FIELD TRIP
GUIDEBOOK

Geology and Utilization of Underground Space in Metropolitan Kansas City, Missouri

ASSOCIATION OF MISSOURI GEOLOGISTS

ANNUAL MEETING
September 23-24, 1994
GUIDEBOOK TO FIELD TRIP:

GEOLOGY AND UTILIZATION OF UNDERGROUND SPACE
IN METROPOLITAN KANSAS CITY, MISSOURI

ASSOCIATION
OF
MISSOURI GEOLOGISTS

41ST ANNUAL MEETING

SEPTEMBER 23-24 1994
INDEPENDENCE, MISSOURI

Richard J. Gentile
Department of Geosciences
University of Missouri-Kansas City
Kansas City, Missouri 64110-2499
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Mason Land Reclamation Company
Missouri Rock Company, Inc.
Park College
Parkville Stone Company
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INTRODUCTION

This field trip is designed to give participants an overview of (a) the exposed rock section that underlies Kansas City and its environs, and (b) the commercial uses of the vast amount of space in the underground mines that is left after mining operations for limestone.

The combined thickness of the exposed rocks is about 350 ft (107 m), measured from the bottom of the lowest valley to the top of the highest hill. All of the exposed rocks are sedimentary in origin and belong to the Pennsylvanian and Quaternary Systems. Excellent exposures of Pennsylvanian strata can be observed in excavations for roads and highways. The excavations or "road cuts" as they are commonly called are in places 75 ft (23 m) high and several hundred feet long. The section of Pennsylvanian rocks consists predominately of limestone and shale with minor amounts of sandstone, coal and conglomerate. These lithologic types occur as "bundles" of strata that alternate in cyclical fashion throughout the section and are commonly called "cycloths." Of most importance economically are the beds of limestone, in particular, the Bethany Falls. The industrial development of Kansas City is closely related to the exploitation of the 20-24 ft (6-7 m) thick "ledge" of Bethany Falls Limestone in quarrying and mining operations. The underground facilities are in the space left after mining operations of the Bethany Falls Limestone and to a lesser amount in the Argentine Limestone, a stratigraphically higher bed 30-35 ft (9-11 m) thick that is separated from the Bethany Falls by about 150 ft (46 m) of strata.

A unique set of favorable conditions including geology, transportation and geography, are major factors that have made Kansas City the international leader in the commercial development of mined out areas for warehousing, manufacturing, offices, business and service-related activities. Over 2,000 people work underground at several sites with a combined floor space of almost one square mile (Stauffer, 1978).

The Pennsylvanian bedrock is overlain by surficial deposits of Pleistocene and Holocene age. The surficial deposits include, glacial drift, loess, alluvium and soil. The glacial drift consisting of till and outwash (stratified drift) is of Kansan age. It is variable in thickness and spotty in areal extent, but thicknesses of over 30 ft (9 m) occur locally. Glacial drift caps many of the higher hills in areas north of the Missouri and Kansas River but it has been removed by erosion along the valleys of the major tributary streams, and in most places south of the Missouri and Kansas River valleys. Deposits south of the major rivers, including downtown Kansas City, is evidence that glacial lobes pushed south of the present day channels of the Missouri and Kansas Rivers.

A cover of windblown silt (loess) overlies the glacial drift except in areas where the drift is absent. At these places, the loess rests on Pennsylvanian bedrock. The loess is thickest along the bluffs of the major river systems where it is 75 ft (23 m) thick.

The floodplains of the Missouri and Kansas Rivers are underlain by alluvium of sand and gravel of Late Pleistocene and Holocene age over 180 ft (55 m) thick in places.
ACKNOWLEDGEMENTS

The following individuals and organizations have provided the opportunity for members of the Association of Missouri Geologists to visit features of geologic and commercial interest in metropolitan Kansas City, Missouri. Their cooperation is gratefully acknowledged: Paul Licaussi, Carefree Industrial Park; Mike Mahoney and Wayne Fletcher, Mason Land Reclamation Company, Inc.; Jesse Case and Julie Eads, Missouri Rock Co. Inc.; Donald Brecken and David Holberg, Park College; and Larry Hudgins, Parkville Stone Company.
FIELD TRIP ITINERARY

DAY 1

FRIDAY, SEPTEMBER 23
I. PARK COLLEGE (UNDERGROUND)

Figure 1. Guide to field trip stops - day 1.
Stop No. 1 Park College

Park College was founded in 1875. It is a private four year liberal arts, non sectarian Christian College. The enrollment in 1993 was about 1,200 on the Parkville Campus, 4,500 at Kansas City, and about 15,000 students in 67 locations in 19 states. Park College is unique among educational institutions in that part of the facilities of the College are underground. The college is engaged in the mining, processing and the sale of crushed rock and is developing the mined-out area for useful purposes as it becomes available after mining operations. A 120,000 volume library, computer labs, faculty offices, mailroom, bookstore, board of trustees room, classrooms and various other administrative, maintenance and service offices are located in part of the 650,000 ft² (15 acres) of space left after mining operations. About 20% of this amount is currently being utilized, the remainder of the space is being developed for rental to private enterprises. This is a relatively recent underground development in the Metropolitan Kansas City area, mining began in 1981. A total of 8,000,000 ft² of new space will be available after mining operations. No buildings in the campus will be undermined.

The mine is in the Argentine Limestone, a 20 ft (6 m) thick bed of limestone that underlies the hilly wooded bluff overlooking the wide floodplain of the Missouri River. The main pedestrian entrance to the underground is through a semi-circular building that is constructed of attractive natural stone, Fig. 2.

The haulage entrance into the mine is a horizontal drift into the hillside. The limestone is mined by the conventional drill and blast method. About 2,000 tons of limestone is mined per working day. Pillars 25 ft (8 m) in diameter are left to support the roof. About 78% of the Argentine is extracted, leaving 22% for pillars. The initial mining plan spaced pillars on 50 ft centers with 25 ft (8 m) galleries between pillars. Rock properties further into the mine permitted spacing of the pillars at 55 ft (17 m) centers creating galleries 30 ft (9 m) wide. The average thickness of the Argentine Limestone is about 20 ft (6 m). The physical properties of the Argentine Limestone and associated strata are shown in Figure 3. The upper six and one half to seven feet is left for roof support after mining operations. The ceiling is roof bolted on various engineered patterns with #7, grade 60, rebar bolts 57 to 72 (145 to 183 cm) inches long and fully grouted with Celtite polyester resin.

The Island Creek Shale, 28 ft (9 m) thick, forms a seal over the Argentine Limestone and prevents water seepage into the mine. Underlying the Argentine Limestone is the Quindaro Shale about nine inches thick. The thin Quindaro Shale is removed in mining operations and the floor of the mine is developed on the Frisbie Limestone. The Quindaro is exposed at the base of the pillars and is protected by a one to two inch thick cover of gunite. Near the entrance to the mine the formations are weathered and small amounts of water move downward along joints in the Argentine Limestone and upon reaching the impermeable Quindaro Shale the migrating ground water moves laterally and emerges as it seeps at the Quindaro-Argentine contact. Water seepage, 200 to 300 ft (61 to 91 m) into the mine from the entrance, is a common occurrence in mines of the Kansas City area. Removal of the Quindaro throughout the mine increases the ceiling height to over 12.5 ft (4 m).

The Frisbie, a dark gray limestone about two feet thick, is typically thick-bedded and relatively hard. Consequently, the Frisbie forms a stable floor. Observe the small ridges and mounds that stand out in relief on the mine floor. These structures called "rolls" by the miners
are typically several inches high and range in areal extent and shape from oval structures a few feet in diameter to long, linear features a few feet wide to over one hundred feet long. The major trends of the rolls are north-south or east-west. Trace one of the rolls across the mine floor and notice that it will pass through a pillar. These structures are not the result of mining activity. They were formed on the sea floor during the Pennsylvanian Period, over 300 million years ago by sediment binding organisms, in particular phylloid algae that lived in grassy patches on the sea floor and trapped fine carbonate sediments transported by the currents. Eventually the sediments accumulated to form the low ridges and mounds that form the upper part of the Frisbie Limestone. The low areas around the rolls are filled with crushed limestone before the asphalt or concrete floor is laid.

The Park College Underground is situated on the east limb of localized anticline. The dip of the strata is approximately 1°E. A horizontal attitude of the floor in the library is constructed by excavating a series of wide benches into the Frisbie Limestone floor. The stair step-like plan places each bench at a successively lower elevation as one moves in an easterly direction.

The ceiling height in part of the mine has been increased to 17 ft (5 m) by excavating the Frisbie Limestone and the upper few feet of the Lane Shale. The additional ceiling height will provide access to tractor trailer trucks. A concrete roadway is constructed on the Lane Shale at places where the Frisbie Limestone has been removed. The Lane Shale is about 30 ft (9 m) thick. Facilities such as sewer lines are laid in excavations into the Lane.

Figure 2. Entrance to McAfee Library and the Park College Underground.
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<td>impermeable forms seal, prevents water seepage into mine</td>
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<td>LIMESTONE, blocky</td>
<td>roof commonly reinforced with concrete bolts</td>
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| SHALE, med. gray, l.t. gray, thin wavy beds; clay seams |
| soft, floor uneven, upper surface easily excavated; soft, unstable |

Figure 3. Graphic column showing the Argentine Limestone and associated strata that figure significantly in the development of underground space.
The mined limestone is crushed and used in construction or as aggregate in asphalt paving. Temperature in the mine is a constant 57°F (14°C), the seasonal average temperature for the Kansas City area.

Mining is presently being conducted at two levels. The Bethany Falls or "Bethany Ledge" of miners terminology lies approximately 150 ft (46 m) below the Argentine Limestone. An inclined adit has been completed to the level of the Bethany Falls. The entrance to the adit is located on the bluff overlooking Mo. Highway 9 that runs along the base of the bluff. The tunnel is of proprietary engineered design. The entrance is just below the Cement City Limestone; the grade of the tunnel is 15% and the length about 500 feet, Fig. 4. The tunnel intersects the Bethany Falls at a depth of about 90 ft (27 m) below the tunnel entrance. The Bethany Falls is about 20 ft (6 m) thick and is similar in thickness to the Argentine but it is a higher quality rock. The Bethany Falls underlies the entire campus and is typically 50 ft (15 m) below the floodplain of the Missouri River. The tunnel entrance is above the 500 year flood level. Access to the Bethany ledge is restricted to miners doing the development work until an air ventilation system is completed.

The geologic setting for a tandem type mining operation of the Bethany Falls and the Argentine Limestones appears to be more favorable at this site than at any of the underground locations in the metropolitan Kansas City area. The Bethany Falls Limestone can be reached only by vertical or near vertical shaft at other sites where the Argentine is mined and at sites where the underground space is in the Bethany Falls Limestone the overlying Argentine Limestone has been removed during the present erosional cycle, replaced by unconsolidated materials of glacial origin or the Argentine lies near the top of the hills and is deeply weathered.

The unique combination of geologic factors including the relatively thick overburden above the Argentine Limestone and the height of the river bluff where almost 200 ft (61 m) of the rock section is accessible contribute to the feasibility of a mining venture of this type at the Park College Underground.

A zoned rock crushing plant is situated in an area excavated along the outcrop band of the Argentine Limestone in the southeastern quadrant of the Park College land close to the entrance tunnel to the Bethany Fall Limestone. Access to the plant site is via Coffey Road and Missouri Highway 9.

The crushing plant, constructed in 1990, was the first in Missouri constructed according to the specifications of the Missouri Department of Natural Resources and EPA Air quality standards and engineering tests. It is a single pass plant equipped with an impact breaker, primary crusher and a triple roll secondary crusher. It is fully automated and operates without a plant operator. Normally eight sizes of rock are produced at one time from this plant. Additionally, the load out system permits proportional blending of combined materials using computer controlled electrically actuated discharge gates and collector belt truck delivery.

It is noteworthy that the crushing plant site was selected to be out of public view, as much as possible. The typical traveler along Mo. Highway 9 is not aware of the plant site which is nearly 100 ft (30 m) above the elevation of the highway. The steep wooded bluff projects a view skyward that conceals the benched plant site. Bluffs rising another 100 ft (30 m) above the site level surround the site on the west, north and east. The Missouri River is visible from the plant site. The site because of being notched into the bluff seems to be
Figure 4. Mining the Bethany Falls Limestone Member by inclined tunnel, Park College, Parkville, Missouri
Figure 5. Composite column of the rock units exposed along the Missouri River Bluff and Missouri Highway 9 from Riverside to Parkville, Missouri.
sheltered from prevailing winds which rise along the bluffs and pass over the plant area to the higher bluffs or blow over the bluffs into the river valley. The benefit is that fugitive dust from stockpiles and haul roads settles on the site rather than becoming visible as a plume. The mining operator has as a goal efficient operation with minimum public awareness of the operation.

The mining company, has a long term lease and is regulated by Park College, local zoning, MSHA, Mo.DNR and the EPA.

RETURN TO HOWARD JOHNSON LODGE
FIELD TRIP ITINERARY

DAY 2

SATURDAY, SEPTEMBER 24
L 87TH STREET AND BLUE RIVER ROAD SECTION
2. MASON LAND RECLAMATION INC.
3. I-470 SECTION & FAULT
4. CAREFREE ENTERPRISES INC. (UNDERGROUND)
5. QUARRY ACCESS ROAD SECTION

Figure 1. Guide to field trip stops - Day 2.
Stop No. 1

87th Street and Blue River Road Section. The site location is shown on Figures 1 and 2.

The lower 95 ft (29 m) of the Kansas City Group (Pennsylvanian System) is exposed in an excavation for 87th Street for a distance of about 1,000 ft (305 m). Three thick limestone members are separated by relatively thin shale units and comprise a sequence of strata upon which most of the city is built. The limestone members are in ascending order: the Sniabar, Bethany Falls, and the Winterset, Figure 3. The section is exposed in a series of benches, each bench is successively higher than the preceding bench. The step-like pattern of rock removal is used to insure rock stability in deep excavations. The nose of a hill over 100 ft (30 m) high was removed to allow construction of 87th Street. Fortunately, the series of benches gives relatively easy access to the rock section.

The section along 87th Street is representative of the sequence of strata that comprises the lower Kansas City Group throughout metropolitan Kansas City. An interesting feature that is well exposed in the 87th Street excavation is the occurrence of two lens-shaped bodies of shale, each 60 to 100 ft (18 to 30 m) wide and with a maximum thickness of four feet. The shale bodies are at the stratigraphic position of the upper part of the Sniabar Limestone but they are genetically related to the overlying Ladore Formation. The lens-shaped bodies of shale are interpreted to have filled a tidal channel eroded into the upper part of the Sniabar Limestone. As the sea retreated across a broad carbonate platform, tidal currents eroded channels into the semiconsolidated sediments that comprise the upper few feet of the Sniabar Limestone. The channels filled with fine clastics of the Ladore Fm. and represent the distal lobe of a delta system that prograded seaward over the emergent tidal flat. The Ladore, a predominately clastic unit, thickens toward the south-southwest in the direction of the source area in the Quachita-Marathon Region of Oklahoma and Arkansas (Wanless and Wright, 1978).

A contributing factor to the geographic location of the channels is the abnormal thickness of the Sniabar Limestone. At most places the Sniabar is six to eight feet thick, and is composed of thick beds of limestone that weather a chocolate brown. At the 87th Street location, the Sniabar is over 14 ft (4 m) thick. The lower one-half is similar in lithology and thickness to the Sniabar in most other areas of metropolitan Kansas City whereas the upper several feet has a nodular-like structure that is contributed to profuse growth of algae. These algal buildups have an areal extent of several acres to several square miles and have been recognized as forming the upper part of several limestone members of the Kansas City Group. The baffling action of sediment-binding organisms such as algae may have produced buildups in intertidal and shallow subtidal areas that altered hydrologic processes. Currents forced to flow over these obstructions eroded channels into them. As the sea retreated, deltaic lobes of mud prograded seaward filling the tidal channels with mud.

The flow direction of the channels in the 87th Street Section was perpendicular to the face of the exposure and accounts for the lenticular shape when viewed in cross section.

The strata overlying the channel-fill deposits are arched to form small anticlines with about 12 in (30 cm) of displacement. The folding began shortly after the section was exposed in 1990 and is attributed to the removal of overburden. The release of pressure allowed the clay particles to absorb water into the crystal lattice and to swell. The arching is particularly
noticeable in the Middle Creek Limestone. The thin even beds of Middle Creek limestone were observed to be horizontally lying over the channel-fill deposits at the time the section was being excavated.

Tidal channels several hundred feet long have been uncovered in quarry operations for limestone as the overburden is removed at other locations in metropolitan Kansas City. Sediment filled channels in the upper part of limestone units, and similar in appearance to the ones exposed in the excavation for 87th Street, are a common occurrence in the rock section. Unfortunately, these features are rarely observed in plan view and only occasionally in cross-sectional profile because they are removed with the quarried rock.

The physical properties of the Bethany Falls limestone are readily visible at this location. The Bethany Falls has been extensively quarried and mined throughout the Kansas

Figure 2. Location map of the 87th Street and Blue River Road Section (Stop 1) and the Mason Land Reclamation Project (Stop 2), Jackson County, Missouri.
Figure 3. Columnar section of the rocks exposed in the excavation for 87th Street at the intersection with Blue River Road
City area since the 1880s. The industrial development of the city is closely related to the exploitation of the Bethany Falls Limestone, informally called the "Bethany Ledge" by quarrymen. Almost all of the underground space left after mining operations in metropolitan Kansas City is in the Bethany Falls Limestone.

The Middle Creek Limestone Member is abundantly fossiliferous with a variety of invertebrates. The most abundant fossils are trepostome "twig-like" bryozoans but also common are brachiopods of the genera Meekella, Derbyia and Composita.

This site is the location of a former quarry. In November, 1989, a fire ignited a tractor trailer load of ammonium nitrate, the ensuing explosion resulted in the deaths of six firemen and extensive property damage to nearby buildings. A memorial to the victims is erected near the north end of the excavation.
Stop No. 2  Mason Land Reclamation Co. Inc.

At this site, the Mason Land Reclamation Company is restoring to useful purposes land that has been disturbed by surface and underground mining of limestone for over 50 years. The 513 acre (2.08 x 10^6 m^2) tract is bounded generally by I-435 on the east; Bannister Road on the south; U.S. 71 on the west; and 87th Street on the north, figure 2. Approximately 350 acres (1.42 x 10^6 m^2) have been mined, the majority of the area is a honeycomb of abandoned underground mine workings in the Bethany Falls Limestone.

Mining operations at this site began in 1938 and over the years limestone has been removed by surface and underground mining methods. Operations moved underground in areas where the removal of a thick section of overburden made surface mining less profitable.

The strata at this site correlate with the section at the 87th Street at Blue River Road section. The major units underlying the site that figure in mining operations are the Bethany Falls Limestone Member, Swope Formation; Galesburg Formation, and Dennis Formation. The overburden thickens in the eastern and southeastern parts of the site where in places the Winterset Limestone Member, Dennis Formation is overlain by greater than 100 feet of section, including the following formations in ascending order, Cherryvale, Drum, Chanute and Iola.

Over the years, the roof support failed in a large part of the area that was mined underground and sections of strata collapsed into the mine. The result was a topography of sinkhole-like structures, troughs and cracks that created a virtual "no mans land." For all practical purposes the land was worthless. Collapsed structures are visible along the highwall of the quarry. Several years ago quarrymen witnessed the slow subsidence into the mine of a section of strata with dimensions of about one acre.

A fault was discovered during mining operations for the Bethany Falls in the southeastern part of the site. The fault is a high angle normal fault. The strike is N.35°W. and the dip angle of the fault plane is 58°NE. The vertical displacement is six to eight feet in the southeastern corner of the mine. When traced in a northwesterly direction for a distance of several hundred feet the vertical displacement gradually decreases and the fault passes into a joint.

A similar type of faulting and structural setting has been documented in the literature at a number of places in western Missouri and eastern Kansas (Hinds and Greene, 1915; O'Connor, 1971; Gentile, 1984a,b). The similarity in structural detail associated with these structurally disturbed areas indicates that the faults have a common origin. The most notable example of faulting is exposed in the excavation for Interstate Route 470 at Raytown Road, Stop No. 3 in this section of the guidebook.

The 513 acre (2.08 x 10^6 m^2) site is attractive to developers because of the large size, location near an interstate highway system and under Chapter 353, urban redevelopment, the developer will receive tax breaks to reclaim the land.

In 1988, Sullivan Hayes, a Denver based corporation proposed to develop the 513 acre tract into a mixed-use facility valued at over $700 million. The project would include office buildings, retail space, warehouses, hotels, and multi-family housing. The land reclamation part of the project was estimated to cost $165 million. The project would be financed, in part, under Chapter 353, urban renewal, and receive $190 million in property tax relief over the 45 year period of the project. Reclaiming the land was to be accomplished in several different
ways. Mined areas that were in stable condition would be renovated and used as parking garages. About 100 acres were inaccessible due to collapse and would be reclaimed by removing the rock in an open pit quarry operation. Some of the mines would be back-filled. A sizeable part of the mined area was to be reclaimed by blasting the pillars and allowing the overlying strata to collapse into the mine. As many as 80 pillars would be dynamited at once. The plan had never been tested and fears were raised that the collapse of several acres of strata would generate earth tremors.

The city approved the plan with modifications but it was never implemented because the company experienced financial insolvency.

In 1990, the Norcal Solid Waste Systems, Inc. of San Francisco and the Leo Eisenberg Company proposed to use the site to dispose of solid waste. The part of the section to the top of the Hushpuckney Shale was to be removed and the excavation, over one hundred feet deep, filled with waste. The development was to proceed in 8 phases. A phase consisted of filling part of the pit with solid waste and preparing the surface for commercial development. The plan, known as the Dominion Point Project, would take 38 years to complete. A proposed commercial development, on top of the landfill consisted of 6,300,000 ft² (585,292 m²) of office space, 423,000 ft² (39,298 m²) of retail space, 85,000 ft² (7,897 m²) of light industrial space, a 250 - 300 room hotel and an 18 hole golf course. The $700 million project would receive $231 million in tax abatements from the city.

Plans were drawn up to pipe the gas from decaying waste to the surface and use it to heat the buildings on top of the landfill. The site is large enough to receive all of Kansas City’s trash for over 30 years. The southeast landfill, about one mile north of the site is rapidly being filled with 140,000 tons of trash each year.

The proposed project met with strenuous opposition from local business leaders and residents. Over 500 boisterous residents filled an auditorium in December 1990 to voice their disapproval of the plan. Consequently, the City Planning and Zoning Commission and the City Council refused to issue a zoning permit to place a landfill at the site.

The Kansas City Council on October 1, 1993, approved a $283 million development plan for the 513 acre tract. The site is being developed by the Mason Land Reclamation Company, a subsidiary of Norcal Solid Waste Systems. The project will receive up to $150 million in public subsidies through tax increment financing over the next 32 years. The perimeter of the 513-acre site is being developed for commercial use. A Home Quarters Warehouse Inc. and a Long John Silver's Sea Food Shoppe is located off Bannister Road on the southeastern corner of the site. A large part of the perimeter acreage has not been mined.

The Mason Land Reclamation Company is removing the rock section consisting of the mine pillars and the overlying strata in a quarrying operation near the center of the site. The quarried rock is sold. Plans are for the excavation to be used for industrial and commercial purposes.
Figure 4. Location map of the Interstate Highway 470 and Raytown Road section and faulting (Stop 3).
Stop No. 3. I-470 Section and Fault

A "textbook example" of normal faulting is well exposed in the thick limestone members of the lower Kansas City Group in a road cut at the I-470 exit at Raytown Road (SW1/4, NW1/4, sec.33, T.48N.,R.32W., Jackson County, Missouri, Lee's Summit 7 1/2-minute Quadrangle (Figures 1 and 4). Park along Raytown Road north of the bridge over I-470 and walk east along the access road and onto the grassy strip of right-of-way about 200 ft (60 m) wide on the north side (westbound lane) of I-470. The section, with faults, is exposed about 1000 ft (300 m) east of Raytown Road. The section of Pennsylvanian strata exposed along I-470 is shown in Figure 5. The strata along the route are faulted at several locations. Figure 5 shows two of the faults shortly after they were exposed in a highway excavation. Fault scarps have been removed and the roadbed graded. The faulting does not extend into the thick covering of unconsolidated loess and soil. The faults shown in Figure 6 form the sides of a northwest-trending structural block about 200 ft (60 m) wide. Figure 7 is a detailed sketch of the fault on the northeastern side of the block.

The Bethany Falls Limestone Member of the Swope Formation, exposed at road level, is a light-gray, finely crystalline limestone mottled with dark-gray spots or blotches. The upper two or three feet (.5-1 m) consists of limestone nodules in a greenish-gray matrix.

The Bethany Falls is overlain by the Galesburg Formation, a medium gray claystone about 3 ft (1 m) thick. The Galesburg forms a seal that prevents water seepage into mined out areas. Above the Galesburg, the Dennis Formation includes, in ascending order, the Canville Member, represented by a thin bed of fossiliferous shale about an inch (2 cm) thick; the Stark Shale Member, about 4 ft (1.5 m) thick, the lower half is black fissile shale with abundant conodonts; and the Winterset Limestone Member, 30-40 ft (9-12 m) thick, the lower part interbedded with shale. At this stop the upper half of the Winterset is deeply weathered. Overlying the Winterset about 20 ft (6 m) of soil and loess form a grass covered slope.

The part of the section below the Bethany Falls Limestone Member shown in Figure 5 is exposed along Buffalo Creek west of Raytown Road. Beds overlying the Winterset were exposed in the roadbed excavation through a low hill west of Buffalo Creek, but the exposure is mostly overgrown by vegetation.

Origin of Structure

The faulting was exposed in construction excavations for I-470 in the fall and winter of 1976, including a 4000-ft (1200-m) long segment of the route from just west of Buffalo Creek to about 3000 ft (910 m) east of the Raytown Bridge (Fig. 8). The faulting comprises a series of ten northwest striking parallel faults, which could be traced along the strike, perpendicular to the roadway, for about 400 ft (120 m) across the area under construction until they became concealed by regolith. All are high-angle normal faults, the fault planes dipping southwest toward a deep structural depression along Buffalo Creek. They are step faults, the downthrown blocks on the southwest sides of several parallel faults; the strata between having moved downward step-wise in relation to the adjacent faults to the northeast.

The steeply dipping strata exposed in the bed of Buffalo Creek can be projected many feet below the level of the valley floor, as determined by the records of core-drill test borings.
Moreover, in most places the hill slopes are normal to the fault strikes, therefore, the faulting is not the result of downhill creep by slump blocks toward the lower elevation of the valley.

Several small faulted areas similar to the one at this stop have been recognized in western Missouri and northeastern Kansas (Gentile, 1984a, b); they contrast sharply with the relatively undisturbed nature of the bedrock surrounding them. The following paragraph discusses their probable origin.

Detailed geologic mapping being conducted in southern Jackson and Cass Counties indicate that these small structurally disturbed areas are located at the intersection of northwest and the northeast striking fold axes. The fold axes and the faults trend in the direction of the joint pattern. The regional joint pattern in western Missouri consists of two joint sets trending almost at right angles to one another (Hinds and Greene, 1915; Ward, 1968). The northwesterly trending set parallels the regional dip and the northeasterly set the regional strike. Consequently, the small structurally disturbed areas including the one at I-470 and Raytown Road are related to the major structural "grain" of the midcontinent. Gentile (1984a, b) has proposed that these small faulted areas formed when the Pennsylvanian strata collapsed into caverns enlarged by dissolution at the intersection of fracture zones almost perpendicular to one another in thick Mississippian limestones and dolomites underlying the region at depths of 600-800 ft (180-240 m). An extensive system of filled solution cavities is known to exist in Mississippian limestones throughout the Midcontinent. Moreover, these limestones are thick enough to account for the displacement recorded at the surface, using key marker beds in Pennsylvanian strata as datums. In comparison, the Pennsylvanian limestones are not thick enough, if removed by cavern development, to allow this much displacement. These structures did not form in modern times, because the faulting does not extend into the thick covering of unconsolidated Late Pleistocene and Holocene surficial materials.

Deep drill tests and detailed geophysical investigations, especially seismic reflection surveys, are needed to determine subsurface structure.
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Figure 5. Composite stratigraphic column of the rocks exposed during construction of Interstate Highway 470 in the vicinity of Raytown Road.
Figure 6. Photograph of exposure showing two small normal faults (below arrows in upper part of photo) in the north (westbound) lane of Interstate Highway 470, east of the Raytown Road Bridge, Jackson County, Missouri. The ledge of limestone at road level is the Bethany Falls.
Figure 7. Block diagram showing interpretation of the fault exposed along Interstate Route 470 about 1200 ft (366 m) east of the Raytown Road Bridge.
Figure 8. Detailed structure map of complex faulting exposed in excavations for construction of I-470 in fall and winter of 1976.
Stop No. 4 Carefree Industrial Park

The Carefree Industrial Park is an underground business complex with 2,500,000 ft\(^2\) (57 acres) of fully developed industrial facilities. The total size of the mined area is 8,000,000 ft\(^2\) (184 acres). Development of the mined area will continue for 10 to 20 years until the entire area is in industrial buildings. The project was initiated in the mid 1960s by Paul Roberts, the founder of Carefree Quarries Inc. The present owner is an insurance company with offices at Omaha, Nebraska.

The unit mined is the Bethany Falls Limestone. At this site the Bethany Falls is 24 ft (7 m) thick, and represents the greatest recorded thickness of Bethany Falls Limestone in metropolitan Kansas City. The average thickness of Bethany Falls Limestone is about 20 ft (6 m) but in this part of Jackson County a localized "reef" of calcium carbonate secreting and sediment binding algae formed a buildup on the sea floor.

The mining was planned with the specific purpose of using the mined space for industrial purposes, consequently, the pillar spacing in the interior of the mine is one of the most consistent in the metropolitan Kansas City area. Mining was done on the room and pillar plan and the pillars are spaced on a grid. The pillar dimensions are 20 x 20 ft (6 x 6 m) and are located 50 ft (15 m) on center. The tunnels or bays are 30 ft (9 m) wide and in most of the mine they are several hundred feet long, the alignment is straight. Five to seven ft (1.5 to 2 m) of Bethany Falls limestone are left after mining to form the roof. The limestone is thick-bedded and forms a stable roof. Roof bolting is not necessary. The ceiling height is 13 ft (4 m) to 18 ft (5.5 m) in storage areas but in truck and loading docks an additional 2 or 3 ft (0.5 to 1 m) of the Hushpuckney Shale floor is removed to allow adequate clearance for large trucks. A concrete apron is built around pillars and loading docks where the shale is exposed. A generalized column of the Bethany Falls Limestone and associated strata is shown in Figure 9. All facilities have docks to accommodate over-the-road trucks.

The standard size industrial facility in the Carefree Underground ranges from 10,000 to 500,000 ft\(^2\). The preparation of mined out area for secondary use is simple and inexpensive when compared to the construction of a surface structure of equal size. A reinforced concrete floor is laid; the area is partitioned with concrete block walls. The walls and ceiling are painted white and adequate ventilation, heat, lighting and water facilities are installed. The temperature is a constant 63°F (17°C) which reduces substantially the cost of heating and air conditioning. The inexpensive operating costs have made the underground a primary location for food companies to operate warehouse and distribution centers. The major types of products currently stored in the Carefree Industrial Park Underground are food products, pharmaceutical products, agricultural product containers, raw material products for the manufacturing of agricultural firm implements, automotive and truck parts, garden implements, and pressure sensitive paper products. The Carefree Underground has received commendations from the American Baker's Association and several government agencies for maintaining high standards of cleanliness and the attractive appearance of their facilities.

The construction timetable for completion of an underground facility typically ranges from 60 to 120 days whereas the construction time for a comparable surface facility is 6 to 12 months. The continual maintenance of an underground facility is considerably lower than that of a surface building over a 5 to 10 year period of time.
Figure 9. Graphic column showing the Bethany Falls Limestone and associated strata that figure significantly in the development of underground space.
During the last 18 months, three new buildings were constructed on a build-to-suit basis. The new buildings resulted in the addition of 1,000,000 square feet of new industrial space to the project. This 1,000,000 square feet consists of buildings of 350,000 square feet, 210,000 square feet, and 440,000 square feet. Currently in 1994, we are continuing the development of an additional 500,000 square feet which will be completed in the later part of 1994.

The major utility suppliers for The Carefree Industrial Park are the Kansas City Power and Light Company (electricity); the City of Independence Water Department (water). The entire project is serviced by a state-of-the-art sewage treatment facility which has been constructed by the ownership of the Carefree Industrial Park to serve specifically the entire underground facility.

All underground space is located west of Missouri Highway 291 and north and south of Kentucky Road. Underground mining has ceased and there are no plans to resume mining in the future because in the western portion of the underground the upper several feet of the Bethany Falls Limestone has been removed by erosion and replaced by channel-fill shale deposits of the Galesburg Formation.

The thickness of strata overlying the Bethany Falls Limestone is 80 to 150 ft (24 to 46 m). An adequate thickness of overburden to prevent surface collapse and roof failure is generally considered to be the rock units that are well exposed at the entrance tunnels, consisting of the Galesburg Shale, Stark Shale and the Winterset Limestone.

An open pit quarrying operation is located east of Mo. Hwy. 291 and north Kentucky Road in the northeast quadrant of the Carefree Industrial Park property. Production is approximately 400,000 tons annually of Bethany Falls Limestone with reserves in excess of 15,000,000 tons. Quarrying of the Bethany Falls is expected to continue for over 20 years. The limestone is crushed on site and sized to meet different customer specifications. The major uses of the crushed rock are as concrete and asphalt aggregate, back filling of retaining walls and residential basement walls, and as rip rap, a classification of building stone that is used for dam, roadway and retaining wall construction.

This site is an example of the two tier occupancy of space-subsurface and surface. The total property size is 416 surface acres. Surface tenants include a drive-in theater, a TV transmission tower, and a ready mix concrete plant. Plans are in progress to locate a 250 acre industrial business center on top of the developed underground space. The surface development would include bulk distribution, warehousing, office, retail and service related companies. Preliminary structural engineering studies indicate that the surface could support a 5 to 10 story office building with no adverse effects to the structural integrity of the underground.
Stop No. 5. Quarry Access Road Section

The relationships of till, stratified drift (outwash) and loess is well displayed in an excavation made in 1991 for a haul road through the bluff about 2.5 mi (4 km) southwest of Missouri City, Clay County, Missouri. The excavation is 1500 ft (457 m) long and gives access to the Missouri Rock Co. quarry in the Bethany Falls Limestone (Pennsylvanian), Fig. 10.

Two or 3 flow lines (shear planes) were well exposed in unweathered till (diamicton) near the southern end of the exposure in 1991. Directly above the shear planes is a large block of Winterset limestone measuring 3 X 6 feet. The shear planes bound curved sections of till several feet thick. The till "slices" represent successive intervals of movement and melting down of the ice front. The lines of flow bent upward because the ice was flowing along a pressure gradient toward the surface.

At the quarry location, near the northern end of the section, the glacial drift rests unconformably on the lower Winterset Limestone Member.

The glacial deposits at this site occupy part of the paleotopographic low interpreted to be a "buried" bedrock valley over 2 miles wide and oriented northwest - southeast. The ice lobe that once filled the valley crossed the Missouri River (or its ancestral counterpart) and advanced over the hills in northeastern Jackson County. Thick sections of unweathered till are exposed at places north of the abandoned Lower Little Blue River Valley between Atherton

![Diagram](image)

Figure 10. Location map of the Quarry Access Road Section, 2.5 miles (4 km) southwest of Missouri City, Clay County, Missouri (Stop 5).
and Sibley (Figures 5 and 6 in section, The General Geology of Metropolitan Kansas City).

Classification of the Pleistocene deposits in the midcontinent U.S. is being revised (Richmond and Fullerton, 1986; Morrison, 1991 and Aber, 1991).

The informal chronostratigraphic division pre-Illinoian is proposed for deposits older than Late Middle Pleistocene, included are deposits of glacial till and outwash commonly designated as Kansan.

The terms Kansan and Nebraskan are not applicable because the deposits assigned to them represent multiple glaciations. Hallberg (1986) recognizes six major pre-Illinoian events. The recognition of multiple glaciations is based to a large extent on age dates of the "Pearlette" ash beds. Once considered to be a single marker bed, "Pearlette" ash beds occur at 3 different stratigraphic levels and represent events spanning more than 1.3 Ma (Hallberg, 1986).

Aber (1991) named deposits of glacial till and outwash the Independence Formation at the type locality of the Kansan Stage along White Clay Creek near Atchison, Kansas. The term Kansan is abandoned and replaced by Pre-Illinoian.

Glacial sediments in northeastern Missouri are assigned to the McCredie Formation and include in part deposits belonging to the Kansan Stage (Guccione, 1983). Correlation of the glacial deposits at Kansas City with sections in Kansas and northeastern Missouri has not been attempted (Colgan, 1992).
**LITHOLOGIC DESCRIPTION AND TENTATIVE CORRELATION OF PLEISTOCENE UNITS**

**PLEISTOCENE SERIES**

**WISCONSINIAN STAGE**

- **Unit 5. Loess (Bignell)** .................................................. 35
  - Silt, dark yellowish-brown (10YR 4/4), noncalcareous

- **Unit 4. Paleosol (Bradyan)** ........................................... 3
  - Silt, clayey, brown (7.5YR 5/4)

- **Unit 3. Loess** ............................................................ 20-30
  - Silt, reddish-brown (5YR 4/4), clayey, plastic; vertical desiccation cracks, columnar jointed; noncalcareous

**SANGAMONIAN STAGE**

- **Unit 2. Paleosol** ....................................................... 3
  - Clay-Silt, yellowish-red (5YR 4/6), brown (7.5YR 4/4), yellowish-brown (10YR 6/6), plastic, noncalcareous; sparse, clear quartz grains and granules. Stone line near top of unit consisting of chert fragments, milky quartz and weathered pebbles of dark igneous rock types.

**KANSAN STAGE (PRE-IILLINOIAN)**

- Unit 1. Till and stratified drift (outwash) ......................... 10-35
  - "boulder clay", very dark gray (5Y 3/1) calcareous till of clay size to boulders and blocks with a predominance of fine clastics. Erratics of quartzite, sandstone, milky quartz, granite, gneiss, diabase and locally derived blocks of limestone (Bethany Falls and Wintermet) and black shale; pieces of brown wood (cedar?). Small thrust faults near southern end of exposure.
  - Weathered to light olive gray (5Y 6/2) to brownish-red (10YR 6/6) with granite cobbles weathered to gray and limestone blocks to white lumps of calcium carbonate.
  - Till is interbedded with outwash but at most places the till underlies the outwash with "diapirs" of till extending into the outwash, especially at the southern end of the exposure.
  - Outwash of fine to medium toed quartz sand coated with iron oxide, light brownish-gray (2Y 6/2) and yellowish-brown (10YR 6/6); grading down section and alternating with very dark gray (5Y 3/1) unleached layers of moderately to well sorted sand to poorly sorted gravely sand, and till.

*Color identification was with the Munsell Soil Color Chart and samples were tested moist.*

Figure 11. Cross-profile of Pleistocene section as it appeared in 1991 in the excavation for the access road to the Missouri City Rock Company Quarry, 2.5 mi (4.0 km) southwest of Missouri City, Clay County, Missouri
THE KANSAS CITY UNDERGROUND

The space left after mining operations in metropolitan Kansas City is utilized for a number of commercial purposes including warehousing, manufacturing, offices, businesses and related activities. Over 2,000 people work underground at 25 sites. The total mined area is over five square miles and of this amount about one half square mile has been developed for commercial use. Almost 90% of the utilized space is for storage. Kansas City lies between the food producing West and the food consuming East and the vast underground is ideal for the storage of foodstuffs. Kansas City is the world leader in the utilization of space left after mining operations.

Several mines are currently producing crushed rock that is used in construction and for a variety of other purposes. As space becomes available after mining operations, it is converted to commercial uses. The mined out area can be converted to warehouse storage at a fraction of the cost of a comparable surface facility. The value of the mined out area is usually more than the mined product. In addition, the surface over the mine is commonly developed to accommodate offices, shops and recreational facilities. The dual usage of the subsurface and the surface is referred to as the two-tier occupancy of space. Mining is no longer being done at many sites and the operation is confined to the utilization of mined-out space and the development of surface facilities.

The underground developments are in the mined-out portions of layers of limestone that underlie a large portion of the seven county metropolitan Kansas City area. The limestone beds are exposed on the hillsides and are essentially horizontally lying. The dip averages 10 ft per mile (1.8 m per km), or less than one degree. Direction of dip is to the north or northwest. The regional dip is not uniform and reversals of dip are common on small folds that range in areal extent from a few acres to several miles. The relatively horizontal attitude of the strata greatly facilitates mining operations. The limestone beds are mined by tunnels excavated directly into the hillside. Some mines extend under the hill only a few hundred feet, whereas in others the working face is over a mile from the entrance. These are shallow mines. Most developed areas are 50 to 200 ft (15 to 61 m) below the surface. Ceiling height in the mines is 12 to 16 ft (4 to 5 m) and is primarily determined by the thickness of the bed.

The underground developments are all in mines. These are not caves. There is a fundamental difference between a mine and a cave. The open space that forms a mine has been excavated by humans, commonly for the extraction of mineral resources. The underground space in a cave has been formed by natural processes such as the dissolution of limestone from migrating ground water. All the underground space in the Kansas City area has been excavated by humans, consequently, these openings are mines. The mistaken belief that the underground developments in the metropolitan Kansas City area are in "caves" or "limestone caverns" may have arisen by analogy to the extensive cavern system formed by natural processes in thick beds of limestone and dolomite in the Ozark Region of southeastern Missouri.
Mined Rock Units

Almost all of the space left after mining operations is in two limestone beds, the Bethany Falls and the Argentine. These units are widespread and underlie most of the seven county metropolitan Kansas City area, Figure 1. The Bethany falls lies stratigraphically about 150 ft (46 m) below the Argentine and is the bed most commonly mined. Because of its high topographic position, the Argentine Limestone has been removed by erosion in many places and is less extensive aerially than the Bethany Falls.

The Bethany Falls Limestone

Of most importance economically is the Bethany Falls, informally called the "Bethany ledge." The exploitation of the Bethany Falls Limestone in quarry and mining operations is closely related to the industrial development of Kansas City. Large scale operations began around the turn of the century and were almost exclusively confined to surface strip mines or quarries and followed the exposure of limestone along the contour of the hill. Some of the quarries eventually grew to be several hundred feet long. The increasing price of real estate combined with the cost of removing a greater thickness of overburden as the ledge was quarried into the hillside are the major reasons for going underground.

By the early 1950s a total area of approximately 4.5 mi² (12 km²) was left after mining operations at over two dozen sites and within a radius of 25 miles (40 km) of the Central Commercial District of Kansas City. It was soon realized that a large portion of the mined-out area could be converted to secondary usage.

The room and pillar method is used almost exclusively in mining operations of the Bethany Falls Limestone. The lower 12 to 16 ft (4 to 5 km) of the unit is mined and about 25% of the rock left as pillars to support the roof. Proper pillar spacing, pillar diameter, roof thickness, overburden, joint patterns, and mine drainage are some features that should be taken into consideration when planning a mining operation.

A well planned mining operation that allows for the regular spacing of pillars in grid pattern results in optimum space usage. The long bays are suitable for assembly line production methods or the arrangement of warehouse products in linear series.

In the early days of mining, prior to about 1950, little consideration was given that some day the space produced by mining operations would be utilized for useful purposes. Consequently, many mining operations were conducted where the only purpose was to extract the maximum tonnage of rock. This resulted in poor pillar spacing, "scalping" the roof (an additional two or three feet of rock is removed from the roof) and extending mining operations into areas where there was insufficient bedrock cover to prevent softening of the roof by weathering and eventual roof collapse. Consequently, many mined-out areas are worthless for all practical purposes.

Most present day operators take into consideration the value of the space left after mining which in many cases, is more than the mined product.

The Bethany Falls is a light-gray, wavy bedded limestone with well-developed, vertically oriented joints. A description of the Bethany Falls Limestone and associated strata
Figure 1. County map of metropolitan Kansas City showing the outcrop bands of the Bethany Falls and the Argentine Limestones. The strata dip slightly in a northwesterly direction, consequently, the Bethany Falls and Argentine limestones are found in the subsurface in areas to the west and northwest of their respective outcrop bands. In areas to the east and southeast of the outcrop band the Bethany Falls and Argentine limestones have been removed by erosion owing to the higher topographic position of the bed.
is given in Figures 3 and 9, Field Trip Itinerary - Day 2. Throughout most of the area the thickness is 20 ft (6 m) with a range of 18 to 22 ft (5 to 6 m). Distinguishing features of the limestone are the dark gray mottles or "blotches" and the upper few inches to three feet consists of nodules of limestone in a light gray claystone. The nodular zone at the top of the Bethany Falls is informally called the "peanut zone" or "rubble zone," the names are in reference to the characteristic appearance. Underlying the peanut zone is 4 or 5 ft (1 or 2 m) of thick-bedded limestone that forms the roof of most mines. In localized areas of Jackson and Clay counties, the peanut zone fills in channels several feet deep, eroded into the top of the thick-bedded limestone that forms the roof support of mines. The considerable increase in the thickness of the rubble zone has caused problems with roof integrity in some mines. The peanut zone is unstable and will cave. Unfortunately, methods have not been found to locate areas where the rubble has replaced the thick limestone beds that form a stable roof support.

The Bethany Falls is a high calcium limestone consisting of over 90% calcium carbonate with only minor amount of deleterious substances. The limestone is widely used for concrete aggregate, road surfacing, railroad ballast, cement, agricultural lime and various specialty products.

Underlying the Bethany Falls Limestone is the Hushpuckney Shale, an medium gray to black fissile shale high in heavy elements, sulfides and phosphate and about four feet thick. The Hushpuckney forms the floor in most mines. Floor problems are occurring in some underground areas that usually take the form of arching between pillars. Warping or heaving of the floor of several inches has been observed over a period of a few years in some mines.

The arching of the floors in underground facilities is a complex problem that needs to be thoroughly investigated. Several possible causes for the stresses that produce the heaving in the Hushpuckney have been considered and include; (a) pressure release resulting from removal of the Bethany Falls Limestone, (b) pressure exerted by the growth of gypsum crystals between shale laminations, (c) weight of the overlying strata on the pillars and (d) expansion of the shale by water absorption (Coveney and Parizek, 1977). The solution favored by many underground operators is to remove the Hushpuckney Shale and place the floor on the Middle Creek Limestone, a hard brittle limestone one or two feet thick. Removal of the Hushpuckney is necessary in some parts of the mine, especially along roadways to give sufficient clearance for large tractor trailer trucks and rail cars that require 14 ft (4 m) or more of clearance space. The removal of the Hushpuckney in storage areas to give three or four more feet of ceiling height is also a widespread practice. The Hushpuckney Shale will absorb water and begin to swell and slake on exposed surfaces. Consequently, along docking areas and around the base of pillars the exposed shale is protected by a concrete apron. Overlying the Bethany Falls is the Galesburg Formation, an impervious claystone about three feet thick that forms a seal and prevents water seepage into mines.

Above the Galesburg is the Dennis Formation, which includes the Stark Shale Member and the Winterset Limestone Member. The Stark consists of three or four feet of shale, the lower part is black and platy with a well developed joint pattern. The Stark does not possess the water inhibiting properties of the Galesburg. Subsurface water moves freely along joint and bedding planes and will seep into mines where penetrated by roof bolts if proper precautions are not taken.

The Winterset Limestone is about 30 ft (9 m) thick but is a poor quality rock that has
numerous shale lenses and a high percentage of silica in the form of chert nodules and lenses, especially in the upper part.

The minimum thickness of strata over a mined-out area for safe roof conditions is considered to be the upper 5 to 7 ft (1.5 to 2 m) of the Bethany Falls Limestone, Galesburg Claystone, Stark Shale and a full thickness of the Winterset Limestone. A representative section of strata at a mine entrance is shown in Figure 2. Overburden in mined areas ranges from a minimum of about 50 feet to a maximum of over 175 feet.

The Argentine Limestone

The Argentine lies stratigraphically about 150 ft (46 m) above the Bethany Falls Limestone. It is exposed on the higher reaches of the hills along the Missouri-Kansas boundary but owing to the northwesterly regional dip the Argentine lies near floodplain level of the Kansas River in northwestern Johnson County. Because of the high topographic position, the Argentine is relatively susceptible to erosion during the present erosional cycle and is much less extensive aerially than the Bethany Falls.

The Argentine is over 50 ft (15 m) thick in northwestern Cass County and is interbedded with chert nodules and lenses. When traced in a northerly direction it thins to about 35 ft (11 m) in the Central Commercial District of Kansas City and is relatively free of chert. It is easily recognizable in numerous street excavations by the light-gray thin, wavy bedding. The Argentine is about 30 ft (9 m) thick at Parkville and thins to less than ten feet at Smithville, about 15 mi (24 km) north of Kansas City. When traced westward into Johnson County, Kansas, the Argentine varies considerably in thickness over short lateral distances. Decreases in thickness from 70 ft (21 m) to a few feet in less than a mile is a common occurrence. Areas of increased thickness are believed to have been marine banks that supported a thick growth of phylloid algae. Fine-grained carbonate sediment trapped by the algae accumulated on the shallow warm sea floor to form carbonate "buildups," (Crowley, 1969).

Mining of the Argentine is by the room and pillar plan. The ceiling height in mines range from 12 to 30 ft (4 to 9 m) and are dependent on the thickness of the unit. Several feet of limestone are left for roof support but roof bolting is necessary because of the thin-bedded nature of the unit. A description of the Argentine Limestone and associated strata is given in Figure 3, Field Trip Itinerary - Day 1.

The overlying Island Creek Shale is relatively impervious and forms a seal preventing water seepage into the mine. The Island Creek varies considerably in thickness. It is 30 to 40 ft (9 to 12 m) thick in southern Platte County and thins to a few inches at places in Johnson County. The Island Creek was deposited around and over the algal banks in the Argentine Limestone and is thickest where the underlying limestone is thin. The lower few feet of the Argentine form the floor in some mines whereas in others the Quindaro Shale is removed and the floor is placed on the Frisbie Limestone. The mined limestone is crushed to various sizes and used in construction and as an aggregate in asphalt paving.
Figure 2. Representative section of rock strata exposed at mine entrance. The rock units are in ascending order: No. 1, Hushpuckney shale; No. 2, Bethany Falls limestone; No. 3, Galesburg clay; No. 4, Stark shale, and No. 5, lower part of Winterset limestone. The ceiling coincides with a prominent bedding plane in the thick, even beds of limestone that form the roof.
Why The Move Underground?

There are many reasons for the large scale development and utilization of mined out areas at Kansas City, but foremost is the (a) availability of vast areas underground that could be developed at low cost, and (b) the geographic location of Kansas City as a hub of transportation near the center of the nation. Kansas City lies between the food producing West and the food consuming East and the vast underground is ideal for the storage of foodstuffs.

The construction costs involved in the preparation of occupancy of most abandoned mines is relatively inexpensive compared to surface facilities of comparable size. The ceiling, foundation and supporting facilities already exist. About 90% of the utilized space is for storage. Preparing an area for storage includes scaling loose rock from the pillars and ceiling, laying a floor of concrete or asphalt, applying a coat of white paint and installing electricity and ventilation systems for heating, cooling and humidity control. The temperature of undeveloped mine areas averages about 56°F (13°C) and the temperature fluctuation between winter and summer seasons is only a few degrees. The cost of heating and dehumidification to bring them to a comfortable temperature is relatively inexpensive. Savings are as much as 90% in warehouse areas to 50% in refrigerated areas.

The savings in rental costs which average 40% less than comparable surface facilities, is the major reason most users give for moving underground but there are other unique advantages. Underground areas are free of surface hazards of tornadoes, high winds, sonic booms and lightening, and are relatively free of noise and vibrations. A vibration free environment is essential for certain manufacturing processes, for example, the manufacture of precision instruments. Underground facilities are virtually burglar and fire proof and as a result insurance rates are generally lower.

An additional advantage is that floor weight capacity is almost unlimited.

There are some disadvantages and these should be considered before the decision is made to move underground.

The ceiling height is limited to about 12 to 14 ft (4 m) in most underground areas and it is economical to store some commodities in surface structures with large vertical dimensions.

Maintaining a fresh air supply to underground facilities adds to the cost, particularly in areas where the removal of toxic and irritating gases, from spray painting, operation of diesel equipment, etc., is a necessity.

Although most workers appear to prefer the underground atmosphere, some people suffer from claustrophobia while others have a psychological fear of going underground.

A fire in an underground area is difficult to extinguish. An adequate sprinkler system is of major importance.

Water seepage sometimes occurs in the best planned and constructed underground areas and prevention measure are costly and difficult to administer.

Last but no least, the possibility of roof failure is always present in an underground area although the likelihood of this happening in properly constructed mines is negligible.
THE GENERAL GEOLOGY OF METROPOLITAN KANSAS CITY

Kansas City is built on layers of sedimentary rock that were formed during two widely separated intervals of geologic time: the Pennsylvanian Period and the Quaternary Period. The Quaternary rocks form a thin, discontinuous sheet and rest unconformably on the older Pennsylvanian rocks. The combined thickness of exposed rocks is about 350 ft. (105 m.), measured from the bottom of the lowest valley to the top of the highest hill.

Pennsylvanian Rocks

The Pennsylvanian rocks consist of beds of limestone and shale with minor amounts of sandstone, coal and conglomerate. The sediments were deposited in a variety of environments including shallow seas, estuaries, lagoons, tidal flats, alluvial plains and swamps. Each distinct environment was characterized by its own sediment types and ecological niches.

In general, the sediments comprising thick limestone beds, most black and some gray shale beds were deposited in shallow seas during times of marine inundations whereas the sediments that comprise most beds of gray shale, sandy shale, sandstone and thin coal beds represent the deltaic lobes that built outward as the sea withdrew. The combined thickness of the two contrasting rock groups ranges from several feet to over 75 ft (23 m) and represent the sediments that were laid down during one inundation (transgression) and one withdrawal (regression) of the sea, sometimes referred to as a depositional cycle or "cyclothem." Several successive depositional cycles arranged in orderly fashion are easily distinguished in the rock section in bluffs and road excavations in the Greater Kansas City area. It is estimated to have taken 235,000 to 400,000 years for one transgression and one regression of the sea across the low lying interior of the North American continent (Heckel, 1986).

The shoreline shifted position with the advances and retreats of the sea across the midsection of the North American continent. At times the shoreline passed through the Greater Kansas City area, extending from Iowa across northwestern Missouri, southeastern Kansas and into Oklahoma. An extensive river system carried large amounts of sediment eroded from the northern Appalachians, southern Canada and to a lesser degree from the Ouachita Mountains of Arkansas and eastern Oklahoma. The loads of sediment were deposited along the shoreline and formed a vast deltaic complex (Fig. 1). Deltaic lobes of soft mud several 10s of feet thick and covering hundreds of square miles spread over the Greater Kansas City area. Numerous environments existed in the coastal waters and on the deltaic plain. A braided system of distributary streams, possibly resembling the birdsfoot pattern of the modern Mississippi delta, spread across the deltaic plain; eventually the channels filled with sediment, especially sand, and were forced to follow new routes. In the areas between the channels there existed fresh to brackish water lakes and ponds, and extensive swamps. Each had its own unique types of organic life and sediment types. Abundant vegetation accumulated in vast swamps to form layers of peat. Thin beds of coal in the rock sequence are evidence that swamp conditions existed for short periods of time; the remains of nonmarine types of organisms, particularly plants found in some of the shale and sandy shale beds, indicate an emergence of the land with sediment deposition taking place under riverine conditions. During time of flood the streams overflowed their banks and plumes of silt and clay spread into the inter-distributary channels.

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Figure 1. Paleogeographic map of the midcontinent United States during the Pennsylvanian Period. The diagram illustrates an instant of time when the sea was retreating westward. Deltaic lobes of mud built outward into the sea that teemed with life. On the deltaic plains, the distributary channels became choked with sand, and peat accumulated in swamps between the channels.
areas. At places where the channels emptied into the sea, currents carried clay and silt offshore into clear warm waters, eventually to settle to the bottom to form thin layers of mud.

A retreat of the sea was followed by a sea advance and as the water level rose, areas of deltaic sedimentation were covered by clear warm marine waters that teemed with life, in particular invertebrate organisms that extracted calcium bicarbonate from the sea water to make their skeletal parts. The shells, spines, plates, etc. of the calcium carbonate-secreting organisms accumulated on the sea floor and covered vast areas. Minute crystals of calcite (calcium carbonate) precipitated from sea water by chemical processes added to the deposit of skeletal debris.

Most of the rock section, especially the limestone beds and some shale beds were deposited in open marine or brackish water environments. They contain the fossilized remains of abundant shallow water marine organisms including algae, protozoans, sponges, corals, brachiopods, bryozoans, mollusca, arthropods, and echinodermata; also, some fossils of unknown zoological affinities such as conodonts and connularids. The remains of vertebrates, particularly the teeth of shark-like fish are found occasionally.

A combined thickness of over 3,000 ft (915 m) of Pennsylvanian age strata arranged into 50 depositional cycles has been recognized in deep well records and surface exposures in the midcontinent region from Texas to Pennsylvania, an indication that the sea transgressed and regressed across the midsection of the continent from west Texas to the foot of the Appalachian Mountains no less than 50 times during the Pennsylvanian Period. Numerous lines of geological data support the premise that the sea was shallow and never more than a few hundred feet deep during maximum transgression. During times of maximum regression the land surface rose 200 or 300 ft (61 to 91 m) above sea level. The mechanism that produced the repeated fluctuations of the sea across the low lying interior of the North American continent has been debated by geologists for over 75 years. A widely accepted scenario attributes the fluctuations in sea level to a combination of factors, including glaciation in the southern hemisphere and the instability of the continental interior caused by the building of the Appalachian and Ouachita Mountains as the continents collided to form the supercontinent of Pangaea (Klein and Willard, 1989). Continental glaciation was widespread in the southern hemisphere during the Late Paleozoic, including the Pennsylvanian Period. During a glacial interval the buildup of thick ice sheets on southern hemisphere continents lowered sea level world wide and resulted in a retreat of shallow seas from low lying continental areas, whereas the disappearance of continental ice sheets by melting during an interglacial warming trend released water into the ocean basins and as sea level rose the low lying regions were inundated by transgressing seas. According to this theory, at least 50 glacial advances and retreats occurred on southern hemisphere continents. The preservation of a thick sequence of sediments is explained by the slow subsidence of the continental interior caused by the crustal forces that built the Appalachian and the Ouachita Mountains as the continents collided to form Pangaea. These forces acted to a lesser degree in the midcontinent region and by slow subsidence a shallow catchment basin was formed in which a thick sequence of sediments accumulated. The filling of the shallow basin with sediments kept pace with subsidence and the elevation of the area remained near sea level. Consequently, a deep marine basin never formed. A rise (or lowering) of sea level a few tens of feet by the waxing and waning of continental glaciers in the southern hemisphere sent the sea pulsating hundreds of miles across
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* Assigned to Holocene Series in Missouri

Figure 2. Stratigraphic units of the Quaternary System in northeastern Kansas and northwestern Missouri (after Bayne et. al, 1971).
the low lying interior of the continent.

Although the details of how the rock section was built are still being debated, there is general agreement that the sequence of strata that we observe in road cuts and river bluffs in the Kansas City area have had a complex history. The processes that formed them acted over a long interval of time and were controlled by regional, as well as, worldwide events.

Quaternary Rocks

Surficial deposits of glacial till, stratified drift (outwash), alluvium, loess and soil of Quaternary age, cover the Pennsylvanian bedrock. The subdivisions of the Quaternary Period in northeastern Kansas and northwestern Missouri are shown in Fig. 2. The till and outwash, of Kansan Age, Pleistocene Epoch, is over 30 ft (9 m) thick and caps many of the higher hills in areas north of the Missouri and Kansas Rivers but it has been removed by erosion along the valleys of the major tributary streams, and in most places south of the Kansas and Missouri River valleys. Deposits of till and outwash gravels are uncovered in excavations in localized areas south of the major rivers, including downtown Kansas City, evidence that glacial lobes pushed south of the modern day channels of the Missouri and Kansas Rivers. The flood plains of the Missouri and Kansas Rivers are underlain by alluvium of sand and gravel of late Pleistocene and Holocene age over 180 ft (55 m) thick in places.

Recently, the Kansan, Aftonian, and Nebraskan stages have been reclassified and placed in the informal division Pre-Illinoian (Richmond and Fullerton, 1986; Morrison, 1991; and Aber, 1991).

The Kansan drift has an age range between 0.7 and 0.6 million years based on radiometric dating of volcanic ash biostratigraphy, and paleomagnetism of till (Aber, 1991).

A cover of loess overlies the glacial till and outwash gravels except in areas where the drift is absent. At these places, the loess rests on Pennsylvanian bedrock.

The loess along the bluffs adjacent to the Missouri and Kansas rivers is over 75 ft (22 m) thick and is well exposed in the face of high road excavations from Highway M210 from North Kansas City to Missouri City. Loess is easily recognized by the brown color and the property of standing in vertical face in excavations. The silt is believed to have been blown from the floodplain of the Missouri River by westerly winds and deposited on the river bluffs. The thickness diminishes with distance away from the major rivers and the loess is less than 15 ft (5 m) thick a few miles from the major rivers.

Modifications of the Stream Drainage Pattern by Glaciation

Preglacial Drainage

The following scenario is presented to explain the modification of the stream drainage pattern in the metropolitan Kansas City area. In pre-Pleistocene time, before the climate grew colder and the first ice sheet advanced, the stream drainage pattern was very different from that of today. The present drainage pattern does not coincide with the earlier channels, Fig. 3. The location of the buried channels and valleys has been reconstructed mostly from test borings but in some places the configuration of the preglacial bedrock surface has been exposed during the
present erosion cycle (Heim and Howe, 1963).

The ancestral Missouri River entered northwestern Missouri near the present-day town of Tarkio and flowed in a southwesterly direction to near Carrollton where it was joined by the ancestral Kansas River. The ancestral Missouri River from Carrollton to Nebraska is believed to have been a southeastern continuation of the present-day Platte River that flows across Nebraska and enters into the Missouri River north of Omaha.

The major river that drained the Greater Kansas City area was the ancestral Kansas River. The segment of the Missouri River from Kansas City to Carrollton is following in the ancestral Kansas River Valley.

![Map of Missouri River Valley](image)

**Figure 3.** Preglacial drainage system of the Lower Missouri River Valley before the land was reshaped by southward advancing ice sheets and the drainage modified during the Pleistocene Epoch (modified after Dreezen and Burchett, 1971).
Glacial Drainage

The continental ice sheets of the Pleistocene reshaped the topography and modified the drainage system. The ancestral Missouri River (Platte) drainage shifted southwestward in front of the advancing glacial lobes.

As successive ice lobes advanced southward, the drainage of the ancestral Missouri River shifted anew along the margin of the ice sheets. The ancestral Missouri River was repeatedly pushed southwestward. Figure 4 is a schematic sketch of the drainage at a time before the arrival of the Kansan ice sheet. The major river draining the area was the ancestral Kansas River.

The Kansan glacier set the course of the present-day Missouri River. As the drainage of the ancestral Missouri River shifted southward in front of the ice advance, the waters of the ancestral Missouri emptied into the valley occupied by the ancestral Kansas River and the waters of the two rivers united to form the segment of the Missouri River from Kansas City to Carrollton.

At the time of maximum ice advance, about half a million years ago, an ice lobe of the Kansan glacier moved into downtown Kansas City (Fig. 5).

An estimate of the thickness of the ice can be made from the difference in elevations of till deposits. Several feet of weathered till was exposed in an excavation for Interstate Route 670 at 14th and Summit Street near the highest elevation in downtown Kansas City, about 950 ft (290 m) above sea level, and samples of till were recovered from bore holes at an elevation of about 550 ft (170 m) above sea level in a buried glacial channel below the floodplain southwest of the confluence of the Kansas and Missouri Rivers (O'Connor and Fowler, 1963). The difference in the elevation of 400 ft (120 m) is an indication of the minimum thickness of the ice sheet that filled the deepest channels and covered the highest hills. This figure is based on the assumption that the till at the two elevations was deposited from one ice lobe.

The ice lobe dammed the eastward flowing ancestral Kansas River. Meanwhile, a second ice lobe moved across the river in eastern Jackson County, just north of the present day town of Buckner. Large ice margin lakes of glacial meltwater formed upstream from the places where the ice obstructed drainage (Fig. 5). Drainage became diverted through outlet channels that breached low divides between streams. Torrent of meltwater were diverted into the Lower Turkey Creek Valley and the Lower Little Blue River Valley, eroding the valley walls and deepening the channels to over 180 ft (55 m).

Localized deposits of drift with glacial erratics are found as far south as Lee’s Summit in southern Jackson County, about 15 mi (24 km) south of the southernmost advance of the ice sheet. These small isolated patches of drift probably are the remnants of an outwash plain or apron that built out from the glacier by meltwater streams flowing from the ice front. Nevertheless, glacial erratics far removed from the ice front present the perplexing problem of how they were transported across deep channels carrying torrents of meltwater along the margin of the ice sheet. Perhaps the ice surged over the river by "bridging" it during an interval of reduced flow.

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Figure 4. Pre-Glacial drainage system at Kansas City.
Figure 5. Drainage at time of maximum glacial advance at Kansas City.
An alternate hypothesis, as the diversion channels overflowed large meltwater lakes were formed and the drift could have been rafted to the present location on icebergs.

Postglacial Drainage

The drainage of the Missouri and Kansas Rivers was re-established with the melting of the ice lobes that blocked them. The torrents of meltwater were no longer diverted through the Lower Turkey Creek Valley and the Lower Little Blue River Valley and as the channels were abandoned, they filled with alluvium. A "boulder bed" over 30 ft (9 m) thick, overlying the Pennsylvanian bedrock, was exposed at Graysone Heights between Turkey Creek and the Kansas River (McCourt et al., 1917). Attesting to the turbulence and velocity of the water was a hornblende gneiss erratic about 2 ft (0.5 m) in diameter that was found embedded in layers of coarse sand in an excavation for the City of Buckner Sewage Treatment plant located in the Lower Little Blue River Valley in Eastern Jackson County.

The wide valleys once filled by raging torrents of water released from the melting ice sheet are visible to the present day (Fig. 6). The Abandoned Lower Turkey Creek Valley, is about 6.5 mi (10.4 km) long and averages 0.5 mi (0.8 km) wide. The principle rail lines entering Kansas City and the terminal at Union Station are constructed on the floor of the abandoned glacial valley.

The Abandoned Lower Little Blue River Valley, also known as the Lake City Valley is approximately 13.0 mi (21 km) long and 0.5 to 1.0 mi (0.8 to 1.6 km) wide. The small towns of Levasy, Buckner and Lake City are located along the valley floor. Floodwaters from the Missouri River may have been diverted through the Little Blue River Valley at the close of the Wisconsinan glaciation, only a few thousand years ago.

As the Kansan glacier continued to recede, the sediment carrying capacity of the Missouri and Kansas rivers decreased; the deep channels eroded by the gouging action of moving ice and large volumes of meltwater became filled with alluvium. Alluvial deposits in places over 100 ft (30 m) thick underlie the broad floodplains of the Missouri and Kansas River valleys and are almost as thick in the lower river valleys of the Little Blue and Big Blue Rivers.

Large quantities of ground water for industrial purposes is obtained from wells drilled into the alluvial deposits of sand and gravel, especially in areas of North Kansas City built on the floodplain.

In upland areas, the streams that had eroded channels into Pennsylvanian age bedrock before the advance of the Pleistocene glaciers became covered by a mantle of glacial drift. The drift sheet filled and covered the preglacial valleys and stream channels. We can only speculate about the configuration of the upland areas shortly after the Kansan ice sheet melted from the area. The terrain was probably poorly drained with numerous lakes and ponds, and may have resemble recently glaciated regions in the Great Lakes Region.

Moving ice, running water and air currents all played a role in the formation of the blanket of loess that covers the Greater Kansas City area.

The thickest loess deposits are believed to have accumulated near the close of a glaciations. Recession of the ice sheet released large volumes of meltwater, with a high sediment load including an abundance of silt (glacial flour), that inundated the floodplains of
Figure 6. Present drainage system and location of abandoned stream valleys at Kansas City.
the Missouri and Kansas Rivers. At the close of a glacionation the flow of meltwater decreased and the rivers returned to their channels but a layer of silt several feet thick was left behind on the floodplains. The exposed silt was picked up by the westerly winds and deposited on the bluffs along the major rivers and in lesser thicknesses over the Greater Kansas City area. The blanket of loess followed the contour of the land, draping itself over the hills and valleys.

The oldest loess deposits date to the retreat of the Kansan glacier about 600,000 years ago. The later ice advances, the Illinoian and the Wisconsin did not extend into northwestern Missouri but stayed far to the north in Iowa. Nonetheless, their presence is represented by the deposits of loess in the Greater Kansas City area. Large volumes of meltwater choked with glacial flour flooded low lying areas far down stream from the ice front. The silt that was left behind on the floodplains after each glacionation was picked up by the wind and deposited over the surrounding uplands. It stands to reason that an appreciable thickness of loess also accumulated during the warming trends within the major glacial intervals.

The youngest deposits of loess were formed as recently as 15,000 years ago, when the Wisconsin glacier was receding from the Upper Mississippi Valley region and large volumes of meltwater from the vanishing ice sheets flooded low lying areas down stream to the Gulf of Mexico.

The loess cover diminishes in thickness away from the major rivers. It is 75 ft. (22 m) thick on the bluffs along the Missouri and Kansas Rivers and is less than 15 ft. (5 m) thick throughout most of the Greater Kansas City area.

Successive layers of loess are separated by unconformities, Fig. 7-8. Physical evidence for an unconformity is a buried soil zone that represents an interval of weathering and soil formation when little, if any windblown silt was deposited on the bluffs. Buried soils technically known as paleosols, are well represented in exposures of loess in the bluffs along the Missouri and Kansas Rivers. The thick, well-developed soils are believed to be evidence of interglacial intervals when the climate moderated and the glaciers became confined to the higher latitudes. Interglacial intervals appear to have lasted over 200,000 years and were somewhat longer than glacial intervals.

Thin, poorly defined soils are believed to have formed in short intervals of time and were controlled by minor climate fluctuations during the glacial intervals. Two or three, poorly defined, buried soils were uncovered in the Wisconsin loess during construction of Highway M 210 near North Kansas City (Bayne et al., 1971). These brief periods of soil formation are believed to correspond to minor advances and retreats of the Wisconsin glacier in areas bordering the Great Lakes Region and in Canada (Fig. 9).

Throughout most of the Greater Kansas City area the loess rests directly on Pennsylvanian-age bedrock because the intervening deposits of glacial drift were removed by erosion subsequent to the deposition of the loess. Although the glacial drift is patchy in areal extent, thick sections of loess rest on glacial drift along the Missouri River bluffs. In deep road excavations for Highway M 210, at Nebo Hill, 4 miles (6.5 km) southwest of Missouri City, the section consists of beds of Pennsylvanian limestone and shale overlain by 50 ft (15 m) of glacial till which in turn was overlain by 75 ft (23 m) of loess. Two well developed buried soil profiles were recorded in the loess and a deep modern soil is developing on the loess.
Figure 7. Excavation in a loess bluff for Missouri Highway 210 at North Kansas City, Missouri. The loess is about 65 ft (20 m) thick and has shown only a slight tendency to slump in 1985 over 10 years after the bluff was excavated. The arcuate-shaped band with the ends dipping below road level is a well-developed, buried soil profile. A close-up photograph of the soil profile is shown in Fig. 8 and a sketch of the bluff is shown in Fig. 9.

Figure 8. Detailed view of a "buried" soil developed on Illinoian loess during the Sangamonian Interglacial. The vertical, closely-spaced fractures are called shrinkage cracks and form when soil with a high clay content loses moisture and contracts.
Legend

4. Wisconsin loess with 2 or 3 poorly defined soils; Holocene (Recent) soil at top.

3. Weathered Illinoisan loess with well-developed soil profile (Sangamonian)

2. Kansan silt (loess?)

1. Kansan outwash and till - sand and gravel, many erratic rock and mineral types, mostly covered

Figure 9. Sketch of the excavation into a loess bluff along Missouri Highway 210 at North Kansas City, shown in photograph, Figure 7.
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