Report for:

Heavy Civil Construction Costs for a Very Large Hadron Collider in Northern Illinois

Prepared for:

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Table of Contents

List of Tables

List of Figures

Executive Summary

The team of CNA Consulting Engineers and the Toronto office of Hatch-Mott-MacDonald developed cost estimates for underground construction of a staged Very Large Hadron Collider (VLHC) project located tangent to the Tevatron at FermiLab. Three alignment alternatives and two main beam tunnel diameters were included. The cost estimates include heavy civil underground construction that produces stable underground excavations, but excludes outfitting. FermiLab provided detailed project descriptions and so-called "lampshades" that defined the subsurface geologic formations encountered by the three tunnel alternatives.

Ten principal tasks were conducted. A brief summary of each is provided below.

1. Review existing geologic data, using published geologic resources—We used the reports listed in the Bibliography to confirm the location and extent of the geologic formations in the study areas. In addition, we formed a conceptual model of the rock conditions present, and identified fourteen rock condition types, which are summarized in the table under item 4 below.

2. Observe pertinent geologic exposures in the field—After review of the available and pertinent geologic exposures, this task was limited to an underground tour of the NuMI project construction, and the a surface and underground tour to the Conco Western Stone Quarry in North Aurora, Il. Both visits were very useful in assessing the underground construction conditions for the VLHC components near FermiLab.

3. Quantify all major underground construction components of the VLHC—Underground construction components of the VLHC project include the main beamline tunnel, many caverns of varying size and shape, straight and bypass tunnels, portals for the equipment tunnels, injection ramp connections to the existing Tevatron, a magnet installation ramp of the far side away from FermiLab, major experiment installation shafts, access shafts, emergency egress and ventilation shafts, site risers, and utility penetrations. Each of these 300 plus components is documented in Appendix A. This report does not include the near-surface structures necessary at the connection from the existing Tevatron to the injection ramps.

4. Categorize anticipated tunneling conditions for major geologic units and contacts between major units—For estimating the cost of cavern construction, an NGI Q rating was estimated for each of the fourteen rock conditions identified in item 1 above. Q values ranged from a minimum of 0.33 to a maximum of 33.75, with cavern rock support and construction conditions depending upon the Q rating.

   For estimating tunnel construction costs, the fourteen rock conditions were assigned to three tunneling conditions types, as shown in Table 4 on page 14. The finished diameter of the tunnels is either 12 ft or 16 ft, and the TBM's are capable of tunnel drives 4844 meters long, equivalent to the shaft spacing. At end of each drive the TBM could be accessed for reconditioning. TBM Type A, for rock conditions 1, 3, and 9 is used in the best rock conditions where minimal ground support and water control is required. TBM Type B, an open TBM with finger shield, is used for rock conditions 2, 5, 6, 7, 8, 10, and 11 where more ground support and water control is required. TBM Type C, a sealed TBM, is used for rock conditions 12, 13, 14, and the injection ramps where water inflow is great enough to require immediate sealing of the tunnel. The ground support, grouting and final lining methods were selected to produce stable excavations with less than 50 gpm average water inflow per mile of tunnel, including the inflow from caverns and shafts. FermiLab will determine the cost of project outfitting (e.g. electrical, ventilation, cooling, cranes, pumping, lighting, etc.).

5. Develop a bottoms-up estimate for each project component—Major cost drivers, e.g. the TBM tunnels, shafts and caverns, were estimated by bottoms-up methods. The design concepts for minor items, e.g.portal structures, site risers and utility penetrations, were not sufficiently developed to warrant a bottoms-up approach.

6. Assemble costs from the kit-of-parts to estimate the cost of three tunnel alternatives (North—Flat, North—Inclined, and South—Inclined) and two tunnel diameters (12 ft and 16 ft finished)—Completed, see Item 9 below.

7. Provide cost ranges or contingency values appropriate to the understanding of ground conditions and design maturity achieved—A 25 percent contingency has been included as a line item in the cost estimate, which is adequate to cover moderate changes in geologic conditions, design, bidding and construction. It is not adequate for major changes like changes in size, length, and number of tunnels, caverns, or shafts. The costs also include 17.5 percent EDIA costs, including site investigation, professional design services, project management and institutional costs.

8. Estimate heavy civil construction duration for each major project component—TBM tunnel construction costs, depending upon the option, are roughly two to eight times shaft costs and four to seven times cavern costs. Hence, TBM tunnels are the critical path for most of the duration of VLHC construction. Sequence and duration for TBM drives and TBM contracts were developed for each option.

9. Incorporate cost summaries in an Excel spreadsheet suitable for sensitivity analysis by FermiLab personnel—Calculation of the estimated underground heavy civil construction costs for the VLHC project is done in an Excel spreadsheet having more than 15 panes containing the following categories of information: geological information for each alignment option, the station location, size and shape of each shaft, tunnel segment, cavern, riser and other component required for the VLHC, cost information for all types of construction, cost calculations, cost summaries, and quality control and quality assurance calculations. Underground heavy civil construction project costs are estimated to be:

Alignment Alternative	Tunnel Diameter	Estimated Cost (millions 2001 $)
North Inclined	12’	$2,419
North Inclined	16’	$2,713
North Flat	12’	$2,550
North Flat	16’	$2,936
South Inclined	12’	$2,571
South Inclined	16’	$2,984

   The cost totals reflect the interaction of three principal factors: geologic conditions, ring depth and tunnel diameter. The North Inclined ring has the best geology, while the South Inclined ring has the poorest. The cost advantage of the good geology of the North Inclined ring is substantially offset by the greater shaft costs resulting from ring depth. Shafts for the North Inclined ring are about 2.4 times more expensive than for the South Inclined ring. TBM tunnel costs are roughly 22 percent more for the 16-ft diameter option.

10. Prepare a written report—Contained herein.

1 Introduction

1.1 Project Description

Conventional construction of the Very Large Hadron Collider (VLHC) consists of a 233 km tunnel ring, caverns, shafts, risers, and other tunnels and facilities. Chapter 7 of "Design Study for a Staged Very Large Hadron Collider," by the VLHC Design Study Group describes the conventional construction.

This report addresses the anticipated construction costs for excavation, ground support, water control and lining of the underground, heavy civil portion of the conventional facilities. Costs are estimated for three tunnel alignments and two tunnel diameters. The three alignments, called the North Inclined Ring, North Flat Ring, and South Inclined Ring, are shown on Figure 1.1. The two tunnel diameters are 12 ft and 16 ft.

Tunnel depths for the alignments vary from 180 ft to 700 ft below the ground surface. The tunnels and caverns for all alignments would be constructed in the limestone, dolomite, shale and sandstone bedrock of northeastern Illinois. Shafts would be constructed in the bedrock and overlying glacial soils.

Each tunnel section, cavern, shaft, riser, portal, and other associated facility was identified and priced. Appendix A contains a listing of the more than 300 project components.

FermiLab personnel determined the cost of outfitting the stable underground excavations studied herein.

1.2 Limitations

The conclusions of this study are limited by several factors:

1. The available geological and geotechnical information and the limited underground construction experience in some formations—The Chicago area is widely known for the amount of tunneling done there recently. However, most of this construction is in the Silurian-age formations, with relatively experience in deeper formations. As a result, there is limited site investigation information and limited underground construction experience in many formations/locations necessary for the VLHC. We believe that our assessments of underground construction conditions is neutral—neither unduly optimistic nor pessimistic. Actual conditions may be different than assumed.
2. The level of design development of the project components—The existing level of design development is very preliminary. Future design development will lead to improved layouts, but will also identify functions and components that have not been included thus far.
3. The limited budget expended—The budget for this study represents about 0.0025 percent of the project heavy civil construction cost. A common rule-of-thumb is that conceptual design and cost estimates require expenditure of 100 to 400 times greater effort.

1.3 Acknowledgements

Many people contributed to this study and report. Successful completion of the study would not have been possible without their assistance.

1. Peter Garbincius was CNA's principal contact and liaison with FermiLab. He provided information, arranged for tours and explained the complexity of the VLHC. Chris Laughton, also of FermiLab, arranged and led an essential tour of NuMI construction, and also provided his insight into the tunneling conditions present in the study area.

2. Robert Bauer of the Illinois Geological Society provided invaluable assistance by serving as a guide to the publications, boring logs and rock core available through the IGS. In addition, his previous and ongoing work on tunneling and underground construction in northern Illinois was the foundation of this study.
3. Peter Conroy, formerly of Harza Engineering, freely shared his underground construction experience and knowledge of northern Illinois geology. He also provided insightful and constructive comments on a draft version of the report.
4. Brian Garrod of HMM produced the TBM production rates and cost estimates.
5. Charles Nelson, Bruce Wagener, Bob Martin and Lee Petersen conducted the ground conditions evaluations and cost estimating done by CNA Consulting Engineers.

2 Geologic Conditions

2.1 Sources of Information

Geologic information used as the basis for the cost estimate was obtained from the following sources. We have not referenced these sources in the report, but the Bibliography contains their listing:

1. Documents listed in the references at the end of this report.
2. Discussions with Robert Bauer, Illinois Geological Survey and Peter Conroy, consulting engineer.
3. A visit to the Conco Western Stone Quarry in North Aurora, Il.
4. A review of available rock core.

Appendix B contains notes from the discussions, quarry visit, and rock core review.

2.2 Geological Information

For the purposes of the cost estimate, the assumed properties of the geological materials that will be encountered during the excavations are described in the sections below and are summarized in table in Appendix C. These assumptions are based on available reports, examination of core, a visit to the Conco Western Stone Quarry in North Aurora, and discussions with other researchers.

2.2.1 Overburden

Construction will take place in layers of glacial soils ranging in thickness from 25 to 400 feet in some areas. Much of Northern Illinois topped with glacial tills, lacustrine silts and clays, and outwash sands and gravels. A large majority of the overburden is well graded, over-consolidated glacial till consisting of silt, sand, gravel, cobbles, and boulders in a clay matrix.

Groundwater is present in glacial soils. Significant groundwater inflows will occur in sand and gravel layers.

2.2.2 Silurian

The Silurian group is divided into the Racine, Joliet, Kankakee and the Elwood formations.

The Racine formation ranges from 0 to 360 feet thick in some areas of Northern Illinois. The Racine is mostly a dolomite largely vuggy to coarsely vuggy, medium grained, light gray to white in color. Some of the rock is impure varying from moderately silty to very silty containing chert and scattered nodules.

The Joliet formation has two members, the Romeo and Margraff, and is present in northeastern Illinois. The Romeo member is 18 to 34 feet thick and is a light gray to white vuggy medium bedded dolomite. The Margraff member is 9 to 51 feet thick and is divided into an upper and lower zone. The upper zone is a fine grain dense dolomite containing a few shale partings and porous chert nodules. The lower zone is silty with closely spaced dolomitic laminae.

The Kankakee formation ranges from 9 to 80 feet and has wavy beds of fine to medium grained dolomite layers 1 to 3 inches thick separated by greenish gray shale.

The Elwood is 20 to 30 feet thick where not eroded and is primarily a cherty dolomite with nodules in layers up to 3 inches thick.

2.2.3 Maquoketa

The Maquoketa group consists of the Neda, Brainard, Fort Atkinson, and the Scales formations.

The Neda ranges in thickness from 0 to 15 feet. The formation consists of red shale that contains hematitic oolites. The Neda is only present where the underlying Brainard has not been eroded away.

The Brainard ranges in thickness from 0 to 140 feet. The formation is a greenish gray, silty dolomitic shale with interbedded layers of silty dolomite.

The Fort Atkinson ranges in thickness from 15 to 50 feet thick. The formation consists of a fine to coarse grained, fossiliferous dolomite or limestone and some interbeds of green or brown shale.

The Scales ranges in thickness from 50 to 150 feet and is the base of the Maquoketa group. The formation is grayish brown shale that is silty and dolomitic. It contains interbeds of silty dolomite that are 2 inches thick.

Little groundwater inflow into the excavations will occur in the Maquoketa. Groundwater inflows will be higher in the Sandwich

2.2.4 Galena—Platteville

The Galena group is the upper most group and is subdivided into the Wise Lake, Dunleith, and Guttenberg formations. The Platteville group is also subdivided into several formations, however these formations are not easily distinguishable in northern Illinois.

Wise Lake ranges in thickness from 0 to 140 feet. The formation consists of a light brown slightly vuggy dolomite and is separated by wavy, thin laminae. The upper 5 to 10 feet is often very vuggy.

The Dunleith ranges in thickness from 0 to 125 feet. The upper 5 to 10 feet is commonly cherty. The remaining has a similar composition to the Wise Lake formation but is typically more vuggy.

The Guttenberg ranges in thickness from 0 to 15 feet. The formation is a pure dolomite separated by reddish brown shale laminae.

2.2.5 Ancell

The Ancell Group is subdivided into the Glenwood and the St. Peter formation.

The Glenwood ranges in thickness from 0 to 75 feet. The formation consists of sandstone, shale and dolomite. The sandstone is generally coarse and not well sorted. The formation is not as easily recognized as you move south in the area.

The St. Peter ranges in thickness from 150 to 250 feet. The formation consists of a fine to medium grained sandstone. At the base of the formation there is a layer of shale and chert rubble.

2.2.6 Prairie du Chien

The Prairie du Chien is subdivided into several formations and ranges in thickness from 0 to 400 feet. The general composition of the formation consists of cherty dolomite, sandstone, siltstone and shale.

2.2.7 Sandwich Fault

The Sandwich Fault Zone crosses the northwest side of the South Ring as shown in Figure 1.1. It has been characterized as an 85-mile long, ½- to 2-mile wide zone of high angle faults with maximum displacements of 800 ft. The maximum displacements occur near where the fault crosses the South Ring. The south side of the fault is upthrown throughout most of the fault zone. Most of the fault zone is concealed by surficial deposits. The Illinois Geological Survey was not aware of any rock cores in the fault zone.

2.2.8 Des Plaines Disturbance

The Des Plaines Disturbance is located on the southeast side of the South Ring as shown in Figure 1.1. It has been characterized as a 5-mile diameter zone of faulting. Within the disturbance, rock has been found to be faulted, tilted, brecciated, and located as much as 800 feet from its expected position. It is believed that the Disturbance was caused by impact from an extraterrestrial body.

2.2.9 Groundwater Conditions

Previous investigations identify three groundwater regimes—the Drift and Upper Bedrock Aquifer, Upper Ordovician Aquitard, and Deep Bedrock Aquifer.

The Drift and Upper Bedrock Aquifer was assumed to consist of the drift and upper 75 ft of the bedrock surface. It was assumed to have a higher permeability due to the presence of the drift and higher degree of weathering.

The Upper Ordovician Aquitard was assumed to consist of the relatively low permeability Maquoketa and the Galena—Platteville. The low permeability is due to the rock's high shale, limestone, and dolomite content and its tight jointing.

The Deep Bedrock Aquifer was assumed to consist of the relatively high permeability Ancell and Prairie Du Chien. The higher permeability is due to the presence of higher permeability sandstones.

Rock in the Sandwich Fault and Des Plaines Disturbance was assumed to have a higher permeability due to increased faulting and fracturing.

For the purposes of the cost estimate, all geologic formations are assumed to be below the water table. Variations in the expected water conditions were assumed to be due to the relative permeabilities of the formations. Recent studies indicate water levels are below the tunnels in some areas, but a shift in water usage from deep wells to surface sources suggests water levels are rising, but this is uncertain. For the purposes of the cost estimate, all geologic formations are assumed to be below the water table.

2.3 Rock Condition Categories

Based on the information in Section 2.1, fourteen rock condition categories were determined to be present along the various alignments. The rock in each category is assumed to be a member of the same geologic formation and have similar rock properties, weathering, and water conditions. These fourteen rock condition categories were then grouped into three tunneling condition categories, discussed in Section 3.4.

Rock condition categories are listed in table below. Distribution of these categories on each alignment is shown in the plan views and lampshades in Figures 2.1 through 2.6. The distinctions between the categories were based on the following:

1. Geologic formation. Each formation has its own characteristics, rock properties, and groundwater permeability.
2. Within or below 75 ft of the bedrock surface. Rock less than 75 ft below the rock surface was considered to be more weathered and have higher groundwater permeability than deeper rocks.

3. Within or outside of 1 mile of the Sandwich Fault. Rock near the Sandwich Fault was considered to be more fractured and have higher groundwater permeability than rock away from the fault.
4. Within or outside the Des Plaines Disturbance. Rock near the Des Plaines Disturbance was considered to be more fractured and have higher groundwater permeability than rock away from the fault.

#	Category Description
1	Galena—Platteville, Under Maquoketa, Dry and Stable
2	Galena—Platteville, Des Plaines Disturbance
3	Galena—Platteville, No Maquoketa, Greater Than 75 Feet Below Bedrock Surface
4	Galena—Platteville, Sandwich Fault Broken and Wet
5	Galena—Platteville, No Maquoketa, Less Than 75 Feet Below Bedrock Surface
6	Maquoketa, Greater Than 75 Feet Below Bedrock Surface, Relatively Dry
7	Maquoketa, Less Than 75 Feet Below Bedrock Surface, Wetter
8	Maquoketa, Des Plaines Disturbance
9	Silurian, Greater Than 75 Feet Below Bedrock Surface, Dry
10	Silurian, Less Than 75 Feet Below Bedrock Surface, Wet
11	Silurian, Des Plaines Disturbance
12	St. Peter, Maquoketa or Galena—Platteville Missing, Below Water Table
13	Prairie du Chien, Sandwich Fault, Broken, Below Water Table
14	Prairie du Chien, Below Water Table

Table 1—Rock Conditions Categories.

3 Assumptions, Construction Conditions and Estimated Construction Costs

This chapter describes the construction conditions and assumptions made for each construction component and summarizes the costs. The following sections describe the major components included in the estimate, which are shafts, caverns, TBM tunnels, drill and blast tunnels, risers, portals, and miscellaneous. Section 3.8 describes the assumptions made for rock disposal. Sections 3.9 and 3.10 describe the construction contingency and price escalation. Section 3.11 describes the cost assumptions made for EDIA. Section 3.12 describes the items not included in the estimate. Section 3.13 contains the cost estimate summary.

3.1 Cost Estimate Methodology

Calculation of the estimated construction costs for the VLHC project is done in an Excel spreadsheet having more than 15 panes. These panes contain the following categories of information:

1. Geological information for each alignment option, in the form of so-called "lampshades," which provide the elevation formation contacts,
2. The station location, size and shape of each shaft, tunnel segment, cavern, riser and other component required for the VLHC,
3. Unit prices for all types of construction,
4. Cost calculations, with one pane per option,
5. Cost summaries, and
6. Quality control and quality assurance calculations.

This spreadsheet approach was developed so that FermiLab personnel could investigate the cost of other options by varying option parameters. For example, if a shallower North Inclined Ring was of interest, the cost could be determined by changing the parameter that controlled ring depth. The spreadsheet would recalculate the shaft depths, rock types, rock quality, support requirements, etc. and provide a new cost.

This objective was realized for all VLHC components except the tunnels. The process of assigning each rock condition type to one of three TBM categories has not been automated. This process is documented in Section 3.4 Tunneling. The difficulty arises because of the additional constraints:

1. The worst ground condition in an alignment interval sets the TBM category,
2. TBM drives must start and end at shafts,
3. TBM drives have minimum and maximum lengths, and
4. The construction schedule also constrains TBM drives.

3.2 Shafts

The current VLHC layout requires mostly round shafts, with a few rectangular shafts in selected locations. With a few exceptions, the shafts service the various A-, B-, Mid-, and E/v sites. The remaining shafts are at the special purpose caverns, e.g. experimental, beam-stop, KMPS, RFKT. Most shafts extend from the ground surface to the main beam tunnel invert, but a few service special needs and are shallower or deeper than the tunnel invert.

The spreadsheet determines the thickness of soil and rock in each shaft. Shaft soil excavation is by an appropriately sized loader, and rock excavation is by drill and blast means. All rock types are considered to be the same for shaft sinking purposes. Initial support, grouting, concrete lining and water control are provided in both soil and rock.

3.3 Caverns and Drill & Blast Tunnel Construction

3.3.1 Excavation

The cost estimate assumes that all caverns are excavated by drill and blast methods, using smoothwall blasting procedures to maintain the integrity of the rock. All caverns are assumed to be excavated using one 6-meter top heading, and zero or more benches depending upon total cavern height. The top headings are drilled horizontally and require longer cycle times due to the installation of roof rockbolts and shotcrete. Cavern benches are drilled vertically and have shorter cycle times, due to less rock support.

3.3.2 Primary Support Requirements Based On Empirical Methods

The primary support requirements have been assessed using the method developed by the Norwegian Geotechnical Institute (NGI, 1984; Barton and Grimstad, 1993). The method, developed from a large number of case histories, relates the required primary support to the rock mass quality, Q. The Q value is determined from the frequency, orientation, roughness and infilling of the discontinuities, the groundwater, and in situ stress conditions. The Q rating is computed from:

$$Q = \frac{RQD}{Jn} x \frac{Jr}{Ja} x \frac{Jw}{SRF}$$

where:

1. RQD = Rock Quality Designation
2. Jn = Joint set number
3. Jr = Joint roughness number
4. Ja = Joint alteration number
5. Jw = Joint water reduction factor
6. SRF = Stress Reduction Factor

Assumed Q ratings for each of the fourteen rock condition types are illustrated in table below.

Category Description	**RQD**	**Jn**	**Jr**	**Ja**	**Jw**	**SRF**	**Q**
Galena—Platteville, Under Maquoketa, Dry and Stable	90	4	3	4	1	0.5	**33.75**
Galena—Platteville, Des Plaines Disturbance	60	9	0.5	2	0.66	2.5	**0.44**
Galena—Platteville, No Maquoketa, Greater Than 75 Feet Below Bedrock	90	4	3	4	0.66	0.5	**22.28**
Galena—Platteville, Sandwich Fault Broken and Wet	60	9	0.5	2	0.66	2.5	**0.44**
Galena—Platteville, No Maquoketa, Less Than 75 Feet Below Bedrock	90	4	3	4	0.66	1	**11.14**
Maquoketa, Greater Than 75 Feet Below Bedrock Surface, Relatively Dry	85	4	2	4	1	1	**10.63**
Maquoketa, Less Than 75 Feet Below Bedrock Surface, Wetter	85	4	2	4	0.66	1	**7.01**
Maquoketa, Des Plaines Disturbance	60	9	0.5	2	0.66	2.5	**0.44**
Silurian, Greater Than 75 Feet Below Bedrock Surface, Dry	90	4	3	4	1	0.5	**33.75**
Silurian, Less Than 75 Feet Below Bedrock Surface, Wet	90	4	3	4	0.66	0.5	**22.28**
Silurian, Des Plaines Disturbance	60	9	0.5	2	0.66	2.5	**0.44**
St. Peter, Maquoketa or Galena—Platteville Missing, Below Water Table	70	4	3	1	0.5	10	**2.63**
Prairie du Chien, Sandwich Fault, Broken, Below Water Table	60	9	0.5	2	0.5	2.5	**0.33**
Prairie du Chien, Below Water Table	90	4	3	1	0.5	7	**4.82**

Table 2—Q Ratings for Each Rock Condition Category.

The highest Q value (33.75) is for the Galena-Platteville and Silurian formations where found greater than 75 feet below the bedrock surface. These rock condition types have higher than average RQD; two joint sets; rough and irregular, undulating joints; low-friction clay mineral coatings; dry or minor water inflow; and tight structure. The lowest common Q value (0.44) are for the Galena-Platteville formation in the vicinity of the Des Plaines disturbance, the same formation in the vicinity of the Sandwich Fault, the Maquoketa shale in the vicinity of the Des Plaines disturbance, and the Silurian dolomites in the vicinity of the Des Plaines disturbance. By comparison, these rocks have lower RQD; three joint sets; slickensided, planar joints; medium water inflow; and weakness zones containing clay. The lowest Q value is for the Prairie du Chien formation in the vicinity of the Sandwich Fault, below the water table. This formation is rated lower than the more common formation because of greater water inflow.

These Q values are used to determine rockbolt spacing and shotcrete thickness, while other methods are be used to estimate the rockbolt length. Cavern rockbolt length is based on one of Lang’s (1961) rules of thumb. The minimum rockbolt length is:

1. one-half the span for spans less than 6 meters, and
2. one-fourth the span for spans of 18 meters to 30 meters.

Figure 3.1 and Figure 3.2 show the Q rating relationships for rockbolt spacing and shotcrete thickness, respectively. The numerical values for rockbolt spacing and shotcrete thickness are:

Q Rating	Rockbolt Spacing (m)	Shotcrete Thickness (mm)
0.33	1.54	220
0.44	1.61	211
2.63	2.01	154
4.82	2.15	135
7.01	2.23	123
10.63	2.32	110
11.14	2.34	108
22.28	2.49	86
33.75	2.58	73

Table 3—Rockbolt Spacing & Shotcrete Thickness vs. Rock Quality.

The estimate assumes that the cavern sidewalls and endwalls require rock support equal to 40 percent of the roof support cost.

3.3.3 Special Components

Six tunnel segments (three each side of FermiLab) require cavern-like construction. These are:

1. Injection-Straight interface—A cavern-like excavation is required where the injection ramp forms a wye with the main beam tunnel. The geometry of this wye depends on the final location and orientation of the ring. For the purposes of this estimate, the interface is assumed to be 7.6 meters wide by 7.6 meters high by 100 meters long. Three are require: two at the FermiLab side of the ring and one at the far side.
2. Abort tunnel cavern—This cavern-like excavation is required where the abort and Stage 2 tunnels wye of the main beam tunnel. A TBM will drive either the abort or Stage 2 tunnel, then drill and blast methods will excavate this 650-meter long wye. The other two tunnels will be TBMed from the widened end of the wye.

3. Utility Straights—This 1380-meter segment must be widened from TBM size to 7.6-meters wide by 7.6-meters high.

3.4 Tunneling

The tunneling can be completed in phases using Tunnel Boring Machines (TBM's). Successful and economical completion of each segment of tunnel requires the proper choice of TBM type and ground support, based on the ground conditions expected. Fourteen different rock conditions were identified on the three alignments as described in Section 2.3. Three different TBM types with various ground support methods were needed to accommodate these ground conditions. The TBM types and rock conditions are listed in the table below and shown in Figures 3.3, 3.4, and 3.5.

#	Rock Condition Categories	Tunneling Conditions (See Sec. 3.4)
1	Galena—Platteville, Under Maquoketa, Dry and Stable	A
2	Galena—Platteville, Des Plaines Disturbance	B
3	Galena—Platteville, No Maquoketa, Greater Than 75 Feet Below Bedrock Surface	A
4	Galena—Platteville, Sandwich Fault Broken and Wet	C
5	Galena—Platteville, No Maquoketa, Less Than 75 Feet Below Bedrock Surface	B
6	Maquoketa, Greater Than 75 Feet Below Bedrock Surface, Relatively Dry	B
7	Maquoketa, Less Than 75 Feet Below Bedrock Surface, Wetter	B
8	Maquoketa, Des Plaines Disturbance	B
9	Silurian, Greater Than 75 Feet Below Bedrock Surface, Dry	A
10	Silurian, Less Than 75 Feet Below Bedrock Surface, Wet	B
11	Silurian, Des Plaines Disturbance	B
12	St. Peter, Maquoketa or Galena—Platteville Missing, Below Water Table	C
13	Prairie du Chien, Sandwich Fault, Broken, Below Water Table	C
14	Prairie du Chien, Below Water Table	C

Table 4—Rock & Tunneling Conditions Groupings.

The tunnel costs were then estimated using TBM cost estimating software and cost database developed by Hatch Mott MacDonald. Appendix D contains output from the software. The costs include tunnel excavation, and primary and secondary support.

Characteristics and cost estimate assumptions common to all three TBM tunnel types are as follows:

1. The finished diameter of the tunnels is either 3.66m or 4.88m. The excavated diameter will be appropriately oversized to allow for installation of the primary and secondary support.
2. The TBM's are capable of tunnel drives of 4844 meters long, equivalent to the shaft spacing. At end of each drive the TBM could be accessed for reconditioning.
3. Separate tunnel contracts are between one and five drives long.
4. 75% of the TBM cost is written off in the first drive, 15% in the second drive, 10% in the third drive, and 0% in the fourth and fifth drives.
5. Workweeks consist of 5 days with 2 ten-hour shifts.
6. Labor rates are based on the Chicago, Illinois area for year 2001.

3.4.1 TBM Type A, Rock Conditions 1,3, and 9.

TBM type A is used in the best rock conditions where minimal ground support and water control is required. It has the following characteristics:

1. Excavated tunnel diameter 3.66m or 4.88m.
2. Unshielded TBM.
3. No areas of difficult excavation.
4. A total of 400 3 meter long rockbolts in each drive installed sporadically in the tunnel crown in jointed or potentially weak zones.
5. Groundwater is not entering the tunnel fast enough to slow TBM advance rate or require a sealed TBM.
6. Grouting required for water control is some areas where groundwater inflow is heavy enough to hinder TBM progress.
7. A concrete invert is installed to provide a working surface.
8. Average tunnel advance rate of 225m per week.
9. No secondary lining required.

3.4.2 TBM Type B, Rock Conditions 2,5,6,7,8,10,11

TBM type B is used in the rock conditions where more ground support and water control is required. It has the following characteristics:

1. Excavated tunnel diameter 4.26m or 5.46m.
2. Open TBM with finger shield.
3. No areas of difficult excavation.
4. Tunnel support consists of 3m long rockbolts, installed in sets of 3 in the tunnel crown. Spacing between sets is 6m for the 12 ft diameter tunnel and 4.5m for the 16 ft diameter tunnel.
5. Groundwater is not entering the tunnel fast enough to slow TBM advance rate or require a sealed TBM.
6. Grouting required for water control in some areas where groundwater inflow is heavy enough to hinder TBM progress.
7. Average tunnel advance rate of 211 meters per week for the 12 ft diameter tunnel and 195m per week for the 16 ft diameter tunnel.
8. 300mm thick concrete secondary lining installed on completion of tunnel boring to control shale slaking and dolomite raveling.

3.4.3 TBM Type C, Rock Conditions 12,13,14, and Declines

TBM type C is used where water inflow is great enough to require immediate sealing of the tunnel. It has the following characteristics:

1. Excavated tunnel diameter 4.06m or 5.28m.
2. Sealed TBM, allows no water to enter the tunnel.
3. Areas of difficult excavation encountered, slowing normal advance rate by 20 percent, over 20 percent of the tunnel length
4. Primary support and water control provided with a 200mm thick segmental, precast, and gasketed concrete liner installed immediately behind the TBM following each excavation cycle.
5. Average tunnel advance rate of 102 meters per week.

3.5 Site Risers

Site risers provide for transferring a precision reference grid, for aligning technical components, from surface to tunnel. Forty site risers are provided at a uniform spacing around the rings. The risers extend from the surface to the main tunnel invert. All risers are 0.5-meter finished diameter, and are priced on the basis of a unit cost per meter of depth.

3.6 Portals

Three portals are included in the estimate, one at the top of each magnet ramp. Two magnet ramps are located at Fermi and one is located on the far side of the ring. A lump sum is included for excavation, ground support, and concrete structure construction.

3.7 Miscellaneous

This category includes utility penetrations and a 5% allowance for items not covered in the estimate. Utility penetrations are required at A sites, B sites, RFKT caverns, and KMPS caverns. These inclined boreholes connect the caverns to the main beam tunnel. Finished diameters are either 0.3 meters or 0.76 meters, and all are costed on the basis of a unit price per meter of length. The allowance includes 5% of the total cost of the other categories.

3.8 Rock Disposal

The cost of moving the rock to the surface was included in the estimate. Disposal costs from the top of shafts were assumed to be zero because disposal costs were assumed to be equally offset by the value of the rock for use as construction materials.

3.9 Contingency

There are three types of cost estimate contingency commonly used in heavy civil estimates:

1. Design contingency—This type of contingency covers new or different designs and costs for project components. All project components deserve a design contingency during preliminary phases. Certain items deserve large contingencies, while other systems do not.

   For example, additional geotechnical exploration may reveal the need for different ground excavation and support methods, which would change the costs significantly. The design contingency typically becomes zero for the final prebid cost estimate. For this project, however, the design will continue to be refined. Some of these changes may occur during construction, which need to be covered by the construction contingency.

2. Bidding contingency—This type of contingency covers contractor bidding climate and differences between the cost estimator's and contractor's perception of project difficulty and cost. The availability of contractors at the time of bidding will affect the bids, especially on a project of this magnitude.

   In addition, the high bid on an underground project can be twice the low bid, so contractor’s perceptions also vary widely. For normal or common construction projects, the bidding contingency should be zero. However, for one-of-a-kind projects like VLHC, it is prudent to maintain some bidding contingency in the cost estimate. Few contractors have experience building the combinations of tunnels, caverns, and shafts required by the separate contracts for the VLHC.

3. Construction contingency—This type of contingency might be better termed a "funding reserve," which would cover construction change orders due to differing site conditions and other reasons.

A 25 percent contingency has been included as a line item in the cost estimate, which covers moderate changes in design, bidding and construction. It is not adequate for major changes like changes in size, length, and number of tunnels, caverns, or shafts.

3.10 Price Escalation

FermiLab directed CNA to estimate project costs without price escalation. Hence, estimated project costs quoted throughout this report are in 2001 dollars.

In addition, FermiLab requested some historical background for construction price escalation. One widely quoted escalation index is the Turner Building Cost Index. The Turner Construction Company has tracked escalation of building construction prices for many years using the Turner Building Cost Index. The index is determined by the following factors considered on a nationwide basis: labor rates and productivity, material prices, and the competitive condition of the marketplace. Figure 3.6 shows the index by year along with the annual percent change. Over the past fifteen years the annual percent change has averaged about 3.2%.

However, heavy civil or tunnel construction cost escalation has typically been less than other construction industry segments. The TBCI is likely an upper bound on underground construction cost escalation.

3.11 EDIA

EDIA includes site investigation, technical permitting and approval, design and construction engineering costs; owner oversight; and construction management. The cost is included as 17.5 percent of the estimated construction costs. The actual value will depend upon the procurement method, structuring of the construction contracts and the level of effort conducted in-house at FermiLab.

3.12 Items not Covered in the Estimate

Per direction by FermiLab, this cost estimate addresses only the excavation and structural issues required to provide excavated, supported, and waterproofed structures. As such, it does not address the following issues:

1. Land acquisition and easement costs.
2. Project public relations and lobbying.
3. Mechanical and electrical, such as permanent ventilation, lighting, heating, and cooling.
4. Construction of experiment components.
5. Operating costs.

3.13 Cost Estimate Summary

The estimated construction costs are summarized in table below for the three tunnel alignments and two tunnel diameters.

Item	North Inclined		North Flat Ring		South Inclined Ring	
	12' Diam. Tunnel	16' Diam. Tunnel	12' Diam. Tunnel	16' Diam. Tunnel	12' Diam. Tunnel	16' Diam. Tunnel
Shafts	$413.6	$413.6	$263.1	$263.1	$174.0	$174.0
Caverns	$232.1	$232.1	$238.2	$238.2	$242.5	$242.5
TBM Tunnels	$875.8	$1,066.3	$1,106.3	$1,356.5	$1,205.3	$1,473.3
DB Tunnel	$36.3	$36.3	$36.3	$36.3	$36.3	$36.3
Risers	$3.3	$3.3	$2.1	$2.1	$1.6	$1.6
Portals	$2.1	$2.1	$2.1	$2.1	$2.1	$2.1
Miscellaneous	$83.6	$93.2	$87.9	$100.4	$88.6	$102.0
Subtotal	$1,646.8	$1,846.9	$1,736.0	$1,998.7	$1,750.4	$2,031.8
Contingency (25%)	$411.7	$461.7	$434.0	$499.7	$437.6	$507.9
Subtotal	$2,058.5	$2,308.6	$2,170.0	$2,498.4	$2,188.0	$2,539.7
EDIA (17.5%)	$360.2	$404.0	$379.7	$437.2	$382.9	$444.4
Grand Total	$2,418.7	$2,712.6	$2,549.7	$2,935.6	$2,570.9	$2,984.2

Table 5—Cost Estimate Summary, Values in Millions of 2001 Dollars.

Figure 3.7 shows the cost breakdown in bar chart form. The detailed cost estimate is contained in the Excel spreadsheet entitled “vlhc_Underground_Construction.xls,” which has been provided to FermiLab. Appendix C contains output of HMM’s TBM Tunnel Cost Estimating Database that was used in developing the cost estimate.

4 Construction Schedule

The construction schedules include time for excavation and support of tunnels and shafts only. They were developed assuming that the construction could start at multiple locations on the tunnel ring, with early construction required at FermiLab and the opposite side to allow for installation of the experiment components. Work would start with the construction of the shafts required for tunneling access. After these were complete, only the TBM tunneling was assumed to be on the critical path because construction of other components could be concurrent and completed more quickly.

HMM maintains an automated system for estimating TBM tunnel costs and advance rates based on experience from previous projects. After the assumed ground conditions were determined, HMM used this system to calculate costs and advance rates using data from projects of similar TBM diameter and ground conditions. TBM Type A tunneling requires the least time and Type C requires the most. Based on the TBM progress rates in the costs analyses, it was determined tunneling for each TBM Type would take approximately the following amount of time:

1. Type A Tunneling—0.5 years for each 4844m drive.
2. Type B Tunneling—0.5 years for each 4844 drive plus a 0.5-year lag to allow the TBM to complete a drive before starting the installation of concrete lining.
3. Type C Tunneling—1 year for each 4844m drive.

Based on these the durations, each alignment option was broken down into separate construction contracts, as shown on the inner rings in Figures 4.1, 4.2, and 4.3. The charts in the upper right corner of each figure show tunnel contract durations. The construction time can also be summarized as follows:

Item	North Inclined Ring	North Flat Ring	South Inclined Ring
Total Project Duration (years)	4.5	5	5
Maximum No. of Concurrent Contracts	8	9	9
No. of Type A Tunnel Contracts	12	7	5
No. of Type B Tunnel Contracts	4	7	9
No. of Type C Tunnel Contracts	0	0	2

Table 6—Summary of Underground Construction Durations.

These durations are the minimum times required to complete the project. This timeline will need to be increased based on contractor availability, project funding profile, and the owner’s ability to manage the project.

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Figures

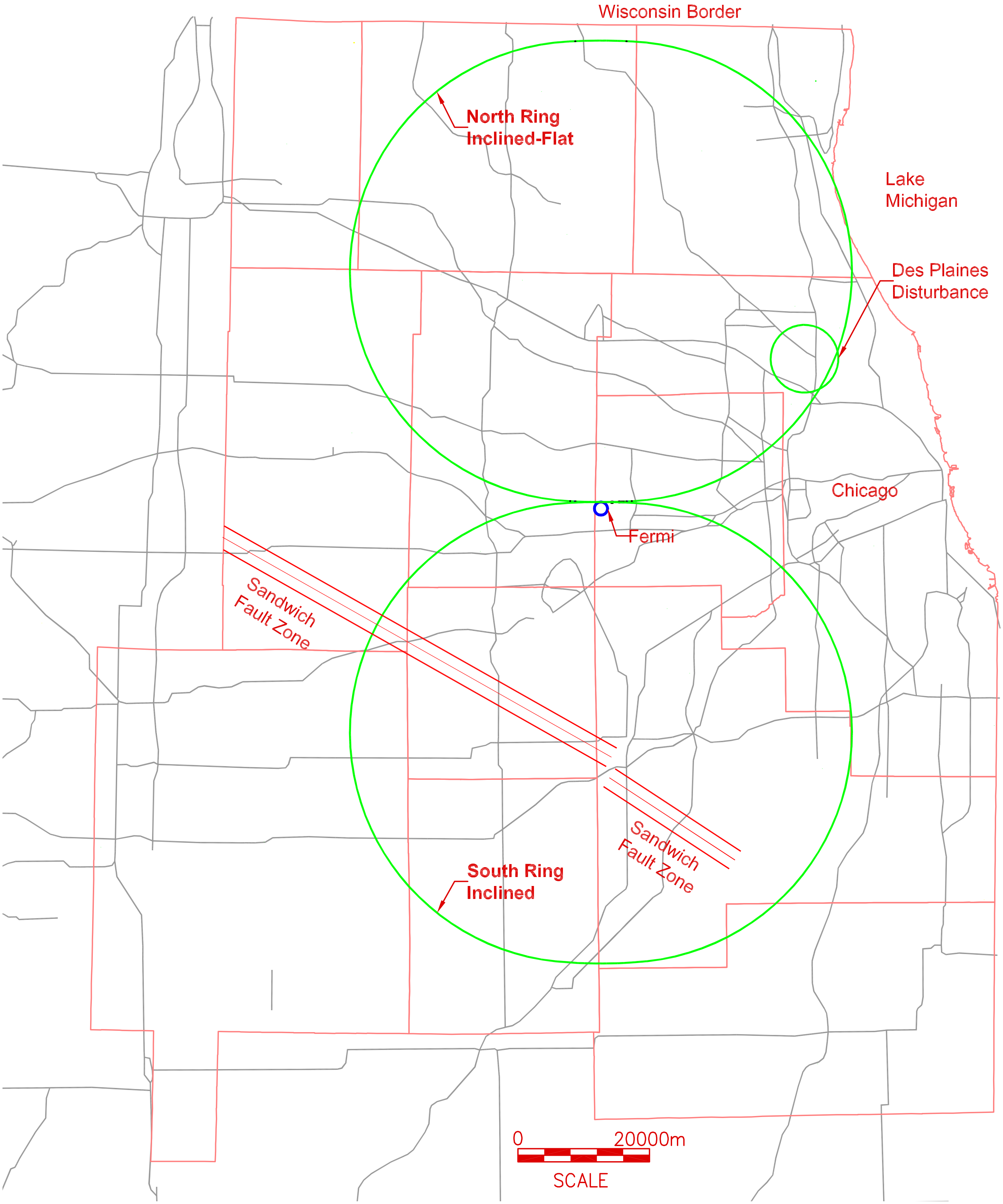


Figure 1.1 - Site Plan

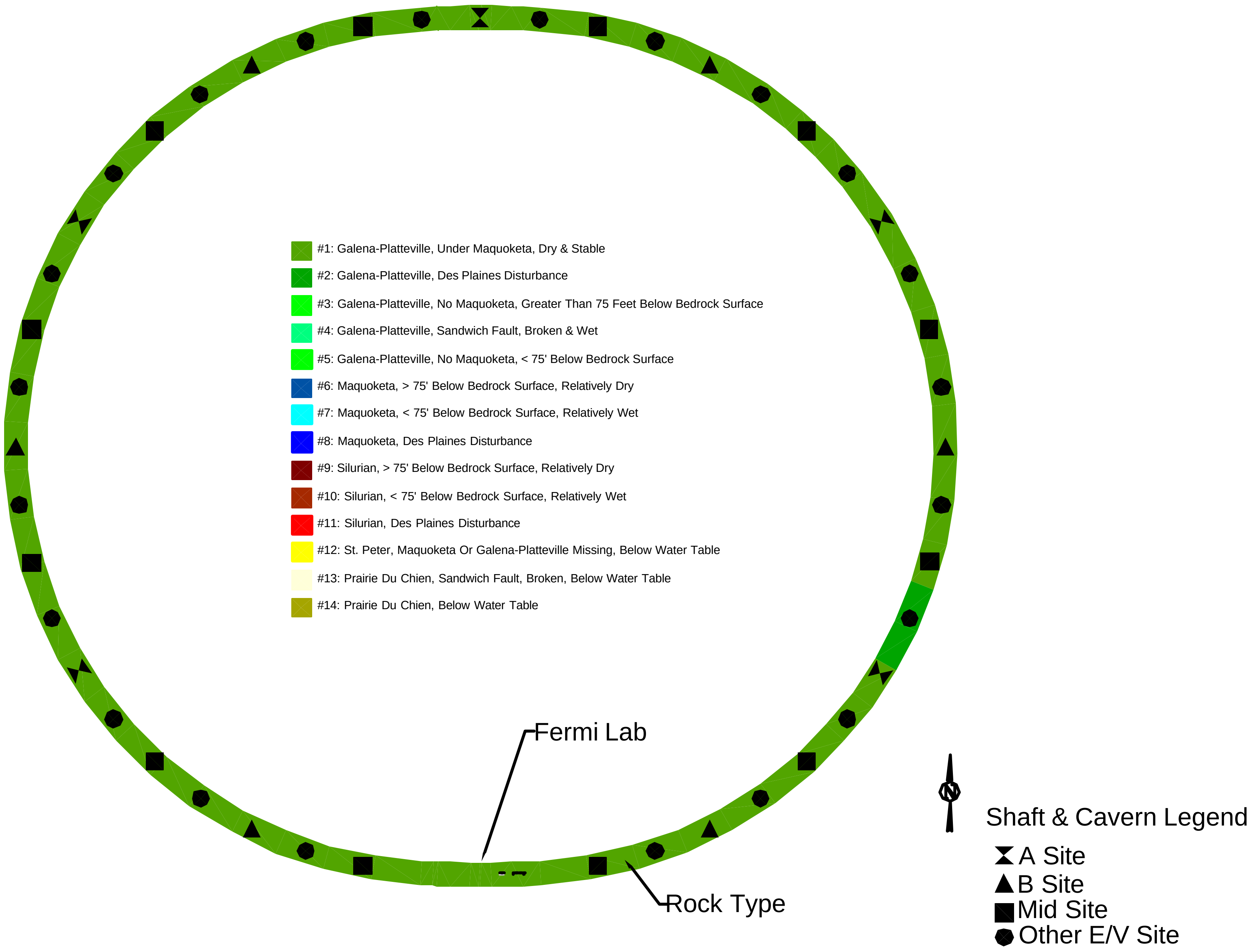


Figure 2.1 North Inclined Ring

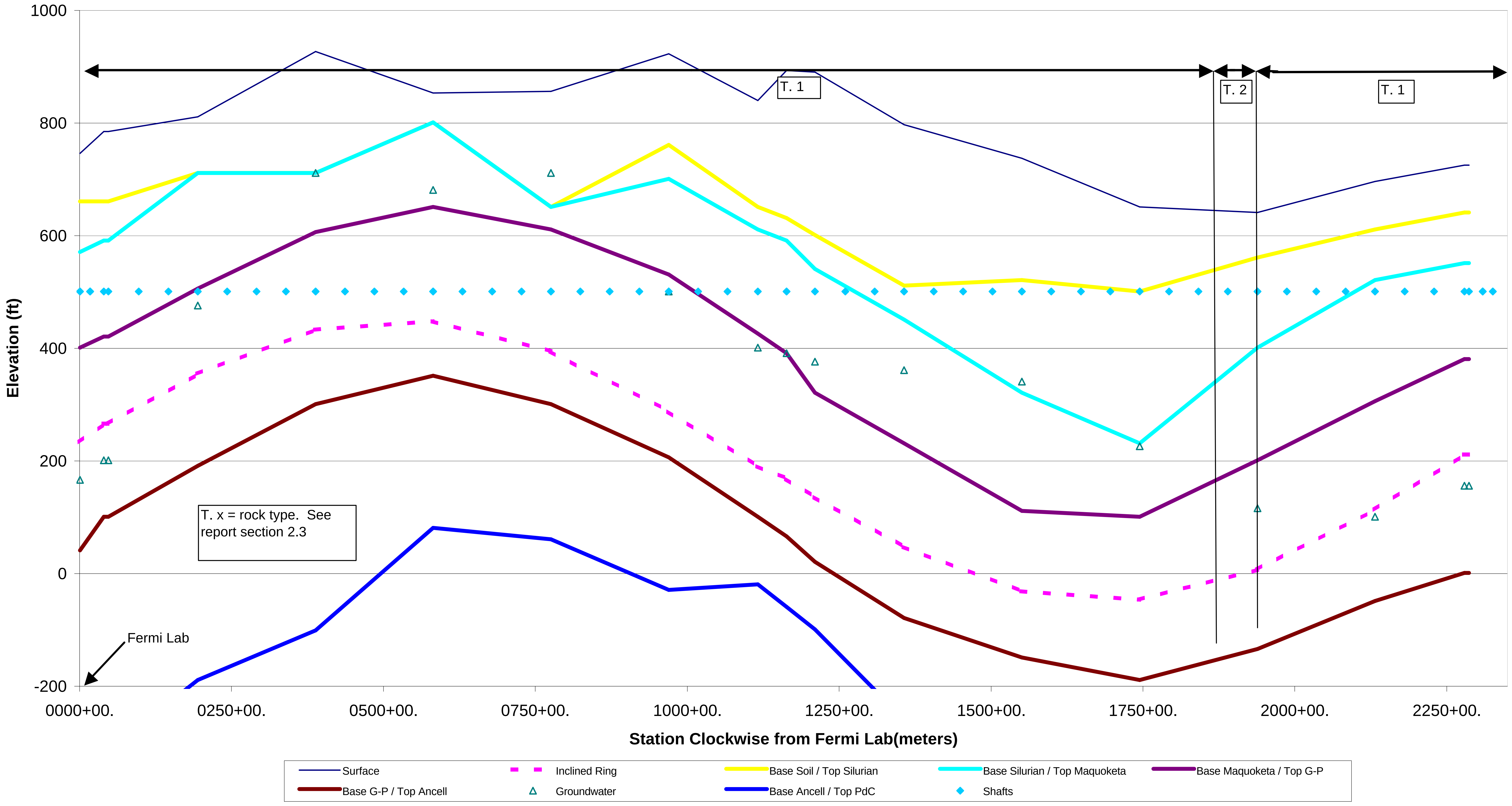


Figure 2.2 - Fermi VLHC -- North Inclined Ring

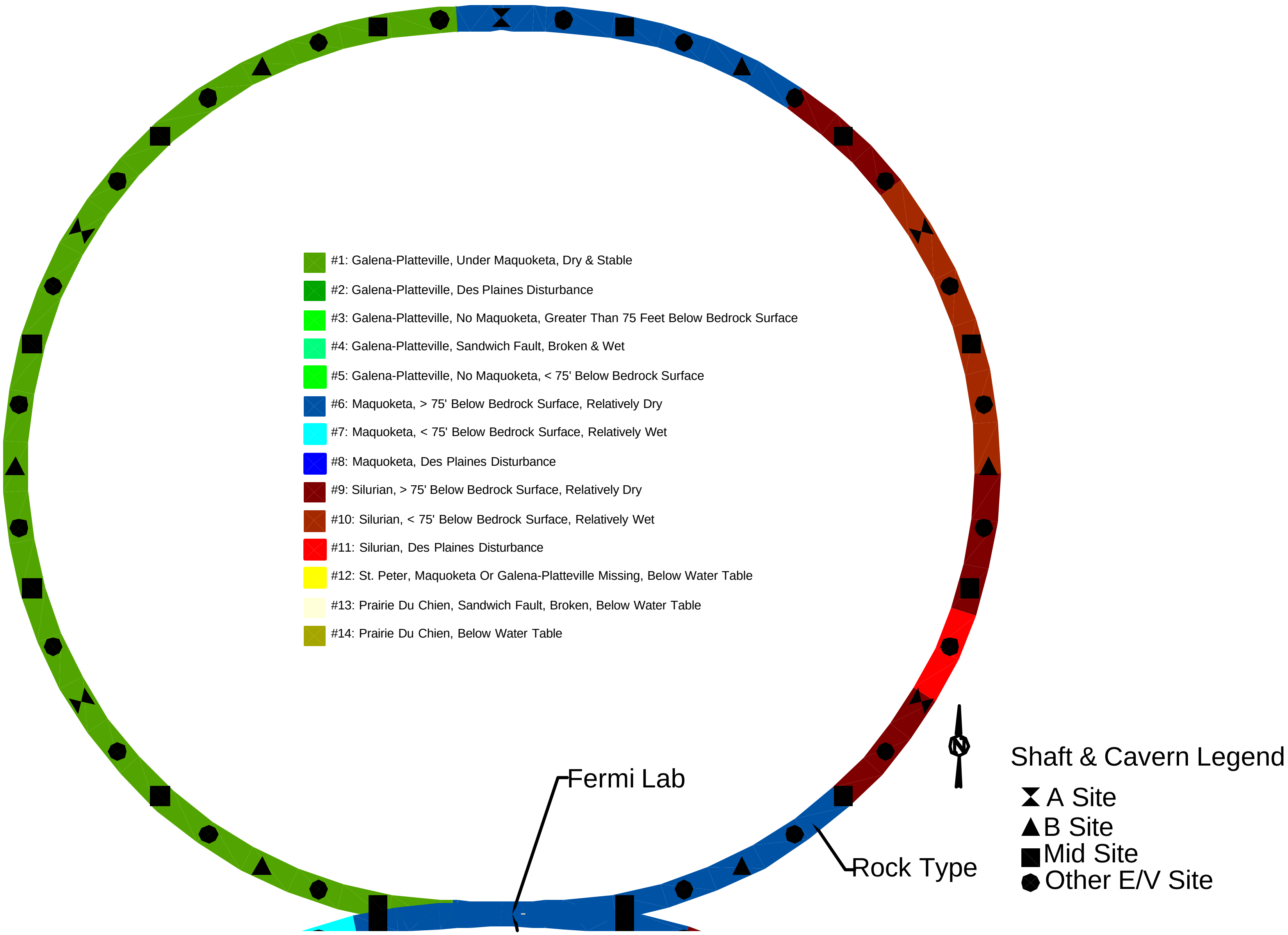
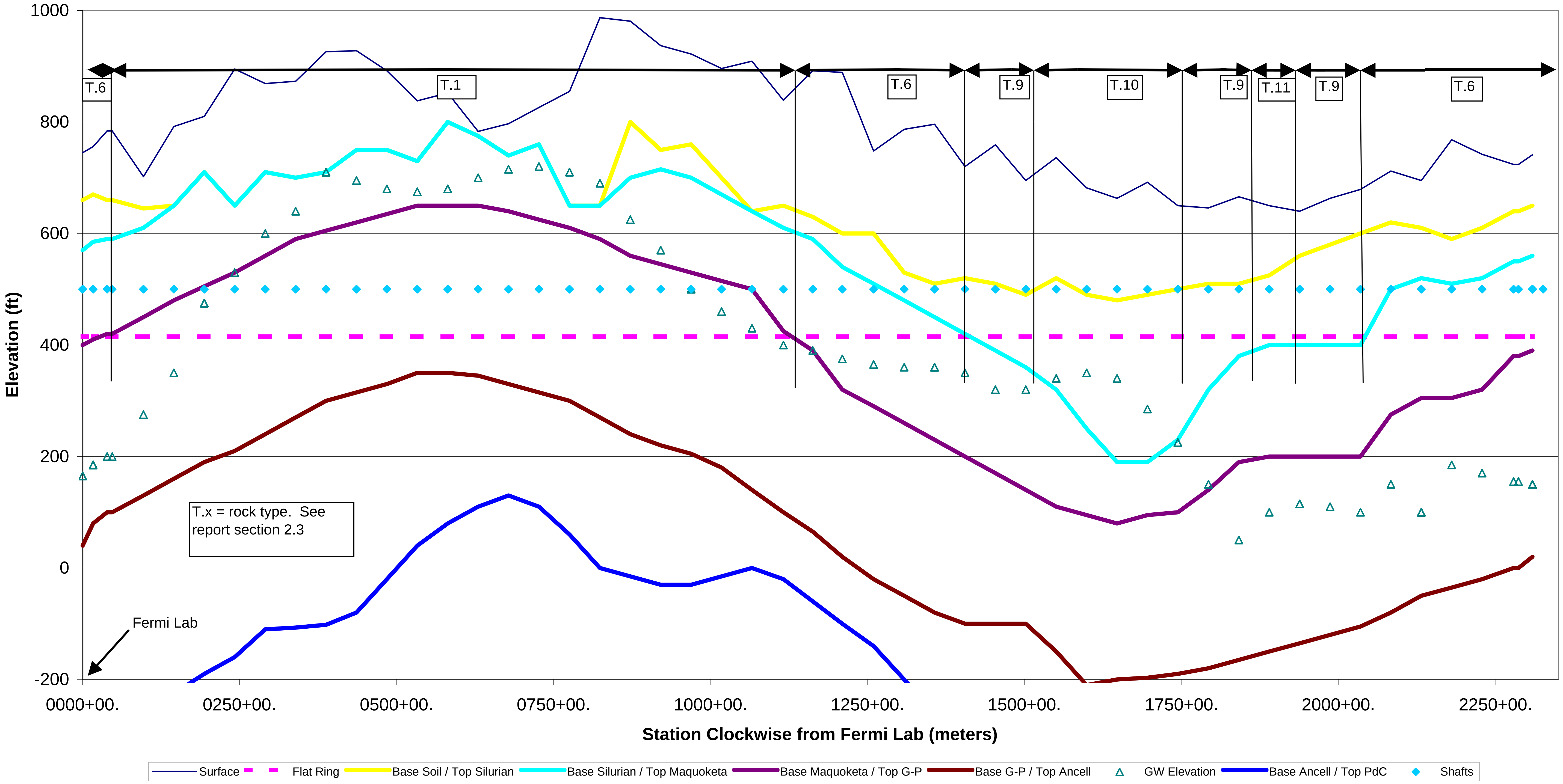


Figure 2.3 North Flat Ring



T.x = rock type. See report section 2.3

Figure 2.4 - Fermi VLHC -- North Flat Ring

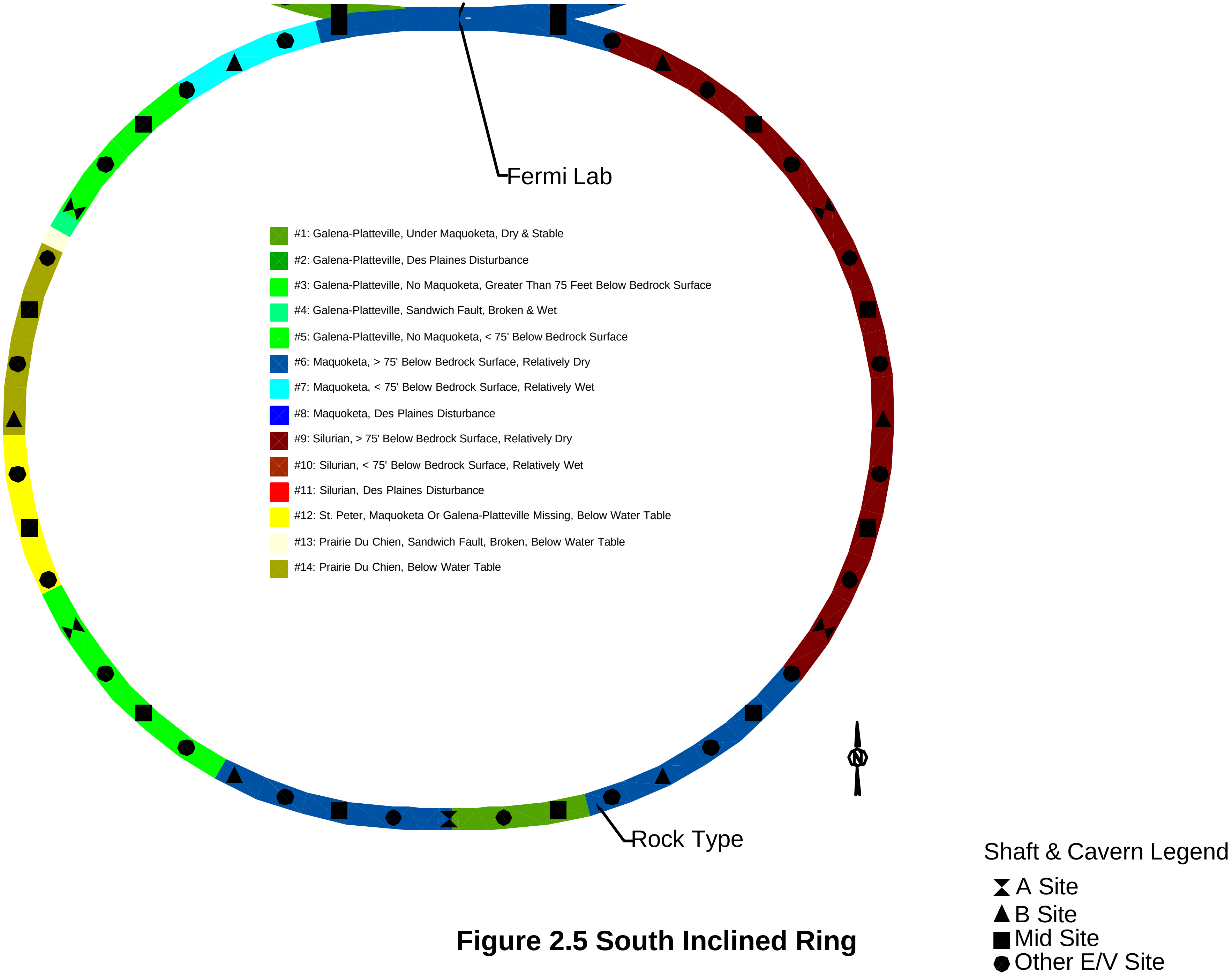


Figure 2.5 South Inclined Ring

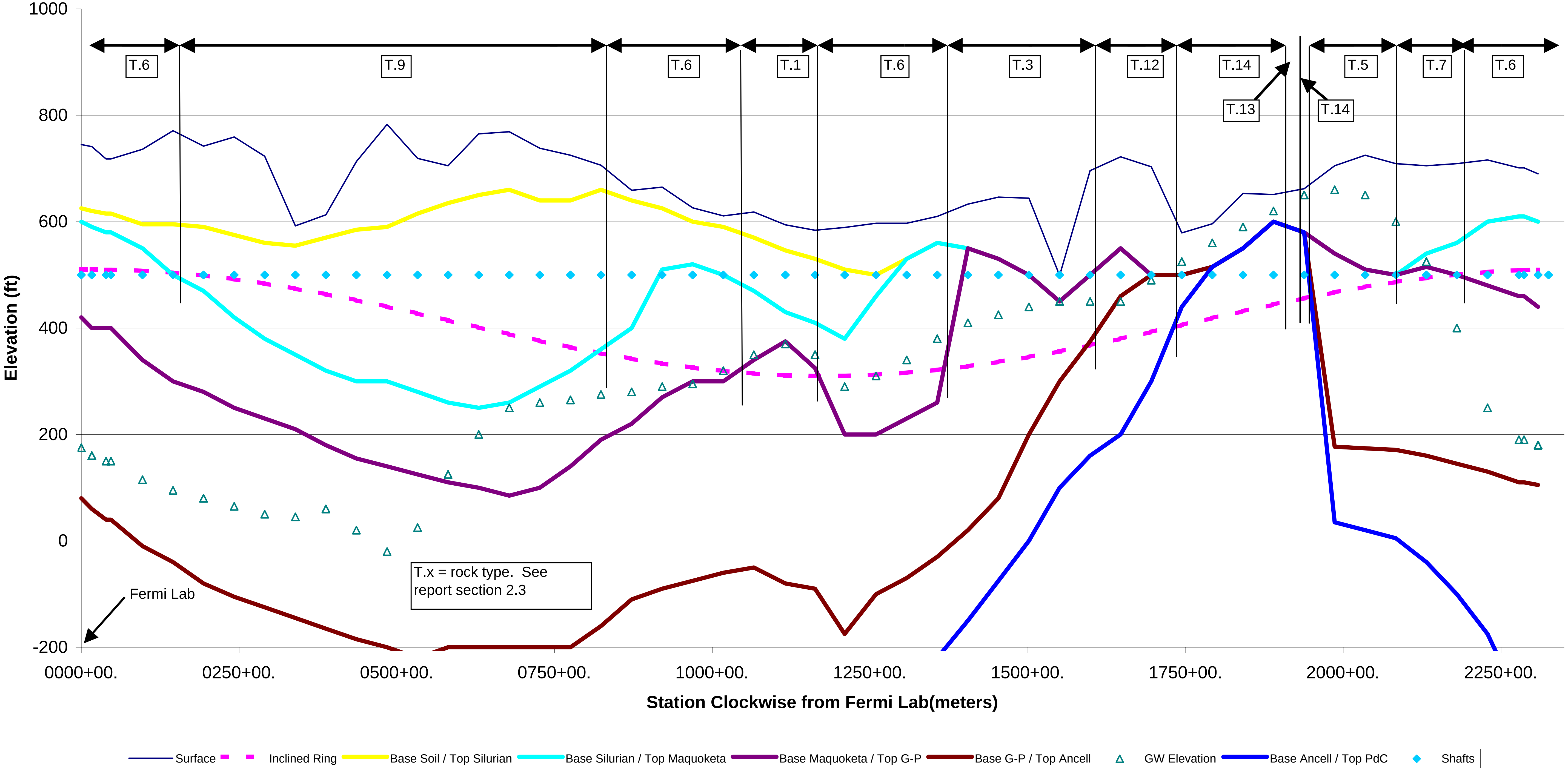


Figure 2.6 - Fermi VLHC -- South Inclined Ring

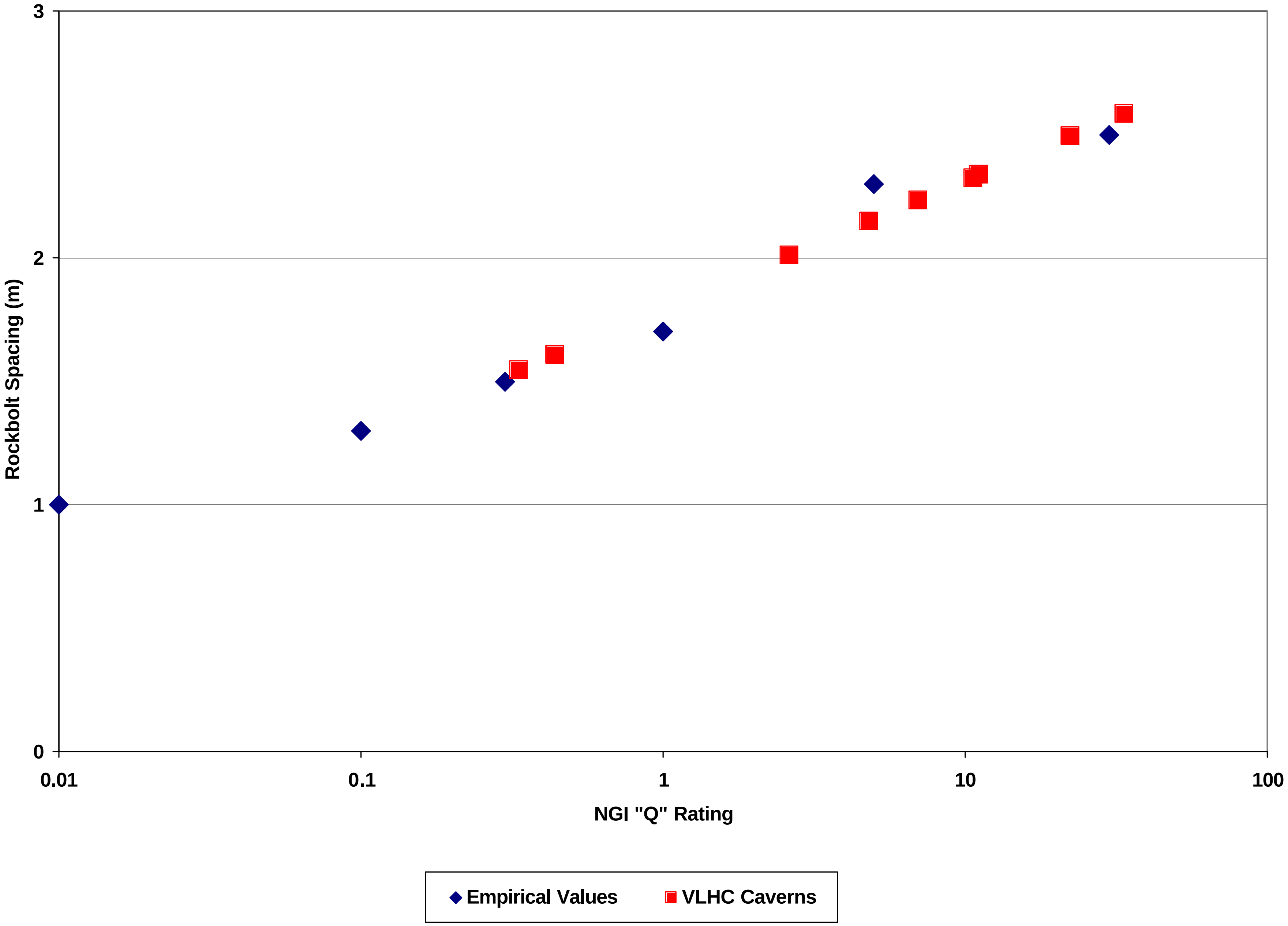


Figure 3.1 - Rockbolt Spacing versus Q Rating

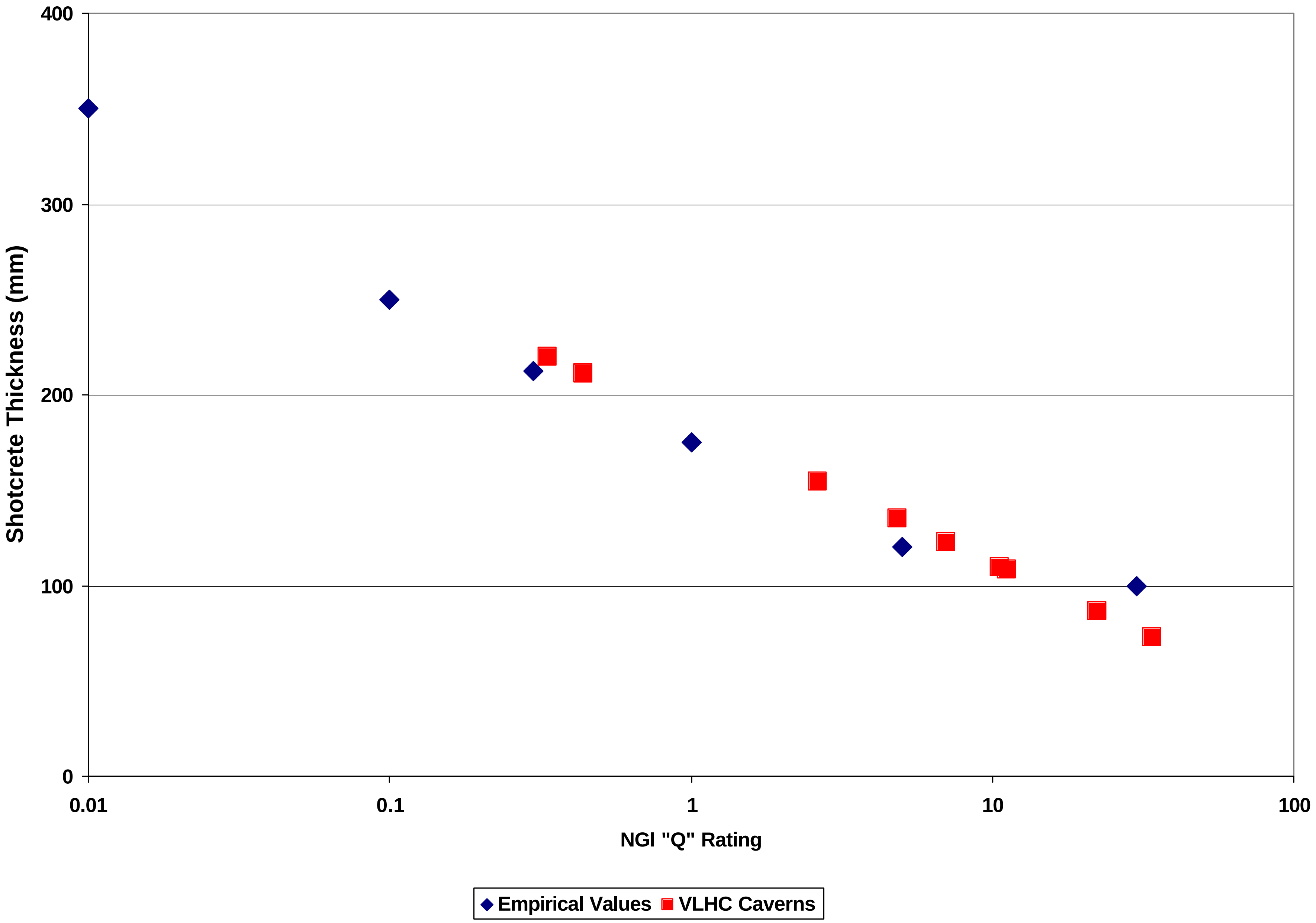


Figure 3.2 Shotcrete Thickness versus Q Rating

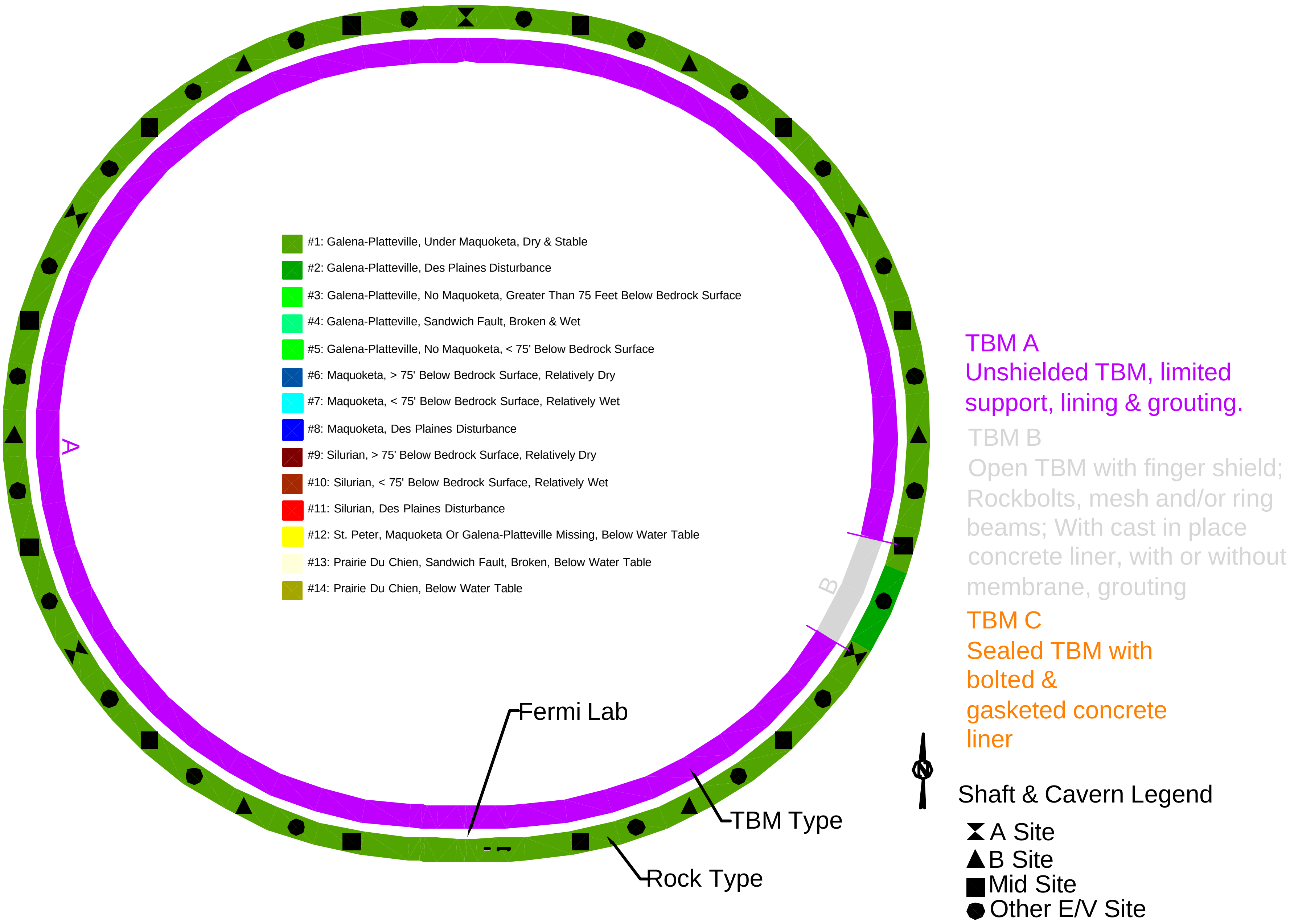


Figure 3.3 North Inclined Ring

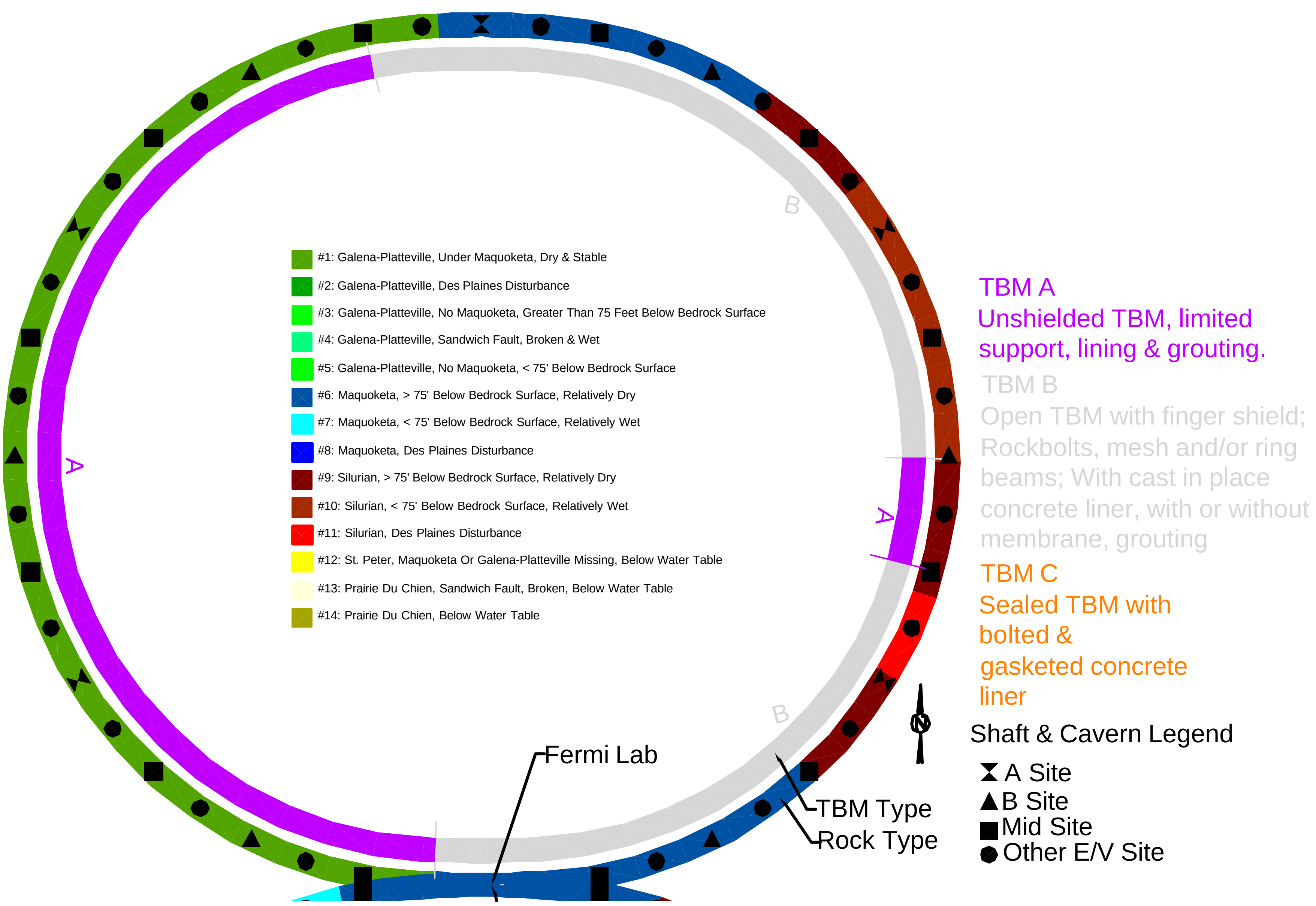


Figure 3.4 North Flat Ring

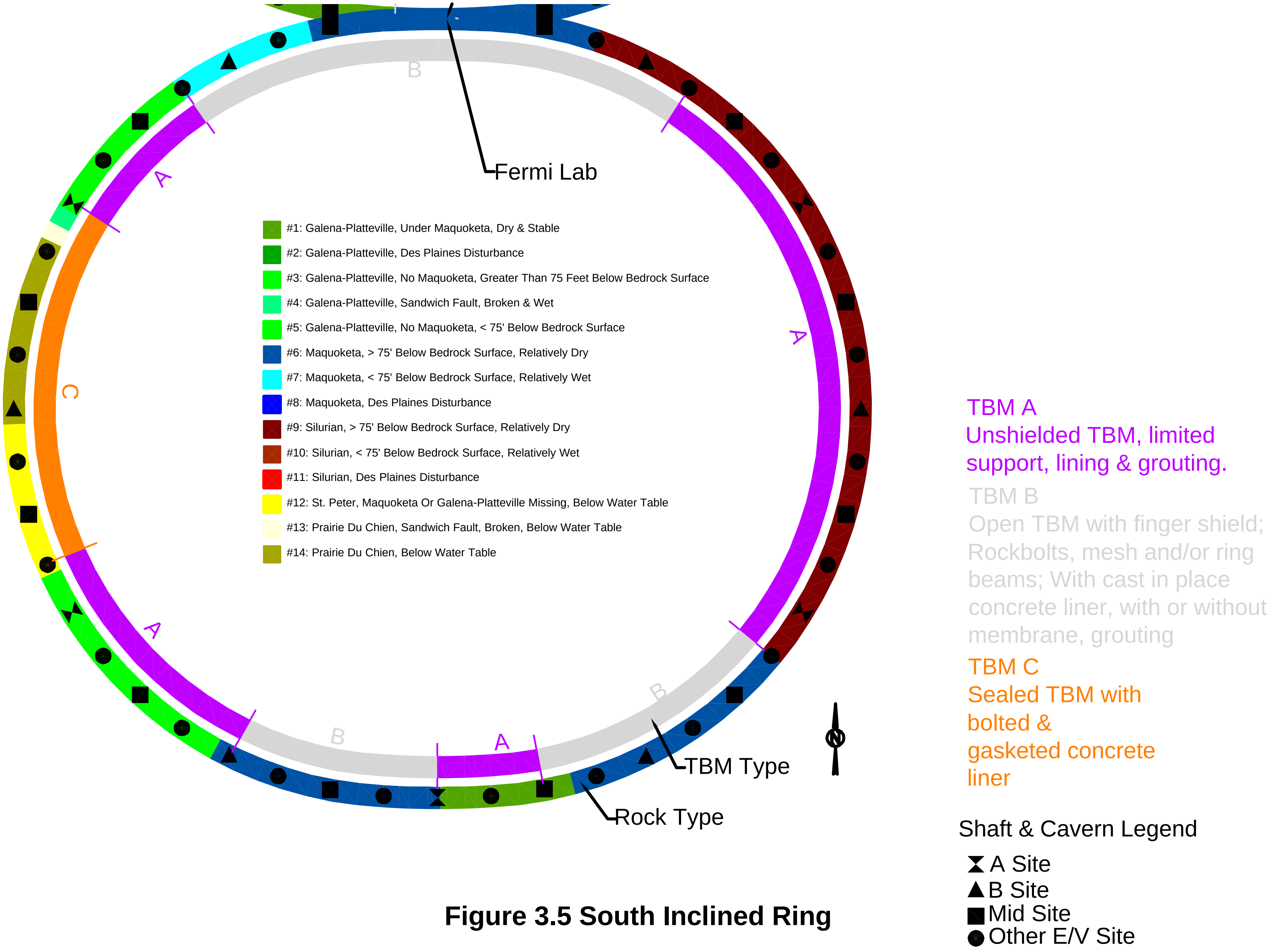


Figure 3.5 South Inclined Ring

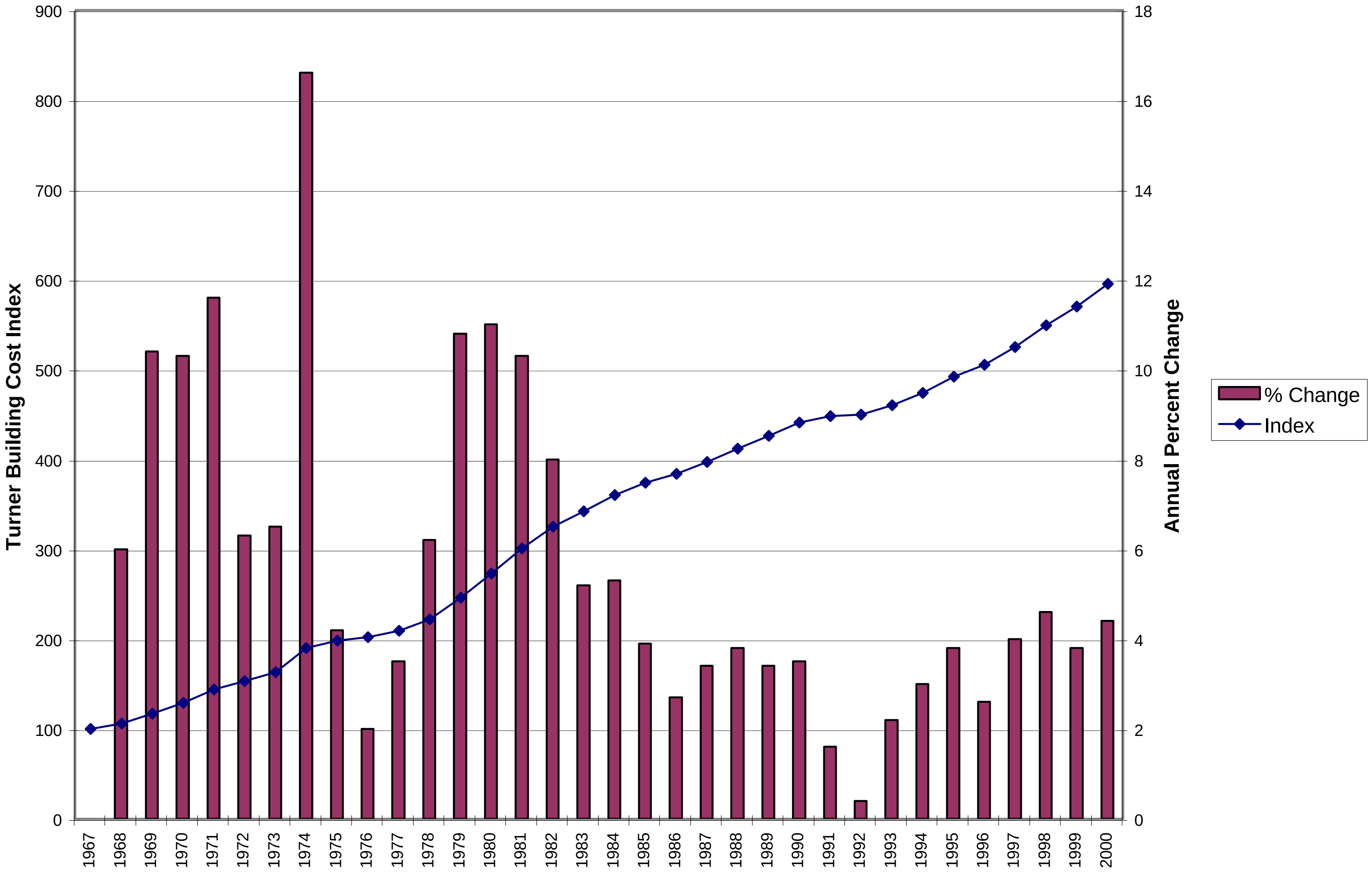


Figure 3.6 - Turner Building Cost Index

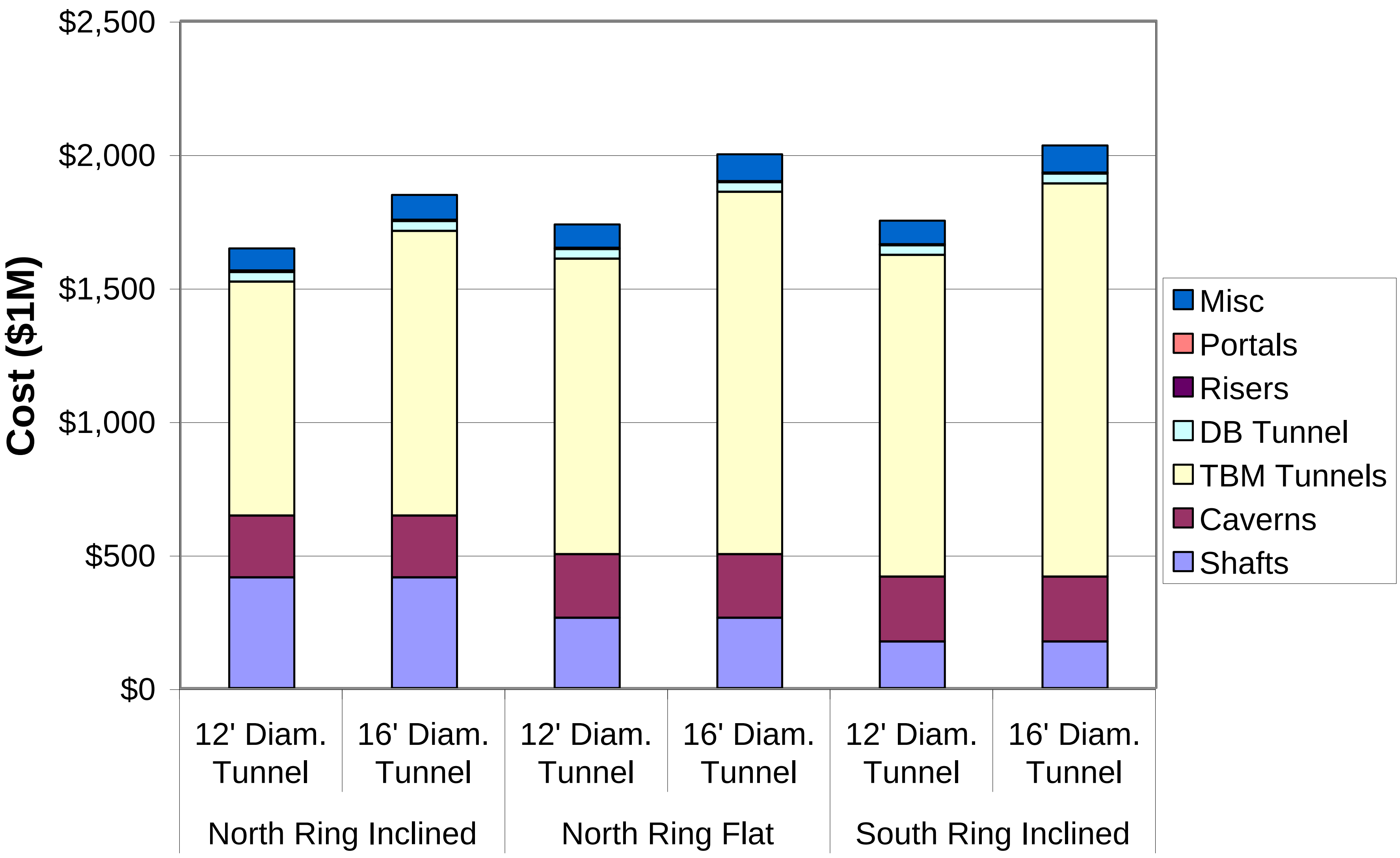
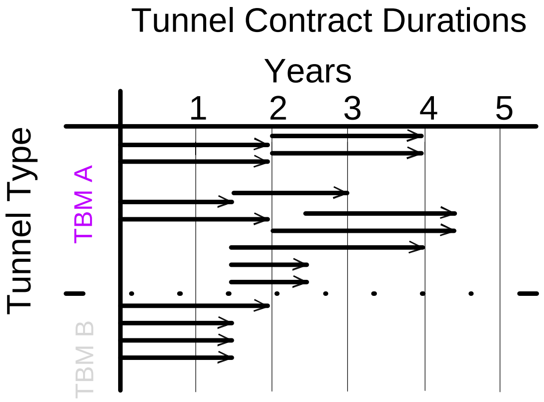
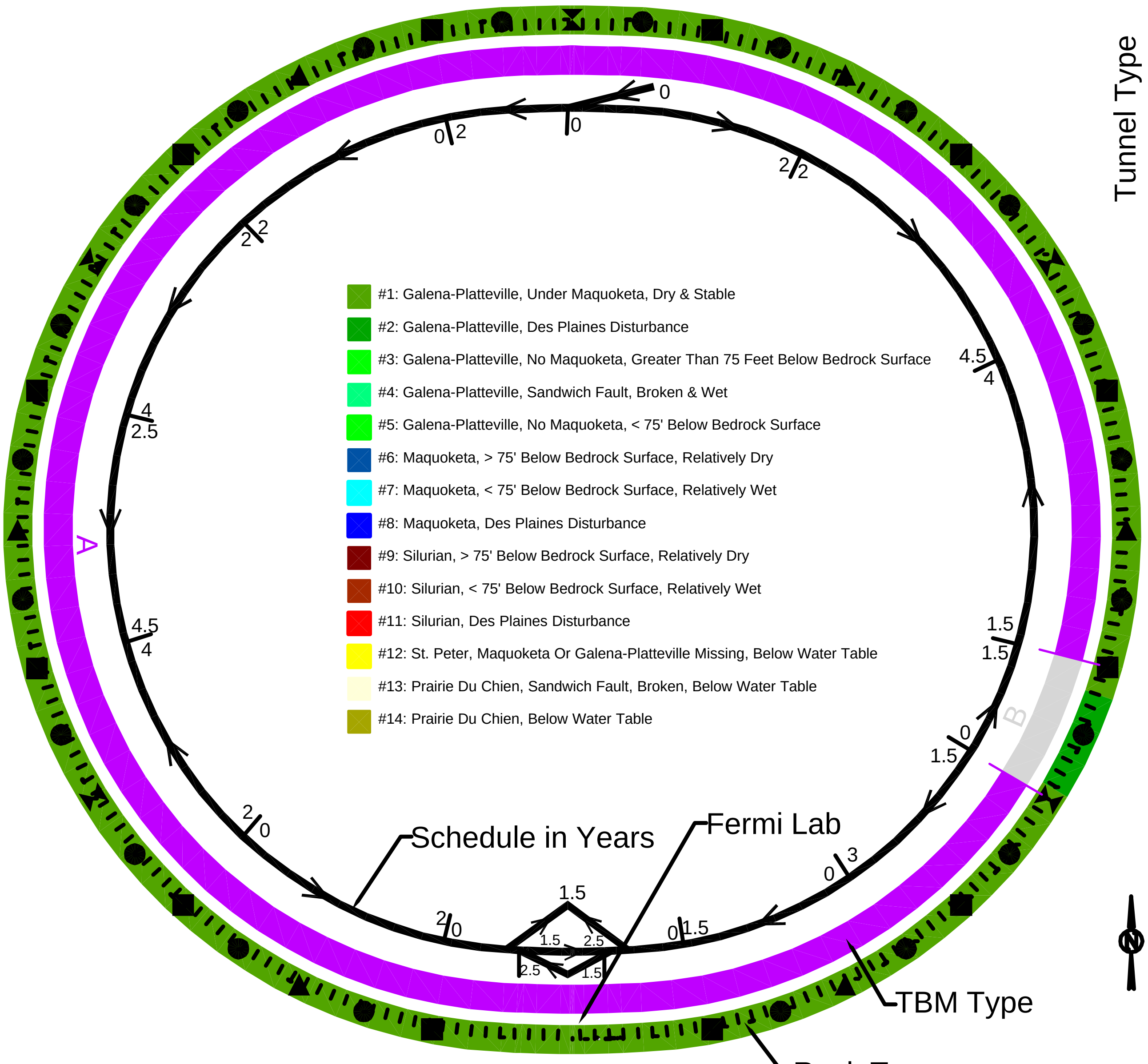


Figure 3.7 - Cost Breakdown





TBM Descriptions

TBM A
Unshielded TBM, limited support, lining & grouting.

TBM B
Open TBM with finger shield; Rockbolts, mesh and/or ring beams; With cast in place concrete liner, with or without membrane, grouting

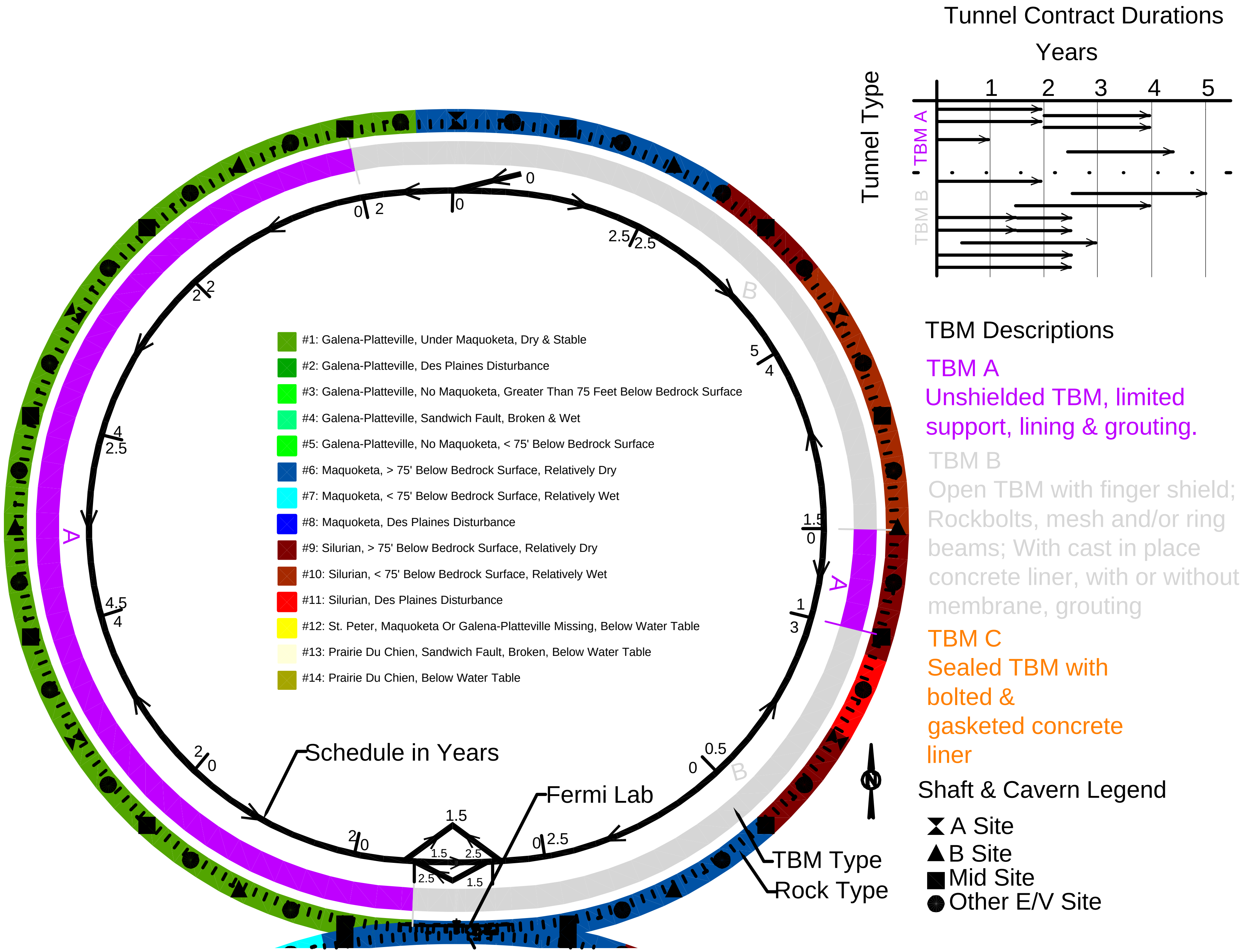
TBM C
Sealed TBM with bolted & gasketed concrete liner

N

Shaft & Cavern Legend

⧗ A Site
▲ B Site
■ Mid Site
● Other E/V Site

Figure 4.1 North Inclined Ring



- 🟩 #1: Galena-Platteville, Under Maquoketa, Dry & Stable
- 🟩 #2: Galena-Platteville, Des Plaines Disturbance
- 🟩 #3: Galena-Platteville, No Maquoketa, Greater Than 75 Feet Below Bedrock Surface
- 🟩 #4: Galena-Platteville, Sandwich Fault, Broken & Wet
- 🟩 #5: Galena-Platteville, No Maquoketa, < 75' Below Bedrock Surface
- 🟦 #6: Maquoketa, > 75' Below Bedrock Surface, Relatively Dry
- 🟦 #7: Maquoketa, < 75' Below Bedrock Surface, Relatively Wet
- 🟦 #8: Maquoketa, Des Plaines Disturbance
- 🟥 #9: Silurian, > 75' Below Bedrock Surface, Relatively Dry
- 🟫 #10: Silurian, < 75' Below Bedrock Surface, Relatively Wet
- 🟥 #11: Silurian, Des Plaines Disturbance
- 🟨 #12: St. Peter, Maquoketa Or Galena-Platteville Missing, Below Water Table
- ⬜ #13: Prairie Du Chien, Sandwich Fault, Broken, Below Water Table
- 🟫 #14: Prairie Du Chien, Below Water Table

TBM Descriptions

TBM A
Unshielded TBM, limited support, lining & grouting.

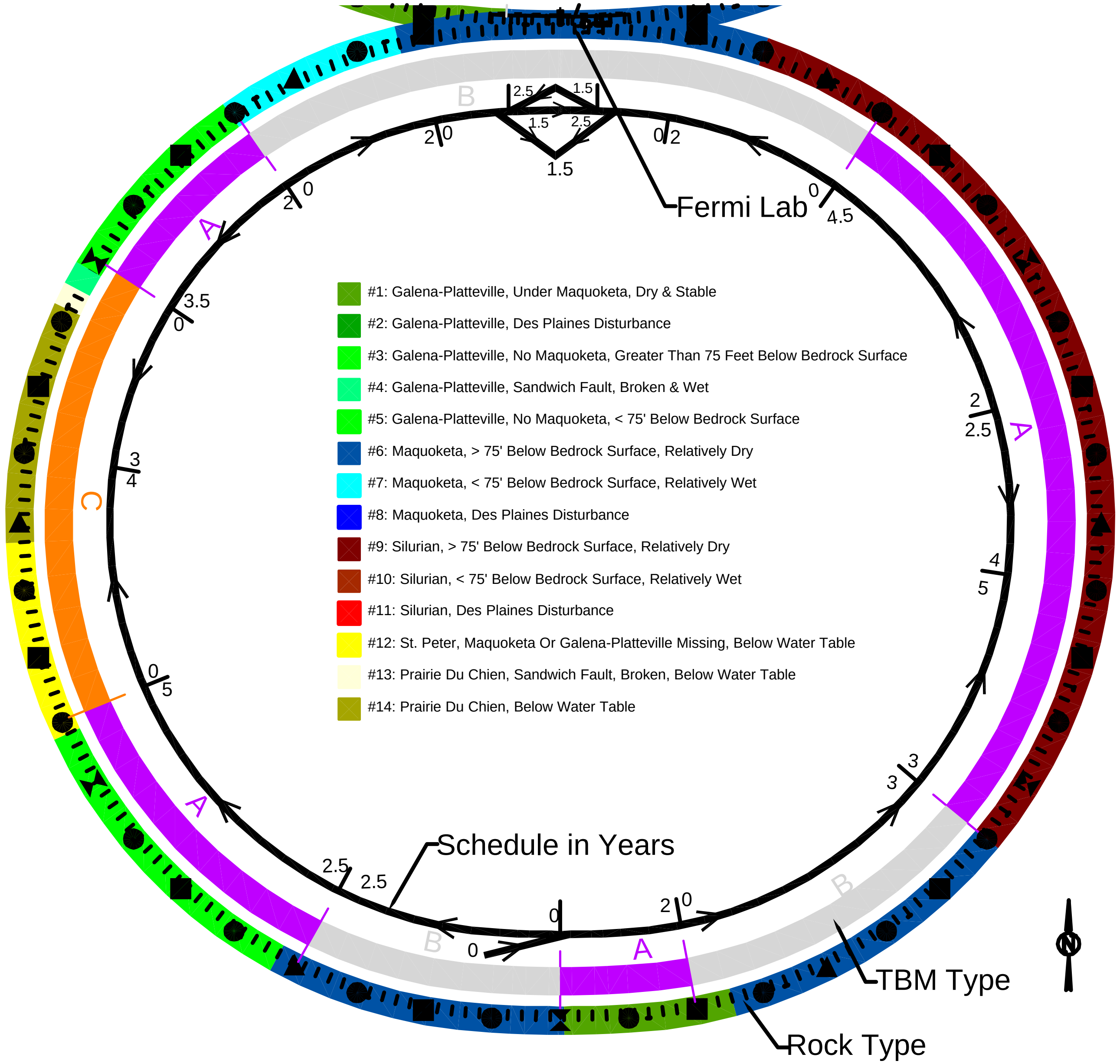
TBM B
Open TBM with finger shield; Rockbolts, mesh and/or ring beams; With cast in place concrete liner, with or without membrane, grouting

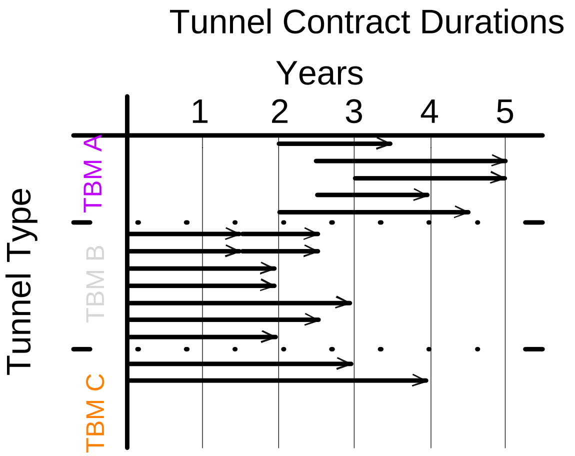
TBM C
Sealed TBM with bolted & gasketed concrete liner

Shaft & Cavern Legend

- ⧗ A Site
- ▲ B Site
- ■ Mid Site
- ● Other E/V Site

Figure 4.2 North Flat Ring





TBM Descriptions

TBM A
Unshielded TBM, limited support, lining & grouting.

TBM B
Open TBM with finger shield; Rockbolts, mesh and/or ring beams; With cast in place concrete liner, with or without membrane, grouting

TBM C
Sealed TBM with bolted & gasketed concrete liner

Shaft & Cavern Legend

⧗ A Site
▲ B Site
■ Mid Site
● Other E/V Site

Figure 4.3 South Inclined Ring

Appendix A—Listing of Project Components

Appendix A -- VLHC Components Summary

vlhc_Underground_Construction.xls

VLHC Component Summary

Ref #	Description	Starting Station	Segment Length	Ending Station	Component Type	Finished Diameter or Width (m)	Finished Height or Width (m)	Finished Length (m)
1	Type A Site Equipment Shaft	0000+00.00		0000+00.00	Shaft	9.25		
2	Type A Site EV Shaft	0000+00.00		0000+00.00	Shaft	4.60		
3	Type A Site Cryogenics Cavern	0000+00.00		0000+00.00	Cavern	12.20	12.20	12.20
4	Type A Site Power Distribution Alcove	0000+00.00		0000+00.00	Cavern	7.62	2.84	12.20
5	Type A Site Personnel Tunnel	0000+00.00		0000+00.00	DB Tunnel	2.44		25.91
6	Type A Site Equipment Tunnel	0000+00.00		0000+00.00	DB Tunnel	3.05		80.79
7	Type A Site Utility Penetrations	0000+00.00		0000+00.00	Misc	0.76		132.41
8	Type A Site Groundwater Cavern	0000+00.00		0000+00.00	Cavern	12.00	12.00	55.00
9	Straight	0000+00.00	137.00	0001+37.00	Tunnel	3.66		
10	Bend	0001+37.00	723.38	0008+60.38	Tunnel	3.66		
11	Straight	0008+60.38	820.00	0016+80.38	Tunnel	3.66		
12	Experimental Cavern	0016+80.38		0016+80.38	Cavern	30.00	45.00	100
13	E.C. Cable Electronics Shaft	0016+80.38		0016+80.38	Shaft	13.00	18.00	
14	E.C. Utility Shaft	0016+80.38		0016+80.38	Shaft	13.00	17.50	
15	E.C. Installation Shaft	0016+80.38		0016+80.38	Shaft	18.00	28.00	
16	E.C. Installation Shaft	0016+80.38		0016+80.38	Shaft	18.00	25.00	
17	E.C. Connection Tunnels	0016+80.38		0016+80.38	DB Tunnel	13.00		95
18	E.C. Utlity Bypass Tunnel	0016+80.38		0016+80.38	DB Tunnel	9.25		294
19	Straight	0016+80.38	820.00	0025+00.38	Tunnel	3.66		
20	Bend	0025+00.38	994.67	0034+95.05	Tunnel	3.66		
21	Abort tunnel cavern	0034+95.05		0034+95.05	Cavern	7.85	5.00	650
22	Straight	0034+95.05	410.00	0039+05.05	Tunnel	7.62		
23	RFKT cavern	0039+05.05		0039+05.05	Cavern	7.60	7.60	75
24	RFKT Equipment shaft	0039+05.05		0039+05.05	Shaft	9.25		
25	RFKT Utility Penetrations	0039+05.05		0039+05.05	Misc	0.76		132.41
26	RFKT Personnel Tunnel	0039+05.05		0039+05.05	DB Tunnel	2.44		25.91
27	Straight	0039+05.05	130.00	0040+35.05	Tunnel	7.62		
28	Injection-Straight interface cavern	0040+35.05		0040+35.05	Cavern	7.62	7.62	100
29	Straight	0040+35.05	660.00	0046+95.05	Tunnel	7.62		
30	KMPS cavern	0046+95.05		0046+95.05	Cavern	7.60	7.60	60
31	KMPS Equipment shaft	0046+95.05		0046+95.05	Shaft	4.60		
32	KMPS utility penetrations	0046+95.05		0046+95.05	Misc	0.30		132.41
33	KMPS personnel tunnel	0046+95.05		0046+95.05	DB Tunnel	3.66		21.36
34	Straight	0046+95.05	180.00	0048+75.05	Tunnel	7.62		
35	Bend	0048+75.05	4814.10	0096+89.15	Tunnel	3.66		
36	Mid site Cavern	0096+89.15		0096+89.15	Cavern	12.20	6.10	28.05
37	Mid-site Shaft	0096+89.15		0096+89.15	Shaft	4.60		
38	Bend	0096+89.15	4844.57	0145+33.72	Tunnel	3.66		
39	E/V shaft	0145+33.72		0145+33.72	Shaft	4.60		
40	Bend	0145+33.72	4844.57	0193+78.29	Tunnel	3.66		
41	Type B Site Equipment Shaft	0193+78.29		0193+78.29	Shaft	9.25		
42	Type B Site EV Shaft	0193+78.29		0193+78.29	Shaft	4.60		
43	Type B Site Cryogenics Cavern	0193+78.29		0193+78.29	Cavern	12.20	12.20	12.20
44	Type B Site Power Distribution Alcove	0193+78.29		0193+78.29	Cavern	7.62	2.84	12.20
45	Type B Site Personnel Tunnel	0193+78.29		0193+78.29	DB Tunnel	2.44		25.91
46	Type B Site Equipment Tunnel	0193+78.29		0193+78.29	DB Tunnel	3.05		80.79
47	Type B Site Utility Penetrations	0193+78.29		0193+78.29	Misc	0.76		132.41
48	Bend	0193+78.29	4844.57	0242+22.86	Tunnel	3.66		
49	E/V shaft	0242+22.86		0242+22.86	Shaft	4.60		
50	Bend	0242+22.86	4844.57	0290+67.44	Tunnel	3.66		
51	Mid site Cavern	0290+67.44		0290+67.44	Cavern	12.20	6.10	28.04878
52	Mid-site Shaft	0290+67.44		0290+67.44	Shaft	4.60		
53	Bend	0290+67.44	4844.57	0339+12.01	Tunnel	3.66		
54	E/V shaft	0339+12.01		0339+12.01	Shaft	4.60		
55	Bend	0339+12.01	4844.57	0387+56.58	Tunnel	3.66		
56	Type A Site Equipment Shaft	0387+56.58		0387+56.58	Shaft	9.25		
57	Type A Site EV Shaft	0387+56.58		0387+56.58	Shaft	4.60		
58	Type A Site Cryogenics Cavern	0387+56.58		0387+56.58	Cavern	12.20	12.20	12.20
59	Type A Site Power Distribution Alcove	0387+56.58		0387+56.58	Cavern	7.62	2.84	12.20

Appendix A -- VLHC Components Summary

vlhc_Underground_Construction.xls

VLHC Component Summary

Ref #	Description	Starting Station	Segment Length	Ending Station	Component Type	Finished Diameter or Width (m)	Finished Height or Width (m)	Finished Length (m)
60	Type A Site Personnel Tunnel	0387+56.58		0387+56.58	DB Tunnel	2.44		25.91
61	Type A Site Equipment Tunnel	0387+56.58		0387+56.58	DB Tunnel	3.05		80.79
62	Type A Site Utility Penetrations	0387+56.58		0387+56.58	Misc	0.76		132.41
63	Type A Site Groundwater Cavern	0387+56.58		0387+56.58	Cavern	12.00	12.00	55.00
64	Bend	0387+56.58	4844.57	0436+01.15	Tunnel	3.66		
65	E/V shaft	0436+01.15		0436+01.15	Shaft	4.60		
66	Bend	0436+01.15	4844.57	0484+45.73	Tunnel	3.66		
67	Mid site Cavern	0484+45.73		0484+45.73	Cavern	12.20	6.10	28.04878
68	Mid-site Shaft	0484+45.73		0484+45.73	Shaft	4.60		
69	Bend	0484+45.73	4844.57	0532+90.30	Tunnel	3.66		
70	E/V shaft	0532+90.30		0532+90.30	Shaft	4.60		
71	Bend	0532+90.30	4844.57	0581+34.87	Tunnel	3.66		
72	Type B Site Equipment Shaft	0581+34.87		0581+34.87	Shaft	9.25		
73	Type B Site EV Shaft	0581+34.87		0581+34.87	Shaft	4.60		
74	Type B Site Cryogenics Cavern	0581+34.87		0581+34.87	Cavern	12.20	12.20	12.20
75	Type B Site Power Distribution Alcove	0581+34.87		0581+34.87	Cavern	7.62	2.84	12.20
76	Type B Site Personnel Tunnel	0581+34.87		0581+34.87	DB Tunnel	2.44		25.91
77	Type B Site Equipment Tunnel	0581+34.87		0581+34.87	DB Tunnel	3.05		80.79
78	Type B Site Utility Penetrations	0581+34.87		0581+34.87	Misc	0.76		132.41
79	Bend	0581+34.87	4844.57	0629+79.44	Tunnel	3.66		
80	E/V shaft	0629+79.44		0629+79.44	Shaft	4.60		
81	Bend	0629+79.44	4844.57	0678+24.02	Tunnel	3.66		
82	Mid site Cavern	0678+24.02		0678+24.02	Cavern	12.20	6.10	28.04878
83	Mid-site Shaft	0678+24.02		0678+24.02	Shaft	4.60		
84	Bend	0678+24.02	4844.57	0726+68.59	Tunnel	3.66		
85	E/V shaft	0726+68.59		0726+68.59	Shaft	4.60		
86	Bend	0726+68.59	4844.57	0775+13.16	Tunnel	3.66		
87	Type A Site Equipment Shaft	0775+13.16		0775+13.16	Shaft	9.25		
88	Type A Site EV Shaft	0775+13.16		0775+13.16	Shaft	4.60		
89	Type A Site Cryogenics Cavern	0775+13.16		0775+13.16	Cavern	12.20	12.20	12.20
90	Type A Site Power Distribution Alcove	0775+13.16		0775+13.16	Cavern	7.62	2.84	12.20
91	Type A Site Personnel Tunnel	0775+13.16		0775+13.16	DB Tunnel	2.44		25.91
92	Type A Site Equipment Tunnel	0775+13.16		0775+13.16	DB Tunnel	3.05		80.79
93	Type A Site Utility Penetrations	0775+13.16		0775+13.16	Misc	0.76		132.41
94	Type A Site Groundwater Cavern	0775+13.16		0775+13.16	Cavern	12.00	12.00	55.00
95	Bend	0775+13.16	4844.57	0823+57.73	Tunnel	3.66		
96	E/V shaft	0823+57.73		0823+57.73	Shaft	4.60		
97	Bend	0823+57.73	4844.57	0872+02.31	Tunnel	3.66		
98	Mid site Cavern	0872+02.31		0872+02.31	Cavern	12.20	6.10	28.04878
99	Mid-site Shaft	0872+02.31		0872+02.31	Shaft	4.60		
100	Bend	0872+02.31	4844.57	0920+46.88	Tunnel	3.66		
101	E/V shaft	0920+46.88		0920+46.88	Shaft	4.60		
102	Bend	0920+46.88	4844.57	0968+91.45	Tunnel	3.66		
103	Type B Site Equipment Shaft	0968+91.45		0968+91.45	Shaft	9.25		
104	Type B Site EV Shaft	0968+91.45		0968+91.45	Shaft	4.60		
105	Type B Site Cryogenics Cavern	0968+91.45		0968+91.45	Cavern	12.20	12.20	12.20
106	Type B Site Power Distribution Alcove	0968+91.45		0968+91.45	Cavern	7.62	2.84	12.20
107	Type B Site Personnel Tunnel	0968+91.45		0968+91.45	DB Tunnel	2.44		25.91
108	Type B Site Equipment Tunnel	0968+91.45		0968+91.45	DB Tunnel	3.05		80.79
109	Type B Site Utility Penetrations	0968+91.45		0968+91.45	Misc	0.76		132.41
110	Bend	0968+91.45	4844.57	1017+36.03	Tunnel	3.66		
111	E/V shaft	1017+36.03		1017+36.03	Shaft	4.60		
112	Bend	1017+36.03	4844.57	1065+80.60	Tunnel	3.66		
113	Mid site Cavern	1065+80.60		1065+80.60	Cavern	12.20	6.10	28.04878
114	Mid-site Shaft	1065+80.60		1065+80.60	Shaft	4.60		
115	Bend	1065+80.60	4814.10	1113+94.70	Tunnel	3.66		
116	Straight	1113+94.70	180.00	1115+74.70	Tunnel	7.62		
117	KMPS cavern	1115+74.70		1115+74.70	Cavern	7.60	7.60	60
118	KMPS Equipment shaft	1115+74.70		1115+74.70	Shaft	4.60		

VLHC Component Summary

Ref #	Description	Starting Station	Segment Length	Ending Station	Component Type	Finished Diameter or Width (m)	Finished Height or Width (m)	Finished Length (m)
119	KMPS utility penetrations	1115+74.70		1115+74.70	Misc	0.30		132.41
120	KMPS personnel tunnel	1115+74.70		1115+74.70	DB Tunnel	3.66		21.36
121	Straight	1115+74.70	660.00	1122+34.70	Tunnel	7.62		
122	Injection-Straight interface cavern	1122+34.70		1122+34.70	Cavern	7.62	7.62	100
123	Straight	1122+34.70	130.00	1123+64.70	Tunnel	7.62		
124	Straight	1123+64.70	410.00	1127+74.70	Tunnel	7.62		
125	Bend	1127+74.70	994.67	1137+69.36	Tunnel	3.66		
126	Straight	1137+69.36	820.00	1145+89.36	Tunnel	3.66		
127	Straight	1145+89.36	820.00	1154+09.36	Tunnel	3.66		
128	Bend	1154+09.36	723.38	1161+32.74	Tunnel	3.66		
129	Straight	1161+32.74	137.00	1162+69.74	Tunnel	3.66		
130	Type A Site Equipment Shaft	1162+69.74		1162+69.74	Shaft	9.25		
131	Type A Site EV Shaft	1162+69.74		1162+69.74	Shaft	4.60		
132	Type A Site Cryogenics Cavern	1162+69.74		1162+69.74	Cavern	12.20	12.20	12.20
133	Type A Site Power Distribution Alcove	1162+69.74		1162+69.74	Cavern	7.62	2.84	12.20
134	Type A Site Personnel Tunnel	1162+69.74		1162+69.74	DB Tunnel	2.44		25.91
135	Type A Site Equipment Tunnel	1162+69.74		1162+69.74	DB Tunnel	3.05		80.79
136	Type A Site Utility Penetrations	1162+69.74		1162+69.74	Misc	0.76		132.41
137	Type A Site Groundwater Cavern	1162+69.74		1162+69.74	Cavern	12.00	12.00	55.00
138	Straight	1162+69.74	137.00	1164+06.74	Tunnel	3.66		
139	Bend	1164+06.74	723.38	1171+30.12	Tunnel	3.66		
140	Straight	1171+30.12	820.00	1179+50.12	Tunnel	3.66		
141	Straight	1179+50.12	820.00	1187+70.12	Tunnel	3.66		
142	Bend	1187+70.12	994.67	1197+64.79	Tunnel	3.66		
143	Straight	1197+64.79	410.00	1201+74.79	Tunnel	7.62		
144	Straight	1201+74.79	130.00	1203+04.79	Tunnel	7.62		
145	Straight	1203+04.79	660.00	1209+64.79	Tunnel	7.62		
146	KMPS cavern	1209+64.79		1209+64.79	Cavern	7.60	7.60	60
147	KMPS Equipment shaft	1209+64.79		1209+64.79	Shaft	4.60		
148	KMPS utility penetrations	1209+64.79		1209+64.79	Misc	0.30		132.41
149	KMPS personnel tunnel	1209+64.79		1209+64.79	DB Tunnel	3.66		21.36
150	Straight	1209+64.79	180.00	1211+44.79	Tunnel	3.66		
151	Bend	1211+44.79	4814.10	1259+58.89	Tunnel	3.66		
152	Mid site Cavern	1259+58.89		1259+58.89	Cavern	12.20	6.10	28.04878
153	Mid-site Shaft	1259+58.89		1259+58.89	Shaft	4.60		
154	Bend	1259+58.89	4844.57	1308+03.46	Tunnel	3.66		
155	E/V shaft	1308+03.46		1308+03.46	Shaft	4.60		
156	Bend	1308+03.46	4844.57	1356+48.03	Tunnel	3.66		
157	Type B Site Equipment Shaft	1356+48.03		1356+48.03	Shaft	9.25		
158	Type B Site EV Shaft	1356+48.03		1356+48.03	Shaft	4.60		
159	Type B Site Cryogenics Cavern	1356+48.03		1356+48.03	Cavern	12.20	12.20	12.20
160	Type B Site Power Distribution Alcove	1356+48.03		1356+48.03	Cavern	7.62	2.84	12.20
161	Type B Site Personnel Tunnel	1356+48.03		1356+48.03	DB Tunnel	2.44		25.91
162	Type B Site Equipment Tunnel	1356+48.03		1356+48.03	DB Tunnel	3.05		80.79
163	Type B Site Utility Penetrations	1356+48.03		1356+48.03	Misc	0.76		132.41
164	Bend	1356+48.03	4844.57	1404+92.61	Tunnel	3.66		
165	E/V shaft	1404+92.61		1404+92.61	Shaft	4.60		
166	Bend	1404+92.61	4844.57	1453+37.18	Tunnel	3.66		
167	Mid site Cavern	1453+37.18		1453+37.18	Cavern	12.20	6.10	28.04878
168	Mid-site Shaft	1453+37.18		1453+37.18	Shaft	4.60		
169	Bend	1453+37.18	4844.57	1501+81.75	Tunnel	3.66		
170	E/V shaft	1501+81.75		1501+81.75	Shaft	4.60		
171	Bend	1501+81.75	4844.57	1550+26.32	Tunnel	3.66		
172	Type A Site Equipment Shaft	1550+26.32		1550+26.32	Shaft	9.25		
173	Type A Site EV Shaft	1550+26.32		1550+26.32	Shaft	4.60		
174	Type A Site Cryogenics Cavern	1550+26.32		1550+26.32	Cavern	12.20	12.20	12.20
175	Type A Site Power Distribution Alcove	1550+26.32		1550+26.32	Cavern	7.62	2.84	12.20
176	Type A Site Personnel Tunnel	1550+26.32		1550+26.32	DB Tunnel	2.44		25.91
177	Type A Site Equipment Tunnel	1550+26.32		1550+26.32	DB Tunnel	3.05		80.79

VLHC Component Summary

Ref #	Description	Starting Station	Segment Length	Ending Station	Component Type	Finished Diameter or Width (m)	Finished Height or Width (m)	Finished Length (m)
178	Type A Site Utility Penetrations	1550+26.32		1550+26.32	Misc	0.76		132.41
179	Type A Site Groundwater Cavern	1550+26.32		1550+26.32	Cavern	12.00	12.00	55.00
180	Bend	1550+26.32	4844.57	1598+70.90	Tunnel	3.66		
181	E/V shaft	1598+70.90		1598+70.90	Shaft	4.60		
182	Bend	1598+70.90	4844.57	1647+15.47	Tunnel	3.66		
183	Mid site Cavern	1647+15.47		1647+15.47	Cavern	12.20	6.10	28.04878
184	Mid-site Shaft	1647+15.47		1647+15.47	Shaft	4.60		
185	Bend	1647+15.47	4844.57	1695+60.04	Tunnel	3.66		
186	E/V shaft	1695+60.04		1695+60.04	Shaft	4.60		
187	Bend	1695+60.04	4844.57	1744+04.61	Tunnel	3.66		
188	Type B Site Equipment Shaft	1744+04.61		1744+04.61	Shaft	9.25		
189	Type B Site EV Shaft	1744+04.61		1744+04.61	Shaft	4.60		
190	Type B Site Cryogenics Cavern	1744+04.61		1744+04.61	Cavern	12.20	12.20	12.20
191	Type B Site Power Distribution Alcove	1744+04.61		1744+04.61	Cavern	7.62	2.84	12.20
192	Type B Site Personnel Tunnel	1744+04.61		1744+04.61	DB Tunnel	2.44		25.91
193	Type B Site Equipment Tunnel	1744+04.61		1744+04.61	DB Tunnel	3.05		80.79
194	Type B Site Utility Penetrations	1744+04.61		1744+04.61	Misc	0.76		132.41
195	Bend	1744+04.61	4844.57	1792+49.19	Tunnel	3.66		
196	E/V shaft	1792+49.19		1792+49.19	Shaft	4.60		
197	Bend	1792+49.19	4844.57	1840+93.76	Tunnel	3.66		
198	Mid site Cavern	1840+93.76		1840+93.76	Cavern	12.20	6.10	28.04878
199	Mid-site Shaft	1840+93.76		1840+93.76	Shaft	4.60		
200	Bend	1840+93.76	4844.57	1889+38.33	Tunnel	3.66		
201	E/V shaft	1889+38.33		1889+38.33	Shaft	4.60		
202	Bend	1889+38.33	4844.57	1937+82.90	Tunnel	3.66		
203	Type A Site Equipment Shaft	1937+82.90		1937+82.90	Shaft	9.25		
204	Type A Site EV Shaft	1937+82.90		1937+82.90	Shaft	4.60		
205	Type A Site Cryogenics Cavern	1937+82.90		1937+82.90	Cavern	12.20	12.20	12.20
206	Type A Site Power Distribution Alcove	1937+82.90		1937+82.90	Cavern	7.62	2.84	12.20
207	Type A Site Personnel Tunnel	1937+82.90		1937+82.90	DB Tunnel	2.44		25.91
208	Type A Site Equipment Tunnel	1937+82.90		1937+82.90	DB Tunnel	3.05		80.79
209	Type A Site Utility Penetrations	1937+82.90		1937+82.90	Misc	0.76		132.41
210	Type A Site Groundwater Cavern	1937+82.90		1937+82.90	Cavern	12.00	12.00	55.00
211	Bend	1937+82.90	4844.57	1986+27.48	Tunnel	3.66		
212	E/V shaft	1986+27.48		1986+27.48	Shaft	4.60		
213	Bend	1986+27.48	4844.57	2034+72.05	Tunnel	3.66		
214	Mid site Cavern	2034+72.05		2034+72.05	Cavern	12.20	6.10	28.04878
215	Mid-site Shaft	2034+72.05		2034+72.05	Shaft	4.60		
216	Bend	2034+72.05	4844.57	2083+16.62	Tunnel	3.66		
217	E/V shaft	2083+16.62		2083+16.62	Shaft	4.60		
218	Bend	2083+16.62	4844.57	2131+61.20	Tunnel	3.66		
219	Type B Site Equipment Shaft	2131+61.20		2131+61.20	Shaft	9.25		
220	Type B Site EV Shaft	2131+61.20		2131+61.20	Shaft	4.60		
221	Type B Site Cryogenics Cavern	2131+61.20		2131+61.20	Cavern	12.20	12.20	12.20
222	Type B Site Power Distribution Alcove	2131+61.20		2131+61.20	Cavern	7.62	2.84	12.20
223	Type B Site Personnel Tunnel	2131+61.20		2131+61.20	DB Tunnel	2.44		25.91
224	Type B Site Equipment Tunnel	2131+61.20		2131+61.20	DB Tunnel	3.05		80.79
225	Type B Site Utility Penetrations	2131+61.20		2131+61.20	Misc	0.76		132.41
226	Bend	2131+61.20	4844.57	2180+05.77	Tunnel	3.66		
227	E/V shaft	2180+05.77		2180+05.77	Shaft	4.60		
228	Bend	2180+05.77	4844.57	2228+50.34	Tunnel	3.66		
229	Mid site Cavern	2228+50.34		2228+50.34	Cavern	12.20	6.10	28.04878
230	Mid-site Shaft	2228+50.34		2228+50.34	Shaft	4.60		
231	Bend	2228+50.34	4814.10	2276+64.44	Tunnel	3.66		
232	Straight	2276+64.44	180.00	2278+44.44	Tunnel	7.62		
233	KMPS cavern	2278+44.44		2278+44.44	Cavern	7.60	7.60	60
234	KMPS Equipment shaft	2278+44.44		2278+44.44	Shaft	4.60		
235	KMPS utility penetrations	2278+44.44		2278+44.44	Misc	0.30		132.41
236	KMPS personnel tunnel	2278+44.44		2278+44.44	DB Tunnel	3.66		21.36

VLHC Component Summary

Ref #	Description	Starting Station	Segment Length	Ending Station	Component Type	Finished Diameter or Width (m)	Finished Height or Width (m)	Finished Length (m)
237	Straight	2278+44.44	660.00	2285+04.44	Tunnel	7.62		
238	Injection-Straight interface cavern	2285+04.44		2285+04.44	Cavern	7.62	7.62	100.00
239	Straight	2285+04.44	130.00	2286+34.44	Tunnel	7.62		
240	RFKT cavern	2286+34.44		2286+34.44	Cavern	7.60	7.60	75.00
241	RFKT Equipment shaft	2286+34.44		2286+34.44	Shaft	9.25		
242	RFKT Utility Penetrations	2286+34.44		2286+34.44	Misc	0.76		132.41
243	RFKT Personnel Tunnel	2286+34.44		2286+34.44	DB Tunnel	2.44		25.91
241	Straight	2286+34.44	410.00	2290+44.44	Tunnel	7.62		
242	Abort tunnel cavern	2290+44.44		2290+44.44	Cavern	7.85	5.00	650
243	Bend	2290+44.44	994.67	2300+39.11	Tunnel	3.66		
244	Straight	2300+39.11	820.00	2308+59.11	Tunnel	3.66		
245	Experimental Cavern	2308+59.11		2308+59.11	Cavern	30.00	45.00	100
246	Cable Electronics Shaft	2308+59.11		2308+59.11	Shaft	9.00		
247	Utility Shaft	2308+59.11		2308+59.11	Shaft	10.00		
248	Installation Shaft	2308+59.11		2308+59.11	Shaft	11.00	18.00	
249	Installation Shaft	2308+59.11		2308+59.11	Shaft	11.00	18.00	
250	Personnel Shaft	2308+59.11		2308+59.11	Shaft	9.00		
251	Connection Tunnels	2308+59.11		2308+59.11	DB Tunnel	13.00		95
252	Utlity Bypass Tunnel	2308+59.11		2308+59.11	DB Tunnel	9.25		294
253	Straight	2308+59.11	820.00	2316+79.11	Tunnel	3.66		
254	Bend	2316+79.11	723.38	2324+02.49	Tunnel	3.66		
255	Straight	2324+02.49	137.00	2325+39.49	Tunnel	3.66		
256	Type A Site (repeat of first)	2325+39.49		2325+39.49				
257	Site Riser 1	0000+00.00		0029+06.74	Riser	0.50		
258	Site Riser 2	0029+06.74		0087+20.23	Riser	0.50		
259	Site Riser 3	0087+20.23		0145+34.58	Riser	0.50		
260	Site Riser 4	0145+34.58		0203+48.94	Riser	0.50		
261	Site Riser 5	0203+48.94		0261+63.29	Riser	0.50		
262	Site Riser 6	0261+63.29		0319+77.64	Riser	0.50		
263	Site Riser 7	0319+77.64		0377+91.99	Riser	0.50		
264	Site Riser 8	0377+91.99		0436+06.34	Riser	0.50		
265	Site Riser 9	0436+06.34		0494+20.70	Riser	0.50		
266	Site Riser 10	0494+20.70		0552+35.05	Riser	0.50		
267	Site Riser 11	0552+35.05		0610+49.40	Riser	0.50		
268	Site Riser 12	0610+49.40		0668+63.75	Riser	0.50		
269	Site Riser 13	0668+63.75		0726+78.11	Riser	0.50		
270	Site Riser 14	0726+78.11		0784+92.46	Riser	0.50		
271	Site Riser 15	0784+92.46		0843+06.81	Riser	0.50		
272	Site Riser 16	0843+06.81		0901+21.16	Riser	0.50		
273	Site Riser 17	0901+21.16		0959+35.51	Riser	0.50		
274	Site Riser 18	0959+35.51		1017+49.87	Riser	0.50		
275	Site Riser 19	1017+49.87		1075+64.22	Riser	0.50		
276	Site Riser 20	1075+64.22		1133+78.57	Riser	0.50		
277	Site Riser 21	1133+78.57		1191+92.92	Riser	0.50		
278	Site Riser 22	1191+92.92		1250+07.28	Riser	0.50		
279	Site Riser 23	1250+07.28		1308+21.63	Riser	0.50		
280	Site Riser 24	1308+21.63		1366+35.98	Riser	0.50		
281	Site Riser 25	1366+35.98		1424+50.33	Riser	0.50		
282	Site Riser 26	1424+50.33		1482+64.68	Riser	0.50		
283	Site Riser 27	1482+64.68		1540+79.04	Riser	0.50		
284	Site Riser 28	1540+79.04		1598+93.39	Riser	0.50		
285	Site Riser 29	1598+93.39		1657+07.74	Riser	0.50		
286	Site Riser 30	1657+07.74		1715+22.09	Riser	0.50		
287	Site Riser 31	1715+22.09		1773+36.45	Riser	0.50		
288	Site Riser 32	1773+36.45		1831+50.80	Riser	0.50		
289	Site Riser 33	1831+50.80		1889+65.15	Riser	0.50		
290	Site Riser 34	1889+65.15		1947+79.50	Riser	0.50		
291	Site Riser 35	1947+79.50		2005+93.85	Riser	0.50		
292	Site Riser 36	2005+93.85		2064+08.21	Riser	0.50		

VLHC Component Summary

Ref #	Description	Starting Station	Segment Length	Ending Station	Component Type	Finished Diameter or Width (m)	Finished Height or Width (m)	Finished Length (m)
293	Site Riser 37	2064+08.21		2122+22.56	Riser	0.50		
294	Site Riser 38	2122+22.56		2180+36.91	Riser	0.50		
295	Site Riser 39	2180+36.91		2238+51.26	Riser	0.50		
296	Site Riser 40	2238+51.26		2296+65.62	Riser	0.50		
297	Abort Line Tunnel	2290+44.44	3495.05	2325+39.49	Tunnel	3.66		
298	Beam Stop Cavern	2325+39.49		2325+39.49	Cavern	16	16	40
299	Beam Stop Cavern Equipment Shaft	2325+39.49		2325+39.49	Shaft	9.25		
300	Beam Stop Cavern E/V Shaft	2325+39.49		2325+39.49	Shaft	4.6		
301	Abort Line Tunnel	0000+00.00	3495.05	0034+95.05	Tunnel	3.66		
302	Stage 2 Bypass Tunnel (1/2)	2290+44.44	3495.05	2325+39.49	Tunnel	3.66		
303	Stage 2 Bypass Tunnel (1/2)	0000+00.00	3495.05	0034+95.05	Tunnel	3.66		
304	Utility Straight East of Fermi	2276+64.44		2276+64.44	Cavern	7.62	7.62	1380.00
305	Utility Straight West of Fermi	0034+95.05		0048+75.05	Cavern	7.62	7.62	1380.00
306	Near Side Magnet Ramp Portal	0048+75.05		0048+75.05	Portal			
307	Near Side Magnet Ramp Portal	0048+75.05		0048+75.05	Portal			
308	Far Side Magnet Ramp Portal	0048+75.05		0048+75.05	Portal			

Appendix B—Notes from Observations and Discussions

VLHC
Notes from meeting/core viewing at Illinois Geological Survey (IGS), University of Illinois, Bob Bauer, IGS Engineering Geologist
4/26/01

Attendees: D. Lee Petersen, Bruce Wagener

We looked at five cores, IGS unique nos. C13175, C9475, C14850, C12955, and C4335. Locations are shown on the attached map. Bob Bauer chose these cores as representative and located on various locations on the VLHC alignments.

Core photos are located in Projects/Fermi_VLHC/images/core photos.

Core C13175

1. This core from SSC (Hole S-25) and CNA has a detailed log.
2. Core is HQ size.
3. We viewed the last few feet of Maquoketa, all of the Galena/Platteville, and a few feet of the Ancell.
4. Sandstone hardness was an 8 or 9.

Core C9475

1. This core was from TARP North Side Rock Tunnel Project and CNA has a detailed log.
2. We viewed the last 20 feet of Maquoketa, all of the Galena/Platteville, and 30 feet of the Ancell.
3. Core size is NX.
4. Sandstone hardness was an 8 or 9.

Core C4335

1. This core is from a gas storage study in the 1960's. We have no log.
2. Only portions were cored – depth 955 ft to 979 ft – Platteville, and 990 to 996 – St. Peter.
3. Core is large diameter, possibly PQ.

Core C12955

1. This core was taken in 1963.
2. Core is small diameter, possibly BX.
3. We viewed the last few feet of Maquoketa, all of the Galena/Platteville, and a few feet of the Ancell.
4. Slickensides were observed near depth 400.
5. Core was taken near the southeast end of the Sandwich fault.
6. Sandstone hardness was an 8 or 9.

Core C14850

1. This core was taken in 2000 for a quarry to determine if the rock could be used for cement production.

2. CNA has a log of lithology only.
3. The entire core has been sawed in half. The IGS has one half.

Discussion

Core C14850 was the highest quality. An IGS geologist said this is because the calcium in the limestone has not been replaced by magnesium. High magnesium rock (dolomite) is weaker due to vugginess. Cores C13175, C9475, and C4335, were of lower, but still good quality, more dolomitic, and more vuggy. Core C12955 was the lowest quality (more broken). This could be due to its proximity to the Sandwich fault, small core diameter, and/or following a vertical joint.

VLHC
Notes from Meeting With Peter Conroy
4/26/01
Attendees: D. Lee Petersen, Bruce Wagener

Notes by Bruce Wagener

On April 26, 2001 D. Lee Petersen and Bruce Wagener of CNA met with Peter Conroy, Consulting Engineer to discuss geotechnical aspects of the VLHC Project. Peter has studied the Fermi area geology and wrote “Characterization of Fermi Region Geology” presented at Second Annual VLHC Meeting, Port Jefferson, Long Island, NY, along with other work in the area. He and Robert Bauer of the Illinois Geological Survey also created the geologic “lampshades” that depict bedrock contacts for the three tunnel alignment options.

Peter had the following comments:

1. He expects that most of the unweathered bedrock will be good for tunneling, compared to other projects. He does not see any advantage to having the tunnel alignment deeper because the rock quality will be will not change appreciably. Therefore it is best to stay shallow to minimize the depths of shafts and the height required to remove muck.
2. He has no evidence that tunneling conditions change vary by location, except in or near the Sandwich fault where more difficult conditions are expected.
3. The contacts between formations should have little effect on the tunneling or mining. Many are conformable with the adjacent formations.
4. If there is a ½ mile of bad ground (e.g. Sandwich Fault), it should have little effect on the total cost because the project is so large.
5. Significant dewatering will be needed in the Ancell because it is saturated and highly permeable.
6. He recommended we study his VLHC report. It contains references to groundwater information that we would find useful.

VLHC
Tour of Conco Western Stone Quarry in North Aurora Illinois and meeting with Mike Dunn, Mine Manager
4/25/01

Attendees: D. Lee Petersen and Bruce Wagener of CNA, Peter Garbincius, and Joe Lach of FermiLab.

The mine is located approximately 4 miles southwest of FermiLab at 105 Conco Street in North Aurora, Il. Currently, the mine is currently excavating Galena/Platteville in a room and pillar mining operation. The mine started in an open pit where the Silurian dolomite was removed. An incline was constructed through the Maquoketa to the Galena. They have been mining underground for 9 years.

We took numerous photos that are located in on the server in projects/Fermi_VLHC/images/north aurora quarry/

We observed or Mike Dunn reported the following information:

1. They are mining on two levels, with plans for a third. A section through the mine is approximately as follows:

    20’+/- Soil
    20’ +/- Silurian
    160’ Maquoketa
    25’ from bottom of Maquoketa to back of first level
    50’ room (first level)
    26’ thick roof beam for second level
    50’ room (second level)
    26’ thick roof beam or third level (future)
    50’ room (third level) (future)

2. Pillars in the upper levels line up with lower levels.
3. The Galena/Platteville is 290 feet thick at the mine.
4. The Glenwood is 6 feet to 14 feet thick at the mine.
5. The operation covers 80 acres the north side of the I-88 the toll way and 50 acres on the south side. The two areas are connected underground.
6. Rooms are 40 to 45 feet wide and 50 feet high.
7. There are better parting planes on the floor and roof of the second level, as compared to the first.
8. Joints are vertical and run NW or NE. They are filled with up to 14 inches of clay. They are undulating and rough, with undulation amplitudes up to 1.5 feet. They do not have a big effect on excavation stability.
9. The mine is dry.
10. Solution cavities along joints can be 8 feet thick and 20 feet long and are filled with decomposed rock. Others are circular “chimney” type.
11. There is very little chert in the Galena/Platteville at the mine.

12. Rockbolts are mostly mechanical anchors, 5’ long, 5/8” diameter, 6” maximum spacing in the roof. No rockbolts in the walls. Resin-grouted rockbolts are used in areas needing more support.
13. They have installed 14 ft extensometers with a potentiometer. They have detected no movement.
14. Tensar type fabric is used in a few areas, mainly the shop area and on solution cavities.
15. The ore has a value of $5.15/ton. The ore is sold for concrete aggregate, bituminous aggregate, roadway aggregate, and backfill.
16. They sold 1.25 million tons of ore last year.
17. They plan to mine for another 30 years.
18. They employ 21 employees, working on two shifts.
19. Blasting is done with ANFO and 1 stick of dynomite for primer.
20. The do not do any trimming or presplitting.
21. The mine permit requires them to stay at least 20 feet from the St. Peter because it is the aquifer for the municipal wells. They need to evaluate if they need to stay farther away so groundwater does not upwell from the St. Peter.
22. A few years ago, the mine flooded in a 17-inch rain. Water was 40 feet deep on the first level.

Appendix C—Rock Type Summaries

Geology of Northern Illinios For VLHC Study

	Overburden	Silurian					Maquoketa			
		Racine	Joliet		Kankakee	Elwood	Neda	Brainard	Fort Atkinson	Scales
			Romeo	Margraff						
Thickness	25 to 400 (ft)	0 to 360 (ft)	18 to 34 (ft)	9 to 51 (ft)	9 to 80 (ft)	20 to 30 (ft)	0 to 15 (ft)	1 to 136 (ft)	15 to 40 (ft)	50 to 150 (ft)
Composition	Clays, silts, sands, gravels	Dolomite	Medium Bedded Dolomite	(3) Zones range from dolomite to shale	Dolomite beds seperated shale	Chert with layers of dolomite	Hematitic shale	Shale with thick beds of dolomite	Dolomite	Dolomitic shale
Color	N/A	Light gray to white	Light gray to white locally mottled with pink	Light gray to white	Light gray to pinkish gray	Brown to gray	Red	Greenish gray	Light olive gray	Olive gray
Characteristics	Interbeded and discontinuous	Vuggy to coarsely vuggy	Thin to medium bedded dolomite	Dense dolomite with thin parting of porous chert	Wavy beds of dolomite 1 to 3 inches thick separated by shale.	Cherty dolomite containing nodules and layers up to 3 inches thick at top	Layer contains flattened iron oxide spheroids	Silty, fossilferous, dolomitic, shale with thin interbeds of dolomite	Dolomite	Laminate dolomitic shale with interbeds of silty dolomite 2" thick
Core Recovery (%) [1]	N/A	96 (average from 14 boreholes)					92 (average from 15 boreholes)			
RQD (%) [1]	N/A	87 (average from 14 boreholes)					87 (average from 15 boreholes)			
Q Rating [1]	N/A	41.8					14		14	
Jointing	N/A	Dominate joint sets are northeast and northwest, vertical [1]								
Depth Below Bedrock for First Core Run [1]	N/A	4.7 (average from 14 boreholes)					3.9 (average from 15 boreholes)			
Fracture Frequency (no / 10 ft) [1]	N/A	2 (average from 14 boreholes)					2 (average from 15 boreholes)			
Hardness (Tarkoy - Hendron Scale)	N/A	No Information	No Information	No Information	No Information	No Information	No Information	No Information	No Information	Extremely Soft (15.4)
Uniaxial Compressive Strength (psi)	N/A	10,000 to 20,000					2,500 to 15,000			
Young's Modulus (psi)	N/A	$2.5x10^6$ to $11x10^6$					$0.3x10^6$ to $5x10^6$			
Muck Value	Fill	Aggregate	Aggregate	No Value	No Value	Aggregate	No Value	No Value	Aggregate	No Value
Average Field Wave Velocity (ft/sec)	N/A	15,787					8,916		12,245	
Hydrogeologic Unit [1]	Outwash sands and gravels	Upper bedrock aquifer					Upper bedrock aquifer		Upper Ordovician aquitard	
Relative Permeability (cm/sec) [1]	$1x10^{-2}$ to $1x10^{-8}$ Moderate / Low	$1x10^{-2}$ to $1x10^{-4}$ Moderate					$1x10^{-4}$ to $1x10^{-6}$ Moderate / Low		$1x10^{-5}$ to $1x10^{-6}$ Low	
Water Yielding Characteristics [1]	Yields Highly Variable	Available from fractures in rock, small to moderate supply					Small supply from fractured dolomite or shale, generally not water bearing			
Thickness Orrientation	Thickens Northwest	Thickens to the Southeast					Missing to the South	No Information	No Information	No Information
Contact Information	N/A	Unconformably with Pensylvanian [3]	Conformably over Kankakee [3]		Conformably over Elwood [3]	Unconformably overlies the Brainard [3]	Conformably over Fort Atkinson [3]		Conformably over Scales [3]	Unconformably over the Galena Group [3]

1 = Geotechnical Properties of Sected Pleistocene, Silurian, and Ordovician Deposits of Northeastern Illinois
2 = Notes from Bob Bauer, U.S. Silica Company Mine - Ottawa, Illinois - 100th year of operation
3 = Sandwich Fault Zone of Northern Illinois

Geology of Northern Illinios For VLHC Study

	Galena			Platteville	Ancell		Prairie du Chien	Sandwich Fault Zone	Des Plains Disturbance
	Wise Lake	Dunleith	Guttenberg		Glenwood	St. Peter			
Thickness	0 to 140 (ft)	0 to 125 (ft)	0 to 15 (ft)	0 to 145 (ft)	0 to 75 (ft)	150 to 250 (ft)	0 to 400 (ft)	Up to 800 feet of vertival displacement	Displacements as much as 600 feet
Composition	Dolomite	Cherty dolomite	Dolomite with interbedded shale	Dolomite	Sandy dolomitic shale	Sandstone	Cherty Dolomite, sandstone, siltstone, shale	Pleistocene sediments overlie the fault	Displacement of Missippian and Pensylvania member carried down 600 feet
Color	Light brown	Brown	Reddish brown	Gray to Brown	Gray	White	White to light gray	N/A	N/A
Characteristics	Slightly vuggy dolomite with thin shaley laminae	Medium grain vuggy dolomite upper 5 to 10 feet normally cherty	Pure dolomite separated by reddish brown shale	Folssiliferous to pure dolomite separated with shaley laminae	Sandstone interbeddeded with shale and silty dolomite	Friable sandstone	Cherty dolomite interbedded with slightly dolomitic sandstone and shale	High angle faults having displacements of a inches to several hundred feet	Disturbance covers 25 square miles that contains numerious high angle faults
Core Recovery (%) [1]	100 (average from 2 boreholes)			No Information	No Information	No Information	No Information	No Information	No Information
RQD (%) [1]	93 (average from 2 boreholes)			No Information	No Information	No Information	No Information	No Information	No Information
Q Rating [1]	41.8	41.8		41.8					
Jointing									
Depth Below Bedrock for First Core Run [1]	0.4 (average from 2 boreholes)			No Information	No Information	No Information	No Information	N/A	N/A
Fracture Frequency (no / 10 ft) [1]	7 (average from 2 boreholes)			No Information	No Information	No Information	No Information	N/A	N/A
Hardness (Tarkoy - Hendron Scale)	Soft (30.7 - 36.2)	Soft (32.28)	No Information	Soft (37.2)	No Information	No Information	No Information	N/A	N/A
Uniaxial Compressive Strength (psi)	10,000 to 20,000			10,000 to 20,000	No Information	No Information	No Information	N/A	N/A
Young's Modulus (psi)	2.5x10^{6} to 11x10^{6}			3x10^{6} to 15x10^{6}	No Information	9.9X10^{5} (dry)[2]	No Information	N/A	N/A
Muck Value	Aggregate	Aggregate	No Value	Aggregate	No Value	Fill	No Value	N/A	N/A
Average Field Wave Velocity (ft/sec)	17,535	16,645	No Information	17,284	No Information	No Information	No Information	N/A	N/A
Hydrogeologic Unit [1]	Upper Ordovician aquitard			Upper Ordovician aquitard	Midwest sandstone aquifer		No Information	N/A	N/A
Relative Permeability (cm/sec) [1]	1x10^{-5} to 1x10^{-6} Low			1x10^{-5} to 1x10^{-6} Low	3x10^{-3} Moderate		No Information	N/A	N/A
Water Yielding Characteristics [1]	Small to moderate supply where fractured and overlain by Maquoketa			Same as Galena	Moderate Supply		Small to moderate, Larger further south	N/A	N/A
Thickness Orrientation	No Information	No Information	No Information	Thickens Southward [3]	Decreases from Northwest to Southeast [3]		No Information	N/A	N/A
Contact Information	No Information	No Information	No Information	No Information	Unconformably over Prairie du Chien [3]		No Information	N/A	N/A

Appendix D
TBM Tunnel Assumptions and Cost Estimating Output