minneapolis campus
university of minnesota

I: potential use of underground space

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prepared by:
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foreword

Underground construction offers a real and significant opportunity for energy conservation and preservation of valuable land resources. It is of particular significance in the Twin Cities area with its extremes of climate, favorable geology and history of preserving open space. This area also has many groups experienced in underground excavation technology both in professional practice and at the University.

This report is concerned with the future use of underground space by the University of Minnesota and outlines the benefits of such use. It will form part of the base information for the long range planning of the Minneapolis Campus. The objectives of this report are to include the use of underground space as an alternative for future projects, to outline the factors important in underground planning and to avoid piecemeal development. This report is not an end product - the planning and engineering information is still qualitative in nature. Work must continue to provide the quantitative information and cost estimates necessary even for long range planning.

The report is in four parts. Part I consists of a general presentation of concept and advantages for underground space. Parts 2, 3, and 4 provide the information and criteria for the planning process as developed to date.

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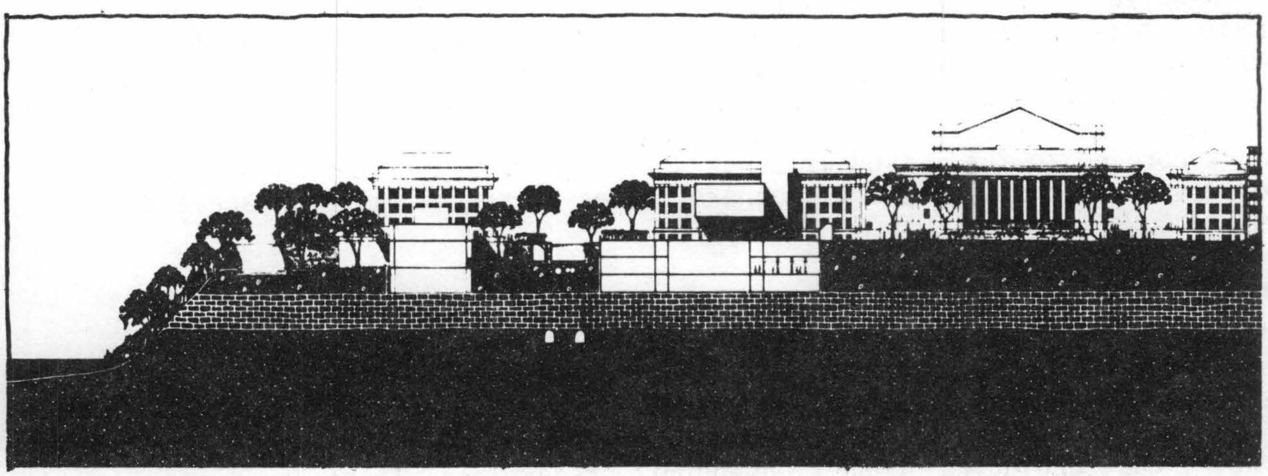
1 presentation of concept

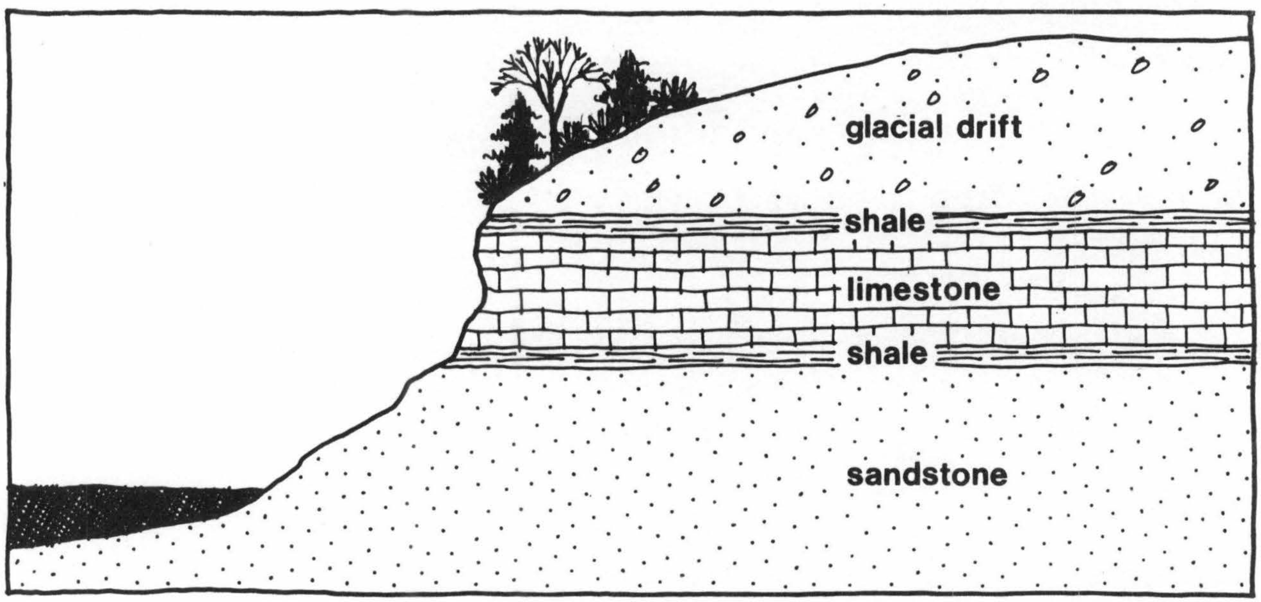
introduction

The purpose of Part 1 is to provide a brief introduction to the concept of underground space by presenting a summary of its major characteristics and some basic issues involved in its use. The first section on geological conditions and the resulting types of space is applicable in the Minneapolis-St. Paul area in particular, while the following sections are generally applicable to all underground space regardless of location. The sections on physical characteristics, environment, energy, and psychological considerations attempt to present an overview of the major advantages and disadvantages of underground space use and the implications for future planning.



geology

The particular geology of an area is a primary factor in determining the type and amount of underground space available. The geological formations of major significance in considering underground space in the University area are shown in the drawing below. They include up to 50 feet of glacial drift, the 25 to 30 foot thick Platteville limestone layer, and the 150 foot thick St. Peter sandstone. The glacial drift or soil layer is a blanket of glacial debris, clay, sand, and gravel. In addition to the major Platteville and St. Peter formations, the upper layers of bedrock include the two relatively thin layers of shale above and below the limestone, however they are not of great importance to underground space development. Maps of the bedrock and surficial geology of the Minneapolis Campus appear in the base information in Part 2 of this report. A more detailed description of the geology and its implications for underground space appears in Part 4.



types of space

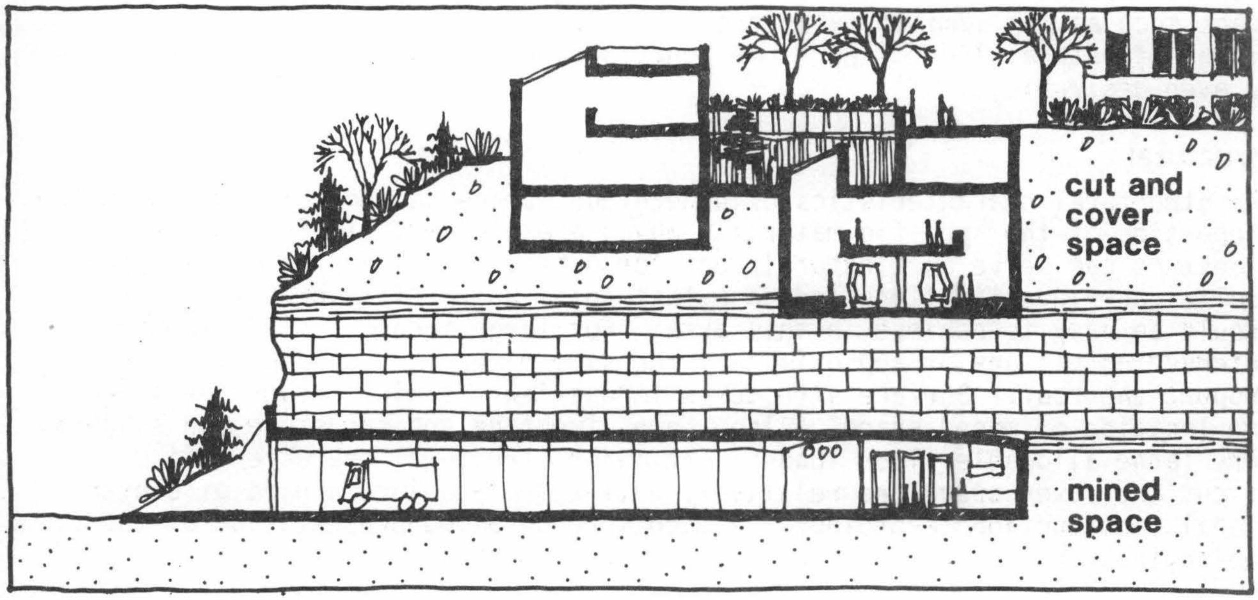
There are numerous approaches for classifying underground space based on various geological and spatial characteristics. Spaces can be categorized according to their relationship to the surface which distinguishes, for example, totally enclosed space beneath the surface from space recessed into a hillside. There is also a common classification of underground space according to its shape which distinguishes a tunnel from a chamber. For the purposes of this study, however, underground space will be generally classified according to the method of construction as well as the proximity to the surface. This suggests two general types of space: mined space and cut and cover space.

mined space

Mined space refers to relatively deep space excavated without significantly disturbing the surface. Usually mined space occurs beneath a substantial rock layer which acts as a natural roof requiring little structural support. An important characteristic of mined space is that it can occur almost anywhere that geological conditions permit, regardless of the location of surface structures.

cut & cover space

Cut and cover space refers to space excavated by conventional means near the surface and covered during construction. The consideration of cut and cover space is not limited to totally sub-surface structures, but also to underground space as a part of typical above ground construction. Nor should cut and cover space be limited in depth by the presence of the bedrock layer. In some cases, extending cut and cover space into the bedrock may prove economically feasible and provide integration with mined space. Due to its relative proximity to the surface, cut and cover space is more easily integrated with existing structures and systems than mined space, however disruption of the surface during construction can obviously be greater.



implications

Within the university area, the geological conditions permit the consideration of both mined space and cut and cover space. Mined space would usually occur in the sandstone layer about 80 feet beneath the surface, although in some cases the mined space could extend partially into the limestone layer as well. The mined space could have possible horizontal access from the river bluffs. The Platteville limestone provides a substantial natural roof and the St. Peter sandstone is relatively easy to excavate. Cut and cover space would usually occur in the glacial drift which has a depth of up to fifty feet from the surface to the top of the bedrock.

physical isolation

The isolation of underground space from the surface environment is one of its most favorable characteristics for many functions. Transit, major roadways, utilities and large scale fuel or waste storage can be isolated underground to improve the surface environment. Other functions may be isolated underground to improve their own environment. For example, a precision laboratory may be located underground to reduce noise and vibrations. In addition, the isolation provides extra protection from such hazards as fire, explosions and radiation as well as reducing exterior maintenance because of fewer exposed surfaces. There are some disadvantages especially of deep underground space such as the limited relationship to outdoor space and the limited amount of natural light. For some functions, however, these are not necessary or even desirable.

structural

The structural characteristics of underground space depend, of course, on the properties of the specific materials which are present. It is known that limestone can serve as a natural roof for substantial spans in mined space. Preliminary investigations indicate that spans up to fifty or sixty feet should be easy to achieve in this area. For large areas of mined space, intervening pillars of approximately the same dimension would be left to support the roof. Surface structures impose few restrictions on the size and location of mined space. Also, both limestone and sandstone can support very large allowable floor loads. The major structural characteristics of cut and cover space are relatively well known and form a part of conventional construction technology. A much more detailed presentation of the geo-engineering aspects of underground space appears in Part 4.

acoustical

The unique acoustical qualities of sub-surface space are a product of the isolation from the surface and the nature of the materials which enclose the space. Naturally a great reduction in noise and vibrations from the surface occurs beneath the surface due to the solid barrier of surrounding earth. In deep space, this isolation from surrounding sounds can produce an almost silent environment within which small sounds become significant and echo effects can occur. Although this acoustical isolation can be considered as an advantage, attention must be paid to the natural materials and their effect on the desired acoustics of a space.

climatic

The insulating capacity of the surrounding earth and isolation from the surface climate can naturally produce nearly constant temperature in underground space. A more complete explanation of these unique characteristics and their implications occurs in the section on energy conservation.

implications

Certain desirable characteristics of underground space are available, such as climatic protection or isolation from noise, that are sometimes difficult or expensive to obtain in conventional surface structures. Benefits for individual spaces as well as large, densely populated areas can be derived.

environmental considerations

surface preservation

In urban areas the demand for more building space and for better transportation and service systems is often quite intense. This presents an obvious threat to existing surface amenities such as open space and natural features which can be vitally important to a densely populated area. Use of the underground can satisfy this demand while preserving existing open spaces, and can change passive areas into more active, desirable areas. Another potential benefit of underground space is the preservation of the scale, character, and even the historical value of certain sites. One important consideration in planning underground space is the impact on natural features such as vegetation. In addition to such specific preservation, the use of sub-surface space can help to protect the total land resource from urban sprawl by providing more efficient use of already built-up areas.

excavation and construction

The two types of space, mined space and cut and cover space, have considerably different effects on the surface environment during construction. While mined space has the advantage of providing minimal disturbance, if the portal can be located at some out-of-way area such as the river flats, cut and cover space can be quite disruptive, especially under existing streets. The problems created by surface disruption serve to emphasize the need to plan underground space in an organized, comprehensive manner to reduce the costly and undesirable effects of construction. For example, the location of utilities should take into consideration possible future uses of the underground space. Another important aspect to be considered is the disposal of soil and rock that is extracted during construction. Depending on the specific material the waste rock can serve as a building material, an industrial mineral, for land reclamation or other more imaginative uses such as modifying the landscape. Also, the effect on the level and quality of the ground water should be examined during as well as after construction. All of the effects on the existing natural systems as a result of excavation and construction must be carefully considered. Part 4 of this report contains a more detailed review of the technical problems and possible implications.

noise and air pollution

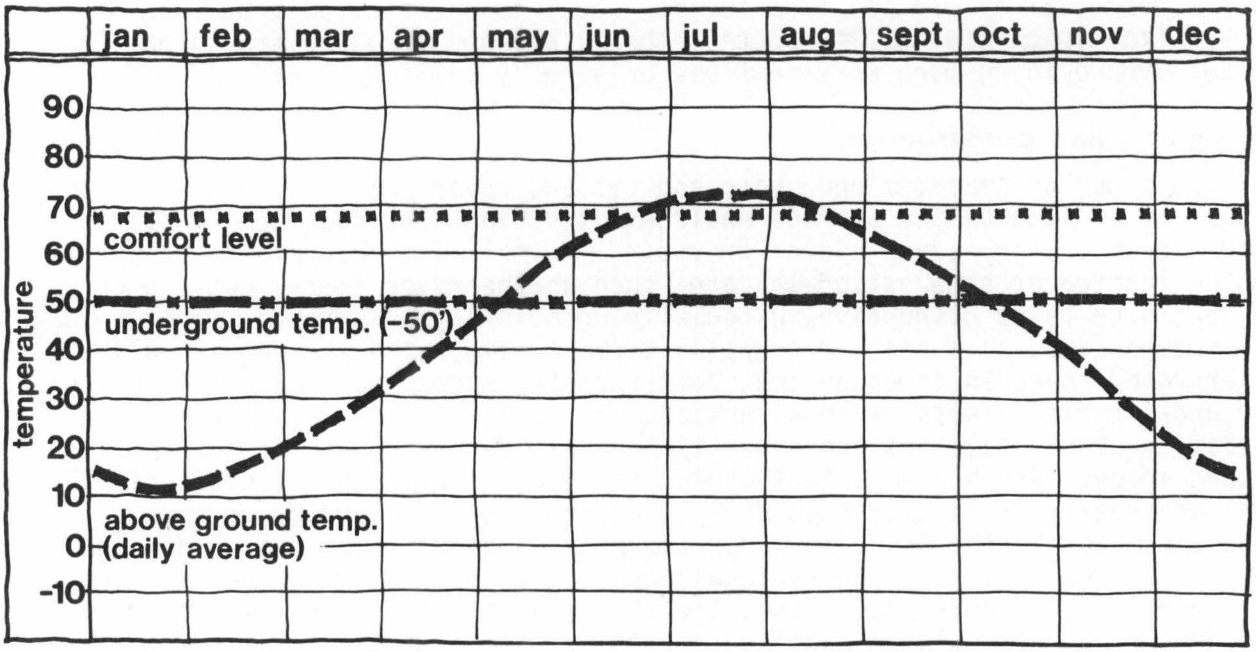
Although some advantages of physical isolation have been previously mentioned, pollution control is important enough to deserve separate emphasis. One means of reducing the effects of noise and air pollution is the sub-surface location of spaces which cannot tolerate the surface environment such as a laboratory or a library. Another means of improving the environment in a built-up area is the sub-surface isolation of some functions which contribute heavily to the noise and air pollution problem such as a major roadway. The reduction in noise is a direct result of this isolation. The reduction in air pollution is not as simple but since the ventilation is controlled pollutants can be filtered, or at least be diverted from the immediate area.

implications

The vast environmental problems which are part of urban society such as congestion, noise and air pollution and inefficient use of land and energy resources, often have contradictory solutions which worsen one problem while solving another. The use of underground space can provide some solutions to these environmental problems with almost no detrimental effects especially when adequate comprehensive planning is applied.

climatic characteristics

The isolation from the surface and the insulating capacity of the surrounding earth combine to provide a unique natural climate in underground space. Almost no daily fluctuation in temperature occurs below three or four feet, and at a depth of fifty feet the temperature is constant year around. In Minnesota this constant temperature corresponds approximately to the annual average temperature of 50 - 55°F. The illustration below demonstrates the vast difference in temperature range between the surface and the sub-surface at depths of ten and fifty feet.



A sub-surface space avoids direct sun radiation which, in the summer, contributes substantially to the cooling load. In the winter, sub-surface space avoids wind chill and significant heat loss through infiltration. Preliminary investigations indicate that the heat loss on a cold day through a well-insulated wall above ground can be 6 to 10 times greater than the loss through an uninsulated wall underground. The significant insulating capacity and mass of the surrounding earth also allows the space to retain heated or cooled air for a longer period of time.

potential cost and energy savings

Substantial amounts of energy are required to heat and cool buildings and control humidity. The nearly constant temperature characteristics of underground space indicate that energy savings and thus, cost savings can be substantial. Some preliminary investigations of sub-surface residences indicate potential savings of 60 to 70%. The actual savings will, of course, depend on several factors including the local climate, the design of the space, thermal characteristics of the soil or rock, and the necessary ventilation requirements. In one example, an underground cold storage facility in Kansas City, operating costs were one tenth of the operating costs of a similar above ground facility. In another example, which corresponds more directly to potential research or educational space, an underground precision manufacturing plant realized considerable cost and energy savings as shown in the chart on the following page.

	heating units (btu/hr.)	refrigeration (tons)[2]	operating costs ($/year)	fire insurance ($/$1000)
above ground	2,000,000	500 - 700	50,000-70,000	2.85
below ground[1]	750,000	57	3200[3]	0.10

1- Bronson Instrument Co., Kansas City, Mo.: 140,000 sq. ft.
125 employees
77 ft. below surface
54°F initial rock temp.

2- refrigeration load is for dehumidification below ground

3- This figure is particularly low since the air conditioning plant is operated only during nights to bring temperature and humidity below that required. Due to the heat capacity of the rock, temperature and relative humidity of the air then slowly rise during the day. This technique reduces the electrical demand factor.

It is interesting to note that the plant was located underground because of the low level of vibration and generally stable environment which are desirable for precision instruments and expensive to obtain above ground. The plant can expand to four times the present number of employees with no more heating equipment required and only a 70% increase in cooling.

implications

The limitations of the available energy supply and the increasing costs are making energy conservation a necessary planning consideration. Sub-surface space, with its unique climatic characteristics, can serve as one potential energy saving solution in future planning for various functions. In addition to providing a smaller temperature difference for heating and cooling, the earth retains heat or cold longer so spaces requiring little ventilation can be heated or cooled in off peak load hours resulting in further savings.

The University is a huge consumer of energy and with projected costs for 1975 of over $1.9 million for electricity and $2.3 million for fuel for the Minneapolis campus alone (including hospital and dormitory space), even a small percentage drop in heating or cooling load could result in substantial energy savings.

psychology of underground space

The psychological impact of an interior space should be an important consideration in the design of any structure or space, however the potential psychological effects of underground space seem even more significant. Some negative attitudes toward the idea of being underground seem to come from associations with burial, claustrophobia, or anxiety over safety. Although many associations with being underground seem to be negative, it is interesting to note that in many cases the only difference between above and below ground space is the absence of a view and many above ground structures such as stores, theaters, museums, laboratories, classrooms, and industrial structures are intentionally built without windows. In addition, in many modern buildings the windows are not used in the design for light or ventilation and the interior spaces are totally artifically controlled environments. Some of the physical characteristics of underground space may actually serve to improve educational, medical or research environments, or even may relieve some anxiety associated with natural disasters. Unfortunately, there is a great lack of information on this subject.

One of the few actual psychological studies in this area concerned the totally underground Abo Elementary School in Artesia, New Mexico. The study concluded not only were there no significant drawbacks to the school, but in some cases the learning environment was actually enhanced by the isolation. In order for underground space to become a successful alternative in campus planning, a more thorough understanding of the psychological aspects must be developed. Studies could be made of the psychological effects of some underground spaces presently in use in the campus area such as the sub-surface levels of the Health Sciences complex or the West Bank. To our knowledge, there are no major problems with any of these areas.

design implications

Specific design criteria for underground space based on psychological considerations naturally must be preceded by the development of adequate data which is lacking at the present time. However, it is possible to suggest a partial list of available techniques and design guidelines that may serve to alleviate some of the negative psychological aspects of underground space. Environmental technology is quite highly developed in the areas of climate control, lighting and acoustics which simply means that adequate techniques are available to provide equally comfortable, usable spaces above or below ground. Variety and stimulation in a totally enclosed environment can be provided through the imaginative use of materials, lighting, color and graphics. Numerous successful sub-surface environments share some basic characteristics which may serve as a partial list of preliminary guidelines.

These include:

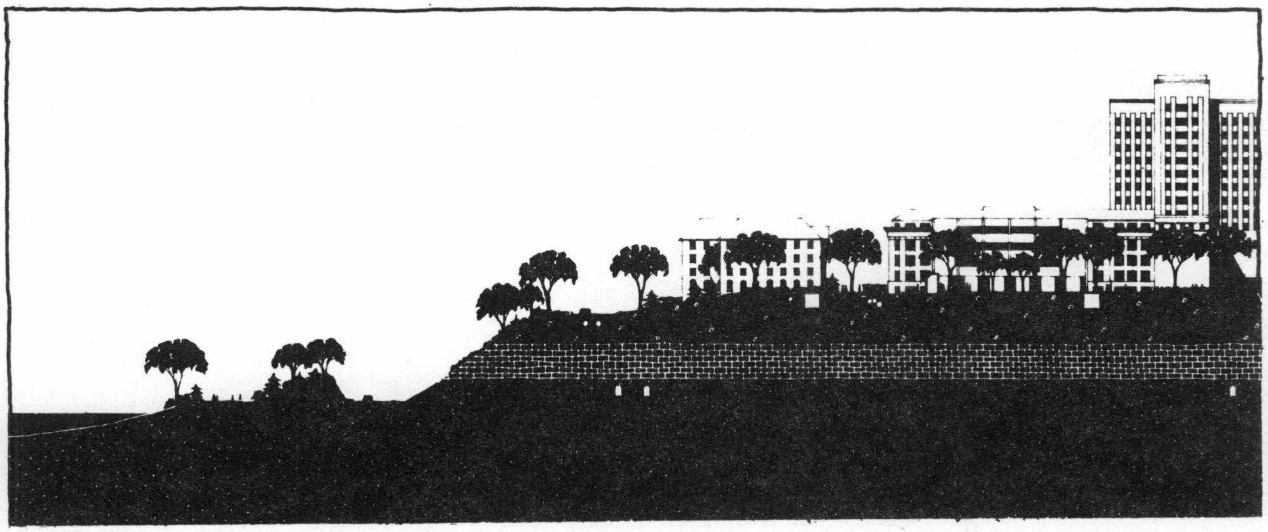
- the maximum integration of underground space with the surface whenever possible through the use of interior and exterior court spaces.
- integration with existing circulation patterns to prevent awkward transitions to the underground.
- the avoidance of long, uninterrupted passages and spaces which tend to cause claustrophobia.
- the assigning of appropriate functions to certain types of space. This is discussed further in Part 3.

social attitudes

The social attitudes toward the use of underground space seem to be directly related to the public's understanding of themselves and their environment. On a small scale, this was demonstrated by the ultimate acceptance by the community of the previously mentioned Abo Elementary School after some initial resistance. In a much larger context, the social acceptance of underground structures most likely will be accompanied by a greater sensitivity to the preservation of land and energy resources, as well as a greater demand for better transportation and service systems. Successful underground developments seem to suggest that social objections are not significant if the public is well informed and allowed to adapt to the concept.

2 base information

The base information consists of the existing conditions on the campus which are relevant to the planning of underground space. This information is presented in two sections, the geology of the campus area and the existing use of underground space. Detailed maps of the sub-surface hydrology on campus are not available at this time but should be included in the base information in the future. Other information relevant to underground space planning such as more detailed descriptions of sub-surface utilities, topography, and existing surface features on potential sites can be found in the planning base inventory for the long range development plan of the Minneapolis campus.



bedrock geology

The metropolitan area of Minneapolis and St. Paul is underlain by a series of gently-dipping to nearly flat-lying sedimentary rock layers which form the Twin Cities structural basin. An inland sea covered southeastern Minnesota from about 500 to 440 million years ago. During this time, sufficient sediments collected to form the 300 to 400 foot thick limestone, sandstone and shale sequence of the Twin Cities Basin.

The main sedimentary materials are:

1. Shakopee-Oneota Dolomite - consists chiefly of dolomite, gray, pink or buff in color and often porous.

2. St. Peter Sandstone - normally a white friable sandstone, with little cement providing a very loose material.

3. Platteville limestone - gray to brown or buff dolomite deposited by a sea favorable to life.

4. Decorah Shale - greenshale with interbedded limestone deposited by sediments.

surficial geology

The surficial geology on campus was layed down during the Pleistocene period (glacial period) of the Cenozoic Era. Glaciation did not consist of a single ice invasion but of a series of invasions with each invasion traveling in a different direction. The phases of advance and recession moved materials back and forth with some ice invasions showing no signs of existence in the Twin Cities Metropolitan Area. The second Wisconsin ice sheet brought the glacial period as we know it to an end, about 20,000 yrs. ago.

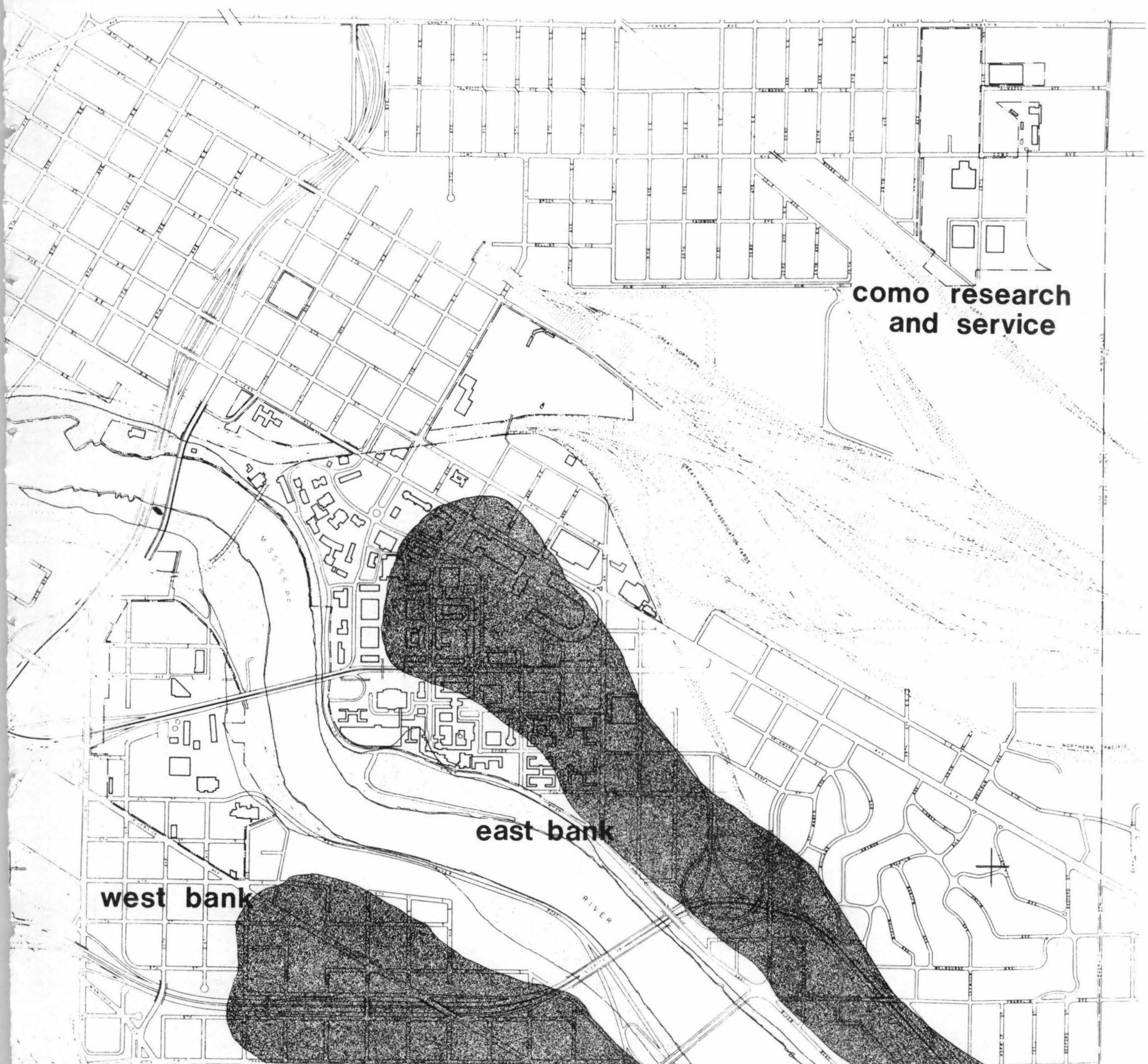
The surficial geology and characteristics of the campus are:

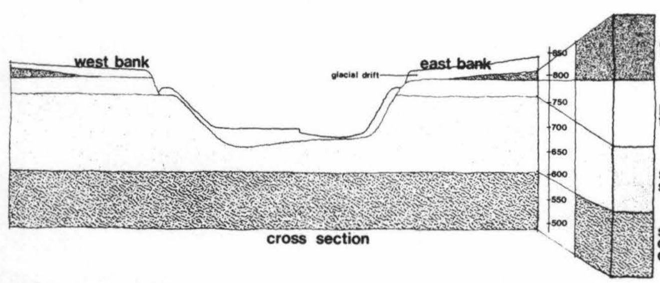
Alluvium deposits - characterized by stratification (layers of different sized particles overlying each other) made up of sands, silts, and clays.

Dune Sand deposits - sands deposited by winds.

Terminal Moraine - composed of an unassorted, heterogeneous mass of boulders, rocks, sands, silts, and clays, called "till".

Soils in the Campus area are well suited for urban development, primarily because these soils are sandy, which are readily compacted, of relatively uniform particle size, and have a low shrinkage-expansion index.





decorah formation — greenshale with interbeded limestone deposited by sediments. depth 0–90 feet.

platteville formation — grey–brown or buff dolomitic limestone deposited by a sea favorable to life. 25' depth.

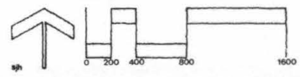
st. peters sandstone — white, fine to medium–grained, well–sorted. friable sandstone. average thickness 150'

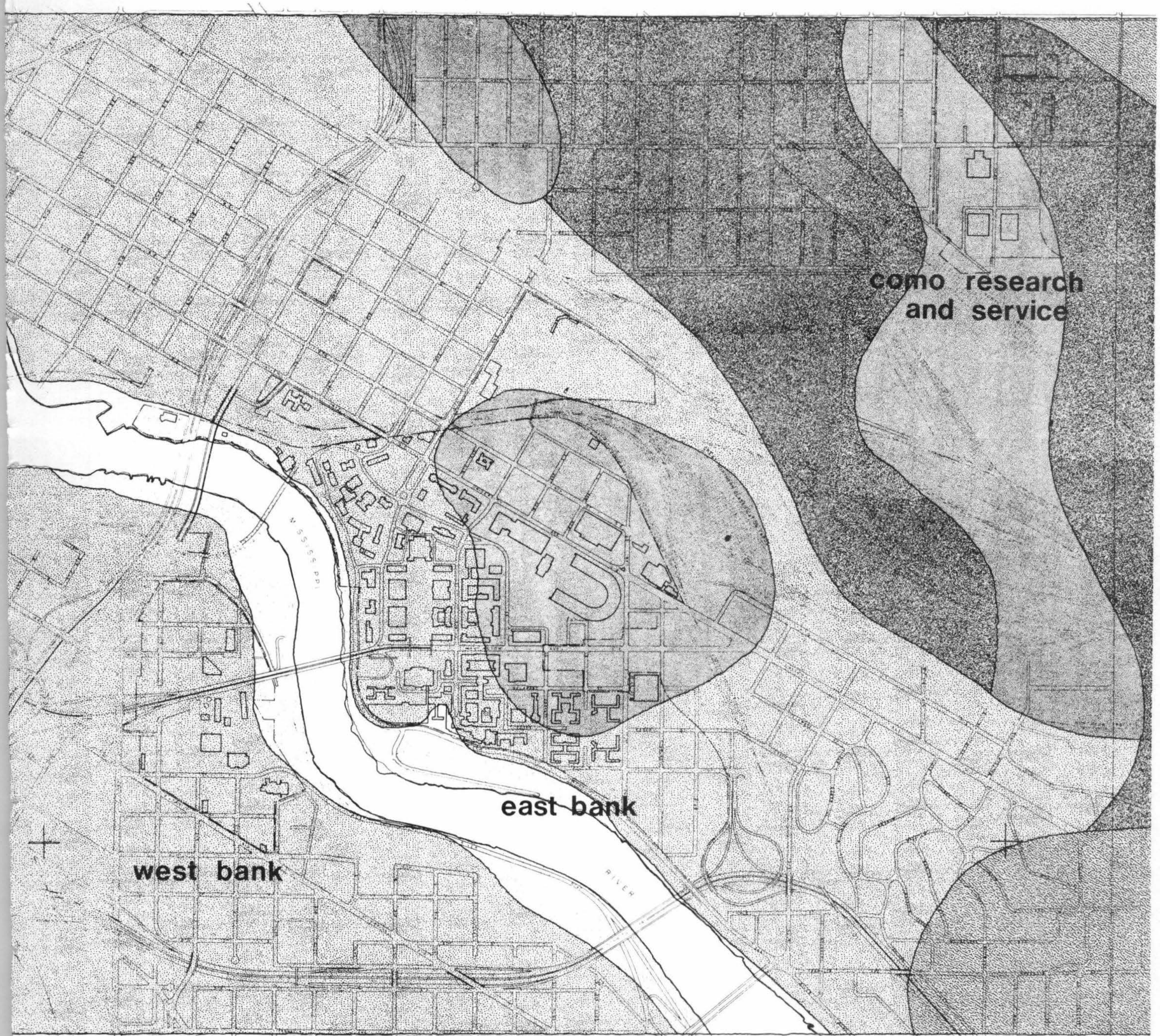
shakopee-oneota dolomite — consists chiefly of dolomite. grey, pink or buff in color and often porous.

geology

details of sources from which this map was compiled are available on request. data source: minnesota geological survey, 'minneapolis, st.paul bedrock geologic map; c.marshall payne. 1965 this map is prepared for planning purposes and should not be used where accurate measurments are required.

university of minnesota minneapolis campus





	bedrock	st. peter sandstone
	alluvium deposit	characterized by stratification, layers of different-sized particles overlaying each other, made up of sands, silts and clays.
	dune sand deposit	sands deposited by winds.
	patrician terminal moraine deposit	characterized by a chocolate brown to red in color unassorted heterogeneous mass of boulders, rocks, sands, silts and clays, deposited by the patrician drift.
	peat deposit	organic matter which still retains some of the original structure of plant tissue.

surficial geology

details of sources from which this map was compiled are available on request. **data source: minnesota geological survey, bulletin 27 plate 4, g.m. schwartz, 1936**
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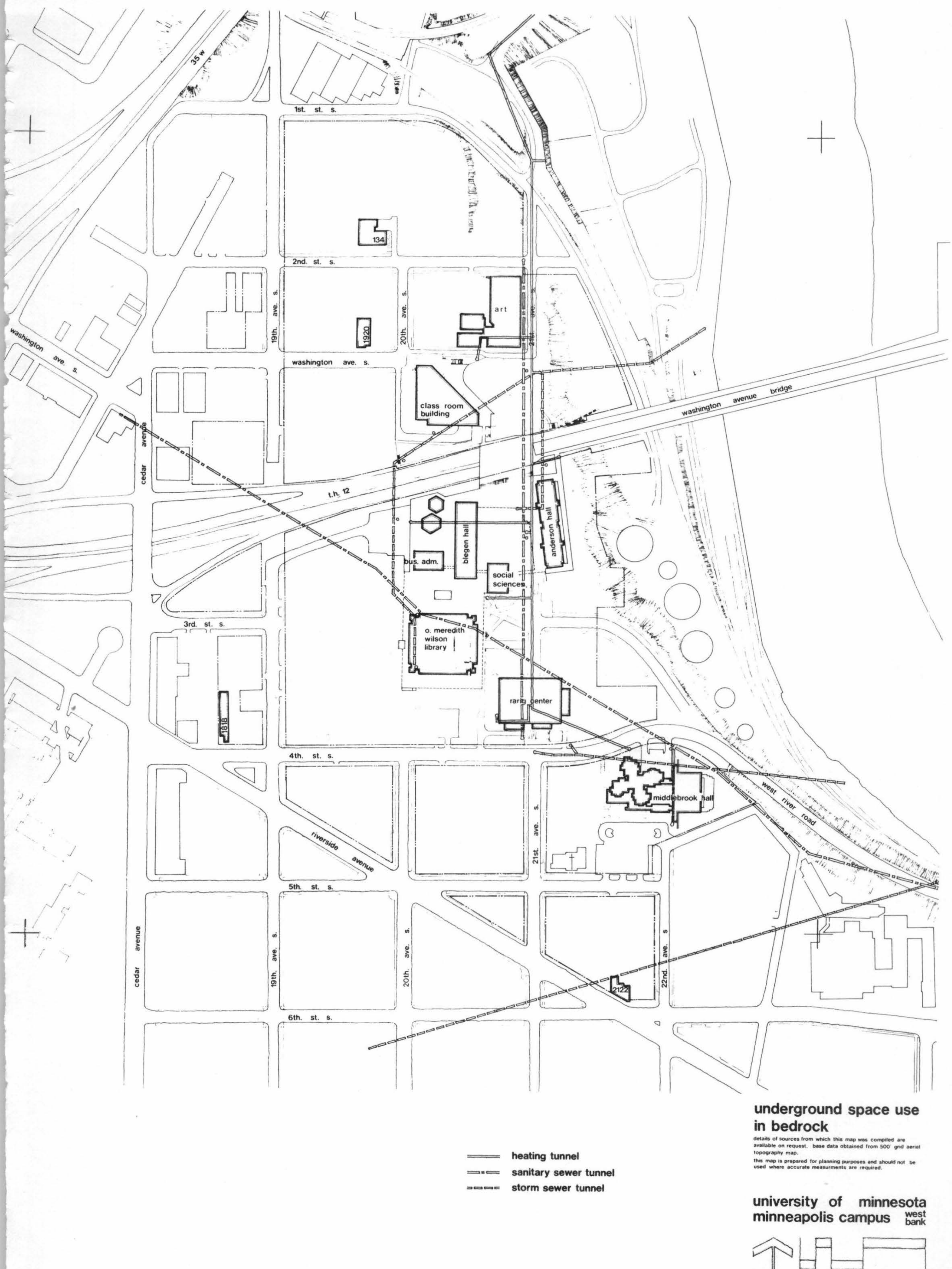
university of minnesota minneapolis campus

sjh

0 200 400 800 1600

existing underground space use in bedrock

These maps indicate the location and use of all underground space in the bedrock of the campus. Any development of sub-surface space in the bedrock would occur in the two upper layers of major significance found on the campus, the Platteville limestone formation and the St. Peter sandstone. There are only remnants of the Decorah shale which occurs above the limestone so it is not important to existing underground space use. The Platteville limestone is approximately thirty feet thick and generally occurs between fifty and eighty feet beneath the surface. The limestone layer is exposed along the river bluffs. The St. Peter sandstone is approximately 150 feet thick and occurs beneath the limestone layer. All of the bedrock uses occurring in the campus area at present are utility tunnels in the upper thirty feet of the sandstone. The water table, which occurs approximately at the level of the river, about 120 feet beneath the level of the main campus, presently serves as a lower limit to the depth of this space. The utility tunnels are designated on the maps as heating, sanitary sewer, and storm sewer tunnels. In addition to these services, the heating tunnels contain telephone lines. The size, exact location, and relative importance of each tunnel can be found on separate utility maps. The location of an experimental test room to determine the properties and potential for development of large spaces at this level is indicated on the east bank map.



underground space use in bedrock

details of sources from which this map was compiled are available on request. base data obtained from 500' grid aerial topography map.

this map is prepared for planning purposes and should not be used where accurate measurments are required.

university of minnesota minneapolis campus west bank

underground space use in bedrock

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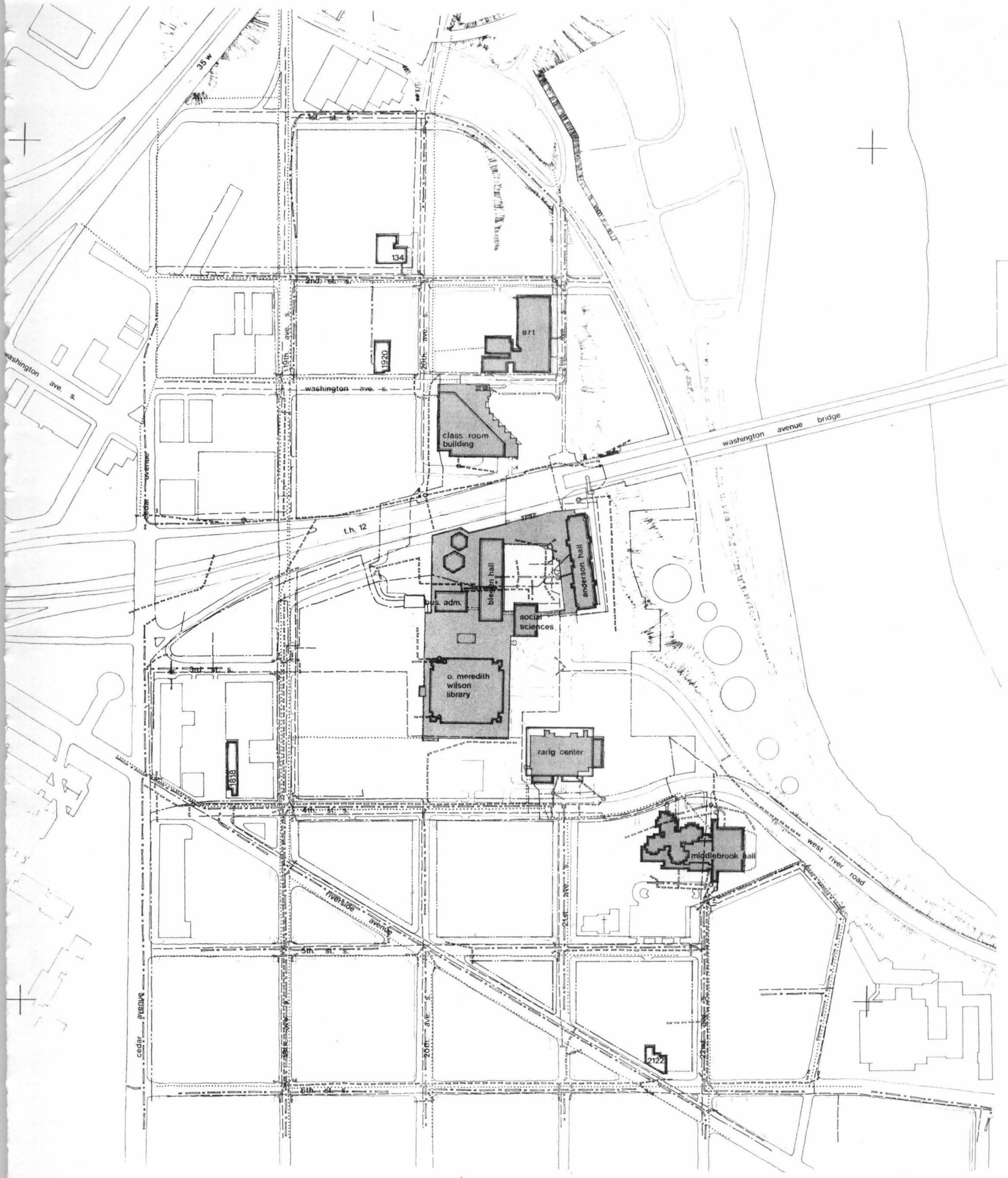
university of minnesota minneapolis campus east bank

heating tunnel
sanitary sewer tunnel
storm sewer tunnel

jk 0 50 100 200 400

existing underground space use in soil

These two maps show the location of underground space and utilities in the soil of the campus. All uses are shown which occur in the soil or glacial drift which is generally the first fifty foot layer beneath the surface. The maps represent the pattern of sub-surface land use without indicating the specific level of each space or utility. For general planning purposes, a structure to any depth, including a building with only its foundation beneath the surface, determines the potential use of this underground space. Most existing sub-surface space use is simply in the basement levels of existing buildings. The depth of the sub-surface space varies considerably from a single level which may be only partially beneath the surface to several levels which go to the bedrock a full fifty feet beneath the surface. The more recent built structures on campus such as the Health Sciences complex and Kolthoff Hall take full advantage of the potential sub-surface space in soil within their respective sites. In addition to the basement levels of existing structures, four sub-surface parking structures and a few pedestrian tunnels exist as totally underground structures. The sub-surface space is used for almost every function which is present on the campus including classroom space, laboratory and research facilities, library space, support and recreation facilities, offices parking, services and utilities. The utilities indicated on the map are intended to show the location and function of all sub-surface utilities in the soil. It should be noted that in some cases heating tunnels also contain other utilities in addition to the steam lines. The size, exact location, and relative importance of each utility can be found on separate utility maps.



existing space

heating tunnel

sanitary sewer

storm sewer

water main

gas main

electric line

telephone line

underground space use in soil

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university of minnesota minneapolis campus west bank

jc

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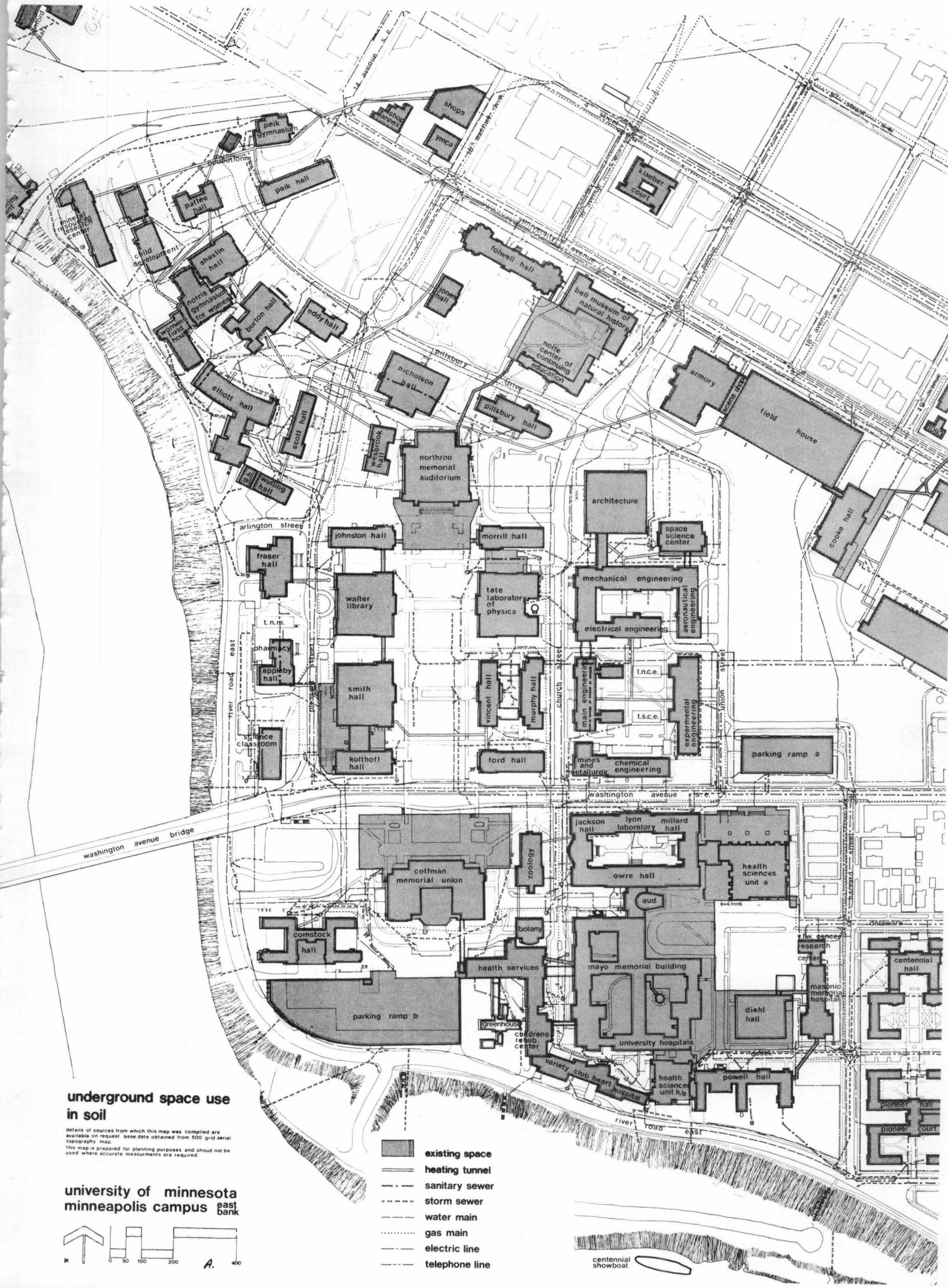

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university of minnesota
minneapolis campus east bank

0 50 100 200 400

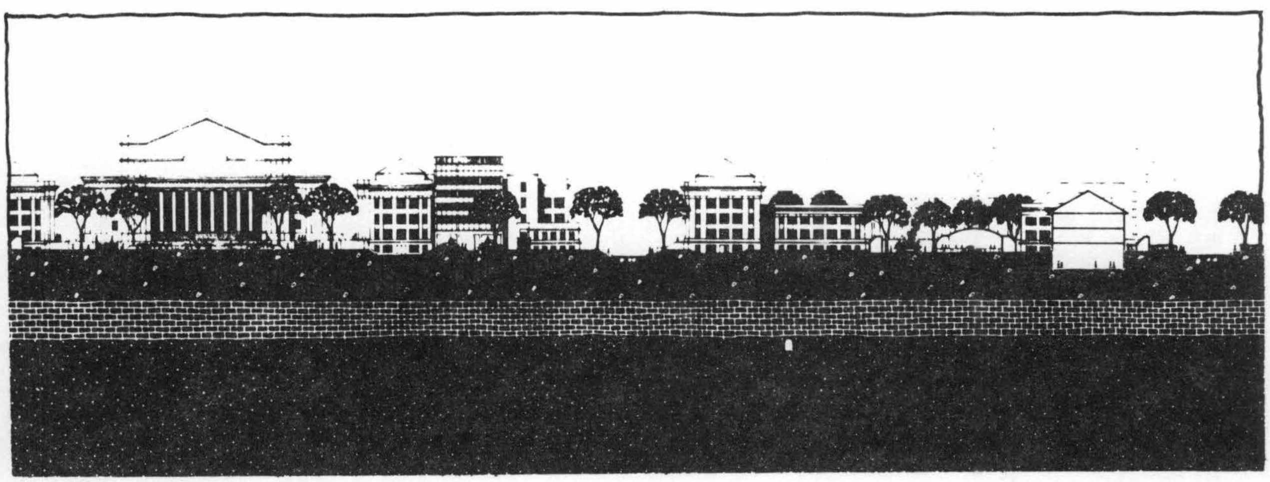
- existing space
- heating tunnel
- sanitary sewer
- storm sewer
- water main
- gas main
- electric line
- telephone line

3 physical planning

introduction

The first section of Part 3 deals with the selection and analysis of sites for underground space in the campus area in both bedrock and soil. Potential sites are identified, major criteria are established to determine the suitability of the sites for mined space and cut and cover space and finally each site is analyzed based on these criteria. Although this process of identification and analysis may be similar to the process used to analyze physical sites for long range planning, it should be emphasized that this analysis is only in terms of underground space. Thus, it represents only one component of a much larger process.

The second section of Part 3 deals with the appropriateness of underground space for several major university functions. Both these sections are intended to be used as tools in the determination of a long range development plan for the University which includes underground space as an integral part of the plan.



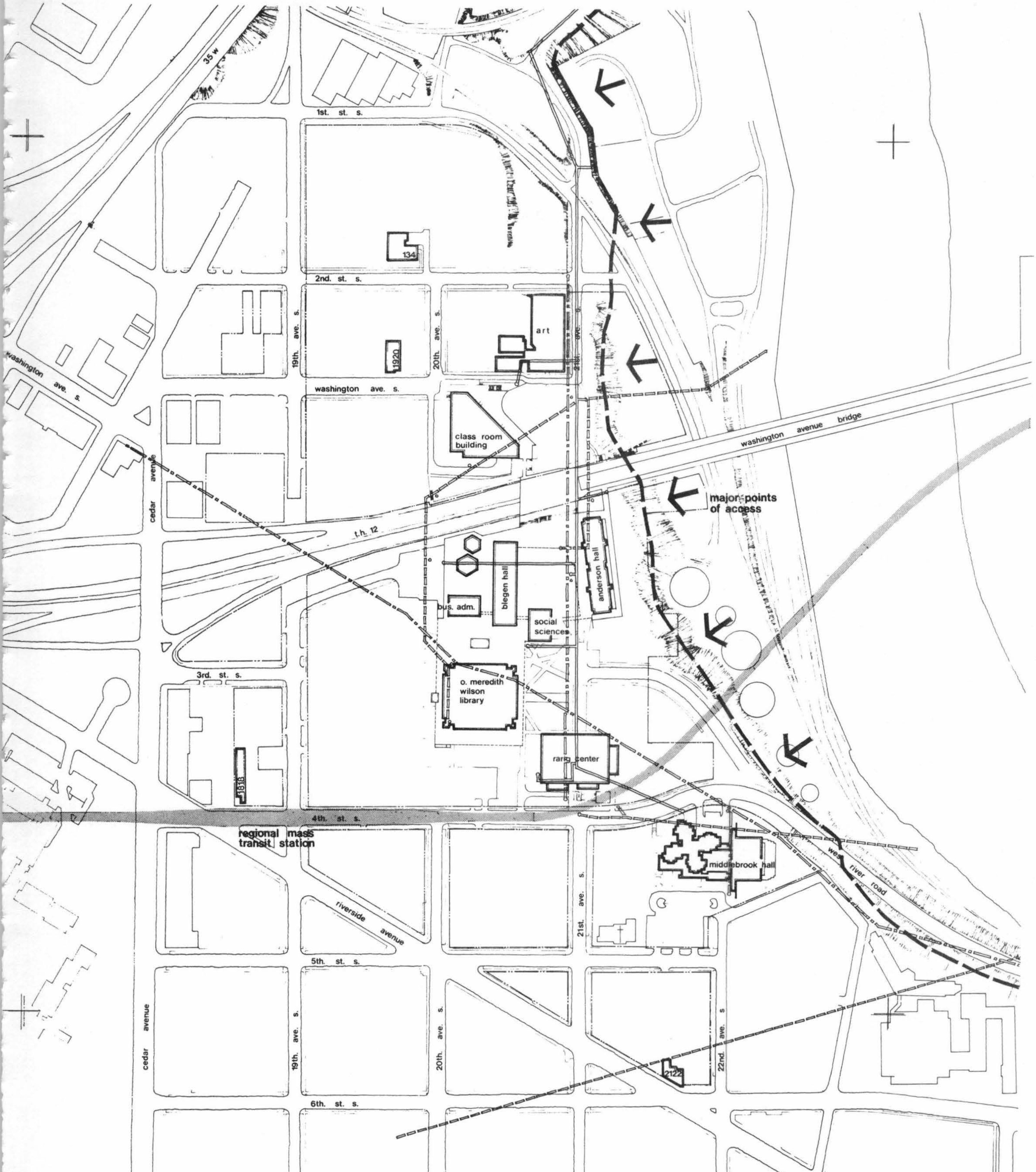
site selection and analysis in bedrock

site selection

Unlike surface and near surface space, there is relatively little development in deep space, and therefore, few determinants of specific sites and boundaries to potential development. Other than the interruption in the limestone layer at the river, the bedrock layers on each bank of the campus are physically consistent and no clearly defined building sites can be identified within them. With the exception of some important utility tunnels, there are few other restrictions, so each bank of the campus is effectively treated as one homogeneous site. The selection of a specific site area in the bedrock is obviously dependent on the use, the type of access required, and the relationship the proposed use must have with the surface. As long range planning is developed for the campus, the bedrock layer should be included as potential future space and be considered as future needs arise.

site maps

These drawings indicate the major site areas for mined space in the bedrock on the west and east banks of the campus. The major site boundary which is the edge of the limestone layer is indicated as well as the possible points of horizontal access. There are minor as well as major points of access shown on the east bank. The major points of access could easily provide vehicular access to the mined space with no significant change in existing land forms. The minor points of access indicate exposure of the bedrock layers along the river bluffs but would require some substantial construction and alteration to provide vehicular access. In addition the maps indicate existing utility tunnels in the sandstone layer and proposed uses in the bedrock. It is important to note that the proposed mass transit corridor and stations are highly speculative and are included mainly to illustrate a potential significant use of this level. The experimental test room, unlike the transit corridor, is a definite project on which construction has begun. (The existing surface structures are also shown on the map).



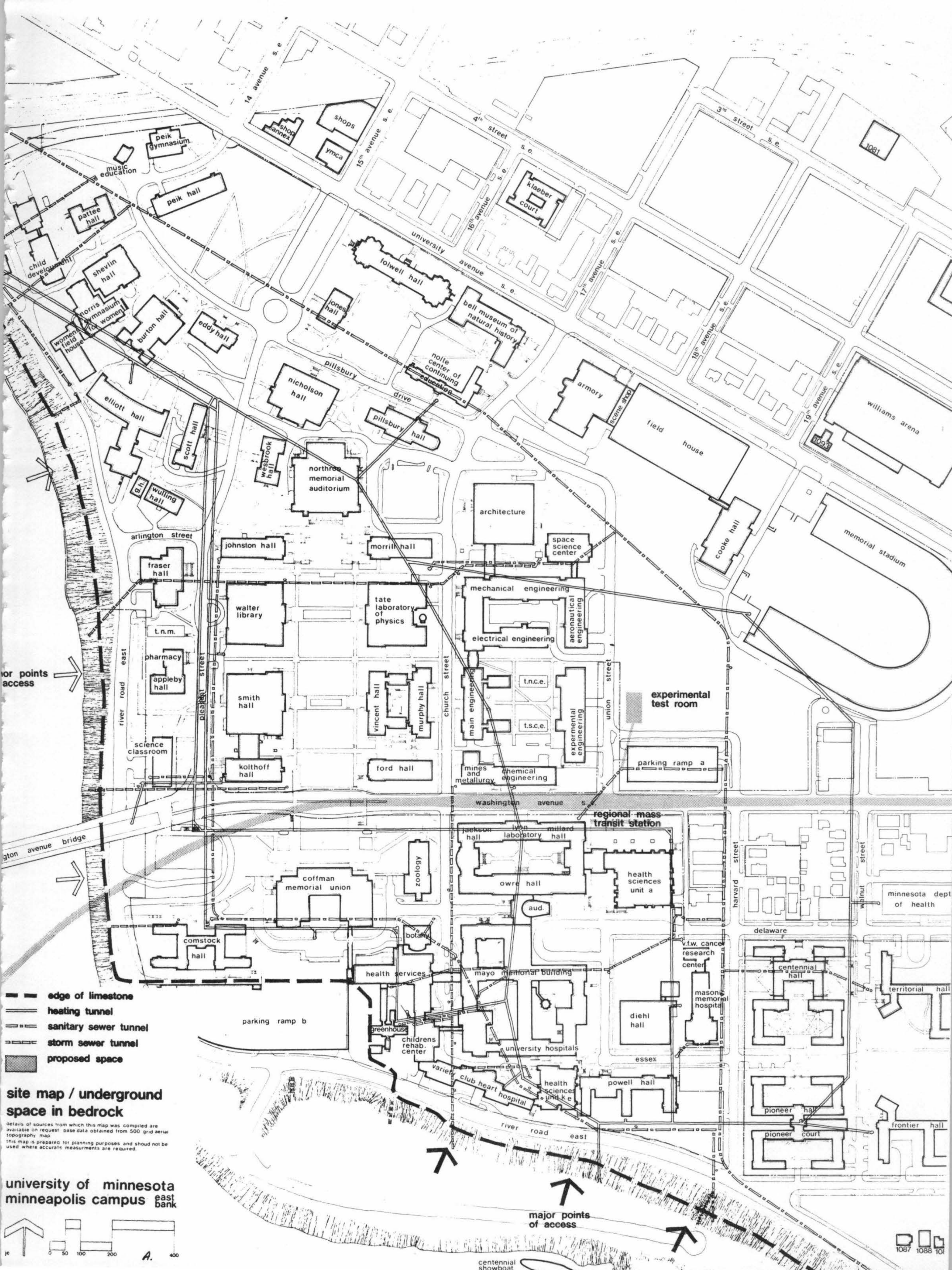
edge of limestone
heating tunnel
sanitary sewer tunnel
storm sewer tunnel
proposed space

site map / underground space in bedrock

details of sources from which this map was compiled are available on request. base data obtained from 500' grid aerial topography map.
this map is prepared for planning purposes and should not be used where accurate measurments are required.

university of minnesota minneapolis campus west bank

0 50 100 200 400



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university of minnesota
minneapolis campus east bank
major points of access
experimental test room
regional mass transit station
14 avenue s. e.
15th avenue s. e.
16th avenue s. e.
17th avenue s. e.
18th avenue s.e.
19th avenue s.e.
4th street s. e.
3rd street s.e.
university avenue s. e.
pillsbury drive
arlington street
river road east
pleasant street
church street
union street
washington avenue s. e.
washington avenue bridge
harvard street
walnut street
delaware
essex
shops
shop annex
ymca
peik gymnasium
music education
peik hall
pattee hall
child development
shevlin hall
norris gymnasium for women
womens field house
burton hall
eddy hall
jones hall
folwell hall
bell museum of natural history
nolte center of continuing education
nicholson hall
pillsbury hall
elliott hall
scott hall
westbrook hall
northrop memorial auditorium
g.h.
wulling hall
klaeber court
armory
scene shop
field house
williams arena
1081
1093
cooke hall
memorial stadium
architecture
space science center
johnston hall
morrill hall
fraser hall
walter library
tate laboratory of physics
mechanical engineering
aeronautical engineering
electrical engineering
t.n.m.
pharmacy
appleby hall
smith hall
vincent hall
murphy hall
main engineering
t.n.c.e.
t.s.c.e.
experimental engineering
science classroom
kolthoff hall
ford hall
mines and metallurgy
chemical engineering
parking ramp a
jackson hall
lyon laboratory
millard hall
owre hall
zoology
coffman memorial union
health sciences unit a
aud.
minnesota dept of health
comstock hall
botany
health services
mayo memorial building
v.f.w. cancer research center
centennial hall
territorial hall
mason memorial hospital
parking ramp b
greenhouse
childrens rehab. center
university hospitals
diehl hall
variety club heart hospital
health sciences unit k e
powell hall
pioneer hall
pioneer court
frontier hall
river road east
centennial showboat
1087
1088
0 50 100 200 400

site analysis factors

Although no features of the bedrock determine distinct suitable and unsuitable sites, several basic physical factors exist which have a significant impact on site selection and analysis. The final selection of a specific site is dependent on the specific requirements of the proposed use of the bedrock space. However, the physical factors listed below are relevant for any foreseeable use of the mined space.

▪ geology

The actual location of the competent limestone layer determines the boundaries of the site areas. At this time the entire area is considered suitable for mined space with the exception of the very edges along the river bluffs for spaces of large spans. The condition and properties of the members of the limestone are important in determining how much vertical height can be achieved. The lower members can be mined if others are capable of supporting the roof. The location of the water table is a possible factor in determining the economic lower limit of the space, although not an absolute restriction.

▪ utilities

The utility tunnels represent the only significant use of mined space at this time. The cost and difficulty of relocation of a tunnel can vary considerably depending on its function and importance, so it can be a significant site determinant. Many of the tunnels are well grouped such as on the West Bank which is desirable for organized, efficient use of the space. Future location of tunnels should take into consideration the impact on underground space development.

▪ points of access

The horizontal points of access for mined space are obviously a major factor in site selection both for construction and later vehicular and service access. The natural points of access along the river flats and their relationship to existing roads will influence development considerably. This does not imply that development would only occur along the edges of the limestone, however. In fact, most parts of the campus bedrock layer can be reached within a reasonable distance of a portal.

The existing vertical points of access to this level are utility shafts. Any future establishment of vertical circulation points to this level will determine site development to some extent. Entire buildings may extend into the bedrock and provide major points of access to mined space.

▪ surface structures

Surface structures influence mined space site selection in two ways. The first is the weight of the structure and the possible limitations it may impose on mined space directly beneath. It is presently believed that few surface structures would hinder the development of mined space. However, until this is more thoroughly documented, initial large openings in the bedrock would probably not be located under the heavier structures. The second influence of surface structures on the selection of mined space sites is simply the proximity the mined space must have to existing surface and near surface spaces.

preliminary site analysis

In general, both the east and west bank bedrock areas have adequate points of access, no presently known geological restrictions, and large areas uninterrupted by major utilities and are suitable for extensive development of mined space. With the present low level of use and relatively unrestricted site selection, any proposed use of the bedrock should consider the impact on future development. For example, a proposed regional mass transit corridor would have a strong influence on underground development by establishing major vertical access to this level. This does not imply that development of mined space is dependent on location of mass transit there, only that the suitability of bedrock areas adjacent to the transit would be affected.

To prevent misuse of this potential resource, the bedrock layer like the surface requires organized, comprehensive planning instead of piecemeal development. Unlike the surface, it is impossible to isolate particular sites in the bedrock based on their physical characteristics alone, however identification and analysis of sites can take place once the uses and extent of the space are determined. The planning and programming of the mined space on campus will depend on and develop with the total long range development plan. For mined space to be a realistic alternative in campus planning, cost-benefit comparisons should be made with surface space along with more detailed site analysis based on specific uses.

site selection and analysis in soil

site selection

The selection and analysis of sites in the soil for cut and cover space is considerably more complex than mined space. The first step in the site selection process is the identification of all potential sites within the campus. In a general sense, all land on the campus without an existing structure is potentially a developable site for underground construction. A relatively small area between two structures may provide necessary expansion space such as the existing sub-surface office space between Morrill Hall and the Physics Building. Almost any space between structures may be a future site for an underground pedestrian walkway such as the connections between Johnston Hall, Walter Library and Smith Hall. For the purposes and scope of this report, however, only larger sites will be considered.

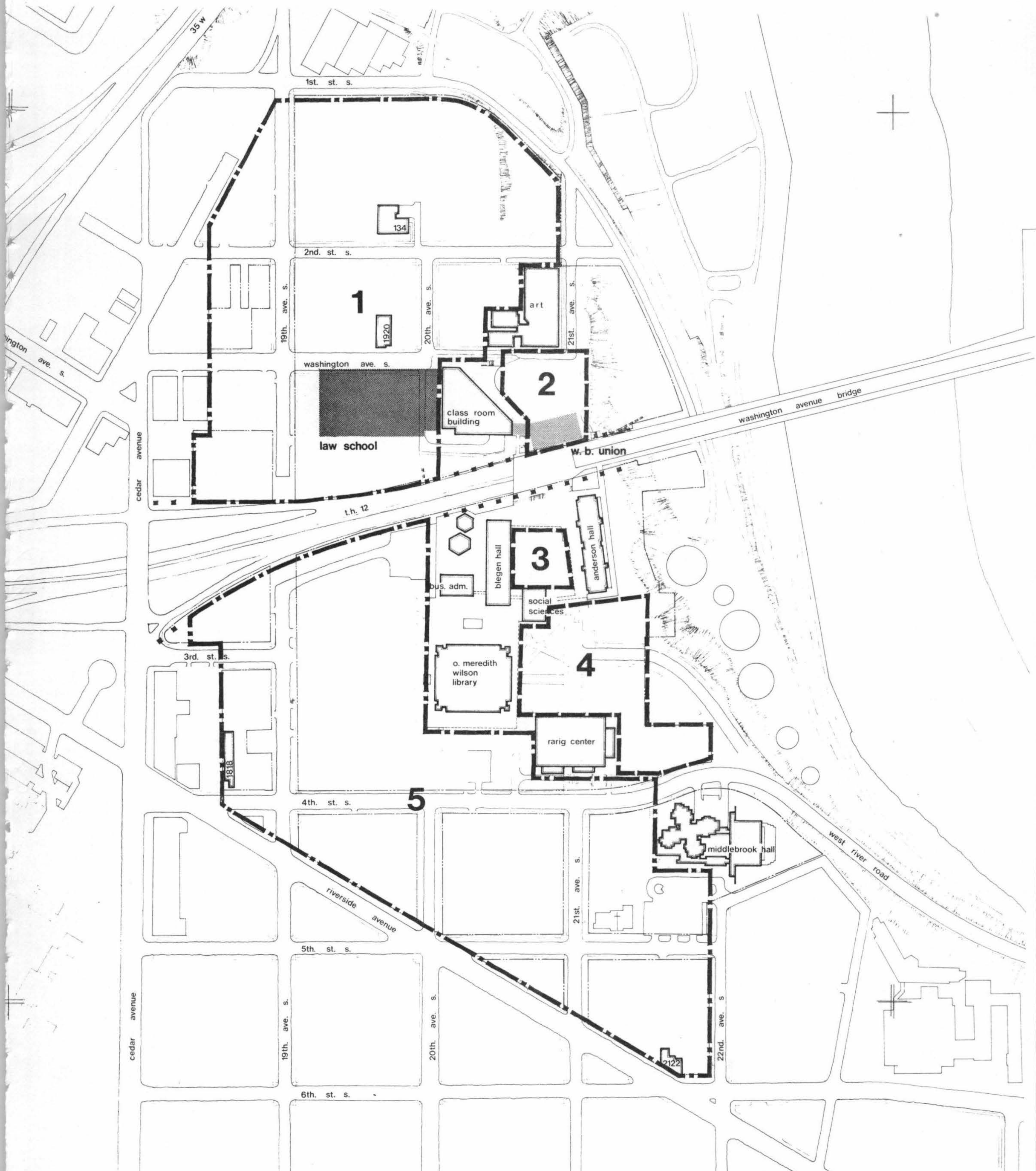
These major sites are all sites that have relatively homogeneous characteristics and are at least the size of a typical campus building site. They are further split into two categories, infill sites and expansion sites. Infill sites are those which are defined by existing buildings such as the mall, while expansion sites are larger areas of land within the university area with future growth potential. Because the development of the expansion areas is presently undetermined, they are considered as homogeneous units even though there are various physical characteristics, existing structures and site determinants within each expansion site area. This identification of sites for potential development applies not only to totally sub-surface development but to the sub-surface as a component part of above and below ground development. This is particularly true of expansion sites where the development of totally underground space is much less likely than in an infill site.

In addition to these major sites, there are other sites with sub-surface development potential that have unique characteristics with implications for special uses. These are corridor spaces which occur mainly under existing streets and are important in the consideration of special linear functions such as mass transit or sub-surface vehicular circulation. Although the unobstructed linear shape of these corridors is a primary characteristic, segments of the corridor spaces can be considered as potential sites for any type of sub-surface function from a major building structure to a pedestrian walkway. Although a clear distinction is made between infill/expansion sites and corridor areas on the maps which follow, the two are actually not clearly separate. It is important to note that corridors can occur through infill or expansion sites, and similarly, building sites can occur partially or even totally within corridor spaces. This type of development, can provide considerably larger building sites as well as enclosed sub-surface connections between two sides of a surface street. The expansion sites obviously contain some defined corridors within them along existing streets, however they are not identified separately within the total expansion site.

There are several physical factors which determine the suitability of each site indicated on the map. These factors are outlined in this section following the map.

site maps

These drawings indicate potential major sites for sub-surface development in the soil within the regent's boundary of the university. The infill sites are distinguished from the expansion areas and the major corridor spaces are identified as well. It is important to note that the drawings show all possible sites of a certain size and do not represent any recommendations as to the development of these sites. Also, the four totally sub-surface existing parking garages are indicated. These garages are also presently used for some enclosed pedestrian circulation and occupy prominent sites on the campus. They are the only existing space represented because they are the only totally sub-surface structures and, unlike the lower level of a building, their use and configuration could be changed significantly in future development. Therefore, they represent unique potential underground space which should be noted. Finally, the drawings indicate both programmed and proposed uses for the underground space in the soil. The programmed structures are definite building projects which are under construction or are definitely programmed to be built in the near future. These include the Bookstore/Admissions and Records Building which is nearly a totally sub-surface structure and an excellent example of the underground development of an infill site. The proposed projects are not as definite and in some cases rather speculative. Nevertheless, these proposals serve to illustrate the pattern of underground development. In the case of a proposed campus transit alignment shown on the map, a significant impact on surface and sub-surface planning is demonstrated.



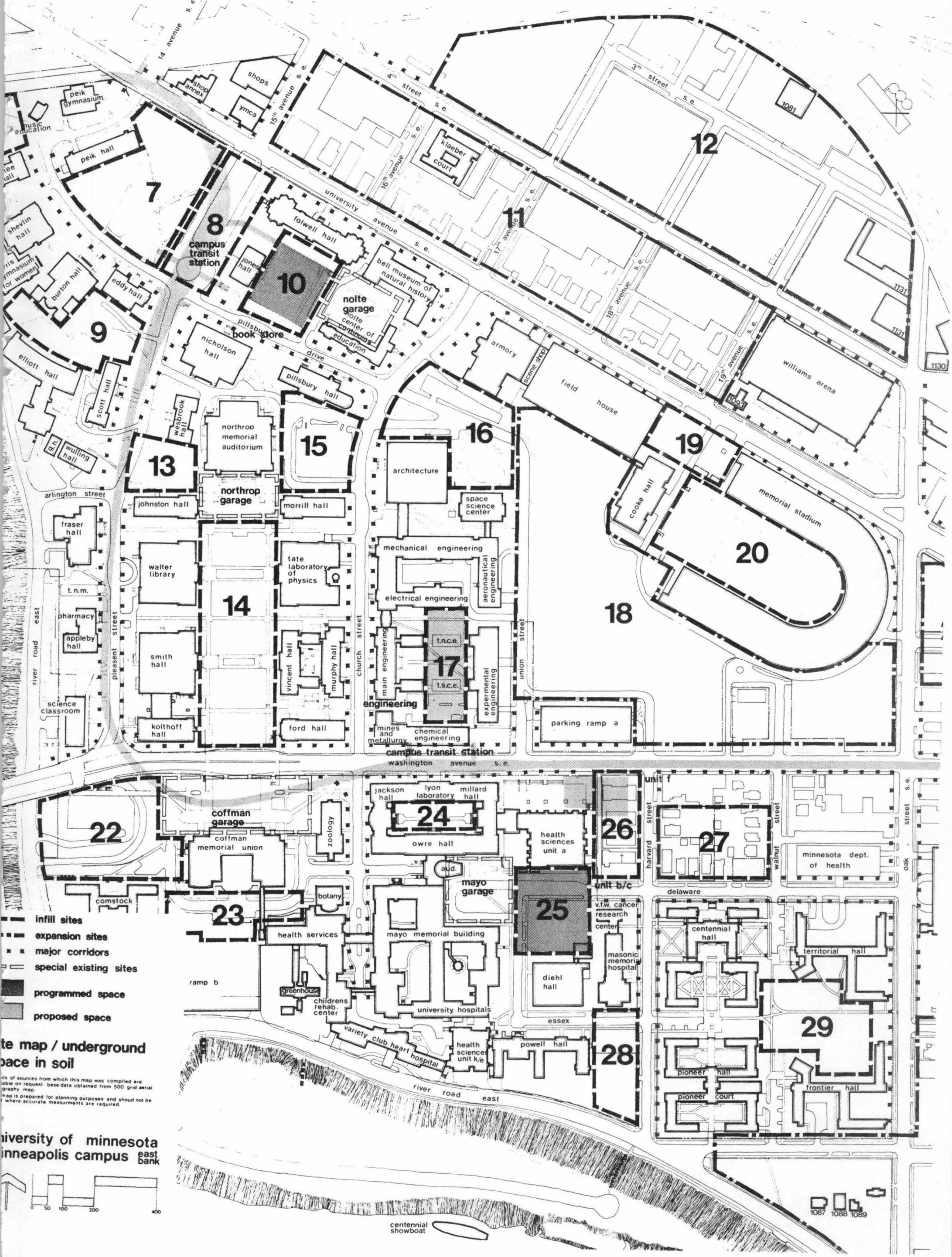
infill sites
expansion sites
major corridors
programmed space
proposed space

site map / underground space in soil

details of sources from which this map was compiled are available on request. base data obtained from 500 gnd aerial topography map.

this map is prepared for planning purposes and should not be used where accurate measurments are required.

university of minnesota minneapolis campus west bank



14 avenue s.e.
shops
shop annex
peik gymnasium
music education
ymca
15th avenue s.e.
4th street s.e.
3rd street s.e.
1081
12
peik hall
7
8
campus transit station
klaeber court
16th avenue s.e.
17th avenue s.e.
11
university avenue s.e.
folwell hall
shevlin hall
jones hall
10
bell museum of natural history
burton hall
eddy hall
nolte garage
nolte center of continuing education
9
pillsbury drive
book store
nicholson hall
18th avenue s.e.
19th avenue s.e.
1131
1130
williams arena
armory
scene shop
field house
elliott hall
pillsbury hall
scott hall
wesbrook hall
northrop memorial auditorium
15
16
19
1093
g.h.
wulling hall
13
architecture
cooke hall
memorial stadium
arlington street
northrop garage
johnston hall
morrill hall
space science center
fraser hall
20
walter library
tate laboratory of physics
mechanical engineering
aeronautical engineering
t.n.m.
14
electrical engineering
18
pharmacy
appleby hall
smith hall
vincent hall
murphy hall
main engineering
t.n.c.e.
17
t.s.c.e.
experimental engineering
union street
church street
pleasent street
river road east
science classroom
engineering
kolthoff hall
ford hall
mines and metallurgy
chemical engineering
parking ramp a
campus transit station
washington avenue s.e.
unit f
jackson hall
lyon laboratory
millard hall
22
coffman garage
coffman memorial union
24
owre hall
zoology
health sciences unit a
26
harvard street
27
walnut street
minnesota dept. of health
oak street s.e.
aud.
mayo garage
unit b/c
delaware
comstock
botany
23
25
v.f.w. cancer research center
centennial hall
health services
mayo memorial building
masonic memorial hospital
territorial hall
ramp b
diehl hall
greenhouse
childrens rehab. center
university hospitals
29
essex
variety club heart hospital
health sciences unit k/e
powell hall
28
pioneer hall
pioneer court
frontier hall
river road east
infill sites
expansion sites
major corridors
special existing sites
programmed space
proposed space
te map / underground
pace in soil
iversity of minnesota
inneapolis campus east bank
0 50 100 200 400
1087 1088 1089
centennial showboat

site analysis factors

The analysis of specific sites for development as underground space is a process which depends on many long range planning policies and strategies. There are, however, some basic factors listed below which affect the suitability of a site for underground space development. These factors, with the possible exception of vehicular access which is not required for all functions, are relevant for any potential use of the space. Other physical factors obviously are relevant for specific uses, however, they are not dealt with in this general site suitability analysis.

▪ geology/soil

The depth and type of soil and bedrock is important to any construction, both in the ease of excavation and ability to support structures. These properties are well known and impose no major restrictions on the campus. Water conditions below the surface can cause serious problems. Some isolated sub-surface water problems have occurred in campus construction, however it is unlikely they are of a magnitude to prevent development. One physical characteristic significant to underground space is the actual distance from the surface to the Bedrock indicating the amount of easily excavatable space. This is important to note but does not necessarily impose a lower limit to space. Although bedrock is more difficult to excavate, support requirements will be less than at an equivalent depth in soil. In the main campus area the depth to bedrock is relatively consistent at about 50 feet on the east bank and 40 feet on the west bank. Deviations from these characteristics will be noted in the site analyses.

▪ utilities

The existing utilities on a potential site can be an important cost factor, but probably not a barrier to development. The difficulty and cost of relocation can vary considerably depending on the type and size of utility. Major restrictions due to existing utilities will be indicated in the site analyses.

▪ adjacent structures

The proximity of a site to existing buildings is important for two main reasons. One is the present use of the sub-surface levels of the buildings. This can influence the suitability of linking an underground structure to these existing buildings. In the site analysis section, particularly good relationships as well as poor ones will be noted. The second reason for considering the proximity to existing buildings is the problems they may create in construction. Generally, older structures with shallow foundations will be more costly to build next to than newer structures with foundations to bedrock. Of course, the size of the site and the location of the proposed construction may not require building extremely close to the existing structures. In the analysis, particularly restricted sites with shallow adjacent foundations and particularly unrestricted sites with deep adjacent foundations will be noted. Most infill sites will present more difficulty than a site in an open area, but these problems can be dealt with as outlined in the engineering construction section of Part 4.

▪ surface features

Underground space has the advantage of preserving surface amenities such as open space, however with cut and cover construction some surface features cannot be preserved. This refers mainly to mature trees and vegetation which can be irreplaceable over a short term, although some unique natural land forms may be affected as well. The relative value of these features is difficult to determine and the ability to preserve them and also build on the site can vary considerably. They are nevertheless mentioned as a factor in site analysis.

▪ vehicular / service access

Unlike the other physical factors listed here, vehicular access does not necessarily apply to all types of cut and cover construction. It is, nevertheless, an important characteristic to document. Most functions require some service access, but this is not necessarily a restriction in that underground space could be serviced through adjacent existing buildings. In the site analysis, conditions of good access for functions such as parking will be noted as well as conditions of very restricted access.

preliminary site analysis

The determination of the suitability of various sites for underground space use is a process which does not produce a clearly suitable or unsuitable label for each site. Although no clear line can be drawn certain general conclusions can be stated about the campus and certain sites do emerge as definitely suitable and others as definitely unsuitable. These summary conclusions for the major types of sites appear here and they are followed by the physical characteristics and comments for each individual site.

▪ infill sites

On the west bank there are two suitable infill sites (2 & 4) along the river bluffs. Both have the potential for integrating the main west bank campus with the future park area below. On the east bank, two obviously suitable sites have already been programmed for the almost totally sub-surface bookstore (10) and Unit B/C of the Health Sciences complex (25) which uses sub-surface space extensively. One main proposed campus transit station in front of Jones Hall is a particularly appropriate use for a suitable site (8). Several sites in the central part of the east bank (13, 15, 16, 17) are physically suitable and seem appropriate for underground space due to the central location, possibility of connecting existing structures, and the desirability of preserving open space in this built-up area. Other sites are physically suitable for development but have very valuable natural features which could not be preserved with any major construction. The Knoll area (7) is covered with large trees and may be considered as an unsuitable site in short range planning, but the mall area (14) is less clear. The large trees on the mall are valuable features but some sub-surface development could take place, linking existing buildings, without destroying the amenities. Trees, of course, can be replaced over time and long range planning should recognize that they are not necessarily an absolute barrier to development. Most other sites present no overwhelming physical restrictions except that they may be too small to justify any substantial development. The sites located more on the periphery of the central campus do not suggest totally underground structures since the issue of preserving open space in a built-up area is not as evident. However, full use of the available underground space in each site should be considered for other reasons such as energy conservation.

▪ expansion sites

The expansion sites are all relatively similar in their physical characteristics. All are suitable for construction, have utilities concentrated under existing streets, and any major trees are located along existing streets as well. Specific comments are difficult to make since development is so uncertain, however the various advantages of underground space outlined in this report make full use of the underground a consideration in expansion. These sites present potential areas where cut and cover space could be extended into the bedrock and mined space development could be more easily integrated with the surface structures. A few points of major access could serve a considerably larger area of mined space.

- **corridor spaces**

The corridor spaces as defined in this report are major, unobstructed, relatively linear spaces through the campus area which are appropriate for special uses such as transit and vehicular corridors. All of the corridor spaces are physically similar in that they occur under existing streets, contain numerous major utilities and are lined with adjacent structures and large trees. Corridor spaces are obviously costly and disruptive to build in, however certain major uses such as transit can occur no where else. Because of the incompatability of surface traffic and pedestrians, crossing corridor spaces with sub-surface walkways is another valid use. The Washington Avenue corridor deserves special mention since it presents many issues, problems and possibilities for campus development. Since it is a major traffic carrier, divides the campus, and the Washington Avenue bridge is already at a lower level than the main campus surface, previous proposals to lower the road surface deserve continued review. The proposed underground campus and regional transit may contribute to the possible sub-surface location of the roadway as well.

- **existing special sites**

The four existing sub-surface parking garages deserve special mention as potential sites for underground development. The uses and configurations of these spaces could be changed and possibly deeper levels could be developed as well. These sites are particularly notable since they occupy such centrally located positions on the campus. The Coffman Garage has been indicated as a part of the proposed campus transit route, and the Northrup Garage occupies a particularly unique site in the mall connecting major buildings.

individual site analysis

west bank

site 1: geology/soil: no major restrictions, 35 to 45 feet to bedrock.
utilities: concentrated under existing streets with major lines under 19th and 20th Avenue South.
adjacent structures: does not apply to most of the area; w. b. auditorium bldg. has no extensive use of sub-surface.
major surface features: none, with the exception of trees along some existing streets.
vehicular/service access: good major access points.
comment: This is a relatively open expansion area with a few major utilities the only restriction.

site 2: geology/soil: topography slopes down toward river, depth of soil to limestone about 20' at bluff edge.
utilities: no major restrictions, a buried telephone line and water line occur at the bluff edge.
adjacent structures: the w. b. auditorium and art bldgs. have no major sub-surface levels; typical adjacent foundation conditions would occur.
major surface features: with the exception of the trees on the bluff, there are no other trees on the site.
vehicular/service access: adequate service access.
comment: The proposed w. b. union presents an opportunity to develop this site and possibly provide access to the river flats park below.

site 3: geology/soil: no major restrictions.
utilities: there are several minor utilities serving surrounding buildings that would require relocation.
adjacent structures: this site is surrounded by a complex with major circulation below grade; any construction would have to closely tie in with the existing buildings.
major surface features: the site is presently a developed plaza with extensive planting.
vehicular/service access: service through existing buildings.
comments: The site is rather small and has been developed as a plaza which would probably not justify any new modifications.

site 4: geology/soil: topography slopes down toward river at the bluff edge.
utilities: no major restrictions, one water line.
adjacent structures: all surrounding structures have one fully developed sub-surface level with major circulation below grade around the site perimeter; typical adjacent foundation conditions would be present but the site is large.
major surface features: there are a few mature trees and the river bluff edge is an attractive amenity.
vehicular/service access: adequate service access.
comment: The existing sub-surface level of circulation, the fairly substantial size of the site, and the opportunity to integrate the west bank with the park below make this a definite possible site.

site 5: geology/soil: no major restrictions, 35 to 45 feet to bedrock.
utilities: mainly under existing streets with major concentrations on 19th Avenue South and 4th Street South.
adjacent structures: does not apply to most of the area; sites adjacent to Wilson Library have possible relation to existing underground circulation level.
major surface features: none, with the exception of trees along some existing streets.
vehicular/service access: good major access points.
comment: This is a primary expansion area with few restrictions besides some major utilities, integration with future space in the bedrock under this area should be considered.

east bank

site 6: geology/soil: no major restrictions, 40 to 50 feet to bedrock.
utilities: there are some shallow steam tunnels, across the site.
adjacent structures: there is no notable use of sub-surface space; foundations are not deep but site is large so no major problems with construction.
major surface features: there are some large mature trees but also large open areas.
vehicular/service access: presently adequate access.
comment: This is a possible site of sufficient size although some trees are worth saving. The development will depend on the future of the Knoll area and the older marginal buildings by the site.

site 7: geology/soil: no major restrictions.
utilities: there are no utilities within the site.
adjacent structures: the only immediately adjacent structure is Peik Hall which has little influence on development of such a large site.
major surface features: substantial and numerous mature trees throughout the site.
vehicular/service access: good access.
comment: The powerful natural features of the site are a predominant characteristic which could not be preserved with any construction. It is possible some development could occur along the Jones Hall side with the transit complex.

site 8: geology/soil: no major restrictions.
utilities: there are several utility lines through the site.
adjacent structures: sub-surface connection to the proposed bookstore is a likely possibility; Folwell and Jones Hall do not have deep foundations but the site is large.
major surface features: mature trees line the edges and more recently planted trees are in the center.
vehicular/service access: good access.
comment: This area has been proposed as a major station area for campus transit. Few surface features, the proposed adjacent bookstore, and major pedestrian circulation conflicting with surface traffic on the site make this a primary site for development.

site 9: geology/soil: no major restrictions.
utilities: significant amount of utilities covering majority of site.
adjacent structures: all adjacent structures have basement levels but have no notable functions or circulation patterns; foundation conditions would be typical but site is more restricted than many possibly creating more problems.
major surface features: there are some substantial mature trees and stands of evergreens.
vehicular/service access: adequate service access.
comment: The large concentration of utilities, reasonably pleasant surface features and rather restricted configuration do not make this a primary site for cut and cover space. However the transit development and the future of some marginal structures may make this area a future possibility.

site 10: geology/soil: no major restrictions.
utilities: no significant utilities.
adjacent structures: sub-surface connection to Jones Hall, Folwell Hall, Nolte Center, and garage is possible; typical adjacent foundation conditions are found here but site is large.
major surface features: none except for a few mature trees on the edges.
vehicular/service access: service is adequate.
comment: This site is already programmed for a sub-surface bookstore/admission and records structure. The lack of surface features, the major pedestrian circulation, and the character of the surrounding buildings make this an obvious primary underground space site.

site 11: geology/soil: no major restrictions.
utilities: concentrated on existing streets.
adjacent structures: this does not apply directly, there are many existing small scale structures within this site area, future use will determine their significance.
major surface features: mature trees along streets.
vehicular/service access: excellent.
comment: This site is included as a possible long range expansion area even though there are considerable existing uses and structures. The predominant characteristics of this area are the University Ave. and 4th Street corridors which have great concentrations of utilities but may be desirable to cross below grade at some points.

site 12: geology/soil: no major restrictions.
utilities: concentrated on existing streets.
adjacent structures: does not apply here.
major surface features: some large trees along existing streets.
vehicular/service access: good.
comment: This is an open expansion area at the edge of campus boundaries. Any development here could take full advantage of available sub-surface space.

site 13: geology/soil: no major restrictions.
utilities: no major utilities, one gas and one water line.
adjacent structures: Northrup Hall, Northrup garage and Johnston Hall have active sub-surface levels which could connect to any sub-surface construction; adjacent foundation problems may exist - since the site is rather small.
major surface features: some fairly substantial trees, but not a great number.
vehicular/service access: adequate service.
comment: There are no major restrictions to this site except that it is rather small and therefore the amount of space may not justify construction. However, the future of the marginal Wesbrook Hall may make this a substantial site in a prime location.

site 14: geology/soil: no major restrictions.
utilities: no significant utilities with the exception of one steam tunnel.
adjacent structures: all adjacent structures have sub-surface levels and some are connected below grade already; the size of the space would not make great foundation problems for most development; Kolthoff Hall goes down to the bedrock.
major surface features: very substantial mature trees of almost irreplaceable quality.
vehicular/service access: adequate service.
comment: Only the substantial trees prevent the mall from being a primary area for underground space. The space is large enough and the trees located mainly at the edges so that some development is possible connecting some buildings and providing space in a central location of the campus.

site 15: geology/soil: no major restrictions.
utilities: no significant utilities except for a steam tunnel along the north edge.
adjacent structures: the adjacent buildings have active sub-surface spaces and the proposed bookstore ties into the northwest corner of the site; typical adjacent foundation conditions but the site is fairly large.
major surface features: only a few mature trees on the edges, some new planting in the center.
vehicular/service access: adequate.
comment: With few utility or natural feature restrictions, surrounding buildings of character and historic value, and a central location within the campus, this is a primary site for underground space development.

site 16: geology/soil: no major restrictions.
utilities: no significant restrictions, some electric and water lines cross the site.
adjacent structures: adjacent Architecture and Space Science bldgs. have active basement space use; no major problem with adjacent foundations would be anticipated.

major surface features: some substantial trees between Arch. and the Armory along the streets, smaller trees elsewhere.
vehicular/service access: adequate.
comment: This site is more complex to define and does not have entirely homogeneous characteristics, however there is potential development space here particularly in the space formed by Arch. and Space Sciences. The development of this site will probably depend on future use of the football practice field, to which it would provide a good link and the future of the Armory.

site 17: geology/soil: no major restrictions.
utilities: there are steam tunnels and electric lines but they would not be major restrictions.
adjacent structures: all surrounding structures have basement levels and could be tied into a sub-surface structure; adjacent foundation problems could be difficult since the site is narrow and some adjacent buildings do not go to bedrock.
major surface features: a few mature trees.
vehicular/service access: adequate service.
comment: This site has been proposed for I. T. expansion connecting existing buildings. Although the site is narrow and existing foundations may require some special treatment in construction, the site is in a good location and underground development could connect the I. T. complex while leaving some surface open space.

site 18: geology/soil: no major restrictions.
utilities: there are some electric, water and sewer lines crossing the space but it is basically unrestricted by major utility concentrations.
adjacent structures: this does not apply as with an infill site but the I. T. buildings along Union St. and the football stadium are adjacent structures which have sub-surface levels and will influence development of the space.
major surface features: some large trees around stadium and along Walnut.
vehicular/service access: good access.
comment: This is the only large expansion area close to the center of the campus. The potential for development of underground space is unrestricted and is enhanced by the possible sub-surface connection to the Health Sciences complex, I. T. area and campus and regional transit. This site is also a possibility for integration with deep mined space by extending a structure into the bedrock.

site 19: geology/soil: no major restrictions.
utilities: no significant restrictions although the adjacent University Ave., corridor is highly concentrated.
adjacent structures: Cooke Hall has significantly use of sub-surface space and underground pedestrian tunnels now cross the site; foundation problems would be typical for utilities.

major surface features: none.
vehicular/service access: good.
comment: This site is relatively small but some unrestricted space is available and would connect well with existing underground uses in surrounding buildings.

site 20: geology/soil: no major restrictions.
utilities: only one electric line and a storm sewer which drains the field area.
adjacent structures: Memorial Stadium surrounds this unique space and presents no major obstacles to any development.
major surface features: the surface is covered by artifical turf which may be reusable if space were constructed under the field.
vehicular/service access: adequate.
comment: The use of space under the football field may seem unlikely considering the possible cost of disrupting and replacing the field, however a major remodeling and expansion of athletic facilities might take advantage of this large volume of space.

site 21: geology/soil: no major restrictions.
utilities: occur within the site under Beacon Street with great concentrations in adjacent Oak Street and University Avenue corridors.
adjacent structures: does not apply here.
major surface features: only trees along Oak Street.
vehicular/service access: good.
comment: This relatively minor expansion site is the proposed site of a fire station. Any significant development of underground space here would probably be tied to the larger expansion area west of Oak Street.

site 22: geology/soil: the topography slopes down toward the river, only 10 to 30 feet of soil to the bedrock.
utilities: no major restrictions although there are many utilities near Comstock Hall and Coffman Union.
adjacent structures: Coffman Union has sub-surface levels of activity and the underground garage is on one edge of the site; no major problems would exist with adjacent foundations since the site is large.
major surface features: no substantial trees but the river bluff is a major natural feature.
vehicular/service access: adequate.
comment: This is unique and complex site. Several levels of underground and partially underground space could be developed here providing access to the river without obstructing other views. There are no physical restrictions to this site but existing vehicular circulation through the site is a factor.

site 23: geology/soil: only 20 to 30 feet of soil above the bedrock exists here.
utilities: several lines cross site near Comstock Hall, otherwise no major restrictions.

adjacent structures: Coffman Union has active sub-surface level and Parking Ramp extends several levels into bedrock; foundations in bedrock would cause no problem.
major surface features: a few substantial trees and several new trees near the ramp.
vehicular/service access: adequate.
comment: Sub-surface construction could provide connection from the basement of Coffman to the parking ramp, however it is rather small and the existing service road dominates the surface.

site 24: geology/soil: no major restrictions.
utilities: some main electric lines.
adjacent structures: the site is very restricted and enclosed; adjacent foundations are notably shallow.
major surface features: some mature trees.
vehicular/service access: service through surrounding buildings.
comment: This site is very small, has substantial trees, and is restricted by the surrounding older buildings. Any additional construction here would be minor.

site 25: geology/soil: no major restrictions.
utilities: removed for new construction.
adjacent structures: all surrounding structures have extensive sub-surface use and circulation; buildings such as Unit A which go to bedrock provide considerably less foundation problems.
major surface features: none.
vehicular/service access: good.
comment: The B/C unit of the Health Sciences complex is under construction on this site. Although the proposed building is largely above ground, it takes full advantage of the available sub-surface space in soil.

site 26: geology/soil: no major restrictions.
utilities: only in adjacent corridors around site.
adjacent structures: the Health Sciences Unit A has extensive use of the underground and goes to the bedrock creating no major foundation problems.
major surface features: substantial trees along edges.
vehicular/service access: good.
comment: This site presently has existing housing and a church structure, however it is within the regents boundary and is considered a possible site. Unit F of the Health Sciences complex is proposed for part of the site and future use would most likely relate to the adjacent Health Sciences complex.

site 27: geology/soil: no major restrictions, although some sub-surface water problems have occurred in this general area.
utilities: only in adjacent corridors around site.

adjacent structures: none with significant sub-surface use; adjacent commercial structures would present typical problems if built close to.
major surface features: substantial trees along edges.
vehicular/service access: good.
comment: This site presently has existing housing and is included since it is within the regents boundary. An underground pedestrian tunnel has been proposed along Delaware and if constructed this site could relate strongly to the sub-surface Medical Complex circulation.

site 28: geology/soil: no major restrictions, site slopes slightly toward river but 35 to 40 feet of soil are still present.
utilities: many utilities in Essex Street part of site, otherwise only in adjacent corridors around site.
adjacent structures: Powell Hall and V. A. Hospital have major sub-surface circulation and a pedestrian tunnel crosses the site; foundation conditions would be typical.
major surface features: substantial trees along edges and on southern half of site.
vehicular/service access: good.
comment: There is presently housing on part of this site but it is a potential building site. Any construction here could strongly tie into the existing sub-surface circulation system.

site 29: geology/soil: no major restrictions, although sub-surface water problems have occurred in this area.
utilities: some utilities cross site where former streets were.
adjacent structures: the surrounding dormitories have basement space and could be connected to any sub-surface development; foundation conditions would be typical but site is fairly large.
major surface features: substantial mature trees although entire site is not covered.
vehicular/service access: good.
comment: This site is a considerable natural amenity to the existing housing and demand for sub-surface space within a housing area may not be as great as an academic area. Some support facilities are a possibility and enclosed connection to the Academic complex may be desirable.

site 30: geology/soil: no major restrictions, topography varies but 30 to 50 feet of soil to bedrock is present throughout.
utilities: occur along existing streets.
adjacent structures: does not apply.
major surface features: mature trees mainly along existing streets and river bluff edge.
vehicular/service access: good.
comment: This is a large expansion area with no major restrictions within campus boundaries with many existing housing structures. Future development is obviously speculative but the possibility of integrating future surface space with mined space in the bedrock below this area should be considered.

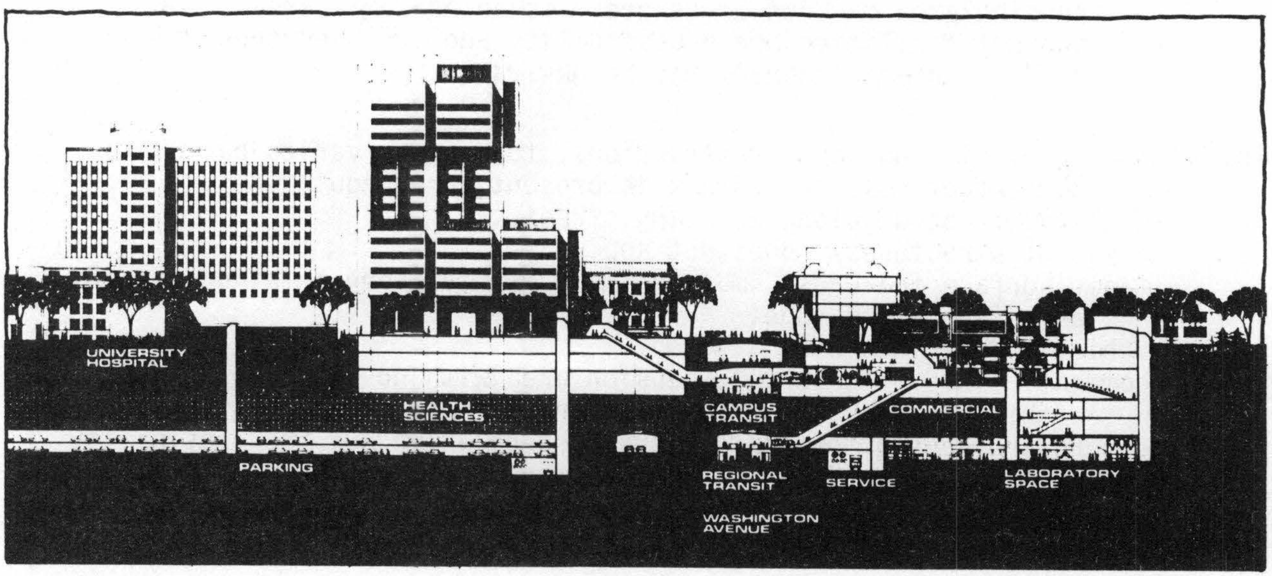
appropriate functions

In addition to determining the suitability of sites for underground space, the appropriateness of various uses of the space is an important consideration. When a particular project or function is proposed for underground space, many specific and detailed requirements will have to be met. In some cases underground space will have distinct advantages, in others distinct disadvantages. Ultimate decisions on the appropriateness of sub-surface space for various uses cannot be absolutely determined within the scope of this study for two reasons. First, the physical characteristics and requirements of a major university function such as laboratory or office space vary considerably and second, the advantages and disadvantages of underground space have very relative degrees of importance for each possible use. However, it is possible to present an illustrative survey of various major university functions which points out some of the substantial advantages and disadvantages of underground space for each function. This survey does not take into consideration some of the general characteristics of underground space such as energy conservation or preservation of surface open space which may be important factors in locating space underground regardless of function. It is intended to indicate some general directions in determining the appropriateness of various uses as well as present some schematic illustrations of possible physical developments. These schematic drawings are only intended to illustrate potential development not to represent specific proposals.

basic characteristics

The following list includes the basic characteristics on which each function will be evaluated. Only the characteristics which differ substantially from a typical surface space and thus represent a major advantage or disadvantage are mentioned under each function.

pedestrian access
vehicular access
proximity to surface spaces
physical isolation
structural characteristics
relation to outdoors/natural light
special requirements of function



suitability of various functions

The following survey includes major use categories of university space and the major circulation and service systems. Each use is evaluated separately for mined space and cut and cover space.

classroom / auditorium

mined space:

- pedestrian access: large assembly spaces have large access requirements, mined space development of considerable size would be required to justify large amounts of vertical circulation.
- physical isolation: advantage of complete isolation from surface noise.
- structural: large spans for large assembly spaces are not proportionately more costly than smaller spans.
- comment: classroom and assembly spaces are physically appropriate in underground space, however the vertical circulation requirements for small developments may be costly.

cut and cover space:

- physical isolation: advantage of some isolation from surface noise.
- comment: cut and cover classroom space does not differ substantially from surface space in other characteristics.

laboratory space

mined space:

- pedestrian access: as with classrooms, instructional labs require extensive access from the surface, a possible drawback; however, many research labs do not have a great access requirement.
- physical isolation: definite advantage for some types of specialized laboratories.
- special needs: the ability to provide a highly controlled environment could be an advantage, other special needs may be more costly below ground.
- structural: relatively large spans can easily be provided, very large allowable floor loads for equipment.
- relation to outdoors/light: studio spaces for art in particular may be unsuitable if natural light is a requirement.
- comment: laboratory spaces vary vastly in requirements and optimal conditions, some characteristics of mined space have definite advantages over the surface for laboratories but a generalization is impossible to make.

cut and cover space:

- physical isolation: the isolation from noise achieved in cut and cover space can be a definite advantage.
- comment: cut and cover space does not differ substantially from surface space in other characteristics.

office space

mined space:

proximity to surface spaces: some offices may require direct proximity to existing surface facilities.

relation to outdoors/light: some private offices may require view or natural light which is unavailable in mined space, but many offices do not.

comment: certain general office space with data-processing equipment may be well suited to mined space with excellent climate control for the equipment, while private offices may be inappropriate here unless related to a larger development.

cut and cover space:

comment: offices in cut and cover space vary little from surface spaces unless a view is required, natural light can even be provided with certain designs.

library

mined space:

pedestrian access: major libraries require extensive access which initially may not be justifiable, but specialized libraries and storage do not require great access.

physical isolation: isolation from sound for a study area is a definite advantage.

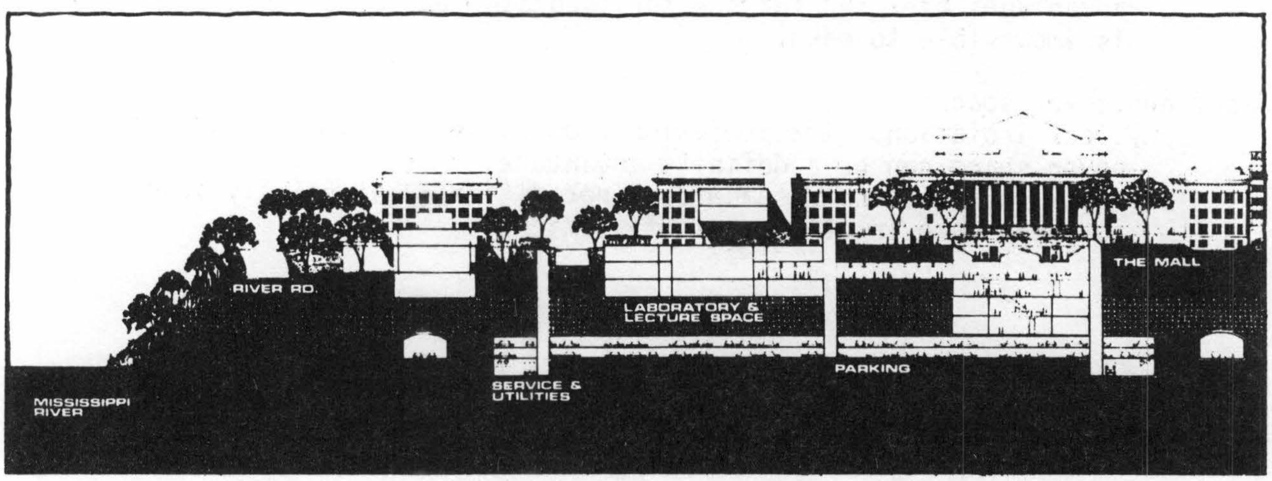
comment: as a single function in deep space, a library seems too isolated; however as part of a larger complex it could be appropriate since other characteristics are advantageous.

cut and cover space:

proximity to surface spaces: a library in cut and cover space could be connected to several existing buildings.

physical isolation: isolation from sound and surface distraction is an advantage.

comment: this is an appropriate use of cut and cover space particularly in central campus areas where library and study space may be in demand.



student services

mined space:

proximity to surface spaces: student services should be in proximity to academic spaces and would be inappropriate alone in mined space.

comment: student services such as lounges and eating facilities serve other spaces, thus any development of mined space may include some supporting common space.

cut and cover space:

proximity to surface spaces: underground common space near the surface can have an excellent relationship to existing buildings and circulation.

comment: student services in built-up areas located below ground can provide services where needed, connect buildings, and not interfere with surface spaces or character.

recreational space / gymnasium

mined space:

proximity to surface spaces: small scale recreational spaces may be inappropriately isolated from other student service areas in mined space; larger scale gymnasiums may be quite appropriate since they require no direct proximity.

structural: large spans up to 60' can be achieved for proportionately no more cost than small spans.

comment: the large land areas and expensive structures required for large scale recreational spaces could make mined space a viable alternative.

cut and cover space:

comment: cut and cover recreational space does not differ substantially from surface spaces based on these physical characteristics.

storage / archives

mined space:

vehicular access: large scale storage requires ample vehicular access, this can be provided in mined space only along the river bluffs.

proximity to surface spaces: direct vertical access to archives storage is possible.

structural: relatively large spans, great allowable floor loads and flexible layout are available for large scale storage.

special needs: constant temperature an humidity can be inexpensively achieved when required for some materials.

comment: the relatively limited access and proximity to the surface required for large scale storage make this an appropriate use of mined space.

cut and cover space:

comment: cut and cover storage space does not differ substantially from surface spaces based on these physical characteristics.

housing

mined space:

relation to outdoors/light: although not an absolute requirement this is a considerable disadvantage unless locationed in a bluff.

comment: the desire for some relation to the outdoors makes housing at this depth basically an inappropriate use at this time.

cut and cover space:

relation to outdoors/light: this requirement can be achieved somewhat by orienting units to exterior or interior court spaces providing natural light.

comment: single units can benefit from being partially underground for energy conservation and isolation, but it may be difficult to provide good relation to the outdoors for all units in a higher density development.

systems:

pedestrian circulation

mined space:

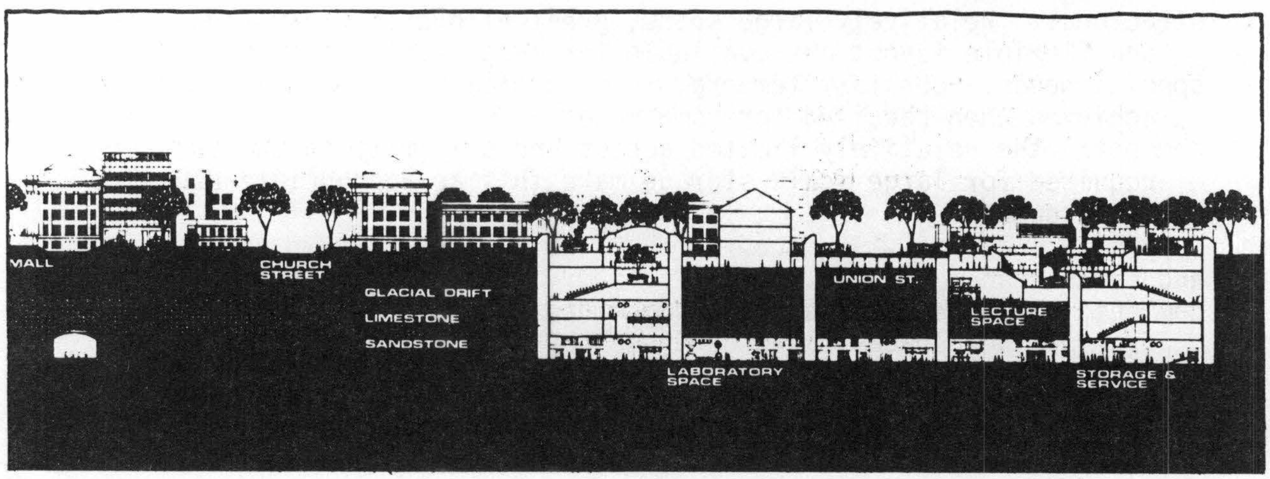
comment: pedestrian circulation in mined space would obviously occur with any major use of the space, but pedestrian walkways alone at this level would be too removed from the surface and vertical circulation unjustified.

cut and cover space:

proximity to surface spaces: nearly all surface structures have at least one sub-surface level which underground pedestrian walkways can be connected to.

physical isolation: sub-surface walkways are well protected from the climate.

comment: cut and cover pedestrian walkways are a good means of providing enclosed circulation without disturbing surface open spaces and buildings, and avoiding any vehicular pedestrian conflict on the surface.



physical plant / fuel storage

mined space:

vehicular access: the ample vehicular access required for this function could be provided only along the river bluffs.

proximity to surface spaces: one planning requirement for physical plant facilities may be separation from the academic area which is achieved in mined space.

physical isolation: the isolation of undesirable areas relating to operation and maintenance of the campus is accomplished in mined space.

structural: relatively large spans are available with substantial allowable floor loads.

special needs: large scale fuel storage may require riverfront access which could be provided without destroying the river as an amenity.

comment: if vehicular access can satisfactorily be worked out, this is a suitable means of housing these facilities within the campus and yet isolating them as well.

cut and cover space:

physical isolation: definitely isolation of undesirable characteristics of this use can be a benefit of underground location.

comment: cut and cover space does not differ considerably from surface space in other characteristics.

parking

mined space:

vehicular access: obviously a major requirement, access to mined space can be provided along river bluffs or by extending underground parking structures from the surface into the bedrock.

proximity to surface spaces: a unique proximity can be achieved by providing parking directly beneath built-up areas with vertical access into existing spaces.

physical isolation: isolation of cars and parking structures can be achieved.

special needs: the ventilation requirements for enclosed parking spaces would obviously be greater than for open structures, however isolation and scrubbing of the pollutants may be desirable.

comment: this appears to be an appropriate use if the development is large enough to justify the cost of vertical circulation and ventilation.

cut and cover space:

proximity to surface spaces: below surface parking with open space or buildings above provides almost an ideal relationship of parking to buildings.

physical isolation: the isolation of the automobile from the surface is an advantage.

comment: sub-surface parking has obvious environmental benefits if access can be handled conveniently and enough space can be provided to justify the construction.

mass transit

mined space:

pedestrian access: extensive access is required for mass transit for large numbers of pedestrians.

proximity to surface space: stations can occur at any location within very built-up areas, an advantage over surface or near surface systems.

physical isolation: the noise can be isolated underground.

structural: spans are adequate for stations.

comment: this is an appropriate use of mined space for regional scale transit where the great vertical circulation requirements can be justified.

cut and cover space:

pedestrian access: transit in cut and cover space is often ideally suited for access from a number of points and helps prevent pedestrian/vehicular conflicts.

physical isolation: the isolation of the noise of transit is an advantage.

comment: transit in cut and cover space, usually under existing streets, can be costly and disruptive to build but has great environmental benefits and proximity to existing circulation and spaces.

vehicular circulation

mined space:

vehicular access: since easy access is limited to river bluff areas, any circulation other than that required for parking or service functions is unlikely.

physical isolation: isolation of air and noise pollution could be a benefit.

structural: adequate for typical roadway spans.

special needs: ventilation requirements for long tunnels could be extensive.

comment: vehicular circulation at this deep level other than for service or parking would be nearly impossible to integrate with the surface road system for any large amount of traffic.

cut and cover space:

vehicular access: some ramping may be required to integrate with the existing road system.

physical isolation: the isolation of a major roadway from a pedestrian surface environment can have numerous benefits.

comment: location of roadways in cut and cover space in a particularly dense area, results in vehicular/pedestrian separation, and reduction in noise and air pollution.

service

mined space:

vehicular access: limited to river bluffs.

proximity to surface space: access to surface space to be serviced is not direct, unless substantial vertical circulation is provided.

physical isolation: there is an advantage to isolating service from the pedestrian environment.

comment: many points of access would be required so it is likely that service by itself would not be justified, however as part of extensive development of academic space, parking or storage, it could be a component part.

cut and cover space:

vehicular access: service below grade is more difficult to connect to existing streets than service on the surface but not a great disadvantage.

physical isolation: separating service from the pedestrian environment can have some benefits.

comment: service in cut and cover space is unlikely as a separate project but as a component of a large development, a possibility.

utilities

mined space:

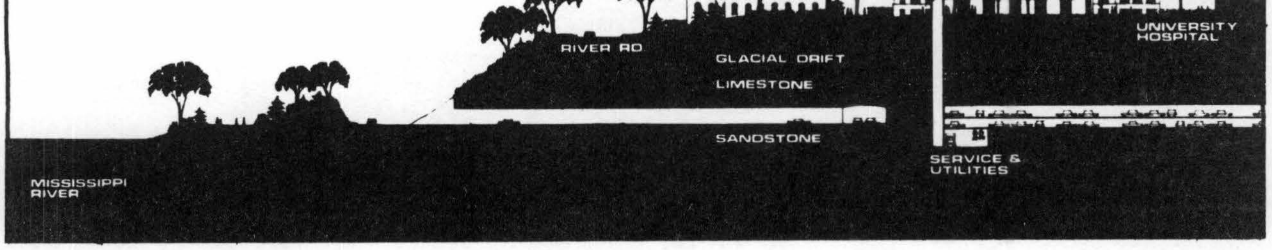
physical isolation: isolation of utilities from the surface environment is a benefit.

comment: many utilities are now located in mined space with obvious advantages to the surface environment.

cut and cover space:

physical isolation: isolation of utilities in near surface underground space has similar environmental benefits.

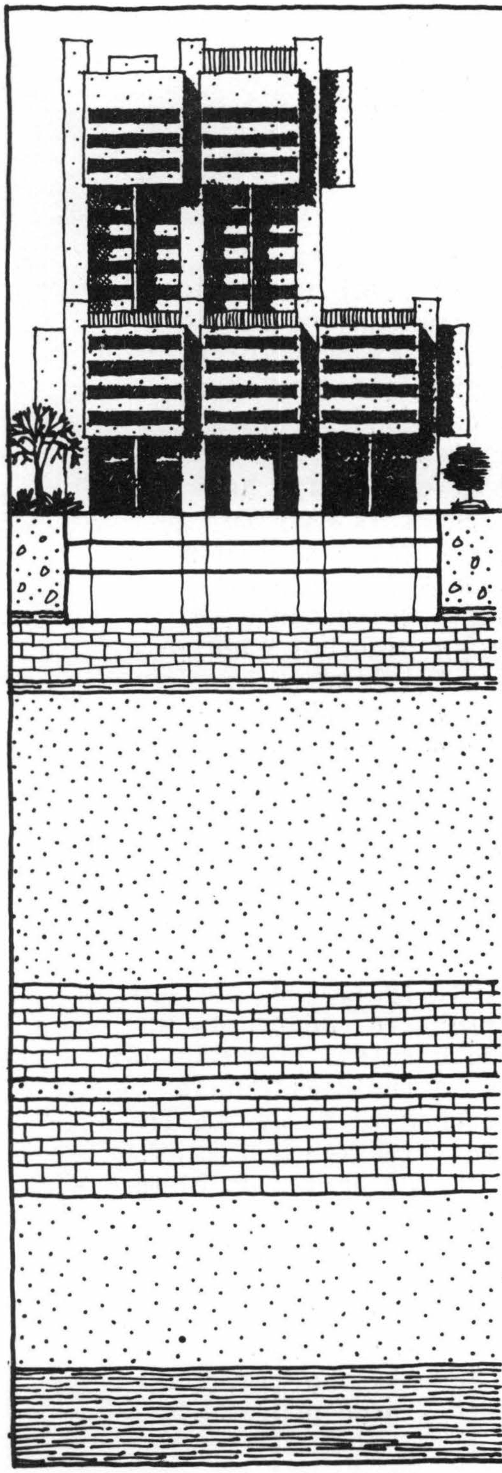
comment: numerous utilities are located in the soil on campus producing a surface environment nearly free of exposed utilities.



4 technical and economic factors

engineering geology

The basic geology of the area was introduced in Part 1 and is outlined in a simplified geologic section below. This section will concentrate on the engineering aspects and properties of the near-surface layers important for underground construction.



formation		description
GLACIAL DRIFT	0-500'	some or all of: clay, peat, sand gravel, boulders
DECORAH FORM.	0-90'	thin bedded shale
PLATTEVILLE FORM.	0-35'	dolomitic limestone
GLENWOOD FORM.	0-5'	shale, generally soft
ST. PETER SANDSTONE	150'	sandstone, white, fine to medium grained
PRAIRIE DU CHIEN FORMATION:		
SHAKOPEE MEMBER	50'	dolomite, shale partings
NEW RICHMOND MEM.	0-10'	sandstone & sandy dolomite often missing
ONNOTA MEMBER	50-120'	dolomite
JORDAN SANDSTONE	90'	sandstone, fine to coarse grained
ST. LAWRENCE FORM.	50'	dolomitic siltstone & fine grained dolomitic sandst.

simplified geologic section of mpls. - st. paul area

topsoil

Starting from ground level which is fairly constant over much of the campus area there is generally about 8" of topsoil. Since most of the campus has been disturbed at one time or another this topsoil has been usually been placed there. The present specification is for 4" of black dirt underlain by 4" clay. In undisturbed areas the topsoil is usually organic black sand perhaps of 1' - 4' thickness. Topsoil is important because if sufficient material and storage area is available it can be used for landscaping or sold to offset excavation costs. Its engineering properties are not generally important since building foundations extend at least below the frost line.

glacial drift

Beneath the topsoil the remainder of the glacial drift can consist of some or all of the following: alluvium, peat, clay, sand, gravel and boulders. The distribution of the various types of drift are shown on the surficial geology map contained in the data base for the planning study. Fortunately in the Minneapolis campus area there is mostly alluvial and dune sand deposits with only occasional clay lenses and scattered boulders. With extensive experience on construction of shallow basements and some deep basements the characteristics of the drift as they affect design and construction are fairly well known. The sand and gravel is easy to excavate, has a good bearing capacity for the normal size of buildings on campus and has more predictable support requirements for retaining walls than other soil materials. It is very permeable which causes high inflows to construction sites where the water table is high but over most of the campus the water table is only a little above the limestone. The boulders present few problems in large excavations but can cause delays when shafts, piles or boreholes are being sunk. Boulders are more likely to be encountered in the bottom layer of the glacial drift although they have been found just below the surface.

decorah shale

The next recognized layer is the Decorah Shale which can vary in thickness from 0' to 90' but is between 0' and 4' thick over most of the campus area. There are often a few limestone lenses present especially towards the bottom of the layer. Since this formation is seldom important in construction very few of its engineering properties are widely documented. Deep foundations in the past have excavated through this shale to the Platteville Limestone and shallow foundations would not have reached this layer. In both cases the properties of the glacial drift and/or limestone would have been of more concern. A potassium bentonite layer in the shale was blamed however for the failure of the Interstate Highway 94 cut at Prospect Park during construction in 1967. The subsequent investigation provided the useful tabulation of the properties of the drift, Decorah & Platteville shown on the following page. With this seam identified and its properties known future design for deep cut and cover space can safely allow for the presence of this layer. The presence of the shale can also be important in indicating that none of the underlying limestone has been eroded by glacial action.

platteville limestone

The Platteville formation is a flat lying sequence of limestone beds. They are a fairly constant 30' thick in the University area and can be seen exposed where they form the bluffs along the Mississippi River. Weathering and the loss of surrounding support increases the number of joints and decreases the quality of rock in such exposures so the condition of the limestone in the bluffs should not be taken as indicative of its quality in a confined situation. The limestone is jointed but mostly at widely spaced intervals when compared to the sizes of excavation considered (except of course adjacent to the river). Such joints are typically vertical and often form nearly perpendicular sets. Where the limestone has been exposed in natural caves or deep excavation these joints are seen to be narrow and irregular in profile and in this condition considerable interlocking occurs providing the necessary stability. Limestone is susceptible to solution action by water passing through these joints and gradually widening them but this seldom occurs in this area because the underlying Glenwood Shale is impervious and rarely penetrated by the limestone joints.

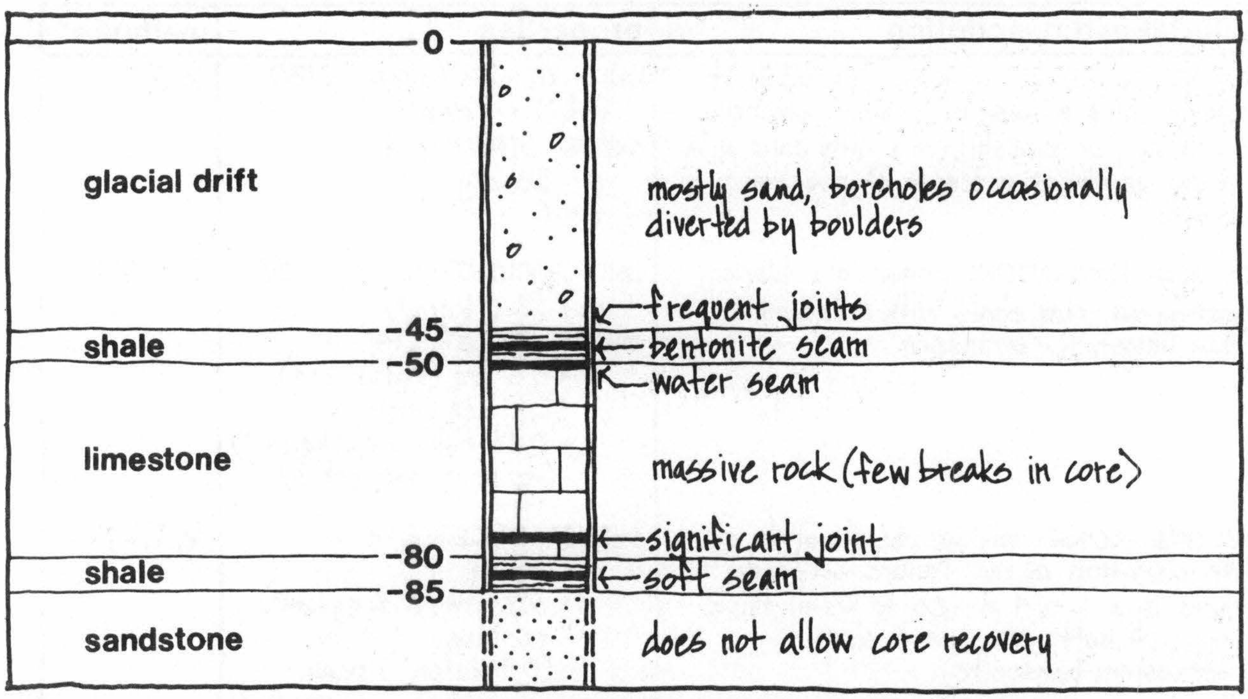
material and description	properties	methods
RECENT DEPOSITS: primarily glacial drift mantle (till & outwash materials); generally brown, tan, or reddish-brown silty sand with varying quantities or lenses of gravel and cobbles	UNIT WEIGHT (moist) = 130 pcf (2.0 kg/m^3) SHEAR STRENGTH ϕ = 35 deg c = 0	M, A
DECORAH FORMATION: primarily a blocky, gray-green, clay shale with occasional thin limestone stringers.	UNIT WEIGHT (moist) = 130 pcf (2.0 kg/m^3) SHEAR STRENGTH ϕ = 9.5 deg (saturated) = 21.5 deg (moist) c = 0.22 tsf (0.22 kg/cm^2) (moist or saturated)	R, F, P, U
FAILURE ZONE: within the decorah at the elevation of the failure surface there is a 1 to 4 in. (2.5 to 10 cm) thick layer of soft, gray-brown clay (potassium bentonite)	SHEAR STRENGTH ϕ = 6 deg c = 0.2 tsf (0.2 kg/cm^2) residual - 0.4 tsf (0.4 kg/cm^2) peak	U, T, L, P
PLATTEVILLE FORMATION: varies from a hard, gray to light gray limestone to a dolomite; the limestone has a relatively insignificant number of solution cavities	UNIT WEIGHT = 165 pcf (2.6 kg/m^3) UNCONFINED STRENGTH 9000 psi (600 kg/cm^2) min MODULUS E = 5,000,000 psi (2500 kg/cm^2) min	S
METABENTONITE LAYER: 0.25 ft. thick, located 2.3 ft. below top of Platteville	not tested during this investigation	

methods used:
- M = average of values
- R = triaxial compression tests
- U = unconfined compression tests
- T = torvane
- F = field torsion shear
- L = laboratory torsion shear
- A = assumed values
- S = Schmidt impact hammer
- P = pocket penetrometer

engineering properties from highway slope failure investigation

As mentioned above the Platteville formation consists of several beds and these have been classified geologically into five main members. Some of these members exhibit different structural characteristics e.g. jointing and the important features of a core log from a borehole sunk in connection with an underground test room on campus are shown below.

The upper few feet of the limestone are in fairly poor condition showing some weathering and frequent fractures. There is a metabentonite layer 2' - 3' below the top of the limestone and a fairly substantial horizontal water seam 6' - 10' down. These features might cause more concern to the engineering integrity of the Platteville if they were lower in the member. Beneath these features, however, the limestone appears very intact and almost unbroken lengths of core were obtained from the boreholes. Only in the last 1' - 2' do significant parting planes again appear closely spaced. From inspection of natural caves under the limestone, structural separation of these layers from the overlying massive beds does not occur, even without any support, until spans reach 50' - 60'. For construction of rooms to these dimensions these layers can either be supported or removed.



significant features of core log from borehole on minneapolis campus

The limestone in small scale intact test specimens exhibits a uniaxial compressive strength of around 15,000 psi which is about 3 x the strength of a normal grade of concrete. Irregularities, joints and bedding planes naturally weaken the rock mass to certain extent but in most places the Platteville constitutes a strong competent layer that can support itself over large openings. The natural caves mentioned above are concrete evidence of this and three examples which might be of interest are:

1. A cave near E 34th Street and W. River Road in Minneapolis which is about 60' wide, 900' long and 20' - 30' deep. This was discovered the late 1930's while driving a major storm sewer tunnel.

2. A cave underneath 4th Street between Marquette and 2nd Ave. South in downtown Minneapolis which is very irregular in shape and contains isolated sandstone pillars. The maximum span is approximately 60' and it was doscovered while driving the 4th Street tunnel in 1905. After discovery brick and concrete piers and retaining walls were built for extra safety to the buildings above. The limestone, however, was already carrying any additional building load since the block had been developed before the tunnel was driven.

3. A cave on the edge of University property on the West Bank of the Minneapolis campus again discovered while driving a sewer tunnel. This cave originally belonged to a brewery which used it for aging their products. The last inscription in the cave is dated 1911 and its span is approximately 20'.

glenwood shale

Immediately beneath the limestone there is a series of layers totalling 3' - 5' thick known as the Glenwood Shale. This formation grades from shaly dolomitic layers at the top to soft argillaceous and sandy shale towards the bottom. Just above mid-height in the formation there is a soft zone about 4" thick which in the natural caves has shown some evidence of sqeezing. Almost no quantitative information is at present available on the Glenwood Shale but it is not a strong formation and weakens further when exposed to air or water. It does not provide a safe roof for widths much more than 5' and would be removed for the roofs of underground rooms.

st. peter sandstone

The next layer is the 150' thick St. Peter Sandstone which obviously extends well below the limits of near surface construction. It is an unusually pure quartz sandstone and published analyses show from 98 to 99.8% silica in the upper 100'.

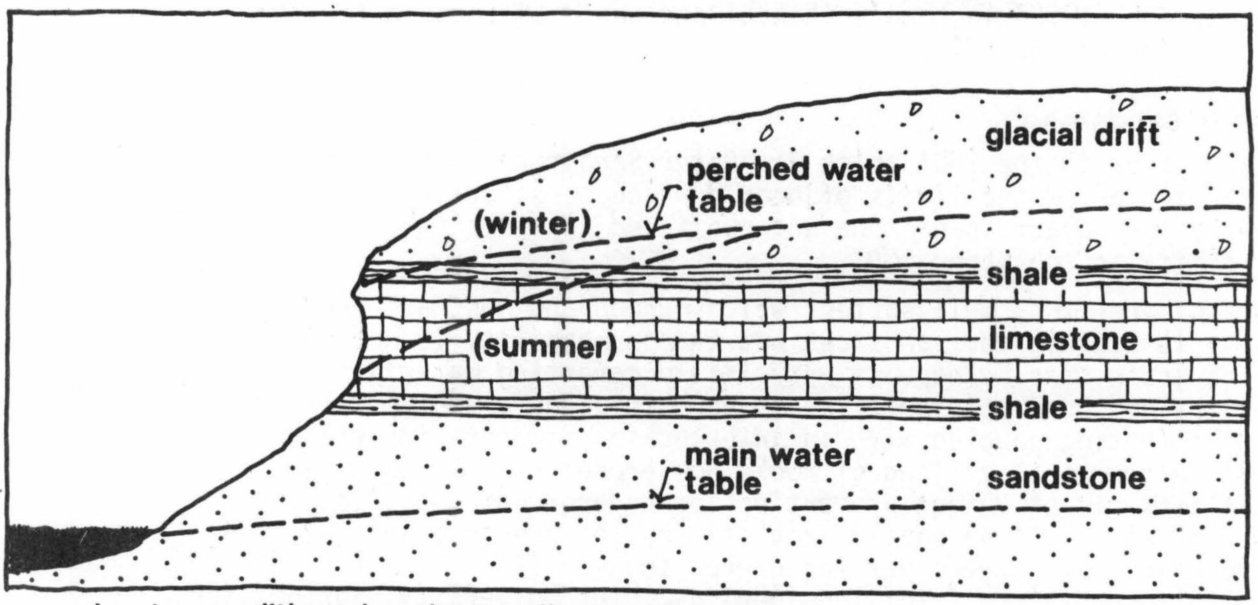
The grains are fine, well sorted, well rounded and most are frosted. Porosity is high in the sandstone but the permeability is not because of the fine grain size. There is very little cementing material between the grains and hence the material is very friable (crumbly). It is this lack of cementing coupled with an interlocking strength imparted by compaction from a heavy load of rocks now eroded away which gives this material its almost unique properties for underground construction. It is weak enough to be easily excavated by low pressure water jets or by hand held jack hammers yet for narrow tunnels (4' - 5') it is strong enough to support itself for long periods. The University, Northwestern Bell and Northern States Power Company together have many miles of unlined sandstone utility tunnels which have been in service for many years.

Joints in the St. Peter are usually quite widely spaced and do not constitute a serious hazard. They do occur and can cause some roof problems where two or more joints intersect at certain orientations. They are mostly vertical and occur in sets. Recent mapping of the joints in several miles of tunnels in downtown St. Paul has shown that they are usually of no great concern except where joints are parallel or nearly so to the wall of an excavation. Extra precautions would be necessary in such a case.

ground water

The layers following the St. Peter sandstone are the Prarie du Chien Group and the Jordan Sandstone. These layers are important because they are the most widely used source of ground water in the area. Beneath these is the St. Lawrence Formation which is an aquitard (sealing layer) and should represent a boundary on the zone of influence of any underground construction in the University area.

Because of its effect on design and construction and its importance to the area's water supply, the ground water regime of the area must be looked at in more detail. There are two near-surface water tables shown diagrammatically below. The Glenwood Shale acts as the sealing layer for the upper water table preventing water from flowing out of joints in the limestone into the sandstone. Although there may be some exceptions to this seal the upper 20' - 30' of the sandstone is mostly dry in the Minneapolis campus area. This is mainly due to drainage into the Mississippi River. The water in the St. Peter sandstone is not used for drinking water supplies because of contamination by leakage from near surface facilities. It is however used for industrial purposes such as air conditioning. Drinking water is drawn from deeper wells in the Prarie du Chien and Jordan formations. These extractions cause a drawdown in the main water table even away from the river. The water tables do vary with the seasons - rising in the winter when exits to the river are plugged with ice and no water is being used for air conditioning. This suggests that construction below or close to the water table is best carried out during summer months.



ground water conditions in minneapolis campus area

The above is an overview of the geologic setting for underground construction in the Minneapolis campus area. Engineering data is also available but rarely as easily obtainable. Existing information should be complied and consolidated to assist the detailed planning and design of underground space.

engineering design and construction

The following section is not intended to be a design guide for the construction of underground space, but rather an outline of the factors most affecting such design and hence influencing the planning process.

The normal breakdown between design and construction method is not as appropriate for below ground work as for most other civil engineering since the two are very much interdependent. It is rarely possible, however, to achieve the ideal integration because of the necessary contract processes. A designer cannot know before a contract is let which contractor will get a job, what equipment will be used on that job and whether the contractor's special set up or experience could change the economic design. For example, in basement construction for a building, should a contractor elect to use tie backs (shown later) which are left in place instead of bracing for his temporary retaining walls during construction; these could be incorporated into the final design and savings in cost made.

Most important for the designers particularly the engineers is a knowledge of the possible construction techniques and how these interact with each portion of his design. Certain decisions must be made early to allow the remainder of the design process to continue but where possible the designer should keep his design flexible either including alternate designs for bidding or being prepared to change some details of his design to take full advantage of a particular construction method. Such changes are planned alterations in design to save money on the project. The other type of late design change, however, is usually forced by unexpected ground conditions and will almost always cause additional expense even when the conditions could have made construction cheaper if known about in advance. Change orders in contracts are usually hotly contested and if sweeping disclaimers are used in the original contract not only can these be struck down in court but the contractor will have added a mark up on his price for the increased risk. This leads to the importance of adequate site investigation. The University is very fortunate in having construction records of basements, shafts, tunnels etc. all over the campus area and hence its knowledge of conditions generally to be expected is very good. Investigations for important projects should check for any local variations however.

factors affecting underground construction

The following section will identify and discuss some of the major factors affecting design and construction for the two basic types of space discussed in earlier sections of the report.

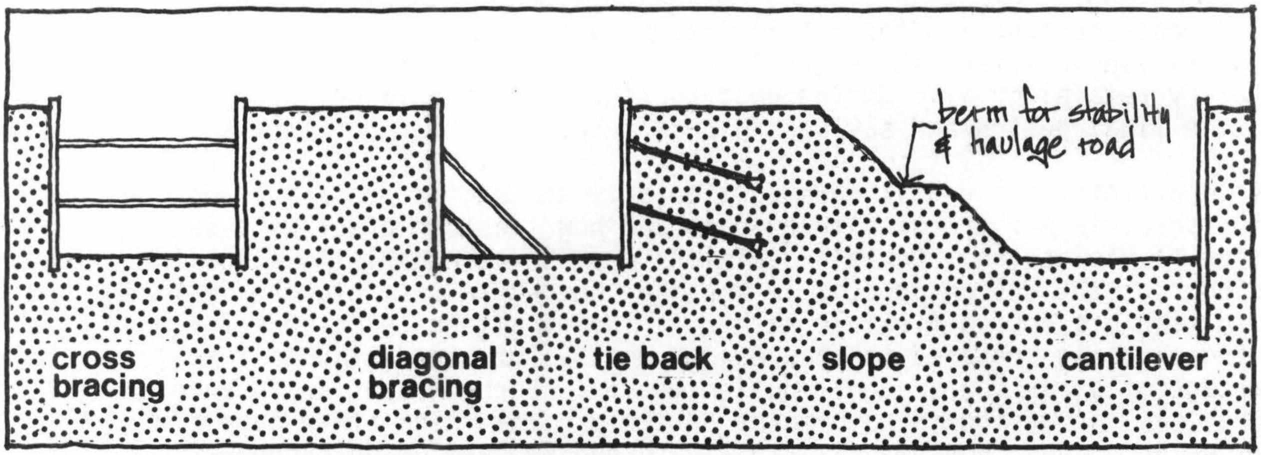
cut and cover space

▪ size of proposed excavation

This includes the horizontal dimensions of the excavation as well as its depth. It may seem too obvious an inclusion, but construction methods particularly are sensitive to both the width and the depth of any excavation. Items of construction equipment such as back hoes have a limited range of operation. A few extra feet in depth or width near the limit of such a class of equipments' range may necessitate a disproportinately costly change to a more expensive method of construction. Or for wide excavations the reverse may be true, a few extra feet in width may allow the provision of truck ramps into the excavation reducing multiple handling of materials.

The designer should know approximately at what limits of excavation size he is forcing or allowing the use of different construction equipment. As a general trend the cost per cubic yard of excavation will tend to decrease with increased width and volume of excavation.

The size of an excavation also obviously affects the temporary and permanent support designs. Although the depth controls much of the design of retaining walls the width determines the lateral span of such walls and their method of bracing. Narrow excavations can be braced directly across from side to side. Wider excavations must be braced diagonally to the floor of the excavation or supported by one of the other methods shown below.



methods of support for sides of excavation

For buildings,their lateral extent will rarely be enough to have a lateral change in geologic section or water table. Hence, for buildings it is mostly the depth of the excavation which determines which materials must be excavated and whether water problems will occur. For linear excavations such as transit or utility tunnels this is certainly not true and changes in geology along a route must be established at an early stage in design.

▪ height of proposed building

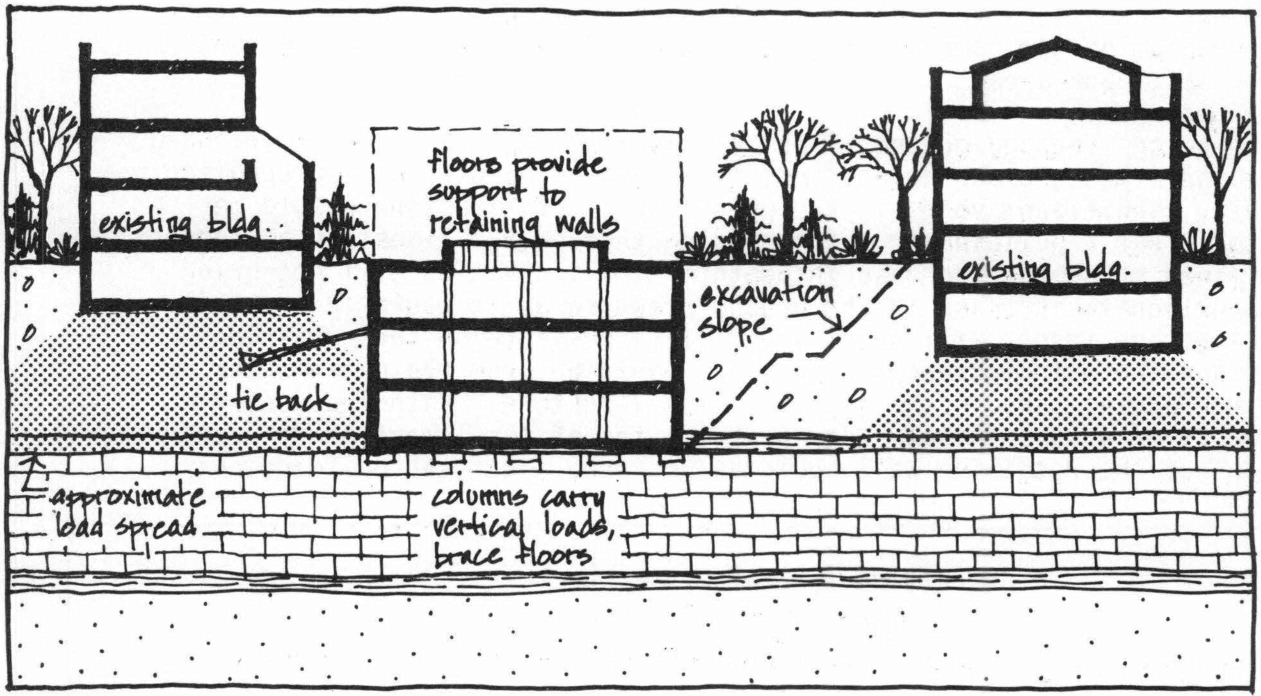
The final height of a building above ground usually determines the magnitude of foundation loads expected. For tall buildings these become too great to rely on the bearing capacity of the glacial drift and foundations must be taken to bedrock either by piling or by excavation. By excavating to bedrock (limestone) for the entire building size or larger, the effective foundation load of the building on the bedrock is reduced because of the weight of glacial drift removed. Hence, less substantial foundations are required. This is not to say that deep basements should only be used for tall buildings, but that their use becomes even more beneficial as the building height increases.

▪ proximity of existing buildings

This concern mainly affects the construction period for the proposed building. If the adjacent buildings are one to two depths away then the edges of the excavation can be sloped or retained without any special precautions. When an adjacent building is very close, however, construction must be carefully planned to avoid disturbing its foundations.

Where the adjacent building's foundation extends below the proposed excavation and especially if it extends to bedrock no major problems should arise. The loads from that building are being carried on an undisturbed strata. The main concern of the contractor should then be to reduce vibrations from pile driving etc. as much as possible, to excavate carefully adjacent to existing walls, to be sure that any lowering of the water table does not cause a settlement of the adjacent building and to prevent a heave in the floor of his excavation which would reduce lateral support at the adjacent building's foundation level.

Where the adjacent building's foundation is above the proposed excavation level the load from that building must either be considered as a surcharge of vertical load for the retaining wall design or else the loads must be carried below the proposed excavation by underpinning. A rule of thumb for the zone of increased loads from a foundation is 45° from the edge of the foundation and the decision to reinforce the retaining wall or underpin would be based on the magnitude of the foundation loads and the extent of the zone of influence on the retaining wall. Such extra support can be very costly and such conditions should be avoided where possible.



cut and cover space in soil

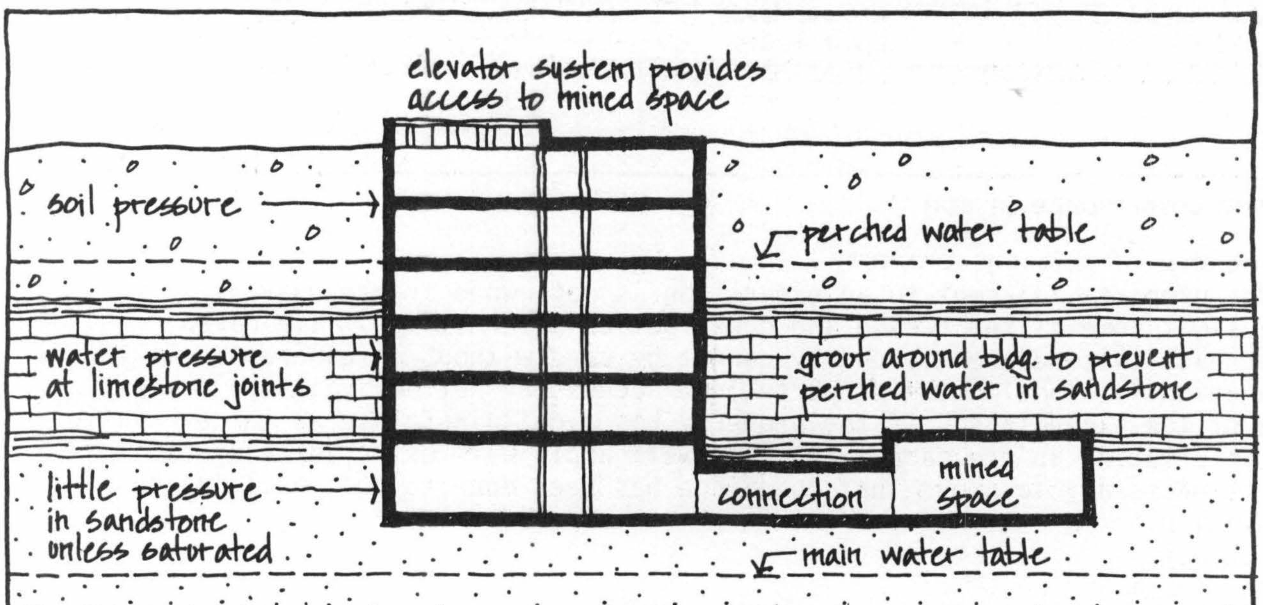
▪ ownership of adjacent property

If the property adjacent to an excavation is not owned by the University this will limit some of the design and construction alternatives. Tie backs underneath that adjacent property cannot be used without an easement. If the excavation is close to the property line access may not be available to that side of the excavation. If the property has a building close to the excavation the information in the paragraph above will apply with extra force since it may be necessary to prove that no damage has been done to that building by excavation.

▪ **soil properties**
The properties of the soil (glacial drift) for cut and cover space obviously affect both design and construction. The individual properties required for retaining wall design, fill compaction, bearing capacity, etc. will not be discussed here, although, some of these properties were listed earlier. It is sufficient for preliminary planning to know what types of soil are present, approximate thicknesses and depths. The quantitative work is then done on the site selected to check the assumptions based on soil classification,

In general the sand and gravel which cover most of the Minneapolis campus is easily excavated, has a good bearing capacity and will form a stable slope beneath its critical angle of repose. Clay generally has a much lower bearing capacity and is subject to swelling and squeezing when wet and shrinkage when dry. The strength of a clay usually increases as its moisture content decreases and depends very much on what geologic loads have compressed it in the past. In the campus area clay generally occurs in thin lenses and does not cause many problems. Peat is a fibrous, organic material which has a very low strength and will allow large settlements under load. If its thickness is not too great it is usually removed to allow foundations to rest on a more stable material. Peat should not be a problem on the campus, although a zone of peat exists to the north of the east bank area.

▪ **rock properties**
For buildings founded on the limestone few problems should be experienced since the limestone can accept very high bearing loads. As a precaution however, significant voids in the upper layers of limestone should be grouted. For a building or shaft passing through the limestone to connect with mined space the increase in depth of the excavation will not bring a proportionate increase in the ground pressure as it would in the soil. The limestone itself will exert very little pressure on the retaining walls and the main increase in pressure would be from the extra water pressure acting through the joints of the limestone. With the use of tie backs or a substantial floor near the top of the limestone the upper portion of the retaining wall could be designed as if the building only



cut and cover space connecting to mined space

extended to the limestone. For this type of structure the building loads would be carried in friction on the limestone walls and in bearing on the St. Peter sandstone. It is probable that for this case the sandstone will have lower loads from the building than from the original weight of soil and rock.

▪ ground water level
The ground water level is very important for both design and construction. Costs of construction below the water table are significantly higher than for dry ground and the permanent design must resist the additional water pressure on the sides and floor of the building. On the Minneapolis campus the water table is mostly well below the surface and hence few water problems occur in basement construction on campus. Even the Health Science Unit A which extends to the limestone had no problems in handling the seepage into the excavation. For a permanent barrier against moisture penetration into the building a waterproof and vapor proof membrane would normally be used on the exterior of the building. When well above the water table this membrane could be omitted providing a thick dense concrete is used for the walls. To lower the water pressure on the exterior of the building permanent underfloor drains have been used. These lower the water table in the vicinity of the building draining it through a shaft in the limestone to sewer tunnels in the sandstone. Careful analysis of the effect of widespread use of this technique on the campus water regime should be made before using it on a large number of projects because of the possible effects a change in the area hydrology might have - for example, settlement by consolidation.

▪ layout of final space
Although this is somewhat of a design detail the layout of the floors and columns underground can affect the support available for the exterior walls of the building which withstand the ground pressure. Large distances between floors, columns or cross walls increase the effective length of unbraced sections. Such decisions must of course be considered with the design and cost of the whole building.

mined space

▪ depth of proposed space
Since mined space is defined as space excavated underground with only indirect access to the surface it can occur at any level beneath the top few feet of soil. Considering the Minneapolis campus geology, however, it is unlikely that mined space would be excavated solely in either the glacial drift, or the Platteville limestone. Space in the glacial drift requires relatively heavy support compared to space under the limestone and such space if used could normally be cut from the surface at lower cost. It is also very unlikely that mined space in the drift would pass under existing buildings. At the other extreme, space in the limestone although, requiring little support requires blasting for excavation. This would be expensive in the confines of mined space as opposed to the situation of an open cut excavation.

Space in the St. Peter sandstone, however, has many advantages which have been discussed throughout this report. The sandstone is easily excavated, it is relatively self supporting for walls of an excavation and the limestone provides a strong roof. The upper 20' - 30' of the sandstone are dry in the campus area and it is expected that most mined space in the campus area would be at this level. Such mined space could have relatively large clear spans (50' - 60') and could be located in most sections of the campus with greater freedom than cut and cover or surface structures.

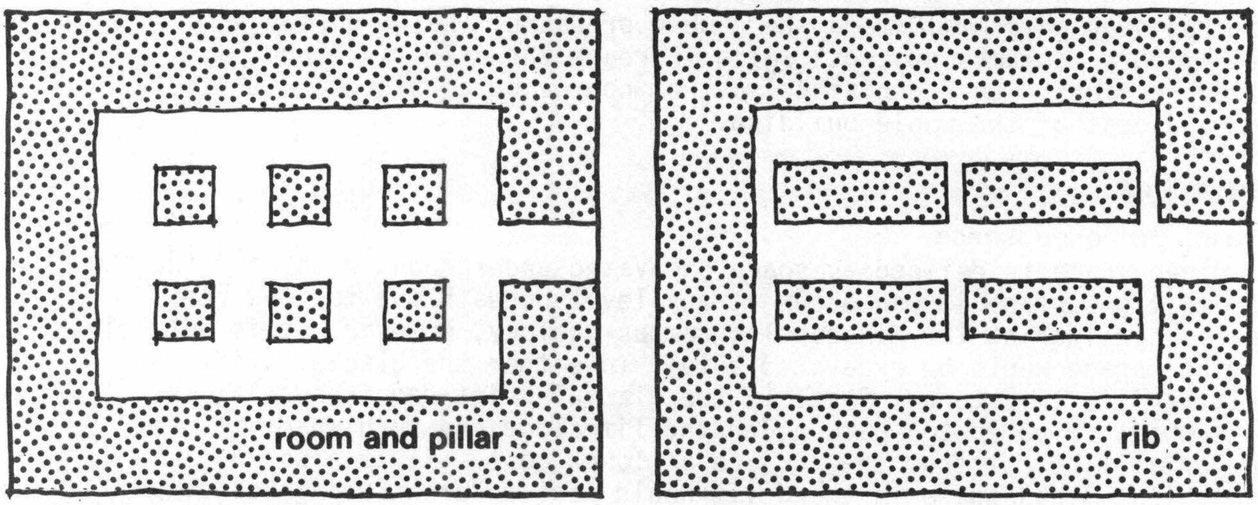
▪ ground water

This has been discussed in the engineering geology section and also in relation to cut and cover space. The problem is quite different from that for cut and cover space, however, since the sandstone is naturally dry at this level. Two sources of water must be considered. Firstly, the water perched above the Glenwood Shale will tend to leak through any joints in the limestone when this shale is removed for an underground room. Since the limestone joints are generally tight the volume of water involved is small and has been handled in similar situations by installing a false ceiling which drains the water to a collection point. If flows are larger than expected pressure grouting of the limestone to plug the joints can be used. The second source of water is a recharge of the main ground water table to the level of the underground room. This can be handled as for the soil installing a waterproof membrane and designing the walls of the room to resist the water pressure.

▪ size and shape of mined space

The layout of space under the limestone is limited by the maximum permissible spans of the limestone and the minimum size of sandstone pillars or ribs between such spans. Based on present technology it is expected that the maximum spans considered will be approximately 50' - 60' and intervening pillar sizes much the same. The space could be laid out on what is known as the room and pillar system or the rib system.

Multi level space under the limestone is also certainly possible although its economics will need to be studied in more detail.



systems of mined space

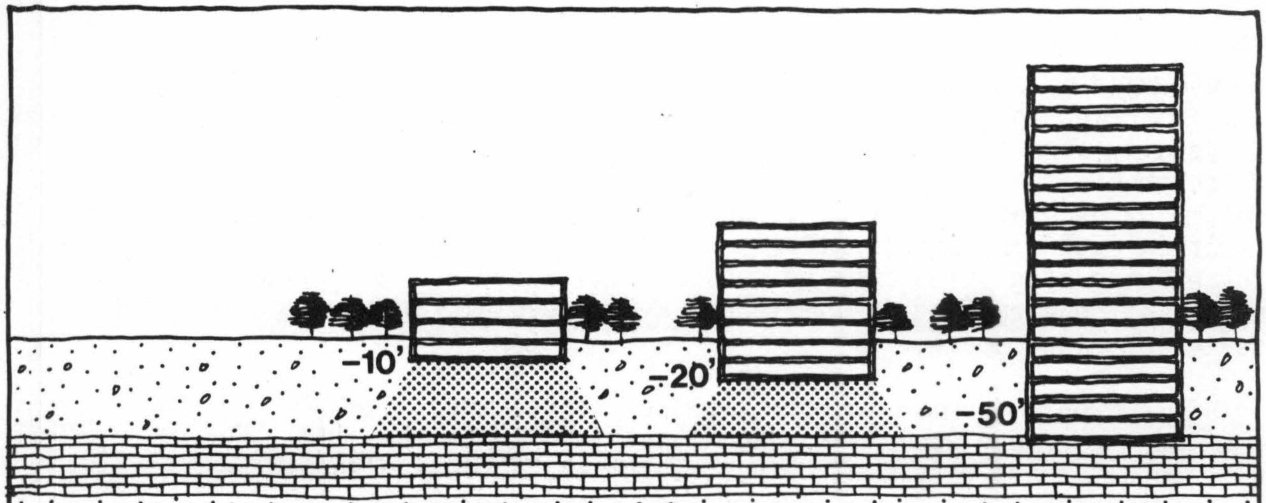
▪ use of mined space

The final use of the mined space will determine the aesthetic treatment necessary for the space. As discussed in the section on social and psychological factors imaginative design can eliminate much of the gloomy association for underground space. Space used for utilities and storage would naturally be given less treatment. The future use of the space would also influence the safety level of the design. For example, for warehousing use the roof could be bolted as normal but the false ceiling omitted providing water was not a problem. The main structure would be just as strong as for a public area but the extra safety from small pieces of rock falling (unlikely for such a limestone roof) would not be present.

▪ surface buildings above mined space

The fact that buildings exist on the surface need not be a deterrent to the utilization of the mined (sandstone) space beneath. The decision obviously depends on the size and layout of the building(s) concerned. Simple calculations for 3 types of building are shown below to illustrate the difference in load on the limestone from that which exists in an area with no buildings.

These calculations are only approximate, but it is clear that for the three buildings shown any increase in load on the limestone is not significant. The only layouts that would greatly increase the load on the limestone would be a much taller building than the 19 story building shown or an equivalent size building with a smaller basement.



	a-4 floors	b-8 floors	c-19 floors
building load	5×250×22,500 lb.	9×250×22,500 lb.	20×250×22,500 lb.
wt. of soil removed	10×100×22,500 lb.	20×100×22,500 lb.	50×100×22,500 lb.
extra load	250×22,500 lb.	250×22,500 lb.	no extra load
area over which load is spread at bedrock	36,100 ft²	32,400 ft²	22,500 ft²
extra pressure at bedrock	$250 \times \frac{22500}{36100} = 156$ lb/ft²	$250 \times \frac{22500}{32400} = 174$ lb/ft²	none
approx. pressure on bedrock in unbuilt area	50×100=5000 lb/ft²	5000 lb/ft²	5000 lb/ft²
increase in pressure on bedrock	3 %	3½ %	none

1- 150 lb/ft² allowed for dead load of bldg., 100 lb/ft² for live load (including roof)
2- no reduction in live load made for size of loaded area
3- bldgs. assumed 150' square, i.e. area = 22500 ft²
4- assume load spread through soil on 2:1 slope

simplified calculations for the effect of surface structures on mined space

factors common to both types of space

▪ utilities

The provision and any necessary diversion of utilities is an important factor in planning underground space. For cut and cover buildings which stay within the limits of previously recognized "sites" the problem of utility diversion will not be difficult. For cut and cover buildings extending across streets or for cut and cover tunnels utility diversion can be a major problem and cost factor. For mined space the existing utilities leave large areas of undisturbed ground. Future utility tunnels should be planned not to cross possible future sites for mined space.

The provision of utilities even for deep space in the campus area is not a difficult problem since most of the campus is served by the utility tunnels in the sandstone.

▪ surface disruption and access for haulage

This is important for its effect during construction on neighboring buildings and University streets. Again for cut and cover buildings on recognized sites the problems are much the same as for any building site except for the volume of excavated material to be hauled away. For cut and cover construction extending across streets the problems of traffic diversion and the ensuing congestion must be considered. For mined space the surface disruption of construction is limited to a few specific areas which form the access to the mined space.

Haulage is a problem common to both types of space except that for cut and cover space the removal point is automatically fixed by the site. For mined space alternative removal points may be available and should be chosen to give the least surface disruption consistent with economic removal. For example, the bluff area could serve as such a removal point and the material hauled away in trucks or barges.

▪ disposal of excavated material

The site or sites chosen for disposal of the excavated material will affect the haulage routes from the site where the material is loaded. The length of the haulage route and the time taken to traverse it greatly affect the costs of excavation. If the contractor is left to find a disposal site between the letting and bidding of contracts, little advance planning can be done to minimize haulage disruption and estimates of excavation cost may not be accurate.

design methods

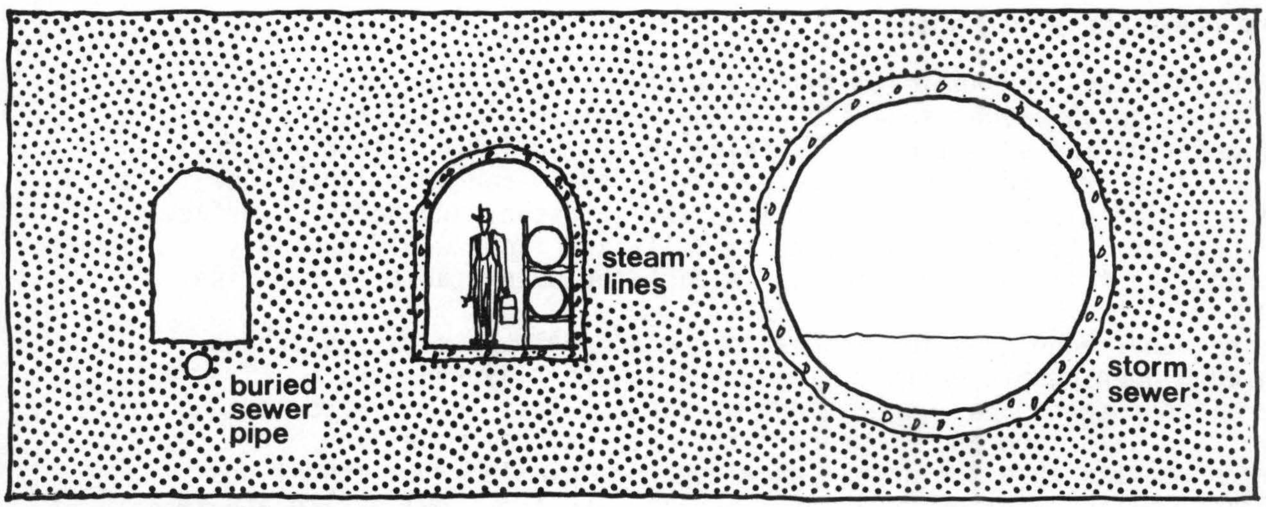
cut and cover space

The design methods for cut and cover space are relatively well developed and well known so they will not be covered in detail here. The main differences from regular surface construction are that the exterior walls of the building must be designed to resist the earth pressure and must protect against moisture penetration from the ground. The ground must also be temporarily supported during construction of the final building. Illustrations of various support techniques both temporary and permanent and discussions of other factors affecting design were covered in the above section.

mined space

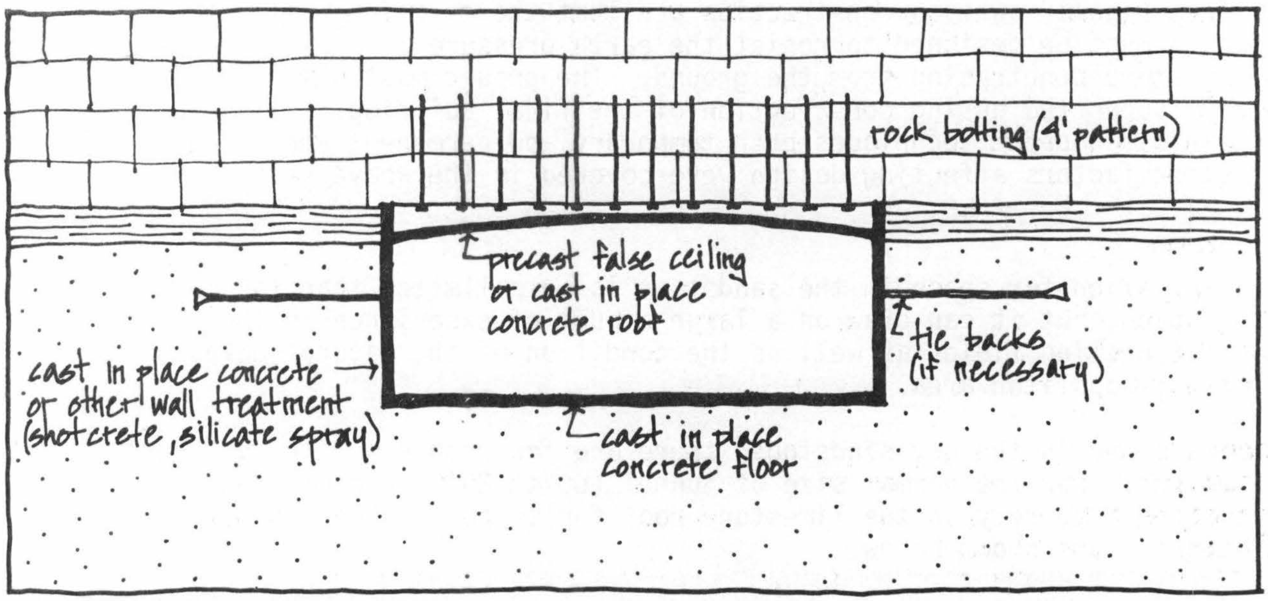
Design information for space in the sandstone is more limited than for cut and cover space, but it can draw on a large amount of experience in the mining and tunneling fields as well as the condition of the natural caves around the metropolitan area.

For tunnels mined in the dry sandstone, there are few problems with construction or support. For the normal size of tunnel (up to 20' diameter) there would be no need to rely on the limestone roof for support. Sections of typical tunnels are shown below.



typical sandstone utility tunnels

For rooms of spans up to 50' - 60' the limestone can be used as a roof. It spans the opening by an arching action of the blocks which comprise the roof. The conditions required for such action to develop are that it is ensured that the limestone blocks act as units (i.e., small blocks do not fret away causing a gradual deterioration) and that the joints have sufficient interlock to prevent excessive sliding. Both conditions can generally be met in the campus area with little difficulty. The limestone layers can be bolted with steel reinforcing bars anchored into the limestone for their full 8' - 12' length as shown on the following page. This anchoring can be done using Portland cement or polyester resin grouts. Such a bolting pattern not only prevents blocks from working loose but prevents sliding along bedding planes and ties the rock mass together. From the condition of natural caves it is evident that for the spans considered the roof would in the great majority of cases stand without any support, but that at 50' spans the bottom 2 or 3 1' thick layers of the limestone may detach from the main rock mass and eventually fall. The use of rock bolts would prevent this and eliminate the need for removing these layers. Should additional headroom be required, however, these layers could be removed with possible increases in the stability of the roof and walls.

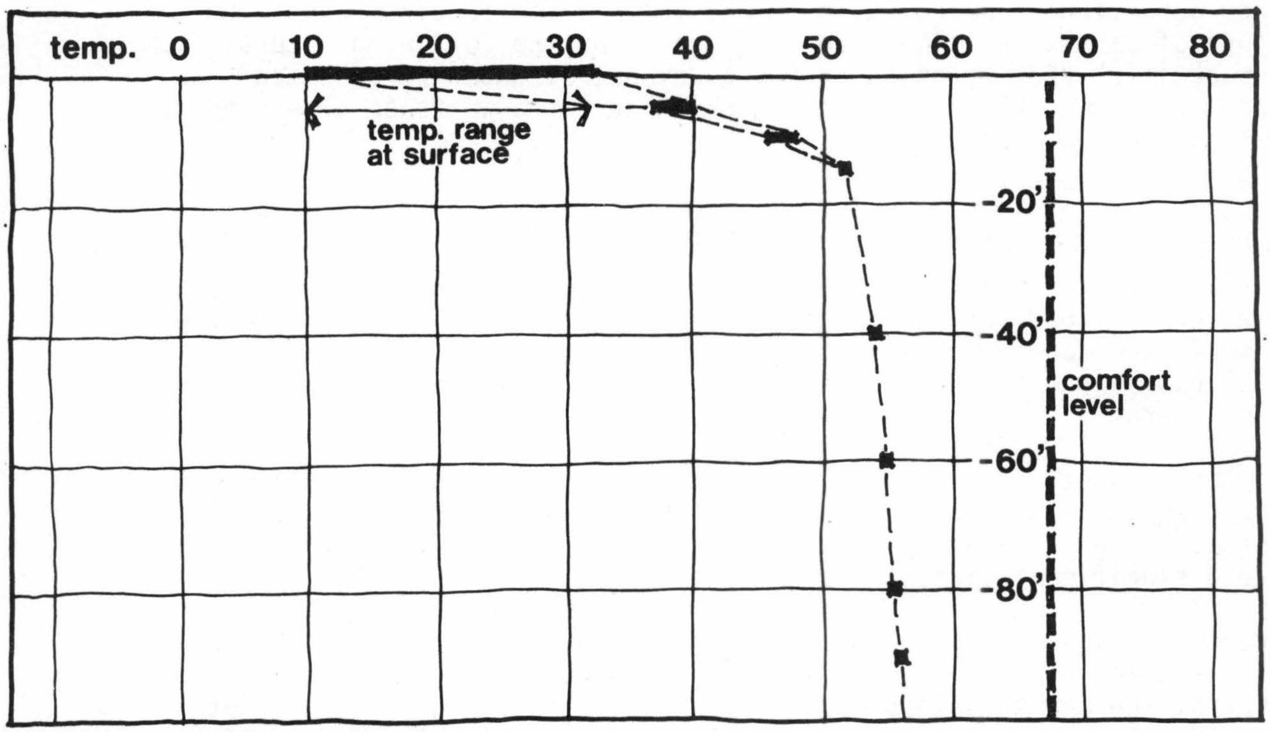


possible design for mined space

The natural caves also indicate that wall stability in good sandstone is not a problem although slight squeezing of the mud layer in the shale and some slabbing off of the sandstone walls is evident. During construction the walls could be treated with shotcrete (a sprayed-on concrete lining) or a sodium silicate spray which soaks into the sandstone and bonds a surface layer together. For final use concrete walls and floor would probably be poured with full water protection in case the water table should rise.

There are many techniques for assessing the approximate stresses around underground openings in uniform strata but few for layered strata. The finite element method has gone a long way in the last 10-15 years to improve this situation and at present the mathematical model can be made more complex than the actual knowledge of detailed rock conditions warrants. To find a happy medium for preliminary and final design and to check the validity of new and existing design methods against a full-size monitored excavation is part of the goal of a research project being conducted at present on campus. The title of the project is "Design Characteristics of Near Surface Rock Formations for Underground Construction of Urban Facilities." Funding is from the National Science Foundation/RANN (Research applied to national needs) program and the project includes the excavation of a 50' x 100' x 12' high underground room in the sandstone beneath the sports practice field opposite the Experimental Engineering building. This will act as the monitored excavation and also as a showpiece for this type of underground space. Other aspects of the research project include development of the sodium silicate spray mentioned above and collecting more engineering data on the local rock formations.

The dwindling supplies of fossil fuels and the increasing cost of energy make the energy saving possibilities of underground construction very timely. Savings which can be pointed to now will almost certainly become larger in the future. These possible savings result from the isolation of the underground from the severe climatic variations of Minnesota weather. The diagram below shows an actual log of the temperature gradient into the ground in winter. These temperature sensors are installed at the site of the underground test room and will be monitored over several years during which time the underground room will be excavated. This will indicate the depth of large temperature fluctuations with season and the extent of modification of the normal temperature by an underground room. At just 14' underground the measured temperature was approximately 50°F in the middle of January, 1975. At 40' the temperature has reached its constant year round value of 55°F. For storage areas underground (requiring little ventilation) for example, the additional heat generated by lighting would mean little or no required heating plant capacity. The mass of the surrounding ground also acts as a large reservoir of heat and in such situations heating during peak load times would be reduced since the temperature would be slow to fluctuate. Examples of the savings possible for particular facilities underground In Kansas City were shown in Part I.



temperature variation with depth in jan. 1975

In summer, underground construction not only eliminates direct heat gain from the sun's radiation, but there is some flow of heat into the surrounding ground assisting in cooling the warm air brought in for ventilation.

Humidity is important in maintaining comfortable conditions with a minimum of heating or cooling and humidity control is made easier underground by the good control over ventilation air. The large amounts of ventilation required for particular uses undoubtedly reduce the potential percentage of energy savings for underground space. The savings in thermal transmission will be made, but the required heating or cooling of the ventilation air will not be altered. One improvement that can be made above or below ground is to bring the stale exhaust air adjacent to the incoming fresh air at some point and insert a heat exchanger (commercially available) between the two air streams. This would reduce the energy load for ventilation by recovering much of the climate of the outgoing air. This has not been used much in existing buildings because the exhaust air has rarely been brought back to the vicinity of the intake air. For underground construction however, the limited access makes it far more likely that this would be the case. Since air leakage is minimal excellent control can also be maintained over the desired ventilation rates reducing waste from excessive ventilation. Most requirements for ventilation apply to the small percentage of time when the space is being fully used and large savings could be made by reducing ventilation for the remaining time. Another possibility is that because the exhaust air would be collected to a few specific points scrubbing the air of odors, smoke, dust and fumes and re-circulating it may prove to be economic. This would reduce the quantity of outside air needed as ventilation requirements are mainly based on the removal of such pollutants.

Ventilation requirements should not, however, overshadow the fact that significant energy savings will be made by underground construction even with high ventilation rates. In fact the energy savings will be approximately the same for a particular space whatever the ventilation requirements. The magnitude of savings possible are illustrated by the following excerpt from a paper entitled "Conservation of Energy by Use of Underground Space" presented by Thomas Bligh and Richard Hamburger at a workshop organized by the National Academy of Sciences.

excerpt from paper on energy conservation:

Neanderthal man lived in caves, not because he was too stupid or too lazy to build a shelter, but for far subtler reasons that only now, as man reaches out beyond the moon, are beginning to dawn on us. A subsurface home is defended easily and can be kept at a pleasant temperature with little expenditure of energy.

Substantial amounts of energy could be saved by greater use of subsurface space for commerce and habitation. Technical changes, however, must be economically and socially sound and must be implemented widely if they are to have a significant impact on energy comsumption.

At a recent energy conservation conference, K. J. Saulter stated, "In particular, potential technical developments which reduce the use of fuels in residential and commercial space heating and cooling, and the transportation section are regarded as those with the largest potential payoffs." Of the total United States energy consumption for 1972, 20.4 percent was used for residential and commercial heating and cooling, and 25.1 percent on all transportation. It is interesting to note that at the conference not one mention was made of the potential use of underground space to conserve energy.

What can be done? Where does the energy go? Energy is wasted by unwanted heating or cooling of the surroundings. By reducing heat transferred to and from surroundings, less energy is consumed to maintain the desired conditions. Architects and engineers alike often affirm that it is more economical and as effective to use better insulation than to build underground. The following example will demonstrate that underground structures are far superior from an energy-conservation standpoint.

The equation for heat flow rate is:

$$q = UA(t_1 - t_2) \quad \text{or}$$

$$Q = q/A = U(t_1 - t_2)$$

q = heat flow rate, Btu/hr
Q = heat flow rate per unit area, Btu/hr/ft^2
U = thermal transmission coefficient, Btu/hr/ft^2/°F
A = area through which heat is transferred, ft^2
t_1 = inside temperature, °F
t_2 = outside temperature, °F
(note that when t_2 is greater than t_1, i.e. during summer, q is negative, thus heat flowing into a bldg. is considered negative)

In a given region the temperature difference is determined by weather extremes for above-ground structures. Underground, however, as noted, the temperature remains almost constant at the yearly mean temperature. For example, the temperature 10 feet underground in the Minneapolis area varies from 47 to 51°F, whereas the daily temperature varies from -30 to 95°F. Table 3 lists typical thermal-transmission coefficients (U values).

material	U value
roof, asphalt plus 1-in. timber	0.45-0.53
windows, double glazed, 70 percent glass	0.45-0.55
wall 1, no insulation	0.30-0.45
wall 2, 4-in. insulation	0.20
wall 3, 8-in. insulation	0.13
basement, in contact with soil, no insulation	0.10

table 3– typical thermal transmission coefficient U value

Table 4 gives Q, the heat flow rate per unit area, above and below ground in Minneapolis, for the mean, maximum, and minimum daily temperatures in winter and summer. This shows, for example, that on a cold winter day the heat flow rate per unit will be 5.5 times greater above ground for a wall with 8 inches of insulation (wall 3), and 8.4 times greater for a wall with 4 inches of insulation (wall 2), compared with an uninsulated wall underground, and Q can be 19 to 22 times greater through a roof than underground.

During summer a large amount of heat that must be removed flows into a building above ground, whereas heat flows out of an underground structure, lowering the cooling load. The ratio Q above/Q below is not given in summer because heat flow underground is out of a building, which is desirable since heat is produced by lights, cooking, machines, and people, whereas heat flow above ground is into a building, which is undesirable as it adds heat to the internal heat load. On a hot summer's day, for example, to maintain an above-ground building (of wall 2 construction) at the same temperature as a similar underground building, (4.0 + 2.5) Btu/h/ft^2 of wall area, plus (9.0 + 2.5) Btu/h/ft^2 of roof area would have to be removed by an air-conditioning plant, assuming the heat loss through the floor to be comparable to that in the underground building.

In no way can improved insulation on an above ground building begin to complete with sub-surface structures from the viewpoint of energy conservation.

	above ground[a]				below ground
	roof	wall 1	wall 2	wall 3	$t^2 = 50°F$
winter mean (Jan.)[bc] $t_1 = 75°F$		$t^2 = 10°F$ $(t_1 - t_2) = 65°F$			$(t_1 - t_2) = 25°F$
Q Btu/hr/ft²	29-35	19-29	13.0	8.5	2.5
ratio Q above/Q below	12-14	8-12	5.2	3.4	
winter minimum (Jan)[d] $t_1 = 75°F$		$t^2 = -30°F$ $(t_1 - t_2) = 105°F$			$(t_1 - t_2) = 25°F$
Q Btu/hr/ft²	47-56	32-47	21.0	13.7	2.5
ratio Q above/Q below	19-22	13-19	8.4	5.5	
summer mean (July)[e] $t_1 = 75°F$		$t^2 = 80°F$ $(t_1 - t_2) = -10°F$			$(t_1 - t_2) = 25°F$
Q Btu/hr/ft²	-4.5 to -5.3	-3.0 to -4.5	-2.0	-1.3	2.5
ratio[f]					
summer maximum (July)[e] $t_1 = 75°F$		$t^2 = 95°F$ $(t_1 - t_2) = -20°F$			$(t_1 - t_2) = 25°F$
Q Btu/hr/ft²	-9.0 to -11.6	-6.0 to -9.0	-4.0	-2.6	2.5
ratio[f]					

a - negative sign indicates heat gained

b - an inside temperature of $t_1 = 75°F$ and underground temperature of $t_2 = 50°$ were used throughout

c - in the winter or heating cycle, the mean temp. for the full 24 hr. period averaged over the month was used since buildings must be heated continuously; here $t_2 = 10°F$

d - a minimum winter temp. of $t_2 = -30°F$ and a maximum summer temp. of $t_2 = 95°F$ were used as an example of the maximum heat flow rate conditions. The heating and cooling plant size must be sufficient for these extremes.

e - during summer the mean temp. during the day was used since buildings need cooling only when the outside temp. exceeds 75° F; here $t_2 = 85°$

f - a ratio Q above/Q below is not listed for summer since above ground heat flows into a building, while underground heat flows out of it.

table 4 - heat flow rate per unit area, Q, for bldgs. above and below ground

economic factors

It has already been mentioned that the Twin Cities area has a very favorable geology for cheap underground space, but it is also fortunate in having a group of local contractors with extensive experience in working with this geology. Outside contractors with no experience in these formations have usually bid substantially higher than local contractors. No specific or detailed costs are included in this section but as mentioned in the Foreword this is one of the main areas in which the report will be expanded as this study continues.

ability to forecast costs

▪ cut and cover building and deep basement construction

These have the same type of costs. Many basements in the downtown areas of Minneapolis and St. Paul and also the basement of the Health Sciences Unit A have been excavated to the limestone. This gives a good data base for cost estimating and the local soil material will allow excavation costs on the low end of any range of cost data.

▪ cut and cover tunnels

The actual cost of forming the space could fall in the above category, except perhaps for the limitations imposed by the narrow width of the excavation. A major difference, however, involves the sequence of operation required over the whole tunnel length. Allied to this is the problem of maintaining traffic and pedestrian circulation through the construction area. A further difference is the increased likelihood of major utility diversions being required. If an area has many utilities this can form an appreciable percentage of the total cost. The local cost data base for cut and cover tunnels is not good, although several major projects containing cut and cover sections have recently been completed in other parts of the country e.g. BART in San Francisco and the Washington Metro. The proposed intercampus transit system is in cut and cover through the campus area and preliminary cost estimates should be available for this.

▪ mined tunnels or connections in the st. peter sandstone

Good data is available in the Twin Cities area for predicting the cost of such tunnels. The cities of Minneapolis and St. Paul, Northern States Power Company, Northwestern Bell and the University itself have many miles of such tunnels. In particular, the University recently completed a million dollar utility tunnel to serve the Health Science Complex. Tunneling costs from other parts of the country should not be used since recorded costs have shown this to be one of the cheapest places to tunnel in the U.S..

▪ mined space

This type of excavation has not been common up to the present time, but some mining of the sandstone has been carried out in the area notably the former mining under the Ford Plant which used the sandstone in the manufacture of glass. The costs should again be much cheaper than those which could be expected in most parts of the country. The advantages of a larger excavation will bring down unit costs considerably from a tunnel situation and the presence of the limestone not only provides a strong roof, but also eliminates the need for excavating an arch to the roof which could greatly increase the volume of excavation for a given amount of space.

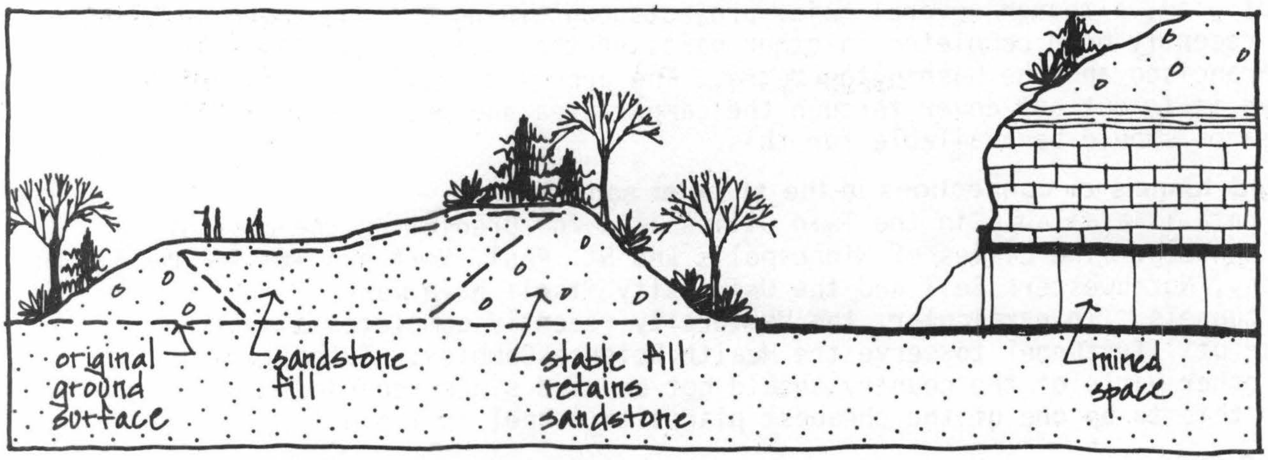
general features of total cost

■ land

The use of underground construction allows an increase in the space available for University purposes without reducing open spaces on campus and without the need for additional purchase of land.

The size and shape of excavation in mined or cut and cover space must again be mentioned. The larger the scale of operation the lower can be the unit costs because more material is removed compared to the cost of equipment and setup. For cut and cover space there is an additional saving in the retaining wall area per unit volume of excavated space as the excavation gets wider. This results in reduced support costs per unit volume.

Haulage and disposal of excavated material can be a major cost in excavation so the distance to a removal point for mined space, the availability of a disposal site and a possible use for the material are important factors. If widespread underground construction is planned, time should be taken in the design process to find the optimum disposal use. The drift material can be used for landscaping with little problem. The St. Peter sandstone cannot be used for landscaping with steep slopes on its own because it will tend to slide to a gentler slope, but it could be used if confined as shown below. The St. Peter is used for making foundry molds and has been used for making glass. If a suitable market for the material could be found construction costs could be substantially reduced. However, given the unsteady supply and probable mixing with shale this is not likely.



use of st. peter sandstone for landscaping

Use of some of the expensive materials for above ground buildings can be eliminated or reduced for underground construction. Savings can be made on architectural treatment of exterior surfaces, insulation and fireproofing costs. In fact, for the new bookstore the site work for the underground construction is estimated to be less than the typical cost to face exterior walls on a building of a similar type and size.

A final point for the Minneapolis campus is that since utility provision is from sandstone tunnels the lengths of vertical utility shafts will be reduced for deep basements and eliminated for mined space.

▪ **use**

The main savings in use are expected to come from the energy conservation discussed previously. In addition, quoted insurance costs for underground space in Kansas City are much lower than for above ground buildings due to the increased protection against extensive fires and the reduced likelihood of damage from natural or man-made catastrophies e.g. storms or explosions.

For cut and cover buildings a deep basement permits service and circulation from ground level to the mid-height of the building which reduces the maximum distances to be travelled in the building and allows the more efficient use of the elevator systems. Circulation times would also be reduced by the greater density of the campus that could be achieved with underground space. Estimates of the value of such lost time have been standard practice in transportation engineering cost-benefit analyses for several years.

▪ **maintenance**

The major savings under maintenance come from the isolation of the underground from the surface environment. Corrosive atmospheres, freeze/thaw problems, snow drifts and storm damage are not a problem underground. Exterior maintenance costs such as painting and cleaning are eliminated and the chance of vandalism is greatly reduced. If the underground is used for circulation either pedestrian or transit, the separation of pedestrian and vehicles is increased promoting extra safety and less interruptions for both. If the underground is used for parking, snow ploughing is not necessary and the extremes of cold temperatures are avoided.

summary

Opening up the underground is similar in many ways to developing any new area such as a shopping center or industrial site - the first few sites are expensive. Service must be brought into the area and facilities established. As the area is developed further, however, the unit costs drop because it costs less to extend service and circulation to these new facilities and in the case of the underground, experience in design and construction will increase. The proposed regional and campus transit systems if built would make underground sites even more attractive in their vicinity because of the large circulation that would occur at these levels.

It is important that the total cost of the underground be considered when making cost comparisons including the land, construction, use and maintenance costs. A step in this direction has already been made by the University in requiring architects to submit computations of the money saved by energy conservation measures for future buildings.

If all these factors are considered then the true dollar cost of underground space can be found which still leaves the intangible benefits of helping to conserve energy supplies for the future and maintaining open space in and around the urban area for the present.