From “Digital Mapping Techniques ‘09—Workshop Proceedings”
U.S. Geological Survey Open-File Report 2010–1335
http://pubs.usgs.gov/of/2010/1335/

Geologic Resources Inventory of Our National Parks: A Case Study of the Timpanogos Cave National Monument

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Introduction

The Geologic Resources Inventory (GRI) is one of 12 inventories funded under the National Park Service (NPS) Natural Resource Challenge. It is designed to enhance baseline information available to park managers. The Geologic Resources Division (GRD) of the Natural Resource Program Center administers this program. To develop its products, the GRI team relies heavily on partnerships with Colorado State University (CSU), the U.S. Geological Survey, individual State geological surveys, and other organizations. The goals of the GRI are to increase understanding of the geologic processes that affect the parks and to provide accurate geologic information for use in park decisionmaking. Sound park stewardship relies on understanding natural resources and their role in the ecosystem, of which geology is the foundation.

CSU plays an integral role in creating and developing geologic products for use in managing the natural resources of the parks. CSU research associates work side-by-side with GRD staff, attending scoping meetings at parks to identify mapping needs and park-specific geologic issues, features, and processes. Research associates then produce a record of those meetings in a scoping summary, write geologic reports about the park’s geology, and create digital geologic-GIS data for use by park staff. CSU research associates have taken the lead in creating the NPS GRI Geology-GIS Geodatabase Data Model (O’Meara and others, 2008) to detail a series of guidelines for the capture and presentation of the geologic-GIS data. In addition, CSU research associates designed the map unit properties table, which provides a link between the properties of the geologic units on the digital map and the geologic information in the report.

This paper presents the GRI map and report products created for Timpanogos Cave National Monument (TICA), focusing on the Mississippian Deseret Limestone and its implications for park resource management.

Scoping

CSU Research Associates participated in a GRI scoping meeting at TICA (see figure 1, Location Map of Timpanogos Cave National Monument, Utah), which involved a site visit and roundtable discussion. The purpose of this meeting was to (1) introduce the GRI program and products, (2) investigate and evaluate existing geologic map coverage and potential mapping needs, (3) discuss geologic resource management issues and potential research and monitoring needs, and (4) identify distinctive geologic features and processes at the monument (for example, see figure 2). The scoping meeting included geologists and local experts from the NPS, Utah Geological Survey, University of Arizona, Brigham Young University, and TICA. A scoping summary generated from discussions at the meeting included:

- Brief description of the GRI
- Overview of the monument’s geologic setting and geologic resources
- Status of mapping coverage and plan for producing the digital geologic map
- Prioritized list of geologic resource management issues

- Description of geologic features and processes of interest
- Lists of research and monitoring recommendations and action items
- Participant list and contact information.

This summary served as an interim geologic report for the monument until the GRI produced the digital geologic map and accompanying final geologic report. The GRI scoping summary for TICA is available for download at *http://www.nature.nps.gov/geology/inventory/publications/s_summaries/TICA_scoping_summary_19990813.pdf*.

Map and Report Production Process

At the scoping meeting for TICA, participants decided that no new mapping was needed to meet the resource management needs of the park and that the digital geologic map for the monument should include the entire Timpanogos Cave quadrangle from the paper map produced by Baker and Crittenden (1961). In general, after available maps are identified, paper maps are scanned at high resolution and digitized, or available digital data are converted to the NPS GRI Geology-GIS Geodatabase Data Model (O'Meara and others, 2008), which specifies standards for attribution and spatial relationships, incorporating topological rules, subtypes, domains, and relationship classes. The goal is to maintain all aspects of the original paper map or data while enhancing usability by providing all elements of the map in a compact digital format that is usable in ArcGIS (*http://www.esri.com*). For TICA, cross sections were provided as separate images linked from ArcMap. Additional information found on the source paper map, such as its report, legend, and references, was included in the accompanying map information document, in Adobe Acrobat PDF format. GIS data layers digitized from the map included attitude measurements, faults, folds, geologic units and contacts, mine features, cross sections, and map symbology. In addition, two tables containing information about the geologic units and source map references were produced. In addition to the GIS data and map information document, the final digital geologic map product for TICA included layer files that record the symbology for each geologic data layer, and FGDC-compliant metadata.

Once the GRI had completed and distributed the digital geologic map for TICA, CSU research associates began production of the final geologic report. The GRI intended the geologic report for TICA to be concise and accessible to non-geoscientists. Information from the digital geologic map (including unit descriptions) and the scoping summary served as the foundation for the report. Through additional research, information from resources such as park planning documents, geologic journals, professional communication with local experts, park-specific publications, and the TICA Web site, were incorporated. The final report included a map unit properties table, which describes each unit that appears on the digital geologic map and delineates geologic properties of interest to monument resource managers. This table serves as a direct connection between the report and digital geologic map. The final geologic report underwent an extensive review

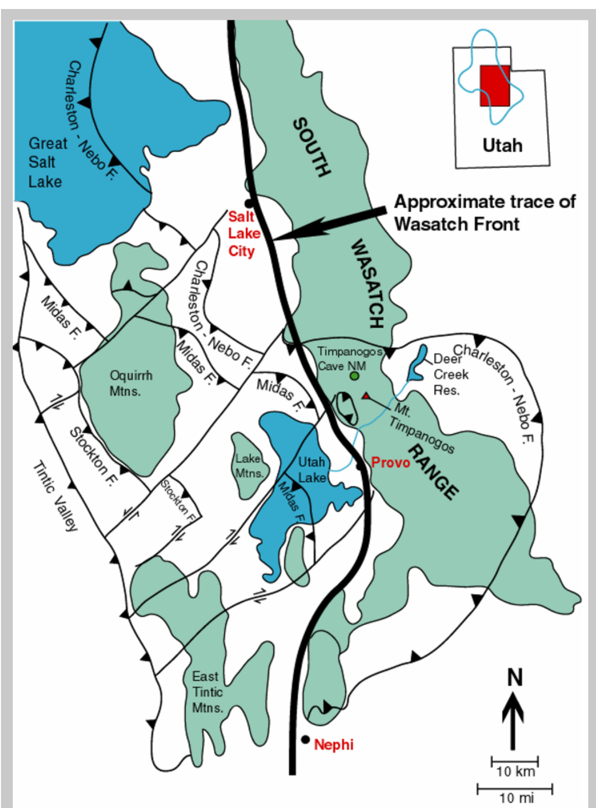


Figure 1. Location Map of Timpanogos Cave National Monument, Utah.

Figure 2. Speleothems in Middle Cave, Timpanogos Cave National Monument (photograph by NPS).

process with input from park staff and GRD technical experts, and final copyediting. Once finalized, the NPS-GRD delivered a hard copy of the GRI report for TICA accompanied by a CD containing a transmittal letter, PDF image of the digital geologic map, guide for using GIS data, the digital geologic map data, an ArcGIS geologic map document (.mxd), the GRI Geology-GIS Geodatabase Data Model, and a PDF of the geologic report.

Map Products

For TICA, the GRI program produced the following map products: GIS data, metadata and readme files, ancillary tables, and map help document. GIS data were delivered in both ESRI Personal Geodatabase and shapefile formats with attribute tables for both formats conveying information about the characteristics and properties of mapped geologic features. These data were accompanied by layer files (.lyr) that display geologic map symbology for individual data layers, and an ArcGIS map document (.mxd) that presents all GIS components of the GRI digital geologic map for Timpanogos Cave in a user-friendly format for viewing and data analysis. The FGDC-compliant metadata (.txt) conveyed layer and map-specific information such as data origin, data scale, how the data were created and the intended use, and whom to contact with questions about the data. The GIS Data Explanation readme file (in .pdf format) described the contents of the GRI GIS product with recommended entry points for viewing and using the data. Several ancillary tables were produced, including the Geologic Unit Information Table and the Source Map Information Table. The Geologic Unit Information Table displays detailed name and age information for geologic units in the map area. The Source Map Information Table contains citation information for all mapping data used in the creation of the GIS data. Both tables were linked through a relationship class, to be viewed with the GIS data in ArcMap. The GRI Map Help Document (.pdf) is intended to supplement the GIS data by providing lithologic descriptions, legends, figures, tables, and citation information from source maps used for this park. The Map Help Document contains information about the GRI program and about the methods and formats employed in the creation of the GIS data, and uses links within the document to enable easy and logical navigation. The GRI map products described above are available for download from the NPS Data Store (*http://science.nature.nps.gov/nrdata*).

Additional products created for TICA included a map layout and cross section graphics. The map layout is a .pdf-format representation of the GIS data; it contains standard geologic map elements such as legends, correlation of units, scale, and so on and is available for download from *http://www.nature.nps.gov/geology/inventory/publications/map_graphics/tica_map_graphic.pdf*. Images of geologic cross sections are annotated with citation information and linked to the geologic cross sections in the GIS data.

The GIS data provide information about the geology of the TICA and surrounding area. The Timpanogos cave complex is composed of three caves called Hansen, Middle, and Timpanogos caves, two of which are shown in figure 3A. The caves formed in the Mississippian Deseret Limestone (Md) through persistent dissolution of the limestone by acidic water along groundwater paths of concentrated flow. The Deseret Limestone is represented in the GIS data with color-filled polygons (defined by the Unit Symbol, fig. 3A), and an attribute table describing basic information about it and other geologic units (fig. 3B). An attribute table describing

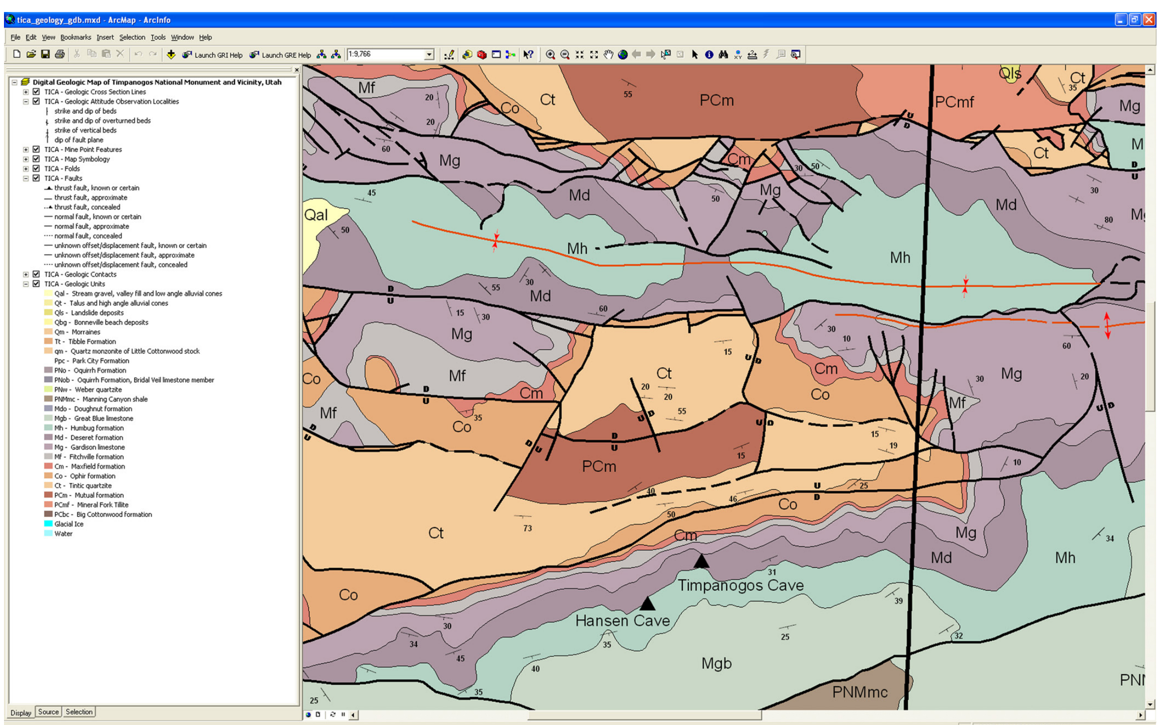
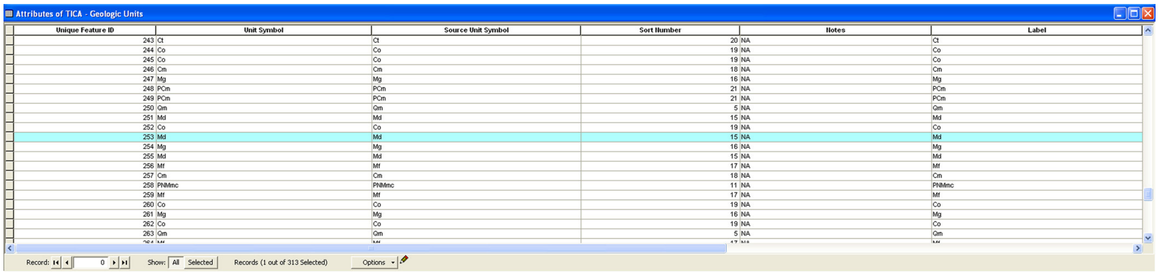


Figure 3A. ArcGIS geologic map document (.mxd) for part of Timpanogos Cave National Monument.


Attributes of TICA - Geologic Units

Unique Feature ID	Unit Symbol	Source Unit Symbol	Sort Number	Notes	Label
243	Ct	Ct	20	NA	Ct
244	Co	Co	19	NA	Co
245	Co	Co	19	NA	Co
246	Cm	Cm	18	NA	Cm
247	Mg	Mg	16	NA	Mg
248	PCm	PCm	21	NA	PCm
249	PCm	PCm	21	NA	PCm
250	Qm	Qm	5	NA	Qm
251	Md	Md	15	NA	Md
252	Co	Co	19	NA	Co
253	Md	Md	15	NA	Md
254	Mg	Mg	16	NA	Mg
255	Md	Md	15	NA	Md
256	Mf	Mf	17	NA	Mf
257	Cm	Cm	18	NA	Cm
258	PNMmc	PNMmc	11	NA	PNMmc
259	Mf	Mf	17	NA	Mf
260	Co	Co	19	NA	Co
261	Mg	Mg	16	NA	Mg
262	Co	Co	19	NA	Co
263	Qm	Qm	5	NA	Qm

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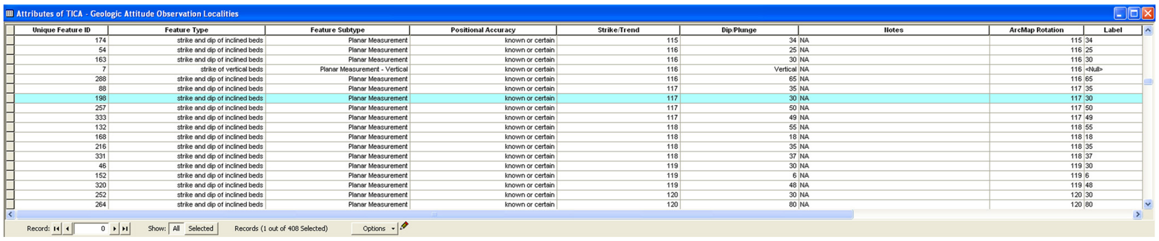
Figure 3B. Geologic Units Attribute Table.


Attributes of TICA - Geologic Attitude Observation Localities

Unique Feature ID	Feature Type	Feature Subtype	Positional Accuracy	Strike/Trend	Dip/Plunge	Notes	ArcMap Rotation	Label
174	strike and dip of inclined beds	Planar Measurement	known or certain	115	34	NA	115	34
54	strike and dip of inclined beds	Planar Measurement	known or certain	116	25	NA	116	25
163	strike and dip of inclined beds	Planar Measurement	known or certain	116	30	NA	116	30
7	strike of vertical beds	Planar Measurement - Vertical	known or certain	116	Vertical	NA	116	<Null>
288	strike and dip of inclined beds	Planar Measurement	known or certain	116	65	NA	116	65
88	strike and dip of inclined beds	Planar Measurement	known or certain	117	35	NA	117	35
198	strike and dip of inclined beds	Planar Measurement	known or certain	117	30	NA	117	30
257	strike and dip of inclined beds	Planar Measurement	known or certain	117	50	NA	117	50
333	strike and dip of inclined beds	Planar Measurement	known or certain	117	49	NA	117	49
132	strike and dip of inclined beds	Planar Measurement	known or certain	118	55	NA	118	55
168	strike and dip of inclined beds	Planar Measurement	known or certain	118	18	NA	118	18
216	strike and dip of inclined beds	Planar Measurement	known or certain	118	35	NA	118	35
331	strike and dip of inclined beds	Planar Measurement	known or certain	118	37	NA	118	37
46	strike and dip of inclined beds	Planar Measurement	known or certain	119	30	NA	119	30
152	strike and dip of inclined beds	Planar Measurement	known or certain	119	6	NA	119	6
320	strike and dip of inclined beds	Planar Measurement	known or certain	119	48	NA	119	48
252	strike and dip of inclined beds	Planar Measurement	known or certain	120	30	NA	120	30
264	strike and dip of inclined beds	Planar Measurement	known or certain	120	80	NA	120	80

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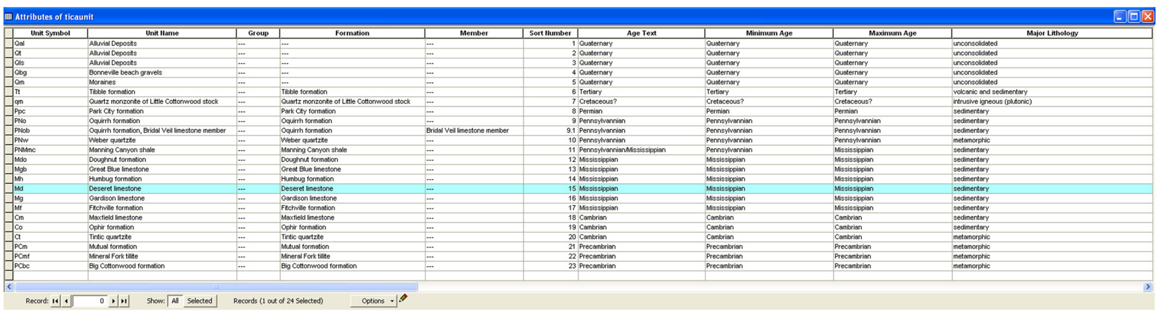
Figure 3C. Geologic Attitude Observation Localities Table.


Attributes of ticaunit

Unit Symbol	Unit Name	Group	Formation	Member	Sort Number	Age Text	Minimum Age	Maximum Age	Major Lithology
Qal	Alluvial Deposits	---	---	---	1	Quaternary	Quaternary	Quaternary	unconsolidated
Qt	Alluvial Deposits	---	---	---	2	Quaternary	Quaternary	Quaternary	unconsolidated
Qls	Alluvial Deposits	---	---	---	3	Quaternary	Quaternary	Quaternary	unconsolidated
Qbg	Bonneville beach gravels	---	---	---	4	Quaternary	Quaternary	Quaternary	unconsolidated
Qm	Moraines	---	---	---	5	Quaternary	Quaternary	Quaternary	unconsolidated
Tt	Tibble formation	---	Tibble formation	---	6	Tertiary	Tertiary	Tertiary	volcanic and sedimentary
qm	Quartz monzonite of Little Cottonwood stock	---	Quartz monzonite of Little Cottonwood stock	---	7	Cretaceous?	Cretaceous?	Cretaceous?	intrusive igneous (plutonic)
Ppc	Park City formation	---	Park City formation	---	8	Permian	Permian	Permian	sedimentary
PNo	Oquirrh formation	---	Oquirrh formation	---	9	Pennsylvanian	Pennsylvanian	Pennsylvanian	sedimentary
PNob	Oquirrh formation, Bridal Veil limestone member	---	Oquirrh formation	Bridal Veil limestone member	9.1	Pennsylvanian	Pennsylvanian	Pennsylvanian	sedimentary
PNw	Weber quartzite	---	Weber quartzite	---	10	Pennsylvanian	Pennsylvanian	Pennsylvanian	metamorphic
PNMmc	Manning Canyon shale	---	Manning Canyon shale	---	11	PennsylvanianMississippian	Pennsylvanian	Mississippian	sedimentary
Mdo	Doughnut formation	---	Doughnut formation	---	12	Mississippian	Mississippian	Mississippian	sedimentary
Mgb	Great Blue limestone	---	Great Blue limestone	---	13	Mississippian	Mississippian	Mississippian	sedimentary
Mh	Humbug formation	---	Humbug formation	---	14	Mississippian	Mississippian	Mississippian	sedimentary
Md	Deseret limestone	---	Deseret limestone	---	15	Mississippian	Mississippian	Mississippian	sedimentary
Mg	Gardison limestone	---	Gardison limestone	---	16	Mississippian	Mississippian	Mississippian	sedimentary
Mf	Fitchville formation	---	Fitchville formation	---	17	Mississippian	Mississippian	Mississippian	sedimentary
Cm	Maxfield limestone	---	Maxfield limestone	---	18	Cambrian	Cambrian	Cambrian	sedimentary
Co	Ophir formation	---	Ophir formation	---	19	Cambrian	Cambrian	Cambrian	sedimentary
Ct	Tintic quartzite	---	Tintic quartzite	---	20	Cambrian	Cambrian	Cambrian	metamorphic
PCm	Mutual formation	---	Mutual formation	---	21	Precambrian	Precambrian	Precambrian	metamorphic
PCmf	Mineral Fork tillite	---	Mineral Fork tillite	---	22	Precambrian	Precambrian	Precambrian	metamorphic
PCbc	Big Cottonwood formation	---	Big Cottonwood formation	---	23	Precambrian	Precambrian	Precambrian	metamorphic

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Figure 4. Geologic Unit Information Table.

the highly inclined bedding near the caves is also presented (fig. 3C). Additional information about the unit, including its age, name, and whether it is a Group, Formation, or Member, is shown in the Geologic Unit Information Table (fig. 4). Finally, a unit description for the Deseret Limestone (Md) and other units, as well as geologic cross sections and other additional source map information, is presented in the GRI Map Help PDF document (figs. 5A and 5B).

Report Products

The GRI geologic report produced for TICA includes the following sections and components: Executive Summary and Introduction, Geologic Issues, Geologic Features and Processes, Map Unit Properties Table, Geologic History, Glossary and References, and Appendices. The Executive Summary and Introduction contains a summary of the key points in the report and describes the GRI program, geologic setting and history of TICA, and cave formation at Timpanogos. The Geologic Issues section describes resource management issues such as seismicity associated with the Wasatch Front, mine features, slope processes, cave restoration and preservation, wind erosion, sediment loading, and stream flow with issue-specific recommendations for inventory, monitoring, and research. The Geologic Features and Processes section describes the Charleston Fault Zone, formation of the cave and karst landscapes, and speleothems at TICA. The Map Unit Properties Table presents physical characteristics, potential resources, cultural information, and scientific significance of each unit on the geologic map. The Geologic History section describes the rocks and unconsolidated deposits that appear on the geologic map, the environment in which those units were deposited, and the timing of geologic events that created the present landscape. Technical geologic terms used throughout the report are defined in the Glossary. The Reference section lists the sources cited in the report and provides a general

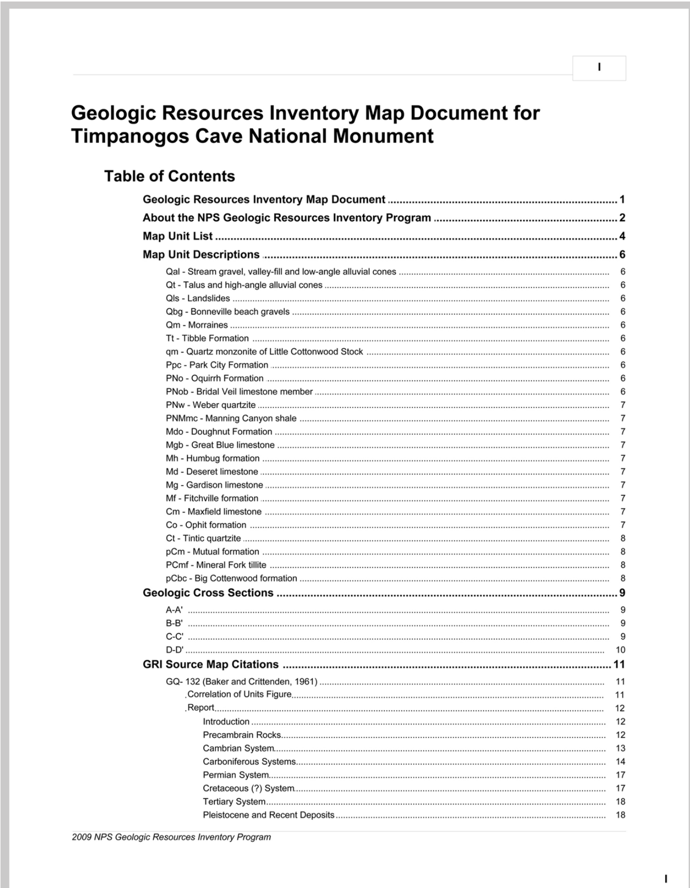

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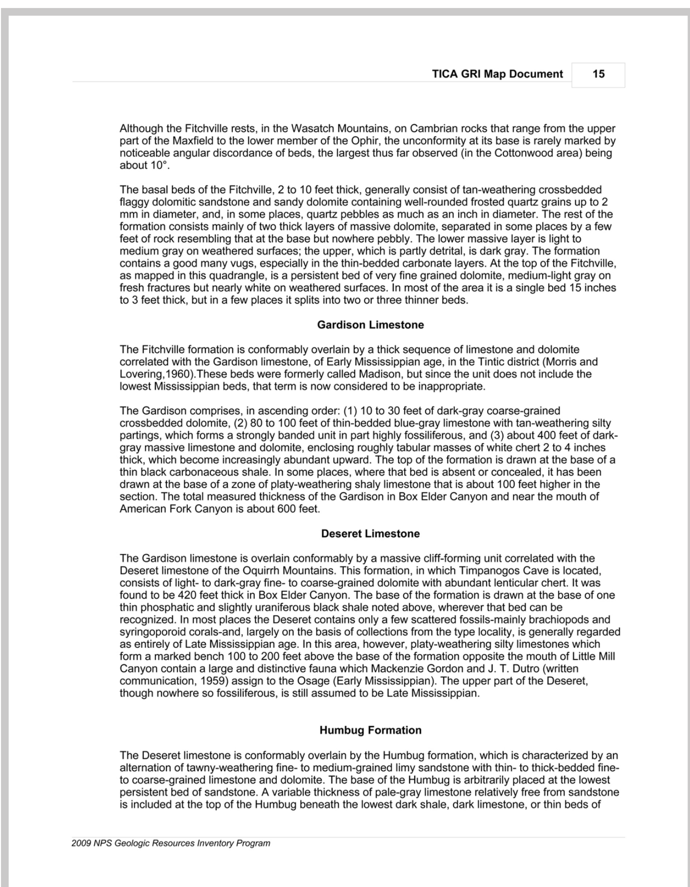
Figure 5A. Table of Contents, in Map Help Document.



TICA GRI Map Document 15

Although the Fitchville rests, in the Wasatch Mountains, on Cambrian rocks that range from the upper part of the Maxfield to the lower member of the Ophir, the unconformity at its base is rarely marked by noticeable angular discordance of beds, the largest thus far observed (in the Cottonwood area) being about 10°.

The basal beds of the Fitchville, 2 to 10 feet thick, generally consist of tan-weathering crossbedded flaggy dolomitic sandstone and sandy dolomite containing well-rounded frosted quartz grains up to 2 mm in diameter, and, in some places, quartz pebbles as much as an inch in diameter. The rest of the formation consists mainly of two thick layers of massive dolomite, separated in some places by a few feet of rock resembling that at the base but nowhere pebbly. The lower massive layer is light to medium gray on weathered surfaces; the upper, which is partly detrital, is dark gray. The formation contains a good many vugs, especially in the thin-bedded carbonate layers. At the top of the Fitchville, as mapped in this quadrangle, is a persistent bed of very fine grained dolomite, medium-light gray on fresh fractures but nearly white on weathered surfaces. In most of the area it is a single bed 15 inches to 3 feet thick, but in a few places it splits into two or three thinner beds.

Gardison Limestone

The Fitchville formation is conformably overlain by a thick sequence of limestone and dolomite correlated with the Gardison limestone, of Early Mississippian age, in the Tintic district (Morris and Lovering,1960).These beds were formerly called Madison, but since the unit does not include the lowest Mississippian beds, that term is now considered to be inappropriate.

The Gardison comprises, in ascending order: (1) 10 to 30 feet of dark-gray coarse-grained crossbedded dolomite, (2) 80 to 100 feet of thin-bedded blue-gray limestone with tan-weathering silty partings, which forms a strongly banded unit in part highly fossiliferous, and (3) about 400 feet of dark-gray massive limestone and dolomite, enclosing roughly tabular masses of white chert 2 to 4 inches thick, which become increasingly abundant upward. The top of the formation is drawn at the base of a thin black carbonaceous shale. In some places, where that bed is absent or concealed, it has been drawn at the base of a zone of platy-weathering shaly limestone that is about 100 feet higher in the section. The total measured thickness of the Gardison in Box Elder Canyon and near the mouth of American Fork Canyon is about 600 feet.

Deseret Limestone

The Gardison limestone is overlain conformably by a massive cliff-forming unit correlated with the Deseret limestone of the Oquirrh Mountains. This formation, in which Timpanogos Cave is located, consists of light- to dark-gray fine- to coarse-grained dolomite with abundant lenticular chert. It was found to be 420 feet thick in Box Elder Canyon. The base of the formation is drawn at the base of one thin phosphatic and slightly uraniferous black shale noted above, wherever that bed can be recognized. In most places the Deseret contains only a few scattered fossils-mainly brachiopods and syringoporoid corals-and, largely on the basis of collections from the type locality, is generally regarded as entirely of Late Mississippian age. In this area, however, platy-weathering silty limestones which form a marked bench 100 to 200 feet above the base of the formation opposite the mouth of Little Mill Canyon contain a large and distinctive fauna which Mackenzie Gordon and J. T. Dutro (written communication, 1959) assign to the Osage (Early Mississippian). The upper part of the Deseret, though nowhere so fossiliferous, is still assumed to be Late Mississippian.

Humbug Formation

The Deseret limestone is conformably overlain by the Humbug formation, which is characterized by an alternation of tawny-weathering fine- to medium-grained limy sandstone with thin- to thick-bedded fine- to coarse-grained limestone and dolomite. The base of the Humbug is arbitrarily placed at the lowest persistent bed of sandstone. A variable thickness of pale-gray limestone relatively free from sandstone is included at the top of the Humbug beneath the lowest dark shale, dark limestone, or thin beds of

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Figure 5B. Description of geologic units, in Map Help Document.

bibliography for use by the resource manager. Appendix A contains the geologic map graphic, which is an 11 by 17-inch browse graphic of the digital geologic map of TICA. Appendix B includes excerpts from the scoping summary. The GRI Geologic Report for TICA is available for download from *http://www.nature.nps.gov/geology/inventory/publications/reports/tica_gre_rpt_view.pdf*.

The GRI report makes the information in the GIS data more relevant and accessible to park resource managers by providing resource-specific information about each geologic unit, and the geologic setting. The Map Unit Properties Table (fig. 6) shows this information more graphically and ties back to the map product by replicating the color of the unit as it appears on the GIS map (fig. 3A).

Resource Management Implications

CSU research associates and GRD staff provided TICA staff with a complete GRI product including a summary of the scoping meeting, digital geologic-GIS data, and the geologic report summarizing the park's geologic issues, features, and processes. The Deseret Limestone is of particular significance because it is the geologic unit that hosts the majority of the cave complex at the national monument (figs. 7 and 8). The GIS data can be used to understand the spatial distribution of the Deseret Limestone, thereby identifying other potential locations of cave formation. The geologic report provides additional detailed information about the unit and its particular properties. Combining information from the GIS data and the report, park resource managers have a powerful tool for determining which locations are suitable for development, which areas need resource protection, and where potential hazards may exist.

At TICA, the Deseret Limestone is relatively resistant to weathering and erosion, forming steep slopes. The limestone is unsuitable for development in areas where dissolution is high, because pervasively dissolved areas do not provide the structural integrity for heavy development nor do they provide the adsorption capabilities necessary for wastewater treatment. The unit is also fossiliferous, posing the potential need to develop a resource management plan to protect exposures of the Deseret Limestone from park visitors in search of fossil samples. In addition, the information contained in the report and GIS data can be used to help identify habitats for various plants and animals. For instance, the caves within the Deseret Limestone may provide habitat for mountain lions as well as cave flora and fauna. The mineralized caves at Timpanogos (fig. 9) are famous for myriad speleothems including rare examples of helictites. Trace elements derived from units such as the Deseret Limestone are responsible for the variety of colored dripstones and flowstones. Geochemical sampling of Deseret Limestone and associated speleothems may yield paleoclimate information and data regarding the timing of cave formation. The GRI product is an informative component available to park interpretive staff for creating programs designed to educate monument visitors about the geology of the area.

Age	Map Unit (Symbol)	Unit Description	Erosion Resistance	Suitability for Development	Hazards	Paleontologic Resources	Cultural Resources	Mineral Specimens	Karst Issues	Mineral Resources	Habitat	Recreation	Global Significance
MISSISSIPPIAN	Great Blue Limestone (Mgb)	Unit is 853 m (2800 ft) thick, informally divided into three parts: lower and upper limestone members, separated by carbonaceous shaly beds (Long Trail shale member). Unit is composed of nearly homogenous, calcitic, dark gray to black limestone and shaly limestone. Bedding is very regular and weathers to light-gray to pinkish-tan flaky, slabby rock. Some black chert nodules occur locally as well as some black shale and rusty weathering fine-grained quartzite.	Moderate	Suitable for most development unless significant dissolution or weathering has occurred. Weathered rock sloughs and flakes and is unstable for permanent structures. Dissolution can pose a problem with waste facilities	Rockfall hazard where unit is weathered and on a slope, can be unstable trail base if severely weathered or dissolved.	Late Mississippian age fossils	Chert nodules could have provided tool material	None	Karst potential exists for this unit	None documented	Vugs on cliff could provide nesting habitat	Good for most uses, weathered surfaces could prove hazardous for rock climbing.	Type locality in the Oquirrh Mountains
MISSISSIPPIAN	Humbug Formation (Mh)	Unit is more than 244 m (800 ft) thick in TICA area. Composed of interbanded dark to light-gray, fine- to coarse-grained dolomite with fine- to medium-grained limey sandstone. Unit appears banded with brown beds layered with gray beds.	Moderate	Good for all development unless highly fractured, which could pose a problem with waste facilities	Rockfall hazard on cliff faces	sparsely fossiliferous in limestone beds	None	None	Karst potential exists for this unit	Attractive building stone	Vugs and ledges on cliffs could provide nesting habitat	Rock climbing and Mountain biking. Good for all uses	Distinct banded unit
MISSISSIPPIAN	Deseret Limestone (Md)	The unit is more than 152 m (500 ft) thick. Unit is a massive to medium-bedded, cliff and cave-forming unit with dark- to light-blue-gray, fine- to coarse-grained dolomite with abundant lenticular, or lens-like, black chert deposits and some interbedded limestone. Timpanogos Cave is contained in this unit.	Moderate to high	Dissolution can create conduits which pose a problem for waste facilities and severe dissolution can make construction on this unit risky	Rockfall on cliff faces, and assorted cave-related hazards such as slippery trails, holes, and sharp speleothems	Late Mississippian age brachiopods and corals, crinoid stems, cup corals and colonial corals.	Native Americans may have used the caves for ceremonial and other purposes, chert masses may have been tool material	Speleothems, fossils	Karst exists in this unit, caves present	None documented	Caves provide animal lion and other mammal habitat	Caving, climbing	Cave and cave formations (speleothems)
MISSISSIPPIAN	Gardison Limestone (Mg)	Unit is more than 183 m (600 ft) thick in monument area. Lower beds are dark-gray, thin-bedded, coarse-grained limestone and dolomite. Middle beds contain thin-bedded, blue-gray limestone with silty partings. Upper beds are dark-gray, massive limestone and dolomite. Light-brown to black, and white chert abundant locally. Carbonaceous shale marks top of unit.	Moderate to high	Shaly partings can render the unit unstable for foundations and other permanent facilities	Shaly partings can pose rockfall hazards	Fossils of *Triplophyllites, Syringopora, Spirifer centronatus*, *Triplophyllites excavatum*, *Cliothyridina* and *Aviculipecten* of Mississippian age.	Many chert nodules useful for ancient tools	Fossils	Some karst potential in carbonate beds	Locally uraniferous and phosphatic layers	Vugs on cliff could provide nesting habitat	Good for all uses	Mississippian fossils of Kinderhookian age
MISSISSIPPIAN	Fitchville Dolomite (Mf)	In the TICA area the unit is more than 152 m (500 ft) thick, composed of coarse, light-gray to tan dolomite and dolomitic sandstone with some pebbly layers. Upper beds are very fine-grained dolomite.	Low to moderate	Dissolution can create water conduit problems and dangerous trail base, but otherwise okay for all uses	Jointed sandstone beds can pose rockfall hazards on cliffs, crystal lined vugs are hazardous hand and foot holds	Mississippian age fossils	None	Crystal lined vugs	Karst potential exists for this unit	Flaggy lower beds are attractive flagstone material	Many vugs present for bird and small creature habitat	Rock climbing and caving potential	Mississippian fossils, records profound unconformity
CAMBRIAN	Maxfield Limestone (Cm)	Unit ranges in thickness between 0 and 91 m (0-300 ft). Unit contains thin- to thick-bedded, blue-gray, mottled or speckled magnesian limestone and dolomite. Some oolitic and pisolitic lower beds and white dolomite upper beds	Moderate	Dissolution can create hazardous trail base and conduits not suitable for waste facilities.	Rockfall hazard potential	Fossils of trilobites *Kootenia* sp., *Doliochometopsis* sp., *Spencia* sp.	None	Fossils, pisolite layers	Karst potential exists for this unit	None documented	Vugs on cliff could provide nesting habitat	Rock climbing potential	Cambrian fossils
CAMBRIAN	Ophir Formation (Co)	Near TICA unit is 91 m (300 ft) thick. Lower beds are olive-green micaceous shale. Middle beds are massive gray limestone and upper beds are brown, calcareous sandstone mixed with shale.	Low	Micaceous shale can be unstable for structure foundations	Unit can be a crumbly trail base	worm tracks, fucoid markings, brachiopods and trilobites. Fossils of *Olenellus, Micromitra, Obolus*	None	Fossils	Middle beds may have dissolution	None documented	Vugs on cliff could provide nesting habitat	Good for trails	Cambrian fossils

Figure 6. Map Unit Properties Table, from the Geologic Report.

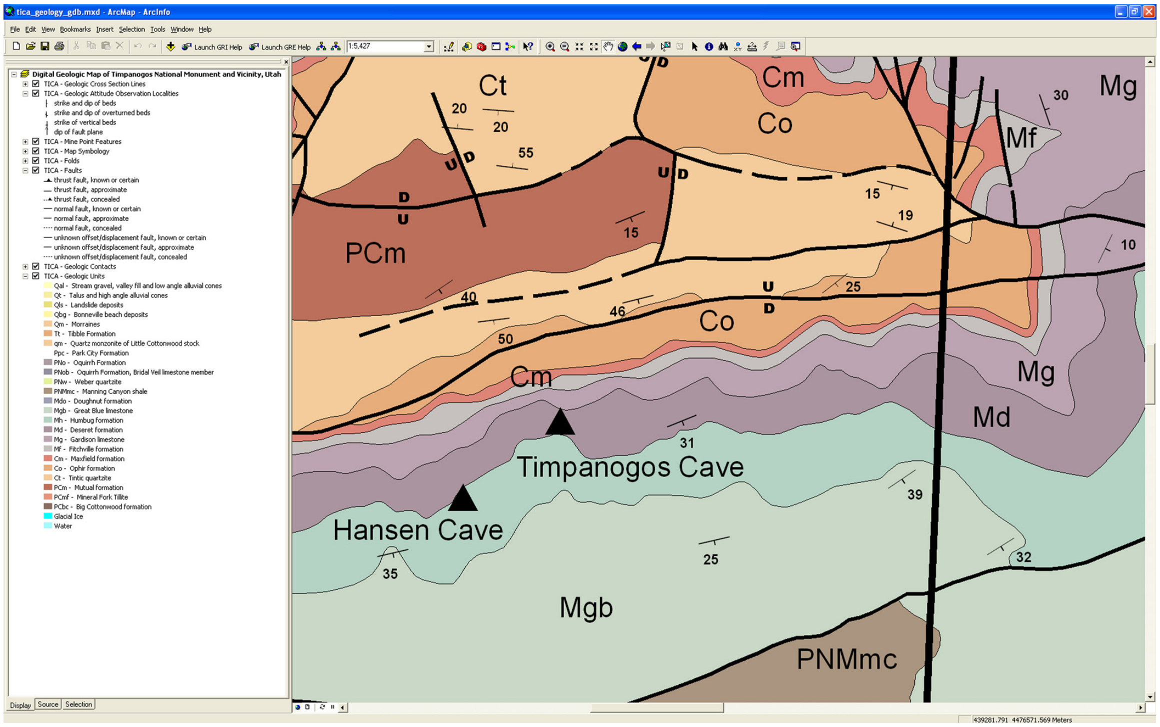

Figure 7. View of the GRI geologic GIS data in American Fork Canyon surrounding Timpanogos Cave National Monument.

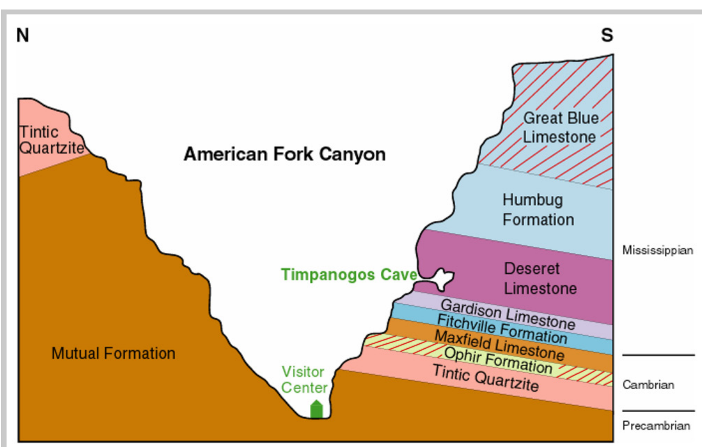

Figure 8. Generalized cross section of American Fork Canyon, including the Timpanogos Cave system (from Timpanogos Geologic Report, adapted from NPS graphic).

Figure 9. Urchin, Chimes Room, Timpanogos Cave National Monument (photograph by NPS).

Additional Information

Additional information is available on the poster presented at the DMT meeting (fig. 10), and at the GRI Web site: *http://www.nature.nps.gov/geology/inventory/*.

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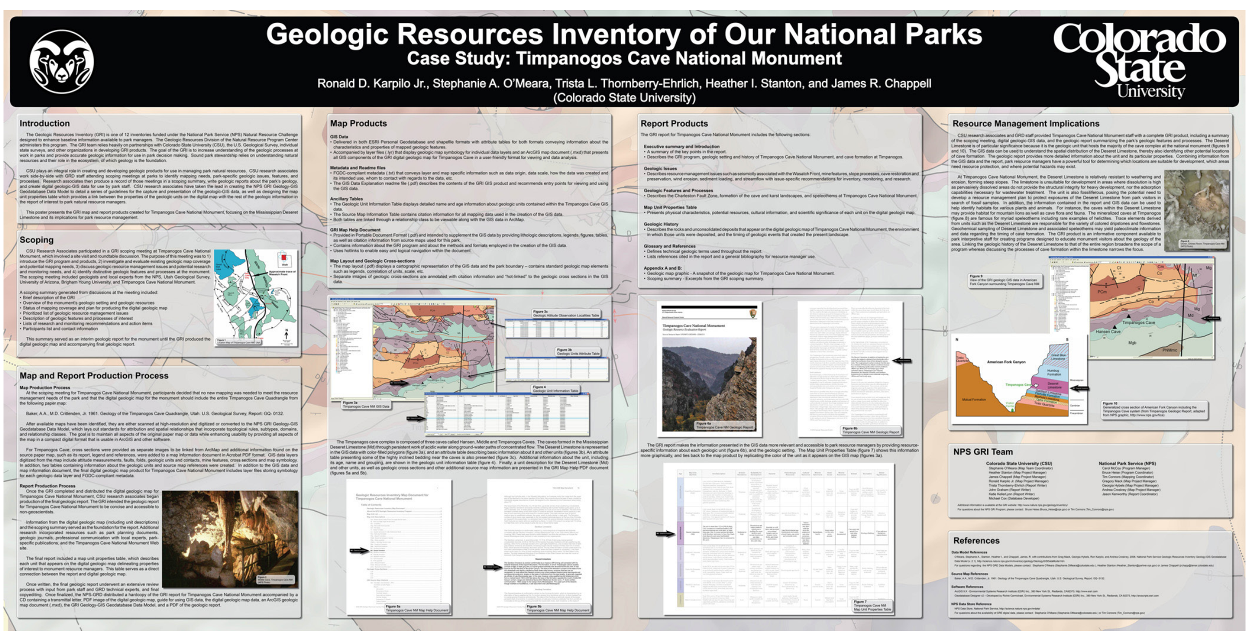

Figure 10. Poster titled "Geologic Resources Inventory of Our National Parks, Case Study: TICA," presented at the Digital Mapping Techniques 2009 workshop in Morgantown, WV. A high-resolution version of this poster is available for download at *http://ngmdb.usgs.gov/Info/dmt/docs/DMT09_Karpilo.pdf*