (180 m) below land surface. The greater the number of contacts encountered, the more useful the core for mapping.*
3. How fractured is the dolostone in the area? *If the dolostone is too fractured, we risk "locking" the drill string, potentially leading to the loss of the unpenetrated section, drill bit, reaming shell, and drill pipe as well as much time.*
4. Can we obtain permission to work in the target area? *Much of the map area is private land, and access is not always granted.*

As a result, some of our 7.5-minute quadrangle map deliverables will not have a new core within its boundaries; however, the geology within the map area will have been re-interpreted based on new data from neighboring quadrangles and nearby cores.

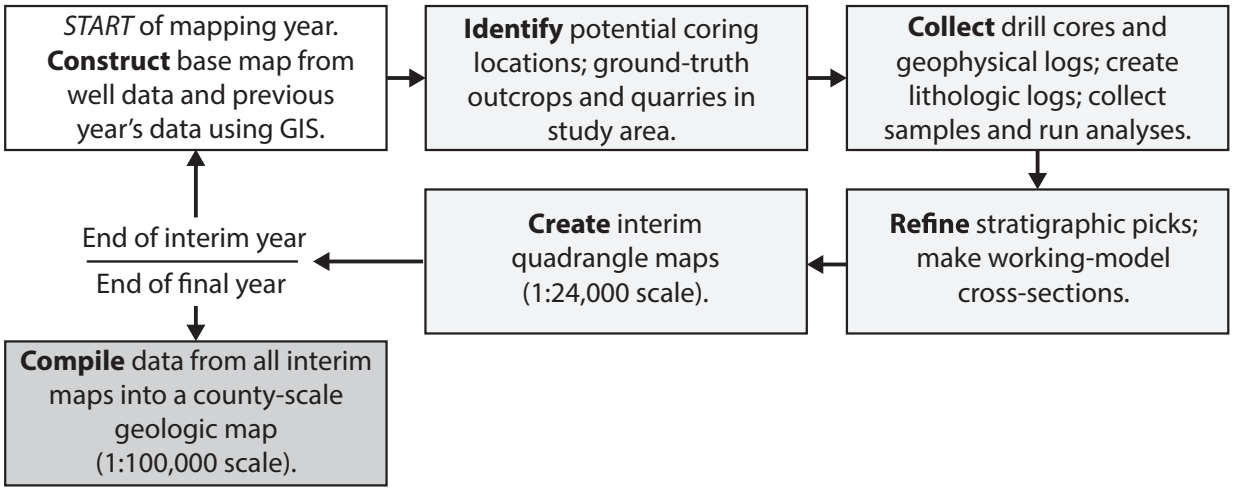

Figure 2: Flow model for the bedrock geology mapping process used in Manitowoc County. This iterative process ensures that preliminary maps created in the beginning phases of this multi-year project are continuously re-evaluated as new data is collected.

Data from drill cores (lithologic logs, XRF elemental analysis, carbon isotope analysis, etc.) and borehole geophysical and optical logs was collected, compiled, and interpreted and then integrated with our preliminary dataset of logs from drill cuttings and well construction reports to form a revised base map for the current study area. This process was iterated throughout the project, as each new dataset collected provides additional insight into the geology of areas mapped in previous years. Previously submitted 7.5-minute quadrangle preliminary (interim) bedrock geology maps are therefore underwent constant revision until all data had been collected for this multi-year project.

The data collected for this project are summarized in table 1 and discussed in more detail below; locations of data sources are shown in figure 3.

All map units used are consistent with current entries in the U.S. Geologic Names Lexicon (GEOLEX). Working-model cross-sections have been used extensively during the mapping process; final versions are part of the ultimate 1:100,000-scale map.

Table 1: Data types and amounts that have been collected and/or processed as part of this 3-year project.

	Collected and/or studied			
	Year 1	**Year 2**	**Year 3**	**Total**
Data sources				
Cores drilled or contracted by WGNHS	2	3	—	5
Archived and industry cores	15	3	21	39
Air rotary holes	1	—	—	1
Geophysical and optical logs	4	3	3	7
Well construction reports and geologic logs	1,705	1,602	835	3,307
Outcrops and quarries	3	3	2	8
Samples and analyses				
Carbonate carbon isotopic analyses	2,000	2,000	441*	4,441
Handheld XRF analyses	—	2,200	—	2,200
Biostratigraphic (conodont) samples	—	30	—	30
Strontium isotope analysis	—	30	—	30

**Number of samples analyzed is lower than budgeted due to a per sample analysis price increase to $15.*

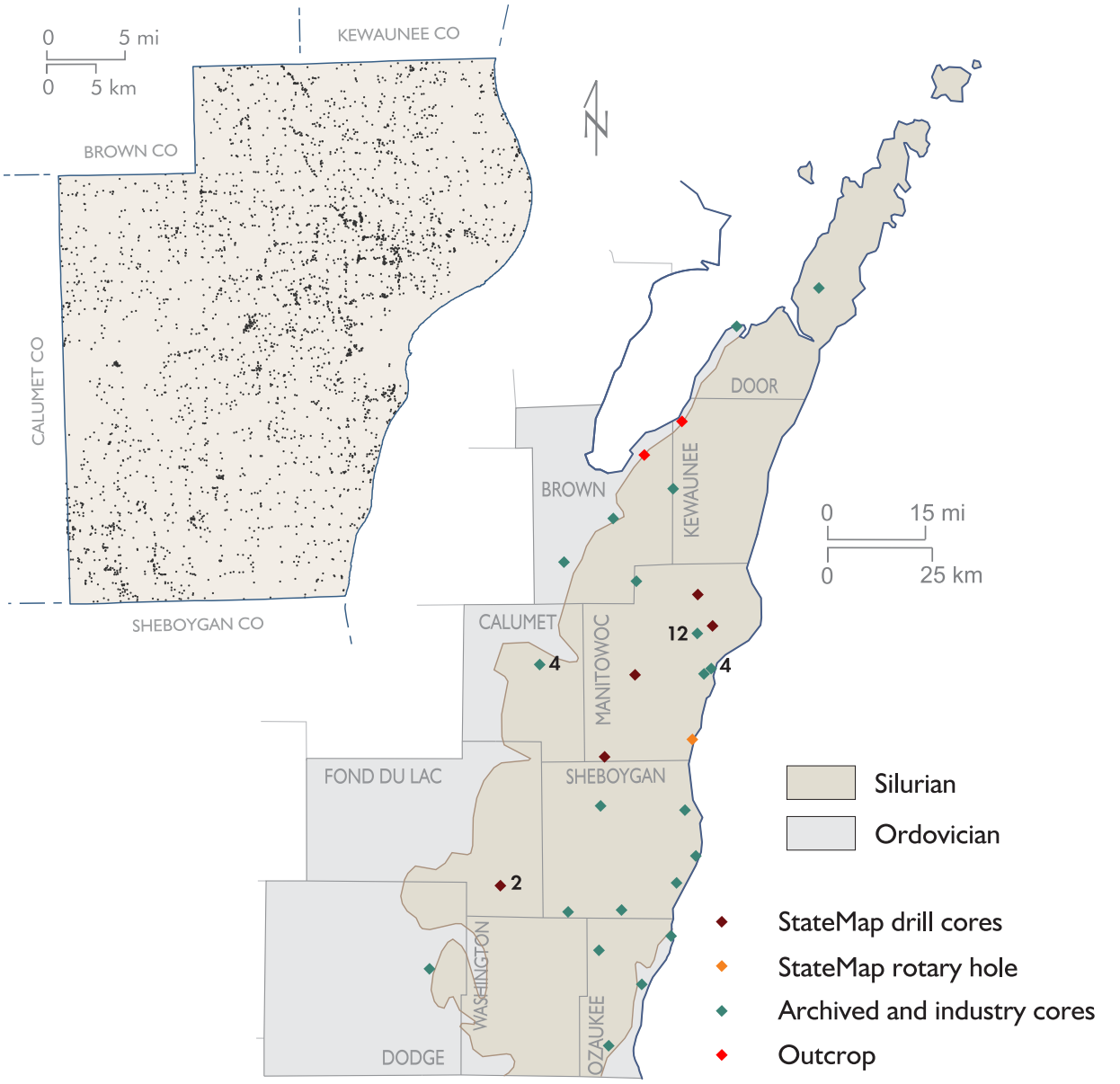

Figure 3. Locations of well construction reports and geologic logs (left) and cores (right) used for this study. Numbers next to points indicate how many cores were studied from a given location.

Discussion of data used in mapping

We used an integrated dataset to construct the spatial and stratigraphic framework of the geology of Manitowoc County. Over the course of the project, we drilled five new cores and one air rotary hole for a total of more than 3,000 ft (900 m) of stratigraphy. At each site we also collected a suite of borehole geophysical data. One of the drill cores was located outside the county to reach the Ordovician–Silurian boundary, the most critical interface for correlation and one of growing importance in Manitowoc drinking water quality due to high concentration of arsenic. We also studied 18 archived and industry cores and 6 quarry sections from within the county plus 19 cores and 2 outcrops from nearby counties. We sampled cores and outcrops for carbonate carbon isotope stratigraphy and conodont biostratigraphy; chemostratigraphic data were collected using a handheld x-ray fluorescence (XRF) analyzer, a tool that quantifies compositional variations of elements in core.

Since glacial deposits cover the majority of Manitowoc County, data collected from drill core has provided great insight into the county's bedrock geology. We subjected each core to detailed study and sampling. For example, figure 4 shows the graphic logs and elemental profiles for the Sheboygan 3 (a regional reference core) and the Shoto core, collected from the north-central part of Manitowoc County. The elemental profile constructed using a handheld XRF was used to quantify relative proportions of carbonate, siliciclastics (clay minerals) and chert, and secondary minerals. Comparison of the Shoto profile against the Sheboygan 3 profile shows the purity and thickness of the biohermal/reef deposits at that locality relative to the cherty and argillaceous non-reefal rocks that are present in the region.

A powerful tool for stratigraphic correlation that we have greatly refined is carbonate carbon isotope stratigraphy (fig. 5). These patterns match the predicted C-isotope profile based on the relatively low-resolution biostratigraphy available for this interval. This tool has not only allowed us to refine our subsurface correlations at a higher resolution, but also provided a new method for recognizing unconformities. Mapping the facies distribution of age-equivalent units allowed us to better recognize paleo-shoreline trajectories, which further improves our ability to predict the broader distribution of shallow marine and terrestrial environments essential in geologic mapping and resource assessment.

After the correlation was completed, the GIS database was updated with elevations of the stratigraphic contacts interpreted in outcrops and cores. These data, along with the bedrock topographic surface, were used to construct a 3-dimensional model of the geologic map units. The intersection of the stratigraphic surfaces with the bedrock surface was converted to contacts and map unit polygons in the database, and the series of maps was produced for review and then finalized for delivery.

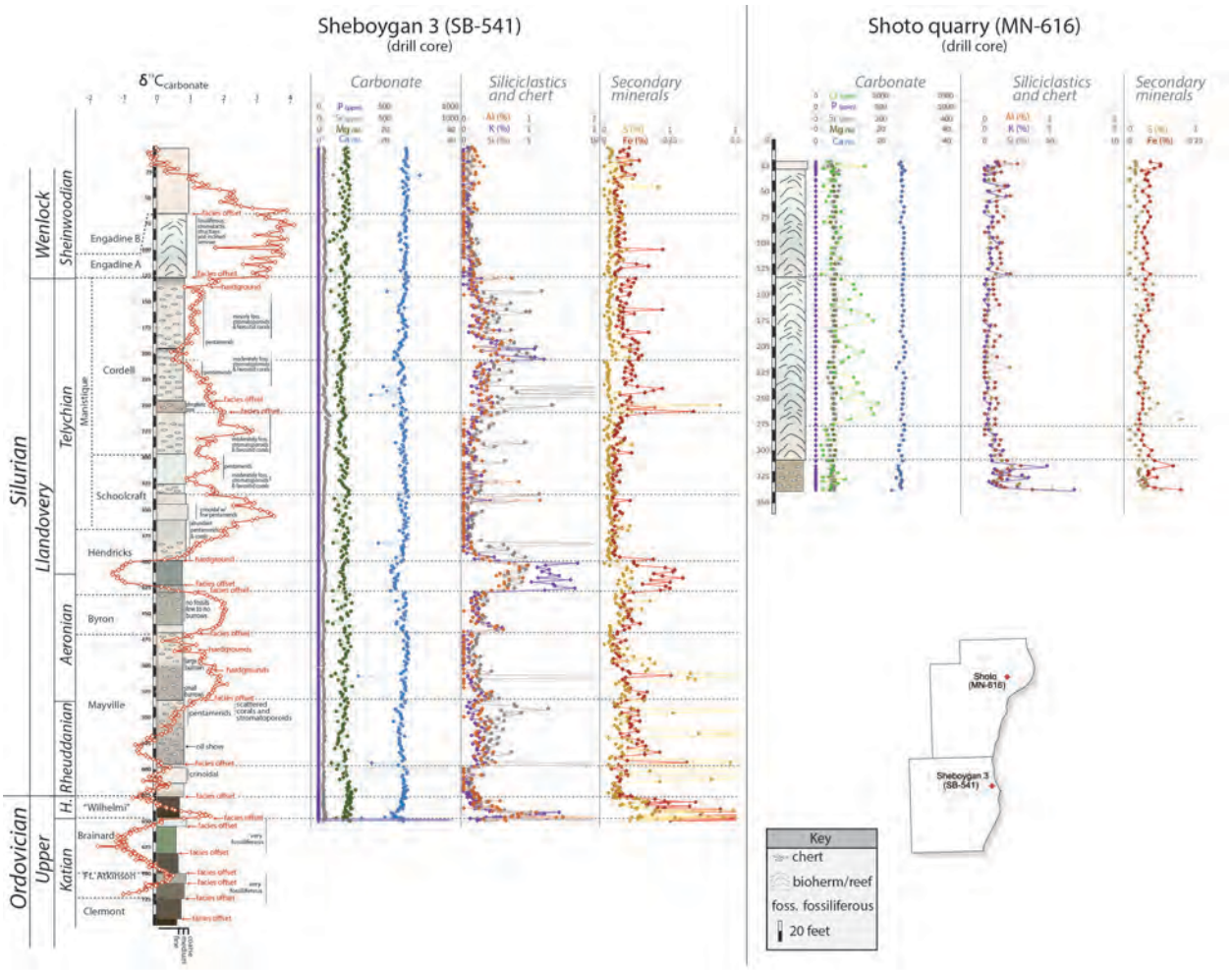

Figure 4. Comparison of the lithologic logs and elemental profiles of the Shoto (MN-616) core in Manitowoc and the regional reference section in Sheboygan. The Shoto core contains nearly 300 ft (90 m) of high-purity reef dolomite as compared to the highly heterogeneous and silicon-rich succession at Sheboygan. Based on regional comparison of carbon isotope profiles, Shoto's upper reef, 30–130 ft (9–40 m) deep, correlates to the Engadine "A" at Sheboygan, and the lower reef, 130–310 ft (40–90 m) deep, correlates to the lower Cordell carbon isotope excursion interval at about 275 ft (85 m). Understanding the position and geometry of the Silurian reefs has improved our ability to predict the distribution of the resource.

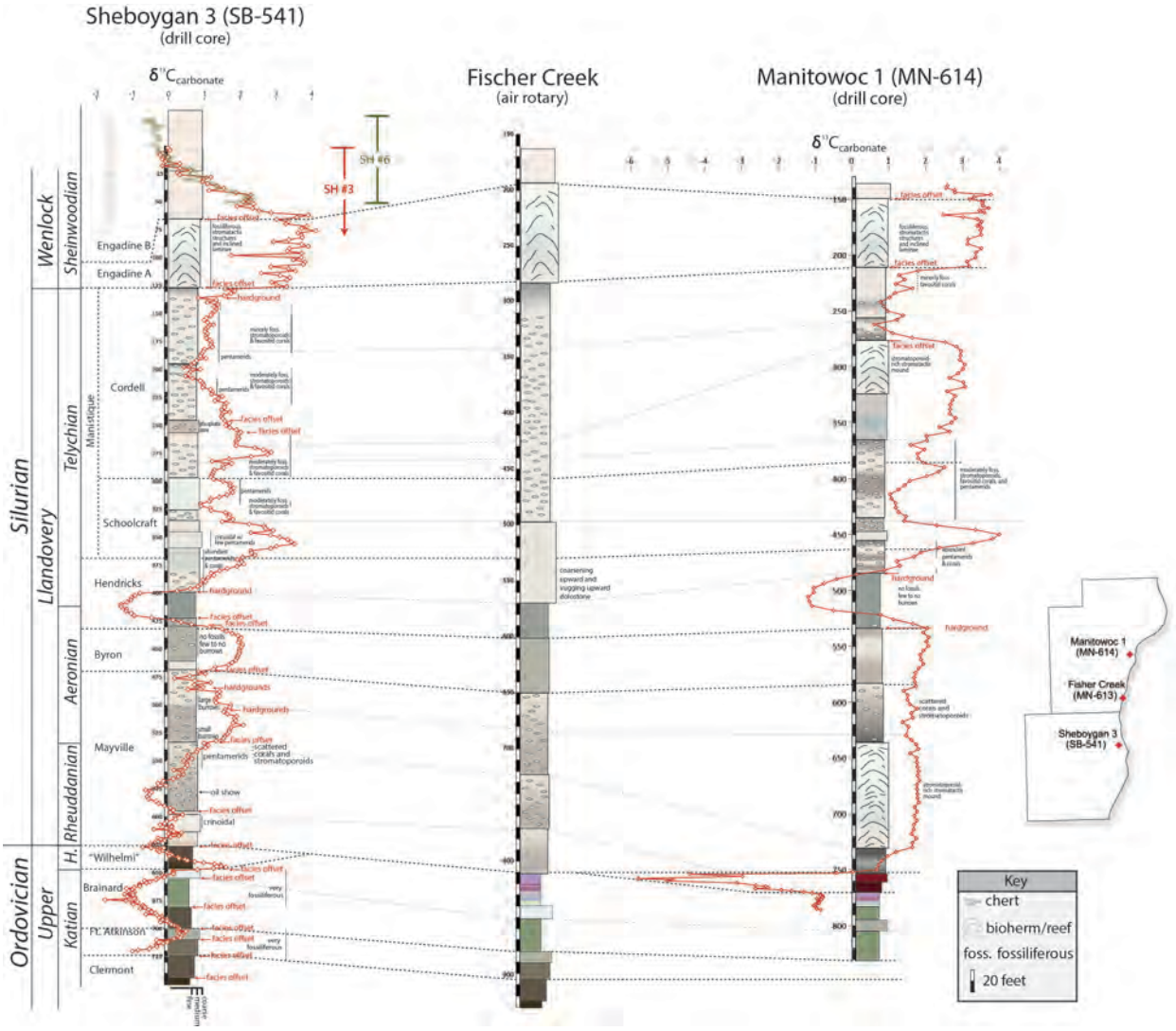

Figure 5. Carbon isotope correlation of long continuous reference cores between Sheboygan (SB-541) and Manitowoc (MN-614). The Sheboygan core closely approximates the global Silurian composite carbon isotope curve (McLaughlin and others, 2013). The optical log from the air-rotary drill hole at Fischer Creek (MN-613) was used to constrain the spatial position of lithologic changes in the succession.

Sharing of results

We have and will continue to share our new knowledge about the bedrock geology of Manitowoc County. During the winter and spring of 2014 we made informal presentations of our preliminary data and mapping to representatives of the USGS, the Wisconsin Department of Natural Resources, and geologists from the mining industry. In addition to sharing the interim deliverables from year 1 of this project, we showcased the cores drilled during years 1 and 2. In 2015, we presented some of our stratigraphic results at the 5th International Symposium on the Silurian System in Quebec, attended by geologists from around the world. The feedback from all these groups was very positive. There, we learned that the results of this mapping project will be central to calibrating the hydrostratigraphy of an ongoing regional groundwater study in Ontario.

Summary

We have completed the bedrock geology mapping of Manitowoc County within the proposed 3-year timetable. Our work in the county has direct application to long-term natural resource management issues, including improved predictive assessment of industrial stone and aggregate resources and creation of the necessary geologic framework for groundwater quantity, quality, and migration studies.

New types of data, such as handheld XRF elemental profiles and carbon isotope stratigraphy have proven extremely useful in increasing our understanding of the county's bedrock geology. Conversely, we struggled with the recovery of biostratigraphically important fossils (conodonts) in numbers necessary to be useful. The use of an integrated stratigraphic approach allowed us to identify and focus on the stratigraphic tools most useful for bedrock geology mapping in Manitowoc County.

The bedrock map and refined stratigraphic framework provide knowledge that has improved our natural resource assessment of Manitowoc County. We find that the Engadine Formation, rich in bioherms composed of high-purity dolostone, dominates the upper bedrock geology of the county. While this is good news for the stone industry, the complex geometries of massive and highly porous bioherms that are surrounded by layered, lower porosity inter-bioherm strata presents special difficulties for groundwater flow modeling.

Citation

Publications

McLaughlin, P.I., Emsbo, P., Brett, C.E., 2015, The *lithuanicus* Event in the Michigan Basin: Rapid platform accretion in response to a perturbation of the mid-Telychian ocean-climate system: 5th International Symposium on the Silurian System, Quebec City, Quebec, Abstracts Volume, p. 30.

McLaughlin, P.I., Mikulic, D.G., Kluessendorf, J., 2013, Age and correlation of Silurian rocks in Sheboygan County, Wisconsin, using integrated stable carbon isotope stratigraphy and facies analysis: *Geoscience Wisconsin,* v. 21, p. 15–38.