The submitted manuscript has been authored by a contractor of the U. S. Government under contract No. W-31-109-ENG-38. Accordingly, the U. S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U. S. Government purposes.

ANL-HEP-PR-85-09
February 1985

PRELIMINARY STUDY OF AN SSC SITE DEEP UNDERGROUND, LINKING ARGONNE AND FERMILAB

TABLE OF CONTENTS

		Page
Summary		1
1.	**SSC Physics**	10
1.1	Accelerators and the Structure of Matter	10
1.2	The "Standard Picture" of Particle Interactions	12
1.3	The Need for Higher Energies	15
1.4	The Accelerator Parameters Required	15
2.	**Description of the Facility**	19
2.1	Accelerator Parameters and Facility Design	19
2.2	Tunnel	20
2.3	Interaction Regions/Experimental Facilities	24
3.	**Geology, Siting and Construction**	29
3.1	Geotechnical Evaluation	29
3.2	SSC Main Ring Facility and Design Construction	77
3.3	Construction Time Schedule	90
3.4	Manpower Requirements	92
3.5	Cost Estimates	92
3.6	Health and Safety	99
4.	**Environmental Evaluation**	104
4.1	Radiological Issues	104
4.2	Environmental Aspects of Surface Disruption	113
4.3	Socioeconomics and Land Use	127

SUMMARY

Brief History of the SSC Project

In July 1983 the High Energy Physics Advisory Panel (HEPAP) recommended the immediate initiation of R&D on the Superconducting Super Collider (SSC), a high-luminosity proton-proton collider of energy in the 20-TeV range. This accelerator would open vast new energy frontiers for basic science and would enable this country to be in the forefront of high energy physics research during the 1990's and beyond. Some aspects of the project have been described in a Science magazine article.[1]

An intensive four-month effort, the SSC Reference Designs Study (RDS),[2] took place this past winter and spring. This study confirmed that the SSC should be technically straightforward to build and that the basic design principles used successfully for existing, lower energy accelerators could be conservatively extended to this machine. The RDS included detailed cost estimates for the SSC based on three different superconducting magnet designs; including contingency allowances, the estimates ranged from $2.70 to $3.05 billion (FY84 dollars). In order to make these cost estimates, the RDS took a fictitious "median site" for which a variety of tunnel construction methods were required.

Plans for R&D leading to the SSC have been presented to Congress by Alvin Trivelpiece (Director of the DOE Office of Energy Research) and Phase 1A, which has the primary aim of determining the magnet style to be used, has recently been approved. This phase will also further refine the accelerator design and establish preliminary site criteria.

It is hoped that the final site selection for this facility can be made early in 1987 and that the notice to proceed with actual construction will be given around October 1987. In order for site selection to be made on this time scale, detailed site proposals will probably be required by late 1985. Site studies in varying detail have already been made in several states by local enthusiasts, and some of these have been compiled in a "Site Atlas".[3]

Purpose of this Study

Considerable thought[4] has been given to siting the SSC near Fermilab because of the accelerator facilities there, which could serve as the injector system for the SSC, saving perhaps $0.5 billion.[5] Most of this effort has been directed at locating the SSC west of Fermilab primarily because of the lower population density. Using technology developed by the mining and tunneling industry, it seems possible, and even advantageous, to locate the SSC several hundred feet underground. At these depths, the safety and environmental concerns associated with population density can easily be satisfied without significantly increasing the cost, or compromising the design.

Because of this, it is natural to consider whether it might not be feasible to bring the SSC ring to the east from Fermilab, passing it under the Argonne National Laboratory site to take the fullest advantage of the facilities available at the two laboratories. This would also be more attractive to both the workers and users of the SSC since it would be closer to housing, schools, the cultural activities of the metropolitan area, and O'Hare airport. The large nearby labor market would be an important asset on which the Laboratory could draw while at the same time providing opportunities for spouses of technical staff. Being closer to the large number of suppliers, scientific and otherwise, in the Chicago area would also be beneficial. The facility would gain from the scientific environment and resources of the two laboratories, including libraries, shops, high bay assembly areas, utilities, etc. These resources would be instrumental in launching the project in a rapid and expeditious manner.

Such an underground site in populated areas follows precedents set by other large accelerators. The SPS and LEP at CERN, near Geneva, Switzerland, are located below farming and residential areas; HERA in Hamburg, Germany, is located only 10-20 meters below ground in a suburban area.

The goals of this study were to make preliminary surveys of the safety, legal, social, environmental, geological, and cost aspects of such a siting scheme. While the same issues must also be addressed for the site to the west of Fermilab, the high population density in parts of the site considered here accentuate the potential safety, legal, social, and environmental issues.

Participants in the Study

The present study was done primarily in July and August by members of the HEP, ER, and EES Divisions; participating individuals include:

HEP	ER	EES
K. Coover	J. Hoffecker	D. Hambley
R. Diebold	J. Jastrow	W. Harrison
J. Norem	R. Olsen	M. Heydari*
M. Barbier*	B. Payne	P. Braam*
	R. Tobin	
	R. Vocke	
	J. Wang	
	G. Williams	

*Consultant

Final editing was done by J. Norem and R. Diebold. This study was supported by K. Kliewer, Argonne Associate Laboratory Director for Physical Research. It has benefitted greatly from the cooperation of many individuals at Fermilab, including L. Lederman, P. Livdahl, J. Lach, L. Coulson, P. Limon, T. Toohig, and others.

Description of the Proposed Facility and Site

To proceed with the study of the issues listed above, the location and other important parameters of the facility were first established. To do this, we started with the work of the Reference Designs Study[2], making modifications as needed.

A number of options for the accelerator location are possible, depending on the radius of arcs, degree of clustering of experimental areas and location and design of utility straight sections. Accelerator physics considerations favor symmetric placement of accelerator components, but the degree of symmetry required for the SSC is still under study. Rings joining Argonne and Fermilab would be symmetric around two, three, or more axes, with a range of arc radii possible (Fig. 1). For the present study, two-fold symmetry with two experimental clusters has been assumed, with cluster geometry as suggested by the PSSC Study.[6]

Injection in both directions was assumed at Fermilab, via injection lines taking the 1-TeV beam from the Tevatron. Extraction lines to remove beam from the SSC were also assumed to be located at Fermilab. The "utility straight sections" in the SSC needed to accomplish this were taken from the Reference Designs Study.[2] Together with the three experimental regions located at Fermilab, this results in a section of the SSC six miles (10 km) long with relatively little bend (11°). At each end of this region, curved tunnel arcs carry the beam around to Argonne where a second set of experimental regions would be located. The fixed location of the two laboratories restricts the radius of the arcs somewhat. For this study, we took the intermediate arc

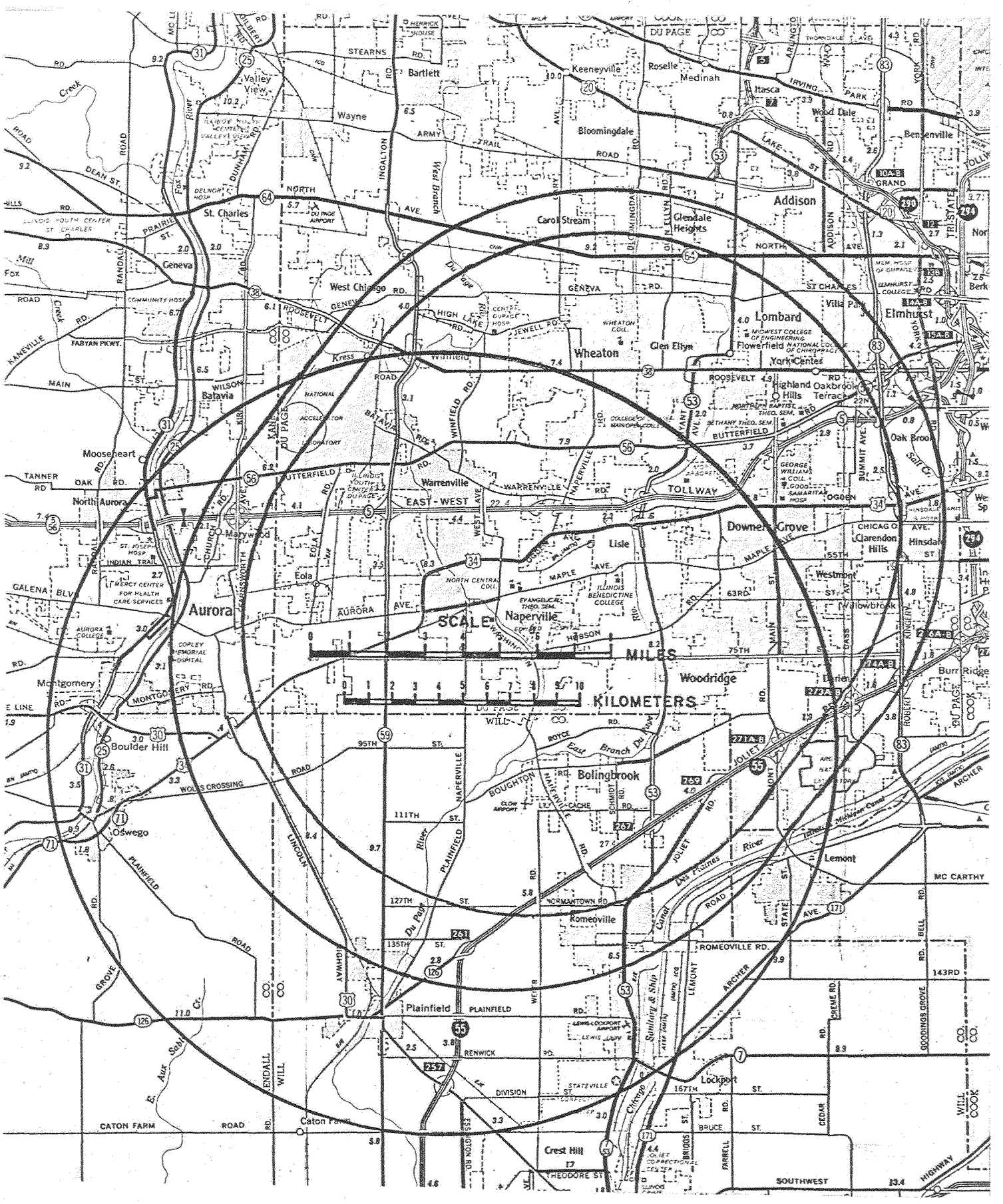


Fig. 1. Some site examples for the SSC between Fermilab and Argonne.

radius of Fig. 1 (about 8.7 miles, 13.95 km); this gives a total circumference of 64 miles (102.3 km). For 20-TeV beam energy, a magnetic field of about 5.75 Tesla is then required (assuming the RDS-A arc packing fraction of 83%), midway between the fields of options A and B of the RDS. The magnet of either of these options might be used for this site; the magnet A field could be reduced (or a higher final energy achieved) or, alternatively, magnet B might be extended to a higher field.

The geology of the site is discussed in Section 3 and summarized in Fig. 3.22. The glacial drift near the surface is too shallow to serve as host for the SSC tunnel in such a highly populated area. The next formation in depth, Silurian dolomite limestone, is thin in places and serves as aquifier for a large number of domestic wells in the area. Below this, the Maquoketa formation is quite variable, with layers of both dolomite and shale. The layers of shale make tunneling more difficult in this formation. These layers do serve, however, as an impermeable layer separating the upper aquifier system from that below. Combined with extensive pumping from the lower aquifier system, this has left the underlying Galena-Platteville formation largely above the water table (piezometric surface).

The Galena-Platteville dolomite limestone appears to be an excellent host for the SSC. It has a uniform thickness in this region, about 325 feet, thick enough to contain 100-foot high experimental areas and still leave a similar thickness of good rock to provide a strong roof. The rock is strong enough to be self-supporting, yet soft enough to be easily mined with tunnel boring machines. This formation is in a plane with a slope of about 1/4% (much less than the 1.4% slope of LEP). The tunnel shown in Fig. 3.22 is at an average depth of 600 feet underground.

Access and maintenance would be through shafts situated at about 5.3-mile intervals. Refrigeration stations, located at these shafts, would be the primary service points for the accelerator. The tunnel would be constructed using tunnel boring machines (TBM's), very similar to those used for the Chicago Tunnel and Reservoir Project (TARP), which has thus far drilled about 50 miles of tunnels 100-200 ft below the surface. The vast amount of experience obtained on this project would be relevant as the Silurian dolomite formation used for TARP is quite similar to that considered here.

Access shaft diameters of 22 feet were determined by the constraints imposed by the handling of the TBM's, tunnel spoil, and the large cryogenic tanks associated with the refrigeration system. Shafts would likely be excavated by conventional drill and blast techniques.

Tunnel costs were examined for diameters of 10, 12 and 15 feet. A diameter of about 12 feet appears optimal; it is only slightly more expensive than the 10-foot case, but provides significantly more flexibility for construction, installation, operation, and eventual additions.[7] The tunnel would be unlined; the shafts and all ancillary caverns and cavities would be lined.

Interaction regions would be located in two clusters on opposite sides of the ring. The general-purpose 4π detectors discussed at the recent Snowmass Workshop[8] would require large caverns underground to accommodate the detectors, maintenance areas and counting rooms. We have assumed that these caverns would be similar to those planned for deep underground at LEP, but somewhat larger. Access shafts to the interaction regions would have 28-foot inside diameter.

It was felt that a consistent, simple, first iteration was the most desirable goal for this study. We have not presented alternatives in any detail (although in many cases they have been developed) or tried to optimize costs. In order to test the ultimate suitability of the site, however, we have examined the most demanding requirements that we thought were appropriate. For example, for the environmental analysis we assumed the cryogenic compressor stations would be located in 5-acre areas on the surface; the cost analysis, however, was done assuming these compressor facilities to be located in mined caverns underground. Likewise we have looked at the overall stability of very large IR caverns (100' × 100' × 250') in order to examine those factors that limit the size of these caverns.

Environmental and Safety Issues

The proposed siting would bring a major scientific facility to a highly populated area, with both potential benefits and costs. A primary concern is the proximity of the accelerator tunnel to residential areas, accentuating the safety and environmental requirements of the facility. Safety considerations were examined with the assumption that the population must not be exposed to any significant risk due to the operation of the accelerator. In practice, this meant that the radiation generated by the SSC and absorbed by the general population would be at a level undetectable by standard means.

A preliminary analysis of safety issues, both for workers and the public, indicates that the site deep underground should be safe under normal operation, accident conditions, and possible upgrades. The depth of the tunnel and wide spacing of access shafts effectively isolate the accelerator from the general public without imposing significant hazards on the workers who construct and operate the facility.

The preliminary study of the facility shows that the location deep underground is safe from a radiological point of view. The general population will not be exposed to any detectable direct radiation passing through the 400-750 feet of shielding. The total activity produced by the accelerator is not large, and the pathways by which this material would come into contact with the general population are either subject to simple, inexpensive, and direct controls, or are sufficiently indirect and slow that little activated material could be released, and even this would be well diluted (and/or have largely decayed) before reaching the general population. Normal handling and monitoring of activated components or materials would take place in the facilities at the two national laboratories, which have been safely carrying out such functions for years.

The mining operation itself utilizes mature technologies with an outstanding safety record. Environmental issues associated with the mining operation have been addressed. For example, disposition of the excavated 4.2 Myd^3 rock and overburden is expedited by the many quarries presently being operated in this area. The mining operation would not significantly alter the volume of traffic in the area, and the permanent facilities outside the laboratory boundaries will be inconspicuous. Disruption of the surface would be minimal.

Given the minimal surface disruption, land need only be purchased at the 10 refrigeration/access sites outside the national laboratories. The remainder of the ring will need easements, however, from local property owners. Acquisition of the required land and underground easements will be more complex than at a site with fewer owners, and careful attention must be given to cooperating with the nearby population to resolve any problems, real or perceived. The land and easement acquisition process itself would probably proceed in a manner similar to the Chicago deep tunnel project (TARP). A total of about 50 acres of land will need to be purchased for the ten surface facilities; possible locations for these facilities have been considered which require minimal changes in zoning and land use.

Advantages of Locating the SSC in the Chicago Metropolitan Area

The proposed site has many technical advantages relative to locations which have been proposed elsewhere.[3] The geology of northern Illinois is highly favorable for the SSC; local rock strata are roughly horizontal and composed of rock with good structural integrity for tunneling and cavern excavations. The area is geologically inactive. The Galena-Platteville formation in the site region is composed of relatively homogeneous layers of dolomite limestone. Although the Galena-Platteville strata extend both east

and west of Fermilab, the environment to the east may be somewhat more favorable for tunneling due to reduced quantity and pressure of underground water. Extensive tunneling experience developed during the construction of TARP in similar material is directly applicable to the proposed SSC siting. The rock can support the long spans required by the interaction halls, yet is soft enough that it can be tunneled easily without high cutter wear. In addition, the tunnels in this formation should not require continuous concrete or shotcrete linings, either for stability or control of seepage.

The advantages of using the Fermilab Tevatron as an SSC injector are considerable, for both scientific and cost reasons. The Tevatron already exists and will, in the near future, be capable of accelerating both protons and antiprotons to 1 TeV, the energy assumed in the RDS for the SSC injector. In addition, the support personnel, buildings, experimental facilities, test facilities, and site already exist.

Use of the Argonne site amplifies many of the same benefits. Using Argonne as the location of one of the experimental clusters eliminates the need for a new satellite laboratory, and permits the rapid development of an experimental program fully supplied with all required mechanical, shop, library, housing, and other utilities and support services. As mentioned above, monitoring and handling of activated materials will be greatly facilitated by the use of the two laboratories on opposite sides of the ring.

As discussed in the introduction, siting the facility near Chicago has many significant advantages - central location; nearby airport, universities, housing, labor market, supplies, etc. Further, being in a populated area will avoid the boom town/high-tech ghetto syndrome which would be experienced at an isolated site.

While siting the SSC in the Chicago area has benefits to the scientific community, there are also benefits to the metropolitan area and to the region as a whole. The midwestern states are presently among the lowest in the fraction of federal revenue returned to the states. Federal expenditures in the aerospace, defense and computer industries, which would tend to stimulate developing technologies, are low. The Great Lakes area has the lowest growth rate of any part of the country.[9] The SSC would bring direct economic benefits from the initial construction along with substantial and indirect benefits to local communities due to increased economic activity. The primary benefit to the community will be associated with the employment of a staff of about 2500 people, plus about 500 visiting scientists at any given time. These employees and visitors will add significantly to the vitality of communities within commuting distance. An economic multiplier applies which will generate additional service jobs (roughly comparable to the number of on

site employees). Perhaps most importantly, there will be the further attraction and expansion of high-tech industries in the Chicago area.

Cost and Schedule Estimates

Detailed costs and schedules have been developed in Section 3. These estimates show that the tunnel, interaction halls, and associated facilities would cost roughly $500M (1984 dollars) and require about five years before civil construction was complete (beneficial occupancy of half the tunnel would be available after about three years). While detailed comparisons with other estimates are difficult, these costs per kilometer are somewhat lower than those for the RDS median site, the CERN LEP tunnel, or the HERA facility, primarily due to the suitability of the local rock strata combined with the simplicity of excavating unlined tunnels using tunnel boring machines. Cost estimates presented here are based on the extensive local experience with TARP and, more generally, with conventional mining techniques.

Conclusions

The short time period of the study (a few months) has allowed only a cursory survey of many important topics. Virtually all the topics covered would benefit from more detailed analysis. Nevertheless, the important conclusions of this preliminary study are:

- The Argonne/Fermilab site for the SSC is desirable from geotechnical and civil engineering perspectives.
- The facility can be constructed, operated, and eventually decommissioned safely, with no significant risk to workers or to the general population.
- Land and easements should be available without significantly inconveniencing either the SSC program or the general public.
- Significant benefits should accrue to local communities due to economic development stimulated by construction and operation of the facility.
- Costs are competitive with the "median site" in the Reference Designs Study.
- Further development of this SSC option would depend on working with public officials, planners, and the public in an interactive planning process.

References

1. "The Desertron: Colliding Beams at 20 TeV," R. Diebold, Science 222, 13 (1983).

2. "Superconducting Super Collider," M. Tigner et al., Reference Designs Study for U. S. Department of Energy (May 8, 1984).

3. "Second Edition of the Site Atlas for the Superconducting Super Collider," R. Slansky, LASL Report LA-UR-84-3893 (1984).

4. "Tunneling Beyond the Fermilab Site," S. Baker, A. Elwyn, J. Lach, A. Read, Fermilab Report TM-1218 (1983); Preliminary Draft Report, "The 20 TeV Accelerator in Illinois: A Preliminary Geological Feasibility Study," J. P. Kempton, et al., Illinois State Geological Survey, Champaign, IL 60820, April 1984.

5. "Conventional 20-TeV, 10-Tesla $p^{\pm}$ Colliders," R. Diebold et al., Proc. 1982 Snowmass Study, p. 307; "Cost Estimate for a National $\bar{p}p$-SSC Located at Fermilab," A. Ruggiero, Proc. 1984 Snowmass Study.

6. "Report of the Interaction Region Group," R. Diebold, Physics at the Superconducting Super Collider Summary Report, P. Hale and B. Winstein, Eds. (Fermilab, 1984).

7. It is interesting to note that the original design for the HERA machine at DESY called for a 5-m (16.4 feet) diameter tunnel in the straight sections and 3.2 m (10.5 feet) in the arcs, but it was found to be cheaper to construct the entire tunnel with the 5-m diameter.

8. "4π Detectors," G. J. Feldman, M. D. G. Gilchriese, and J. Kirkby, Proc. 1984 Snowmass Study.

9. Time Magazine, p. 54, June 25, 1984.

1. SSC PHYSICS

1.1. ACCELERATORS AND THE STRUCTURE OF MATTER

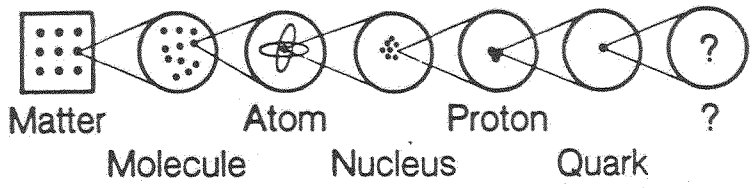
During the past 50 years, our basic understanding of the properties of matter has depended on the construction of particle accelerators of ever increasing energy. Figure 1.1(a) shows constituents of matter as presently understood, and Fig. 1(b) shows the energy range required to study these constituents plotted as a function of accelerator type and year. Each accelerator has contributed to scientific progress, however, the most productive devices at any given time were generally those with the highest available energy. These opened up new fields and explored new phenomena.

Before the use of accelerators, matter was assumed to be composed of electrons and nuclei (composed of protons and neutrons). When cyclotrons and electrostatic accelerators were developed in the 1930's and 40's, experiments began to reveal some of the properties of nuclei, enabling a better understanding of nuclear interactions. Direct applications of this work were immediately made in astrophysics, where a study of the cross sections of stable and excited nuclei was used to understand the mechanism by which stars burn. The way in which the heavy nuclei, which we see (and are composed of), were produced from protons and neutrons of the primordial universe, also followed from detailed study of nuclear interactions.

As accelerator energies increased, structure within the proton began to be revealed. Experiments at high energy synchrocyclotrons and synchrotrons in the 1950's began to show that instead of just a proton and a neutron, there seemed to be large numbers of proton-like objects, with heavier masses and different charge, which seemed to imply that protons were composite particles as are nuclei. Just as Be^{12}, B^{12}, C^{12}, and N^{12} can be obtained from switching neutrons to protons within nuclei, other particles could presumably be made from protons by switching around constituent subparticles. In addition to these discoveries, particles which seemed to help hold nuclei together (pions) were found as well as particles which seemed to have no purpose whatever (muons).

As higher energies became available in the 1960's and 70's, accelerators began to reveal more of the complexity of the nucleon interactions and theoretical understanding as this subject progressed. Protons began to be understood as composite structures composed of stable particles (called quarks by Zweig and Gell-Mann, who first suggested them) and the properties of quarks themselves began to be understood, both in terms of

Successive Levels in the Structure of Matter



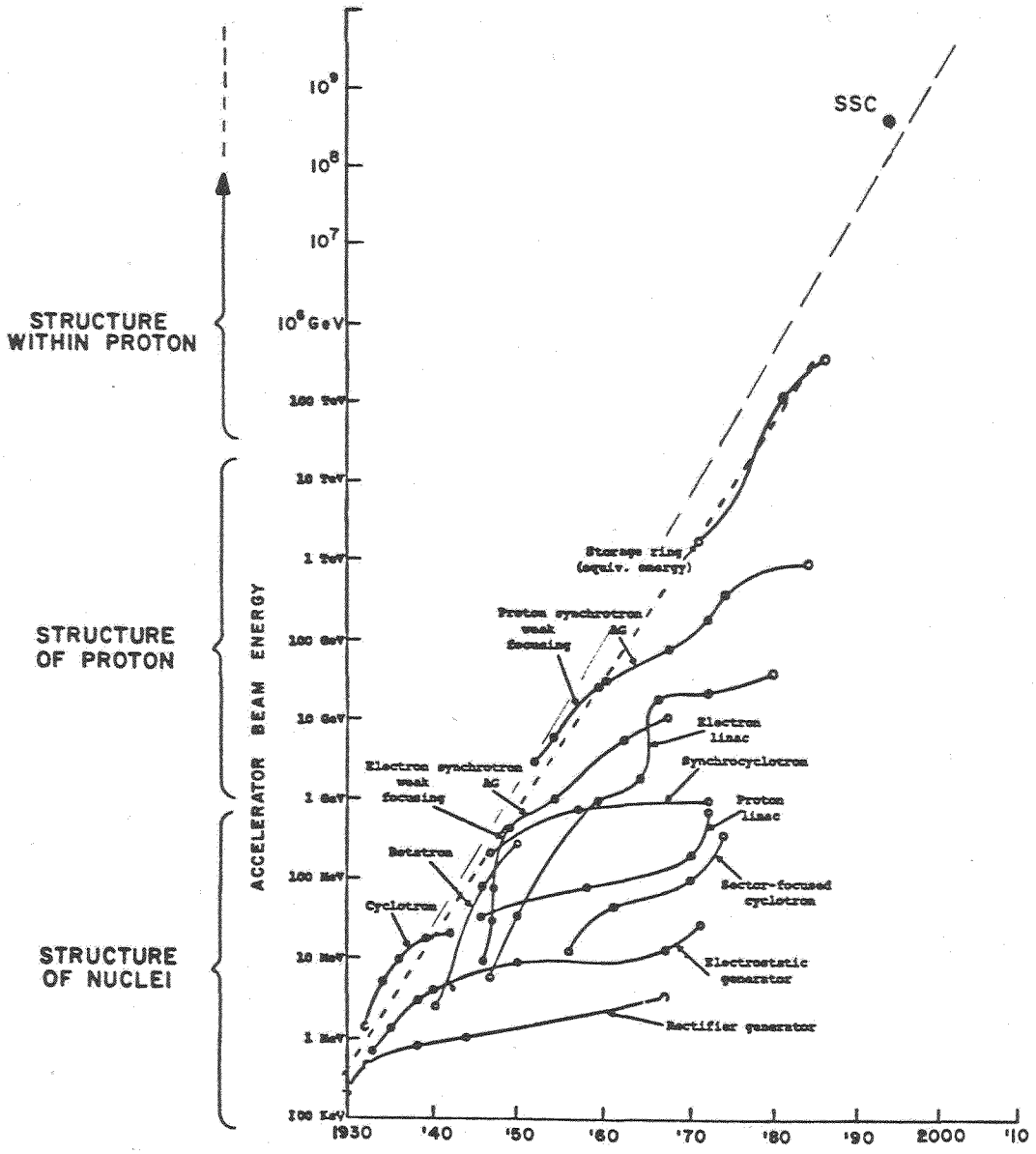


Fig. 1.1 Understanding the structure of matter depends on the energy available at accelerators.

the stable particles produced when they bind themselves together and the final states produced in high energy interactions. Recent understanding of high energy physics has had immediate application in cosmology, specifically our understanding of the big bang from which our universe ultimately evolved. Experimental data from accelerator laboratories have led to the understanding of such diverse topics as why there seems to be so little antimatter in the universe and why electromagnetic radiation from the big bang is still present.

The next step in this search is to look at even higher energies, both to test our understanding of the "Standard Picture" and to probe for new phenomena which can only be seen at higher energies.

1.2 THE "STANDARD PICTURE" OF PARTICLE INTERACTIONS

During the past 20 years, our understanding of the structure of matter has increased profoundly. Experimental discoveries and theoretical advances have produced a model of considerable simplicity and elegance. The model, called the "Standard Picture," assumes that all matter is composed of two types of particles, called quarks and leptons, Fig. 1.2(a), which interact with one another through four forces (strong, electromagnetic, weak, and gravity), Fig. 1.2(b). The quarks combine in threes to form protons and neutrons (as well as an enormous number of similar particles), and the electron is the commonest form of lepton.

Twenty years ago, the four forces were thought to be completely independent. Recent experimental data from CERN and elsewhere, however, have verified the detailed predictions of the theory of Glashow, Weinberg and Salam, which treats the electromagnetic and weak forces as different aspects of the same phenomena. This unified theory predicted the weak neutral currents discovered in the early 1970's and the recent discovery and detailed properties of the W and Z bosons, which are carriers of the weak force. The existence of the W had been suspected since the 1930's, when it was originally postulated by Fermi to explain radioactive decay of nuclei.

While the electroweak theory produces a number of precise predictions, the theory of strong interactions is less advanced. The understanding of the interactions of strongly interacting particles now parallels the electroweak theory and is called quantum chromodynamics (QCD). The theory assumes that particles such as protons are composed of quarks held together by gluons as indicated in Fig. 1.3.

Experimental data produced at the highest available energies have confirmed much of the Standard Picture only very recently. The W and Z

Constituents in the Standard Picture

Quarks		Leptons	
u	Up	e	Electron
d	Down	ν_e	Electron neutrino
c	Charm	μ	Muon
s	Strange	ν_μ	Muon neutrino
t ?	Top	τ	Tau lepton
b	Bottom	ν_τ ?	Tau neutrino

Elementary Particle Interactions

Force	Physical Phenomena	Relative Strength	Effective Range	Carriers of Force	Other Particles	Proposed Theory
Strong	nuclear bonds, fission, fusion	1	10^{-13} cm	gluons	quarks	quantum chromodynamics
Electromagnetic	electricity, magnetism, light	10^{-2}	infinite	photon	quarks, charged leptons	quantum electrodynamics ↓ unified electroweak theory ↑
Weak	radioactive decay	10^{-5}	10^{-16} cm	W, Z, Higgs	quarks, leptons	Fermi beta decay theory
Gravity	planetary motion, curved space-time	10^{-38}	infinite	graviton	all particles	Einstein's general relativity

Fig. 1.2 The standard picture explains the structure of matter in terms of quarks, leptons, and the interactions between them.

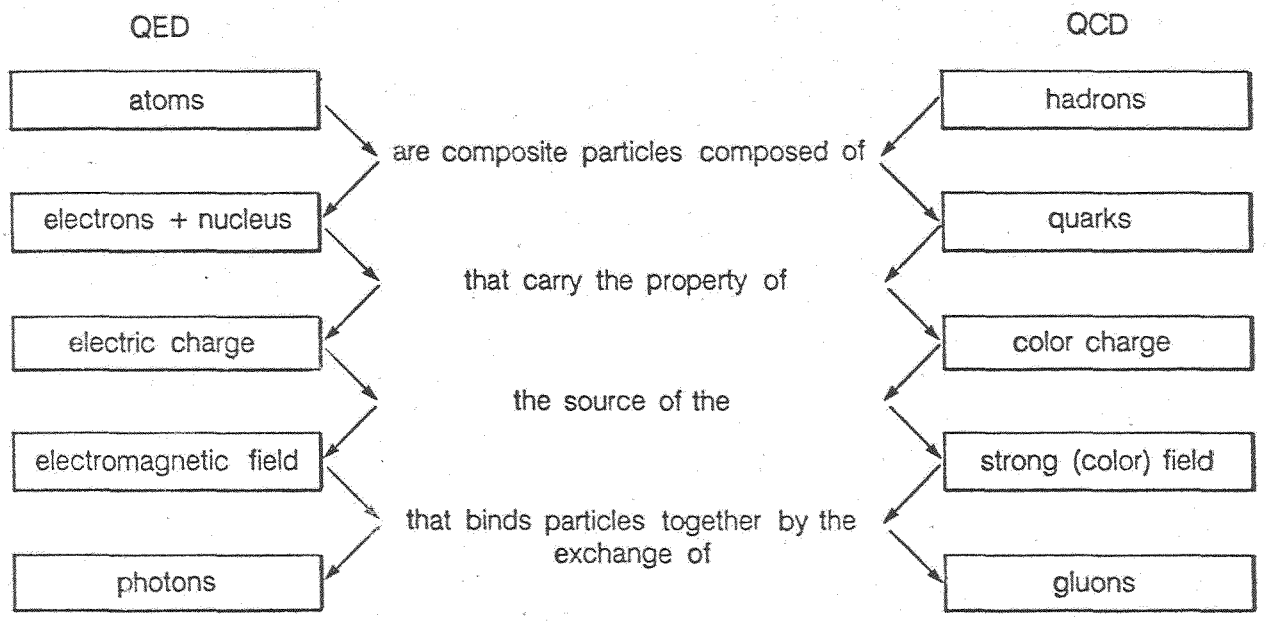


Fig. 1.3 The theory of quantum chromodynamics (QCD) extends insights from quantum electrodynamics (QED), gained from the study of electromagnetic phenomena, to the domain of quarks confined within hadrons.

particles were only seen for the first time within the past two years and experimental evidence for gluons is still being evaluated. Evidence for the top quark was only produced in July 1984.

1.3 THE NEED FOR HIGHER ENERGIES

Despite its impressive recent success in predicting both the existence of new particles and describing the interactions of these particles at high energy, the standard picture is known to be incomplete. There are unexplained phenomena which seem to require new particles. The recently discovered W and Z particles, for example, are bosons (similar to photons) which seem to owe their high mass (about 100 times the proton mass) to broken symmetries which should be associated with particles called Higgs bosons. Though the masses of these Higgs bosons are unknown, recent analysis (Eichten et al., 1984) has shown that either (1) the Higgs boson mass is below 1 TeV or (2) the weak interactions must become strong at TeV energies. In either case, new physics must appear at energies around 1 TeV.

In addition to the Higgs boson, a number of other phenomena require study at higher energies. For example, a large number of arbitrary parameters seem to be required to specify the properties of quarks and leptons. This implies that some simple structure might exist which would be the basis for the observed complexity. Likewise, violation of CP invariance does not arise neatly from the standard picture and could be a manifestation of more basic phenomena. Even the number of quarks and leptons is a mystery, and might be explained by the fact that quarks and leptons themselves are composite particles just as the large variety of nuclei are made up of neutrons and protons. The standard picture implies that if substructure exists, then energies of at least 1 TeV are required to detect it. The reason for and basis of symmetries is also not understood and may be the result of undetected interactions. In addition, a variety of other effects could be seen at threshold energies of around 1 TeV (Fig. 1.4).

1.4 THE ACCELERATOR PARAMETERS REQUIRED

A number of detailed arguments recently summarized most completely by Eichten, Hinchliffe, Lane, and Quigg, have shown that energies of $\geqslant 1$ TeV must be available in the quark-quark center of mass to open up new experimental possibilities. Since each proton consists of three quarks and a gluon cloud, and experimental evidence seems to show that available energy is divided between the quarks and gluons, each quark has typically about one-sixth to one-tenth of the available proton center-of-mass energy. If, to be safe, one wants $\sim$ 2-3 TeV available energy to be above threshold effects, then the

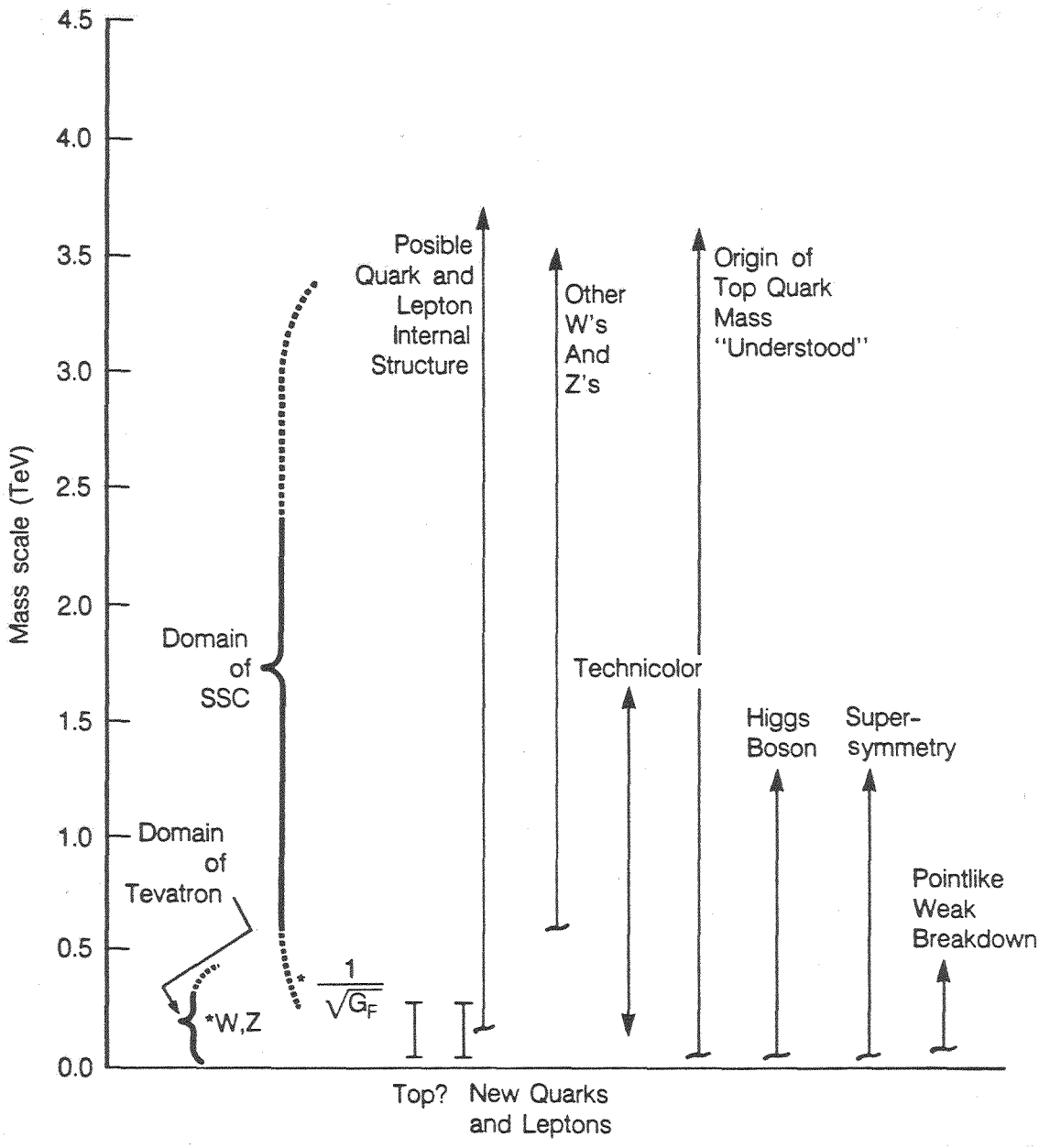


Fig. 1.4 The SSC should be able to study and search for a wide range of phenomena.

accelerator must produce protons at 20 TeV in the center of mass. This can be done by colliding 20-TeV particles together head on, following the example of the Tevatron at Fermilab and the SPS at CERN. This method yields energies comparable to an accelerator of about 10^9 GeV firing protons at a stationary target.

While a pp collider has been the primary focus of the reference design, the use of an antiproton source capable of producing the luminosity specified in the reference designs has been presented in the University of Chicago workshop (Pilcher 1984). Antiprotons might permit some additional experiments to be done, and $\bar{p}p$ acceleration could be done in one magnet ring, perhaps with some cost savings. The Fermilab $\bar{p}$ source might provide sufficient fluxes for initial experiments and could be improved (Ruggiero 1984).

The intensity of the machine should be high. Since many of the interactions of great interest are expected to have small cross sections (probability of occurrence), it is desirable to have as high an event rate as the accelerator and detectors can stand. The luminosity of the SSC, which is proportional to the event rate for a given cross section is expected to be about 1000 times that of the Tevatron now being completed at Fermilab. This will enable the experimenters to accumulate high statistics for commmon events and to examine rare phenomena at the highest possible energies.

Section 1 - References

*Appelquist, T., Gaillard, M. K., and Jackson, J.D., "Physics at the Superconducting Super Collider," Am. Sci. 72, 151 (1984).

*Close, F., "The Cosmic Onion: Quarks and the Nature of the Universe," Heinemann Educational Books, London (1983).

*Gaillard, M. K., "Toward a Unified Picture of Elementary Particle Interactions," Am. Sci. 70, 506 (1984).

Eichten, E., Hinchliffe, I., Lane, K., and Quigg, C., "Supercollider Physics," Fermilab Report FERMILAB-PUB-84/17-T (February 1984), to be published in Rev. Mod. Physics.

Pilcher, J. E. and White, A. R., Editors, "$\bar{p}p$ Options for the Supercollider" Proceedings of a DPF Workshop sponsored by Argonne National Laboratory and the University of Chicago, February 1984.

*Rebbi, C., "The Lattice Theory of Quark Confinement," Sci. Am. 248, 54 (February 1983).

Reference Design Study (RDS), "Report of the Reference Designs Study Group on the Superconducting Supercollider," (May 8, 1984), with appendices.

Ruggiero, A., "A Proton-Antiproton Superconducting Super Collider, Proc. of 1984 Summer Study on the Design and Utilization of the Superconducting Super Collider (Snowmass, July 1984).

---

*These references were written for nonspecialists.

2. DESCRIPTION OF THE FACILITY

The Reference Designs Study, published in May 1984, contains accelerator options using three styles of magnets with fields of 6.5, 5.0, and 3.0 Tesla, producing essentially circular machines with diameters of 29 to 52 km. Since the distance from Argonne to Fermilab is in this range, it seems natural to explore the option of a machine with experimental facilities located at each site in order to make full use of the existing expertise and facilities. Because of the high population density, the machine would be deep underground in order to have minimal impact on the surface.

2.1 ACCELERATOR PARAMETERS AND FACILITY DESIGN

The overall dimensions and orientation of the accelerator are determined by the location of the two laboratories and by accelerator physics constraints. Although one could consider the more general case, we have concentrated on a design with Fermilab and Argonne at opposite ends of a diameter so that the interaction regions (IR's) could be placed symmetrically at the two laboratories.

Machine insertions for the IR's and utility straight section insertions have been sized according to the Reference Designs Study, but it was assumed that 3 IR's would be clustered below the sites of each laboratory with a 48-mrad bending angle and 1.5 km separation between neighboring IR's. Injection would be accomplished in utility straight sections at each end of the Fermilab IR cluster. For symmetry, utility straight sections would be similarly placed on either side of the IR's at Argonne. Since the rf, injection and abort systems do not require all the utility straight section space, these latter straight sections could be used as IR's, as was outlined at the recent Snowmass study. The "4π" detector designs developed at Snowmass were used to size the collisions halls and associated facilities.

Assuming the Tevatron is used as an injector with beams extracted at A0, protons for one of the SSC rings could be extracted using the existing fixed-target beam lines. The second ring could be filled with protons from the Tevatron if the field was reversed or with antiprotons using the existing or an upgraded $\bar{p}$ source. Assuming beams from both directions are extracted from A0, two 3-km injection lines would carry the beam from the Tevatron down to the SSC, roughly 500 feet below the Tevatron.

The exact dimensions and location of the ring then depend on the placement of the experimental facilities at symmetry points at Fermilab and Argonne. The radius of the arcs is roughly 14 km. Assuming that the bending magnets occupy 83% of the arcs (as in the Reference Design), the required field is 5.8 T, halfway between the fields of Options A and B of the RDS.

As discussed in Section 4, locations for the vertical access shafts not on the national laboratory sites were found in areas presently being used for agricultural or industrial uses, such that the shafts would have a minimal effect on surrounding land use. For the specific ring chosen for this study, this could be done in a straightforward way for 8 to 12 refrigeration stations. For three of the locations, the vertical shafts would be offset from the accelerator geometric symmetry points by 1000-2000 feet and then connected to the accelerator tunnel by horizontal access tunnels. The last location has several nearby small parcels available, large enough for the refrigeration station and its shaft, but small enough to make difficult the removal of rock spoil from the tunnel (see Section 3). While these problems can all be handled in a straightforward way, a more detailed study will likely find a more optimal solution by small shifts of the parameters and/or orientation of the accelerator.

In the present study, as in the Reference Design, we have assumed that 12 refrigeration stations would be placed roughly equidistant around the ring. This results in intervals of about 5.3 miles between refrigeration stations. We have assumed that no shafts or connections with the surface would be located between refrigerator access shafts except at the interaction regions.

2.2 TUNNEL

At the beginning of this study, in order to better understand the various tradeoffs, three tunnel diameters were chosen for study: 10, 12 and 15 feet. As the costs turned out to increase only slowly with diameter (Section 3.5), the choice between these sizes is not clear cut. While an operating accelerator does not require much space beyond that occupied by the magnets, the logistics of drilling the tunnel and installing the accelerator make additional space underground highly desirable. (It is interesting to note that the tunnel boring trade regards tunnels of less than 13' diameter as "small tunnels.") At present, the optimal inside diameter of the unlined tunnel appears to be about 12 feet. As suggested by Fig. 2.1, this allows space for the magnet ring, utilities, magnet transporter, drains, and work space for assembly and maintenance.

Locating the plane of the ring in the bottom half of the Galena-Plattville formation (Section 3.1.1) puts the ring at sea level at its lowest point (near Argonne), and at 200 feet above sea level at its highest point (near Fermilab). The resulting gentle slope might complicate the cryogenic system, but solutions have been proposed by Brianti et al. (1984). The slope does have the advantage of making drainage easier.

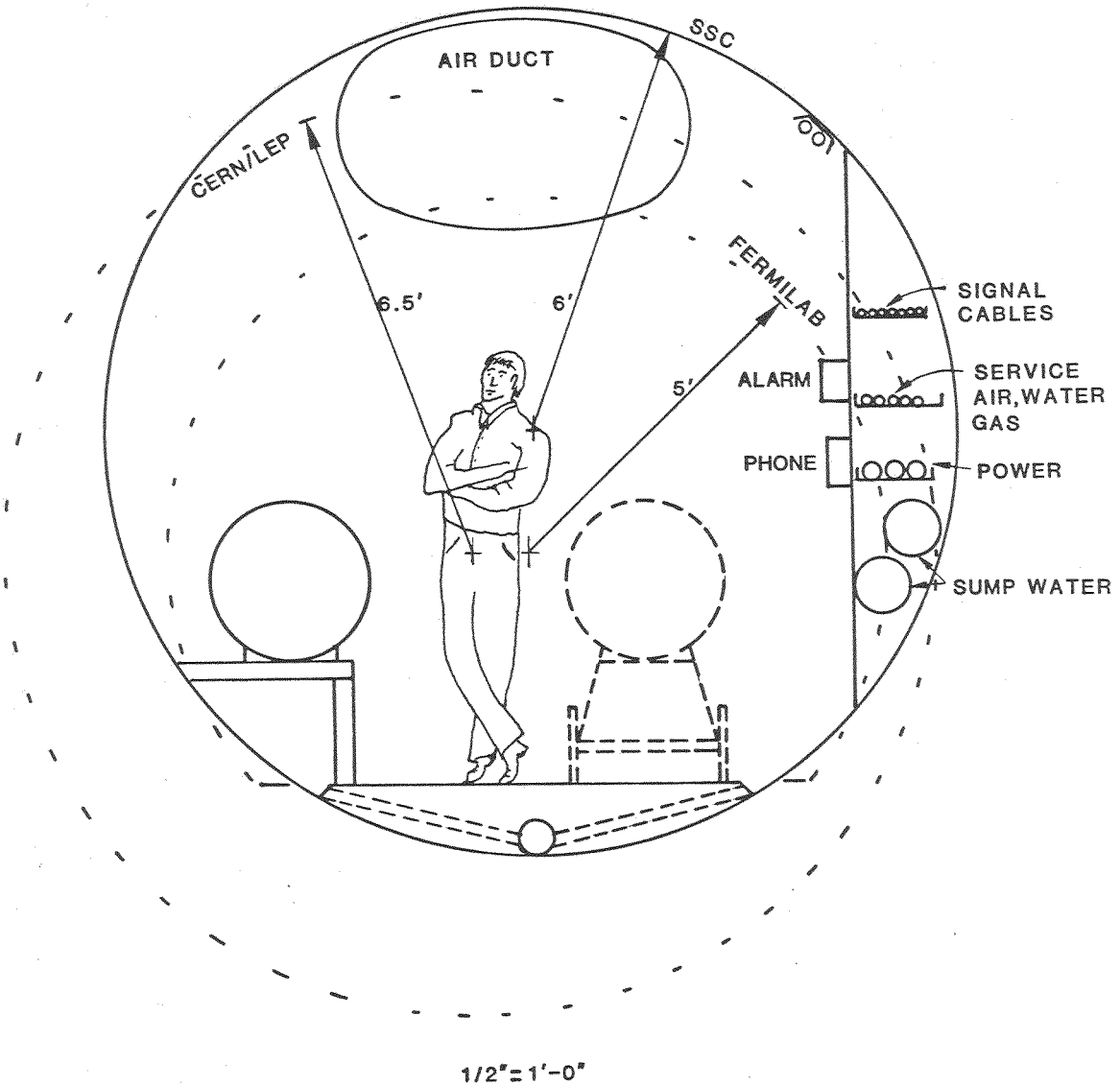


Fig. 2.1 Section of SSC accelerator tunnel; for comparison, tunnel outlines of the Fermilab main ring and of the LEP machine presently under construction) are indicated.

At every other quadrupole (i.e. intervals of ~ 200 m = 660 feet), it seems highly desirable to have an alcove in the tunnel which can be used for electronics to encode control signals such as beam position, quench sensing, trim magnet, etc. onto the local area network. These alcoves only need to be a few cubic feet although space for movable shielding might be desirable. These alcoves are shown in Fig. 2.2(a).

The quench protection system requires a number of dump resistors to be located around the ring. If a system like that proposed in the Reference Design is used, the magnet arcs are divided into 12 separate magnetic circuits, each requiring 4 resistors. Since the total magnetic energy of the ring is roughly (2 MJ/magnet) × (4000 magnets) = 8000 MJ, each resistor should be able to dissipate 8000 MJ/(4 resistors/sector × 12 sectors) = 167 MJ = 38 Mcal. Since the tunnel will contain dependable sources of water at 55°F (13°C), water-cooled discharge resistors with a large ΔT (70°C) temperature swing and small mass are possible. These resistors would be stainless steel tubes in a water bath containing at least 0.6 m^3 of water. A similar design was successfully used for load resistors for the 80-MJ UTSI magnet (UTSI 1984). Resistors must be located at, and midway between, each of the refrigerator stations. In addition, space for switching and control electronics is required. Rooms between refrigeration stations for this use can be excavated by drilling and blasting, Fig. 2.2(b). These rooms could contain other equipment such as cryogenic isolation controls, first-aid, oxygen deficiency hazard equipment, etc., as well as component storage. Since these areas could be used as refuge areas, they could contain a full allotment of safety equipment and should be large enough to accommodate those working in one sector.

The primary underground support facilities will be the cold box and dewars connected to the cryogenic system, which will fit in a volume as shown in Fig. 2.2(c). Additional space has also been provided at these locations for the hoisting and storage of magnets and other components. Quench protection resistors and accelerator diagnostics and controls will also be located there. The spacing of these facilities has been set at about 5.3 mi, however. We have assumed that, if necessary, the compressor and cold box could be as much as a half mile from the ring. Accelerator operation and service would be centered at these access points, thus surface facilities would be provided for ring magnet power supply controls, helium compressors, ventilation equipment, liquid nitrogen storage, shops, control and operations areas.

We have assumed that these underground areas would be shielded and could be occupied during machine operation by placing them on the inside of the arc.

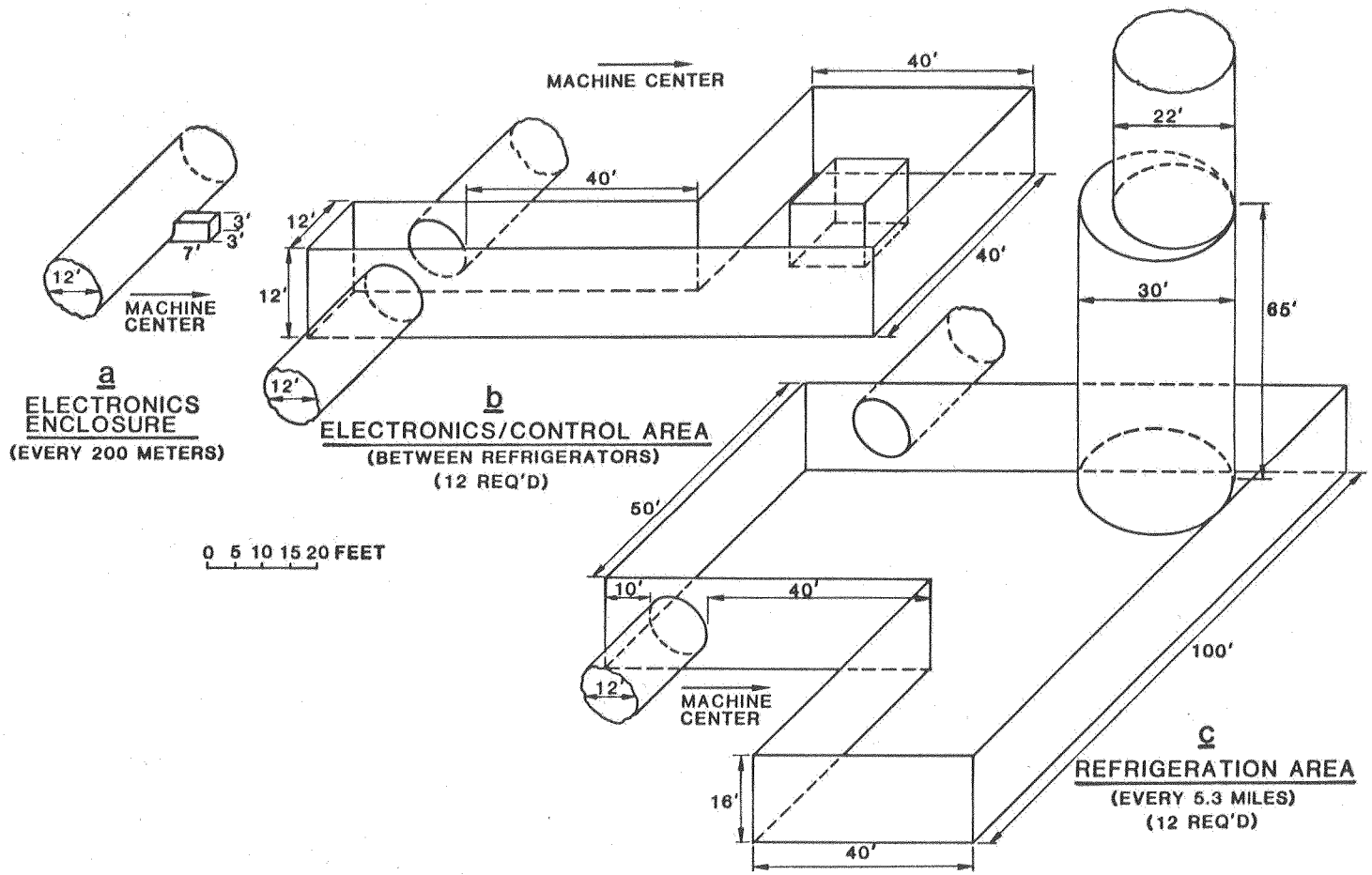


Fig. 2.2 Underground Areas for SSC Facilities

With an underground ring, it will be necessary to collect and pump out any water seepage. For the purpose of this design, we have assumed that this water will be collected, monitored, and pumped at the two laboratories. Although a concrete tunnel liner would reduce seepage considerably, the liner would be expensive (Section 3.5) and probably not 100% effective. Experience with TARP has shown that seepage in 8-12' diameter tunnels in silurian dolomite can be controlled to about 10-30 gal min^{-1} mi^{-1} simply by grouting and local sealing where needed, and the Galena-Platteville should have less water since we are above the piezometric surface (Section 3.1). The total produced in a 70-mile tunnel would then be 700-2100 gal/min or less, easily handled by sump pumps. Backup pumps and electrical generators would, of course, be required as well as some underground storage. If, for example, a 10-foot "crawl space" was provided below the floor of the refrigeration areas and the electronics control areas, the total storage volume in the arcs would be $\sim 1.9 \times 10^6$ ft^3 or 14×10^6 gal, equivalent to 5 days seepage at 2000 gal/min, which is the maximum flow expected. A simple alternative sump area would be the pits dug at each shaft during construction to facilitate the transfer of tunnel spoil from railway cars to hoisting buckets.

The tunnel will have a natural temperature of about 53°F, and a high humidity. Ventilation systems should lower the tunnel humidity and perhaps raise the temperature somewhat. It will be necessary to insure that the injected air is dry enough that the dew point remains well below 50°F. During accelerator operation, we have assumed that normal ventilation of the tunnel would be accomplished by intakes at the midpoints of the arcs and exhausts at the laboratories, allowing constant monitoring of air quality.

During maintenance periods, ventilation will be provided by injecting and exhausting air at alternate refrigeration stations to give a net ventilation rate of

$$\text{air changes/hour} = \frac{\text{velocity of air in tunnel}}{\text{shaft separation}} \sim \frac{10 \text{ mph}}{5 \text{ mi}} \sim 2 \ .$$

Higher ventilation rates at lower velocities could be achieved locally by using ducts which could be left in the tunnel by the construction crew. Supplying all facilities (Fig. 2.2a-c) with connections to outside air via these ducts might be an inexpensive safety precaution. Using ducted air as a second source of ventilation might be desirable during surveying, for example, when a high rate of circulation through the tunnel might be undesirable.

2.3 INTERACTION REGIONS/EXPERIMENTAL FACILITIES

A wide variety of experimental apparatus will be developed for the SSC and some effort has already begun towards defining the requirements for the

larger detectors. The recent Snowmass workshop concluded that the SSC should be provided with two "4π" detectors; three possible designs for these detectors were discussed and their dimensions are summarized in Fig. 2.3. The experimental areas should provide large caverns for the assembly and operation of the detectors, both the 4π detectors and more specialized detectors. These latter detectors are not well defined at this point, and only rough dimensions are available. We have taken a simple design for the interaction region halls. The largest, shown in Fig. 2.4, could contain a large 4π detector and service areas.

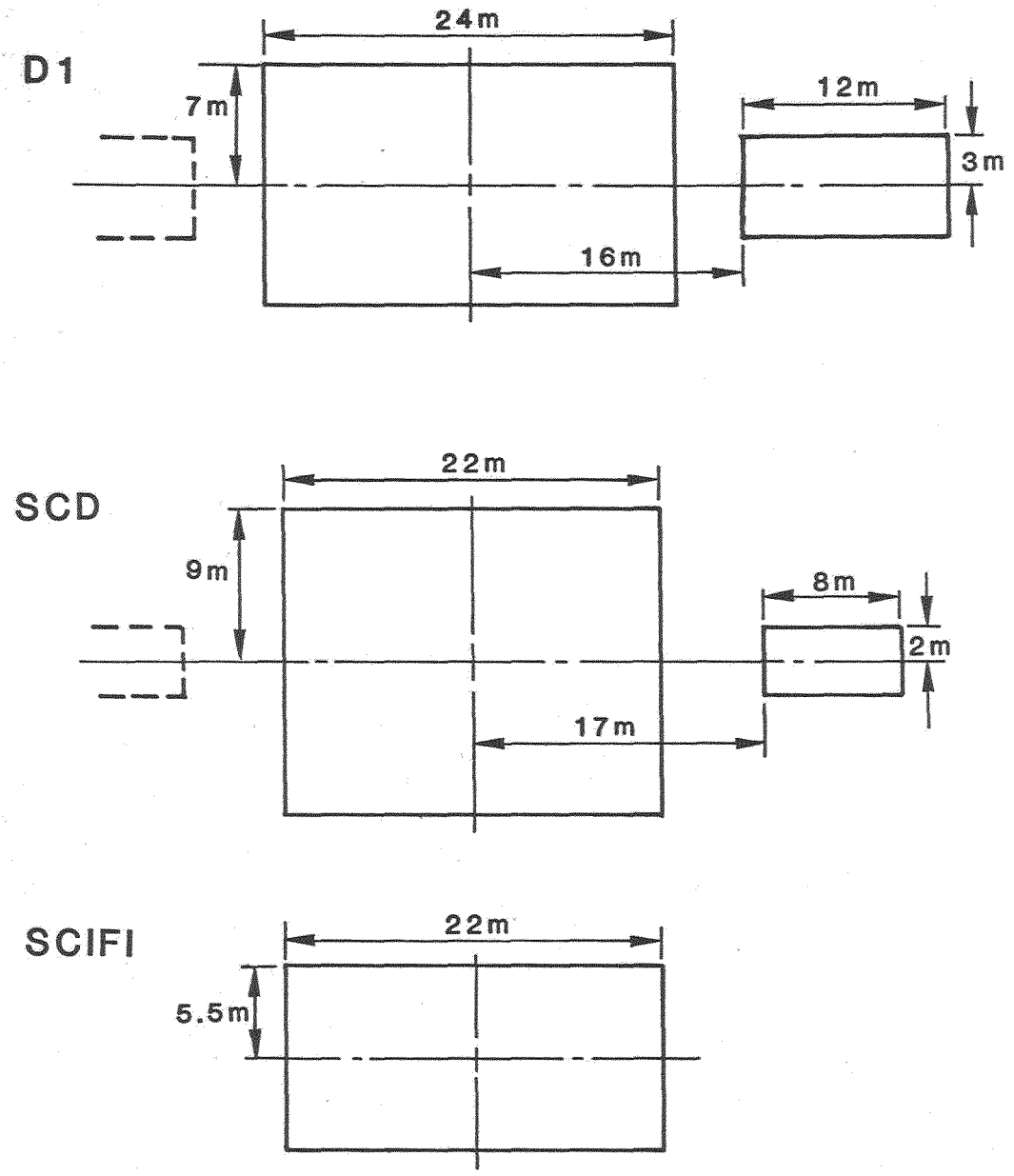


Fig. 2.3 Dimensions of the large 4π detectors studied at Snowmass (a) non-magnetic detector, (b) superconducting conventional detector, (c) scintillating fiber detector.

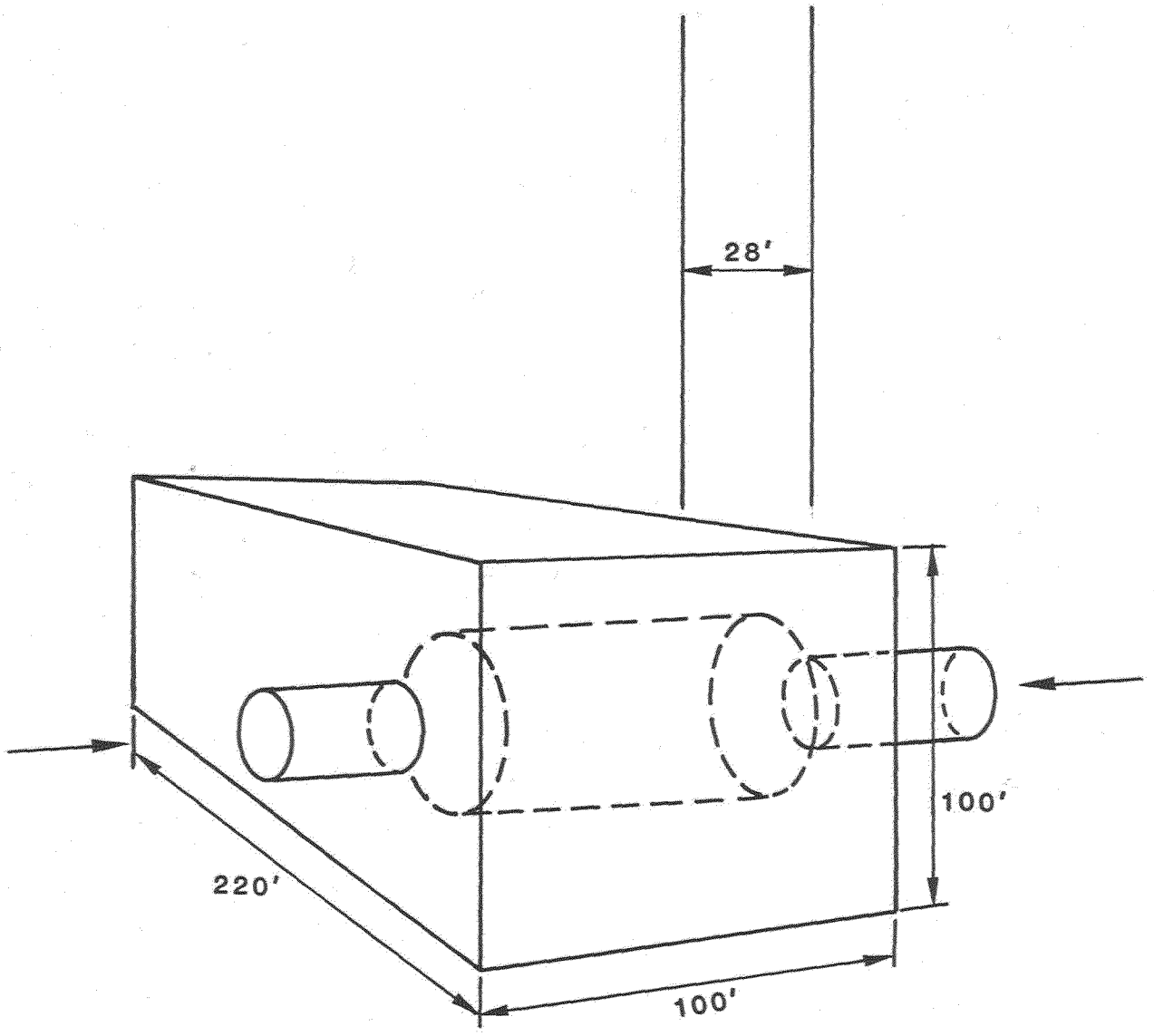


Fig. 2.4 Dimensions of the interaction/assembly halls. The horizontal cylinders schematically indicate a large 4π detector, including the forward/backward elements; the vertical cylinder is the access shaft.

Section 2 - References

Brianti, G., and Hubner, K., "The Large Hadron Collider in the LEP Tunnel," CERN Report DIR-TECH/84-01 (May 1984).

Diebold, R., "Report of the Interaction Region Group" in Physics at the Superconducting Super Collider Summary Report, Hale, P. and Winstein, B., Editors, Fermilab Report (June 1984).

Reference Design Study (RDS), "Report of the Reference Designs Study Group on the Superconducting Super Collider," May 8, 1984 (with appendices).

Snowmass Workshop - 1984, "Proceedings of the 1984 Snowmass Study on the Design and Utilization of the Superconducting Super Collider," to be published.

SSC Fixed Target Workshop, "Proceedings of the SSC Fixed Target Workshop," The Woodlands, TX (January 26-30, 1984).

UTSI "Design, Construction, and Performance Tests of the 6T Superconducting Dipole System for MHD Energy Conversion Research," Argonne Report ANL/MHD-84-2 (1984).

3. GEOLOGY, SITING AND CONSTRUCTION

3.1 GEOTECHNICAL EVALUATION

3.1.1 Regional Geology

This geotechnical evaluation concentrates on an area of about 30 × 30 miles referred to as the "project area" (Fig. 3.1), which includes all of DuPage County and parts of Cook, Will, Kendall, and Kane counties. Maximum relief in the project area is slightly greater than 250 feet, with the highest elevations occurring in the northwestern corner at about 800 feet above mean sea level (MSL). Most of the area is a glaciated plain consisting of pitted and knolled flatlands and low hills, both of which are crossed by the south-trending valleys of the Fox River, the west and east branches of the DuPage River, Salt Creek, and the Des Plaines River. The lake plain on which the city of Chicago is situated extends westward across the eastern boundary of the project area.

Northern Illinois is overlain by glacial material deposited by Pleistocene glaciers that repeatedly covered the area (Fig. 3.2). Between 22,000 and 14,000 years ago, the area was buried at various times under several thousands of feet of ice. The glaciers not only deposited glacial drift (unconsolidated deposits) but also reshaped the land surface. Each glacier flowed west across the project area from the basin that now holds Lake Michigan. The valleys of the various south-trending streams mentioned above were cut by meltwater rivers that flowed along several of the last glacial fronts. These glacial fronts formed successive moraines as the glacier retreated in a northeasterly direction. Although bedrock is exposed along some of the river valleys within the project area, the glacial drift is generally 50-200 feet thick. Depressions in the land surface left by the glaciers contain ponds, bogs, and wetlands, while lake bed sediments deposited during various high-level stages of Lake Michigan cover the flat area to the east.

Paleozoic sedimentary bedrock formations deposited during the Silurian and earlier periods underlie the project area (Fig. 3.3). Thus, the contact between the drift and bedrock represents a time gap of over 400 million years. The total thickness of Paleozoic sedimentary rocks underlying the project area is about 4000 feet. Shale, dolomite, and about 3000 feet of sandstone overlie a crystalline basement of Precambrian age.

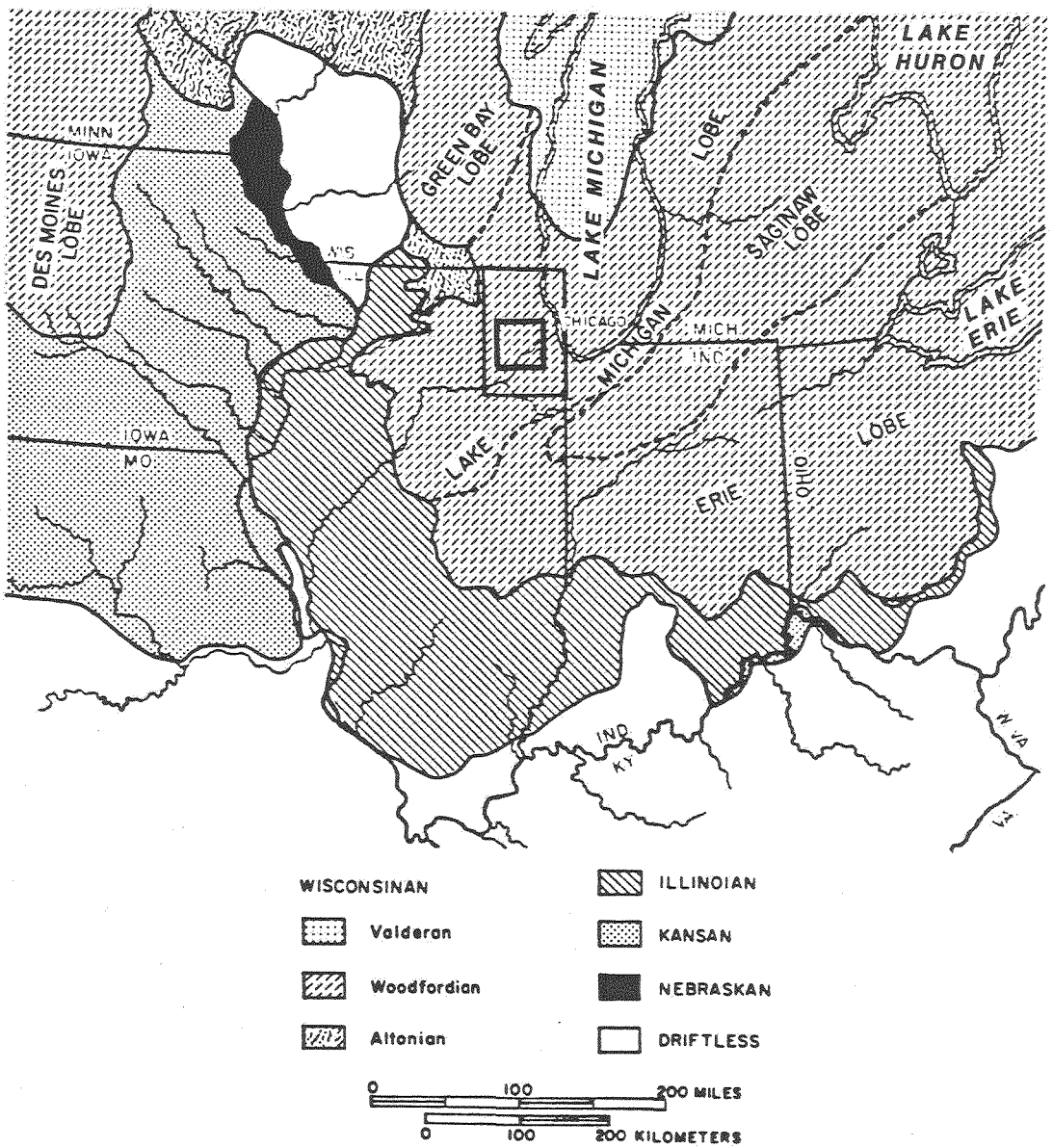


Fig. 3.2 Glacial Geology Map of the North-Central United States (Source: Willman, 1971)

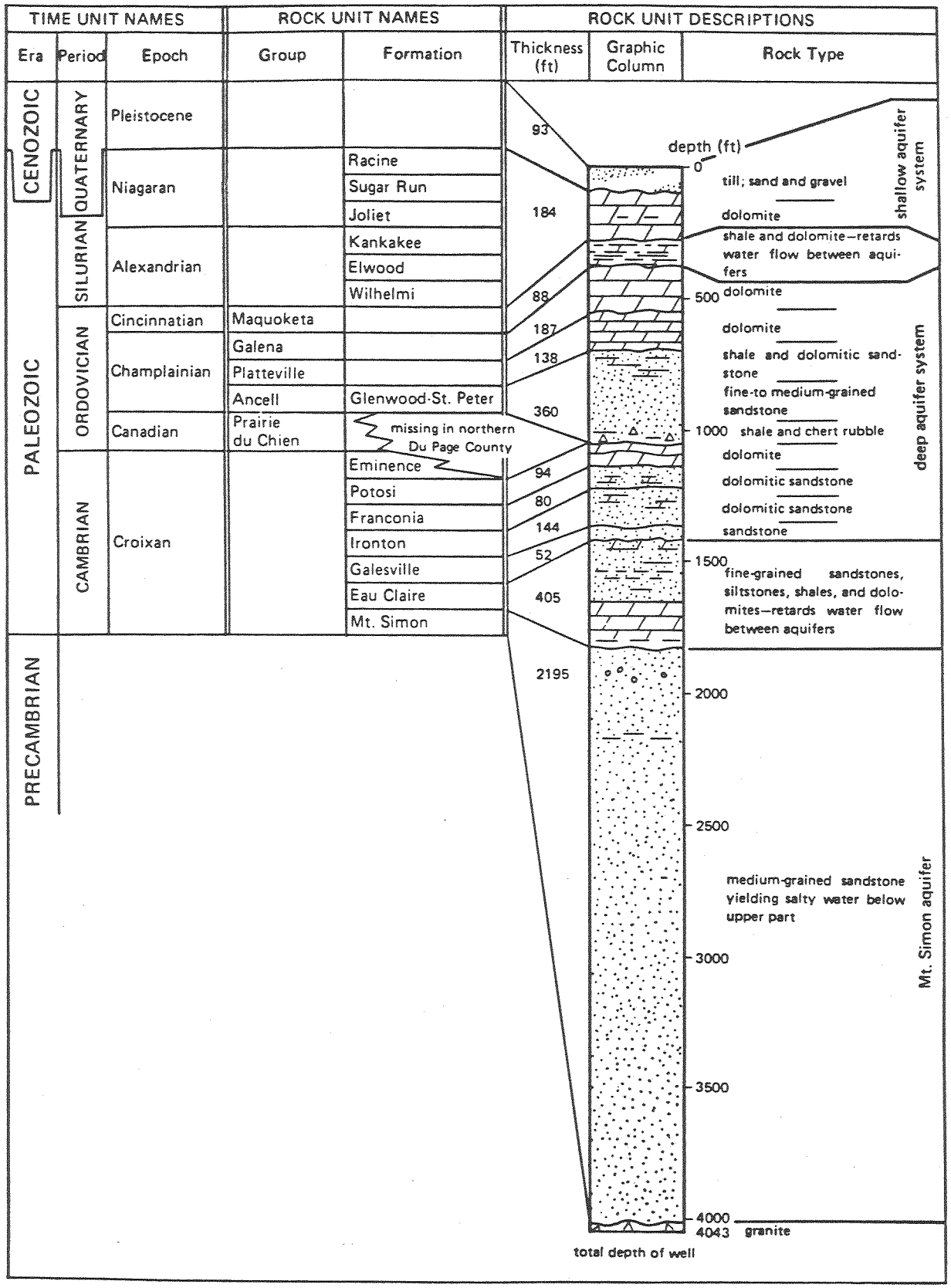


Fig. 3.3 Log of Deep Well in West Chicago (SW 1/4 SE 1/4 SE 1/4 sec 9, T. 39 N., R. 15 E.) (Source: Berggren et al., 1978)

The project area is situated on a broad, gently sloping bedrock arch, the Kankakee Arch (Fig. 3.4), which separates the Illinois Basin from the Michigan Basin (Fig. 3.5). Erosion by streams and glaciers has truncated the arch to produce a surface that, in broad aspects, is a plain. As a result, older rocks are exposed along the axis of the truncated arch, while younger rocks are found in the bordering basins.

Two areas of major disturbance attributed to faulting have been recognized near the project area: the Sandwich Fault Zone situated near the southwestern corner and the Des Plaines disturbance found just outside the northeastern corner (Fig. 3.11).

The Sandwich Fault Zone extends northwesterly for a distance of about 85 miles. It is about one-half to two miles wide and is upthrown to the south. Maximum cumulative displacement of about 800 feet occurs at the midpoint of the fault zone. Geologic relationships suggest that the major movements along the fault zone occurred in late Paleozoic time. Pleistocene deposits as old as the Illinoian glaciation cover the zone but show no offsets or disturbed zones that correspond to the faults in the bedrock, thus indicating that no movement has occurred on these faults during the past 100,000 years. Earthquake epicenters in northern Illinois show no relationship to the Sandwich Fault Zone (Kolata et al., 1978).

The Des Plaines disturbance is an area of intense faulting, about 30 square miles in extent. Nearly vertical faults with displacements of up to 600 feet have placed rocks as old as the St. Peter Sandstone at the bedrock surface. At the same time, rocks of more recent age, such as Pennsylvanian strata, are preserved in some of the downthrown blocks. Several hypotheses for the origin of the structure are being considered, including meteorite impact. No seismic activity has been associated with the Des Plaines disturbance in historic times.

The effects of normal ground motion on accelerators have been summarized by Fischer (1984). Motion occurs at a wide spectrum of frequencies and amplitudes, and most of these effects can be corrected using comparatively straightforward techniques such as position feedback systems. An important geologic component of the SSC site requirements will have to do with seismic activity, however. Several evaluations of seismic risks, containing relevant geotechnical analyses have been made for nuclear plants sited by the Commonwealth Edison Company in northeastern Illinois. Four such sites are located within 70 miles of the center of the project area:

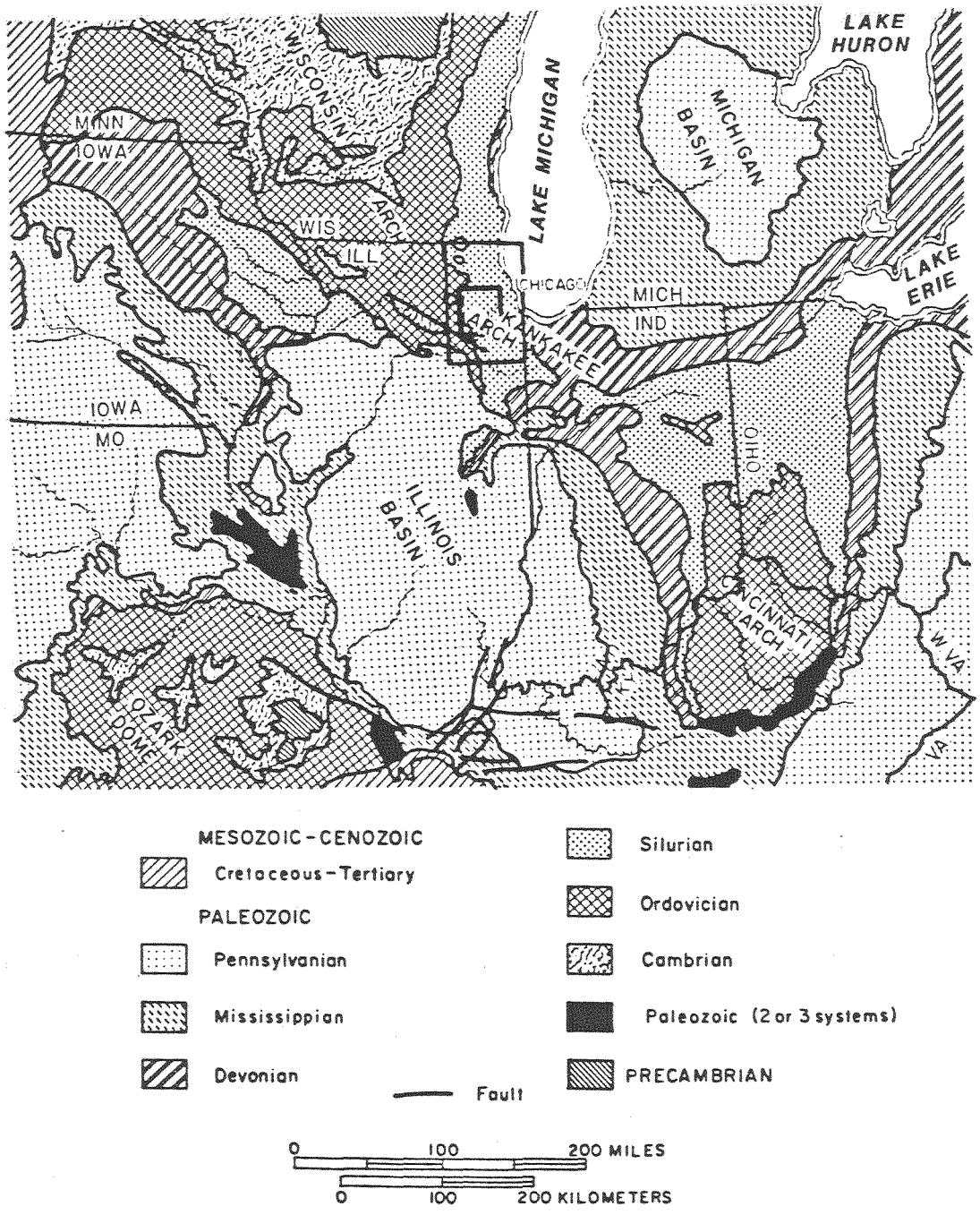


Fig. 3.4 Bedrock Geology Map of the North-Central United States (Source: Willman, 1971)

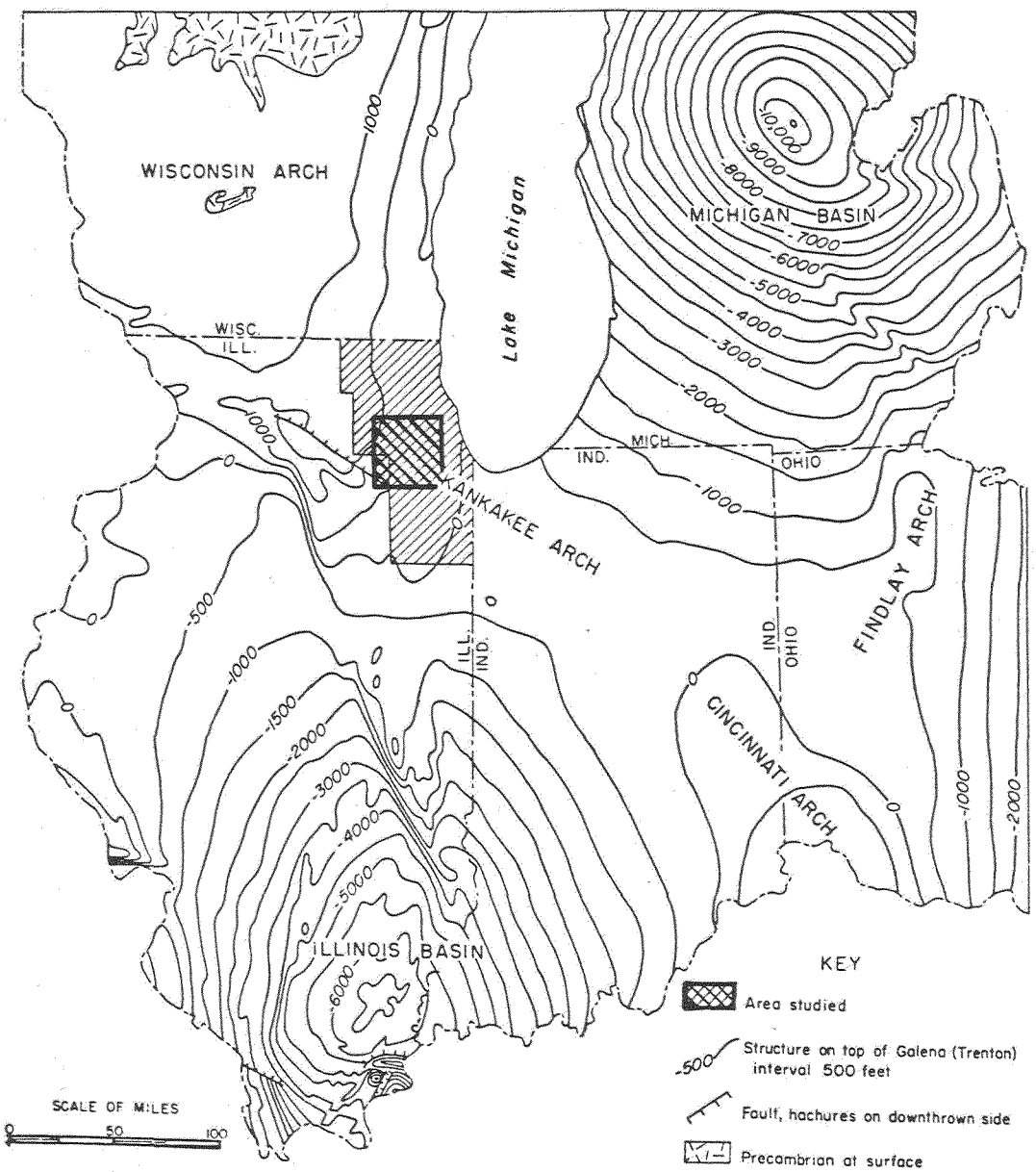


Fig. 3.5 Contour Map of the Top of the Galena-Platteville Dolomite (Source: Buschbach, 1964)

- Zion - 47 miles to the north-northeast,
- Braidwood - 38 miles to the south,
- Dresden - 29 miles to the south-southeast, and
- Byron - 64 miles to the northwest.

Based on the conclusions reached in the safety evaluation reports for these sites, these facilities are designed assuming the maximum earthquake that could be expected near the sites is of intensity VII on the Modified Mercalli Scale (Table 3.1).

Hazard analyses require definition not only of the maximum possible earthquake, but also of source zones and activity rate. To do this, current knowledge of earthquake locations is correlated with geological information (Fig. 3.6). However, the absence of definite surface faulting makes it difficult to specify source zones in the central United States (Herrmann, 1982). Two possible source zone models have been presented for the central region of the United States (Nuttli and Herrmann, 1978; Nuttli and Brill, 1980). The project area is situated within the Northern Illinois zone of the 1978 model, but is considered part of the Cincinnati Arch zone in the 1980 model. Probability studies by Herrmann (1982) show that for both models the peak ground acceleration (with an annual probability of 0.0005 of being exceeded) for the project area is about 150 cm/s^2, as shown in Fig. 3.7. Herrmann (1982) recommends that this 0.0005 annual probability level be used for planning.

The acceleration of 150 cm/s^2 refers to ground acceleration at the surface. The effects of an earthquake on underground structures will probably be somewhat less than on surface structures. At this stage, it is not considered practical to make reliable estimates of potential earthquake effects on subsurface structures. Although the structural stability of openings should not be threatened, further consideration should be given to the effects of earthquakes on equipment installed in the tunnel system.

3.1.2 **Potential Host Units**

In siting an SSC beam tunnel within the project area, certain technical, geological, economic, and environmental factors will need to be considered. The overall layout of the system will depend primarily on technical and economic considerations. The system as presently envisioned consists of a 63.6-mile tunnel, roughly in plan, that passes under both Fermilab and Argonne. Twelve shafts will be required (one every 5.3 miles along the tunnel) to connect the refrigeration/compressor stations. Two of these shafts will also service two of the six interaction region (IR) halls --

Table 3.1 **Modified Mercalli Intensity Scale of 1931**

Scale Degree	Effects on Persons	Effects on Structures	Other Effects	Equivalent Shallow Magnitude (Richter Scale)
I	Not felt except by a few under favorable circumstances			
II	Felt by a few at rest		Delicately suspended objects swing	2.5
III	Felt noticeably indoors; standing cars may rock		Duration estimated	
IV	Felt generally indoors; people awakened		Cars rocked; windows, etc., rattled	3.5
V	Felt generally	Some plaster falls	Dishes and windows broken; pendulum clocks stop	
VI	Felt by all; many frightened	Chimneys and plaster damaged	Furniture moved; objects upset	
VII	Everyone runs outdoors; felt in moving cars	Moderate damage		5.5
VIII	General alarm	Very destructive and general damage to weak structures; little damage to well-built structures	Monuments and walls down; furniture overturned; sand and mud ejected; changes in well-water levels	6.0
IX	Panic	Total destruction of weak structures; considerable damage to well-built structures	Foundations damaged; underground pipes broken; ground fissured and cracked	

TABLE 3.1 (Cont'd)

Scale Degree	Effects on Persons	Effects on Structures	Other Effects	Equivalent Shallow Magnitude
X	Panic	Masonry and frame structures commonly destroyed; only best buildings survive; foundations ruined	Ground badly cracked; rails bent; water slopped over banks	
XI	Panic	Few buildings survive	Broad fissures; fault scarps; underground pipes out of service	8.0
XII	Panic	Total destruction	Acceleration exceeds gravity; waves seen in ground; lines of sight and level distorted; objects thrown in air	8.5

Source: Heigold (1972).

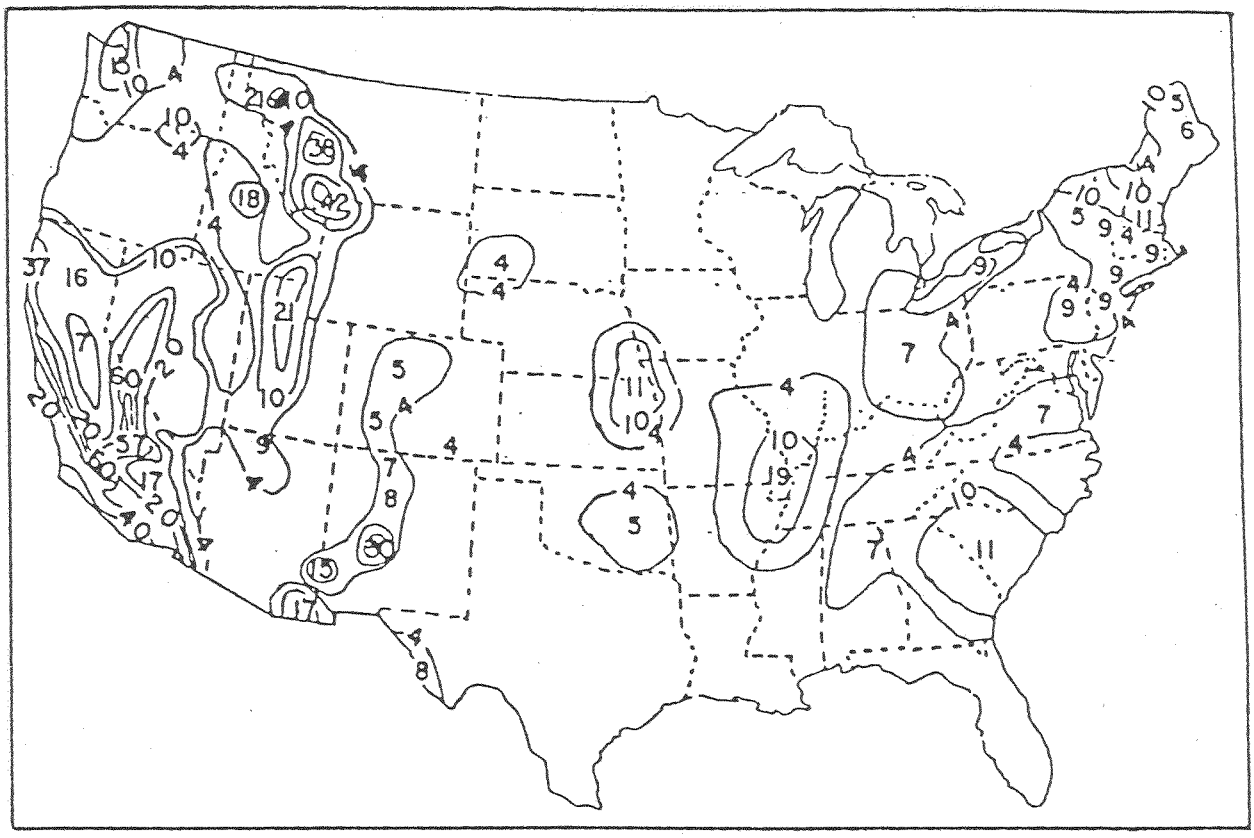


Fig. 3.6 Probabilistic Seismic Hazard Map of United States, after Algermissen and Perkins (2). (The numbers refer to the horizontal acceleration, in percent of the acceleration of gravity, on rock surface which have a 90% probability of not being exceeded in a 50-year time interval.)

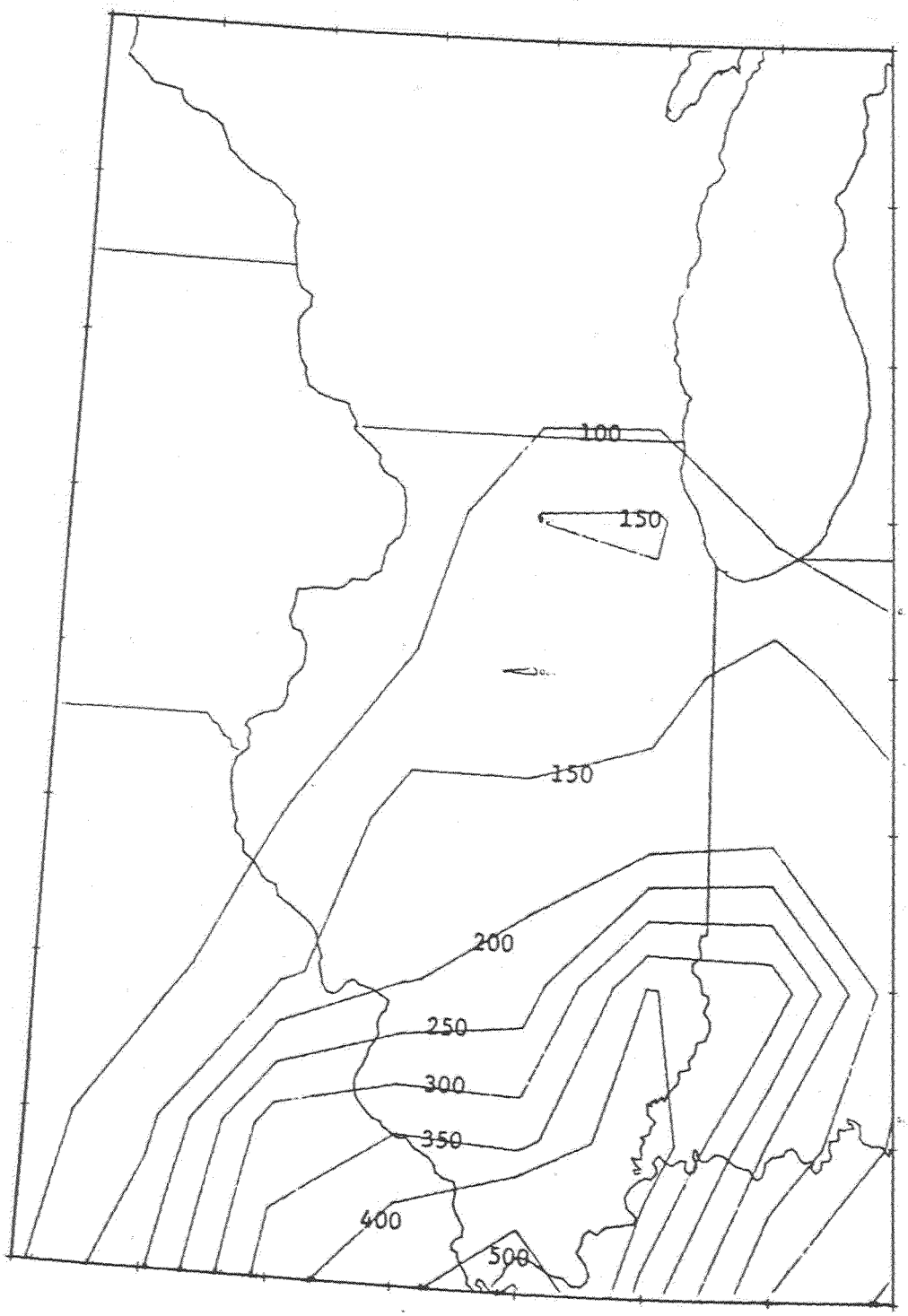


Fig. 3.7 Contours of Peak Ground Acceleration with an Annual Probability of 0.0005 of Being Exceeded, Nuttli-Brill Model (cm/s^2) (Source: Herrmann, 1982)

three at Fermilab and three at Argonne. Four additional shafts will be required to serve the other four IR halls. Two inclined shafts (ramps) will be required at Fermilab to inject the beam from the present accelerator near the surface down into the SSC tunnel.

The planned layout of the system leaves little flexibility in alignment. The tunnel loop will be in one plane, but not necessarily level, and its depth can be varied. These constraints must be considered in selecting the geologically most favorable environment for the tunnel.

The description of the regional geology in Sec. 3.1.1 makes clear that the project area is characterized by "layer cake" geology. Drift covers most of the surface and is 0-200 feet thick. The underlying sedimentary bedrock formations are subhorizontal and show little variation in lateral extent. Geological and mining considerations suggest that the tunnel should be sited within a rock unit that presents the same type of lithology over the full length of the tunnel. Four such units have been evaluated as potential hosts:

- Glacial drift, 0-200 feet from the surface,
- Silurian Dolomite, 0-350 feet,
- Maquoketa Shale, 0-250 feet, and
- Galena-Platteville Dolomite, 150-325 feet.

The sandstones below the Galena-Platteville Dolomite are not considered possible host units because of their greater depth, potential water inflow problems, limited structural strength, and interference with aquifers.

Glacial Drift

In this document, the terms "drift" and "unconsolidated deposits" are used synonymously to refer to glacial, interglacial, and Holocene ("Recent") deposits. These deposits include unsorted, glacially deposited rock material called "till"; sorted, meltwater-deposited sand and gravel called "outwash"; fine-grained sediments deposited in glacial lakes; windblown silt called "loess"; and fine- to coarse-grained sediments deposited by modern streams. In mining terms, these types of material are referred to as "overburden" and are distinct from the underlying bedrock. The thickness of the drift in the project area varies from 0 to 200 feet (Fig. 3.8). While some of this variation in thickness reflects the topography of the area, the topography of the underlying bedrock is also rather irregular. One interpretation of the configuration of the top of bedrock postulates the pattern of streambeds shown in Fig. 3.9.

The drift material poses no technical problems as far as constructing the tunnel loop. Numerous sewer and water supply lines have been constructed

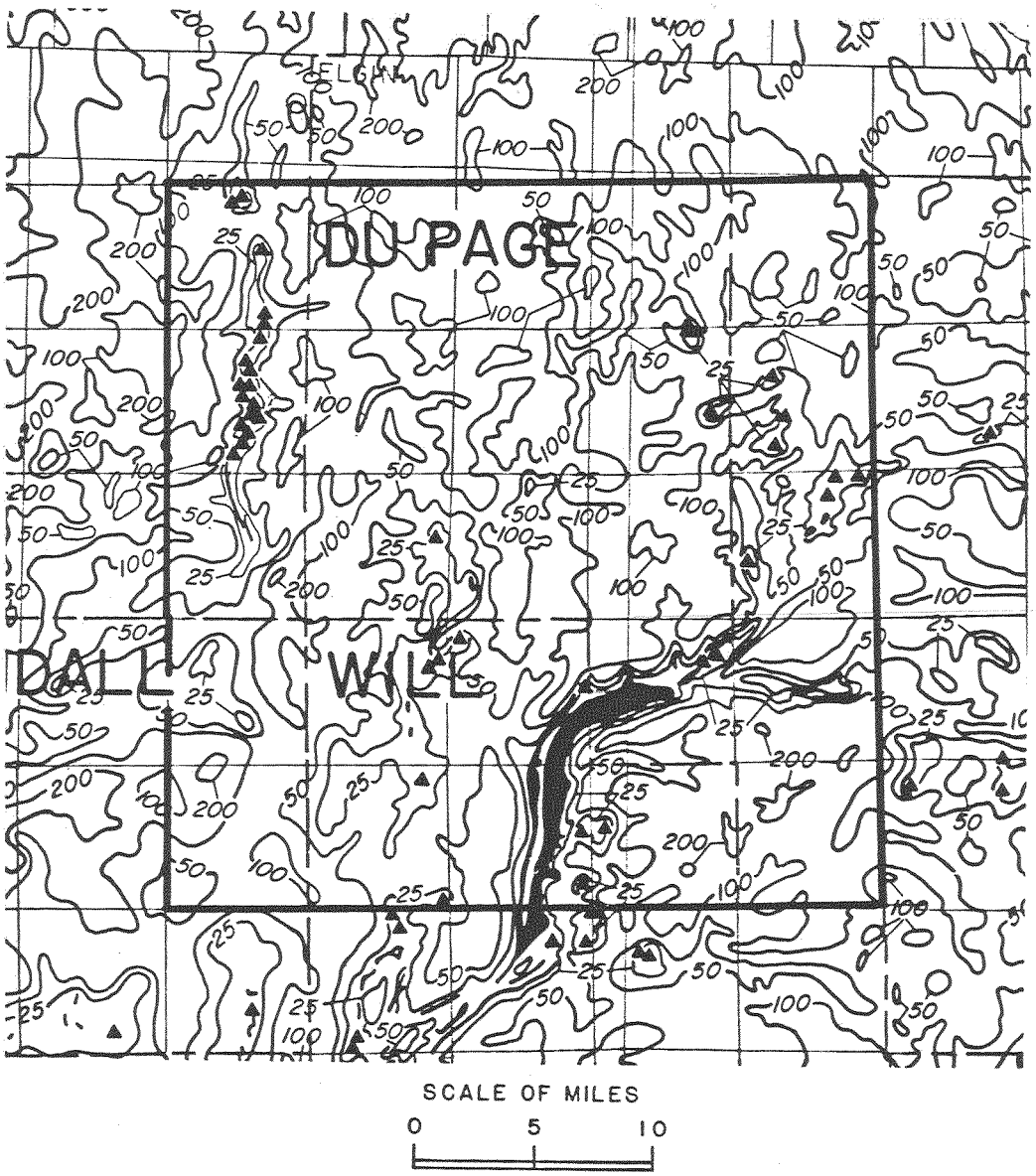


Fig. 3.8 Thickness of Glacial Drift (feet)
(Source: Piskin and Bergstrom, 1975)

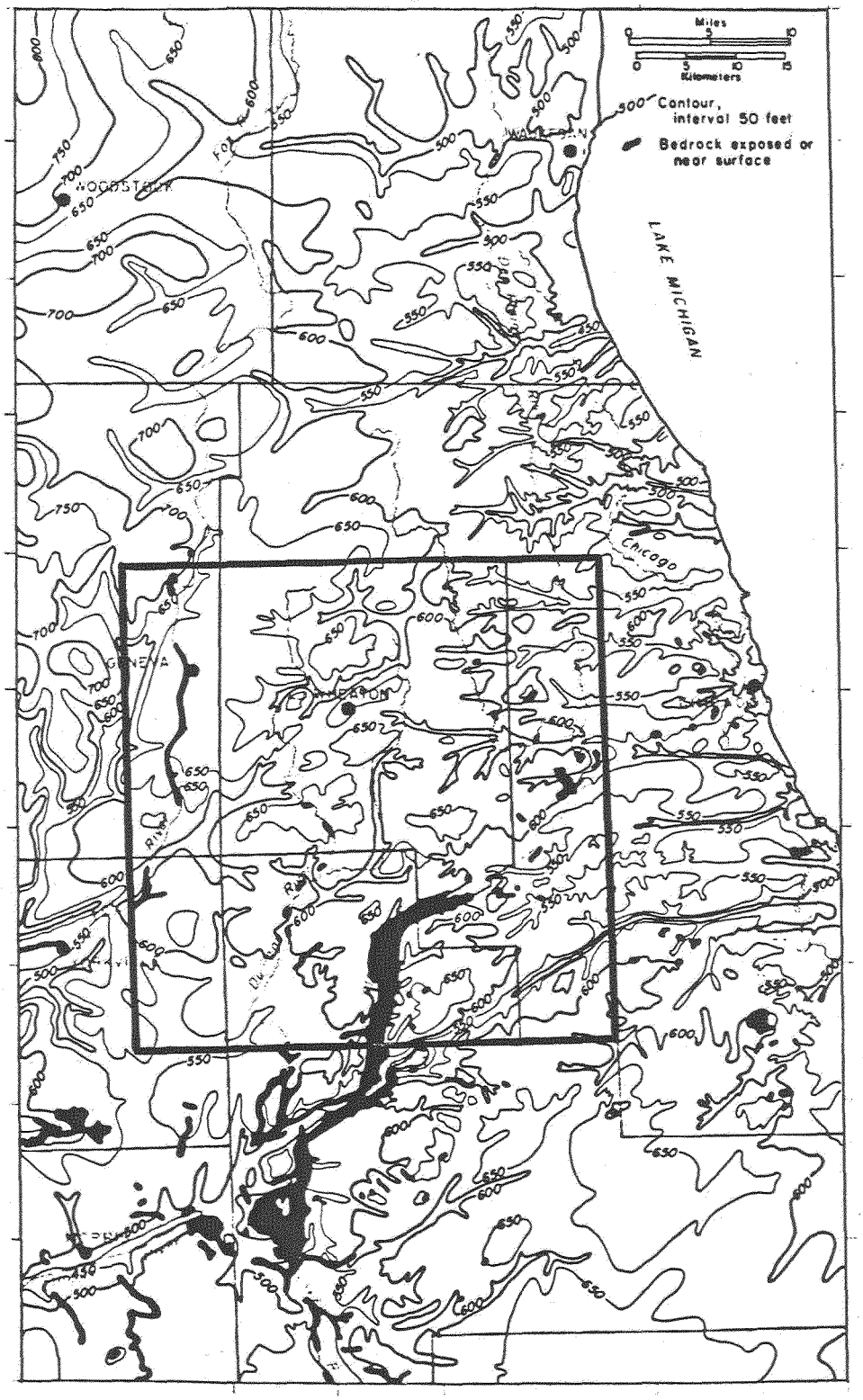


Fig. 3.9 Topographic Map of the Bedrock Surface
(Source: Willman, 1971)

in such units in and around the project area by open-cut construction, shield tunneling, or pipe jacking. However, any of these types of construction would have enormous environmental impact, especially in relatively densely populated areas such as the one under consideration.

Tunneling through the drift could be considered, but it would be impossible to site the entire 60-mile loop within drift because, in many places, the drift would be either too thin or lacking altogether. Locating the tunnel partly in drift and partly in underlying bedrock is undesirable from a technical standpoint because mixed-face tunneling is difficult and expensive. Rock tunneling and soft-ground tunneling require different techniques, materials, and equipment. Combining the two types should be avoided, except for the necessary access through the drift to a bedrock tunnel at depth. In short, the drift is the least desirable of the four potential host units.

Silurian Dolomite

Silurian strata form the bedrock surface over about 90% of the project area (Fig. 3.10). The total stratigraphic thickness of the Silurian in northeastern Illinois is more than 400 feet. However, because of truncation of the Kankakee Arch (Sec. 3.1.1), its thickness decreases in a westerly direction. Along the eastern side of the project area, the thickness of the Silurian is 230-350 feet (Fig 3.11); however, toward the west, the Silurian pinches out to 50 feet or less, and it is completely missing along most of the western side of the project area.

Silurian age rocks in the project area are almost entirely dolomite, which varies from argillaceous, to silty and cherty, to pure.* The lower part of the Silurian Dolomite consists of distinctive units that have lateral continuity throughout the region. The upper part is characterized by reefs of pure dolomite surrounded by well-bedded and slightly argillaceous to very impure and generally cherty dolomite.

The Silurian Dolomite is the host formation for the Chicago Tunnel and Reservoir Plan (TARP), a system of deep tunnels and reservoirs to convey and store storm-water runoff and sewage. This system is designed to include over 120 miles of tunnels ranging in diameter from 9 feet to 36 feet and is under construction. Extensive subsurface exploration, including a regional geophysical survey and numerous exploratory borings, preceded the design of

*Argillaceous -- containing clay minerals; silty -- containing detrital particles smaller than very fine sand and larger than coarse clay; and cherty -- containing cryptocrystalline silica, mainly as nodules.

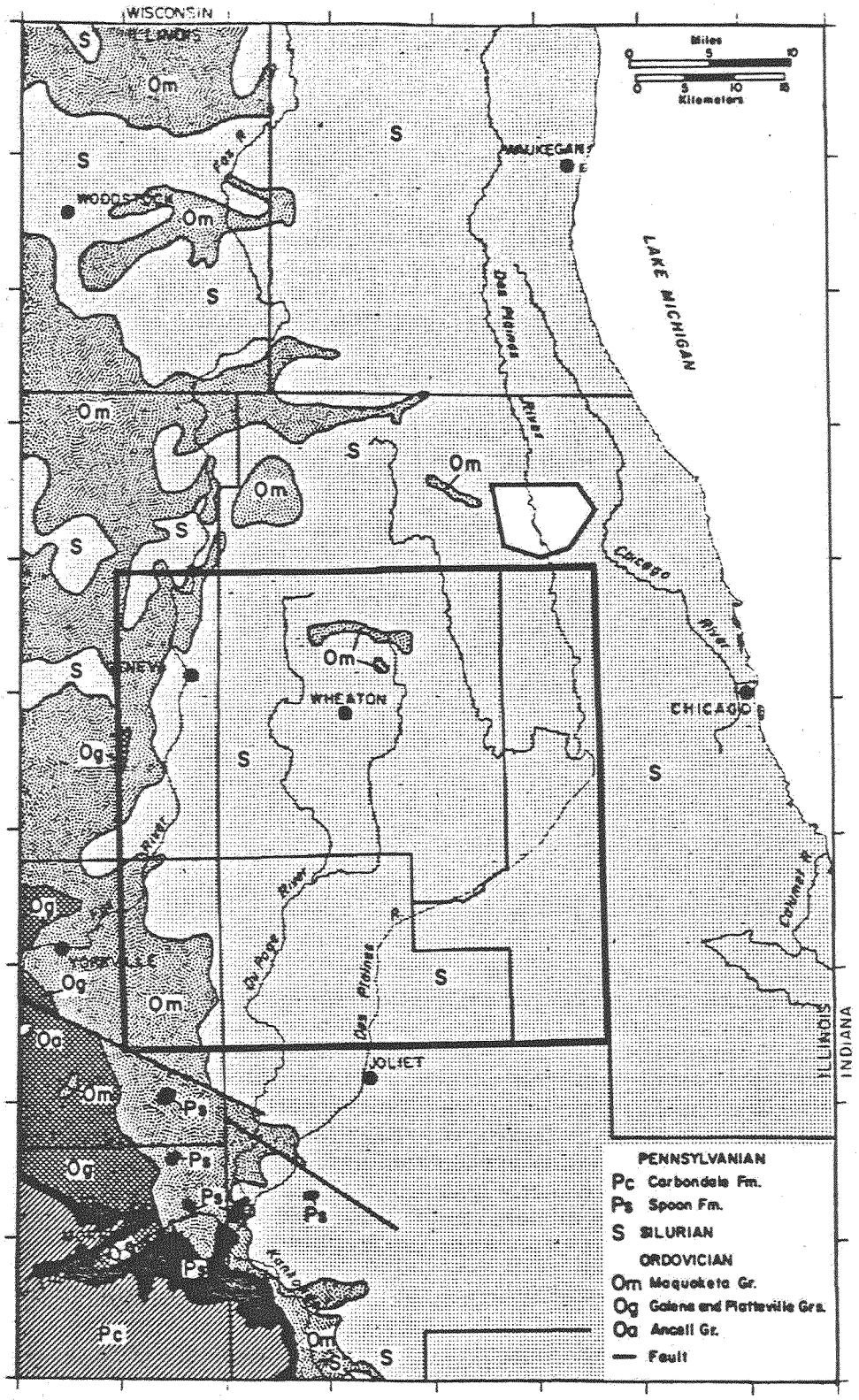


Fig. 3.10 Geologic Map of the Bedrock Surface
(Source: Willman, 1971)

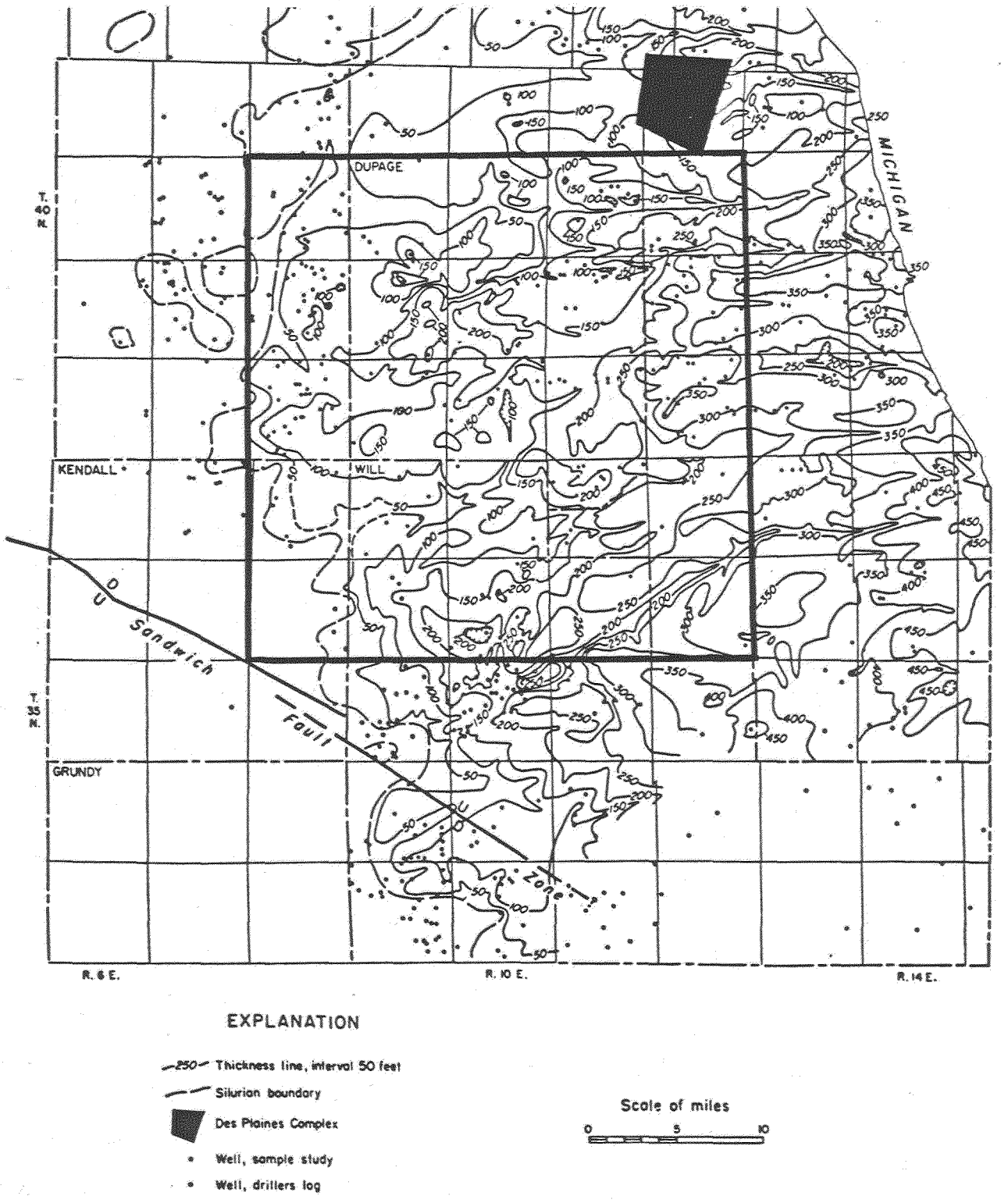


Fig. 3.11 Thickness of the Silurian Dolomite (Source: Suter et al., 1959)

this system, resulting in a wealth of geotechnical data on the Silurian Dolomite. Nearly 100 of these exploratory borings were made within the project area to evaluate subsurface conditions along the Des Plaines River for the design of a TARP tunnel that is yet to be constructed. At this time, over 50 miles of tunnels have been excavated in the Silurian; as expected, the dolomite is an excellent rock for tunneling.

In view of the extensive experience with the TARP tunnels in the Silurian Dolomite around Chicago, it is tempting to recommend siting the SSC tunnel in the same unit. However, the thinning of this dolomite in the western part of the project area might make for less favorable tunneling conditions.

Given that the tunnel should project within a plane, even if this plane is inclined, it appears nearly impossible to locate the entire tunnel within the Silurian Dolomite in the western and southwestern parts of the project area. The two remaining options are (1) siting part of the tunnel in drift, which results in undesirable mixed-face conditions, or (2) projecting the tunnel into the underlying Maquoketa Shale in areas where the Silurian Dolomite is too thin or the attitude of the formation is such that the dolomite is too high.

Of these two options, penetrating the shale is preferred. While the shale is not nearly as good a tunneling rock as the dolomite, similar mining methods and equipment could be used for both rock types. The Maquoketa Shale, which is discussed in detail in the next section, will require (1) application of shotcrete upon exposure to prevent slaking, (2) steel support if plastic strain is experienced, and (3) concrete linings throughout.

The Silurian Dolomite and parts of the Maquoketa Shale are the source of much of the domestic groundwater in the project area. Numerous domestic wells and a number of public, industrial, and irrigation wells tap this shallow aquifer (Sec. 3.1.3). Therefore, excavation of a 60-mile tunnel system in this aquifer could have some environmental impact. Even if this impact could be made acceptable, the tunneling work would generate significant water inflow problems, necessitating extensive grouting. The tunnel would also require a concrete lining wherever it projects into perhaps the upper 40 feet of the Silurian. In that zone, the rock joints tend to be open; weathering of the rock along joints will be more significant, resulting in reduced quality of the rock mass.

In conclusion, constructing the tunnel in rock at shallow depth is technically possible, but the cost of such a tunnel will be relatively high because of the grouting, support, and lining requirements. Constructing the tunnel in the shallow aquifer (Sec. 3.1.3) might affect the groundwater supply

pattern of the project area.

Maquoketa Shale

The Ordovician Maquoketa Group in northern Illinois consists primarily of olive-gray and greenish gray shale, with some dolomite and limestone. Due to post-Silurian erosion, the Maquoketa is missing farther west in north-central Illinois. It rests disconformably on the Galena Dolomite and is disconformably overlain by Silurian strata, which locally truncate the upper part of the Maquoketa (Kolata and Graese, 1983). In northern Illinois, the Maquoketa Group is divided into the following four formations (in descending order) (Willman, 1971):

- Neda Formation (0-15 feet thick, but mostly lacking in the project area) -- a reddish, silty, hematitic shale containing iron-oxide spheroids.

- Brainard Formation (0-100 feet thick) -- a dolomite and silty shale with interbeds of dolomite.

- Fort Atkinson Formation (5-50 feet thick) -- dolomite with interbeds of shale.

- Scales Formation (90-120 feet thick) -- a dolomitic, locally silty shale with interbeds of argillaceous dolomite.

In northern Illinois, the Maquoketa Group is generally about 200 feet thick. However, in the southern and western parts of the project area, where it is deeply dissected by pre-Silurian erosion, it thins abruptly to 100 feet or less. As a result, the Silurian Dolomite in places directly overlies the dolomite of the Fort Atkinson Formation. Because of such complications, the topography of the Maquoketa-Silurian contact is often poorly defined, and interpretations of the thickness of the Maquoketa vary, as can be seen by comparing Figs. 3.12 and 3.13.

As a tunneling rock, Maquoketa Group rocks are less favorable than either the overlying Silurian Dolomite or the underlying Galena-Platteville Dolomite. The TARP exploration efforts have resulted in the following description of the Maquoketa, which is paraphrased from Harza (1972).

The Brainard and Scales formations of the Maquoketa Group exhibit slaking and crumbling in rock core samples exposed to the atmosphere. Slaking has occurred during construction of storage caverns in northern Illinois and Indiana that were excavated in part in the Scales Formation. Pronounced slaking seriously impairs rock strength. Some reports indicate that, for

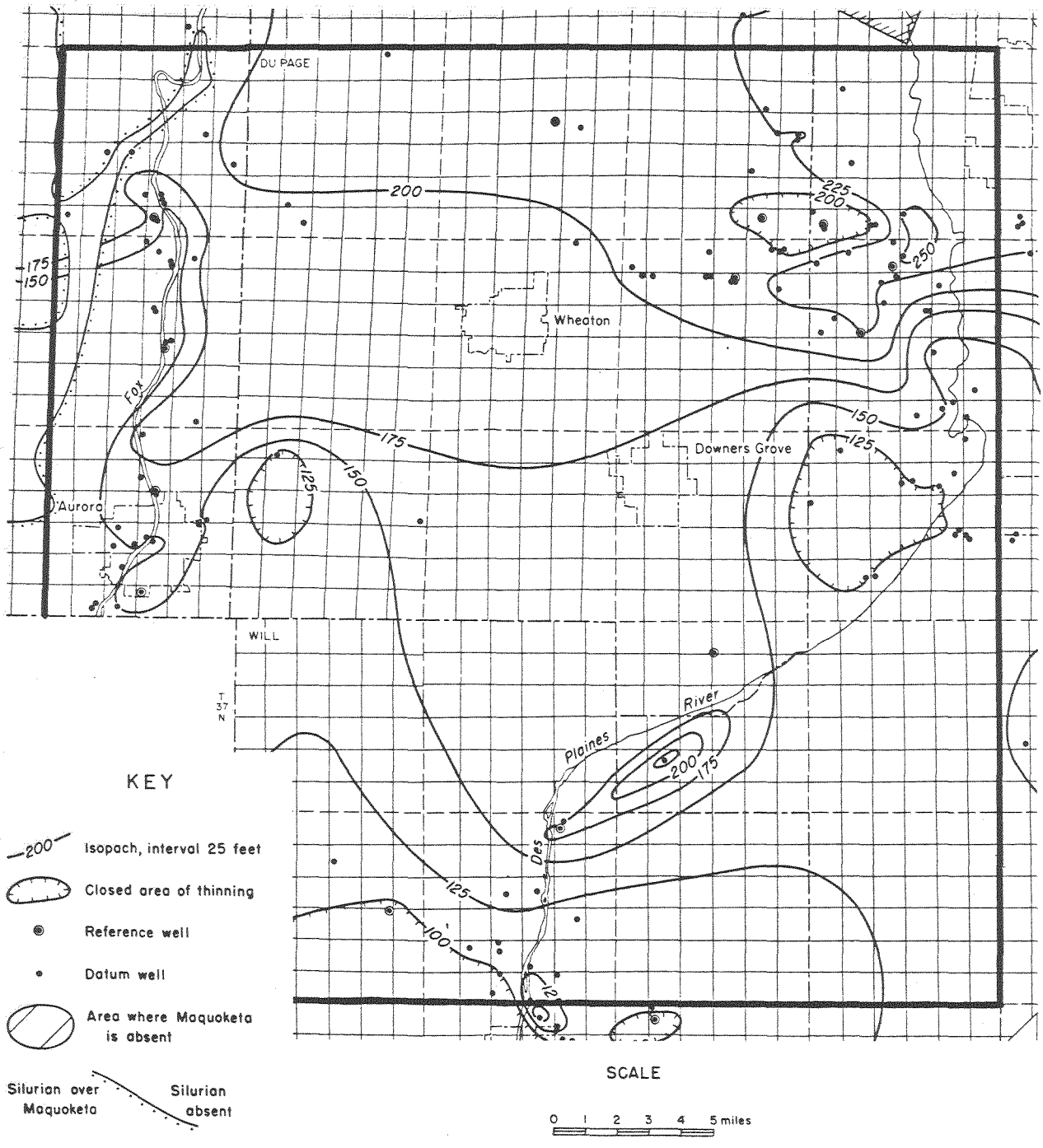


Fig. 3.12 Thickness of the Maquoketa Shale according to Buschbach (feet) (Source: Buschbach, 1964)

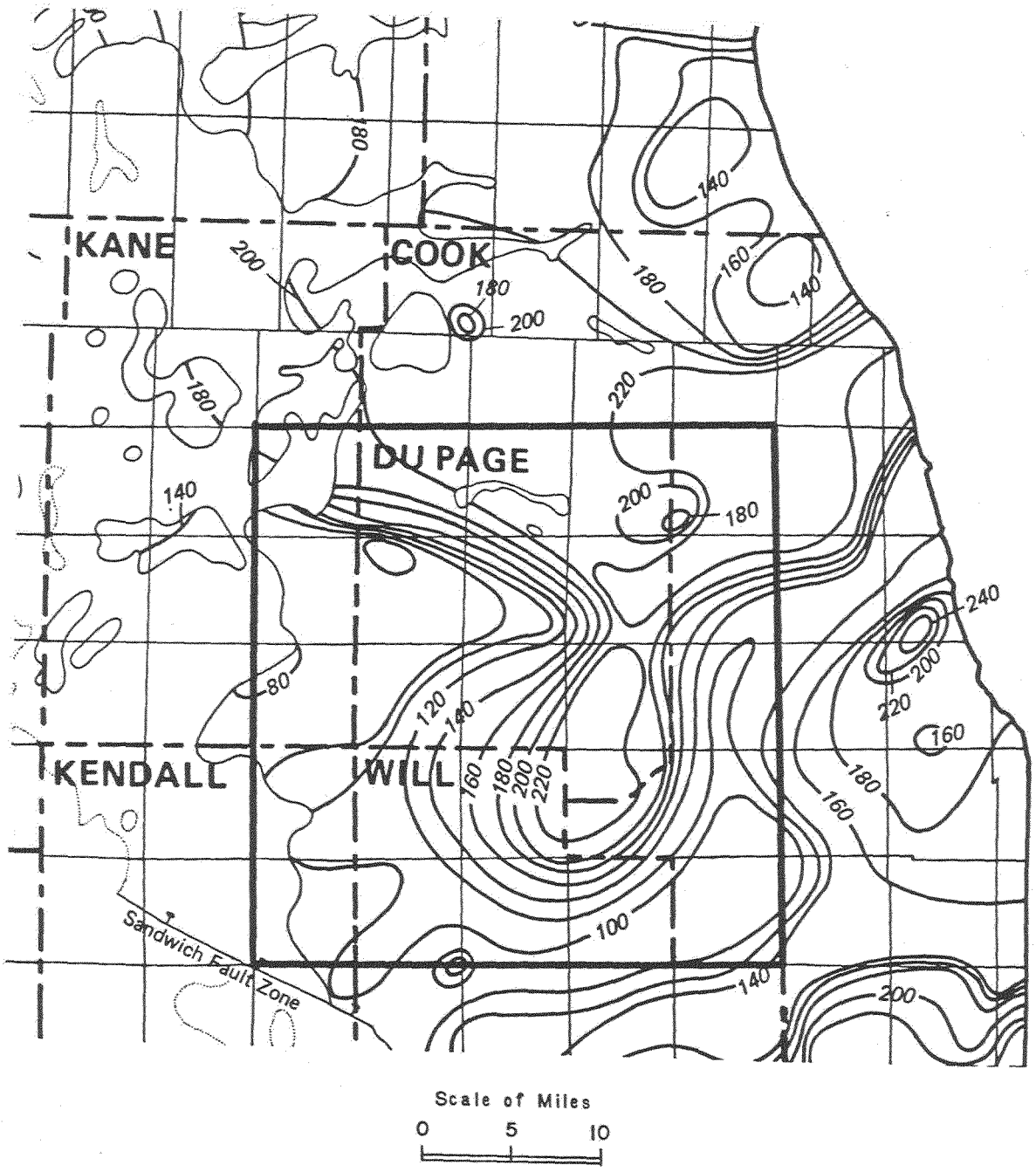


Fig. 3.13 Thickness of the Maquoketa Shale according to Kolata and Graese (feet)
(Source: Kolata and Graese, 1983)

excavations of limited extent, slaking of these shale units can be controlled and even prevented by conditioning the ventilating air circulated through the underground chambers. Temperatures must be maintained within a very narrow range, and the relative humidity must be high. While this procedure would be of great assistance during construction, it is not considered to be a totally reliable scheme in itself.

Rock core samples of the Scales Formation become soft and plastic when wetted. This characteristic, and other experience with shales, suggests that plastic flow may occur in portions of this unit when the rock is exposed to air and humidity in a free face.

In view of the tendency of the shale to slake and possibly swell on contact with the atmosphere, it will be necessary to cover the excavated surfaces with gunite or shotcrete as soon as possible after exposure. Wherever a tendency toward plastic strain is experienced, steel supports or equivalent bracing will be required. Slaking and plastic strain are expected to occur throughout significant segments of excavation in these rocks.

It would be difficult, and perhaps impossible, to position a significant length of the tunnel in the Brainard Formation because of its variable thickness. Also, the shales of the Brainard and Scales formations will require structural concrete linings for long-term stability. Where it is relatively massive and pure, the Fort Atkinson Dolomite would make a good tunneling rock. However, indications are that shale interbeds are numerous. Shale interbeds weaken the rock mass, thereby requiring tunnel support or rock reinforcement. More significantly, this dolomite is too thin to accommodate the SSC tunnel. In summary, the Maquoketa Group is not a favorable unit to host the SSC tunnel.

Galena-Platteville Dolomite

The Platteville and Galena groups are 300-350 feet thick in northern Illinois and are almost entirely of carbonate composition. The Platteville, which consists mainly of fine-grained dolomite, overlies the sandy and argillaceous strata of the Glenwood Formation and underlies the coarser grained dolomite of the Galena Group (Fig. 3.3). The Galena, in turn, underlies shales of the Maquoketa Group.

Although largely dolomite, both groups contain limestone in parts of the project area. Except for a few thin units, the relatively pure carbonate rocks contain less than 10% impurities -- mostly argillaceous material and chert. Because of the overall similarity of the groups, they are frequently referred to in northeastern Illinois as the Galena-Platteville Dolomite, or as the "Lower" Dolomite, thereby distinguishing it from the higher Silurian

Dolomite, or "Upper" Dolomite.

Present knowledge of the Galena-Platteville Dolomite is summarized in Buschbach (1964) and Willman and Kolata (1978). Additional information specific to the Chicago area can be obtained from drill-hole data for TARP and from Harza (1971). Vertical variations in and lateral persistence of impurities impart sufficiently distinct characteristics so that Willman and Kolata (1978) could classify the Galena-Platteville Dolomite into the 10 formations shown in Figs. 3.14 and 3.15.

It appears that the Dubuque Formation is absent in northern Illinois and that the Dunleith and Wise Lake formations are so similar that they cannot be readily distinguished. Therefore, in the following description of subsurface conditions, the name Wise Lake-Dunleith Formation is used. Because the Spechts Ferry Formation is restricted to the northwestern corner of Illinois, it is not considered further in this report.

The Galena-Platteville Dolomite does not crop out in the project area. Therefore, our knowledge of this unit is based mainly on subsurface information obtained from well logs, geophysical tests, underground mining information from the Elmhurst-Chicago Stone Co. (Hammersmith, 1984), and core holes drilled over the period 1967-1971 to investigate conditions for the deep tunnel system (TARP).

The Elmhurst-Chicago Stone Company has been excavating the Galena-Platteville formation since 1983, using the room and pillar method. A visit to this facility and discussions with J. Leuver revealed that the Galena strata presently being excavated consist of excellent rock for tunneling. Joints appear to occur at larger intervals than in the Silurian dolomite and the excavation is dry, with the only moisture being occasional slight dampness in joints.

The deep tunnel exploration work for the Galena-Platteville Dolomite included 18 core holes drilled in 1967/1968 in the Calumet area. Although these borings provided considerable stratigraphic knowledge, few tests were performed. Considerably more information was gained from a 1971 drilling program during which 45 holes were cored through the Silurian, Maquoketa, and Galena-Platteville units. The locations of these borings are shown in Fig. 3.16; the borings that explored the Lower Dolomite are underlined. Thirteen of these deeper borings are located within the eastern boundary of the project area. The following detailed description of the Galena-Platteville Dolomite in the Chicago area, as paraphrased from Harza (1971), is based on the logs of these 45 core holes.

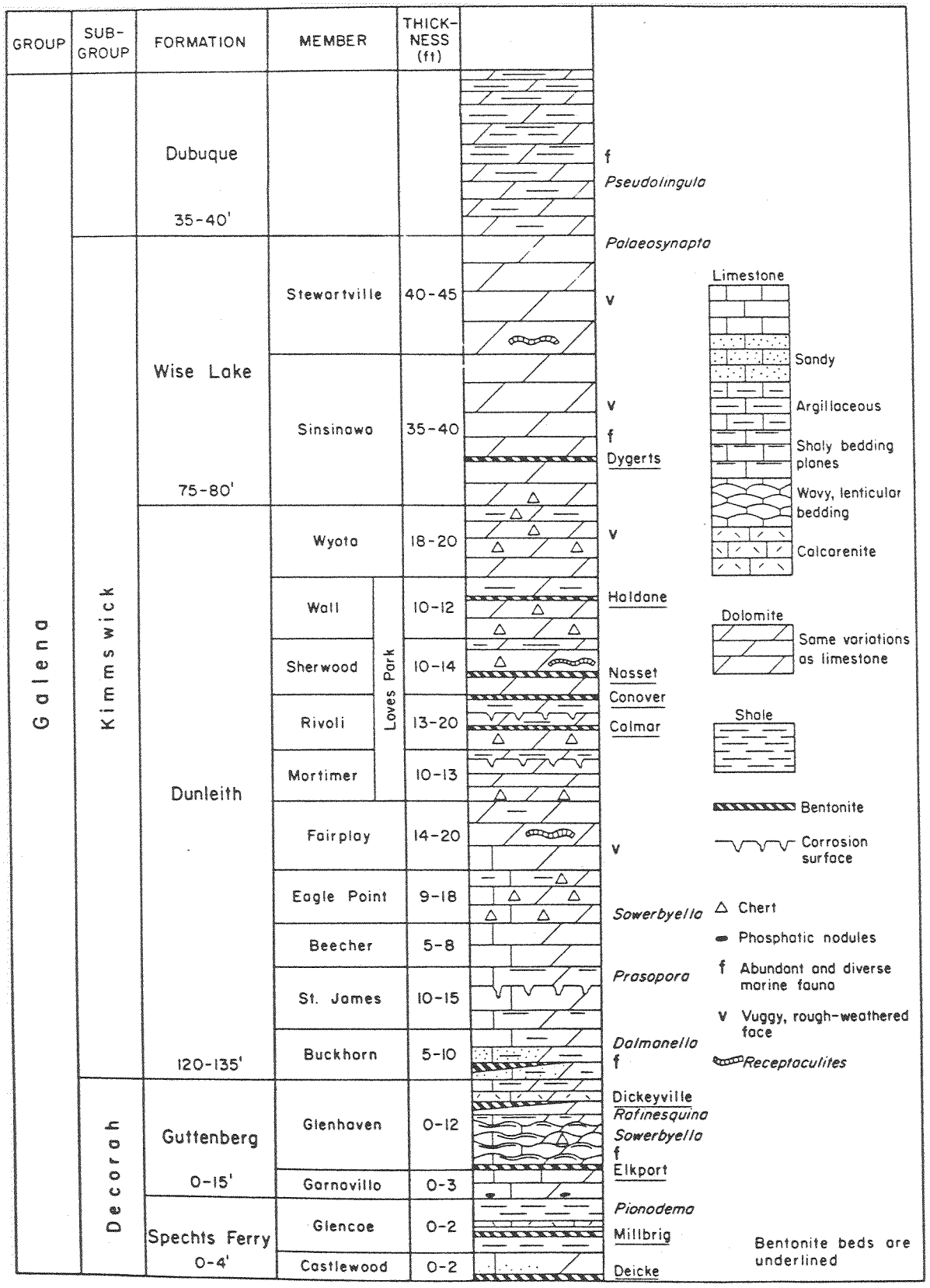


Fig. 3.14 Columnar Section of the Galena Group
(Source: Willman and Kolata, 1978)

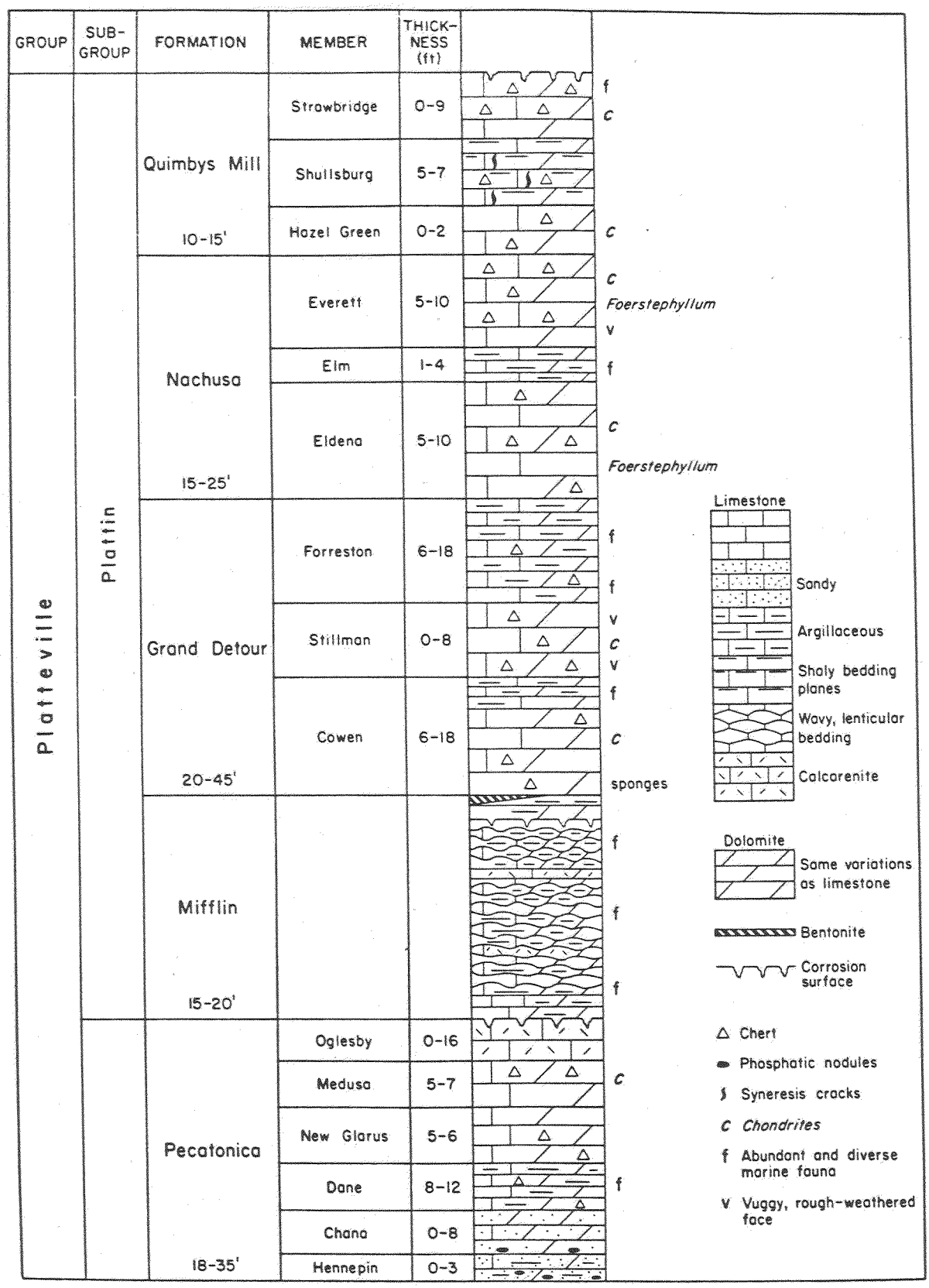


Fig. 3.15 Columnar Section of the Platteville Group
(Source: Willman and Kolata, 1978)

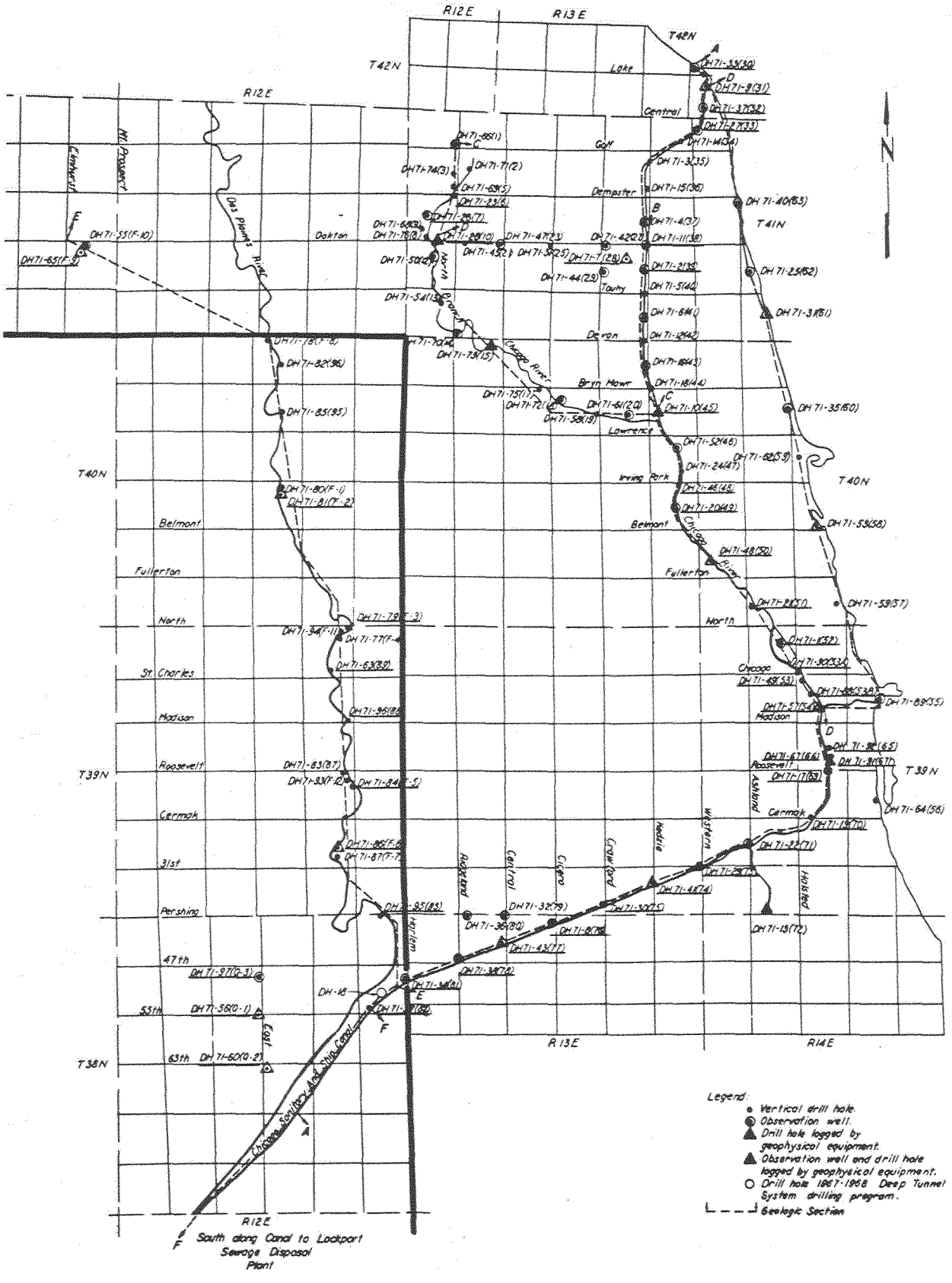


Fig. 3.16 Drill Hole Location Map of 1971 Deep Tunnel Exploration Program
(Source: Harza, 1971)

The Wise Lake-Dunleith Formation is a uniform, light (distinctively brownish) gray, medium-grained, crystalline, vuggy,* and thick-bedded dolomite from 182 to 215 feet thick that in some ways resembles the reef facies of the Racine Formation of Silurian age. The contact with the Scales Shale at the top of the Wise Lake-Dunleith Formation is clean and sharp and marked by a two- to three-inch irregular layer of pyrite. Hydrocarbon stains are found in some vugs in the top 25 feet of the formation. Scattered throughout the Wise Lake-Dunleith Formation are discontinuous dolomitic siltstone partings that are less than one inch. Otherwise, the formation is massive. Fossils and disseminated pyrite are common, as are pyrite-bearing joints.

In about 20% of the holes, dense massive limestone occurred in the lower part of the Wise Lake and in the underlying Nachusa, Grand Detour, and Mifflin formations of the Platteville Group. Petrographic analyses revealed granular interlocking grains of dolomite 0.05 to 0.2 millimeters in diameter, as well as scattered fossil fragments, calcite-filled cavities, and finely disseminated sulfides. Laboratory tests indicated low primary permeability.

The results of the unconfined compressive tests are consistent with the uniform lithology of the Wise Lake-Dunleith unit. Eighty-eight tests yielded a range of values from 3,000 to 18,590 psi, but 82% of the test values fell between 5,000 and 15,000 psi, and 50% were less than 10,000 psi. With regard to tensile strength, 40% of 51 test values were between 1,500 and 2,000 psi; the minimum value was 970 psi, whereas the maximum was 2,430 psi.

The Guttenberg Formation, which occurs at the base of the Galena Group, ranges in thickness from zero to nine feet. It is distinguished by traces of thin red shale partings but is otherwise a thick-bedded dolomite similar to the overlying Wise Lake-Dunleith Formation. Locally, the Guttenberg can be limey. It serves as a useful marker bed in the Ordovician section.

The Quimbys Mill Formation is a thin layer of hard, dense dolomite (occasionally limestone) that occurs between the Guttenberg and Nachusa formations. It is zero to two feet thick.

The Nachusa Formation is mostly a gray (partly a light brownish gray), fine- to medium-grained, thick-bedded, and vugular dolomite that would be difficult to distinguish from the overlying Wise Lake-Dunleith Formation were

*Vuggy -- descriptive of a rock having small cavities that are usually lined with crystals of a different mineral composition from the enclosing rock.

it not for the Guttenberg red marker bed at the base of the Wise Lake-Dunleith Formation and the presence of chert in the Upper Nachusa Formation. In 20% of the borings, the Nachusa Formation, along with the Mifflin, Grand Detour, and Lower Wise Lake-Dunleith formations, is a dense and nonporous limestone.

The Nachusa Formation is quite uniform in thickness, averaging about 35-40 feet. In the upper 15 feet, soft, porous, and "chalky" chert nodules occur; thin dolomitic shale partings are sparsely present throughout. Laboratory tests indicated low primary permeability. Sixteen unconfined compression tests carried out as part of the 1971 program yielded values between 5,500 and 34,200 psi, with 70% of the values falling between 5,500 and 15,000 psi. Seven tensile strength determinations ranged from 880 to 1,510 psi.

Most of the Grand Detour Formation is a very fine grained, dense, thick-bedded brownish gray dolomite characterized by dark "birds-eye," or fucoidal, markings. As is the case with the Wise Lake-Dunleith, Nachusa, and Mifflin formations, a limestone facies was observed in about 20% of the holes. Little or no chert was found. The thickness of the Grand Detour Formation averages about 30 feet.

Petrographic examination of the Grand Detour Formation revealed an interlocking texture of dolomite grains 0.05 to 0.15 millimeters in diameter, with 0.1-millimeter-wide bands of finer grained material and small calcite-lined cavities. Primary permeability is low, but some secondary permeability should be anticipated along joints and fracture zones. In 14 unconfined compressive tests, values ranged from 5,500 to 43,930 psi, with 75% falling between 5,500 and 20,000 psi. Fifty percent of 10 tensile strength tests yielded values above 2,000 psi.

Below the Grand Detour Formation is the Mifflin Formation, a fine- to medium-grained, light to medium gray, thin- to medium-bedded, slightly porous dolomite with shale partings. The contact between the two formations is transitional. Alternating with the dolomites are numerous, continuous wavy dolomitic shale partings. In approximately 20% of the holes, the Mifflin (and the Lower Wise Lake-Dunleith, Nachusa, and Grand Detour formations) is a dense limestone. The Mifflin Formation averages 20 feet thick.

Petrographic analysis of the Mifflin Formation indicated a granular interlocking texture of dolomite grains 0.03 to 0.05 millimeters in diameter, sparsely disseminated angular grains of quartz as large as 0.03 millimeters in diameter, and darker zones 0.03 to 2.0 millimeters wide of finer (probably argillaceous) material. Low primary permeability is anticipated. Geophysical logs indicated considerable vertical variation in the Mifflin Formation. Preliminary results of the unconfined compression test program varied from

5,100 to 32,000 psi. Of these, 45% were between 5,100 and 10,000 psi. Most of the seven tensile strength tests yielded values greater than 2,000 psi.

The Pecatonica Formation is a medium-grained, finely porous, medium-bedded to massively bedded gray dolomite that is generally about 34-45 feet thick and that in some ways resembles the Nachusa and Wise Lake-Dunleith formations. However, unlike the other two units, no calcareous facies have been observed. Examination of the cores indicated that the upper 20 feet of the formation is more porous than the bottom 10-20 feet. This result is at variance with data obtained in the 1967/1968 exploration, where numerous vugs up to three inches in diameter were reported in the lower eight feet.

Petrographic analysis of the Pecatonica Formation revealed a granular texture of interlocking dolomite grains. Areas of different average grain size corresponded to the mottling seen in hand specimens. In some places, these areas were separated by irregular partings of brown iron oxide 0.02 to 0.04 millimeters thick. Primary permeability was low, but secondary fracture permeability was high. Values resulting from eight unconfined compression test results ranged from 11,500 to 22,500 psi, whereas six tensile tests recorded values between 1,500 and 2,000 psi.

Our present knowledge shows the geology of the Galena-Platteville Dolomite to be rather uniform throughout the area explored for the deep tunnel system. Good correlation is found between the well data and the geophysical data available for the project area. It therefore seems reasonable to assume that the characteristics of the Galena-Platteville Dolomite throughout the project area will be similar to those defined in the exploration work described above.

On the basis of the results of 63 core holes, the average thickness of the Lower Dolomite is 326 feet. Very uniform in thickness, it has a minimum thickness of 312 feet and a maximum thickness of 337 feet. The average thickness in feet of the various formations is Wise Lake-Dunleith (193), Guttenberg (4), Quimbys Mill (1), Nachusa (38), Grand Detour (30), Mifflin (22), and Pecatonica (38).

Core recovery was excellent on all of the borings, and the rock quality designation (RQD)* was 82%, which indicates good quality rock. A total of 242 core samples of two-inch diameter (NX size) were tested for unconfined

*RQD is defined as the percentage of core recovered in intact pieces of four inches or more in length in the total length of a core run.

compressive strength. The mean value was reported to be 11,952 psi (say 12,000 psi) (standard deviation = 6,082 psi). The rock is generally strong, but not abrasive. These properties offer ideal conditions for TBM's. Most of the deep tunnel core holes were water-pressure tested as an aid in determining the permeability of the formation. The results of this testing, as shown on the drill-hole data sheets, indicated low permeability for most of the Galena-Platteville Dolomite.

Figures 3.15 and 3.16 show a number of bentonite horizons that deserve further attention. Bentonite is a greasy, soaplike rock composed mainly of montmorillonitic clay minerals derived from volcanic ash. It can absorb large quantities of water, which results in an enormous increase in volume (up to eight times its original volume). Having beds of bentonite with these characteristics in the crown of some of the proposed underground excavations could potentially cause some problems. However, the bentonite beds in the Galena-Platteville Dolomite are discontinuous and have never been found to be more than four inches thick and are usually only one to two inches thick. More importantly, the clay does not show a tendency to swell because it is mostly altered to a mixture of about 25% smectite and 75% illite (Kolata, 1984). The bentonite horizons described by Willman and Kolata (1978) have all been recognized and described on the basis of surface outcrops. It is likely that similar beds occur in the Galena Group in northeastern Illinois. The reason why they have not been recognized in the subsurface exploration in the Chicago area is that a one- to two-inch-thick clay seam can easily be lost in the drilling operation, even just from the washing effect of the drill water. Furthermore, the beds are too thin to be detected in the down-the-hole geophysical logging that was done for a number of holes in the area. Given our present knowledge, it does not appear that the bentonite horizons will present a problem for the underground excavation work.

In the project area, the Galena-Platteville Dolomite dips to the east-southeast at the rate of 11 feet per mile (Fig. 3.17). An interpretation of the structure on top of the Galena-Platteville Dolomite is presented in Fig. 3.18. This map is based on the results of a seismic survey conducted in 1967/1968 as part of the early subsurface exploration work for TARP. At first glance, the structure indicated in Fig. 3.18 scarcely agrees with that shown in Fig. 3.17. However, more detailed analysis showed that the two maps are in basic agreement. Figure 3.18 shows a number of faults, but only some of those were confirmed during the exploration drilling.

Many tunneling hazards are associated with faults because displacement often causes the rock to be crushed and gouge material can cause stability problems. Also, faults are often associated with severe groundwater inflow. No significant faulting has been encountered in any of the TARP tunnels so

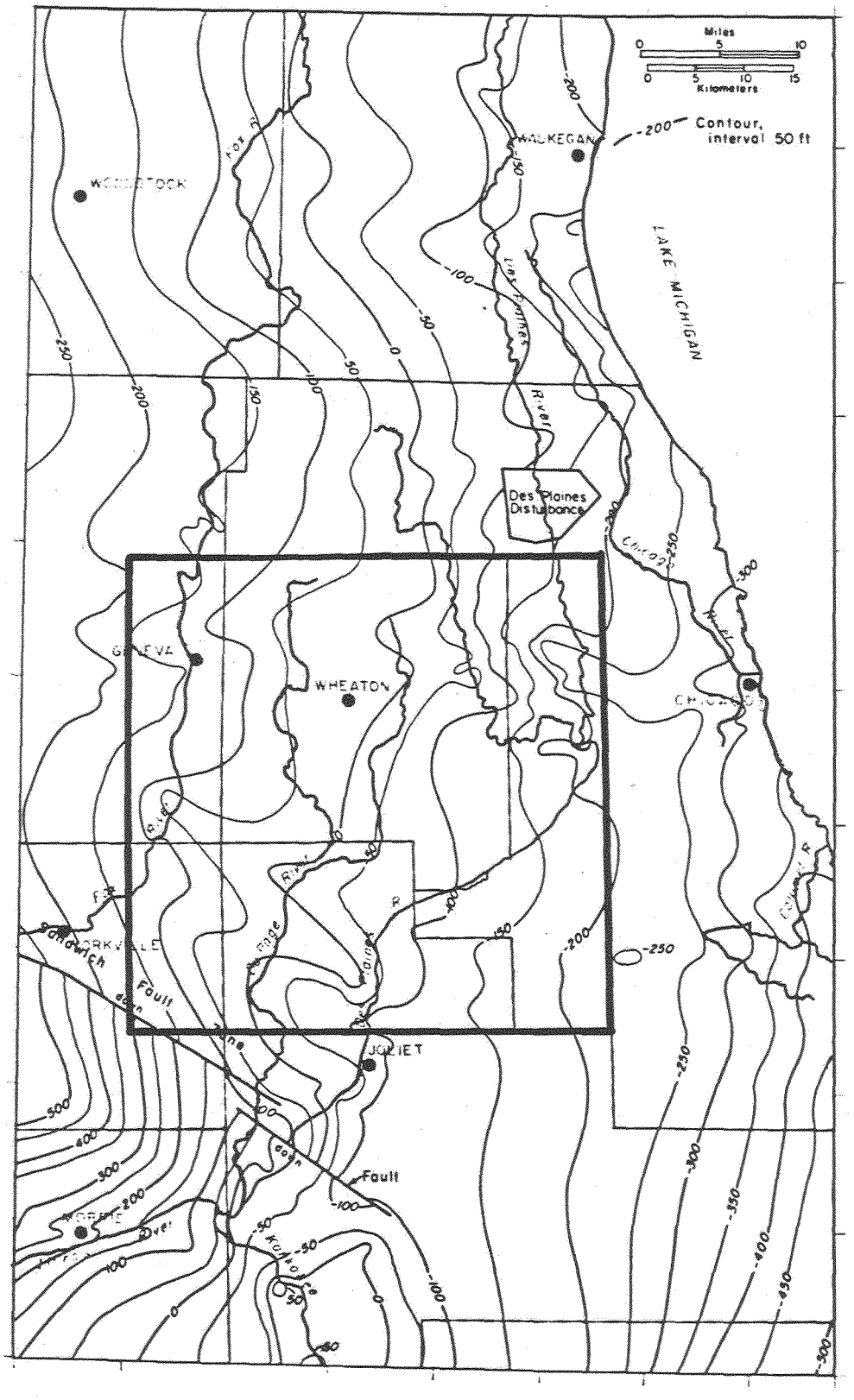


Fig. 3.17 Contour Map of the Base of the Galena-Platteville Dolomite (Source: Willman, 1971)

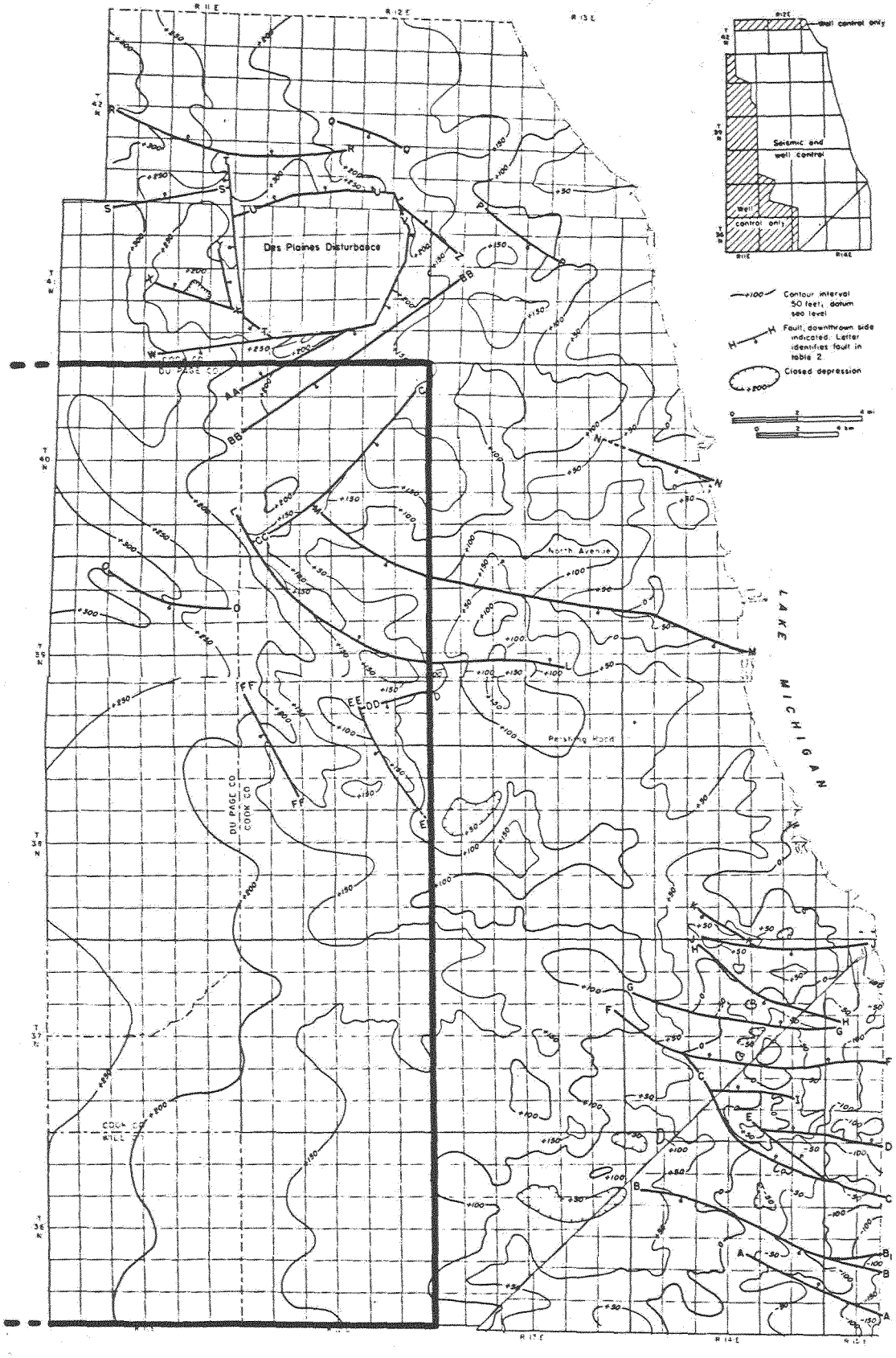


Fig. 3.18 Contour Map of the Top of the Galena-Platteville Dolomite (Source: Buschbach and Heim, 1972)

far, which tends to indicate that faulting in the Lower Galena-Platteville Dolomite will not be a major risk.

The various characteristics described above (i.e., a thick homogeneous formation, good RQD, medium strength, and low permeability) demonstrate the feasibility of a machine-excavated tunnel in the Galena-Platteville Dolomite at relatively low expense. Indications are that such a tunnel will not require a lining. A number of the TARP tunnels have been completed as unlined tunnels. For those tunnels that are lined, the lining does not serve a structural purpose, but ensures smooth hydraulic flow and prevents deterioration of the tunnel wall by water (sewage) flow. A certain amount of grouting will be required to limit groundwater inflow, and "dental" work will be required to secure certain joints, fracture zones, bentonite beds, etc. However, based on TARP experience, it is expected that dental work will be required for only a very small portion (say a fraction of one percent) of the total tunnel periphery.

Considering that the costs of lining tunnels can approach as much as 50% of the tunnel excavation cost, an unlined tunnel is attractive. On the basis of our present knowledge of both rock and groundwater properties, the Galena-Platteville Dolomite appears to be the most favorable host unit for the SSC tunnel in the project area.

3.1.3 Groundwater

Groundwater is the main source of potable and industrial water for most of the project area. The several aquifer systems that underlie the area are, in descending order: (1) glacial drift, (2) shallow bedrock, (3) Cambrian-Ordovician, and (4) Mt. Simon. Figure 3.19 gives the hydrologic properties of the main water-yielding bedrock units.

The glacial drift system is hydraulically connected with the shallow bedrock system. The water yield from shallow bedrock is mainly from the Silurian Dolomite, but some of it is contributed by dolomite beds in the Maquoketa Group. The combination of the drift and the shallow bedrock aquifer is often referred to as the shallow aquifer. The underlying Maquoketa Group, especially the Scales Formation (Sec. 3.1.2), forms a layer of low permeability (aquitard) that separates the shallow aquifer from the deeper aquifer systems.

Groundwater in the drift is obtained from sands and gravels that occur as surface deposits or, more commonly, as deposits underlying, or interbedded with, glacial till. Moderate to large supplies of groundwater are primarily encountered in sand and gravel at the base of the drift, directly above

SYSTEM	SERIES	MEGA-GROUP	GROUP OR FORMATION	GRAPHIC LOG	THICKNESS (FEET)	DESCRIPTION	AQUIFER SYSTEMS	
QUATERNARY	PLEISTOCENE				0 - 400 +	Unconsolidated ice- and water-laid deposits, pebbly clay (till), silt, sand and gravel, generally discontinuous and interbedded; alluvial silts and sands commonly present along streams.	Glacial drift aquifer system	Sand and gravel beds serve as aquifers. Some wells yield more than 1000 gpm. Large supplies of water available from thick, relatively continuous sand and gravel deposits.
PENNSYLVANIAN					0 - 175	Shale; sandstones, fine grained; limestones; coal; clay.	Shallow bedrock aquifer system	Fractured beds yield small supplies locally.
MISSISSIPPIAN* DEVONIAN								
SILURIAN	NIAGARAN				0 - 400 +	Dolomite, very pure to very silty, cherty; shale partings; thin shales and argillaceous beds frequently present in lower parts of Silurian dolomite.		Not consistent; some wells yield more than 1000 gpm. Crevices and solution channels more abundant near bedrock surface.
	ALEXANDRIAN				0 - 165	Upper and middle units—shale, light gray to green, plastic to brittle, some dolomite, silty; dolomite, mostly silty, argillaceous; minor limestone. Lower unit—shale, dark gray, black, brown, plastic to brittle; some dolomite in upper part; silty, argillaceous.		Yields water from fractured beds. Shales, particularly in lower unit, act as confining beds at the base of the shallow bedrock aquifer system.
ORDOVICIAN	CINCINNATIAN		Maquoketa		0 - 250 +			
	CHAMPLAINIAN	OTTAWA	Galena Platteville		150 - 350 +	Dolomite, cherty; sandy at base; limestone; shale partings.	Deep bedrock aquifer systems: Cambrian-Ordovician aquifer system	Where below shales, development and yields of crevices are small; where not capped by shales, dolomites are fairly permeable.
			Glenwood St. Peter		75 - 650	Sandstone, fine to coarse grained; shale at top; locally cherty red shale at base.		Glenwood-St. Peter Sandstone. Small to moderate quantities of water. T probably about 15% of that of Cambrian-Ordovician aquifer system.
	CANADIAN	KNOX	Prairie du Chien		0 - 340	Dolomite, sandy, cherty, interbedded with sandstone.		Crevices in dolomite and sandstone generally yield small amounts of water. Potosi dolomite locally well creviced and partly responsible for exceptionally high yields of several deep wells. T probably about 35% of that of Cambrian-Ordovician aquifer system.
CAMBRIAN	CROIXAN		Eminence Potosi		0 - 225	Dolomite, white, fine grained, sandy at base; drusy quartz.		
			Franconia		45 - 175	Sandstone, dolomite, and shale, glauconitic, green to red, micaceous.		
			Ironton Galesville		103 - 275	Sandstone, fine to medium grained, well sorted, upper part dolomitic.		Ironton-Galesville Sandstone. Most productive part of Cambrian-Ordovician aquifer system. T probably about 50% of entire system.
			Eau Claire		235 - 450	Shale and siltstone, dolomitic, glauconitic; sandstone, dolomitic, glauconitic; dolomite, sandy.		Shales generally not water yielding; act as confining bed at the base of the Cambrian-Ordovician aquifer system.
		POTSDAM	Mt. Simon		2000 ±	Sandstone, coarse grained, white, red in lower half; lenses of shale and siltstone, red, micaceous.	Mt. Simon aquifer system	Mt. Simon Sandstone. Data sparse; probably less permeable than Ironton-Galesville; quality of water deteriorates with depth.
PRECAMBRIAN						Not penetrated by wells in Chicago area. Nearby wells encounter red or gray granite or similar rocks.		

* Mississippian rocks present in Des Plaines Disturbance.
Devonian rocks present as crevice fillings in Silurian rocks.

Fig. 3.19 Stratigraphy and Aquifer Systems of Northeastern Illinois
(Source: Hughes et al., 1966)

bedrock (Sasman et al., 1981). The water that recharges the sand and gravel aquifers is derived mostly from precipitation.

Groundwater in the shallow bedrock aquifer occurs in joints, fissures, and solution cavities. Because the water-bearing openings are irregularly distributed both vertically and horizontally, the yields of wells in this aquifer vary greatly from place to place. The shallow bedrock aquifer is recharged from overlying glacial deposits or directly from precipitation where it is not covered by drift. The upper part of the Silurian Dolomite is usually the most productive.

The groundwater yield of various units is strongly affected by the geologic "setting," but particularly by the material that overlies the unit. As mentioned earlier, a good hydraulic connection exists between Silurian Dolomite and overlying glacial drift. The yield of the deeper sandstones is mainly a function of primary permeability, that is, the movement of water through openings between individual grains. Table 3.2 illustrates how variations in geologic setting affect the specific capacity* of certain geologic units.

All of the domestic wells and some of the public and industrial wells in the project area tap the shallow aquifer. Although detailed data are not available on the water withdrawals for domestic use, it is estimated that in 1982 in DuPage County about 22% of the water pumped from the shallow aquifer was used for domestic use and irrigation (Sasman, 1984).

An overview of public and industrial water withdrawals within the project area is presented in Table 3.3. The table shows that public wells make far greater demands on the aquifer systems than industry. Total withdrawal from the shallow aquifer for public and industrial use is about 59 million gallons per day. Allowing for an additional 22% of domestic withdrawal, it can be concluded that 72 million gallons per day was withdrawn during 1980 from the shallow aquifer in the project area. The greatest demand on the shallow aquifer is made in the townships T. 38 N., R. 11 E. and T. 39 N., R. 10 E., in the northeastern portion of DuPage County. Demand in the Cook County portion of the project area (R. 12 E.) is rather low because most of that area is supplied with water from Lake Michigan. Plans to supply the rest of the project area with water from Lake Michigan have been under development for years. These plans have not been taken into consideration in this report.

*Specific capacity refers to the yield of a well in gallons per minute, divided by the drawdown in the well, expressed in feet.

Table 3.2 Specific Capacities of the Silurian Dolomite, Galena-Platteville Dolomite, and Maquoketa Group under Various Geologic Conditions

Unit	Conditions	Specific Capacity[a] [gal/min • ft]
Silurian Dolomite	Directly underlies glacial drift	0.1
	Underlies bedrock	0.012
	Silurian in bedrock upland	0.23
	Silurian in bedrock valley	0.067
	Upper 33% of aquifer	0.20
	McHenry County	
	Lower 67% of aquifer	0.039
Galena-Platteville Dolomite	Directly underlies glacial drift	0.071
	Directly underlies bedrock (not uppermost bedrock)	0.018
Maquoketa Group	Overlain by bedrock - DuPage County	0.015

[a]Values represent specific capacities per foot of penetration measured in 50% of the wells and adjusted to a well radius of 0.5 foot and a pumping period of 12 hours.

Source: Hughes et al. (1966).

Town-ship and Range	Public				Self-Supplied Industry					
	Sand and Gravel	Silurian	Cambrian-Ordovician	Total	Surface Water	Sand and Gravel	Silurian	Cambrian-Ordovician	Total	Total
36N08E	0	0	0	0	0	0	0	0	0	0
36N09E	0	0.376	0.611	0.987	0.468	0	0.005	0	0.474	1.461
36N10E	0	0.965	2.638	3.604	629.183	0	0.201	0.738	630.122	633.726
36N11E	1.609	1.030	0	2.639	1638.554	0	0.050	0	1638.604	1641.243
36N12E	0	2.411	0.761	3.172	0	0	0.281	0	0.281	3.454
37N08E	0	0.113	0.422	0.536	0	0	0	0.744	0.744	1.279
37N09E	0	0	0	0	0	0	0	0.005	0.005	0.005
37N10E	0	3.731	0.458	4.190	6.148	0	0.030	0.202	6.380	10.569
37N11E	0	0.003	1.156	1.159	4.117	0	0.839	0.386	5.343	6.501
37N12E	0	0.054	0.440	0.493	0	0	0.130	0.010	0.140	0.633
38N08E	0	0.164	8.819	8.983	0	0	1.377	0.125	1.502	10.485
38N09E	0	3.329	2.378	5.707	0	0	0.146	0.122	0.268	5.975
38N10E	0	5.350	1.441	6.791	0	0	0.134	0.036	0.170	6.961
38N11E	0	9.300	2.671	11.971	0	0	0.385	0	0.385	12.355
38N12E	0	2.843	2.098	4.942	0.960	0	0.327	3.344	4.631	9.573
39N08E	0	0	3.271	3.271	0.168	0	0.118	0.036	0.322	3.592
39N09E	0	0.765	1.767	2.532	1.149	0	0.053	<0.001	1.202	3.734
39N10E	0	8.138	0	8.138	0.002	0	0.092	0	0.094	8.232
39N11E	0	2.317	10.996	13.313	0.015	0.015	0.070	0.172	0.272	13.585
39N12E	0	0	4.108	4.108	0.651	0	0.061	0.232	0.944	5.052
40N08E	1.203	0	2.356	3.559	0	0	<0.001	0.144	0.144	3.703
40N09E	0.179	0	1.248	1.426	3.552	0	0.110	0.205	3.866	5.293
40N10E	1.129	4.894	1.166	7.188	0	0	0.050	0	0.050	7.238
40N11E	1.296	3.474	5.889	10.660	0	0	0.047	0	0.047	10.707
40N12E	0	0	0	0	0	0	0.033	0.768	0.801	0.801
Total	5.416	49.257	54.694	109.369	2284.967	0.015	4.539	7.269	2296.791	2406.157

Source: Modified from Kirk et al. (1982).

TABLE 3.3 Public and Industrial Water Withdrawals within the Project Area, 1980

Most production from the deeper aquifers is from T. 38 N., R. 08 E., the southeastern corner of Kane County, including the City of Aurora; and T. 39 N., R. 11 E., which includes Elmhurst (see Fig. 3.11).

Records of the Illinois State Water Survey show a total of 531 public and industrial wells within the project area for which current production is recorded. Out of this total, 145 wells draw from the deeper aquifers. The greatest concentration of these deep wells is in T. 38 N., R. 08 E. (22 wells) and T. 39 N., R. 11 E. (19 wells).

The deep bedrock aquifer systems -- Cambrian-Ordovician and Mt. Simon -- are recharged where they crop out at the surface or where they immediately underlie glacial drift to the west and north. In addition, they gain some water from downward leakage through the Maquoketa Shale. The Galena-Platteville Dolomite, which is hydraulically connected to the underlying sandstones, forms the upper unit of the deep bedrock aquifer systems. The base of the lower unit is the top of the Precambrian crystalline basement (Fig. 3.3). Rocks of lower permeability in the upper and middle parts of the Eau Claire Formation (Fig. 3.19) separate the two deep bedrock aquifer systems.

Groundwater production from the Galena-Platteville Dolomite in the project area is practically nil, which can be attributed to several factors. The main factor is that the drop in the piezometric surface (groundwater level) of the Cambrian-Ordovician aquifer has resulted in dewatering of this unit. The lower dolomite is, furthermore, rather impermeable, resulting in low yields even before the piezometric surface dropped to its present level. Finally, the dolomite underlies the Maquoketa Shale, which restricts its potential yield even further (Table 3.2).

Extensive development in the project area has greatly increased the demand for groundwater. Because groundwater is being extracted at a rate that exceeds recharge, critical drops have occurred in the piezometric surface. Pumpage from deep wells in the Chicago region increased from 200,000 gallons per day in 1864 to 177 million gallons per day in 1980. As a result, water levels in wells tapping the deep aquifers in the Chicago area have declined more than 850 feet (Kirk et al., 1982). On the basis of 1980 data, it can be determined that the piezometric surface of the deep aquifer projects within or below the Galena-Platteville Dolomite over most of the project area.

In 1980 the deepest cones of depression in the Chicago region were in the vicinity of Elk Grove Village, Elmhurst, and Joliet, where some levels were more than 200 feet below MSL (Sasman et al., 1982). Pronounced cones of depression (Fig. 3.20) were apparent at Arlington Heights, Mt. Prospect,

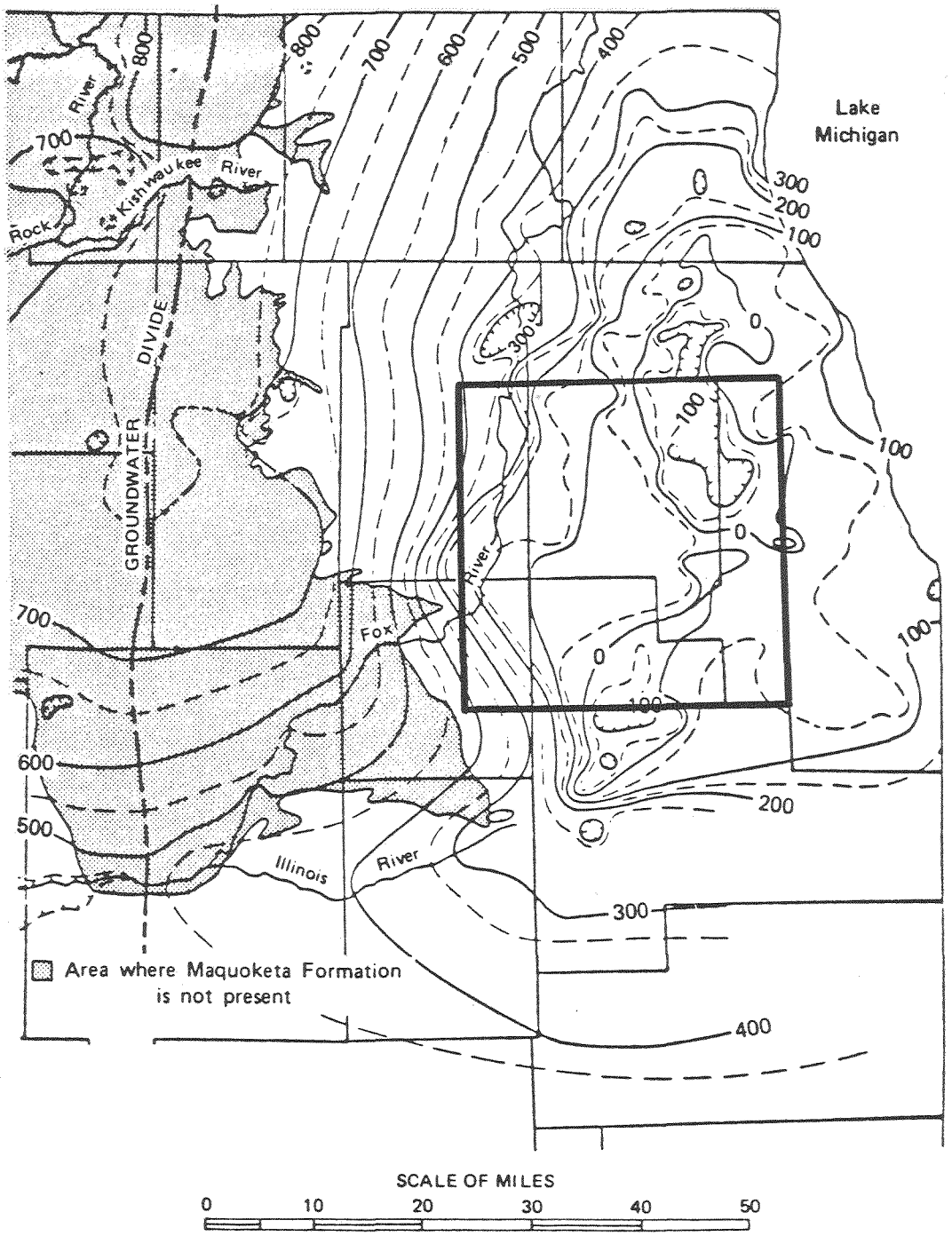


Fig. 3.20 Elevation of the Piezometric Surface of the Cambrian-Ordovician Aquifer in the Chicago Region, October 1980 (feet above mean sea-level) (Source: Sasman et al.,1982)

Bensenville, Bellwood, Oakbrook, and Elgin. Areas enclosed by the zero-foot MSL piezometric contour centered around Joliet and Elmhurst, but included almost all of western Cook, most of eastern DuPage, and a large area of northwestern Will counties. Contours of -100 feet MSL enclosed several square miles in northern Cook County, western Cook and eastern DuPage counties, and the Joliet area in Will County. The piezometric surface was below the top of the St. Peter Sandstone in large areas of northern Cook and eastern DuPage counties and in the Joliet area.

Construction of the proposed SSC tunnel system is expected to have little or no effect on the deep wells that penetrate the Galena-Platteville Dolomite, except for wells whose locations happen to coincide with the tunnel alignment. Wells tapping the deeper aquifer receive practically no water from the Lower Dolomite. More recent wells are cased through this unit, whereas older wells are cased only into the upper part of the Galena Dolomite. For these older wells, a slight risk exists of a hydraulic connection between the tunnel and the well which could result in cement grout reaching the well. If this were to occur, it might not only affect the quality of the well water, but might also potentially damage the well pump.

3.1.4 Rock Mass Evaluation

A considerable amount of geologic investigation will have to precede the design of the SSC beam tunnel. The first phase should include collection, analysis, and evaluation of all existing pertinent data. Initial efforts should be concentrated on the western portion of the project area to confirm the present recommendation that the Silurian Dolomite be excluded from consideration as a host unit. Should the initial work, including a certain amount of subsurface exploration, indeed preclude using the Silurian Dolomite, then all further efforts should be concentrated on the favorable, but deeper, Galena-Platteville Dolomite.

The first phase of work should also include an inventory of all the wells that reach or penetrate the potential host unit(s) within about five miles of either side of the projected tunnel alignment. Logs of these wells should be evaluated to determine subsurface geology, well diameters, casing schedules, pump characteristics, etc. Further information can be gathered for the Galena-Platteville Dolomite by examining natural outcrops and additional quarries, and by visiting some of the old lead mines in northwestern Illinois that are situated in this unit.

Subsurface exploration will require a number of core holes, the most reliable means of evaluating subsurface conditions. Core holes should be located at or near each of the projected shaft sites. Each of these borings

should be cored and sampled over the entire stratigraphic section, from "top of rock" to the base of the Platteville. For economy, tunnel conditions in the Lower Dolomite between shafts can be evaluated by tri-cone drilling through the Maquoketa Shale, with coring limited to the Galena-Platteville Dolomite. A minimum of about 75 core holes will probably be required for the subsurface evaluation: one hole per mile of tunnel, with about 15 additional holes to check anomalies. If each hole is considered representative of an area of 0.5 mile radius, the borings do not have to coincide exactly with the tunnel alignment.

All cores must be described in detail, with special attention paid to the description of joints and other rock defects. Comprehensive laboratory tests should be performed on representative core samples to determine such characteristics as unconfined compressive strength, tensile strength, specific gravity, static and dynamic modulus of elasticity, abrasion resistance, chemical composition, etc. In situ testing, such as water-pressure testing and potentially some down-the-hole geophysical logging, should be conducted on the boreholes.

Correlation of geologic characteristics and laboratory and field data should lead to a geotechnical design report that can serve as the basis for the final tunnel and shaft design.

During the geologic investigations, it is particularly important to obtain information on the defects of the rock mass through which the tunnel will be excavated. In other words, the structural condition of the rock mass is one of the most important criteria in designing a deep underground excavation. To quote Terzaghi (1946): "From an engineering point of view, a knowledge of the type and intensity of the rock defects may be much more important than the type of rock which will be encountered."

To arrive at an objective evaluation of the rock mass, one has to determine not only the quality of the intact rock material, but also the larger framework within which the various pieces fit, that is, the rock mass (Fig. 3.21). One also has to employ a suitable classification of rock mass.

Various classifications have been suggested to aid in describing a rock mass for underground excavation using data that can be obtained during initial investigations. One such classification was proposed by Bieniawski of the South African Council of Scientific and Industrial Research (CSIR). This classification, which is described by Hoek and Brown (1980), is finding general acceptance. Its main parameters are given in Table 3.4. Ratings are given for various ranges of values of the parameters, and certain adjustments are made for the effect of the strike and dip orientation of joints relative

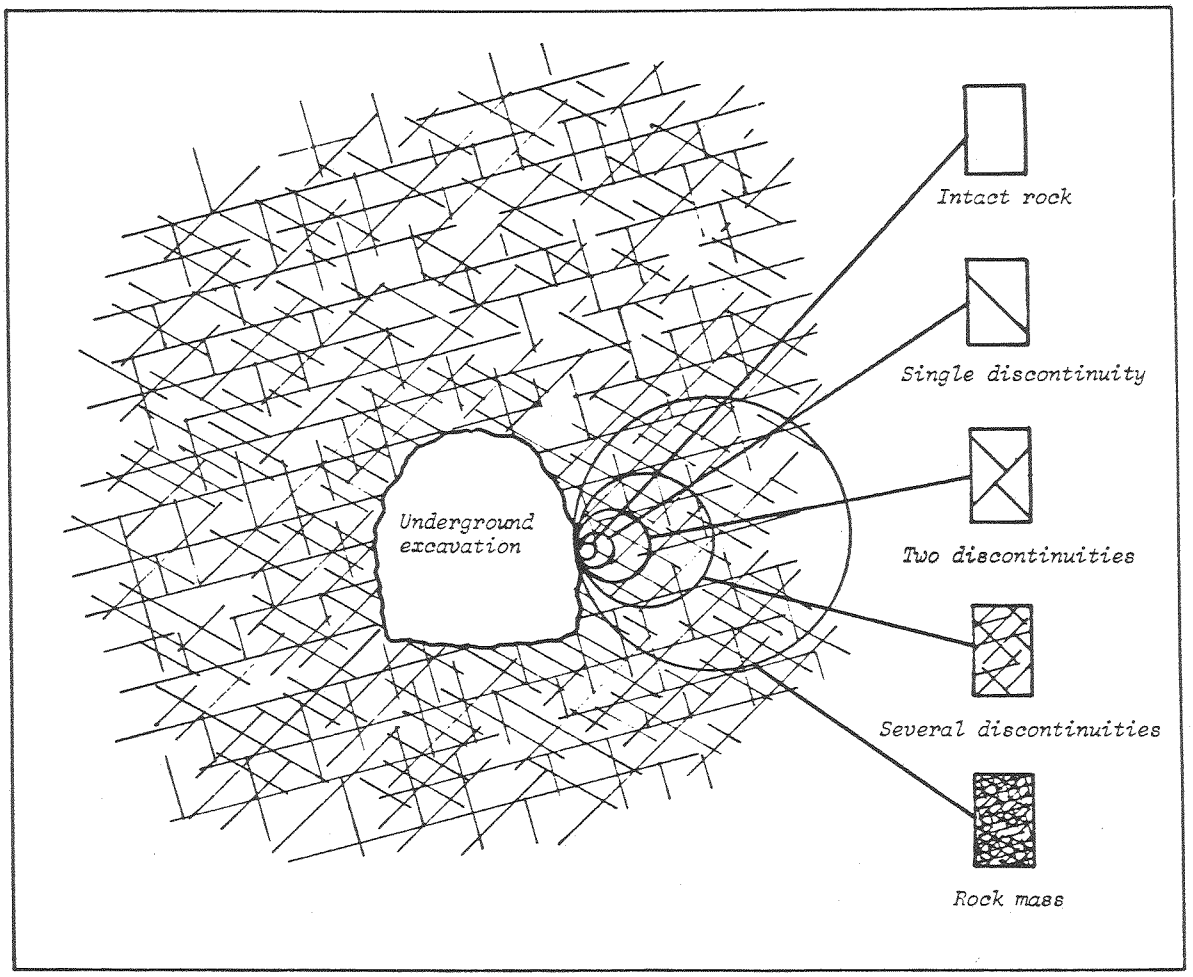


Fig. 3.21 Diagram Showing the Relationship of Intact Rock and Rock Mass with Increasing Sample Size (Source: Hoek and Brown, 1980)

Table 3.4 CSIR Geomechanics Classification for Jointed Rock Masses

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

PARAMETER			RANGES OF VALUES						
1	Strength of intact rock material	Point load strength index	> 8 MPa	4 - 8 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred		
		Uniaxial compressive strength	> 200 MPa	100 - 200 MPa	50 - 100 MPa	25 - 50 MPa	10-25 MPa	3-10 MPa	1-3 MPa
	Rating		15	12	7	4	2	1	0
2	Drill core quality RQD		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%		
	Rating		20	17	13	8	3		
3	Spacing of joints		> 3 m	1 - 3 m	0.3 - 1 m	50 - 300 mm	< 50 mm		
	Rating		30	25	20	10	5		
4	Condition of joints		Very rough surfaces Not continuous No separation Hard joint wall rock	Slightly rough surfaces Separation < 1 mm Hard joint wall rock	Slightly rough surfaces Separation < 1 mm Soft joint wall rock	Slickensided surfaces or Gouge < 5 mm thick or Joints open 1 - 5 mm Continuous joints	Soft gouge > 5 mm thick or Joints open > 5 mm Continuous joints		
	Rating		25	20	12	6	0		
5	Ground water	Inflow per 10 m tunnel length	None		< 25 litres/min.	25 - 125 litres/min	> 125 litres/min		
			OR		OR	OR	OR		
		Ratio $\frac{\text{joint water pressure}}{\text{major principal stress}}$	0		0.0 - 0.2	0.2 - 0.5	> 0.5		
			OR		OR	OR	OR		
		General conditions	Completely dry		Moist only (interstitial water)	Water under moderate pressure	Severe water problems		
	Rating		10		7	4	0		

B. RATING ADJUSTMENT FOR JOINT ORIENTATIONS

Strike and dip orientations of joints		Very favourable	Favourable	Fair	Unfavourable	Very unfavourable
Ratings	Tunnels	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	-60

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 — 81	80 — 61	60 — 41	40 — 21	< 20
Class No	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. MEANING OF ROCK MASS CLASSES

Class No	I	II	III	IV	V
Average stand-up time	10 years for 5 m span	6 months for 4 m span	1 week for 3 m span	5 hours for 1.5 m span	10 min. for 0.5 m span
Cohesion of the rock mass	> 300 kPa	200 - 300 kPa	150 - 200 kPa	100 - 150 kPa	< 100 kPa
Friction angle of the rock mass	> 45°	40° - 45°	35° - 40°	30° - 35°	< 30°

THE EFFECT OF JOINT STRIKE AND DIP ORIENTATIONS IN TUNNELLING

Strike perpendicular to tunnel axis				Strike parallel to tunnel axis		Dip 0° - 20° irrespective of strike
Drive with dip		Drive against dip				
Dip 45° - 90°	Dip 20° - 45°	Dip 45° - 90°	Dip 20° - 45°	Dip 45° - 90°	Dip 20° - 45°	
Very favourable	Favourable	Fair	Unfavourable	Very unfavourable	Fair	Unfavourable

Fig. 3.22 Geologic Cross Section along Proposed Tunnel Alignment

to tunnel orientation.

If our present knowledge about the Galena-Platteville Dolomite is conservatively applied to the CSIR classification, the rock mass can be classed as "good rock." This conclusion can be reached as follows:

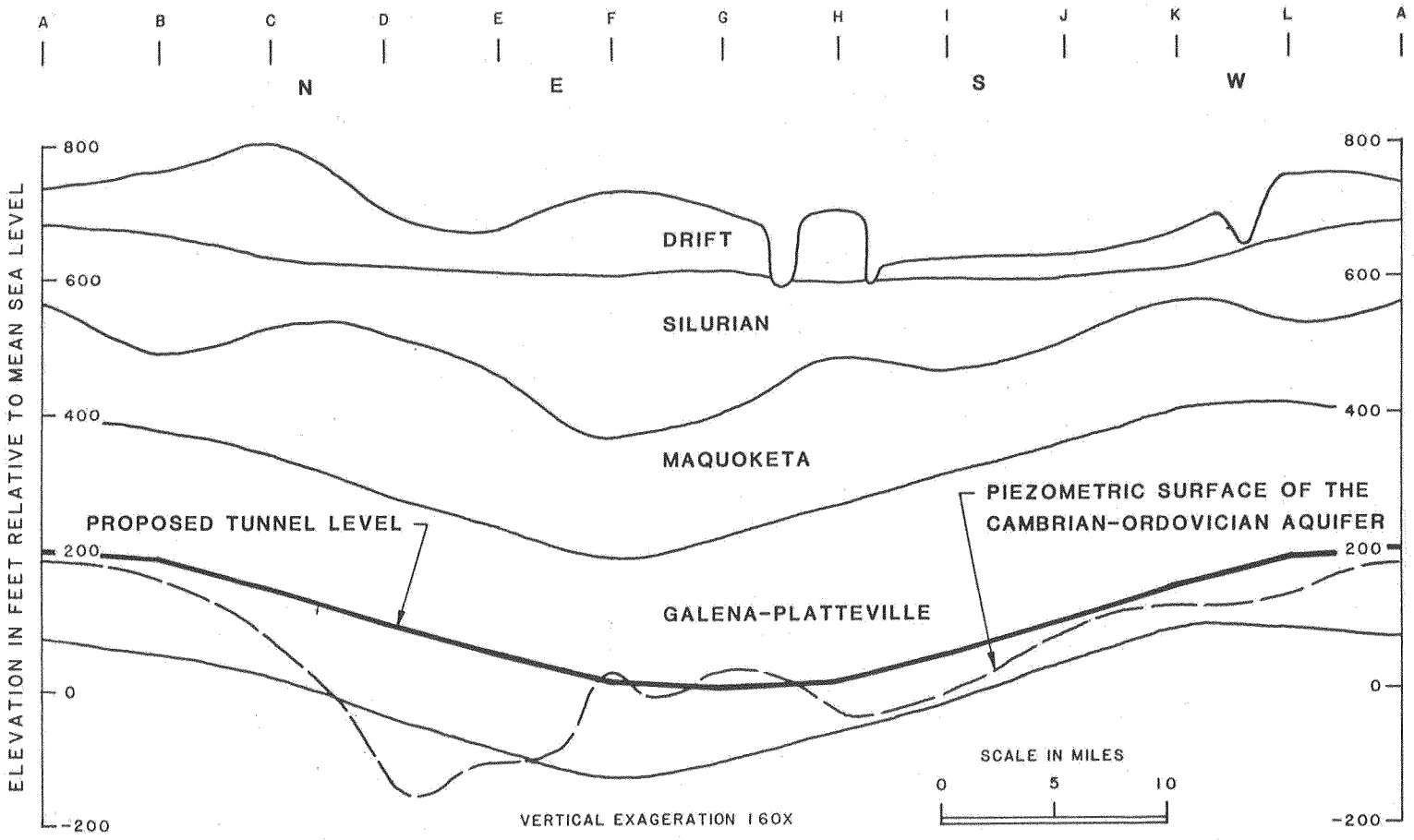
1. Uniaxial (unconfined) compression strength is 12,000 psi (= 83 MPa) -- rating 8.
2. Average RQD is 82% -- rating 17.
3. Joint spacing is assumed to be comparable to that encountered in the Silurian Dolomite, that is, greater than three meters -- rating 30.
4. On the basis of the descriptions of the cores from the 63 TARP holes, the joints should have slightly rough surfaces and a separation of less than one millimeter -- rating 12.
5. Groundwater inflow can be expected to be less than 25 liters per minute per 10 meters of tunnel length - rating 7.

These five factors result in a total rating of 74. Because the joints are expected to be subvertical and because the effects of strike will range from very favorable to unfavorable around the subcircular plan of the tunnel, an adjustment factor of 5 is warranted, resulting in an adjusted rating of 69. Even with this adjustment, the rock mass is classed as good rock (Table 3.4). It should be noted, however, that further west the rock mass rating for the Galena-Platteville is expected to be a few points lower when it is not covered by the Maquoketa Shale and where, as a result, it will have a higher groundwater yield and ground water pressure.

3.1.5 **Recommendations**

On the basis of our present knowledge of subsurface conditions in the project area, the Galena-Platteville Dolomite best satisfies the criteria of a good host unit for the SSC tunnel system. The general attitude of the unit along the proposed alignment is shown in Fig. 3.22. Subsequent review of all available well logs for the project area will permit refinement of this cross section, but the general position of the various units is believed to be as shown. The regional dip of the 325-foot thick Galena-Platteville Dolomite is about 11 feet per mile to the east-southeast. To minimize geologic constraints, the SSC tunnel system should have a dip that generally coincides with the regional dip of the strata. Such an attitude will result in the base elevation of the system being 200 feet lower at Argonne (shaft G) than at Fermilab (shaft A). The proposed system is symmetrical around the line A-G.

Projection of the tunnel system within the host unit must take into account that not only the tunnel, but also the various chambers, must be


A
B
C
D
E
F
G
H
I
J
K
L
A
N
E
S
W
800
600
400
200
0
-200
ELEVATION IN FEET RELATIVE TO MEAN SEA LEVEL
DRIFT
SILURIAN
MAQUOKETA
GALENA-PLATTEVILLE
PROPOSED TUNNEL LEVEL
PIEZOMETRIC SURFACE OF THE
CAMBRIAN-ORDOVICIAN AQUIFER
SCALE IN MILES
0
5
10
VERTICAL EXAGERATION 160X

located within the favorable host rock such that a sufficient thickness of sound rock be maintained above the crown of the excavations to ensure optimum stability. The thickness of rock above the crown should at least equal the width of the excavation. Some of the IR halls at Fermilab and Argonne could have a height of about 100 feet and a maximum width of 100 feet. To ensure sufficient rock mass above the crown of the excavations, these halls will have to be sited rather deep in the Galena-Platteville Dolomite. The hall floor elevation at Fermilab would have to be at least as deep as 160 feet above MSL, whereas the corresponding elevation at Argonne would have to be about 40 feet below MSL.

The center of the detectors projects about 40 feet above the floor level of these halls. As a consequence, the tunnel will have to cross the IR hall(s) at Fermilab at an elevation of about 200 feet above MSL. At Argonne this elevation will have to coincide with MSL.

Tunnel elevations and depths below the land surface at the sites of shafts A-L are presented in Table 3.5. The maximum tunnel slope (at D and J) will be about 2.1/1000. On this projection, the tunnel would be in the Nachusa or the Grand Detour formations (Fig. 3.15) for most of its length and in the lowest part of the Wise Lake-Dunleith Formation (Fig. 3.14) for the northerly portion.

On the basis of our current knowledge of these formations, most of the machine-bored tunnel will not require a lining. However, some form of support may be required for the occasional shear zones that are encountered. Rock reinforcement by means of rock bolts or applications of shotcrete may be needed; in some instances, a cast-in-place concrete lining may even be required. At this time, it is expected that a lining will be required for less than 5% of the tunnel. However, linings will definitely be required for the various shafts, especially where they pass through overburden and the Maquoketa Shale. Furthermore, it is assumed in this document that all of the chambers will be lined. Many large underground chambers, however, rely solely on rock bolts, often in combination with shotcrete, for structural support. Further work may well prove that at least some of the chambers will not require a cast-in-place concrete lining, provided the excavation work is done by controlled drilling and blasting.

Local remedial work is referred to in this text as "dental" work and will be required throughout the rock excavations. Such dental work generally requires the removal of loose, broken, or soft material along rock joints, bedding seams, or fracture zones. The resulting voids, as well as any other open spaces such as those along fractures, are subsequently filled with concrete or mortar to ensure the structural integrity of the excavation.

Table 3.5 Depths and Elevations for Shafts A-L (feet)

Shaft	Approximate Surface Elevation[a]	Tunnel Floor		Galena-Platteville	
		Elevation[a]	Depth[b]	Top Elevation[a]	Base Elevation[a]
A	740	+200	540	+425	+100
B	760	+190	570	+375	+ 50
C	800	+150	650	+345	+20
D	700	+100	600	+290	-35
E	675	+50	625	+250	-75
F	730	+10	720	+195	-130
G	700	MSL	700	+225	-100
H	700	+10	690	+245	-80
I	630	+50	580	+330	+5
J	635	+100	535	+325	MSL
K	670	+150	520	+415	+90
L	750	+190	560	+415	+90

[a]All elevations are referenced to the MSL datum.

[b]Depth below ground surface.

To limit groundwater inflow into the underground workings, a certain amount of grouting will have to be done. Conventional cement grouting is expected to eliminate most of the water inflow. Chemical grout may be required in areas where the fractures are too tight to permit entry of cement. The grouting work should eliminate any significant water inflow. However, the final excavation should not be expected to be dust dry. Water inflow for the completed tunnel may well be on the order of 15 gallons per minute per mile. Some leaks cannot be grouted, and eliminating the last few gallons of inflow becomes prohibitively expensive.

It should be realized that at some time in the not too distant future, water from Lake Michigan may be supplied to most of the project area. Should this occur, a recovery of the piezometric surface of the Cambrian-Ordovician aquifer system can be expected. Therefore, grouting of the tunnel system will have to aim not only at precluding water inflow based on current piezometric surfaces but also at sealing potential pathways for groundwater inflow.

Favorable geologic conditions in the Chicago area have contributed significantly to the relatively low cost of the TARP tunnels constructed over the past 10 years. A study by the National Committee on Tunneling Technology confirmed the TARP tunnels to be less costly than any other tunnels constructed in the United States over the last 20 years, when tunnel costs are compared on a volume basis (Rose, 1984). In view of the many similarities between the upper and lower dolomites, the cost for the SSC tunnel can be expected to be low relative to similar tunnels excavated in other parts of the United States.

3.2 SSC MAIN RING FACILITY DESIGN AND CONSTRUCTION

Components of the SSC main ring facility include the main tunnel, access shafts, refrigeration/compressor stations, power supplies, buildings, underground enclosures for radio frequency cavities, injection systems, beam dumps, and experimental areas where the beams collide. On the basis of the arguments outlined in Sec. 3.1, it is assumed that all underground facilities will be located in the Galena-Platteville Dolomite.

3.2.1 Main Tunnel

The main tunnel is projected to have a total length of 63.6 miles and to be constructed at an average depth of 600 feet below the surface. To optimize both costs and scheduling, the project has been divided into six tunneling contracts, each covering a 10.6-mile section.

The main tunnel will likely be excavated by tunnel boring machines (TBM's). The advantages of tunnel boring are:

A smooth excavation surface,
Minimal disturbance of surrounding rock,
Minimal lining requirements,
Little or no disturbance for people at the surface,
Reduced safety hazards compared with the drill-and-blast method (no personnel at the face), and
Low manpower requirements.

TBM's designed to excavate 10- to 15-foot diameter tunnels are electrically powered and typically require 1-1.5 megavolt-amperes, which can be provided through a 13,200 volt power line.

Construction of the TARP project in the Chicago area has generated extensive information on advance rates in the Silurian Dolomite. It is expected that the rate of penetration in the Galena-Platteville Dolomite will be comparable to that in the Silurian Dolomite because the mechanical properties of the two formations are similar. Based on the TARP experience, the following values are assumed for the penetration rate:

Tunnel Diameter (feet)	Instantaneous Rate of Penetration (linear feet/hour)
10	12
12	10
15	8

As might be expected, the instantaneous rate of penetration decreases as the tunnel diameter increases. A 10-foot diameter tunnel is the smallest that can efficiently accommodate the materials-handling function and the movement of personnel over long distances in the tunnel during construction. In addition, at least a 10- or 12-foot diameter tunnel will be required for efficient installation and operation of the SSC machine. For these reasons and others outlined in Sec. 2.2, smaller-diameter tunnels were not considered.

The overall rate of advance, which is related to the instantaneous penetration rate, also depends on a host of other parameters such as the extent of ground support requirements, cycle time of the muck-handling system, machine repair and maintenance downtime, and operator skill and competence.

The combined effect of the above factors is a reduction of the penetration rate by a multiplication factor referred to as machine utilization. For a tunnel bored with a TBM, machine utilization is typically 30-50%.

It is the consensus of this study group and the tunnel contractors that were contacted that the 10-foot diameter tunnel will be subject to lower machine utilization than the 12- and 15-foot diameter tunnels. The smaller size of the 10-foot diameter tunnel makes muck handling and movement of materials and personnel less efficient. Therefore, it is assumed that machine utilization is 40% for 12-foot and 15-foot diameter tunnels and only 33% for 10-foot diameter tunnels.

Based on the above discussion, the average monthly advance rate for differently sized tunnels and the tunnel completion period for each 10.6-mi tunnel segment are as follows:

Tunnel Diameter (feet)	Average Monthly Advance Rate (feet)	Tunnel Construction Period (months)
10	1620	35
12	1560	36
15	1260	45

The above data show that the advance rate for a 12-foot diameter tunnel is only slightly lower than the rate for a 10-foot diameter tunnel. Because of the increased efficiency and working space gained from selecting a 12-foot diameter tunnel, this diameter is recommended for the SSC beam tunnel.

The time needed for tunnel construction can be decreased by using more TBM's. However, increasing the number of TBM's will result in substantial increases in total costs due to capital expenditures for extra TBM's and perhaps for additional access shafts.

Excavation Plan

Although there are many possible ways to proceed with the tunnel construction, we have focussed on one particular scheme as an example. Tunnel excavation using TBM's is assumed to start from five points on the ring (points A, C, G, I, and K in Fig. 3.23). Thus, each TBM will excavate a 10.6-mile section as follows:

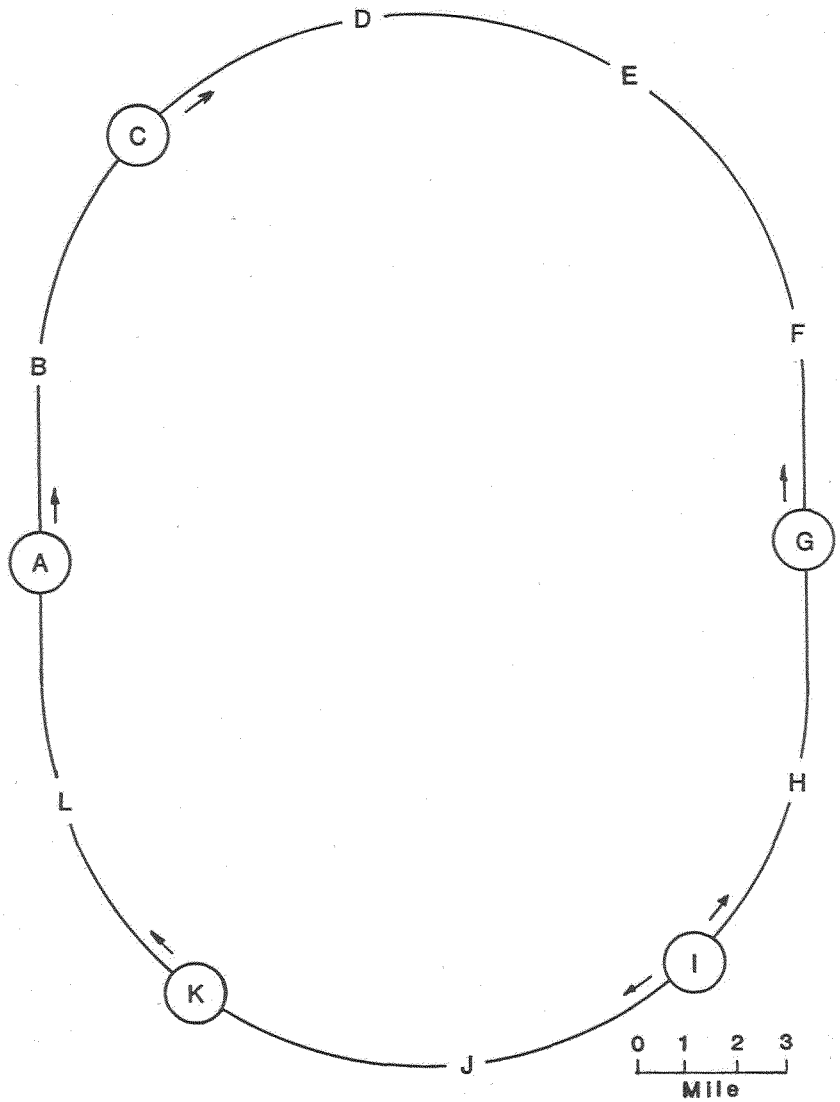


Fig. 3.23 Beam Tunnel Layout; the Six Tunnel Boring Machines Will Start From the Circled Shafts and Work in the Directions Shown.

1. From point A clockwise to C. Once point B is reached, the muck (spoil) will be hoisted to the surface from shaft B.
2. Same procedure as in 1 for the K-A and C-E sections.
3. Same procedure as 1 for the G-E section, except that excavation will proceed counterclockwise.
4. Two TBM's will start excavating from point I in opposite directions to complete the I-K and I-G sections. The shaft at I must be large enough to handle the muck excavated by both TBM's. Ample acreage is available around point I for temporary stockpiling of spoil.
5. Once the TBM's reach the next shaft location (midpoint of their run), the muck will be hoisted from the new shaft. Grouting of the tunnel, dental work, and pouring concrete floors will be carried out in the first portion (5.3 miles) of each tunnel section. Upon completion of these tasks, magnet installation can proceed.

Following this anticipated scheme, muck will be taken out at each of the 12 shafts except E, where the C-E and G-E TBM's would meet at the end of their run. (Actually, one of the TBM's would excavate a little beyond E to permit shaft excavation and removal of TBM's.) Once these two sections are completed, a raise would be bored to the surface at E and subsequently slashed to full size, with the muck being hauled away to either point F or point D and hoisted to the surface. Therefore, disturbance of the surface at E will be at an absolute minimum during construction and will occur only during the final phase of tunnel excavation.

Materials Handling

From the standpoint of energy consumption, a rail system is by far the most efficient materials-handling system presently available for tunnel construction. It also satisfies all materials-handling needs by allowing transport of supplies, spare parts, and construction materials to the tunnel face. Because of its fixed guidance system, relatively small clearance limits can be tolerated. Rails are attached to specially shaped ties so that backfilling the floor to obtain a flat surface is not required. This configuration results in maximum clearance between the vent line and the muck cars.

To transfer rock from the TBM to the muck cars, a trailing floor and mobile gantry is used (Meyer and Paschen, 1981). The installation consists of a number of individual rolling platforms approximately 20 feet in length that are coupled to form a continuous mobile platform ranging in length from 250 to 800 feet. The trailing floor and gantry is towed with cables that are attached to the rear of the TBM and rides on tunnel track that is laid

directly behind the mining machine. Empty muck cars are moved up a ramp onto the trailing floor, loaded with tunnel muck, and returned to a work shaft for transfer of the rock to the surface. The gantry is also the superstructure base that supports conveyors, electrical transformers and switchgear, ventilation pipe erectors, and other equipment.

Mechanical excavation results in small prismatic fragments, or chips. The resulting increase in volume is usually higher than that experienced when excavating by drilling and blasting. Based on the TARP experience, a "swell factor" of 1.8 is assumed.

Given the train cycle time (average travel speed = 10 miles per hour) and the need for peak production, the number and size of muck cars and locomotives needed per tunnel segment for each tunnel size are shown in Table 3.6.

Three types of locomotives are in common use in mining and tunnel construction: diesel, battery, and trolley powered. The choice of locomotive is usually made by the tunnel contractor. Diesel locomotives require a large fresh air flow to dilute the exhaust fumes. Battery-powered locomotives need to be recharged regularly. Trolley-powered locomotives require installation of overhead lines along the whole length of the tunnel and grounding of the rails. Battery- and trolley-powered locomotives are used extensively in mining operations both in North America and overseas. However, because U.S. tunnel contractors prefer diesel-powered locomotives, it is assumed that diesel-powered locomotives will be used for the SSC tunnel system.

Ventilation Requirements

Life support is the primary goal of ventilation. However, proper ventilation, including conditioning and cooling of the air when necessary, provides other important benefits: dilution and removal of dust and toxic and explosive gases (if any), and removal of heat and excess humidity from the work environment.

Calculation of the total fresh air requirement is based on the diesel fumes emitted from the locomotives and assumes a dilution factor of 100 cubic feet per minute per horsepower. The required amounts of air for the 10-, 12-, and 15-foot diameter tunnels are 20,000, 25,000, and 30,000 cubic feet per minute, respectively. For very long tunnels, current practice is to install axial booster fans in the vent line as the tunnel progresses. With this system, pressure extremes are reduced, and capacity is added only as it is needed. If it is assumed that fans will be added every 3000 feet, 20 fans, each capable of providing a pressure of 10 inches water gauge, are needed for each 10.6 miles of tunnel. Based on the air flows given above, ventilation

ducts of 34-, 38-, and 40-inch diameters are needed for the 10-, 12-, and 15-foot diameter tunnels, respectively. Tunnel cross sections with ventilation ducts and muck cars are shown in Fig. 3.24.

3.2.2 Access Shafts

To provide cooling for the superconducting magnets, 12 equally spaced refrigeration/compressor stations are called for in the design of the SSC ring. The vertical shafts associated with these stations will also be used as access shafts for construction, human and materials access, and ventilation purposes. We have assumed that, except for the IR's, no additional shafts will be required. Six of the shafts will be used by tunnel contractors to access the tunnel horizon and lower the TBM's. Once the first six shafts are completed, tunnel boring can start, and the remaining shafts can be sunk. In

Table 3.6 Materials-Handling Requirements per Contract

Equipment Requirements	Tunnel Diameter 10 feet	12 feet	15 feet
Number of locomotives	2	2	2
Locomotive size (tons)	15	20	25
Locomotive horsepower	200	250	300
Track gauge (inches)	24	30	36
Number of cars per train	10	10	10
Muck car size (cubic yards)	6	8	10
Muck car length (inches)	120	120	120
Muck car width (inches)	42	54	60
Muck car height (inches)	54	60	66

addition to the 12 shafts associated with the refrigeration stations, a minimum of four shafts with an outside diameter of 28 feet are needed to provide access to the IR halls. All shafts will be excavated to the depth of the tunnel or the floors of the IR halls.

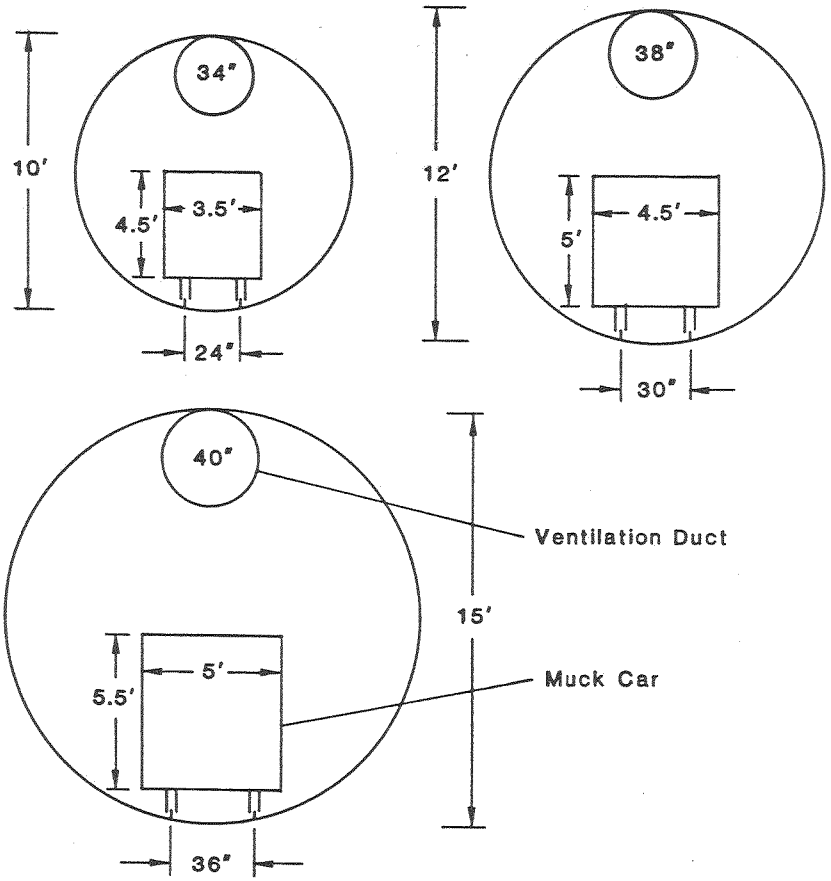


Fig. 3.24 Tunnel Cross Section Showing Ventilation Ducts and Muck Cars for Three Sizes of Tunnel

Either drum-type or friction-type hoisting systems will be used to hoist the broken rock (muck) and to handle supplies, equipment, and personnel. The shafts must be large enough for the above-mentioned functions and must provide space for utilities, emergency ladderways, and ventilation ducts (Fig. 3.25). In the longer term, the hoisting compartments in the shafts must be large enough to lower the dewars and cold boxes to be used in the refrigeration systems. Based on these requirements, shafts of 20-, 22-, and 26-foot inside diameter are required for 10-, 12-, and 15-foot diameter tunnels, respectively.

Once the 100 feet of overburden has been removed, shafts can be constructed by conventional drill and blast methods, blind drilling, or raise boring. Conventional drilling and blasting is the most common technique used for sinking large shafts because of its greater flexibility and lower capital expenditure requirements.

Blind drilling of shafts is performed by rotating a drill bit, stabilizers, and weights at the lower end of a string of drill pipe. Rotary drilling becomes advantageous only as the hole size decreases or as the formations become softer. Drilled shafts are generally used for smaller-diameter holes, such as ventilation and emergency-escape shafts. Blind drilling is usually competitive with drill-and-blast techniques for shaft diameters less than 12 feet.

Raise boring of shafts is subject to the same restrictions as blind drilling, as regards shaft diameter and rock hardness. In addition, raise boring requires that the bottom of the shaft be accessible to attach the cutterhead to the drill string and ream the hole upward. This requirement causes scheduling problems, because construction of the shaft cannot start until tunnel excavation has proceeded past the shaft location.

Therefore, it is assumed that all shafts except E will be sunk conventionally by drilling and blasting. A particular contractor could choose an alternative method of shaft sinking, but for the relatively large diameter shafts envisioned in this study, the use of alternative methods appears neither practical nor economical.

In conventional drill-and-blast methods, shaft sinking proceeds by drilling a pattern of small-diameter blastholes in the shaft bottom, loading them with explosives, detonating the explosives to fracture the rock, and removing the broken rock. The cycle is then repeated. The broken rock (muck)

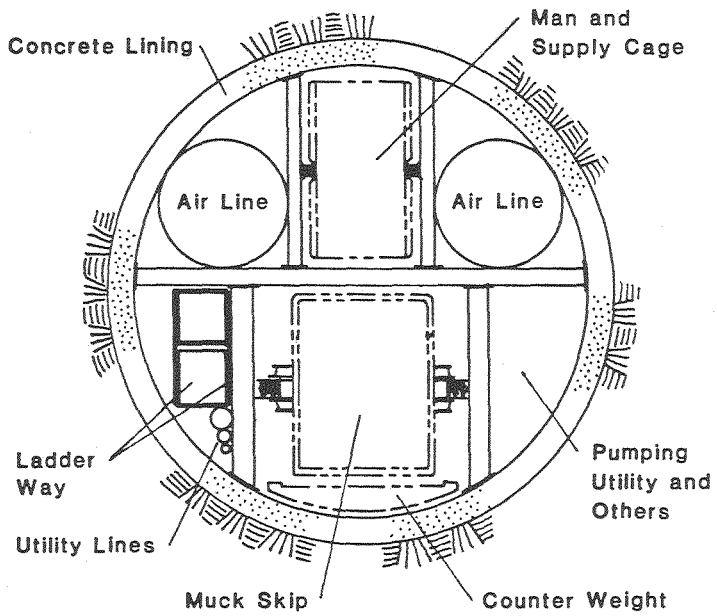


Fig. 3.25 Typical Circular, Concrete-Lined Vertical Shaft

is loaded into buckets suspended from a headframe and hoisted to the surface. As the shaft advances downward, concrete is poured against the rock walls to protect against sloughing or cave-ins. Once the shaft has been sunk to the total depth, it is equipped from the bottom up. Dividers, guides, and a manway are installed.

Access shafts can be rectangular instead of circular, which would allow more efficient use of space. Circular shafts, however, are by far more stable than rectangular shafts when subjected to lateral pressures from groundwater or incompetent rock. Such considerations will be important when sinking shafts through the Maquoketa Shale, which has an average compressive strength of less than 5000 psi. Circular shafts are preferred.

A headframe straddles the shaft and supports the muck storage bins. Permanent shaft headframes will be required for long-term hoisting functions, including magnet installation and maintenance. Headframes are fabricated from wood, steel, or concrete. The conventional type of headframe has backlegs, with the hoist mounted on the ground as illustrated in Fig. 3.26. Friction hoists are usually mounted in the headframe, eliminating the need for backlegs (Fig. 3.27).

Excavation for the 16 shafts will generate 330,000, 370,000, and 440,000 cubic yards for the 10-, 12-, and 15-foot diameter tunnels, respectively. The first five shafts will be ready to accept the tunnel boring machines 18 months after the awarding of contracts. All shaft sinking operations should be completed by the end of the third year.

3.2.3 Underground Facility Requirements

The first major facilities to be discussed are the refrigeration and power supply stations. These stations are identical and will be located every 5.3 miles around the ring. The refrigeration/compressor facilities will cool the helium to the proper cryogenic temperature before it enters the magnets located in the tunnel. A computer control room will be located in the power supply portion of the station. This computer control room will monitor and control operation of the refrigeration/compressor equipment and will have full heating, ventilating, and air-conditioning services.

To minimize space requirements and disturbances at the surface, such as noise to the immediate surroundings, the cold box and dewars stations will be excavated underground and will consist of large underground chambers, each

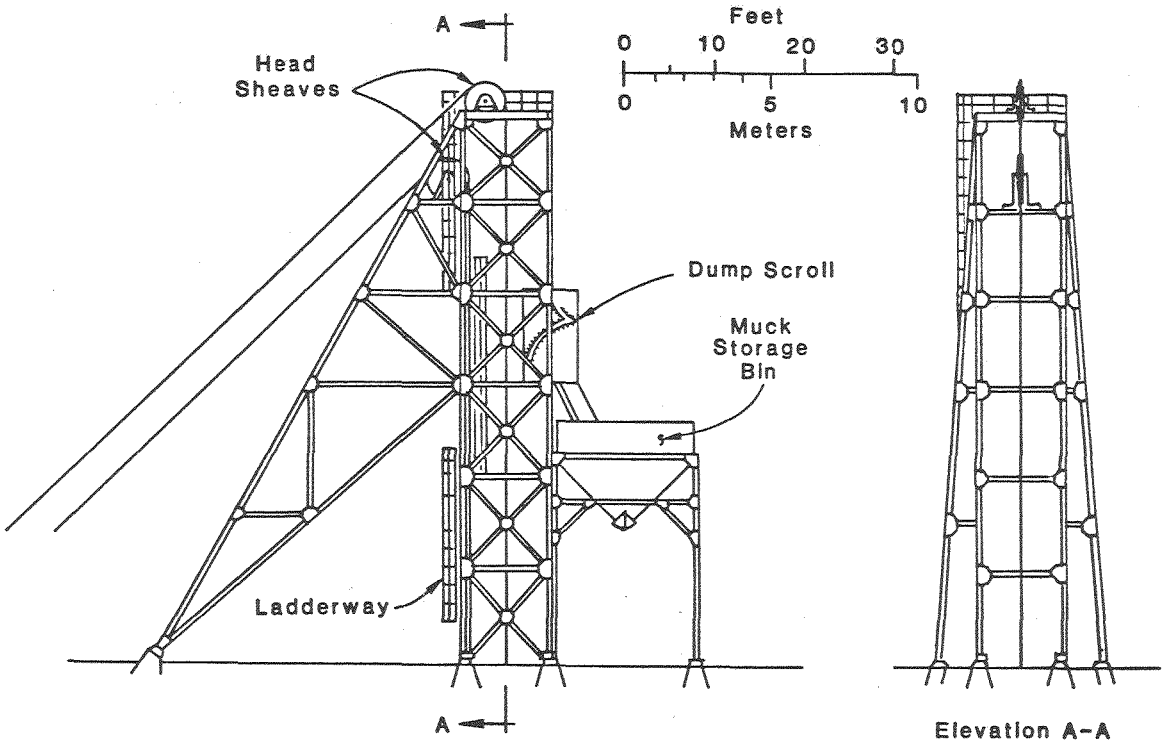


Fig. 3.26 Typical Conventional Steel Headframe
(Source: Modified from Bickel and Kuesel, 1982)

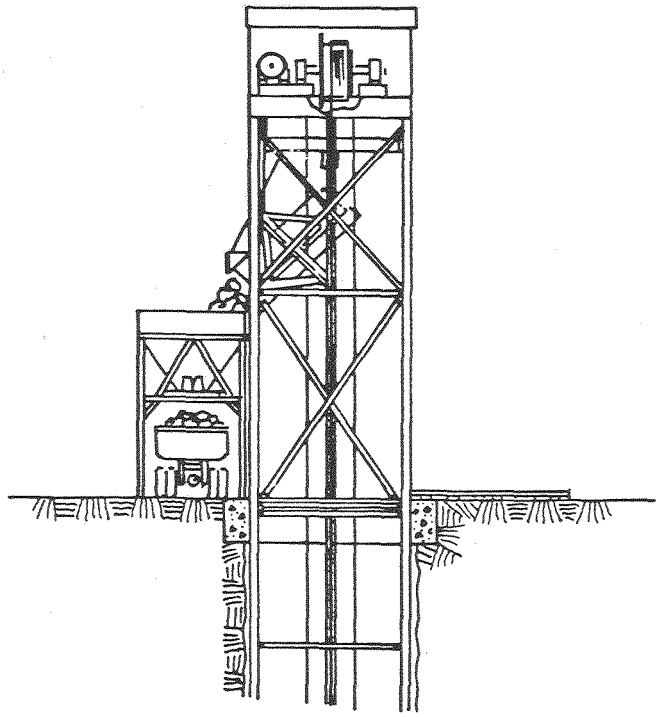


Fig. 3.27 Tower-Mounted Friction Hoist
(Source: Modified from Bickel and Kuesel, 1982)

having dimensions of 250 × 60 × 50 feet.* Using TBM's to construct openings of such shape and dimension is not practical; therefore, drill-and-blast techniques will be used. Excavation of these stations will generate a total of 600,000 cubic yards of muck that will have to be hoisted to the surface via the shafts.

Six underground IR (collision) halls of various sizes will be constructed using conventional drill-and-blast techniques. For simplicity, in this study we have assumed that the largest of these halls will be approximately 100 feet wide, 220 feet long, and 100 feet high.*

It is assumed that two ramps (inclined tunnels) will be constructed to connect the ring with the existing Fermilab accelerator. The first 3300 feet of each ramp will be at the surface and flat, and will be excavated by the cut-and-cover method. The next 6600 feet will be sloped downward at an average angle of 5 degrees. Assuming a 12-foot diameter circular ramp, the total excavation for the two ramps will generate about 150,000 cubic yards of spoil.

3.2.4 Excavation Summary

Table 3.7 summarizes the excavation requirements for the various components of the main ring. Figures are given for each of the three tunnel diameters considered. The shafts and excavations for underground refrigeration stations and IR halls are assumed to be the same for the three tunnel sizes. As can be seen from Table 3.7, the projected excavation will generate from 3.5 million cubic yards for a 10-foot diameter tunnel to 5.8 million cubic yards for a 15-foot diameter tunnel. For the 12-foot diameter presently preferred, the total is 4.2 million cubic yards.

3.3 CONSTRUCTION TIME SCHEDULE

The start of the construction activities described in Sec. 3.2 will coincide with the awarding of the construction contracts. Construction management and inspection activities are scheduled to begin in the first year

*The actual sizes and geometries of the underground excavations may differ from these assumed figures. Although underground spans of greater than 60 feet are uncommon, it is feasible to excavate larger spans in competent rock under controlled conditions, but only with increased support measures. Larger spans would not, however, be feasible in less-competent materials like the Maquoketa Shale.

Table 3.7 SSC Ring Excavation Summary. All Volumes Shown Include a Swell Factor of 1.8.

Construction Parameter	Tunnel Diameter		
	10 feet	12 feet	15 feet
Tunnel average advance rate per contract (feet/month)	1,620	1,560	1,260
Tunnel construction period (months)	35	36	45
Total tunnel construction (six contracts) (cubic yards)	1,800,000	2,500,000	4,000,000
Shaft excavation (12 access plus four IR shafts) (cubic yards)	330,000	370,000	440,000
Ramps (cubic yards)	150,000	150,000	150,000
Underground refrigeration stations (cubic yards)	600,000	600,000	600,000
Underground IR halls (cubic yards)	600,000	600,000	600,000
Total excavation (cubic yards)	3,480,000	4,220,000	5,790,000

and should be complete within five years. The overall schedule is shown in Fig. 3.28.

As soon as the construction contracts have been awarded, mobilization activities can be undertaken by the various contractors and subcontractors. Mobilization includes site preparation, crew selection, surface facilities setup, and overall preparation for the start of shaft-sinking activities. During the same period, the TBM's will be designed and manufactured based on tunnel size and rock properties. It should be emphasized that TBM's are not off-the-shelf pieces of equipment and are usually custom-designed for a specific job. During the manufacturing process, the manufacturer will undertake an extensive testing program to design the cutterhead configuration properly and to select the correct spacing and type of cutters, as well as other machine parameters (e.g., thrust, torque, and revolutions per minute). It is anticipated that a period of one year will be needed for the manufacture and delivery of the TBM's.

Shaft-sinking operations can start as soon as necessary preparations and contractor mobilization have been completed. Once the first series of shafts has been completed to the desired depth, the TBM's can be lowered through the shafts in pieces, assembled at the bottom, and tunneling begun eighteen months after awarding the contracts. At the same time, excavation could begin on the underground refrigeration/compressor stations, IR halls, auxiliary access ramps, and other peripheral facilities. At the end of the fifth year, excavation should be complete.

3.4 MANPOWER REQUIREMENT

The manpower requirement for construction of the SSC main ring facility was estimated based on anticipated crew sizes for tunneling, shaft sinking, underground excavation, and materials handling and stockpiling. A work schedule of three shifts per day and five days per week was assumed. An additional 30% was added to the direct labor for supervisors, office workers, and support staff. The summary and profile of construction manpower are illustrated in Figs. 3.29 and 3.30, respectively. As can be seen from Fig. 3.30, construction-related activities of the SSC project will provide employment for an average of about 1250 persons over a period of five years, or a total of 6255 man years. The construction crew will peak in year three at 1980 and will decline to 1210 in years four and five.

3.5 COST ESTIMATES

Costs were estimated for each activity within the overall construction operation. The total cost of each activity was computed by calculating the

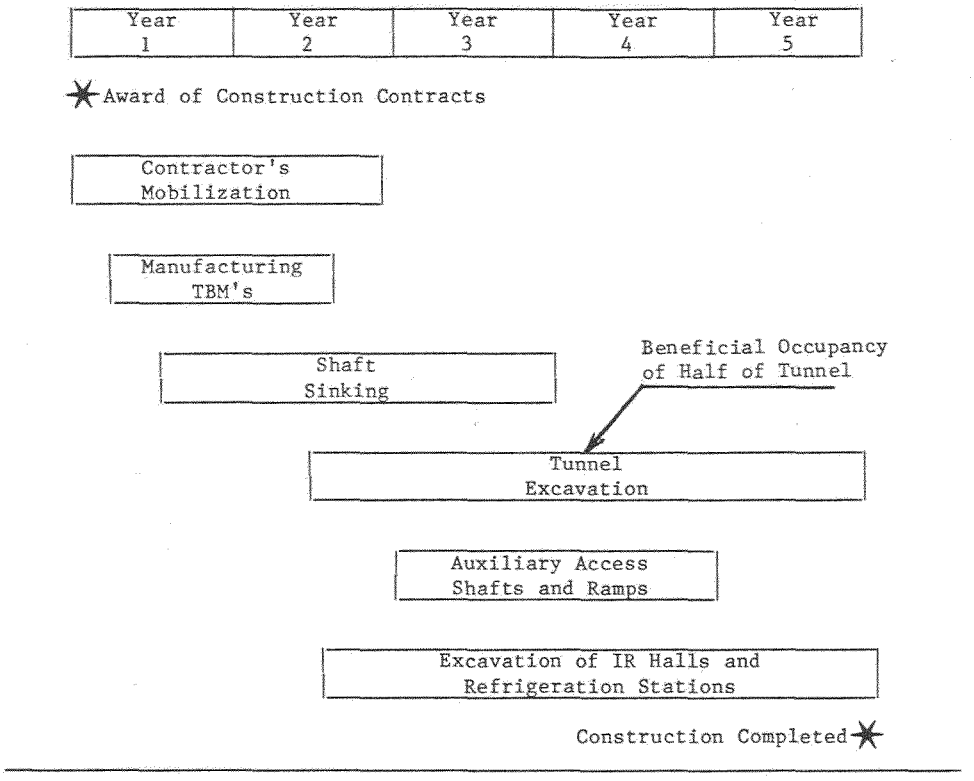


Fig. 3.28 Summary Schedule of SSC Conventional Underground Construction

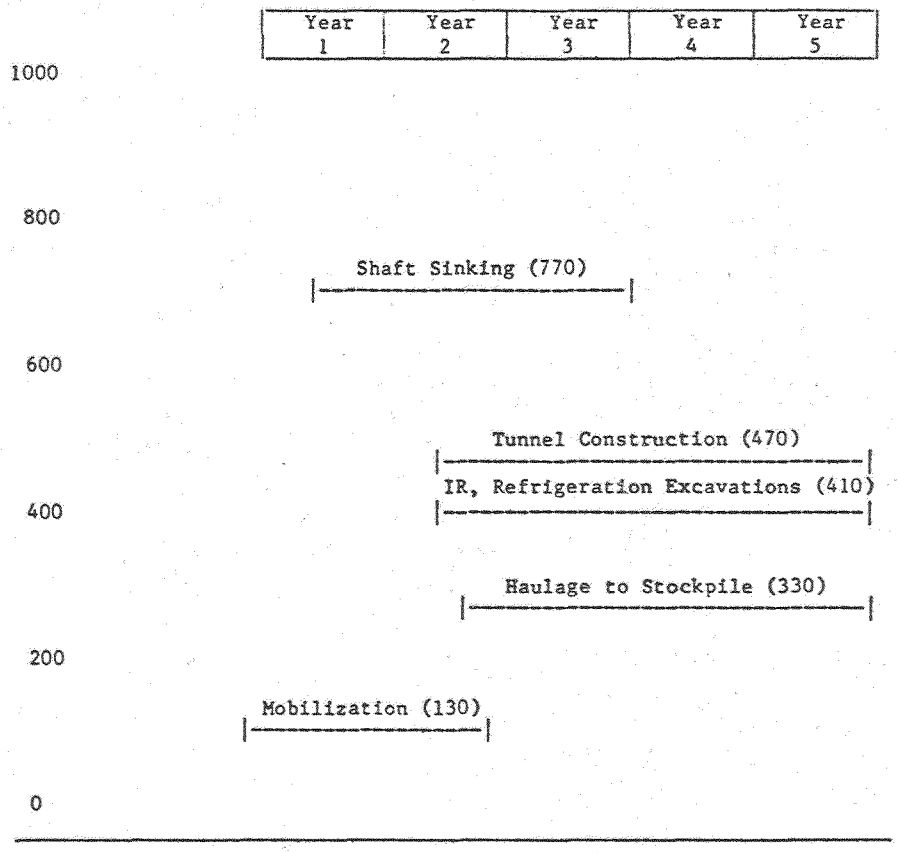


Fig. 3.29 Summary of Construction Manpower

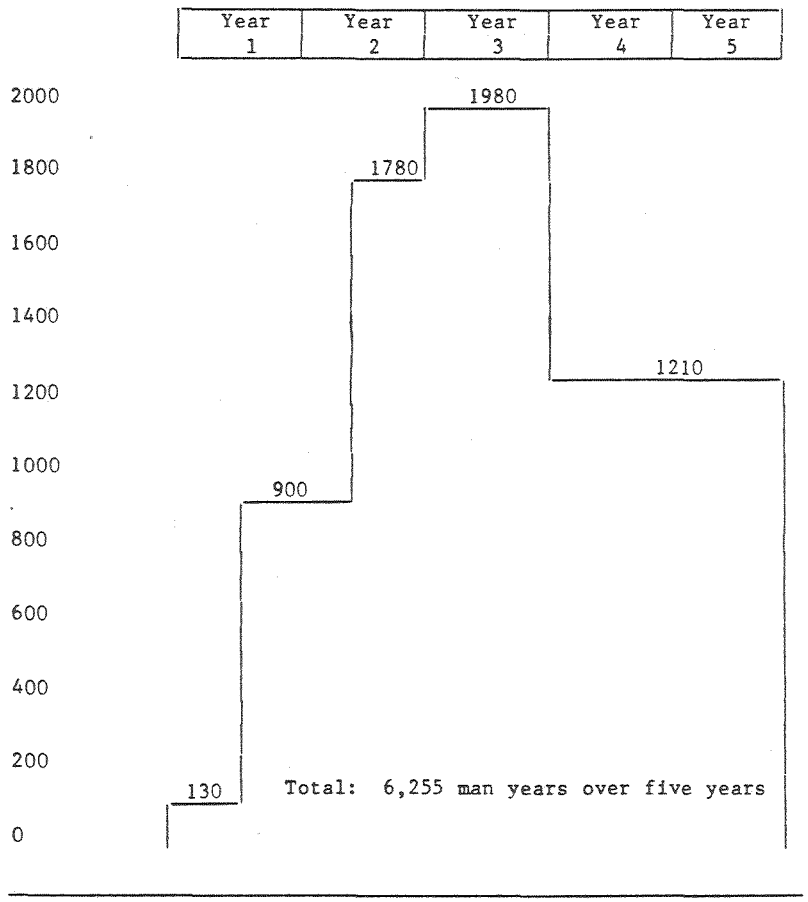


Fig. 3.30 Profile of Construction Manpower Over Five Years

cost of equipment, labor, and materials and supplies. The costs of various items were obtained from equipment manufacturers and construction contractors in the Chicago area. In some cases, actual bid prices for TARP project construction were consulted (Weaver, 1984), and costs were updated by applying appropriate cost indices or escalation factors.

The cost estimates for 10-, 12-, and 15-foot diameter tunnels (Table 3.8) include direct administrative and overhead costs, as well as provisions for contractor profit. Basic costs were increased by a factor of 15% to reflect engineering, design, and inspection, and contingencies, as was done with TARP.

In calculating the cost of surface haulage and disposal of muck, it was assumed that the contractors will receive proceeds of $2 per ton (O'Connor, 1984) from selling one-half of the muck. This revenue ($4M to $7M) was deducted from the total cost of disposal, with the result shown as the net cost of surface muck haulage and disposal.

The percentage breakdown of the total cost into different activities, for a 12-ft diameter tunnel, is as follows:

Activity	Percent
Mobilization	5
Shaft sinking	22
Underground excavations	30
Tunnel construction (includes grouting and concrete floors)	41
Muck disposal	2
Total	100

Approximately the same percentages would hold for 10- and 15-foot diameter tunnels.

As shown in Table 3.8, the cost of sinking the shafts amounts to 22% of the total construction cost. Fixed costs, such as the cost of the headframe, hoisting systems, and other shaft installations, make up the major part of the shaft-sinking expenses. The depth-dependent component of the shaft-sinking cost is about $5000 per linear foot of shaft for the range of diameters considered in this study. Although the depth of this site may be deeper than for other locations, cost comparisons must consider whether the rock is as competent as the Galena-Platteville Dolomite. If it is not, more tunnel

support will be required, thereby considerably increasing the tunnel cost. For example, a four-inch thickness of shotcrete over the top half of a 12-foot diameter tunnel would increase the cost by $22.6 million, assuming shotcrete costs of $300 per cubic yard, and a one-foot thick, cast-in-place concrete liner would increase the cost by about $105 million ($1.6 million/mile).

As can be seen from Table 3.8, the total cost of civil construction is only 5% greater for the 12-foot than for the 10-foot diameter tunnel. The cost increase for a 15-foot tunnel diameter versus a 10-foot diameter tunnel is about 16%. The total cost (including engineering, design, and inspection, and contingencies) is between $478 million and $554 million for the three tunnel-diameter alternatives. These figures translate into an average of $1420-1650 per linear foot of tunnel, including the costs for shafts, collision halls, etc. (The tunnel itself contributes somewhat less than half of these costs.)

These cost estimates are based on the design outlined in Section 2, including very preliminary estimates of IR hall and injection line requirements. As the design of these components continues, the precision of the cost estimates will improve.

The above cost estimates can be compared with those made for other projects of similar type and magnitude.

1. Parsons, Brinkerhoff, Quade, & Douglas, Inc., Superconducting Super Collider, Reference Designs Study -- Conventional Facilities (May 8, 1984). The total cost of roughly comparable facilities presented in the Reference Designs Study can be obtained by interpolating between the estimates made for civil construction for Options A and B. We considered conventional construction for the collider facilities (land improvements, tunnel enclosures, cryogenic facilities, and support buildings), plus the costs for experimental facilities (land improvements, interaction enclosures, staging buildings, and ancillary buildings) and the costs for engineering design and inspection of ring and experimental facilities. The RDS cost equivalent to those in Table 3.8 is about $570M. Comparisons of this type are, of course, difficult due to different assumptions on timescales, different costing methods, manpower rates, and precise definitions of items being costed. Nevertheless, we feel that the proposed site between Argonne and Fermilab does offer real cost advantages due to both the use of existing surface facilities and to the desirable subsurface environment provided by the Galena-Platteville strata (Section 3.1.5).

3.7 Section 3 References

Algermissen, S. T., and Perkins, D. M., "A Probabilistic Estimate of Maximum Acceleration in Rock in the Contiguous United States," U. S. Geological Survey Open-File Report 76-416, 1976, p. 45.

Berggren, D., et al., "A Guide to the Environmental Geology of the Elmhurst-Naperville Area, DuPage County, Illinois," Illinois State Geological Survey Field Trip Guide Leaflet 1978B (1978).

Bickel, J.O., and T.R. Kuesel, Tunnel Engineering Handbook, Van Nostrand Reinhold Company, New York (1982).

Buschbach, T.C., "Cambrian and Ordovician Strata of Northeastern Illinois," Illinois State Geological Survey Report of Investigations 218 (1964).

Buschbach, T.C., and G.E. Heim, "Preliminary Geologic Investigations of Rock Tunnel Sites for Flood and Pollution Control in the Greater Chicago Area," Illinois State Geological Survey Environmental Geology Notes No. 52 (1972).

Fischer, G. E., "Ground Motion and Its Effect on Accelerator Design," to be published in the 1984 U.S. Summer School on High Energy Particle Accelerators, Fermilab (August 1-24, 1984).

Fowler, W. B., "Vacuum Breaks of the Doubler Magnet Systems (Failure Mode Analysis of Insulating Vacuum and Beam Tube Vacuum), CCI Report 390-124 (updated 1983).

Hammersmith, G., Elmhurst-Chicago Stone Co., Elmhurst, Ill., personal communication (1984).

Harza Engineering Company, "Development of a Flood and Pollution Control Plan for the Chicagoland Area, Part 4: Geology and Water Supply," prepared for the Metropolitan Sanitary District of Greater Chicago (Dec. 1972).

Harza Engineering Company, "Interim Report, Geology and Related Studies, Chicagoland Flood Control and Pollution Abatement Program," prepared for the Metropolitan Sanitary District of Greater Chicago (1971).

Heigold, P.C., "Notes on the Earthquake of September 15, 1972, in Northern Illinois," Illinois State Geological Survey Environmental Geology Notes No. 59 (1972).

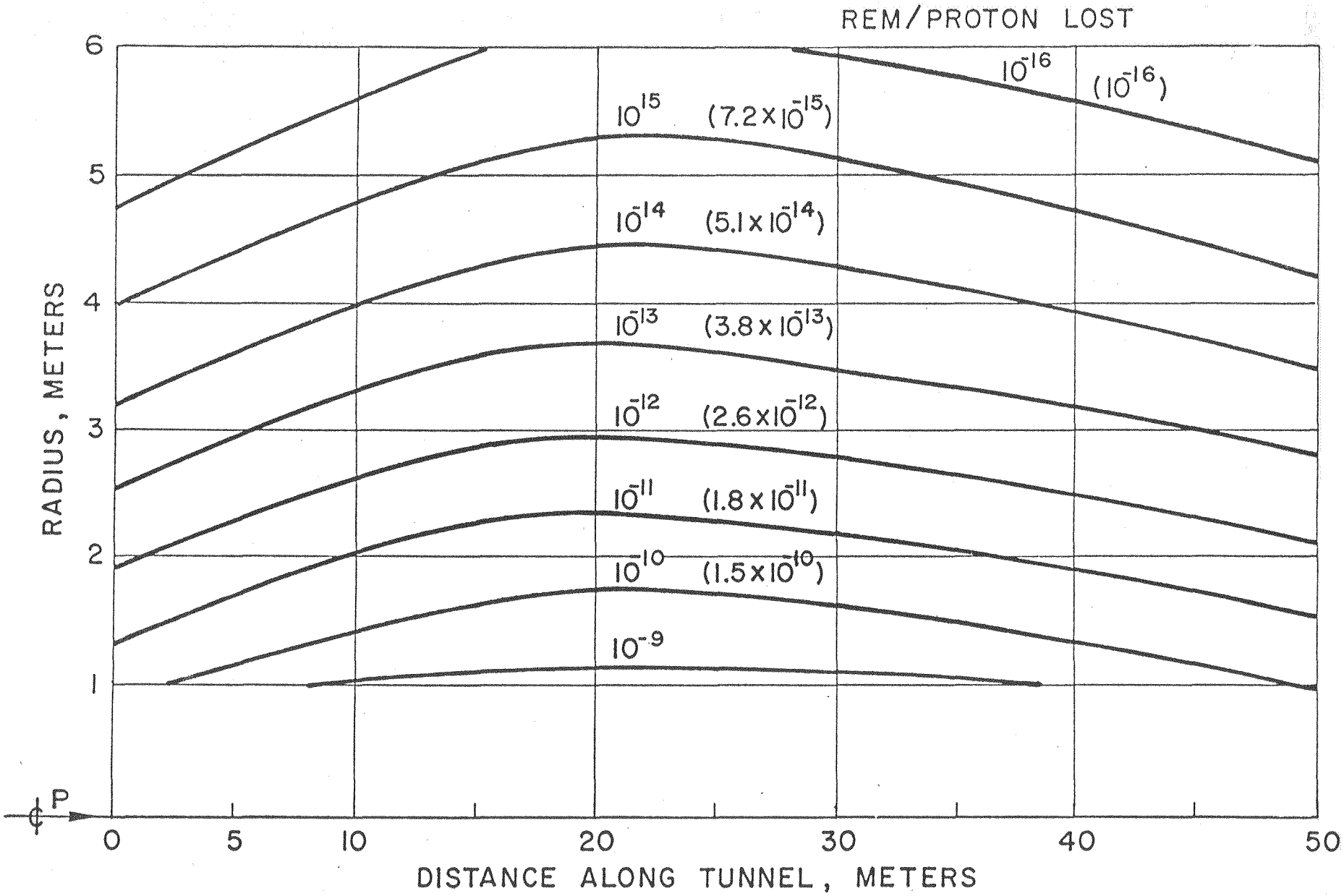


Fig. 4.1. Hadron Isodose (from Van Ginneken, 1983). Lines of constant dose of hadrons (rem/20-TeV proton lost) for wet (dry) soil.

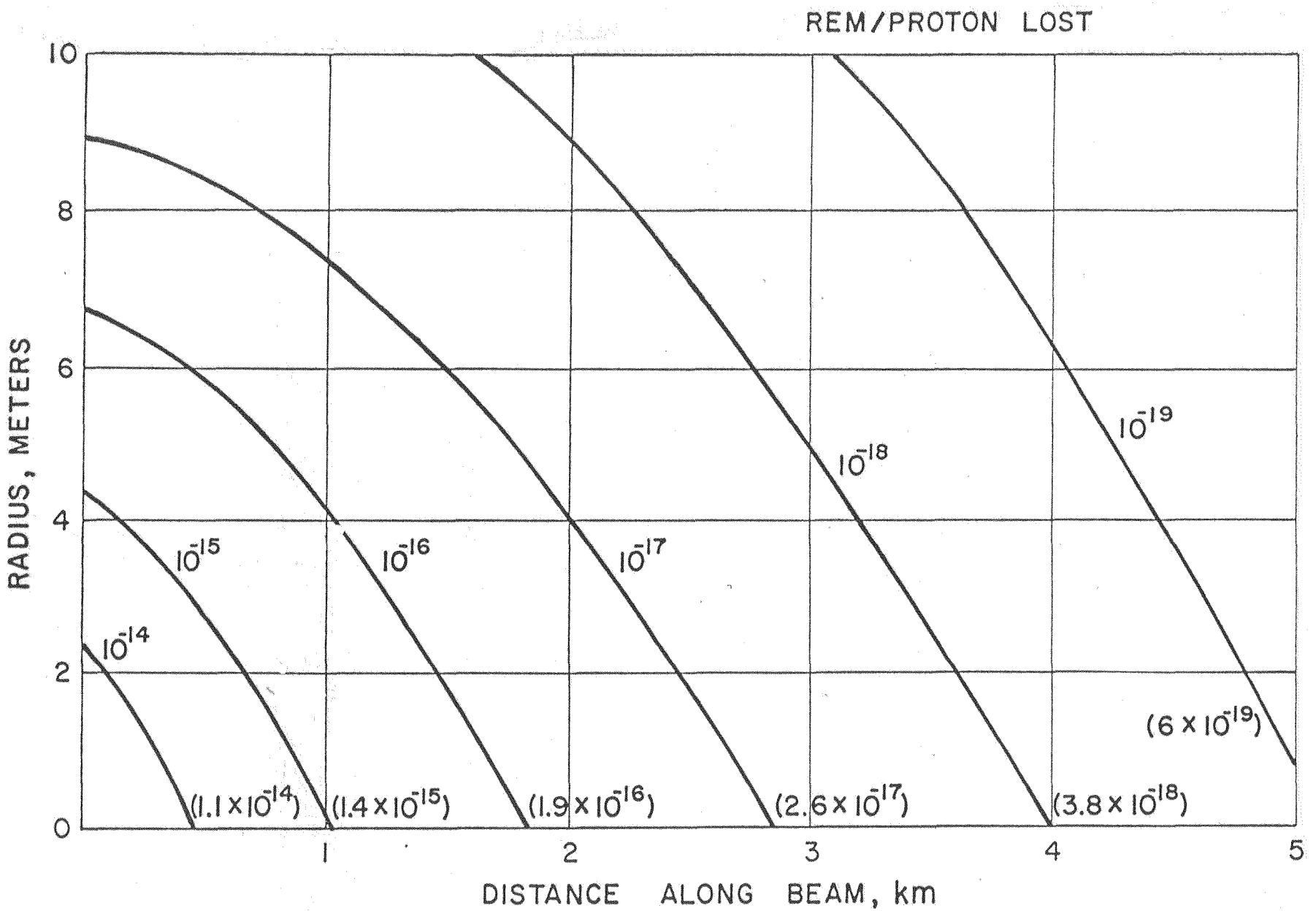


Fig. 4.2. Muon Isodose (from Van Ginneken, 1983). Lines of constant dose of muons (rem/20-TeV proton lost) for wet (dry) soil.

produced in the tunnel walls is 80 μCi per loss of 1.3×10^{14} protons. The production of leachable Na^{22} is 5 μCi.

We have also estimated induced activity due to activation of helium coolant from the reaction He(p,2p)T. This reaction could, in principle, produce tritium that would go into the atmosphere in the case of a rupture of the cryogenic system during total beam loss. We have estimated the activity of this tritium using the relation

$$A = \frac{f}{\tau} S \frac{V_{He}}{V_{Fe}} \frac{L_{Fe}}{L_{He}} \frac{N_p}{3.7 \times 10^{10}} ,$$

where V_{He} and V_{Fe} are the volumes of He coolant and iron in the magnets, L_{Fe} and L_{He} are the collision lengths in iron and liquid helium, f is the ratio of the cross section for the tritium production from helium to the total cross section (40 mb/110 mb), and τ, S and N_p are defined above. About 30 μCi of tritium would be produced from hadronic showers in the He coolant per 1.3×10^{14} protons lost (Barbier 1984). Assuming this tritium to be liberated along 100 m of tunnel (generally assumed to be the length of the beam loss region), this would result in tritium levels in air roughly a small fraction of that allowed for workers (who, in any case, would not be permitted in the tunnel during operation).

After many years of operation, equilibrium will be reached between the production and decay of active material and the magnitude of this equilibrium is relevant. Cossairt and Elwyn (1984) have estimated the magnitudes of the total radiological inventory for the RDS SSC when operated in a fixed target mode with 5×10^{14} protons per fill and 3.2×10^4 fills per year (cf 2.6×10^{14} and 400 for the collider mode). Using a water content of 10% by volume, saturation concentrations of 1.5 pCi/mℓ for T, 0.06 pCi/mℓ of ^{22}Na, 0.01 pCi/mℓ for ^{41}Ca and 0.002 pCi/mℓ for ^{54}Mn would be produced in water at 1 meter into the wall of the tunnel. (Water less than one meter from the tunnel wall would presumably drain into the tunnel, where it could be monitored and controlled.) Even if used as drinking water, the total concentration of all nuclides in water beyond one meter would produce doses of 2.2 mrem/year or less, which meets current health and safety standards if no other radionuclides were present.

Although these calculations were made for glacial drift, similar numbers result from an environment in rock. The water content of rock is much smaller, with most of the circulating water in joints. The fraction of the total activity which is leachable within timescales of a few years must be roughly proportional to the fraction of water volume in joints. Since the

Galena-Platteville dolomite is in blocks with dimensions of 3 m or greater with little water and negligible circulation within blocks, most activated material is trapped within blocks (Section 3.1.2-3.1.3).

4.1.2 **Migration of Induced Activity**

Migration of induced activity could occur along a number of possible pathways. We can itemize these pathways and consider how the activity can be isolated both from workers and the general population for each pathway.

(a) Activation of solid materials can be handled using existing procedures. Laundry, waste, shielding, activated components, etc. require standardized handling procedures to ensure that activated material will not be dispersed. These procedures have been developed over the years at many accelerator facilities. It would not be a significant inconvenience for all activated solid material to be transported in the tunnel to allow handling at the two labs.

(b) Water seepage into the accelerator tunnel could be contaminated as a result of induced activity and then become a source of human exposure if not properly handled. Thus, the seepage water should be collected, monitored, and managed as appropriate if contaminated. The total rate of this seepage is estimated to be at most about 2000 gallons per minute.

(c) Migration of activated nuclides through magnet coolants has been studied at Fermilab (Pollock 1981). Cryogenic magnets are cooled with liquid helium, and tritium can be produced via the reaction $He(p,2p)H^3$. During routine operation of the accelerator, most of the tritium will be trapped in the oil of the compressor pump. Proper precautions must be taken to protect workers when working on the pumps, and the oil disposed of as a radioactive liquid waste so as to protect the general public. The carbon-11, similarly produced in the nitrogen coolant, can be easily handled because of its short half-life (20.3 minutes).

(d) Some radioactive gases (tritium, A^{41}, etc.) will be produced, and we assume that during operation the atmosphere in the tunnel will be exhausted at the two laboratories, where it can be monitored and the releases controlled, as is presently done at Fermilab. Except for tritium, those gases have half-lives no longer than a few hours. Proper monitoring and control of radioactivity in the ventilated air will minimize the impact of these gases to the surrounding environment.

(e) Migration of induced activity through groundwater is more

complicated. During both normal operation and accident conditions, beam losses in the tunnel wall would give rise to local hadronic cascades, which in turn would produce radionuclides that could possibly be leached into an aquifier and then into potential or existing water supplies. Even for the worst-case scenario of a local loss of the whole beam, however, the contamination of groundwater from the induced radioactivity is expected to be small. Based on the estimated source terms in Section 4.1.1, the concentrations of tritium and sodium-22 in well water can be calculated assuming fixed target operation and neglecting any decay or dilution of the induced radionuclides. Using these assumptions, the tritium and sodium-22 concentrations in the water are calculated to be 1.5 pCi/mℓ and 0.006 pCi/mℓ, respectively (Cossairt and Elwyn, 1984). Drinking water limits (EPA) are 20 pCi/mℓ for tritium and 0.2 pCi/mℓ for sodium-22 if one nuclide is present. Thus, the worst-case concentrations are at least one order of magnitude below regulatory limits. As mentioned before (Section 3.1.3), since the primary permeability of the rock is low and the water concentrations are low, the vast majority of this activity will be effectively sealed in the rock and water moving through joints will have its sodium and tritium concentrations further reduced by the dilution associated with higher flow velocities.

In a more realistic model considerable dilution and decay should apply between material produced near the tunnel walls and any water withdrawn in wells. Deep wells (more than 160 meters underground) are very unlikely to be a single-user private well. In public or industrial wells the pumping rates are expected to be high. Therefore, the radionuclide concentrations in the well water will be greatly reduced as a result of the dilution. Since the piezometric profile of the Cambrian-Ordovician aquifier is below the accelerator (see Fig. 3.22) for most of the circumference, the rock around the tunnel is expected to be unsaturated, i.e., the groundwater concentration and flow rates should be low. If concern for a few nearby wells persisted, these could be moved or cased at the elevation of the SSC tunnel.

4.1.3 **Occupational Exposure**

Issues pertaining to the safety of workers are generally site-independent and are very similar to those already resolved at existing accelerators. For completeness, however, we include a short discussion of this problem. As mentioned above, roughly half the beam accelerated to 20 TeV will be lost in the interaction regions, where large and complex detectors will be located. These detectors will be operated at high counting rates necessitating considerable beam loss in these regions. In addition, possible accidents might require accelerator components to be repaired after absorbing significant beam loss. For these reasons, it is desirable that the occupational exposure to workers should receive careful attention, and

procedures and equipment should be devised to minimize exposure of personnel.

During operation, the direct worker exposure to man-made radiation from accelerator operation will be controlled by ventilation and shielding (Cossairt and Elwyn 1984). These techniques have been demonstrated at Fermilab, CERN, and other laboratories.

During maintenance and decommissioning of the accelerator, occupational risk due to induced activity can be minimized. Schemes for maintaining activated components have been developed at Fermilab, Los Alamos and elsewhere, and these practices would be applied to the SSC. The total saturated induced activity in the surrounding soil near the abort beam dump in the collider model is expected to be about 100 mCi, based on an assumption of 5% of the lost protons in 30% of the stored beam in the collider mode penetrating into soil (RDS). (For fixed target operation, the corresponding number would be $\leqslant$ 70 Ci.) Because most of the induced radionuclides have short half-lives and virtually all would be sealed in components such as magnets and iron detectors, the radiation problem would be manageable. Thus, proper timing of work could be effectively used to reduce occupational radiation exposure levels for both maintenance and decommissioning.

Decommissioning issues would be similar to those already addressed by other accelerators. Options include (1) mothballing (simply clean-up), (2) entombment (seal all accesses with concrete), (3) dismantlement with permanent disposal, and (4) reuse and recycle. Because of the low-levels of radioactivity in the acccelerator, most shielding, magnets, and electronic equipment can be reused. Accelerator components excessively contaminated during operation and radioactive waste generated during operation and during dismantlement and decommissioning would be be shipped to appropriate radioactive waste burial grounds for disposal. Such transport and disposal operations would result in minimal occupational exposure to transportation workers and operations of the disposal site(s).

4.1.4 **Summary of Radiological Impact**

Most radioactive waste from the operation of an accelerator is of short half-life with low levels of radionuclides produced. Satisfactory occupational exposure control and waste management have been demonstrated at other high-energy accelerators for such wastes (Opelka et al., 1979).

Direct exposure to the general public will be minimal due to proper design of shielding, operating procedure, and by the location of the accelerator 400-750 feet underground. Possible exposure to induced activity

through possible transport of contaminated groundwater to water supplies has been considered. Based on their half-lives and transport characteristics, tritium and sodium-22 would be the only radionuclides of possible concern. The proposed SSC location in a deep tunnel should result in a large margin of safety relative to groundwater contamination. The large decay and dilution effects and the low availability of water in the rock strata all contribute to this safety margin.

4.2 ENVIRONMENTAL ASPECTS OF SURFACE DISRUPTION

4.2.1 Spoil Disposal

In previous tunneling projects, disposal of soil, unconsolidated overburden, and rock spoil has traditionally been carried out by the tunneling contractors. However, with projects involving large amounts of spoil, there has been a trend for tunnel owners to develop spoil disposal plans (Liu et al. 1977b; Milwaukee Metropolitan Sewerage District 1983). This practice potentially can provide additional benefits to the community, allow contractors to more accurately estimate costs, and help to prevent undesirable environmental impacts. Disposal plans must be based on evaluation of many factors such as general spoil characteristics, suitability of spoil for each disposal option, costs of modifying spoil to be compatible with disposal options, haul distances and costs, disposal site capacities and costs, coordination of tunnel construction with availability of disposal site, and potential public benefits. This report, however, is limited to identification of potential spoil characteristics uses, and disposal options.

Spoil Characteristics

Most of the rock excavated for the SSC would be dolomite from the Galena-Platteville formation. Lesser amounts of other dolomite formations, shales, and unconsolidated overburden would be excavated for construction of ramps and refrigeration/access shafts. Geologic stratigraphy and characteristics of the various formations are presented in Section 3.1.

Most large spoil particles produced by tunnel boring machines are expected to have a maximum dimension of about 3 to 4 inches (7 to 10 cm); the largest particles would probably have a maximum dimension of 5 to 6 inches (13 to 15 cm). In addition, a substantial fraction of fines is expected, with as much as 15% to 20% (by weight) of silt-size particles (less than 200 mesh) (Milwaukee Metropolitan Sewerage District 1983). The larger particles would typically be elongated in one dimension (prism) or two dimensions (plate) and might be slightly curved (Milwaukee Metropolitan Sewerage District). Specific

sizes and shapes can be affected by such factors as type of cutting bit, degree of machine thrust, and rate of machine revolution (Liu et al. 1977a).

Spoil particles produced by drill and blast excavation methods would likely range in size from silt-size to cobbles and boulders. Fines are produced when rock near drill holes is crushed or pulverized by exploding gases. The sizes of larger particles, including cobbles and boulders, is determined by rock properties and excavation method--such as borehole spacing and configuration; type, amount, and distribution of explosives; and firing sequence (Milwaukee Metropolitan Sewerage District 1983). Unlike many surface excavations, where the primary objective is the end use of the rock, the primary objective of underground excavation is to open the greatest volume (chamber or shaft) in the shortest amount of time at the lowest cost. Thus, the rock is usually fragmented to optimum handling size for the confined underground conditions, and often little consideration is given to potential uses (Milwaukee Metropolitan Sewerage District 1983). On the basis of the experience with other tunneling projects, much of the spoil excavated by drill and blast methods would probably be larger and more angular than the bulk of the spoil produced by tunnel-boring machines. Boulder-size particles could have maximum dimensions as large as several feet (Milwaukee Metropolitan Sewerage District 1983).

Unconsolidated overburden is expected to consist of outwash materials and glacial till. Outwash materials were deposited by glacial meltwaters. They can vary in texture from coarse gravels to clay and may be stratified by texture in some areas. Glacial tills are extremely variable in texture, ranging from loamy gravel to clay. In addition, till commonly contains pebbles and various-sized boulders (Fehrenbacher et al. 1967).

As part of a spoil disposal plan, specific testing would be necessary to determine the suitability of spoil materials for various potential uses (Liu et al. 1977a).

Potential Spoil Uses

Most of the dolomite that would be excavated from the tunnel, shafts, and the various underground chambers potentially could be used for such things as various types of fill material, paving aggregate, rip rap, landfill covers and liners, and agricultural lime. However, with the exception of some types of fill, all uses would require processing of the dolomite, e.g., crushing, sorting, and washing (Liu et al. 1977a; Milwaukee Metropolitan Sewerage District 1983). In many cases the necessary processing could make some uses of the SSC spoil uneconomical.

To use SSC spoil to produce agricultural lime would require crushing and grinding to a relatively uniform fineness. However, such processing is required to produce agricultural lime from normal sources. The major factors that could limit such use would probably be the costs required to transport the spoil to producer/processors and the chemical composition and moisture content of the dolomite (Milwaukee Metropolitan Sewerage District 1983).

Use of the SSC spoil to cover sanitary landfills would probably require screening to remove large particles. However, use as a sanitary landfill liner would essentially require crushing and grinding of the spoil to produce agricultural limestone (Milwaukee Metropolitan Sewerage District 1983).

Unprocessed spoil could probably be used as low-grade uncontrolled fill for such uses as filling depressions, site grading, improving marginal areas, or filling inactive or abandoned quarries or sand and gravel pits. Areas of this type might be developed for such uses as parks and recreational areas but would probably be limited for most building purposes. Use of the spoil for more controlled fill applications (e.g., road embankments, backfill around buildings or in trenches, and subgrade preparation for parking lots) would probably require some processing and would depend on such factors as the strength, compressibility, and permeability of the spoil material (Liu et al. 1977a; Milwaukee Metropolitan Sewerage District 1983).

Any potential use of SSC spoil would be affected by coordination of timing between the user's needs and availability of the spoil. In addition, the potential impacts of spoil sale or donation on the existing industry providing similar materials would have to be evaluated.

Spoil Production and Disposal Options

Approximations of the bulk volume of spoil that would be generated by construction of the SSC tunnel (various diameters), refrigeration/access shafts, ramps, and related underground chambers are presented in Table 4.2.1-1. Including a swell factor of 1.8 from in situ rock volume to bulk spoil volume gives a total of 4.16 million cubic yards of material for the 12-foot tunnel diameter favored in this report. If this were all deposited in a single 40-acre site, the average depth would be 65 feet.

Depending on the tunnel diameter, from 52% to 71% of the total spoil generated would be produced by tunnel-boring machines. Except for about 10,000 yd^3 (7,600 m^3) of soil and overburden, the rest of the spoil would be produced by drill and blast excavation. Overburden disposal is discussed in Section 4.2.3.

Table 4.2.1-1 Bulk Spoil Volume Produced by Construction of the SSC Project

Spoil Type	Approximate Volume of Spoil Produced (yd^3)*		
	10 ft	12 ft	15 ft
Tunnel Construction (Tunnel boring machine spoil)	1,800,000	2,500,000	4,000,000
Refrigeration/Access Shaft Construction (Overburden plus drill and blast spoil)	210,000	210,000	210,000
Interaction Halls, Underground Refrigeration Stations, Ramps, and Other Underground Construction (Drill and blast spoil)	1,450,000	1,450,000	1,450,000
Total Excavation	3,460,000	4,160,000	5,660,000
Spoil Volume for Locations			
B, C, D, F, H, J, K, L	217,000	278,000	406,000
I	434,000	556,000	812,000
E	0	0	0
A (Fermilab)	728,000	796,000	937,000
G (Argonne)	578,000	646,000	787,000

*All values assume a swell factor from in situ rock volume to bulk spoil volume of 1.8.

Although it is possible that other uses or disposal options might be found, the most likely disposal options for rock spoil appear to be (1) sale or donation of spoil to existing quarry or sand and gravel operations for stockpiling and later sale as fill material (or processing for sale as aggregate) by the operators, and/or (2) sale or donation of the material to fill old quarry sites or sand and gravel pits that are no longer active. Disposal of the spoil via these two options would not be expected to be a major impediment to development of the SSC project because of the relatively large numbers of active and inactive quarries and sand and gravel pits within a 15-mi (24-km) radius of each proposed refrigeration/access shaft from which spoil would be brought to the surface (Table 4.2.1-2). Furthermore, there are a number of such sites within a 5-mi (8-km) radius of most proposed shaft sites.

An inventory of sand and gravel pits and quarry sites in operation as of March 1984 is presented in Table 4.2.1-3, and a similar inventory of sites that were operating in October 1977 but were no longer active in March 1984 is presented in Table 4.2.1-4. From these tables it should be noted that there are three active operations within the ring (near Naperville, Warrenville, and Romeoville) that are located within a 15-mi (24-km) radius of all 11 shafts that would produce spoil. In addition, there are quite a few active and inactive sites that are located near the curved ends of the ring and would be within a 15-mi (24-km) radius of at least half of the proposed shaft sites. Thus, there is a good chance that the number of disposal sites could be limited to three or less and still have reasonable haul distances for the spoil. It is also likely that the option of using more disposal sites with shorter haul distances could be used. Because of the level of detail of this study, not all the factors that would have to be studied in the development of a spoil-disposal plan can be taken into consideration. Such factors would include willingness or ability of quarry or pit owners/operators to purchase or accept spoil material, size (volume) of potential quarry/pit disposal sites, selection of acceptable haul routes, and actual haulage distances and times. The information presented in Tables 4.2.1-2 through 4.2.1-4 does, however, indicate that there would be numerous potential disposal sites that could be investigated in the development of a spoil-disposal plan.

Federal, state, and local authorities should be consulted during the development of a spoil-disposal plan. Preliminary indications are that location of disposal sites should avoid wetlands or other environmentally sensitive areas. In addition, the USEPA and the Illinois EPA should be consulted concerning fugitive dust and water discharges at disposal sites; operating quarries and sand and gravel pits are permitted under the National Pollutant Discharge Elimination System (NPDES). The Illinois EPA Land Pollution Division (which is generally concerned with regulation of sanitary

Table 4.2.1-2. Number of Active and Inactive Quarries or Sand and Gravel Pits Located Within a 5-, 10-, or 15-Mile Radius of Each Shaft from Which Spoil Would Be Brought to the Surface

	Number of Quarries or Sand and Gravel Pits†[1]					
	Within 5 Miles		5 - 10 Miles		10 - 15 Miles	
Shaft	Active	Inactive	Active	Inactive	Active	Inactive
A	1	0	10	7	14	17
B	0	4	13	7	10	10
C	1	4	8	4	9	4
D	1	1	2	4	11	5
F	2	1	4	6	7	5
G	1	5	4	1	11	5
H	3	5	6	4	8	4
I	7	4	4	7	8	5
J	6	4	7	3	8	9
K	3	1	10	4	7	16
L	2	1	7	8	19	15

†[1] Active implies in operation as of March 1984. Inactive implies sites that were active in October 1977 but were no longer operating in March 1984. Distances are straight-line distances between pit or quarry locations and proposed shaft locations.

Conversion: To convert miles to kilometers, multiply by 1.6. Source: Illinois DOT (1977, 1984).

Table 4.2.1-3. Sand and Gravel Pits and Quarry Sites in Operation as of March 1984 That Are Located Within Fifteen Miles of Proposed Access Shafts

County and General Location	Producer	Local Name	Type†[1]	Average Plant Capacity†[2],†[3] (tons/day 1977)	Access Shafts Within†[4] 5 mi	10 mi	15 mi
COOK							
Bartlett (2 mi W)	Elmhurst Chicago Stone		SG	1,750	-	BC	ADL
Elk Grove (E)	I.M. Sales		CS	N.O.	-	D	C
LaGrange	Material Service Corp.	Federal Quarry	CS	7,000	F	G	DH
Lyons (1 mi SW)	Material Service Corp.	Riverside Quarry	CS	1,500	-	F	DG
McCook	Vulcan Materials	McCook Yard 378	CS	15,000	F	G	DH
DU PAGE							
Bartlett (2 mi SW)	Elmhurst Chicago Stone	Reese Pit	SG	600	-	ABC	DL
Bloomingdale (2 mi W)	Plote, Inc.		SG	3,400	C	BD	AL
Elmhurst (1.75 mi NW)	Elmhurst Chicago Stone	Elmhurst Quarry	CS	1,500	D	CF	BG
Naperville (0.5 mi N)	Ted Sirek	Erb Pit	SG	N.A.	-	ABCKL	DFGHIJ
Warrenville (W)	Elmhurst Chicago Stone		SG	600	-	ABCKL	DFGHIJ
KANE							
Aurora (SW)	Feltes Sand and Gravel	Jericho Road Pit	SG	1,400	KL	AJ	BI
Big Rock (2 mi SE)	Meyer Aggregate Co.	Podschwit	CS	1,600	-	-	AKL
Dundee (1 mi E)	Material Service Corp.		SG	3,200	-	-	BC
East Dundee	Road Materials Corp.		SG	N.G.	-	-	BC
Elburn (2.5 mi S)	Feltes Sand and Gravel	Meredith Pit	SG	1,400	-	L	ABK
Elgin (1 mi S)	Chicago Gravel Co.		SG	2,500	-	BC	AD
Elgin (0.5 mi NE)	Plote, Inc.	Beverly Sand and Gravel	SG	1,500	-	ABC	DL
Elgin (0.25 mi NE)	Meyer Aggregate Co.	McGraw Pit	SG	4,000	-	ABC	DL
Geneva (4.5 mi W)	Ted Sirek	Bald Mound	SG	2,000	-	ABL	K
Kaneville (2.5 mi W)	Elmhurst Chicago Stone		SG	3,000	-	-	AL
Kaneville (1 mi E)	Road Materials Corp.		SG	N.O.	-	-	ABKL
North Aurora	Conco Western Stone Co.		CS	2,000	AL	BK	CJ
Sleepy Hollow (0.25 mi SE)	Elmhurst Chicago Stone	Scheutz Pit	SG	1,200	-	-	BC
South Elgin	Road Materials Corp.	Giertz-Melahn	SG	1,200	-	B	ACL
South Elgin (0.5 mi SW)	Van Acker Sand and Gravel		SG/CS	1,500/N.O.	-	AB	CL
South Elgin (2 mi SE)	Fox River Stone		CS	2,500	-	AB	CL

Table 4.2.1-3. Continued

County and General Location	Producer	Local Name	Type†[1]	Average Plant Capacity†[2],†[3] (tons/day 1977)	Access Shafts Within†[4] 5 mi	10 mi	15 mi
KENDALL							
Bristol (2 mi NW)	Feltes Sand and Gravel	Kendall County Pit	SG	1,200	-	K	AJL
Oswego (1 mi W)	Fox Ridge Stone		SG	N.O.	K	JL	AI
Oswego (3 mi E)	Hafenrichter Gravel		SG	N.O.	K	AJL	BHI
WILL							
Channahon (1 mi NW)	Termar Industries	Gaskill Pit	SG	600	-	-	IJ
Channahon (2.5 mi NE)	Channahon Material		SG	N.O.	-	-	HIJ
Channahon (2 mi E)	Meyer Aggregate Co.	Vick Pit Quarry	CS	1,600	-	-	IJ
Joliet (S)	Vulcan Materials	National Stone	CS	4,000	-	I	GHJ
Plainfield (1 mi SE)	Chicago Gravel Co.		SG	2,500	IJ	HK	GL
Plainfield (2 mi NE)	Elmhurst Chicago Stone	Plainfield Pit	SG/CS	1,600/3,000	IJ	HK	FGL
Plainfield (2 mi SE)	Avery Gravel Co.	Fouser Pit	SG/CS	2,000/1,500	IJ	HK	GL
Plainfield (4 mi N)	Avery Gravel Co.	Avery Gravel No. 3	SG/CS	2,500/2,500	IJ	HKL	ABFG
Plainfield (119th St.)	W. Boughton Trucking		CS	1,500	IJ	HK	AFGL
Plainfield (3 mi NE)	E & E Hauling		CS	1,500	IJ	HK	AFGL
Rockdale (2.5 mi W)	Joliet Sand and Gravel		CS	N.O.	-	IJ	H
Romeoville (4.5 mi N)	Elmhurst Chicago Stone	Barbers Corners	SG/CS	2,500/3,000	H	FGIJ	ABCDKL
Romeoville (1 mi W)	Material Service Corp.	Romeoville Quarry	CS	5,600	HI	GJ	FK
Romeoville (1 mi NE)	Vulcan Materials	Willow Ranch, Inc.	CS	3,500	GH	FIJ	KL

†[1] SG = Sand and gravel (natural aggregate); CS = Crushed stone.

†[2] Average plant capacity in tons/day as given in Illinois DOT (1977) for 1977.

†[3] N.O. = Not operating or opened in 1977; N.A. = No active in 1977; N.G. = Not given in Illinois DOT (1977).

†[4] Distances are straight-line distances between pit or quarry locations and proposed shaft locations.

Conversion: To convert miles (mi) to kilometers (km), multiply by 1.6; to convert tons/day to tonnes/day, multiply by 0.907.

Source: Illinois DOT (1977, 1984).

Table 4.2.1-4. Sand and Gravel Pits and Quarry Sites Within Fifteen Miles of Proposed Access Shafts That Were Active in October 1977 But No Longer Operating in March 1984

County and General Location	Producer	Local Name	Type†[1]	Average Plant Capacity†[2],†[3] (tons/day 1977)	Access Shafts Within†[4] 5 mi	10 mi	15 mi
COOK							
Barlett	Elgin Aggregates		SG	2,000	-	BC	ADL
Elgin (1 mi E)	Elgin Aggregates		SG	1,600	-	BC	AD
Hillside	Hillside Stone Corp.	Bellwood Quarry	CS	4,000	-	DF	CG
Hodgkins	Vulcan Materials	Yard 380	CS	N.G.	F	G	DH
Lemont	R.P. Donohoe Co., Inc.		CS	2,000	GH	FI	JK
Lemont	Dehertogh		CS	65	GH	FI	JK
Lemont	Vulcan Materials	Lemont Yard 350	CS	N.G.	GH	FI	JK
DU PAGE							
Bloomingdale	Ajax Sand and Gravel		SG	200	CD	B	FA
Cloverdale (3 mi W)	River Dell Gravel		SG	1,000	BC	AD	L
Cloverdale (2.5 mi W)	East River Dale Gravel Co.		SG	800	BC	AD	L
Winfield (2 mi S)	Elmhurst Chicago Stone		SG	600	BC	AD	FKL
KANE							
Aurora (SW)	Feltes Sand and Gravel	Fox Valley Gravel	SG	1,400	KL	AJ	BI
Elgin (2 mi W)	Edward Schneider	Highland Avenue Pit	SG	1,000	-	-	B
Kaneville (3 mi E)	Feltes Sand and Gravel	Nichols Pit	SG	1,400	-	L	ABK
St. Charles (NE)	Edward Schneider		SG	1,000	B	ACL	DK
St. Charles (2 mi N)	Van Acker Sand and Gravel		SG	300	-	ABC	DL
South Elgin	Edward Schneider		SG	1,000	-	B	ACL
South Elgin	Edward Schneider		SG	1,000	-	B	ACL
South Elgin (2 mi SW)	Fox River Stone		SG	1,500	-	AB	CL
Sugar Grove (2 mi NW)	Kane County Concrete, Inc.	Kane County Sand and Gravel	SG	400	-	L	ABK
Sugar Grove (3 mi NW)	Meyer Aggregate Co.	Kuggler Pit	SG	2,200	-	L	ABK
Sugar Grove (4 mi NW)	Meyer Aggregate Co.	Lawson Pit	SG	2,200	-	L	ABK
Sugar Grove (2 mi N)	Feltes Sand and Gravel	Divicki Pit	SG	1,400	-	L	ABK
Sugar Grove (3.5 mi NW)	Feltes Sand and Gravel	Harker Pit	SG	1,400	-	L	ABK
Sugar Grove (2 mi NW)	Feltes Sand and Gravel	Probst Pit	SG	1,400	-	L	ABK
Wasco (1 mi NW)	Edward Schneider		SG	N.G.	-	-	ABL

Table 4.2.1-4. Continued

County and General Location	Producer	Local Name	Type†[1]	Average Plant Capacity†[2],†[3] (tons/day 1977)	Access Shafts Within†[4] 5 mi	10 mi	15 mi
KENDALL							
Plano (SE)	Meyer Aggregate Co.	Plano Pit	SG	1,800	-	-	K
Plano (1 mi E)	Zwart Gravel Co.	Sandwich Ready Mix Sand and Gravel	SG	1,000	-	-	KL
WILL							
Channahon (2.5 mi NE)	Meyer Aggregate Co.	Perona Pit	SG	1,600	-	-	IJ
Channahon (2 mi E)	Meyer Aggregate Co.	Vick Pit	SG	1,000	-	-	IJ
Channahon (SW)	D. Koerner, Inc.		SG	N.G.	-	-	IJ
Joliet (S)	Lincoln Stone Quarry		CS	4,000	-	I	HJ
Plainfield (N)	Avery Gravel Co.		SG	500	IJ	HK	AGL
Plainfield (2 mi NE)	Material Service Corp.		SG/CS	5,600/2,000	IJ	HK	AFGL
Plainfield (2 mi N)	Naperville Trucking Co.	Patterson Pit	SG	1,200	IJ	HK	AFGL
Plainfield (3 mi NE)	E & E Hauling		SG	N.G.	IJ	HK	AFGL
Rockdale (3 mi W)	Chicago Gravel Co.		SG	2,500	-	-	HIJ
Rockdale (1 mi W)	Chicago Gravel Co.	Murphy Farm	SG	1,000	-	I	HJ
Romeoville (1 mi NE)	Turner Stone, Inc.		SG	1,500	GH	FIJ	KL
Romeoville (2 mi NE)	Tri-County Land Corp.		SG	1,000	GH	FIJ	K

†[1] SG = Sand and gravel (natural aggregate); CS = Crushed stone.

†[2] Average plant capacity in tons/day as given in Illinois DOT (1977) for 1977.

†[3] N.G. = Not given in Illinois DOT (1977).

†[4] Distances are straight-line distances between pit or quarry locations and proposed shaft locations.

Conversion: To convert miles (mi) to kilometers (km), multiply by 1.6; to convert tons/day to tonnes/day, multiply by 0.907.

Source: Illinois DOT (1977).

landfills and disposal of hazardous wastes) should also be consulted; however, preliminary indications are that the spoil should be fairly innocuous and, thus, permits would not be required. Particularly, if the spoil is sold, the Illinois Department of Mines and Minerals should be consulted to determine whether any mining or reclamation regulations or permits would apply. Additional information on permits and regulations is presented in Section 4.3.1.

4.2.2 Spoils Transportation

Tractor-trailer rigs with dump trailers would be used to transport the spoils from the access shafts to the disposal sites. The actual routes used would depend on the locations of disposal sites selected for the spoils from each access shaft. To calculate reasonable upper limits on the effects of spoil transportation, it is assumed in this section that the average over-the-road transport distance to disposal sites would be 15 mi. Because there are generally several potential disposal locations with a 5-mile radius of each shaft, this is probably an overestimate by a factor of 2 or 3.

Transportation Requirements

The quantities of spoils for the three tunnel diameter alternatives and the resulting transportation requirements for disposal of spoil are summarized in Table 4.2.2-1. For this transportation analysis, the spoils are assumed to have a density of 88 lb/ft3. This is based on a specific gravity for dolomite of 2.82 and a swell factor for tunneling spoils after handling of 2.0. At this density, a full 20-yd^3 dump trailer combination would be very close to axle loading limits. For this reason and to provide conservative estimates of transportation impacts, it is assumed that 15-yd^3 dump trailers will be used.

To estimate maximum transportation impacts, maximum spoil removal rates were calculated for each access shaft. The maximum rates would occur during the period of approximately two years when both tunnel construction and excavation of IR halls, refrigeration stations, auxilliary access shafts, and ramps are occuring simultaneously. These maximum rates, along with the resulting truckloads per day and maximum number of trucks required for each access shaft, are shown in Table 4.2.2-1.

Excavation will be taking place over a number of years, and the spoil removal rates will vary greatly over this period, from the maximum rate discussed above to very low or zero rates for short periods. The average spoil removal rates over a 5-year period, along with the average number of truckloads per day, are also shown in 4.2.2-1.

Table 4.2.2-1. Summary of Transportation Requirements.

Tunnel Diameter (ft)	10	12	15
Total volume to be transported (10^6 yd^3)[1]	3.8	4.6	6.3
Total weight to be transported[2] (10^6 tons)	4.5	5.5	7.5
Total truckloads[3]	254,000	367,000	500,000
Maximum spoil removal per day per access shaft (yd^3)[1,4,5]	700	836	1,047
Maximum truckloads per day per access shaft[5]	47	56	70
Maximum number of trucks required for each access shaft.[5,6]	5	6	7
Average spoil removal per day per access shaft (yd^3)[1,5,7]	240	290	398
Average truckloads per day per access shaft[5]	16	19	27
Average number of trucks required for each access shaft[5,6]	3	3	4

[1] Assumes a swell factor of 2.0 for transportation purposes.
[2] Based on specific gravity of 2.82.
[3] Based on 15-yd^3 dump trailer.
[4] This rate would occur during the period of time (2 years) that both tunnel construction and excavation of IR halls, refrigeration stations, auxilliary access shafts, and ramps occur.
[5] Averaged over the access shafts.
[6] This assumes one round trip covers 30 miles, makes 4 cycles per shift, and includes a spare truck for repair and maintenance purposes.
[7] This average is over a 5-year period.

Transportation Impacts

The transport of spoils to the disposal sites will have associated environmental impacts. These include increased traffic congestion and noise, increased risk of accidents, and increased air pollution.

The maximum number of truckloads leaving all access shafts used for spoils removal (except sites A, G and I) would be in the range of 50-70 daily. This would result in a maximum of 100-140 daily one-way trips in the vicinity of each of these shafts. This would represent an increase in traffic on the order of 1% for most major arterial streets likely to be used by these trucks. This increase in congestion and noise would not represent a significant impact. The maximum number of one-way trips near shaft I would be 200-280 daily. However, site I is in a sparsely populated area and although the percent increase in traffic levels would be greater on the lightly traveled roads in this area, the total traffic levels, and therefore the congestion and noise levels, would remain low. These maximum traffic levels would have a duration of approximately two years. The average level of truck traffic would be less than half the maximum levels. Based on accident statistics for the United States (rural and urban areas), the average injury rate for truck accidents is 8.2×10^{-7} injuries per mile, and the fatality rate is 4.8×10^{-8} per mile (Gay 1979). Based on these national averages, it is estimated that few accidents would occur during transport of spoils.

Since the total increases in truck traffic would be small relative to total traffic levels, and since these truck movements would be spread over a very large area, the increase in air pollution due to these truck movements would be negligible. Estimates of the average daily emissions for working days from the trucks hauling spoils for the duration of the project are shown in Table 4.2.2-2. These values can be compared to 6,000 kg/day CO, 780 kg/day HC, 560 kg/day NOx, and 360 kg/day TSP for one mile of the Eisenhower Expressway in the vicinity of First Avenue.

4.2.3 Surface Disruption

It is expected that surface disturbance at most refrigeration/access shaft sites would be limited to about 5 acres (2 ha). Since spoil would be removed from two tunneling directions at shaft site I, surface disturbance could be somewhat larger for this site. However, this would probably not create a major problem because of the rural location of shaft site I. In addition, greater than average spoil volumes will be removed from shaft sites A and G because of the locations of interaction halls and related facilities, and this will cause somewhat larger surface disturbances at the national

Table 4.2.2-2. Average Daily Emissions for Working Days from All Spoils Transport Trucks.

Tunnel Diameter (ft)	Average Miles Per Working Day	Pollutant (kg/day)			
		CO[1]	HC[1]	NO[1]	TSP[2]
10	6,350	95.3	33.7	164.5	15.2
12	9,175	137.7	48.6	237.7	22.0
15	12,500	187.6	66.3	323.9	30.0

[1] User's Guide to Mobile 3 (Mobile Source Emissions Model) U.S. E.P.A., EPA 460/3-84-00 (June 1984).
[2] Historical and Projected Emissions Conversion Factor and Fuel Economy for Heavy-Duty Trucks, 1962-2002, Energy and Environmental Analysis, Inc., Arlington, Virginia (December 1983).

laboratory sites.

Surface disturbances would include excavation of soil and unconsolidated overburden at the start of shaft sinking, and installation of (1) hoist facilities to remove rock spoil, (2) a temporary storage pile for rock spoil, (3) a sedimentation pond for desilting of water discharges, (4) conveyer facilities or vehicular maneuvering space for loading spoil onto trucks, (5) temporary roads for truck movements, (6) contractor facilities and work areas, such as an office trailer, storage areas, and temporary shop facilities, and (7) parking areas. Since no rock spoil would be removed from shaft site E, surface disturbance at that site would be minimal.

Overburden excavation at the start of shaft sinking would encompass a wider area than the shaft itself and would probably extend to an average depth of 30 to 40 ft (9 to 12 m). Some of this material probably could be sold as fill at local construction sites, and the rest probably would be stored temporarily at the shaft site for use as backfill around the top of the shaft.

In addition, topsoil should be removed from temporary storage areas, from areas receiving heavy vehicular traffic, or from other areas that would be subject to compaction. Topsoil would either be stockpiled until cleanup of the shaft site or sold locally. If the latter occurs, replacement topsoil would then have to be purchased for landscaping after site cleanup. Whether topsoil was stored onsite or sold and replaced by purchase later would probably depend on the area available at each shaft site. Gravel or rock spoil might be used to provide a surface for temporary roads or vehicular maneuvering areas in order to reduce fugitive dusting and provide stable surfaces.

Estimates of the maximum average area required at each shaft site for temporary storage of rock spoil have been made for storage of one day's production and also for an accumulation of spoil from five days of production. It was assumed that longer delays in the transport of material from the temporary storage pile would result in a halt of excavation activities. Areas were calculated assuming that the shape of temporary storage piles would approximate that of a 21-ft (6.4-m) high cone. Less than 0.1 acre (0.04 ha) would be required for one-day storage at most sites; whereas five-day storage could require about 0.42 acre (0.16 ha) for a 15-ft (4.6-m) tunnel at most sites.

Federal, state, and local authorities should be consulted concerning any regulations or permits required for surface disturbances at the shaft sites. Shaft sites should not be located in wetlands or other environmentally sensitive areas. The USEPA and the Illinois EPA should be consulted concerning fugitive dust and water discharges from the shaft sites. Fugitive dusting from the hoist area, spoil stockpile, spoil-loading operation, and vehicle movements might require control with water or tacking agents. The area around the temporary spoil storage piles might have to be graded and bermed to direct runoff into a sedimentation pond before discharge from the site. Any water pumped from the tunnels would also probably have to be pumped into the sedimentation pond before discharge from the site. Discharges might have to be monitored, and National Pollutant Discharge Elimination System (NPDES) permits would probably be required. Other than suspended fines from the spoil, the effluents would be expected to have a quality similar to local groundwater and should not be a source of contamination unless they were contaminated with oils, grease, or other materials from the drilling, blasting, tunneling, and transportation processes. Measures to avoid such contamination would probably be necessary, and monitoring for contaminants might be required. Additional information on permits and regulations is presented in Section 4.3.1.

Following completion of work at each shaft site, equipment, debris, and temporary surfacing materials for roads and other areas would have to be removed. The site would have to be ripped (to reduce compaction) and graded following the construction of any permanent buildings. Topsoiling and landscaping would then be required to complete the cleanup of the site.

4.3 SOCIOECONOMICS AND LAND USE

This section contains a preliminary assessment of potential social, economic, and political problems associated with the development of the SSC Project. The focus on potential problems instead of potential benefits is

justifiable at this stage of project development because it answers the question "Is it feasible to plan to build the SSC in this location given the current socioeconomic environment, population density, and land use patterns?" The preliminary assessment of these conditions indicate that it is feasible, from a socioeconomic and land use perspective, to continue the planning for development of the SSC Project in this location as described earlier in this document.

4.3.1 Institutional Issues

Property Acquisition

The SSC would involve tunneling under numerous parcels of private property in four counties and several municipalities. This tunneling would have no effect on the surface because of the depth of the tunnel (400 to 750 feet). The project would also include sinking ten vertical access tunnels outside of the DOE laboratories. Acquisition of the subterranean easements for the tunnel and of the parcels of land needed for the vertical access shafts would have to be carried out prior to project construction. It is assumed that the land acquisition process for this project would probably be carried out by the state, and plans for this process would be included in the site proposal.

Subterranean Easements

The basic approach to acquiring an easement to property would involve having the owner of a given piece of property grant an easement to the federal government. In the case of subterranean easement, the surface would not be disturbed nor would the property owner likely suffer negative consequences from tunnel construction (such as noise or vibration). The granting of an easement would involve compensation for the value of the easement.

Another approach to acquiring an easement to property involves envoking the principle of eminent domain, which gives government the right to acquire property for the public good. The United States government has the power of eminent domain and derives its general statutory authority from statute 40.U.S.C.§257 "which provides that the Department of Justice shall institute judicial proceedings for condemnation upon the application of 'any officer' of the United States, when in his or her opinion it is 'necessary or advantageous' to acquire the land" (Tanzman and Lerner 1981, p. 14). Condemnation procedures require just compensation for easements or property taken, and compensation has generally been the focal point for disagreement. Such a procedure allows for construction to take place in a timely manner

while allowing just compensation to be established at a later date and/or in court. Several federal acts give particular types of projects specific rights of eminent domain (electric power projects, interstate highways, waterways, and natural gas pipelines). A project in the immediate area that involved use of emminent domain for deep tunneling was the Chicago Sanitation District's Tunnel and Reservoir Project (TARP). The Chicago Sanitation District utilized the procedures outlined above in acquiring both subterranean and surface easements for TARP. The Sanitation District developed a mathematical computer-aided approach to providing the exact legal description of where the tunnel crosses under each piece of property. The Sanitation District then sent out one of several "land men" to acquire an owner's signature on a standard easement form. This form provided a legal description of where the tunnel would pass under the property. Compensation was handled on a case-by-case basis and generally ranged between $100 and $300. If the district could not acquire an easement in this manner, a declaration was filed. Special problems arose in acquiring subterranean easements under waterways (involving the Corps of Engineers) and railroad rights-of-way (involving large bureaucracies and the Interstate Commerce Commission). Appointment of a special federal attorney was recommended by the Chicago Sanitation District as the best way to streamline the court process in exercising the right of eminent domain.

Land and easement acquisition would take time, however, this process can be accomplished in parallel with other efforts such as compliance with NEPA regulations. Thus no additional delay due to acquisition of land and subterranean easements should be expected.

Surface Land Acquisition

Nine sites of about five acres each and one of about two acres would have to be acquired through purchase, lease, or condemnation for location of the vertical access shafts, construction equipment, truck loading facilities, muck storage piles, etc. These sites would be staging areas for muck removal during the construction phase and would be used for refrigeration/compressor units, auxiliary generators, and ventilation during the operational phase. Current plans call for locating these vertical access shafts and associated aboveground facilities in areas zoned for industrial or agricultural use, and on land that is currently unoccupied. Example locations have been identified and are discussed in the section on land use. Although rights of eminent domain could be used (as described above) for acquiring these sites, it is anticipated that the required land could be purchased outright, thus minimizing potential conflict with property owners.

Permits and Regulations

DOE has primary responsibility for managing health, safety, and environmental protection programs at DOE-owned, contractor-operated facilities. With respect to most radiological matters, DOE is largely "self regulating" in that it is not subject to the authority of other federal agencies (there is an exception with accelerator-produced isotopes, however, where EPA does have regulative authority). With respect to nonradiological matters, DOE is generally subject to both the substantive and procedural requirements of most of the major environmental statutes. DOE has issued several operating orders that contain environmental guidelines for its various operations. It is important to note that these regulations would apply to any accelerator built anywhere in the United States.

These regulations are outlined here to provide an identification of what factors need to be taken into consideration during the project planning stage.

DOE Orders and Internal Guidelines

In the area of radiological regulation, DOE's self-regulation derives primarily from Section 110 (a) of the Atomic Energy Act (42 USC 2011 et seq.), wherein DOE-owned, contractor-operated facilities are excluded from licensing and other regulatory functions of the U.S. Nuclear Regulatory Commission (NRC). The following DOE orders would apply to the construction and/or operation of the SSC.

Order 5480.1A (Environmental Protection, Safety and Health Protection Program for DOE Operations). DOE's primary standards for radiation protection are contained in DOE Order 5480.1A, Chapter XI ("Requirements for Radiation Protection"). Allowable concentrations of various radionuclides in air and water, both onsite and offsite, are also specified in Order 5480.1A. The SSC would operate within the limits specified in this order. (See Section 4.1 for a discussion on radiological risk assessment.)

Order 5480.1 (Environmental Protection, Safety and Health Protection Information Reporting Requirements). An environmental monitoring program would be implemented in accordance with Chapter III of DOE Order 5484.1. The program would be designed to determine:

- Whether containment and control measures to limit releases of radioactivity from the site are functioning as planned.

- Whether, and to what extent, environmental levels of radioactivity and other pollutants released from the site comply with applicable DOE guidelines.

- The overall impact of the site operation on the environment.

Order 5480.2 (Hazardous and Radioactive Mixed Waste Management). The provisions of Order 5480.2 apply to all DOE operations conducted under the authority of the Atomic Energy Act of 1954 that result in the generation, transportation, treatment, storage and/or disposal of hazardous waste. The procedures follow, to the extent practicable, regulations issued by the Environmental Protection Agency (EPA) pursuant to the Resource Conservation and Recovery Act (RCRA) as discussed below. Currently, there are unresolved issues between DOE and EPA concerning mixed wastes. It is expected that DOE-approved waste management practices would be utilized both at Fermi National Accelerator Laboratory and at Argonne National Laboratory. The amount of waste produced in the SSC during operation would be quite small and could be easily handled within the existing hazardous waste management systems at the two Laboratories.

Environmental Laws

In the area of nonradiological environmental regulation, DOE facilities are specifically subject to both the substantive and procedural requirements of most of the major federal environmental statutes and, where legally mandated, to parallel provisions in state environmental laws. This was clearly established in 1974 when the President of the United States executed Executive Order 12088, "Federal Compliance with Pollution Control Standards". Prior to this Executive Order, the doctrine of federal supremacy had maintained that federal agencies were exempt from the procedural requirements of state or local environmental regulatory programs.

The regulatory programs and enforcement authorities for environmental statutes are generally shared by the states, the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers, and other agencies. The more substantive environmental laws that may apply to a DOE decision regarding the SSC include: the National Environmental Policy Act; the Clean Air Act; the Federal Water Pollution Control Act; the Safe Drinking Water Act; the Historic Preservation Act; the Resource Conservation and Recovery Act; and the Farmland Protection Policy Act. These laws, with their many requirements, could represent a potential problem area for the SSC if not addressed effectively early in the project. In order to minimize the potential for delay, these

laws should be taken into account in the earliest planning stages.

National Environmental Policy Act (NEPA). For the SSC Project, this would likely be the most important environmental statute. NEPA requires that for major federal actions that may significantly affect the quality of the human environment, responsible officials shall prepare a detailed statement on the following:

(i) the environmental impact of the proposed action,

(ii) any adverse environmental effects that cannot be avoided if the proposed action is implemented,

(iii) alternatives to the proposed action,

(iv) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and

(v) any irreversible and irretrievable commitments of resources that would be involved in the proposed action if it were implemented.

The provisions of NEPA would be satisfied by following the procedures outlined by the Council on Environmental Quality and the DOE NEPA compliance guidelines. DOE will have to determine what level of NEPA compliance is necessary for each stage of the decision-making process for the SSC.

Clean Air Act. The Clean Air Act imposes certain restrictions and permit requirements on activities that result in the emission of pollutants to the air. Some activities associated with the SSC could result in nominal releases of radioactivity to the atmosphere from the tunnel ventilation shafts. It is possible that air emission permits issued by the EPA under Section 12 of the Clean Air Act could be required. On April 6, 1983, EPA proposed control standards for radionuclides under 40 CFR 61, National Emission Standards for Hazardous Air Pollutants (NESHAP), that--when promulgated--will apply to DOE facilities. These proposed regulations would limit radionuclide emission to the amount that would not allow a dose equivalent of more than 10 mrem/yr to any organ of an individual living nearby. The releases described in Section 4.1 are expected to be well within these limits.

Federal Water Pollution Control Act. Under Section 404 of the Clean Water Act, and 40 CFR 122, a discharge permit is usually required

for waste water releases to public waters of the United States. Waste water from the mining operation would be discharged to the environment. The nonradioactive parameters of that waste water would be subject to the usual concentration and/or quantity restrictions imposed by permits issued under the National Pollutant Discharge Elimination System (NPDES), and an NPDES permit would have to be coordinated through EPA, Region V.

Safe Drinking Water Act (SDWA). The Safe Drinking Water Act of 1974 protects the public health "from contaminants present in or likely to enter a public water system" (Tanzman et al. 1982). Routine monitoring of groundwater near the SSC will guard against an unlikely situation in which there is an unexpected migration of radionuclides.

National Historic Preservation Act. Section 106b of the National Historic Preservation Act requires careful consideration of potential impacts to cultural resources for actions undertaken by or on behalf of any federal agency. A professional cultural resources survey of the vertical shaft sites would have to be conducted prior to the commencement of the project. The tunnel itself would be too deep to require a survey.

Resource Conservation and Recovery Act (RCRA). Among other things, RCRA provides authority to the states to "regulate the treatment, storage, transportation, and disposal of hazardous wastes which have adverse effects on health and the environment" (Section 1003). Because of the suit Train vs. Colorado Public Interest Research Group, Inc., it was found that although the EPA could not control radioactive effluents from nuclear power plants, the EPA could "regulate radioactive materials such as radium, accelerator-produced isotopes, and thermal pollution without encroaching on the Atomic Energy Act". This case suggests a very narrow area of radioactive waste that would be subject to RCRA regulation (Tanzman et al. 1982, p. 6).

Farmland Protection Policy Act. The Farmland Protection Policy Act was enacted to help minimize the conversion of farmland to non-farm uses. This act requires that decision makers take into account the impact of a given project on agricultural land. The act does not require that a project be changed because of potential land use impacts. The act simply seeks to "minimize the federal role in conversion of farmland and to keep federal actions compatible with local and private policies" (Land Use Planning Report 1984, p. 218). Indeed, the site proposed here will have minimal effect on farmlands, due both

to its effective use of existing DOE lands and to the tunnel being deep underground.

In addition to the above regulations and orders, the SSC Reference Designs Study (Parsons, Brinckerhoff, Quade, and Douglas, Inc. 1984) listed other regulations that could possibly apply in locating the SSC anywhere in the United States. These regulations, of varying importance, are listed below:

General Environmental

- Environmental Quality Improvement Act of 1970 (42 U.S.C. 4371 et seq.).

- Executive Order 11514, Protection and Enhancement of Environmental Quality.

Water

- Flood Disaster Protection Act of 1973 (42 U.S.C. 4001 et seq.) as amended.

- Executive Order 11988, Floodplain Management, May 24, 1977 (42 FR 26951).

Conservation

- Endangered Species Act of 1972 (16 U.S.C. 1531 et seq.) as amended.

- Fish and Wildlife Coordination Act (16 U.S.C. 661-666c et seq.) as amended.

- Soil and Water Resources Conservation Act of 1977 (16 U.S.C. 2001).

- Executive Order 11990, Protection of Wetlands, May 27, 1977 (42 FR 26961).

- Executive Order 11870, Environmental Safeguards on Activities for Animal Damage Control on Federal Lands, July 17, 1975.

Noise

- Noise Control Act of 1972 (42 U.S.C. 4901 et seq.).

Solid and Hazardous Wastes, and Toxic Chemicals

- Toxic Substances Control Act of 1976 (15 U.S.C. 2601 et seq.) as amended.

Historic and Archaeological Resources

- Executive Order 11593, Protection and Enhancement of the Cultural Environment, May 13, 1971 (36 FR 8921 et seq.).

Permits

The SSC project would require limited permitting at the federal, state, or local levels, as described below. It should be noted that the permitting process at each governmental level could represent a potential focal point of public opposition and consequent impediment to project construction.

Federal

Since the proposed project would require the construction of a tunnel under a navigable waterway (in this case the Des Plaines River and associated canals), it could require a permit (River and Harbor Act of 1899, Section 10; and Clean Water Act, Section 404) from the U.S. Army Corps of Engineers. At minimum, consultation and a letter of permission would be needed to proceed with the project (U.S. Army Corps of Engineers 1983).

State

Permits from the State of Illinois could be required under certain conditions for spoil disposal and disposal of water from spoils and from the tunnel. The sale of spoil material could potentially require a permit from the Department of Mines and Minerals; consultation would be necessary. Temporary spoil-disposal sites subject to discharge of water and water discharged from the tunnel could require a permit from the state Environmental Protection Agency. No permits for the type of tunnel construction and operation associated with the proposed project would be necessary at the state level.

County and Municipal

In compliance with local regulations, county or municipal building permits would be required for the construction of the access shaft facilities, depending on the zoning jurisdiction.

Land Use Considerations and Constraints

The SSC tunnel would have no effect on surface land use and zoning. The ten vertical access shafts outside of ANL and FNAL linking the tunnel to the surface could potentially affect existing land use patterns. The vertical

access shafts would be used for removing tunnel muck during construction. (Refer to Section 3.2 for a discussion of surface facilities needed during the construction phase.) During the operational phase, a building approximately 240 ft by 50 ft, which would house refrigeration units for cooling the SSC magnets, would be located on each vertical access shaft site. These buildings could be designed to blend in with existing buildings in agricultural, industrial, and manufacturing areas and thus would not appear unusual in these settings. As examples, specific vertical access shafts have been assigned specific hypothetical locations for this study. These locations are consistent with project requirements and, therefore, permit a realistic assessment of project feasibility within the context of current land use and zoning patterns.

Existing Land Use and Zoning Patterns

Ten of the twelve vertical access shafts would be located outside of national laboratory property, on land presently used for agriculture or industry. The sites would be in four counties (five in DuPage, one in Kane, one in Kendall, and three in Will). Example sites within about a half a mile of the ideal refrigeration station locations have been found; all vacant and either on land zoned by the respective county, or on areas subject to local municipal zoning. For the particular example chosen, displaced access shafts were required in only three sites and the largest displacment was ~ 2000 ft. Five of the sites would be located on agricultural land, and five would be constructed on industrial* land. Crop production (chiefly corn and soybeans) characterizes current agricultural land use patterns, while general manufacturing is predominant in the industrial areas under consideration. Individual site descriptions are presented below.

Site A is located at Fermi National Accelerator Laboratory (Fermilab) near Batavia. No land use considerations are analyzed for the national laboratory site, since the proposed action would be consistent with laboratory activities.

Site B is located in DuPage County adjacent to a railroad line. The area is within municipal zoning boundaries and is classified as business and industrial (both limited and general). An undeveloped residential zone is situated to the northeast. Several open lots occupy areas on both sides of the railroad line. The terrain is characterized by low hills, and is partly

*This includes a designated site location on land currently zoned as "residential", but leased for industrial use by a large landfill project.

wooded.

Site C is located in DuPage County. The area is zoned for agricultural use by the county; several farm houses are situated nearby. Southeast of the example site location there is a suburban residential development. Immediately to the south, all land is zoned for agriculture. Further to the south, offices and warehouses occur in municipal zoning districts. The terrain here is relatively subdued, with low rolling hills and limited wooded areas. Corn is the chief crop under cultivation.

Site D is located in DuPage County, in an industrial park area zoned for general manufacturing (by the local municipality). Additional industrial-zoned land lies to the west, south, and southwest, while residential areas occur to the east, north, and northwest. The terrain here is relatively flat; a large pond is situated immediately to the northeast.

Site E is located in DuPage County. The example site is currently leased to a large, privately owned landfill project. Although this property is zoned residential, there are no housing units on or in proximity to the site. Its eastern margin adjoins a ten-acre undeveloped (zoned commercial high rise) plot, which surrounds a several hundred-foot-high water tower. The landscape is relatively open; high slopes and a wooded area along the south edge conceal most of the landfill activity.

Site F is located in DuPage County. The area is within municipal zoning boundaries. It has been zoned for light manufacturing and, in certain locations, office research. A multiple-acre vacant lot occupies the south end of the area. The terrain is relatively flat and unwooded, although some regrowth (weeds and shrubs) has occurred.

Site G is located at Argonne National Laboratory. No land use considerations are analyzed for the site, since the proposed action would be consistent with Laboratory activities.

Site H is located in Will County in an area that is county-zoned chiefly for industrial use, but contains several residential units as well. The industrial facilities include storage tank complexes situated along road and railroad lines, as well as on a high ridge (Des Plaines River terrace) above the rail lines. Specific siting localities seem to be available in both areas, as well as on the terrace slope, which has not been subject to substantial development or recent forest clearance.

Site I is located in Will County. The area is zoned by the county for agricultural use, although an agricultural "special use" designation has been given to a multiple acre lot, adjacent to the example access shaft site.* An abandoned railroad line is also situated close to the site, and several farm houses and associated buildings are located to the north, west, and south (approximately 1/4 to 1/2 mile away). The terrain is relatively flat and largely treeless. Crop production includes corn and soybeans.

Site J is located in Will County in an area zoned (by the county) for agricultural use, but within half a mile of an industrial district (occupied by a plant, warehouse, and lumber yard). The terrain is slightly rolling and unforested, and several farm houses are situated nearby (north, southwest, and east of the tentative siting location). Crops under production include corn and soybeans.

Site K is located in Kendall County, in an area zoned (by the county) for agricultural use. A light manufacturing zone (municipal) occurs to the north. Several farm houses are situated within 1/4 to 1/2 mile. The terrain is relatively flat and unforested, and crops under production here include soybeans

Site L is located in Kane County, in a municipally-zoned general manufacturing district. The site location adjoins additional general manufacturing areas to the east and limited manufacturing districts to the southeast and west. Some residential areas lie to the south and west, and county agricultural and residential land occurs to the north and northeast. The terrain is slightly hilly with occasional trees and wooded stands.

Changes in Land Use and Zoning for SSC Facilities

Considerations regarding potential public concerns over land use impacts make voluntary compliance with all pertinent state and local regulations the preferable procedure. This option, if chosen, would involve the steps outlined below.

Five of the example access shaft sites outside of national laboratory boundaries are located in areas zoned for industrial use which would appear to require no change in existing zoning classification. Four of these occur in municipally zoned "general industrial" (or manufacturing) areas (see

*No construction presently observable; this may be a dump site.

Table 4.3.1-1. Existing Zoning Classification and Anticipated Changes of Example Access Shaft Sites

Access Shaft Site Desgination	Present Zoning Classification	Zoning Jurisdiction	Change Required?	Zoning Anticipate Impact
A	National Laboratory	(Fermilab)	No	None
B	General Industrial	Municipal	No	None
C	Agricultural	County (DuPage)	Yes	Limited
D	General Industrial	Municipal	No	None
E	Residential*	County (Cook)	Yes	Minimal
F	Limited Industrial	Municipal	No(?)	Limited
G	National Laboratory	(ANL)	No	None
H	Industrial	County (Will)	No	None
I	Agricultural	County (Will)	Yes	Limited
J	Agricultural	County (Will)	Yes	Minimal
K	Agricultural	County (Kendall)	Yes	Limited
L	General Industrial	Municipal	No	None

*Currently leased for large landfill project.

Table 4.3.1-1), which would be fully compatible with the design and operation characteristics of the access shafts and associated facilities.

The fifth example site is in an area currently municipally-zoned for "limited industrial" (or manufacturing) use. The municipal definition of a limited industrial district does not normally specifically address compressor stations such as those that would be associated with the access shafts for the proposed project, but does include similar installations such as pipeline compressor stations and water-pumping stations. The definition appears to be of sufficient latitude, with respect to overall design features, to encompass the access shafts and associated facilities.

An important additional consideration in assessing the compatibility of the proposed access shaft sites with any areas zoned for limited industrial use is the amount of noise generated by the site facilities. Noise levels beyond site boundaries in excess of existing ambient levels (60-65 dba in this case) are precluded under current zoning law. Measurements of sound generated by the central helium liquifier compressor at Fermilab indicate a mean level of approximately 70 dba (measured at a distance of 120 feet). Since this level could potentially be reduced by supplementary housing and insulation of shaft facilities, a zoning classification change to general industrial probably would not be required.

The remaining five example access shaft sites outside national laboratory properties are in agricultural and (in one case) residential districts, which would require classification changes under existing local zoning ordinances (see Table 4.3.1-1). All of the anticipated zoning changes would occur within county jurisdiction; no changes in municipal zoning would be necessary. Four of these sites would be situated on agricultural land and one on residential land, all of which would have to be changed to limited, or perhaps even general, industrial (or manufacturing) districts.

The process of obtaining a county zoning district change (or "map amendment") begins with an application to the zoning board of appeals with accompanying survey plats, recommendations from local bodies (e.g., health department, fire department, township supervisor) and fee, followed by a public hearing (advertised in advance) before the board. Upon approval by the zoning board, the requested change passes to the county board for a final decision. (See Appendix B for map amendment procedures in Will County, which recommends an informal hearing before the appropriate local and regional planning commissions prior to consideration by the zoning board, and approval by the Land Use Committee of the county board prior to the latter's decision.) The entire process may last three months or more.

It should be noted that the designated access shaft sites located on land currently used for agriculture occur in areas of relatively low population density where occasional isolated industrial or manufacturing zones already exist. The residential zone, despite its present classification, is occupied by a large landfill project which precludes the presence (or construction in the near future) of dwelling units. Thus, the changes in land use patterns generated by the proposed project would be small and would not be significantly disruptive of or substantially incompatible with existing usage.

4.3.2 Political and Economic Environment

Population Trends by County

There are five counties that would be involved in this SSC site - Cook, DuPage, Kane, Kendall, and Will; however, there will be no surface activity in Cook County. All counties have gained population from 1960 to 1980 (Table 4.3.2-1). A recent loss in Cook County is somewhat misleading since the population loss most likely represents county-to-county migration within the metropolitan Chicago area. The population of the metropolitan Chicago area, although not shown in the table, grew slightly from 1970 to 1980.

Employment by County

Cook and DuPage counties have the largest number of employed persons within the five counties encompassing the SSC Project. Employment figures for the five counties are shown in Table 4.3.2-2. Of particular importance to the SSC Project is the total number of persons employed in the areas of mining and construction. In the five-county area there were 3,913 persons employed in mining and 122,907 employed in construction.

Unemployment rates for 1983 for the five-county area are shown in Table 4.3.2-3. These rates range from a high of 13.6% in Will County to a low of 7.9% in Kendall County. These rates indicate that expansion of the economic base would be desirable to reduce unemployment.

Economic Benefits of the SSC Project

The SSC project would employ an average of 1,250 workers over a five-year construction period. Figure 3.30 shows the construction and operation workforce schedule for project years one through five. As can be noted from the figure, construction employment peaks in year three at 1,980 employees. This construction workforce estimate only includes tunnel and access shaft

Table 4.3.2-1. Population Trends by County - 1970, 1980

	1970	% Change from 1960 to 1970	1980	% Change from 1970 to 1980
Cook	5,492,369	+7.1	5,253,655	- 4.3
DuPage	491,882	+56.9	658,835	+33.9
Kane	251,005	+20.5	278,405	+10.9
Kendall	26,374	+50.4	37,202	+41.1
Will	249,498	+30.2	324,460	+30.0

Source: U.S. Department of Commerce, Bureau of the Census, 1970, "Characteristics of the Population", Volume 1, Part 15, Illinois Section 1, and PC 80-1-A15, 1980.

Table 4.3.2-2. Industry of Employed Persons by County - 1980

Industry	Cook		Dupage		Kane		Kendall		Will	
	#	%	#	%	#	%	#	%	#	%
Agriculture	7,112	0.3	2,030	0.6	1,890	1.4	754	4.1	1,885	1.4
Mining	2,624	0.1	576	0.2	212	0.2	34	0.2	467	0.3
Construction	88,668	3.8	18,090	5.3	6,732	5.1	1,102	6.1	8,315	5.9
Manufacturing	612,828	26.0	83,464	24.4	44,827	33.7	6,832	37.6	40,702	29.1
Transportation and Public Utilities	207,619	8.8	28,375	8.3	8,703	6.6	1,355	7.5	13,063	9.3
Trade (wholesale & retail)	490,678	20.9	79,892	23.3	25,171	19.0	3,162	17.4	28,942	20.7
Finance, Insurance and Real Estate	190,050	8.1	25,705	7.5	7,926	6.0	1,027	5.6	7,342	5.2
Services	649,291	27.6	95,199	27.8	33,275	25.1	3,425	18.8	33,979	24.3
Government	103,838	4.4	9,121	2.7	4,056	3.1	505	2.8	5,358	3.8
Forest and Fisheries	709	-	133	-	55	-	-	-	26	-
TOTAL	2,353,417		342,585		132,847		18,196		140,079	

Source: U.S. Department of Commerce, Bureau of the Census, 1980, "General Social and Economic Characteristics - Illinois", PC 80-1-C15.

requirements for installation of the accelerator. Operational employment is expected to build up to and remain at approximately 3000 during the operational life of the project.

Increases in employment in the basic sectors* of the economy can be expected to increase demand for goods and services in other sectors of the economy. The construction and operation of the SSC would generate and support jobs in the secondary sectors of the economy.

An economic base multiplier approach can be used to forecast the secondary employment expected in relation to a given construction project. The ratio of basic to secondary employment must first be established in a given economy to project employment benefits. The economic multiplier of 1:0.45 (basic construction to secondary employment) will be used in this report for the construction effort. This ratio is an average ratio of basic construction employment to secondary employment in areas on the fringe of a metropolitan area (Denver Research Institute and Browne, Bortz and Coddington 1982). The ratio for basic operating employment to secondary employment is 1:0.7 (Denver Research Institute and Browne, Bortz, and Coddington 1982). The reason for the different ratios is that economies generally do not respond in the same way to construction workforces as they do to permanent operating workforces. Table 4.3.2-4 shows the projected increases in basic and secondary employment by year for the SSC Project.

Table 4.3.2-3. Unemployment Rate by County - 1983 Annual Average

Cook	10.7%
DuPage	8.6%
Kane	10.8%
Kendall	7.9%
Will	13.6%

Source: U.S. Department of Labor, Bureau of Labor Statistics, 1984, "Employment and Unemployment in States and Local Areas 1983", March.

*Basic sectors of the economy are those sectors that bring income into the region from other areas either through export of commodities or through federal spending. Secondary sectors of the economy represent the production of non-exported goods and services generated by income that remains in the region.

Total employment benefits attributable to the SSC project would average 2290 primary and 1288 secondary jobs during the construction phase of five years, after which operational levels would be reached. Undoubtedly, income generated through project-related employment will have a positive effect on state and local government through increased collection of sales tax, property taxes, vehicle registration, personal income tax, and use taxes of various kinds. Increased purchasing power will have a positive benefit on area businesses.

Material purchases for the SSC project are not subject to state sales and use tax. Therefore, no increased revenue from the SSC Project will accrue to the state and local governments directly. Because the SSC Project would be a federal project, no property tax would be paid on the facility. However, as mentioned above, secondary impacts of the SSC Project would include increased tax revenue.

Economic Development Plans by County

All of the counties that would be affected by the SSC Project have established economic development commissions, reflecting a concern with continuing economic and industrial growth and associated benefits. One county has also established an explicit policy for the encouragement and promotion of "high tech" industry and research facility expansion. Kane County has articulated a policy specifically favoring development of the "high tech corridor" between north Aurora and Batavia, which includes Fermi National

Table 4.3.2-4. Estimated Increases in Basic and Secondary Employment per Year for the SSC Project (Totals in Parentheses)

Construction	**Civil Construction**	**Technical**
Project Employment	1250 (6225)	1040 (5200)
Secondary Employment	560 (2814)	728 (3640)
Total	1810 (9069)	1768 (8840)
Operation		
Project Employment		3000
Secondary Employment		2100
Total		5100

Accelerator Laboratory and designated access shaft site "L" (see Section 4.3.1.). Such county economic development policies should contribute substantially to a positive climate for the SSC project.

Interaction with the Public and Public Participation

Throughout the SSC planning process, one policy concerning the public should predominate: straightforward, honest interaction with the public. If trust is not developed with community members and leaders, little constructive interaction will take place. Citizens and local leaders must know by the statements and behavior of project personnel and decision-makers that the public is being told the technical "facts" as well as those facts are known, that uncertainties remain, that differences of opinion exist among "experts" and the reasons for those differences, that community members and organizations would have active, acknowledged, and real input to the decision-making, and that the public would be informed as to why a decision is made one way or the other. Citizens and local officials should be able to expect timely responses to their questions and admissions of gaps in knowledge.

It is imperative that a public interaction program be established during the early planning stages of the SSC Project. Although the development of such a program involves a specific management decision, the following recommendations are offered as a guide for the eventual development of such a program.

The guiding goal of a public involvement program is to develop "informed consent" on the part of the potentially affected public entities. To develop informed consent, the public has to have a way of learning about the project and a way for letting the project planners know about public concerns in reference to the project.

As a first step, it is recommended that ANL and FNAL develop a community liaison team consisting of key SSC project people and laboratory officials. The team should be relatively small (three to five individuals) and remain constant (in terms of membership) over time. A high-status individual should be appointed to a leadership role in interacting with government leaders. Such an individual should be known, trusted, of sufficiently high status to be on equal footing with government leaders, and have in-depth knowledge of the SSC project.

This group would meet with elected public officials at all levels of government to inform them of the project and of the processes by which public concern will be taken into account during the project planning stages. These

initial meetings would be a basic courtesy and would be conducted in private during the pre-public phase of the project. The following elected officials should be sought out for meetings:

Congressional Representatives from the State of Illinois
Governor
State Senators and Representatives from the affected districts
County Commissioners
Local Mayors

The initial meetings would best be conducted on an individual basis with one or two members from the community liaison team.

Additional meetings may be called for by government leaders for informing technical staff. In a second tier of meetings, key agency personnel representing the following agencies (at the different levels of government) should be consulted:

Planning Departments
Economic/Industrial Development Committees
Public Works
Transportation
EPA
Corps of Engineers

After this second level of meetings, the community liaison team should consider how to present the plans to the public. It is suggested that formal presentations be made to the county commissioners, city/town councils, and other political entities likely to be affected by the project. Such presentations would take place during regular public meetings and thus would be included in the official record and reported in the press.

Not only should the project plans be presented in these meetings, but the process by which the project team will interact with the public should be made explicit. It is important that the public realizes that a process for public interaction exists and that such a process can adequately deal with public concerns. This interaction process will have to be developed by the community liaison team and evolve through consultation with the affected public entities.

Once the project plans have been made public, the community liaison team should appoint a community development/interaction specialist. This

person would be responsible for monitoring news coverage, public meetings, etc., to identify groups that have particular problems with the project. The object is to identify potentially affected groups and involve the groups in the planning process. By taking into account concerns early in the project planning stages, the chances of developing informed consent for the project are improved. It should be pointed out that involvement of the public in the planning process may involve some project changes by project management; however, development of informed consent also involves some compromises on the part of the public.

The numerous environmental laws and required permits will afford additional opportunities for public input. The laws and required permits also allow for formalized intervention. However, by interacting with the public and taking public concerns into account during the planning stages, and by preparing a good technical case well in advance that specifically addresses public concerns, intervention and delay can be minimized.

References

Section 4.1

Baker, S., Private communcation, Fermi National Accelerator Laboratory (July 1984).

Baker, S., Elwyn, A., Lack, J., and Read, A, "Tunneling Beyond Fermilab Site," Technical Memorandum 1218, Fermilab National Accelerator Laboratory (July 1983).

Barbier, M., "Tritium Production in SSC Coolant," Report MM-26, Marcel M. Barbier, Inc,, Herndon, VA (1984).

Borak, T.B., Awschalom, M., Fairman, W., Iwami, F., and Sedlet, J., "The Underground Migration of Radionuclides Produced in Soil near High Energy Proton Accelerators," Health Physics 23:679-687 (November 1972).

Cossairt, J.D., and Elwyn, A. J., "Shielding Considerations for Fixed Target Usage of the SSC," Superconducting Super Collider Workshop on Fixed Target Physics (January 1984).

Fasso, A. et al., "Radiation Problems in the Design of the Large Electron-Positron Collider (LEP)," CERN Report 84-02 (1984).

Gollon, P. J., "Soil Activation Calculations for the Antiproton Target Area," Fermilab Technical Memorandum 1104 (September 1978).

Kondo, K., Hirayma, H., Ban, S., Taino, M., and Ishii, H., "Induced Radioactivities in Concrete Constituents Irradiated by High-Energy Particles," Health Physics 46:1221-1239 (1984).

Opelka, J. H., Mundis, R. L., Marmer, G. J., Peterson, J. M., Siskind, B., and Kikta, J.M., "Particle Accelerator Decommissioning," ANL/ES-82, Argonne National Laboratory (1979).

Pollock, R. W., "Tritium Contamination in Accelerator Cryogenic Facilities," Health Physics 40:565

Thomas, R. T., and McCaslin, J. B., "General Shielding for the 20-TeV Collider Facility: Hadron Considerations," Report of the 20-TeV Hadron Collider Technical Workshop, Cornell University (1983).

Van Ginneken, A., "Shielding Calculations from 2-20 TeV," Report of the 20-TeV Hadron Collider Workshop, Cornell University (1983).

Section 4.2

Gay, W.F. 1979. National Transportation Statistics. DOT-TSC-RSPA-79-19, U.S. Department of Transportation.

Fehrenbacher, J.B., G.O. Walker, and H.L. Wascher. 1967. Soils of Illinois University of Illinois, College of Agriculture Experiment Station (in cooperation with USDA Soil Conservation Service), Bulletin 725.

Illinois DOT. 1977. Sources and Producers of Aggregates for Highway Construction in Illinois. Illinois Department of Transportation, Division of Highways, Bulletin No. 23.

Illinois DOT. 1984. Computer printouts updating Illinois DOT (1977) provided by William Sheftick, Liaison Geologist, Illinois Department of Transportation, Bureau of Materials and Physical Research, Springfield.

Liu, T.K., D.G. Gifford, and J.P. Dugan. 1977a. Muck Utilization Planning-Urban Transportation Tunneling: A Handbook of Rational Practices for Planners and Designers. Report No. UMTA-MA-06-0025-77-11. Prepared by Haley and Aldrich, Inc. for the U.S. Department of Transportation, Urban Mass Transportation Administration.

Liu, T.K., D.G. Gifford, R.P. Stulgis, and D.L. Freed. 1977b. Muck Utilization in the Urban Transportation Tunneling Process. Report No. UMTA-MA-06-0025-77-15. Prepared by Haley and Aldrich, Inc. for the U.S. Department of Transportation, Urban Mass Transportation Administration.

Milwaukee Metropolitan Sewerage District. 1983. Spoil Disposal Plan for the Crosstown Interceptor and Inline Pump Station. Milwaukee Water Pollution Abatement Program.

Section 4.3

Denver Research Institute and Browne, Bortz and Coddington. 1982. Socioeconomic Impact of Power Plants. Electric Power Research Institute, EA-2228.

Hohenemser, C., R.W. Kates, and P. Slovic. 1983. "The nature of technological hazard." Science 220:378-384.

Land Use Planning Report. 1984. New Regulations Clarify Implementation of Farmland Protection Policy Act. Vol. 12, No. 28.

Parsons, Brinckerhoff, Quade, and Douglas, Inc. 1984. Superconducting Super Collider Reference Designs Study Conventional Facilities.

Reed, R.J., and J. Wilkes. 1980. Nuclear knowledge and nuclear attitude: An examination of informed opinion. Paper presented at meetings of the American Association for the Advancement of Science, San Francisco, CA, January 1980.

Tanzman, E., B. LaBrie, and K. Lerner. 1982. Overview of Hazardous Waste Regulation at Federal Facilities. Technical Memorandum ANL/EES-TM-182, Argonne National Laboratory.

Tanzman, E., and K. Lerner. 1981. An Assessment of Eminent Domain as It Relates to Land-Use Issues in Energy Transportation Corridors. Technical Memorandum ANL/EES-TM-194, Argonne National Laboratory.

U.S. Army Corps of Engineers. 1983. Public Notice: Navigable Waters of the United States Within the U.S. Army Engineer District, Chicago, Illinois.

United States v. 58.16 Acres of Land, 478 F.2d 1055 (7th Cir. 1973).

United States v. 12,918.28 Acres of Land in Webster Parish, La, et. al., 5 F. Supp. 712 (W.D. La. 1943); U.S. v. Cobb 328 F. 2d 115 (9th Cir. 1964).

United States v. 18.2 Acres of Land, More or Less, In the County of Butte, State of California, 442 F. Supp. 800 (E.D. Cal. 1977).

United States, Tennessee Valley Authority v. Three Tracts of Land, 377 F. Supp. 631 (N.D. Ala. 1974); U.S. v. 255.25 Acres of Land, More or Less, 553 F. 2d 571 (8th Cir. 1977).