

Kansas City: World Leader in Underground Space Utilization

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Geologic and Engineering Aspects of Space Development

Introduction

The area around Kansas City, Missouri, supports the greatest concentration of limestone mines developed for human occupancy in the world (Stauffer, 1978a), and serves as a model for adaptation of underground space to secondary commercial uses. Of thirty-five local limestone mines, eighteen are currently adapted for some type of secondary use, and 12 lease to tenants (Spencer, 1990). More than 300 tenants lease space, employing more than 3000 people. The first large mined space in the area to be adapted to secondary use was probably in Atchison, Kansas, located about 80 km northwest of Kansas City, where, in 1944, the Commodity Credit Corporation developed about 60,000 m² (15 acres) for storage of commodities (Dean, 1975). The area's second development was opened in 1946 in Bonner Springs, Kansas, just west of Kansas City. In 1953, a cold storage operation was started in Kansas City, Kansas, by two developers in partnership with the Santa Fe Railroad. In 1955, the Brunson Instrument Company completed the first mine developed specifically for a single manufacturing use. One impetus for increased secondary development of underground space in the region was provided by the Cold War events of the early 1960s, when the federal government expressed interest in utilizing underground space in Kansas City, and elsewhere, for Civil Defense purposes. Today, more than 2,000,000 m² of developed space are in use, with an additional 6,000,000 m² of potentially-developable space available in the local mines.

Geologic Considerations

The Kansas City area is underlain by sequences of shale, limestone, and sandstone (Fig. 1). Two limestone members are mined to create space for secondary occupancy: the Bethany Falls Limestone and the Argentine Limestone. Several characteristics of the local geology combine to create suitable environments for mining and secondary development of space:

1. Adequate limestone thickness: room heights of 3.6-4.5 m (12-15 feet, ft.) are required for developments. In addition, the upper 1-2 m (3-6 ft.) of the limestone are left in place to provide roof support. Where mined, the thickness of each unit is greater than 6 m (20 ft.).
2. Compositional uniformity: the mined limestones are relatively homogeneous and uniformly-bedded, with thin shale partings. This provides high-quality rock for primary use (mostly crushed-rock aggregates), as well as sufficient strength for pillars to support the mine roof.
3. Adequate, competent overburden: an adequate thickness of overlying rocks is needed to provide roof stability, preserve surface integrity, minimize water seepage, and protect against erosion and mass wasting. An overburden thickness of at least 12 m (40 ft.) is desirable.
4. Favorable geologic structure: regional dip is generally less than 1° to the northwest, off the Ozark Uplift, and in many places beds are practically horizontal. This simplifies both the mining and construction phases of

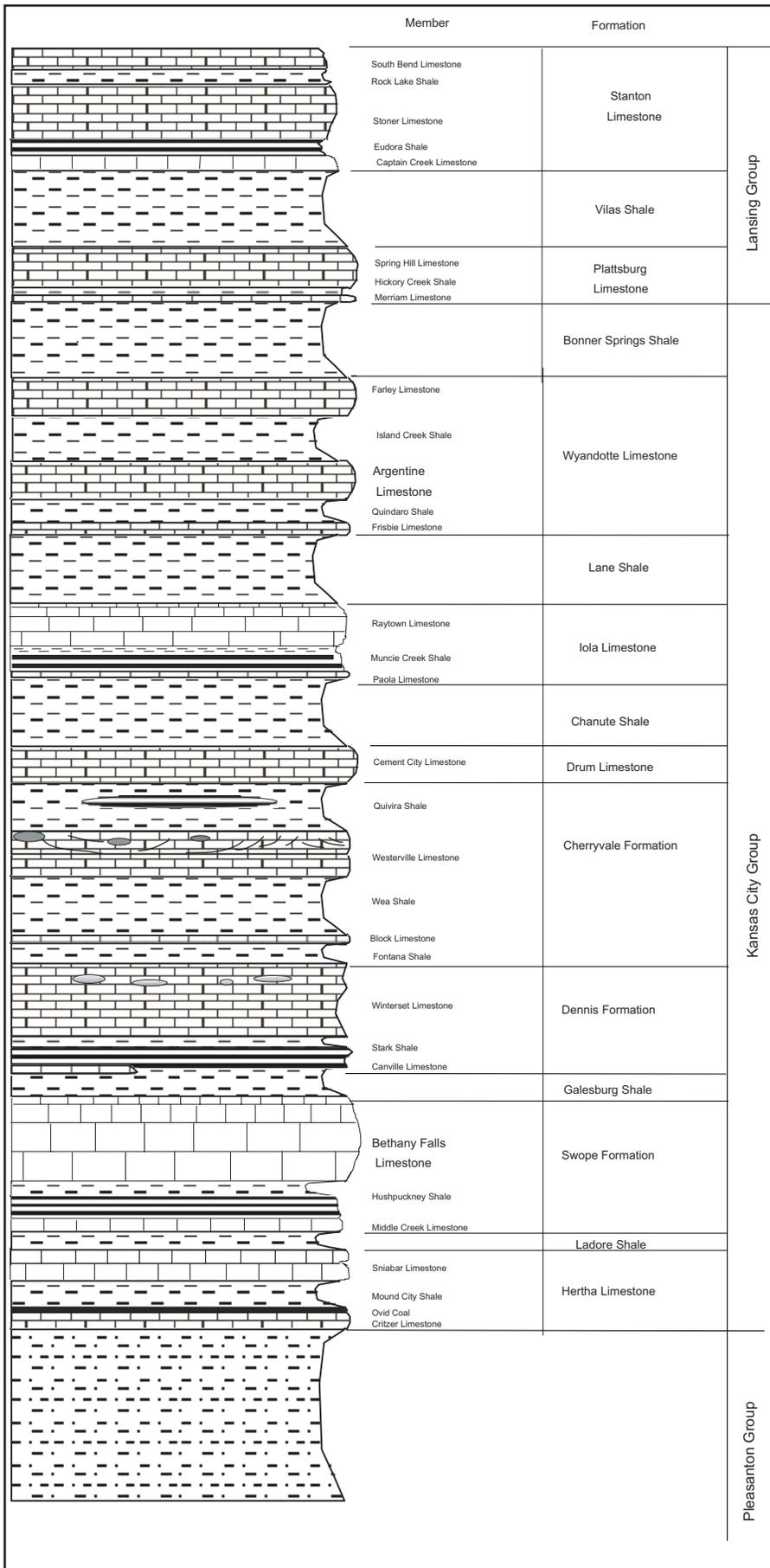


Figure 1. Stratigraphic section of Pennsylvanian System rocks exposed around Kansas City, Missouri. The two locally mined limestone units are the Argentine Member, Wyandotte Formation, and the Bethany Falls Member, Swope Formation.

development. In addition, the fairly uniform spacing of vertical joints facilitates mining and pillar placement.

5. Accessibility: limestone beds are exposed along the sides of stream valleys, which allows for construction of roadways directly into the mines (as opposed to requiring the use of elevators or lifts that limit access).

Despite the overall favorable geologic environment, several minor issues exist related to the local geology. One problem that has occurred in mines developed in the Bethany Falls is floor heave, which can produce damage ranging from slight cracking or bulging of floor slabs, to offsets of several centimeters in floors and damage to concrete block or other interior walls. The phenomenon was first noted during ceiling-height inspections in one of the older mines. Periodic measurements indicated that the floor-to-ceiling height was decreasing, yet close examination of the roof revealed no evidence of rock slab separation. After considerable investigation, it was discovered that the floor slab was moving upwards due to heaving in the underlying Hushpuckney Shale. The Hushpuckney contains a layer of hard, thin-bedded shale. Heaving is the result of a combination of pressure release produced by the removal of overlying limestone (which creates separation along bedding planes), followed by growth of hydrated sulfate minerals in the bedding planes (Coveney and Parizek, 1977). Heaving is practically impossible to prevent if the Hushpuckney Shale is left in place, so in many of the newer mines the shale is removed and concrete floors are constructed atop the Middle Creek Limestone.

The limestones contain small amounts of uranium, and the Hushpuckney Shale is a uranium-rich rock. Radon gas generated from these rocks can migrate into the mines. The identification of radon as a possible health risk (in the mid-1980s), and of black shales (like the Hushpuckney) as possible radon sources, prompted a concern that the local underground developments might contain elevated levels of radon. However, the results of radon testing in nearly all of the local developed mines (Hilpman et al., 1988) revealed radon concentrations generally below 37 Bq/m³ (10 pCi/L), with occasional higher concentrations found in spaces where air circulation is restricted. Areas in which there is considerable air flow may have radon levels of only 4 to 8 Bq/m³ (1 to 2 pCi/L). In general, the ventilation required to achieve acceptable CO levels (resulting from vehicle exhaust) also reduces the concentration of

radon. The fact that radon levels were so low in the mines, even where black shales were exposed, led to further studies that concluded that the black shales are not particularly significant sources for radon in local homes and businesses (Spencer, 1993; 1995; 2000).

Ground water seepage, which occurs along bedding planes and weathered joints, may also pose problems. Areas near the perimeter of the mines, close to the hillsides, are most susceptible and these areas are not typically used for secondary development. Seepage through overburden and roof rocks may affect roof stability. Several cases of piping of overburden soil into mines have been reported over the years. This process has led in some instances to surface subsidence.

Mining and Engineering Considerations

All of the local mines are “room-and-pillar” operations. Because the original purpose of most of the mines was solely the extraction of rock, early mining practices sometimes resulted in irregularly-shaped pillars and room patterns (see Fig. 2, upper portion). In some cases, the pillars were not large enough to provide adequate roof support, which resulted in roof collapse. In addition, blasting often produced “overbreak” in the roof rock, which reduced the thickness of

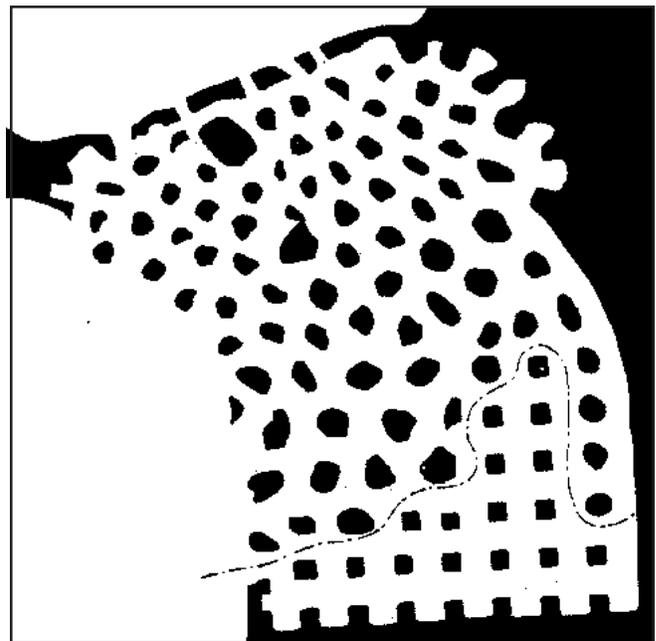


Figure 2. Diagram illustrating pillar dimension and placement. In early mining operations, less attention was paid to pillar size, shape and placement (upper part of diagram), whereas more recent practices involve creation of a pillar pattern that is conducive to secondary development (lower part of diagram).

the roof, and also contributed to potential roof instability. Because the locations of most of the mines were originally on the fringe of the urban area, little attention was paid to the effects of mine design or instability on the property above.

Failures of mine roofs typically occur in two ways: debris fall and slab fall. Debris fall - the less serious of the two - involves displacement of small pieces of rock that were loosened during mining. Although most of these fragments are scraped off (scaled) prior to painting the ceiling, it is common for pieces ranging in size from a few millimeters to a few centimeters to continue to dislodge long after secondary development has occurred. Slab falls are major collapse events that involve large, tabular pieces of limestone up to several tenths of a meter in thickness, which fail along bedding planes in the roof rock. Collapse can also involve overburden rocks, an event called a "dome out," which may produce surface subsidence. For example, an office park located south of the Indian Springs Shopping Center (in Kansas City, KS) had to be abandoned due to the formation of sinkholes following two roof collapses in the mine beneath. All occupied underground space developments carry out periodic inspections of ceilings for loose rock and evidence of movement. Measurements of ceiling height are made with an extendible steel rod, called an extensometer, which is placed atop a surveyed benchmark (a steel pin embedded into the mine floor) and extended to a pin in the ceiling. Ceiling height data are plotted over time, and analyzed for any decreases that might indicate movement of the roof.

The recognition that the mined-out space could be adapted for secondary uses, combined with the incorporation of many of the mines into urban or suburban communities (where the lack of ability to use the surface land productively became an issue) required some changes in the approach to mining. Emphasis is now placed on roof stability, consistent ceiling height and regularity in pillar spacing and room size.

Stabilization of the mine roof is achieved using roof bolts, steel rods (about 20 mm in diameter and 1 to 3 m long) that have an expansion shell at the top, and threads at the lower end. The bolt is inserted, expansion shell first, into a hole drilled through the ceiling into overlying rock layers. It is torqued to set the expansion shell, which holds the bolt in place by friction. Bolts may also be held in place with grout or epoxy. A steel bearing plate (about 15 cm square and 6.5 mm thick) with a center hole is placed over the threaded end of the bolt and

secured with a nut. The required number and spacing of roof bolts depends on the amount of extra support needed, but generally they are placed at 1 to 2 m intervals.

Current mining practice involves creating a rectilinear pattern of pillars and rooms (see the lower portion of Fig. 2). Pillars are square, or rectangular, with dimensions of 6 to 9 m (20-30 ft.) on a side, placed approximately 15 to 18 m (50-60 ft.) on center. This leaves a corridor between the pillars of about 9 m (30 ft). Although these revised practices yield less rock, the value of the secondary space far exceeds the loss in crushed-rock revenues.

Mine entrance points are typically "at-grade" (Fig. 3). The typical pillar spacing permits the construction of roads wide enough for two-way traffic (about 7.5 m, 25 ft). Truck and railroad docks in the mine are designed so that the

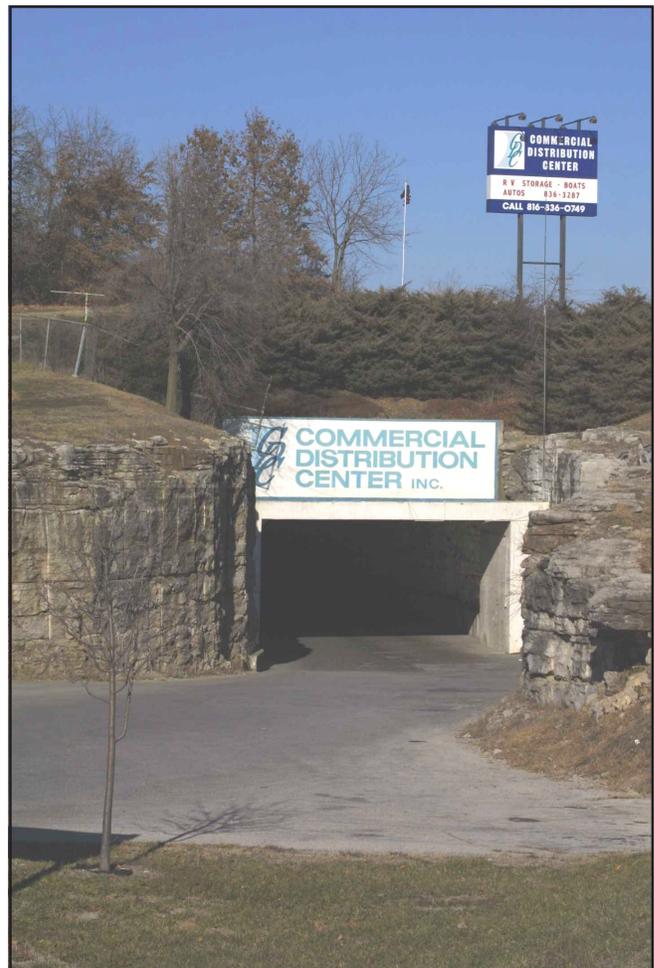


Figure 3. Entrance to Commercial Distribution Center, an underground warehouse facility developed in the Bethany Falls limestone. Note that the upper 1-2 meters of rock have been left in-place above the tunnel ceiling, to form the mine roof. (Image by Ken Stalder)

warehouse floor elevation is at the same height as the trailer (or rail car) floor. This requires that road beds in dock areas be excavated about 1 m below the warehouse floor elevation. Mines generally have two roadway entrances, on opposite sides of the mine, which facilitate traffic movements and allow cross-ventilation of the mine. Additional air flow is achieved through the use of fans in roadways, and in some cases installation of air shafts to the surface.

Construction, and Types, of Secondary Development

Construction practices in the underground are generally the same as those used to build surface facilities. Local building and fire safety codes apply (newer developments have sprinkler systems and emergency lighting). Water and electrical supply lines are generally suspended from the mine ceilings. Floor drains and sewer lines are typically installed in subfloor trenches,

and directed to either gravity flow sanitary sewers, or to collection sumps (from which sewage is pumped into ceiling-mounted sewer lines). Pillars are usually painted white to improve lighting efficiency, and suspended ceilings are common in office spaces (Fig. 4).

Underground warehouse and office space can usually be constructed at considerable savings over surface facilities, and these savings are passed along to tenants in the form of lease rates up to 40% lower than in equivalent surface buildings. One of the greatest attractions for locating underground is reduction in heating and cooling costs. Average temperatures in the mines approximate the mean annual temperature in Kansas City (about 14 °C, or 58 °F). Furthermore, mine temperatures exhibit annual variation of only a few degrees (depending on extent of mine ventilation and proximity of a space to the mine entrance). This temperature stability results in substantial energy savings. Humidity levels in the mines are also relatively stable, and facilities that require



Figure 4. Entrance to the McAfee Library at Park University, developed in the Argentine Limestone, showing the typical appearance of an office space development in the underground. Pillars are painted white to improve lighting. (Image by Ken Stalder)

humidity control can achieve it with minimal additional dehumidification costs.

Freezer (and refrigeration) operations realize energy conservation in part from the efficiencies attained by “freezing down” the surrounding bedrock. In the freezer storage operations in Kansas City, the temperature of the surrounding bedrock has been found to be below 0°C at distances of nearly 7 m from the interior surfaces, and the limestone pillars within the storage spaces are entirely at the operating temperature (Stauffer, 1976). Refrigeration costs decline over approximately three years as the temperature of the surrounding rock reaches the optimum level. Once operating temperatures are achieved, temperatures can be maintained using about two-thirds of the compressor capacity initially required (Williams,

1978). In addition, underground freezer/cooler spaces utilize the heat-sink capacity of the surrounding chilled rock to avoid the need to use refrigeration equipment to compensate for short-term, additional cooling demand (such as when new product is added to storage).

The major types of secondary developments fall into three categories: office, manufacturing and assembly, and storage. The latter category is further subdivided into dry storage (such as warehousing, record archives, etc.), cooler storage (temperatures around 5 °C, for food items that require refrigeration) and freezer storage (at temperatures well below 0 °C, for frozen food items). A summary of the usage categories, along with the approximate percentage of total area devoted to each, are presented in Table 1.

Table 1. Approximate proportion of developed secondary space devoted to major uses in limestone mines around Kansas City, Missouri, USA (data from Spencer, 1990).

Usage	Percentage of Total Developed Mine Area
Offices	4 %
Manufacturing/Assembly	9 %
Dry Storage	61 %
Cooler Storage	4 %
Freezer Storage	11 %
Roads, Docks, Railroads	11 %

Road Log

(Field trip stops shown on Figure 5)

Mileage

- 0.0 Airport Hilton, front parking lot. Exit the lot and turn east (right) onto 112th Street.
- 0.2 Ambassador Drive. Turn north (left).
- 1.2 County Highway D. Turn east (right).
- 1.5 I-435. Continue east on I-435.
- 20.0 Worlds of Fun amusement park located on the east side of the highway. Part of the park is situated above the Hunt-Midwest SubTropolis, the largest underground business development in the world.
- 21.4 Missouri Highway 210. Loess in roadcuts.
- 22.0 Missouri River. Sand dredging operation on the north bank of the river, east of the bridge. Station Casino, one of several local “River Boat” casino operations (which never actually cruised the river) is seen a bit farther east.
- 24.2 Hawthorne Road. The Hawthorne Power Plant (coal-fired) is seen to the east. Any interesting odors are emanating from the sewage treatment plant along the west side of the highway.
- 26.0 Truman Road. Turn east (left) onto Truman Road. The Bethany Falls limestone outcrops near road level.
- 30.0 Delaware Street. The Bess and Harry Truman home is located on the southeast corner of the intersection.

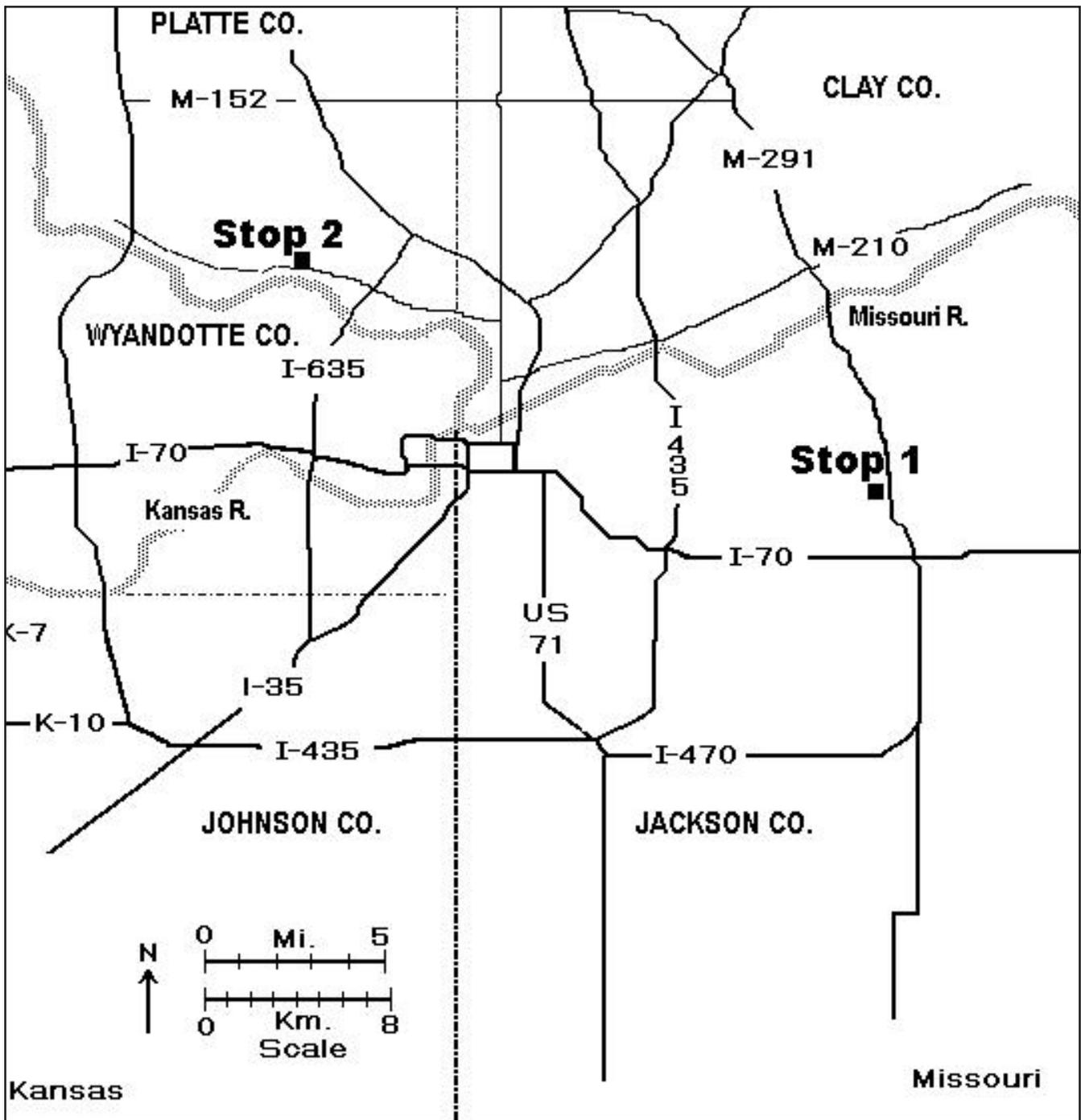


Figure 5. Map of the location of field trip stops within the Greater Kansas City metropolitan area.

32.2 **Stop 1. Commercial Distribution Center** (16500 East Truman Road, Independence, Mo 64051) (see Fig. 5) contains over 84,000 m² (900,000 sq. ft.) of developed space, much of it in freezer and refrigeration operations, in a mine developed in the Bethany Falls Limestone. We will spend about 2 hours touring the facility, looking at several types of developments, and discussing the geological and engineering aspects of using the underground.

Continue log from CDC entrance. Proceed east (left) on Truman Road.

32.5 Missouri Highway 291. Proceed under the highway to the ramp to northbound M-291. The lower exposed limestone is the Sniabar Member, Hertha Formation. The Bethany Falls is the next higher limestone unit. Turn north (left).

- 33.2 Independence Avenue. Entrance to Space Center underground storage facility.
- 35.5 Bethany Falls was mined in quarries along the roadway for use as crushed rock aggregate in construction of the highway.
- 37.3 Missouri River valley. City of Independence municipal well field is located along the west side of the highway. The metallic “mushrooms” are the well heads.
- 39.3 Missouri Highway 210. Turn west (left).
- 44.5 Hunt-Midwest SubTropolis is located on the north side of the highway.
- 45.4 Loess in road cut along south side of highway. We will pass several road cuts in loess over the next few miles. Notice that the cuts are made nearly vertically. Loess will stand in a vertical cut, however it is very erodible when cut at a lower angle.
- 45.9 I-435. Continue west on M-210.
- 49.7 City of North Kansas City, MO. This town is a separate entity from Kansas City (which surrounds it).
- 50.7 Burlington Avenue. Turn north (right).
- 51.3 Missouri Highway 9. Veer west (left) at intersection. The Kansas City Water Treatment plant is located north of the highway. Treated water is sent to the south side of the river through the Trans-Missouri River Tunnel, excavated in rocks of the Lower Marmaton and Upper Cherokee Groups, about 90 m (300 feet) below the floodplain elevation.
- 54.4 Interstate 635. (Our return route to the Hilton will be north on I-635 to I-29, then north to 112th Street). Just west of the interchange, along the north side of Highway 9, are exposed a section of rocks from about the Block Limestone Member, Cherryvale Formation (at road level) to the Lane (Shale) Formation.
- 56.2 Gasoline storage facility on the south side of the highway. Note the elevation of the 1993 flood marked on the side of one tank.
- 68.7 Entrance to **Stop 2. Park University** (8700 NW River Park Drive, Parkville, MO 64152) operates a commercial space development, and has several academic facilities, in a mine developed in the Argentine Limestone. We will spend about 1 hour touring the library, offices, and adjacent underground area.

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