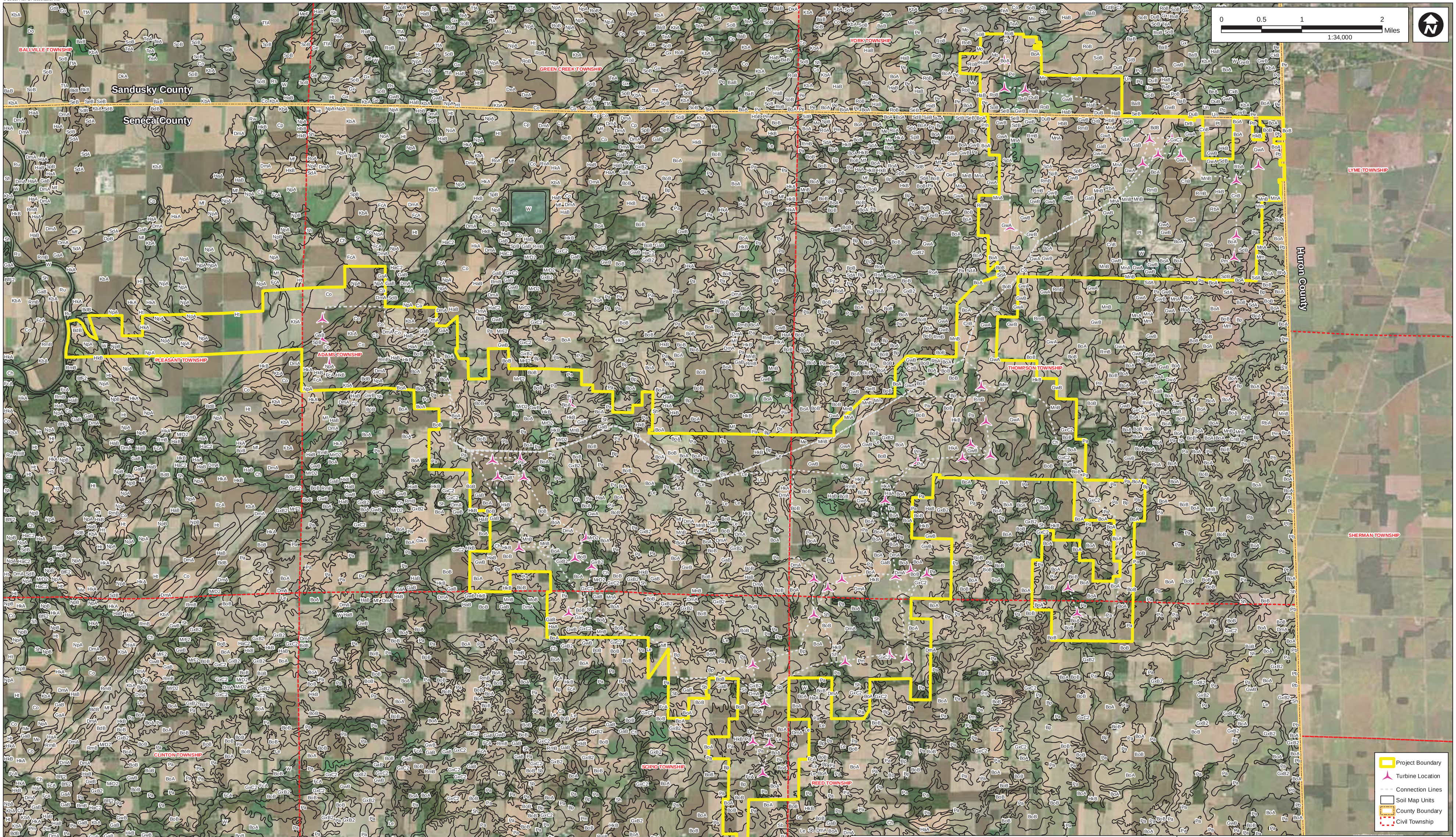

Notes:
The aerial photo was acquired through the ESRI Imagery web service. Aerial photography dated 2015.

Produced using ArcGIS 10.5

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November 2018

Republic Wind

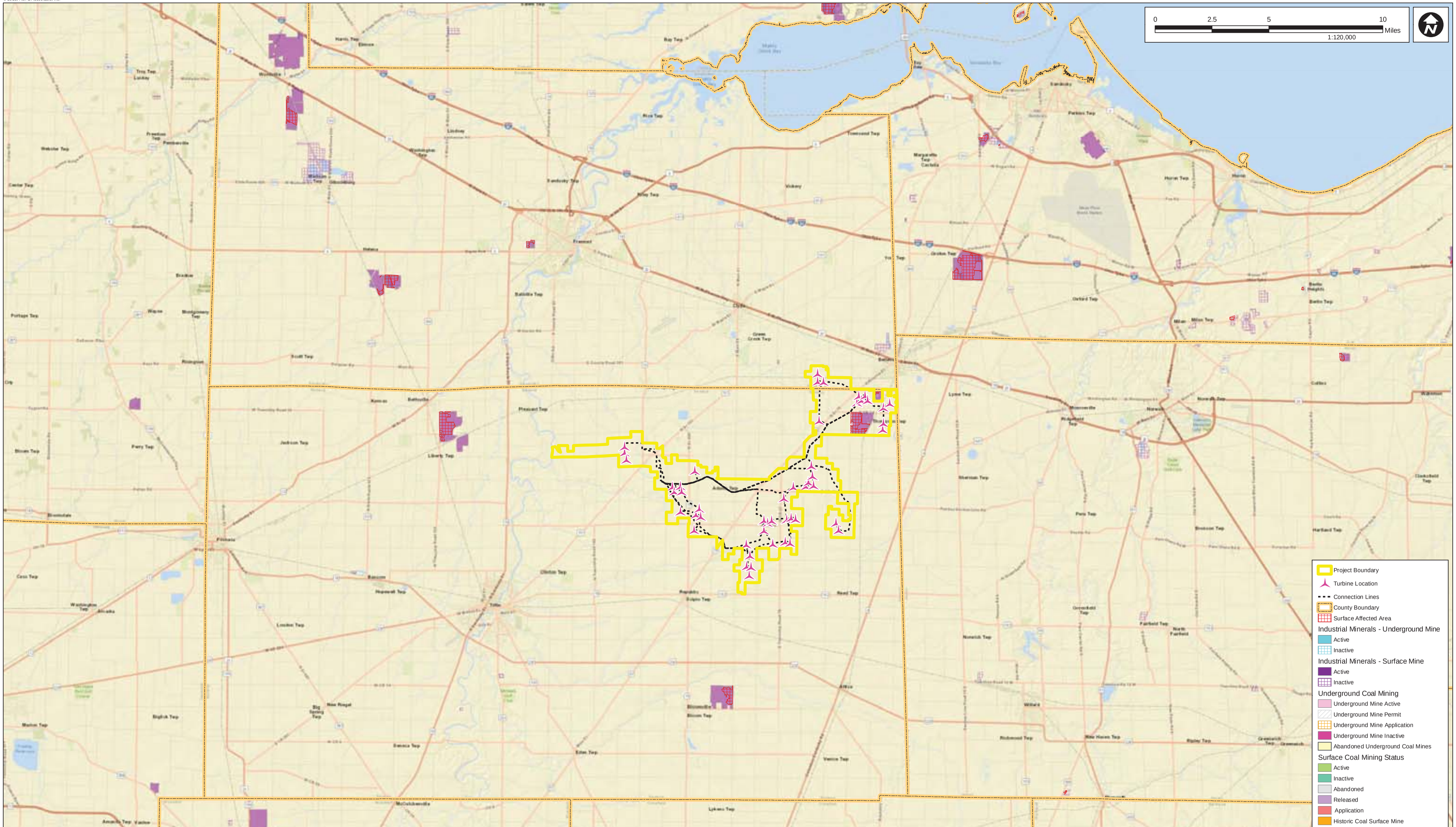
Soils Map

Seneca and Sandusky Counties, Ohio

Figure 8

File Name: ACX002_02_Fig08_Soils.mxd

Edited: 12/3/2018 By: rkaip



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November 2018
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Mining Map

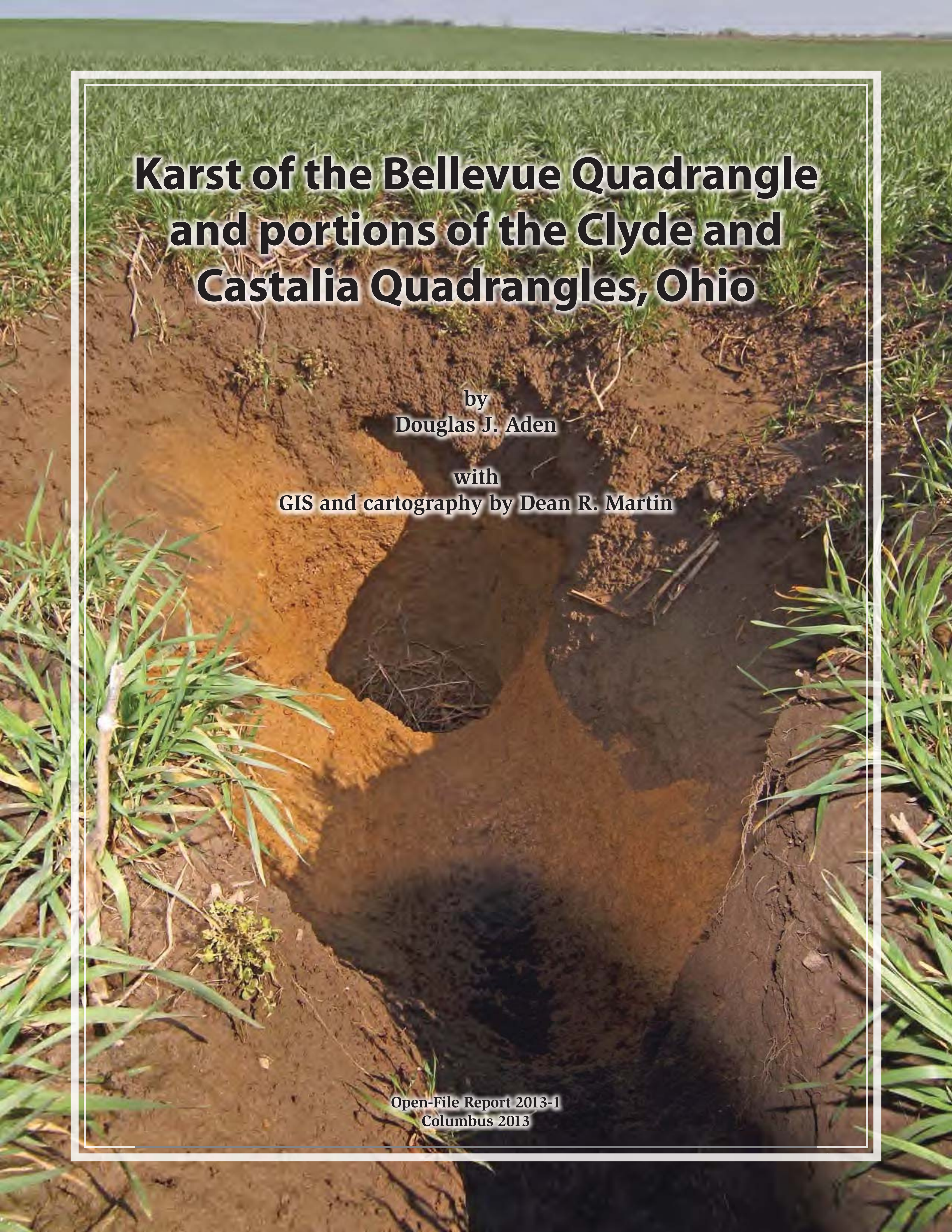
Seneca and Sandusky Counties, Ohio

Figure
9

Produced using ArcGIS 10.5
File Name: ACX002_02_Fig09_Mines.mxd
Edited: 12/3/2018 By: rkaip

APPENDIX A

Karst Studies:
Karst of the Bellevue Quadrangle and portions of the Clyde and Castalia Quadrangles, OH (Aden 2013)
Karst of the Fireside Quadrangle and portions of the Flat Rock and Clyde Quadrangles, OH (Aden 2014)



Karst of the Bellevue Quadrangle and portions of the Clyde and Castalia Quadrangles, Ohio

by
Douglas J. Aden

with
GIS and cartography by Dean R. Martin

Open-File Report 2013-1
Columbus 2013

DISCLAIMER

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Cover image: At about 6 ft deep, this sink has formed since the winter wheat was planted eight months prior. Brown top soil is visible above the orange till and plant material has been washed in by rain and fills the sink throat. Photo faces north and a truck can be seen on Interstate 80 on the horizon. Eighty-five feet SW of this sink is an intermittent disappearing stream that aligns with the trend of the much larger depression containing these features. The overall depression is 10 ft deep (with the pictured sink another 6 ft deeper) about 1.25 mi long, 1000 ft wide, and bisected by the Interstate.

Recommended citation: Aden, D.J., 2013, Karst of the Bellevue Quadrangle and portions of the Clyde and Castalia Quadrangles, Ohio: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Open-File Report 2013-1, 4 p., 59 maps.

Karst of the Bellevue Quadrangle and portions of the Clyde and Castalia Quadrangles, Ohio

by

Douglas J. Aden, with GIS and cartography by Dean R. Martin

Introduction

Karst terrain forms by dissolution of carbonate rocks, such as limestone or dolomite, or evaporites, such as gypsum or salt, and is characterized by features including sinkholes, disappearing streams, caves, and springs. *Sinkholes* (or *sinks*) are enclosed depressions that do not usually hold water; they often have a "throat" or opening at the bottom where they drain to the subsurface. When a stream flows into a sinkhole, it is known as a *disappearing stream* or *losing stream*. Water flowing into the ground can cause solution enlargement of natural fractures in the rock and eventually can grow into caves. In Ohio, a *cave* is defined as "…a naturally occurring void, cavity, recess, or system of interconnecting passages beneath the surface of the earth or within a cliff or ledge…" (State of Ohio, 1989).

The many passageways formed in karst terrain allow for high connectivity between the land surface and the water table. These passageways permit water to bypass soil and rock layers that filter out contaminants. Consequently, when compounds such as fertilizers, pesticides, and waste enter sinkholes, they are rapidly transported to the water table and quickly pollute water wells, streams, and rivers. When water exits these solutional features, a *spring* is formed. Such springs enable release of these contaminants at the surface.

The different types of karst features may pose infrastructure complications; roads, utilities, houses, and other facilities built in karst areas are at risk of subsidence, collapse, or other damage. In order to provide a reference for future planning on both the local and regional scale, the Ohio Geological Survey has produced this map book identifying the known and suspected karst areas in the vicinity of Bellevue, Ohio.

Previous Work

Karst areas have been studied in Ohio for many years. In the 1980s and 1990s, karst was researched for the proposed Superconducting Super Collider and was mapped statewide to determine areas suitable for storage of low-level nuclear byproducts. Ohio's preliminary map of karst features (Pavey and others, 1999) was completed in 1997 and released in 1999; it since has been updated with new data in 2003, 2005, and 2007 and will be updated again in the near future.

In the spring of 2008, severe karst-related flooding occurred in Bellevue and initiated increased concern regarding Ohio's geohazards (Raab and others, 2009; Pavey and others, 2012). From 2011 to 2012, karst was mapped in the Delaware County region (Aden and others, 2011) and in the Springfield and Donnelsville 7.5-minute quadrangles (Aden 2012). Finally, from fall 2012 to spring 2013 karst was mapped in the Bellevue 7.5-minute quadrangle and parts of the Clyde and Castalia quadrangles.

Methodology

A digital elevation map (DEM), generated from LiDAR (Light Detection and Ranging) data, was used to create a map layer that identified low, enclosed areas. To locate potential sinkholes, these low spots were cross referenced with known karst points, bedrock geology, aerial photography of multiple sources and ages, soil maps, glacial drift thickness maps, and water well logs. Suspect locations were then visited in the field, evaluated, and photographed. Through this process many of the LiDAR returns were found not to be sinkholes; features such as building foundations, broken field tiles, steep-walled streams, road culverts, and glacial features often produced enclosed areas similar in shape to sinkholes. Many of these misleading features were eliminated remotely using both 6-inches-per-pixel aerial photography and experience from past field verification. However, many points remained that could not be distinguished remotely and these were visited in the field.

Results

The resulting karst feature data set was overlain on four different geologic data sets—the Land Surface, the Bedrock Geology, the Bedrock Topography, and the Drift Thickness maps—to show how the features are related to the local geology. The first of these is the Land Surface map (p. 5), which shows the 107 two-km^2 tiles and the 7.5-minute quadrangles that form the project area overlain on the DEM of the land surface. The Bellevue quad was the core project area. However, some adjacent points were mapped as time allowed, particularly in Clyde and Castalia; these areas will be completed as part of next year's project. The land surface map shows that in Bellevue sinks are concentrated to the south and east while springs are found down gradient north and west.

On the Land Surface map, tiles outlined in red contain the karst features identified through this project. No karst was identified in black-outline tiles. In total there are 997 karst features, including 29 springs, in 107 tiles. On the top left of each aerial imagery page (p. 9–68) is a Tile Number that references the corresponding numbered tile on the four overlay maps.

There are four types of karst features identified on each map:

- Red circles indicate field-verified features, i.e., those that have been visited in the field and confirmed as karst.
- Orange circles indicate sites that were visited but could not be verified at the time, for example a suspicious depression that is flooded or that lacks an active sink throat and cannot be clearly classified.
- Yellow circles represent areas with suspect characteristics, such as a distinct LiDAR depression, but where access to the property could not be gained or where there was not enough time to check the point.
- Blue squares represent springs, including "blue holes," where water was found flowing from the subsurface, primarily to the north.

The next overlay map is the Bedrock Geology map (p. 6). This map shows that the karst features are forming primarily by dissolution of the Columbus Limestone; however, it is thought that the Salina undifferentiated below is also affecting the sinks. The Salina contains beds of the mineral anhydrite, which alters to gypsum by hydration. This change causes swelling of about 40 percent (Boggs, 2006), which could help to fracture surrounding rocks; but more importantly, gypsum is easily dissolved by additional ground water, removing roof support and leading to collapse. In the Bellevue region there are two main ways that karst is expressed: one where catastrophic collapse forms a steep-walled, cone-shaped depression with active sinking and a second that is much more broad and shallow and may or may not have an active sink throat where water is draining into it.

Eight hundred and twenty three of the 997 karst features are within the Columbus Limestone (**Dc** on the Bedrock Geology map) with the majority of the remaining features in the Bass Islands Dolomite or Salina undifferentiated (within the **Sbi** or **Ssu**). These formations and the others on the Bedrock Geology map are buried in many places by surficial glacial materials. The elevation of the bedrock below the surficial materials is called Bedrock Topography and is shown on page 7. The elevations of the bedrock surface were subtracted from the DEM (p. 5) to create the Drift Thickness map (p. 8). Knowing the drift thickness is useful because where the drift is shallow—about 25 ft or less—sinkholes are commonly expressed. Other sinkholes may exist but were either buried beneath the glacial drift or prevented from forming by thick drift. The Drift Thickness map clearly shows that in the Bellevue area the sinkholes are concentrated along areas of thin glacial drift.

Conclusions

Of the 997 mapped karst features, 415 have photos and 838 appear on LiDAR. Of the 29 springs, nine have a LiDAR response while 20 do not. Springs do not typically show up as depressions unless a catch basin was built and subsequently failed or a build-up of material deposits from carbonate-rich spring waters forms a mound. The large number of sinks and springs found without LiDAR attests to the need for spending time in the field near known karst areas, looking for new features and talking to the public; many of the springs in the Bellevue area were reported by a local resident, Jim Norrocky. Farmers and other land holders are still one of the best sources of local information, particularly for historical features, such as drained ponds, old mill races, and even sinkholes that have been periodically filled in.

In addition to this map book, a DVD containing the GIS data, metadata, LiDAR depressions, and photographs of many of the features is available. The GIS data contains details such as the location of each point and a brief description of what was found there. The metadata provides information on the sources and quality of the data used in this project. The LiDAR depressions layer records the depth and area for many of the sinkholes. In addition, the collection of photographs captured for many of these features can be used to monitor the growth of preexisting sinkholes and development of new karst features, as well as assisting in identification. Identification is important because karst regions are highly susceptible to pollution and structures built near them may subside. Furthermore, in the Bellevue region, low-lying karst features may be subject to flooding during periods of unusually high precipitation when the water table rises above the land surface. The maps in this report will allow areas of land development near karst features to be better planned and maintained.

Acknowledgments

The Bellevue project, the Delaware County region project, and the Springfield project were funded by the Great Lakes Geologic Mapping Coalition surficial mapping grant program.

References Cited

Aden, D.J., 2012, Karst of Springfield, Ohio: Ohio Department of Natural Resources, Division of Geological Survey Open-File Report 2012-2, 3 p., 25 maps, accessible at <http://geosurvey.ohiodnr.gov/portals/geosurvey/PDFs/OpenFileReports/OFR_2012-2.pdf>.

Aden, D.J., Powers, D.M., Pavey, R.R., Jones, D.M., Martin, D.R., Shrake, D.L., and Angle, M.P., 2011, Karst of the western Delaware County, Ohio, region: Ohio Department of Natural Resources, Division of Geological Survey Open-File Report 2011-4, 2 p., 35 maps, accessible at <http://geosurvey.ohiodnr.gov/portals/geosurvey/PDFs/OpenFileReports/OFR_2011-4.pdf>.

Boggs, Sam, Jr., 2006, Principles of sedimentology and stratigraphy (4th ed.): Upper Saddle River, NJ, Pearson Prentice Hall, p.199.

State of Ohio, 1989, Ohio Revised Code 1517.21 Cave definitions, *in* chap. 1517 *of* Title 15 Conservation of Natural Resources: State of Ohio, Ohio Revised Code, accessible at <http://codes.ohio.gov/orc/1517.21>.

Pavey, R.R., Angle, M.P., Powers, D.M., Swinford, E.M., 2012, Karst flooding in Bellevue, Ohio, and vicinity—2008: Ohio Department of Natural Resources, Division of Geological Survey Map EG-5, scale 1:24,000.

Pavey, R.R., Hull, D.N., Brockman, C.S., Schumacher, G.A., Stith, D.A., Swinford, E.M., Sole, T.L., Vorbau, K.E., Kallini, K.D., Evans, E.E., Slucher, E.R., and Van Horn, R.G., with GIS and cartography by Powers, D.M., and Vogt, K.L., 1999, Known and probable karst in Ohio: Ohio Department of Natural Resources, Division of Geological Survey Map EG-1, scale 1:500,000. [Revised 2002, 2004, 2007.]

Raab, James, Haiker, Bill, Jones, Wayne, Angle, Michael, Pavey, Rick, Swinford, Mac, and Powers, Donovan, 2009, Ground water induced flooding in the Bellevue Ohio area, spring and summer 2008: Ohio Department of Natural Resources, Division of Water Technical Report of Investigation 2009-1, 19 p., accessible at <http://geosurvey.ohiodnr.gov/portals/geosurvey/PDFs/Karst/Bellevue_Final_Report.pdf>.

Further Reading

For more information on karst in Ohio, visit the Ohio Geological Survey website, **OhioGeology.com.** The following resources also provide additional information on karst and its effects in Ohio and beyond.

Ohio Department of Natural Resources

Ground Water Induced Flooding in the Bellevue Ohio Area Spring and Summer 2008, ODNR Division of Water Technical Report of Investigation 2009-1, 19 p.

Karst Flooding in Bellevue, Ohio, and Vicinity—2008, ODNR Division of Geological Survey Map EG-5, 2012, scale 1:24,000.

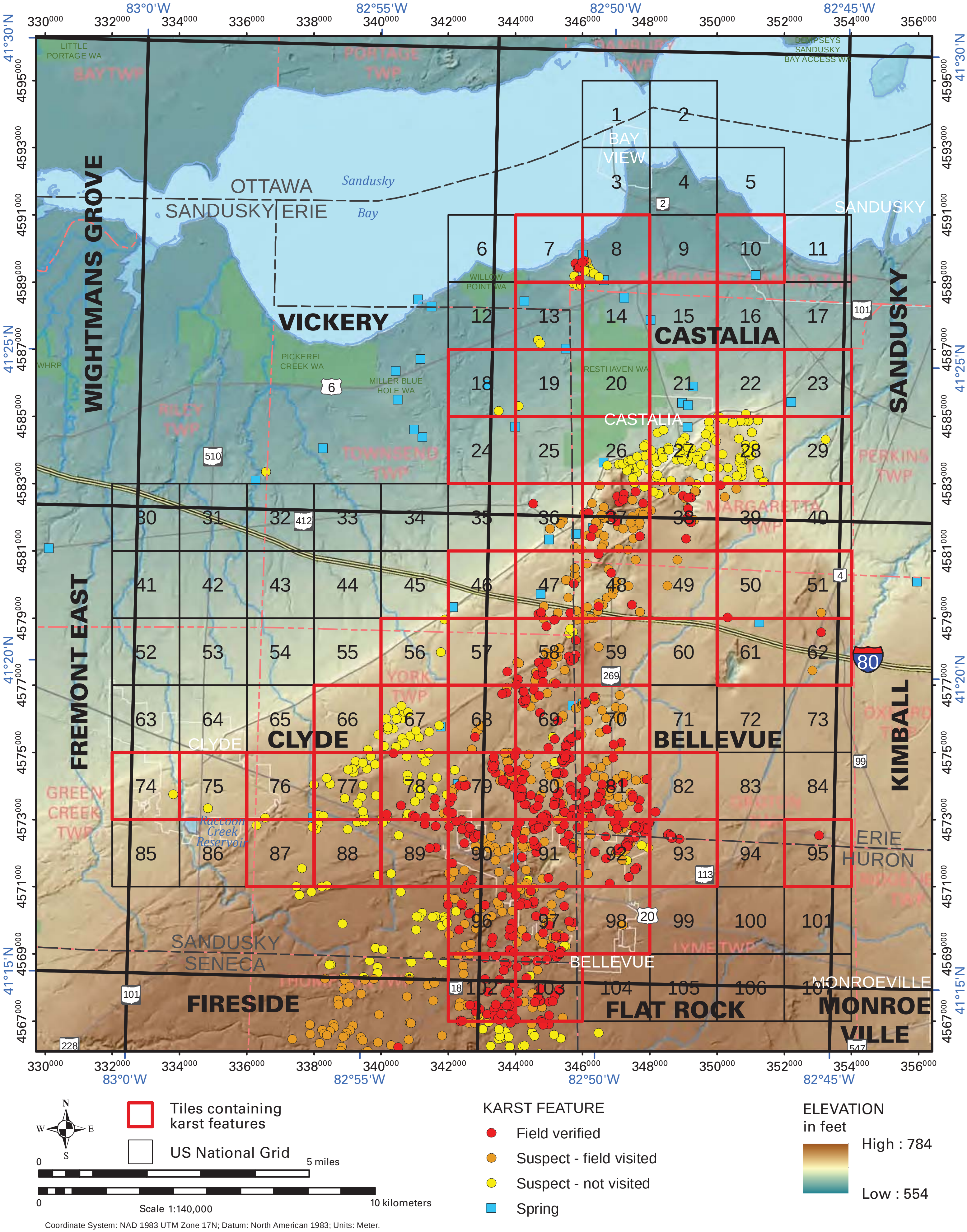
Known and Probable Karst in Ohio, ODNR Division of Geological Survey Map EG-1, generalized page-size version with text, 2 p., scale 1:2,000,000.

American Geological Institute

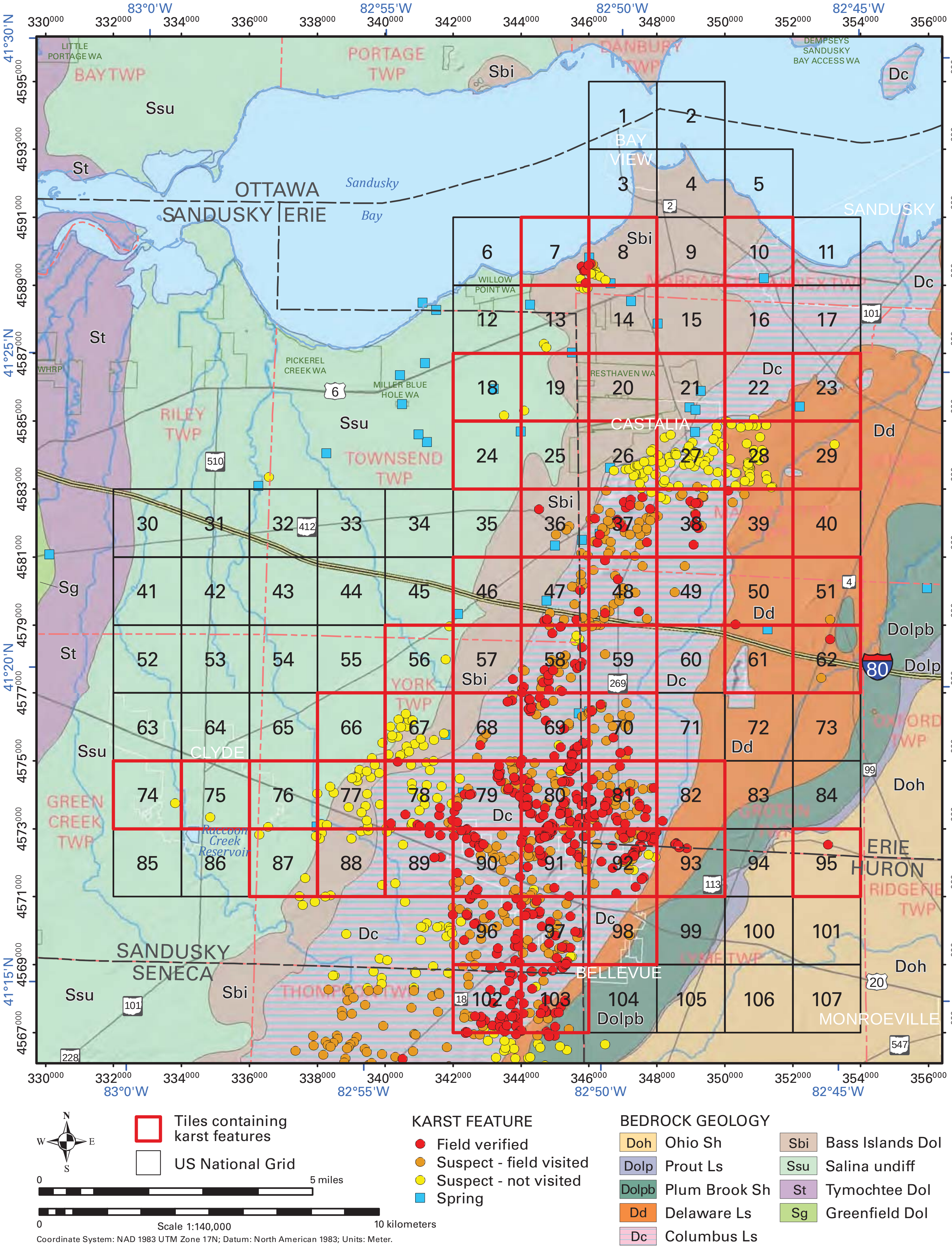
Living with Karst—A Fragile Foundation, AGI Environmental Awareness Series, no. 4, accessible at <http://www.agiweb.org/environment/publications/karst.pdf>.

U.S. Geological Survey

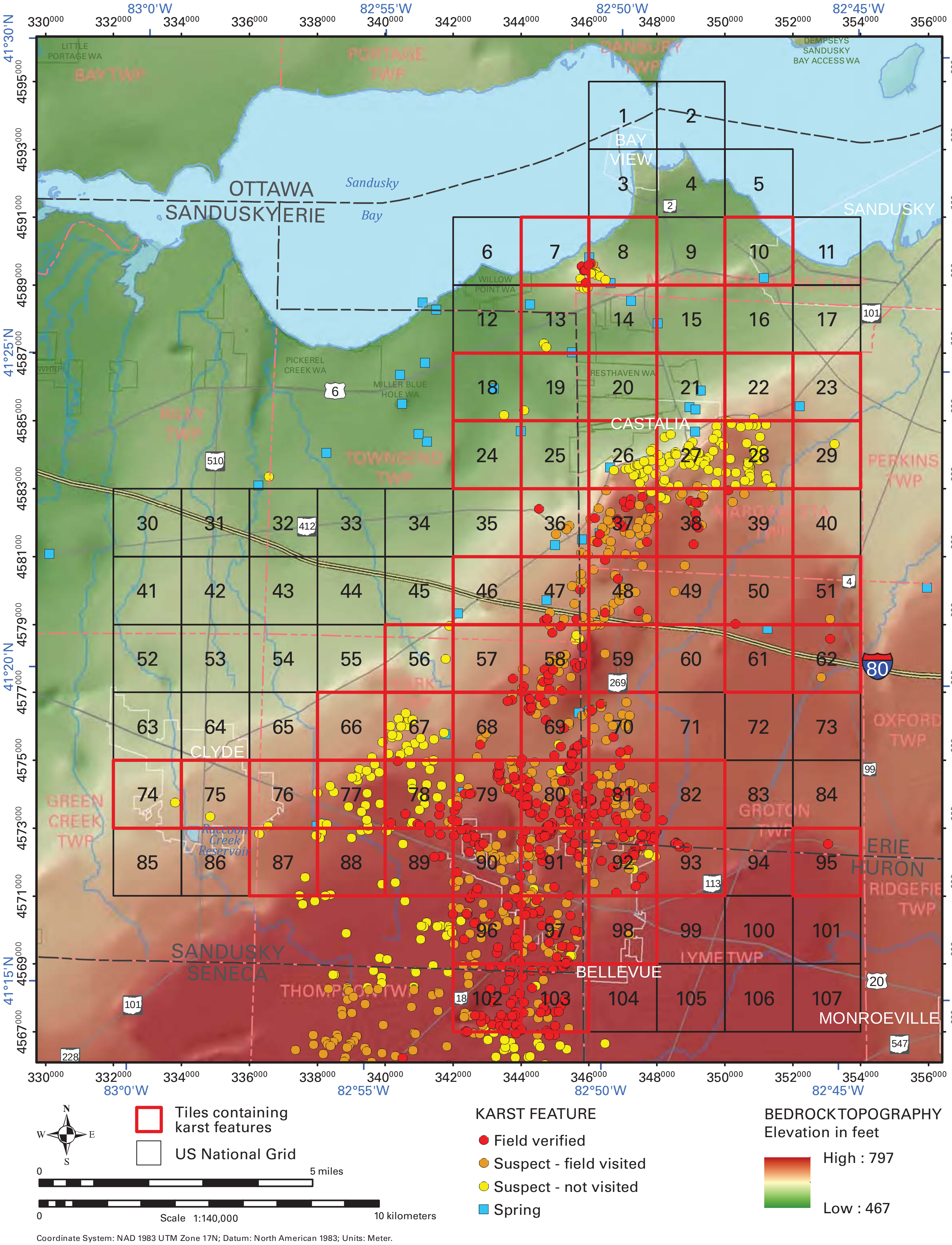
USGS Groundwater Information, Karst and the USGS, accessible at <http://water.usgs.gov/ogw/karst/>.

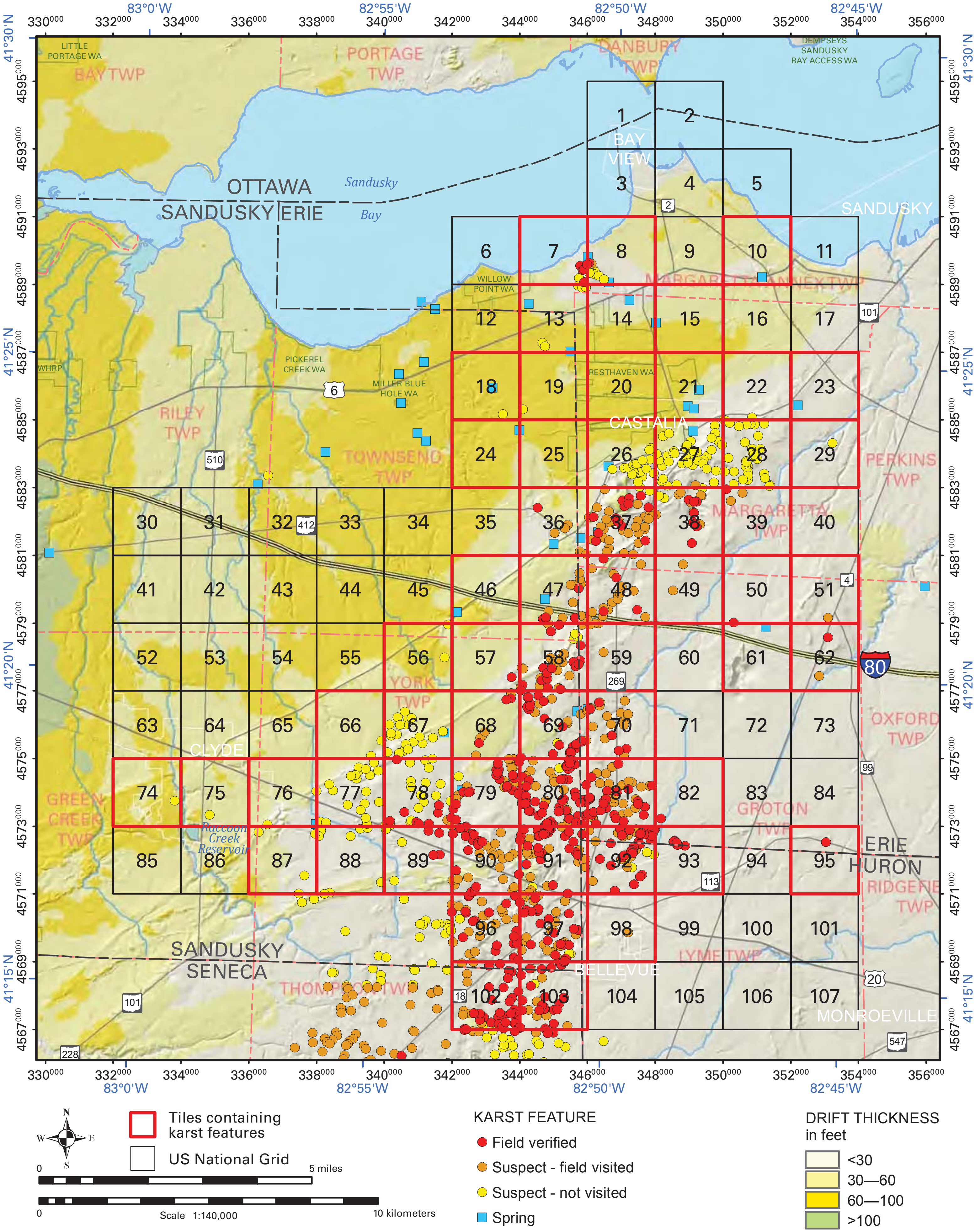


83°0'W
82°55'W
82°50'W
82°45'W
41°30'N
41°25'N
41°20'N
41°15'N
OTTAWA
SANDUSKY
ERIE
Sandusky Bay
WIGHTMANS GROVE
VICKERY
CASTALIA
SANDUSKY
FREMONT EAST
CLYDE
BELLEVUE
KIMBALL
FIRESIDE
FLAT ROCK
MONROEVILLE
BAY VIEW
LITTLE PORTAGE WA
WILLOW POINT WA
PICKEREL CREEK WA
MILLER BLUE HOLE WA
RESTHAVEN WA
DEMPSEYS SANDUSKY BAY ACCESS WA
Raccoon Creek Reservoir
HURON
SENECA
Tiles containing karst features
US National Grid
KARST FEATURE
Field verified
Suspect - field visited
Suspect - not visited
Spring
ELEVATION in feet
High : 784
Low : 554
0
5 miles
10 kilometers
Scale 1:140,000
Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.



Tiles containing karst features
US National Grid
KARST FEATURE
Field verified
Suspect - field visited
Suspect - not visited
Spring
BEDROCK GEOLOGY
Doh Ohio Sh
Dolp Prout Ls
Dolpb Plum Brook Sh
Dd Delaware Ls
Dc Columbus Ls
Sbi Bass Islands Dol
Ssu Salina undiff
St Tymochtee Dol
Sg Greenfield Dol
0 5 miles
0 10 kilometers
Scale 1:140,000
Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.
OTTAWA
SANDUSKY
ERIE
HURON
SENECA
Sandusky Bay
CASTALIA
BELLEVUE
CLYDE
MONROEVILLE
BAY VIEW


OTTAWA
SANDUSKY
ERIE
Sandusky Bay
BAY VIEW
SANDUSKY
CASTALIA
CLYDE
BELLEVUE
MONROEVILLE
SANDUSKY
SENECA
ERIE
HURON
PORTAGE TWP
DANBURY TWP
BAY TWP
RILEY TWP
TOWNSEND TWP
PERKINS TWP
MARGARETTA TWP
OXFORD TWP
GREEN CREEK TWP
GROTON TWP
LYME TWP
THOMPSON TWP
RIDGEFIELD TWP
YORK TWP
LITTLE PORTAGE WA
DEMPSEYS SANDUSKY BAY ACCESS WA
PICKEREL CREEK WA
MILLER BLUE HOLE WA
WILLOW POINT WA
RESTHAVEN WA
Raccoon Creek Reservoir
Tiles containing karst features
US National Grid
KARST FEATURE
Field verified
Suspect - field visited
Suspect - not visited
Spring
BEDROCK TOPOGRAPHY
Elevation in feet
High : 797
Low : 467
0
5 miles
0
Scale 1:140,000
10 kilometers
Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.



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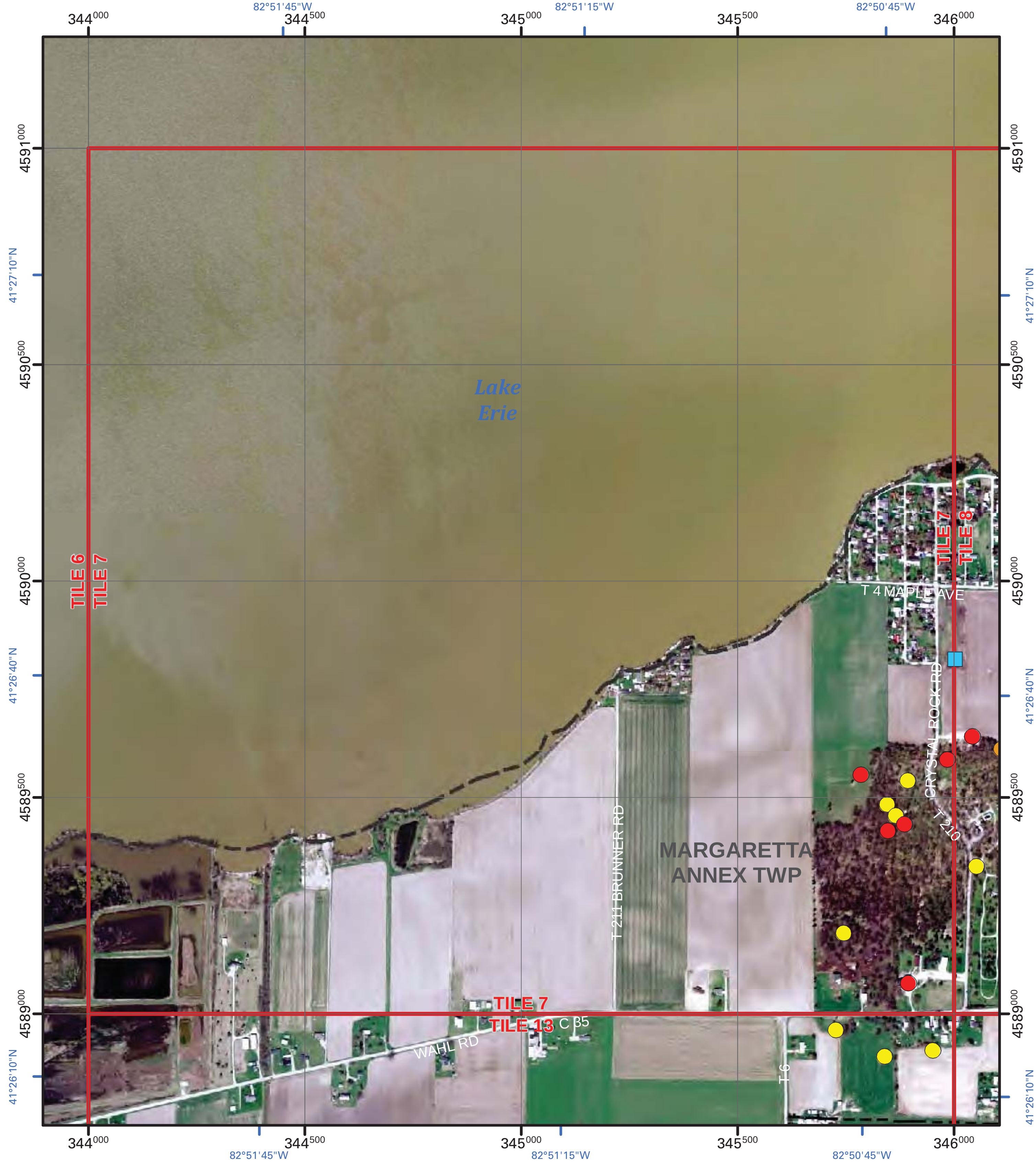
Tile Number: 7



US National Grid

100,000-m Square ID: LF

Grid Zone Designation: 17T

0 — 0.5 miles

0 — 1 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURE

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

Tile Number: 8

Tile Number: 10

US National Grid

100,000-m Square ID	Grid Zone Designation
LF	17T

0 0.5 miles

0 Scale 1:12,000 1 kilometers

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURE

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

Tile Number: 13

US National Grid
100,000-m Square ID **LF**
Grid Zone Designation **17T**

0 — 0.5 miles

0 — 1 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURE
- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

Tile Number: 14

US National Grid

100,000-m Square ID	Grid Zone Designation
LF	17T

0 0.5 miles

0 1 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURE

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

Tile Number: 15

US National Grid

100,000-m Square ID: LF

Grid Zone Designation: 17T

0 — 0.5 miles

0 — 1 kilometers

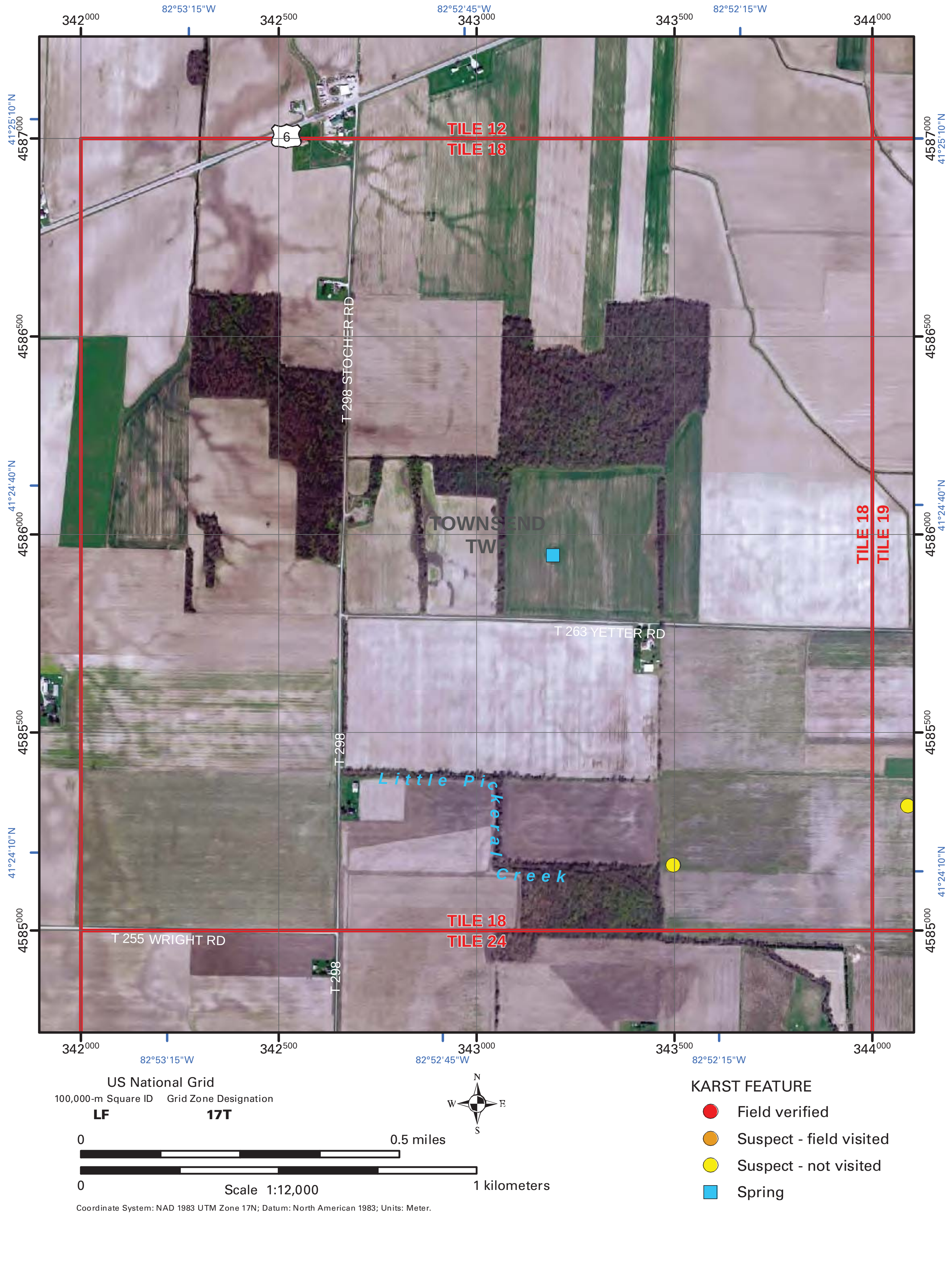
Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURE

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

Tile Number: 18



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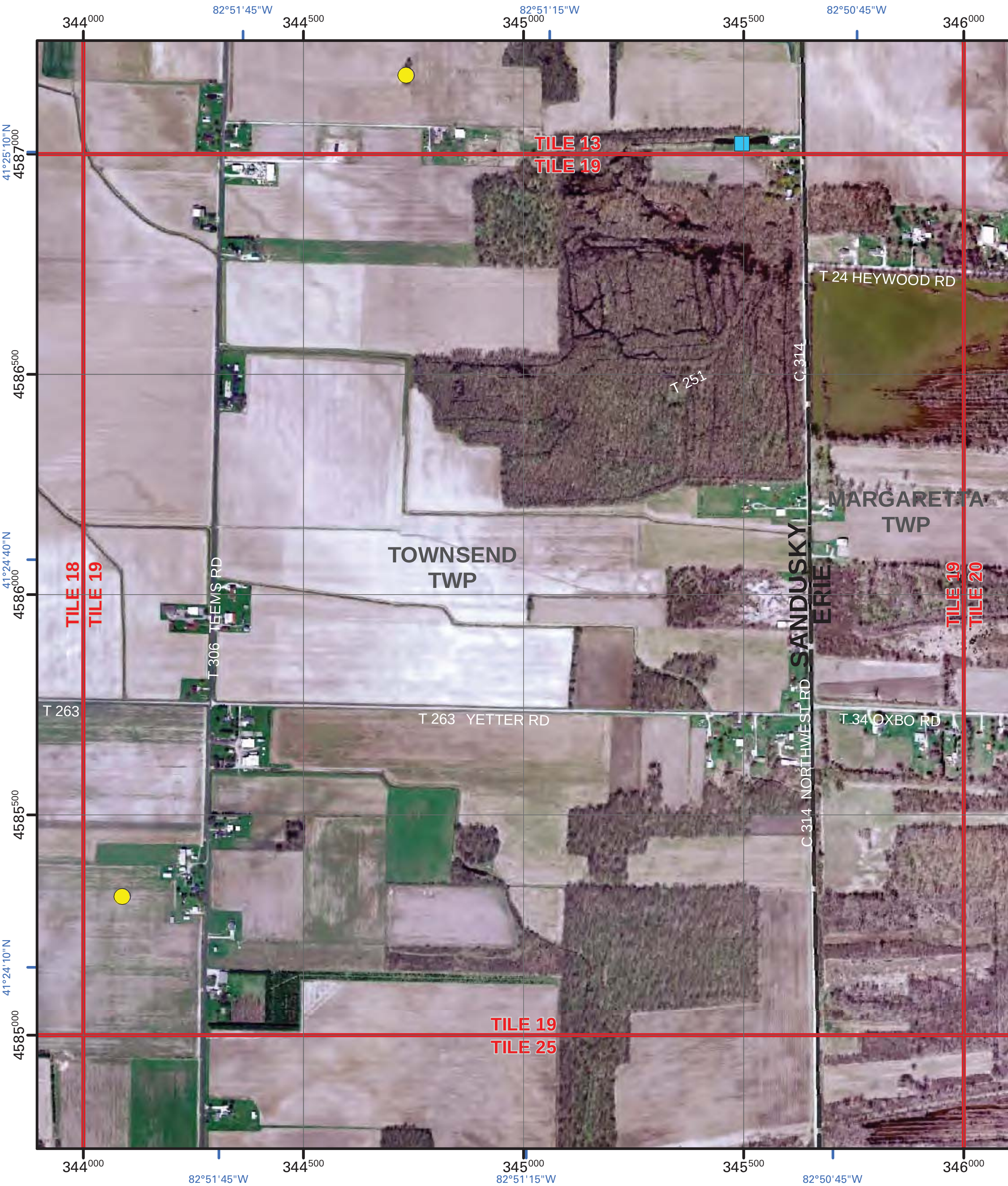


US National Grid

100,000-m Square ID: LF

Grid Zone Designation: 17T

0 — 0.5 miles

0 — 1 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

N, E, S, W

KARST FEATURE

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

Tile Number: 21

US National Grid

100,000-m Square ID: LF

Grid Zone Designation: 17T

N, S, E, W

0 — 0.5 miles

0 — 1 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURE

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

Tile Number: 22

US National Grid

100,000-m Square ID	Grid Zone Designation
LF	17T

0 — 0.5 miles

0 — 1 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

N E S W

KARST FEATURE

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

Tile Number: 23

US National Grid

100,000-m Square ID **LF**

Grid Zone Designation **17T**

0 — 0.5 miles

0 — 1 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURE

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

Tile Number: 24

US National Grid

100,000-m Square ID: **LF**

Grid Zone Designation: **17T**

0 — 0.5 miles

0 — 1 kilometers

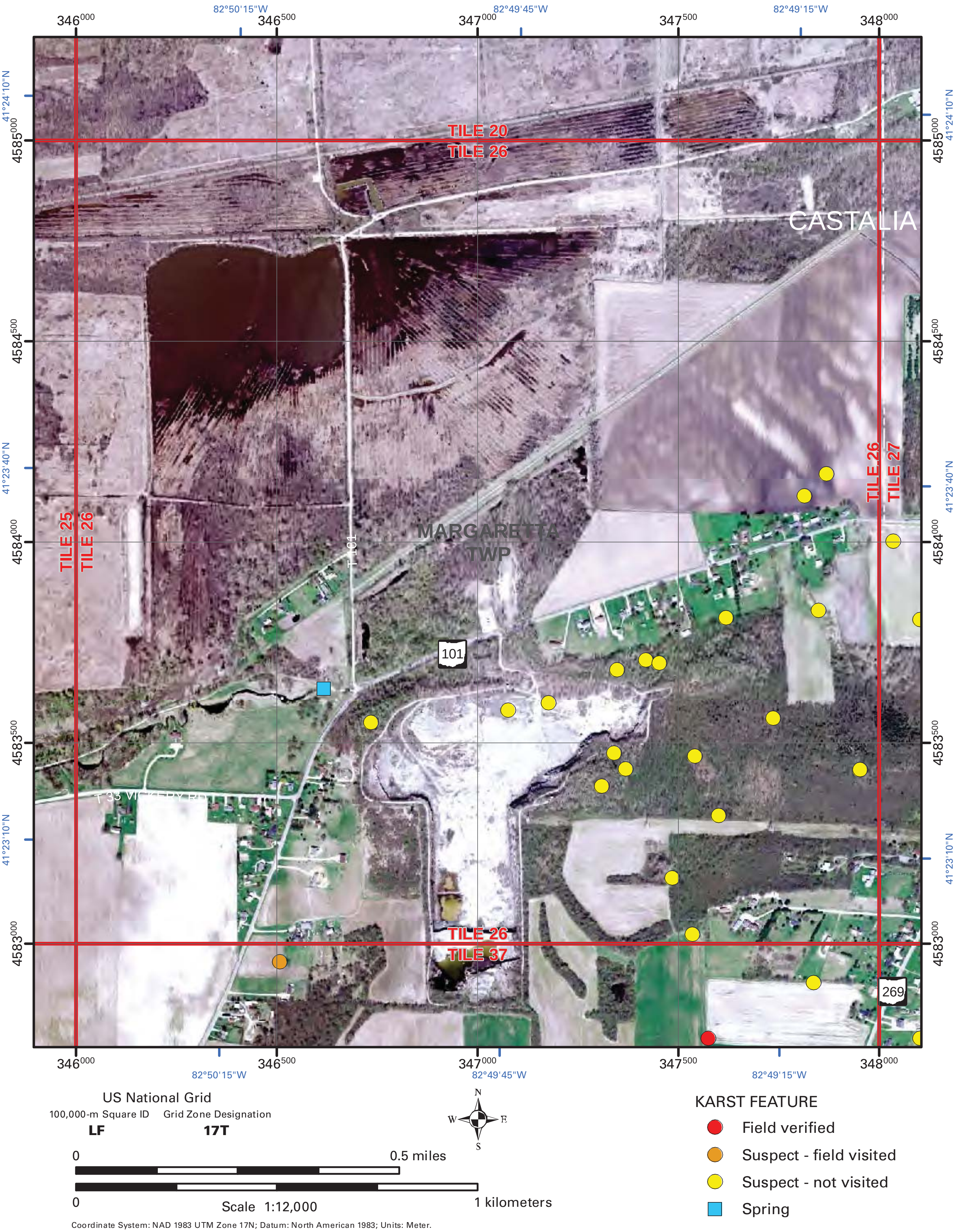
Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURE

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

Tile Number: 26

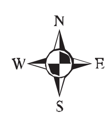


Tile Number: 27

US National Grid

100,000-m Square ID: LF

Grid Zone Designation: 17T



0 — 0.5 miles

0 — 1 kilometers

Scale 1:12,000

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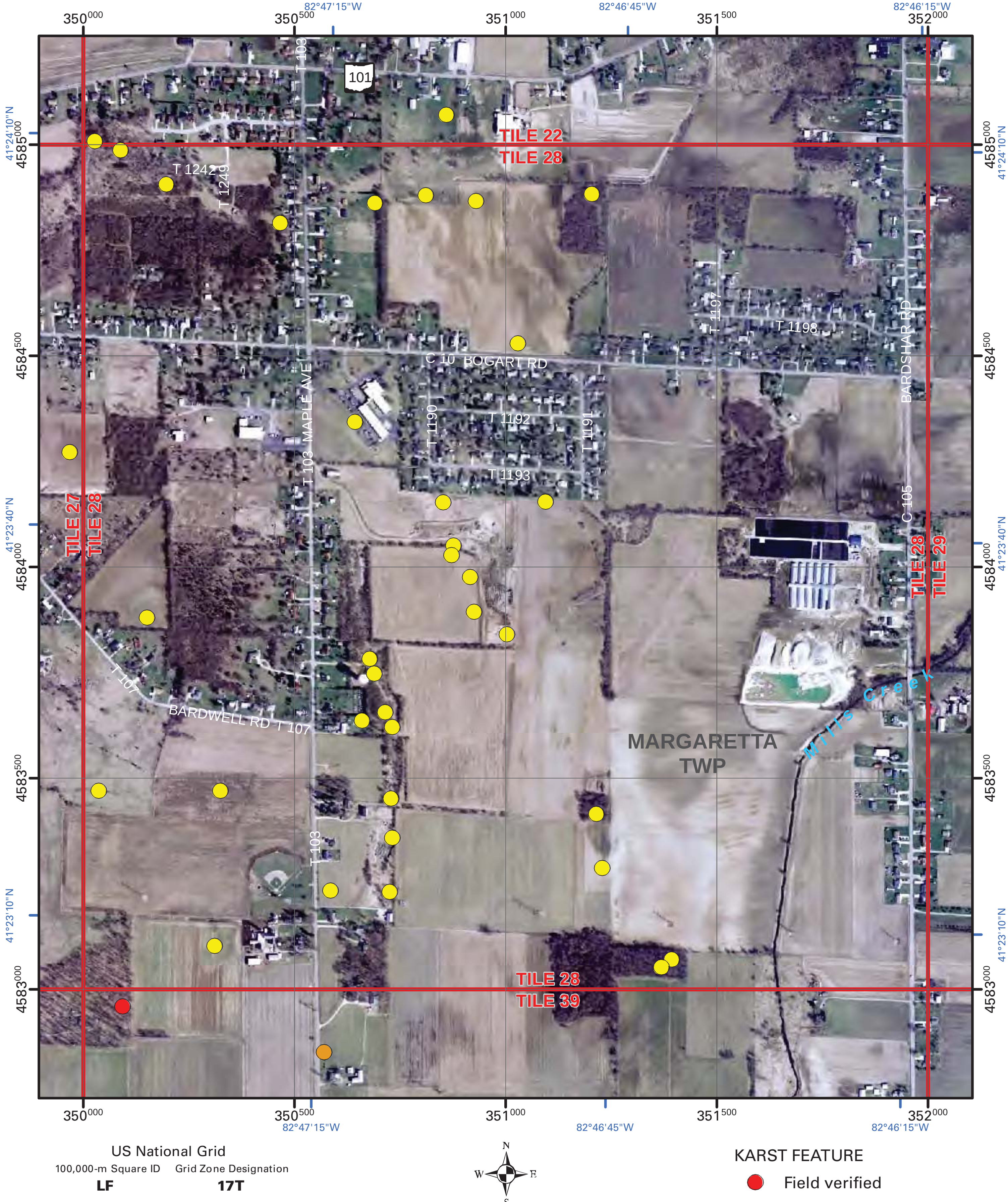
KARST FEATURE

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

Tile Number: 28



US National Grid

100,000-m Square ID: LF

Grid Zone Designation: 17T

0 — 0.5 miles

0 — 1 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURE

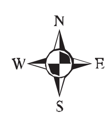
- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

Tile Number: 29

US National Grid

100,000-m Square ID: LF

Grid Zone Designation: 17T



0 — 0.5 miles

0 — 1 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURE

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

Tile Number: 36

US National Grid
100,000-m Square ID: LF
Grid Zone Designation: 17T

0 — 0.5 miles
0 — 1 kilometers
Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURE
- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

Tile Number: 37

US National Grid

100,000-m Square ID: **LF**

Grid Zone Designation: **17T**

0 — 0.5 miles

0 — 1 kilometers

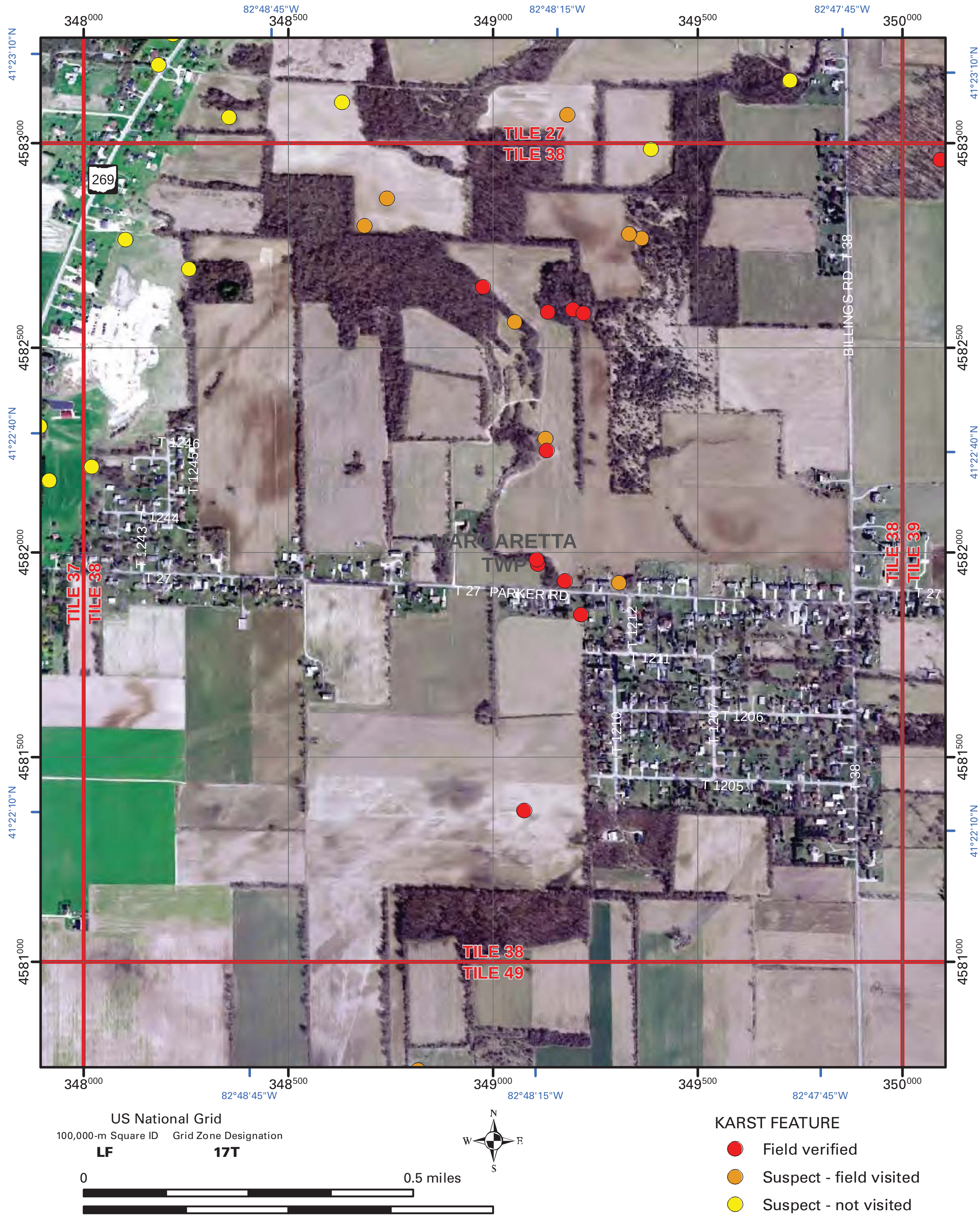
Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURE

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

Tile Number: 38

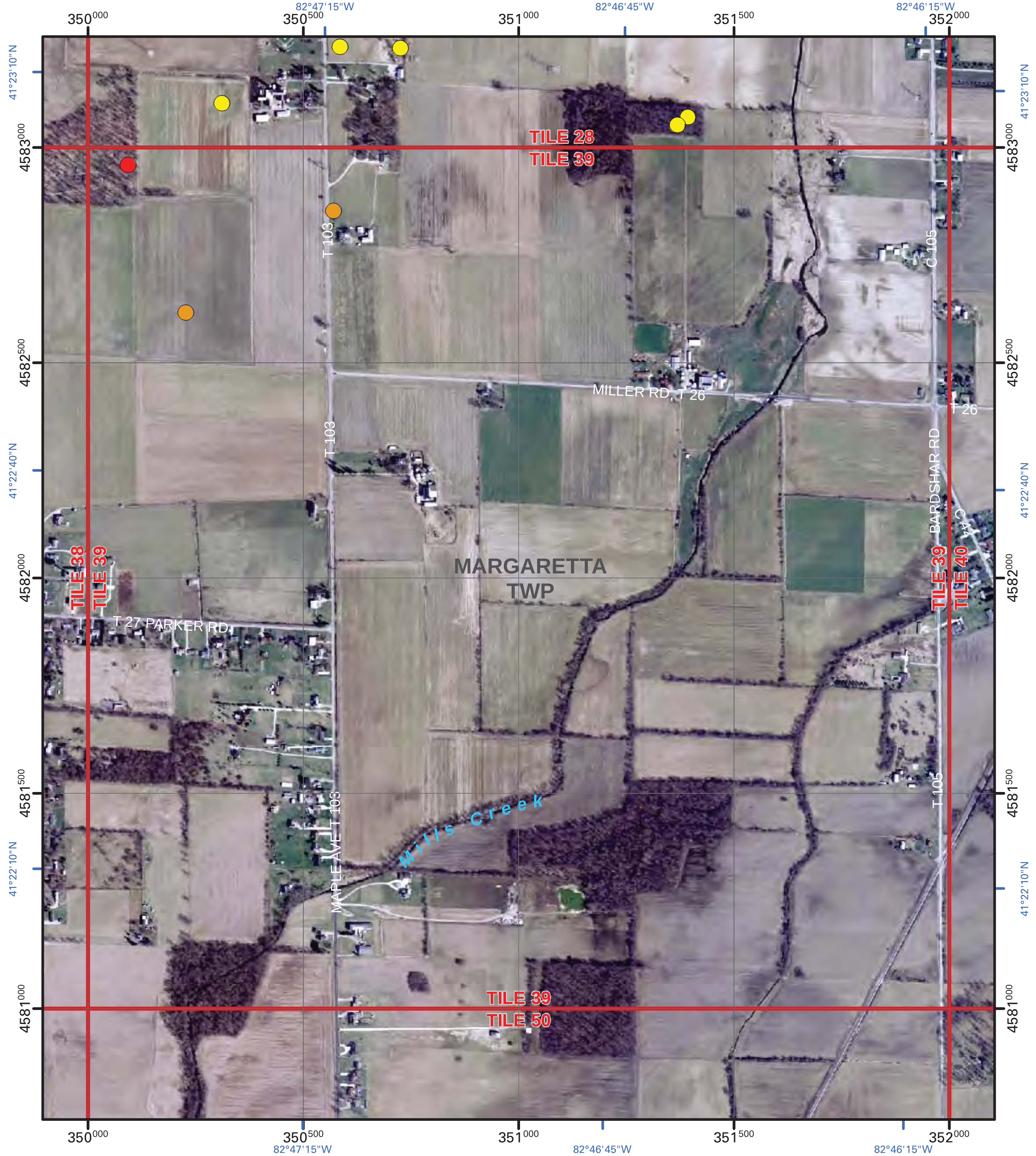


Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURE

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

Tile Number: 39



US National Grid

100,000-m Square ID: LF

Grid Zone Designation: 17T

0 — 0.5 miles

0 — 1 kilometers

Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURE

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

Tile Number: 46

US National Grid
100,000-m Square ID: LF
Grid Zone Designation: 17T

0 — 0.5 miles
0 — 1 kilometers
Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURE
- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

Tile Number: 47

US National Grid

100,000-m Square ID: LF

Grid Zone Designation: 17T

N W E S

0 0.5 miles

0 1 kilometers

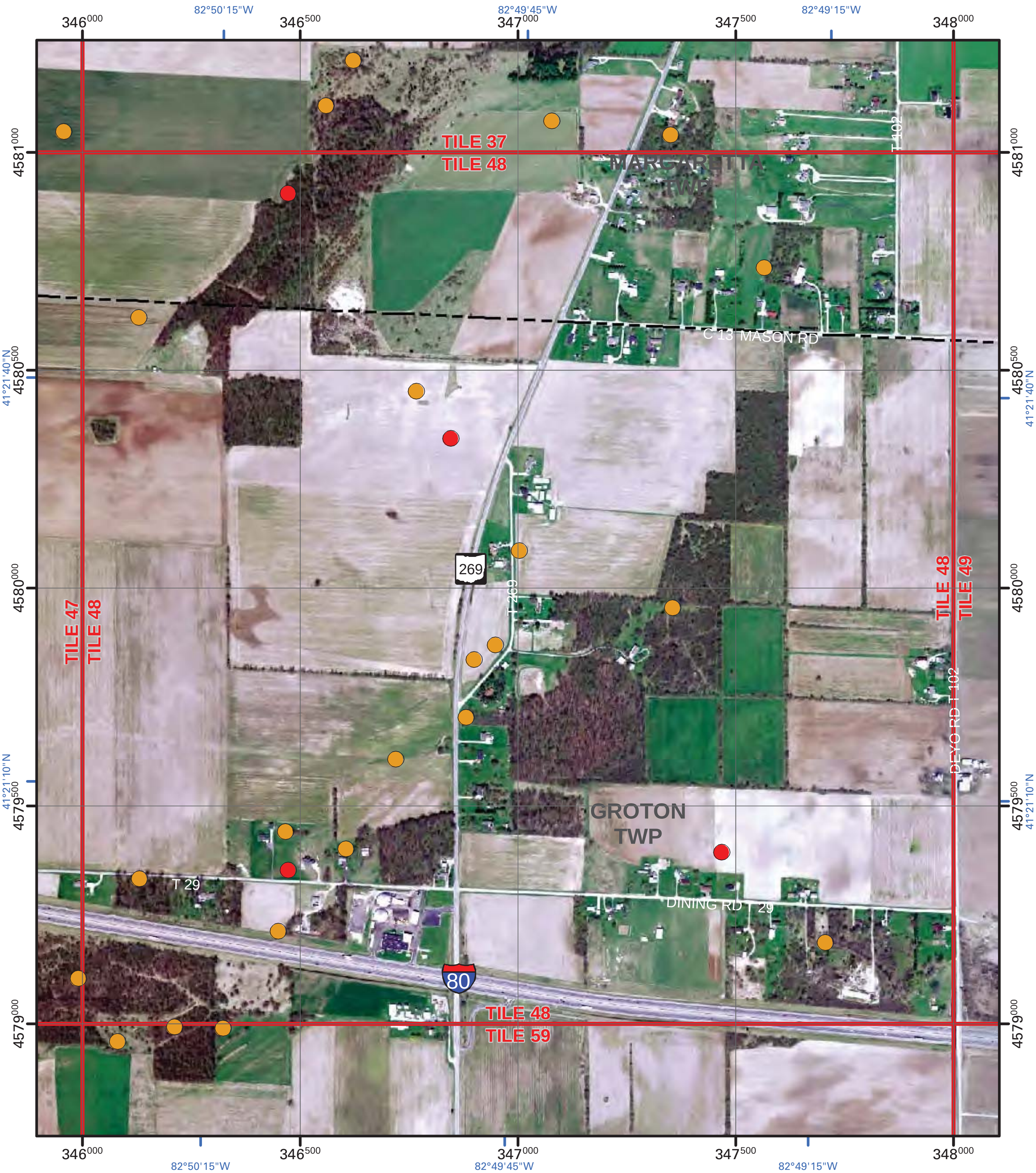
Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURE

- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring

Tile Number: 48



US National Grid
100,000-m Square ID **LF**
Grid Zone Designation **17T**

0 0.5 miles
0 1 kilometers
Scale 1:12,000

Coordinate System: NAD 1983 UTM Zone 17N; Datum: North American 1983; Units: Meter.

KARST FEATURE
- Field verified
- Suspect - field visited
- Suspect - not visited
- Spring