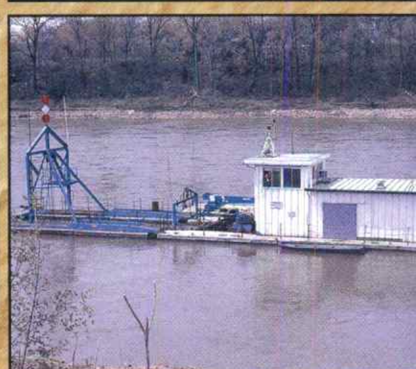
Primer of Industrial Minerals for Kansas





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Educational Series 13
Kansas Geological Survey
Lawrence, Kansas 66047
1999

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Introduction

The purpose of this publication is to educate and inform the public about various aspects of non-fuel industrial minerals that are found in Kansas and the impact of these minerals on our daily lives. The publication is written in non-technical language and discusses early mining in Kansas; the geology of the state; minerals that are currently mined, including where they are found, as well as how they are mined and processed into useful products; environmental concerns and the costs associated with these concerns; and a peek into the future.

Two terms that are used throughout this publication warrant definitions. An ***industrial mineral*** is any rock or mineral that has economic value, excluding metallic rocks or ores and fuels such as coal, oil, and natural gas. However, because lead and zinc production was so important in Kansas during the past, these metals are included in the discussion of industrial minerals. Helium also will be briefly discussed because it was and continues to be a major contributor to the state's economy. An ***aggregate*** is any hard, inert material that is used for mixing with a cementing or bituminous material to form concrete, mortar, asphalt, or similar product, or used alone, as in railroad ballast, road base, road covering, or fill.

We tend to take industrial minerals for granted; however, their products are everywhere. It is impossible to be in any area of construction without seeing them or their products. Consider buildings: at least some part is made from concrete that contains cement (fabricated from industrial minerals) and aggregate, the latter including crushed stone as well as sand and gravel. Cement block, lightweight concrete, sheetrock for interior use: all are made from industrial minerals. Most roads are constructed from concrete or asphalt that contain aggregate, and these roads also use aggregate as a road base. Unpaved county roads are often covered with aggregates. It is hardly surprising that aggregates are among the major industrial minerals produced in the United States with respect to tonnage. According to the U.S. Geological Survey (USGS), over 2.6 billion tons of aggregate were sold or used by U.S. producers during 1997. In Kansas alone, aggregate production included nearly 26 million tons of crushed stone and 12 million tons of sand and gravel, collectively valued at over $148 million. The U.S. Bureau of Mines estimated in 1990 that, considering all uses, nearly one million pounds of cement, sand, gravel, and stone are used per average lifetime of every American.

Early Mining History of Kansas

Mining in Kansas began hundreds of years ago with Native Americans who used clay for making pottery. Pottery shards that date back to around 1,200 A.D. have been submitted to the Kansas Geological Survey for examination. Flint and chert also were collected and processed by chipping into such useful products as scrapers, arrow and spear points, and other tools.

Mining continued with the early European settlers who sometimes used mud as a matrix or "cement" for stone construction during the 1800's. Other settlers and Army personnel used sand and gravel deposits for making sand-lime mortars and local stone for buildings. Much of Kansas was prairie, so trees were scarce (except along waterways). Stone was often used for permanent buildings such as churches, rather than hauling in lumber from other states. Salt marshes were used for early salt production. Coal was the first fuel-mineral mined in Kansas, as early as 1827 in Leavenworth County (Schoewe, 1958).

Although they are not industrial minerals, lead and zinc were important and their mining deserves mention. Except for Linn County (near Pleasanton), where galena was mined as early as the late 1830's (Mudge, 1866), metal production in Kansas has primarily been in the southeastern part of the state. Cherokee County, where lead-zinc deposits were worked beginning in the 1870's, is probably the best known area of occurrence. This area is part of the old Tri-state mining district, along with northeastern Oklahoma and southwestern Missouri. Lead-zinc operations in Kansas ended around 1970 due to low metal prices and marginal ore values.

During the late 1800's, commercial developments using industrial minerals included salt (underground production began in 1888); dimension stone for churches such as the Pottawatomie Mission at Topeka (1848), the northern portion of the United Church of Christ Congregational Church in Manhattan (1858), and other buildings including the east wing of the State Capitol (1867); clay for brick plants; crushed stone for construction purposes; gypsum for plaster (Keene's cement was produced in Barber County in 1891, although plaster production might have been even earlier in Marshall County); and a natural cement produced from limestone in Bourbon County (1868). Abundant and inexpensive natural gas was a major contributor to the development of mining and processing industrial minerals in southeastern Kansas during this period. The presence of suitable clays, shales, limestones and sandstones, along with the natural gas, led to the construction of many brick plants and cement plants. With the recent closure of a plant in northeastern Kansas, the state's four cement plants are located in southeastern Kansas. Two brick plants and a sewer-pipe plant also operate in southeastern Kansas.

During recent decades, Kansas has produced a variety of industrial minerals, including 1) evaporative and rock salt, 2) crushed stone (including fine limestone for agricultural lime), 3) dimension limestone and sandstone, 4) portland and masonry cements, 5) construction and industrial sand and gravel, 6) clays and shales for brick, cement, sewer pipe, lightweight aggregate or expanded shale, pottery, and decorative tile as well as some 7) bentonite clay and a 8) weathered peridotite (micaceous clay), 9) volcanic ash for filter and abrasive applications, 10) gypsum for wallboard or sheetrock and a variety of plasters, and 11) diatomaceous marl for paint filler. Except for diatomaceous marl, all these commodities are still produced in Kansas. In addition, industrial minerals extracted from fuel sources include by-product sulfur from petroleum and helium from natural gas.

Surface Geology (Where Industrial Minerals are Found)

Geologists divide rocks into three general types. Igneous rocks are those formed during the cooling of molten materials. Metamorphic rocks are those formed by alteration of existing rock through exposure to high temperature and pressure. Sedimentary rocks, the type found at the surface in Kansas, are formed from sediments. Such sediments are often the weathered or eroded products of existing rocks or may be the remains of marine life. They are transported into low areas, buried deeper and deeper as more sediments are deposited on top of them and, with compaction and cementation, gradually form solid rock. This is a simplified explanation of the rock-forming process for most sedimentary rocks. Later, solution action may alter the composition of these rocks, either when ground water or mineral-rich solutions leach or dissolve part of the rock and remove it or perhaps add to it by mineral deposition or reaction. A group of sedimentary rocks called evaporites are formed by evaporation of water in relatively shallow seas and lakes. As the water evaporates, the dissolved salts fall out of solution and crystallize as layers on the floor of the sea or lake. Nearly all industrial minerals at or near the surface in Kansas are sedimentary. They include limestone, dolomite, sandstone, clay, shale, and the evaporite minerals salt and gypsum.

Rock layers in Kansas generally dip to the west (fig. 1) and, as a result, the surface rocks in the eastern part of the state are older than those farther west. The oldest rocks at the surface in Kansas are rocks of Mississippian age in the extreme southeastern corner of the state (Cherokee County), deposited about 330 million years ago (fig. 2). These Mississippian limestones are dense and contain some of the highest concentrations of calcium carbonate (the basic component of limestones) found in Kansas. Although this limestone makes good building stone (a similar limestone was used extensively in southwestern Missouri for building), demand in southeastern Kansas is limited, and hauling costs prohibit the development of these deposits.

Moving westward, we encounter rocks of Pennsylvanian age, deposited about 300 million years ago, that are important sources of industrial minerals. Limestone from Pennsylvanian formations provides crushed stone for construction in the populous Kansas City-to-Topeka corridor, as well as for much of eastern Kansas. Pennsylvanian clay or shale, used for brick, sewer pipe, pottery, and lightweight aggregate, are present, mostly in the southeastern portion of the state. In southeastern Kansas, limestone, sandstone, and clay/shale are blended and fired to form chunks of cement rock (called clinker in the cement trade). In addition to limestone and shales, the Pennsylvanian also includes the Bandera Quarry sandstone in southeastern Kansas. At one time, this sandstone was used extensively in eastern Kansas and adjacent states for flagstone, curbing, and buildings. This sandstone and a few Pennsylvanian limestones are still used for building stone. Unique among the limestones is the highly fossiliferous Five Point Limestone Member of the Admire Group near the top of the Pennsylvanian. Quarried in the past in northern Pottawatomie County where it contained numerous fossil shells and was a chestnut color, the Five Point was known in the trade as "the chestnut shell limestone." Although gray in color and not as fossiliferous, the stone is now quarried in Wabaunsee County for building construction.

Overlying the Pennsylvanian are rocks of the Permian, deposited around 250 million years ago. These are another important source of industrial minerals in Kansas. Large amounts of crushed stone come from Permian rocks. Most of the dimension limestones produced in large tonnages in Kansas, both now and in the past, are of Permian age, particularly the Cottonwood and Fort Riley limestones from the Lower Permian. In the past, the Funston Limestone (called Onaga limestone in the building-stone trade) also was used in large quantities for buildings. Salt and gypsum are Permian evaporites that are important industrial minerals in Kansas. Except for a large gypsum open-pit mine in Barber County, all the salt and gypsum operations are underground mines.

Cretaceous rocks, deposited about 100 million years ago (fig. 2), cover most of the north-central portion of the state. The Fencepost limestone of the Greenhorn Limestone was used for constructing buildings as well as the famous limestone fenceposts. Probably the best-known building utilizing this limestone is the St. Fidelis Church, better known as the Cathedral of the Plains, at Victoria, Kansas. Also present in the Cretaceous is the thick Niobrara Chalk, which includes the Fort Hays Limestone and Smoky Hill Chalk Members, also used as building stone in western Kansas. Where present, the Fort Hays and Smoky Hill Members have often been crushed and used for local county road surfaces. The Niobrara Chalk is also the source of many outstanding marine fossils, some of which are displayed in the Sternberg Museum at Fort Hays State University, Hays, Kansas. In northeastern Rice County, crushed dolomite, a calcium-magnesium carbonate rock, has been produced for road usage. Cretaceous-age rocks also include the Dakota Formation, which contains some of the best clays in the state for the production of bricks. At present, the clay deposits are among the most economically important resources in the Cretaceous rocks. Another economically important material is the crushed stone produced from large, densely cemented (by calcium carbonate) boulders of Dakota sandstone. Examples of these boulders are found at Mushroom Rock State Park in Ellsworth County and Rock City in Ottawa County. The rock is hard enough to be crushed and used as concrete aggregate and railroad ballast and is currently quarried in Lincoln County.

Some time during the Cretaceous Period, two very small areas of igneous intrusive material worked their way

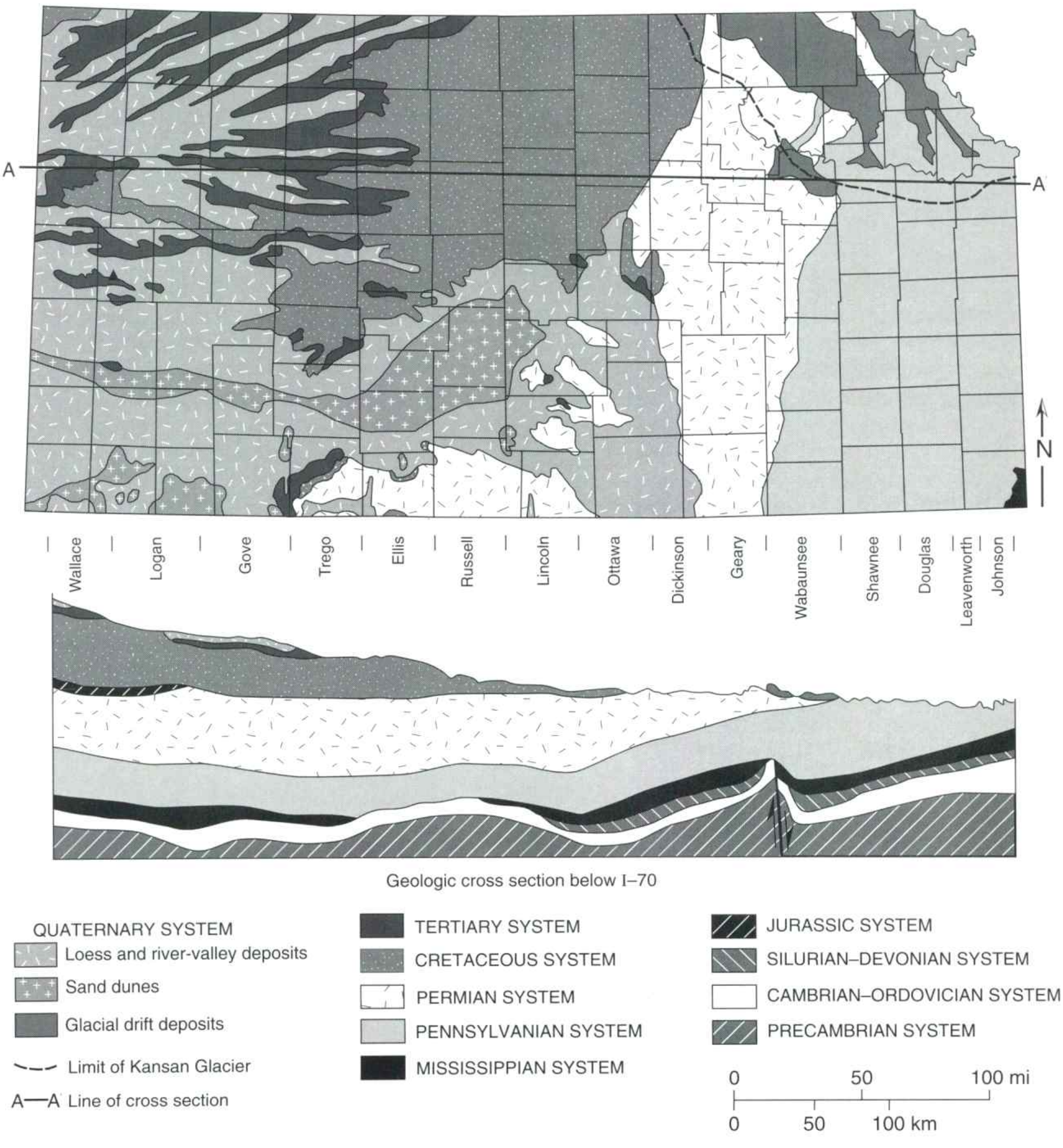
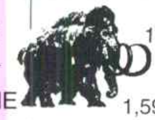
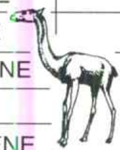
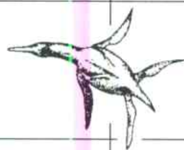
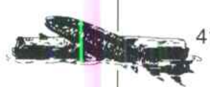
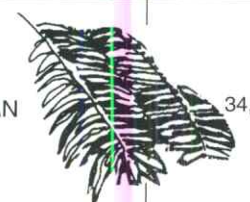
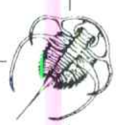


FIGURE 1—Generalized geologic map of Kansas.

KANSAS GEOLOGIC TIMETABLE

(Not scaled for geologic time or thickness of deposits)

ERAS	PERIODS	EPOCHS	EST. LENGTH (YEARS)*	DESCRIPTION	MILLION YEARS PAST
CENOZOIC	QUATERNARY	HOLOCENE 	10,000+	Early, the land was stable with some erosion. Glaciers moved into the northeast at least twice. Later the climate was dry. Sand dunes were formed by wind in the west. Volcanic ash was blown in from California, New Mexico, and Wyoming.	
		PLEISTOCENE	1,590,000		1.6
	TERTIARY	PLIOCENE 	3,700,000	Rocks found are part of the Ogallala Formation (sand, gravel, and porous rock), which contains a large quantity of ground water and occurs only in the western third of the state. No rocks were formed in eastern Kansas.	
		MIOCENE	18,400,000		
		OLIGOCENE	12,900,000		
		EOCENE	21,200,000		
		PALEOCENE	8,600,000		66.4
MESOZOIC	CRETACEOUS		77,600,000	Much of the western half was covered by seas. Limestone, sandstone, and chalk formed from sea deposits. Fossils can be found in these rocks, which crop out in central and western Kansas.	144
	JURASSIC		64,000,000	Subsurface only.	208
	TRIASSIC		37,000,000	Mostly in subsurface. A few small outcrops are found in the southwest corner of the state.	245
PALEOZOIC	PERMIAN		41,000,000	Much of Kansas was covered by several seas. As they rose and fell, limestone, shale, and chert were deposited. The Flint Hills were formed. When the seas dried up, salt and gypsum were left behind. Salt, now underground, is mined in central Kansas. The Red Hills were formed from deposits of shale, siltstone, sandstone, gypsum, and dolomite.	286
	PENNSYLVANIAN		34,000,000	For much of the period the land was flat. Seas and swamps came and went; coal formed in swamps from dead plants. Shale, limestone, sandstone, chert, and conglomerates were deposited. Two ridges of hills, the Nemaha uplift and the Central Kansas uplift, appeared; both are now buried. Pennsylvanian rocks are found at the surface in eastern Kansas.	320
	MISSISSIPPIAN		40,000,000	Repeated layers of limestone, shale, and sandstone indicate that seas rose and fell. Mississippian rocks are the oldest found at the surface and are in the southeast corner; elsewhere these rocks are only underground.	360
	DEVONIAN		48,000,000	Seas covered Kansas during much of the period. Limestone, shale, and sandstone deposits are only underground.	408
	SILURIAN		30,000,000	Land was uplifted and seas disappeared. Limestone deposits are found only underground.	438
	ORDOVICIAN		67,000,000	Seas covered parts of Kansas during much of the period. Dolomite and sandstone are only underground.	505
	CAMBRIAN		65,000,000	Early, the climate was dry and many rocks eroded. Later, parts of Kansas were covered by seas. Dolomite, sandstone, limestone, and shale are now underground.	570
PRECAMBRIAN			3,930,000,000	These rocks are the oldest on earth. In Kansas, they are only found deep below the surface and not much is known about them. Many are igneous and metamorphic and have gone through many changes.	4,500?

Eons not shown

* Decade of North American Geology, 1983 Geology Time Scale, Geological Society of America

Kansas Geological Survey, Lawrence, Kansas, 1998

FIGURE 2—Generalized geologic timetable for Kansas.

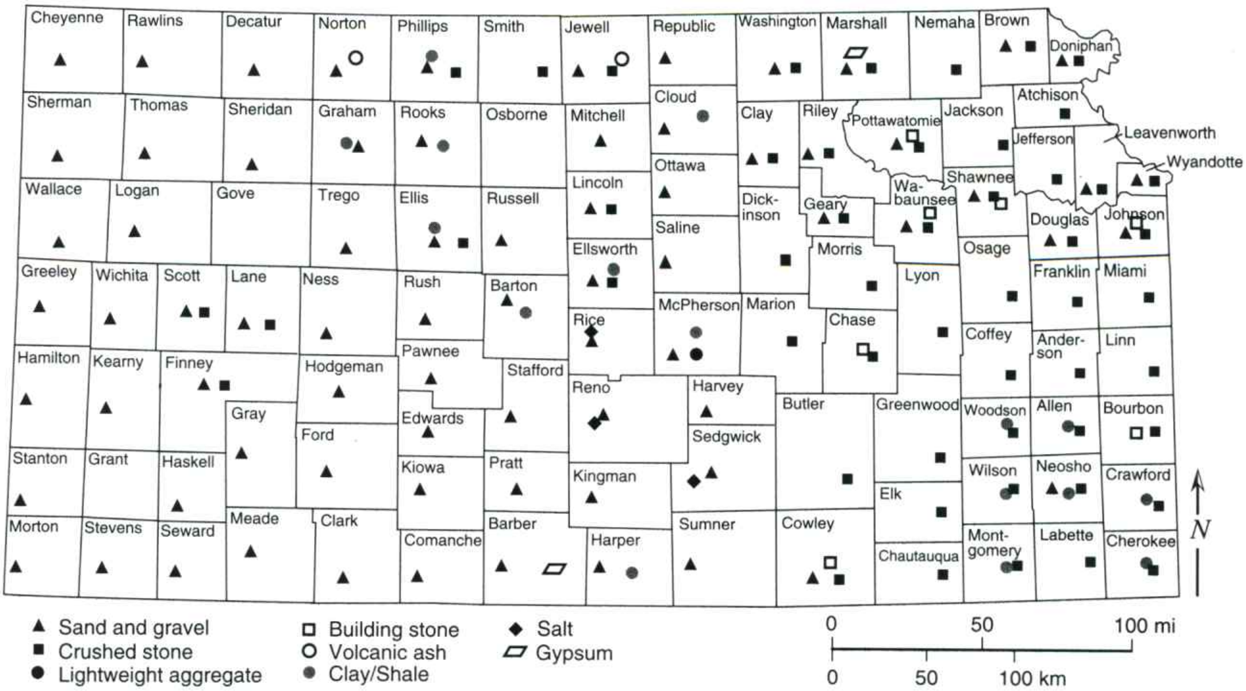


FIGURE 3—Map of Kansas showing industrial minerals produced in each county.

upward through overlying strata in the area that is now Wilson and Woodson counties. Although not Cretaceous rocks, they are included here because the event occurred during the Cretaceous time period. The weathered material from one of them is rich in certain trace elements and is used as an animal-feed supplement. Igneous intrusives in the form of kimberlite pipes occur in Riley County, again an event that occurred during Cretaceous times.

Industrial minerals deposited during the Tertiary Period include terrace deposits of sand and gravel and the Ogallala Formation. The former assume special importance in many areas that lack sources of stone or other sand and gravel deposits while the latter is an important aquifer. In some cases, sufficiently hard rock can be obtained from the Ogallala for crushed stone. Tertiary-age material is the source for many sand and gravel deposits in the rivers of central and eastern Kansas. In addition, the Tertiary System also includes volcanic ash deposits such as the one currently mined at Calvert in Norton County. The overlying Quaternary System (Pleistocene Series) also includes sand and gravel and volcanic ash, the latter mined in Jewell County and processed at Mankato, Kansas. The Quaternary included the Ice Ages that provided sand and gravel from glacial outwash in northeastern Kansas.

Finally, oil and gas production occurs from various depths over many areas of Kansas. In addition to petroleum being the source of a variety of hydrocarbons, during its processing, by-product sulfur may be extracted. The Hugoton field in southwestern Kansas is particularly important because the natural gas contains a high concentration of helium. As a result, Kansas has been and continues to be the largest producer of helium in the United States.

Figure 3 shows a county map for the state, illustrating the industrial minerals produced in each county.

Industrial Minerals—Their Composition

Limestone is primarily composed of the mineral calcite, chemically known as calcium carbonate and represented by the formula $CaCO_3$. The primary sources of calcite are from the shells of various marine organisms and from marine plant life. When these plants and animals die, their remains settle and collect on the floor of the ocean. Frequently, other minerals such as clay (composed of hydrated aluminum silicate minerals), or silt and sand (composed of the mineral quartz) are washed into the area and settle to the bottom along with the plant and animal remains. Thus, the resulting limestone is not pure calcium carbonate. All the limestones in Kansas contain varying amounts of these minerals, and some contain other minerals such as iron oxide(s). In addition, mineral-rich waters may also alter the composition of the limestone by depositing small amounts of minerals in minute voids within the stone.

Lime is not really an industrial mineral but is included here following the custom of both the U.S. Bureau of Mines and the U.S. Geological Survey. Lime is calcium oxide and is produced by calcining (heating) limestone to a sufficiently high temperature to decompose the calcium carbonate into gaseous carbon dioxide and calcium oxide. (Lime should not to be confused with "ag lime" or agricultural lime, which is finely ground calcium carbonate.) The purity of the calcined product depends on the purity of the limestone; for most applications, the limestone needs to have a high calcium carbonate content. At one time, Kansas had several lime production plants, including two that used vertical kilns to make the product. The most recent was at Goodland, Kansas, where the product was used in the purification process of beet sugar. At present, there are no lime production facilities in Kansas.

Dolomite is less common than limestone among the surface rocks of Kansas, but it is another important carbonate mineral used in the same fashion as limestone. The mineral dolomite that forms the majority of the rock is actually a double carbonate consisting of one molecule each of calcium carbonate and magnesium carbonate combined into one mineral structure and represented by the formula $CaMg(CO_3)_2$. It has been quarried southeast of Little River, Kansas, in Rice County from the Stone Corral Formation. In the past, it was also quarried in Dickinson County where the Cresswell Limestone was dolomite.

Sandstone is a relatively common rock in Kansas and is mostly composed of the mineral quartz, chemically silicon dioxide (SiO_2). However, all the sandstones in the state contain other minerals such as clays, micas, feldspars, iron-bearing minerals, and carbonate minerals. Many of these minerals are deposited along with the sand and thus incorporated into the sandstone during rock formation. In some cases, strong, hard sandstones occur where the grains of sand become cemented together by the precipitation of carbonate or silica from solutions filling the pores. In other cases, the quartz grains are held together weakly by clay and/or iron minerals. In central Kansas some deposits of Dakota sandstone are held together by interlocking quartz grains rather than by being cemented. With such a diversity of bonding mechanisms, it is hardly surprising that the physical properties of the stone (strength, porosity, hardness, durability) vary greatly. Furthermore, such diversity in bonding can occur over short distances, even in the same quarry. Under these circumstances, selective mining is necessary to produce the desired product.

Clay and ***shale*** are mineralogically similar. They are composed of weathered silicate minerals such as feldspars that, grouped together, are classed as hydrated aluminum silicates that may also contain other ions in the structure. Clay minerals are complex and therefore will not be discussed except to say they are platy in appearance under high-powered magnification. When wet, the platy particles slide over one another and give the clay a slippery feel. Shales tend to be thinly laminated rocks while clay deposits do not appear as laminated and are generally softer than shales.

Gypsum beds are exposed at the surface in Barber County where gypsum is quarried. The mineral also is produced from underground mines in Barber and Marshall counties. Gypsum belongs to a group of minerals called evaporites that are formed in relatively shallow seas. In the case of gypsum, continued evaporation of water rich in sulfate and calcium causes the calcium and sulfate to crystallize from the solution as gypsum. Over a long time, this process can form thick beds of gypsum. In Barber County, the gypsum is quarried from the Medicine Lodge Gypsum Member (lowest member of the Blaine Formation) and ranges from 10 to 30 feet (3–9 m) in thickness.

Salt (NaCl) beds, like gypsum, are formed from the evaporation of water—in this case,in seas containing large amounts of sodium and chloride ions. Because salt (chemically sodium chloride or NaCl) is easily dissolved in water, we never see salt beds at the surface in Kansas. The salt marshes mentioned earlier in the history of mining in Kansas are the remnants of salt beds that are near the surface. Kansas salt beds were deposited during the Permian Period when a large, shallow sea of saline water covered south-central Kansas. Repeated cycles of inundation and evaporation gradually formed thick layers of salt. The salt beds in the areas of current mining are tens of feet thick and lie hundreds of feet below the surface.

Volcanic ash is present in sizable amounts in western Kansas. This material is actually small shards of glassy volcanic material that volcanic eruptions in the western United States threw high into the air. The rapid cooling of the ash caused it to remained in a glassy state. The ash settled over large areas and was gradually carried by water and wind into shallow depressions. It is a siliceous glass, meaning it contains large amounts of silica, but also contains smaller amounts of several other metal oxides besides silicon fused together in the glassy phase. The ash is normally unconsolidated, meaning it is not cemented together, and can be easily excavated. In time, ash deposits exposed to the elements weather to a bentonite clay.

Sand and ***gravel*** deposits are mostly composed of the mineral quartz or silicon dioxide. However, sometimes the sand is actually a mixture of quartz and sand-sized grains of other minerals that have been deposited together. Feldspars, a group of silicate minerals that often occur in igneous rocks, are common in Kansas sand. Sand in the lower portion of the Kansas River contains approximately 15% feldspar. Other common rock fragments and minerals in sand deposits include limestone, clays, and iron minerals.

Sulfur is a non-fuel industrial mineral that is produced as a by-product from the processing of petroleum at refineries. We refer to this as by-product sulfur to distinguish it from sulfur produced from elemental or mineral deposits. At present, by-product sulfur is produced in Kansas from refineries located at Coffeyville and El Dorado.

Helium is a gas that is extracted from natural gas. Much of the natural gas from the Hugoton field contains 0.3% or more helium, which is a rich source of helium relative to most gas fields. Helium is used in the field of cryogenics (low-temperature applications), as an inert atmosphere in welding, in breathing mixtures, as a purging and pressurizing agent in spacecraft, and in lighter-than-air craft (dirigibles). It is also used to fill balloons.

Properties of Industrial Minerals

A discussion of the chemical and physical properties of industrial minerals would make a publication in itself. For the purpose of this primer, discussion will be limited to the basics and provide some examples.

What makes a good industrial mineral for a particular application or use? The answer always involves the chemical and physical properties of that mineral deposit. However, it is important to remember that these properties are usually not consistent throughout rock layers. In some cases the change may be small, while in others, drastic changes may occur both laterally and vertically in very short distances. A good example of the latter is the Dakota Formation sandstone of Cretaceous age in Ellsworth, Ottawa, and Lincoln counties, where the stone ranges from essentially soft, porous, uncemented (held together by interlocking grains) deposits to hard, dense, chemically bonded by calcium carbonate deposits in the same area.

Obviously, the chemical purity of an industrial-mineral deposit determines the suitability of the material for a particular application and whether it is economical to mine and process the deposit. Removing large amounts of impurities may increase processing costs enough to make using the deposit too expensive. Depending on the application, some impurities may be acceptable. For example, small amounts of shale impurities can be tolerated in rock salt, whereas table salt must be pure. Thus, the application or use is always affected by purity. In some cases, impurities may be beneficial. For example, a clay deposit with an iron oxide/hydroxide impurity can be used to produce the typical red-colored brick. Impurities in a gypsum deposit may produce a better-quality sheetrock than pure gypsum, as long as the impurities do not appreciably discolor the product.

In addition to the amount, the type of impurity is important. Consider a brick plant that wishes to mine and process a clay deposit. Clay deposits in Kansas are usually not very pure and almost always contain varying amounts of quartz (sand or silt). If the deposit contains 5% quartz, it could be used for brick production. However, if it contains 5% soluble sulfate salts, the deposit is undesirable. As bricks dry, the soluble salts are carried by water to the surface and deposited as a white scum. This phenomenon is called efflorescence. A common way to minimize or eliminate the problem is to add a barium salt to the wet clay: the resulting barium sulfate is very insoluble and will not be carried to the surface. Small additions of barium are often added to brick batches as an insurance policy. However, imagine the cost associated with this cure when the soluble salts are present in a large amount. Thus, both the amount and type of impurity must be considered for a given application.

Limestone is another impurity to be avoided in clays used for ceramic products. Most clays have a range of firing temperatures (maturing range) that can be used to produce the optimum shrinkage and porosity characteristics for brick, tiles, sewer pipe, pottery, etc. The presence of limestone in any significant quantity normally narrows the optimum firing range, thus mandating an accurate kiln control to produce a satisfactory product. In addition, any limestone that remains unground produces a pocket of lime that, with time, may rehydrate, expand, and cause a pop-out or pit (commonly called lime pops) in the finished product.

Problems can sometimes be avoided by simply not mining the undesirable portion of the deposit or separating it from the raw material being produced. As mentioned earlier, processing methods can often separate the impurity from the desired product. But sometimes the impurity is "fixed" in the industrial mineral, as in the case of Kansas sand. All the sand deposits examined in the state contain iron minerals as impurities, some of which are within the sand grains and cannot be separated. Because iron, even in relatively small amounts, produces an undesirable color in the glass and because decolorizing agents are expensive, Kansas sand deposits are useless for typical glass production on any sizable scale.

The amount, type, and location of impurities are also important for construction materials such as crushed stone and building stone. In this case, both the chemical and physical properties are important. Common impurities in stone such as quartz and clay can often be tolerated when present in small amounts and thoroughly dispersed throughout the deposit. However, the same impurities when present in concentrated, thin zones within the stone can produce disastrous results when the stone is laid with bedding planes perpendicular to the ground and is exposed to the extremes of climate in Kansas. Differences in the thermal expansion, temperature variations or heat-cool cycling, wet-dry cycling, and freeze-thaw cycling can lead to deterioration of these zones relative to the bulk of the deposit. In other words, seams of impurities act as zones of weakness and can lead to failure. Such zones are avoided if possible but unfortunately, many are very thin and not obvious, showing up only after years of weathering. The Capitol building in Topeka contains many examples (Grisafe, 1982, 1983). To avoid this problem, buildings today are usually constructed with the natural bedding-plane direction of the blocks being laid horizontally or parallel to the ground.

Physical properties such as porosity (amount of pore space), pore-size distribution, and permeability (a measure of how the pores are connected as measured by liquid or vapor transport through a given thickness for a given time) affect the durability of the stone, for example, upon exposure to freeze-thaw conditions. The durability of stone can be affected by the presence of soluble salts. Salts also can be absorbed by the stone from ground moisture moving into and through the stone or brought into the stone by pollution, including acid rain that introduces sulfate salts. Salts present in the stone may crystallize within pores during dry periods, and certain salts can expand by forming hydrates during wet periods. Both mechanisms are thought to produce large pressures at the pore site that can disrupt bonding. Many carbonate stone statuary and buildings throughout the world have been damaged as a result of salts as well as exposure to acid rain. With respect to acid rain, Kansas is fortunate to have relatively clean air in most of the state.

At one time, it was assumed that a stone with a small amount of porosity (the open spaces or pores in the stone) was the most durable for building purposes. Now we know that this is not always true. If the stone happens to be a granite with less than 0.2% porosity, it will normally be a durable stone. Occasionally, granitic compositions do contain minerals that weather rapidly and may lead to problems. Marble often has a very low porosity (a fraction of one percent) and is fairly durable. However, acidic pollutants such as those in acid rain can attack the stone along its grain boundaries, dissolving the bonding between grains. This causes the exterior to fall off like grains of sugar.

Both porosity and permeability determine how limestone holds up to freezing and thawing. When a pore is filled with moisture that freezes, disruptive pressure occurs unless the stone has some permeability that allows the ice to flow (which it does under pressure) into adjacent pores that are not filled. Thus, a stone with considerable porosity and permeability will often be more freeze-thaw resistant than a stone with little porosity and permeability. Of course, the freeze-thaw resistance of the stone also depends on its compressive strength. A hard, dense limestone may have sufficient strength to withstand normal freeze-thaw stresses.

Another mineral commodity for which both physical and chemical properties are important is clay (or shale). Not only are type and amount of impurities considered, the clay itself can be variable. While most industrial minerals can be represented by a simple formula to describe their composition, clay (or shale) is a collective term for a variety of compositions. Clays are composed of three general types of minerals: kaolinite, illite, and montmorillonite, all of which are found in Kansas. Although all are classified as aluminum silicates, the three clay types vary with respect to the size of their basic structural unit and the foreign ions from which they are made.

Kaolinite is the simplest of the clay types because it is a relatively pure, hydrated aluminum silicate. Although kaolinite deposits may contain impurities, there is very little foreign ion content within the structure itself. Thus, processing can often physically remove undesirable impurities. Kaolinites are the most refractory of the clay minerals—that is, they require the highest temperature for making brick because the firing forms a mixture of two high-temperature minerals, quartz and mullite (an aluminum silicate). In addition, kaolinites are not very plastic and for certain ceramic applications such as slip casting or pottery making, an additive or blend of clays are used to give the body the necessary plasticity for workability purposes.

At the opposite end of the spectrum are the class of clays known as montmorillonites. Such clays are usually very plastic, absorb large amounts of water and, hence, have the greatest drying shrinkage of the three classes of clays. High drying shrinkage is undesirable because it can lead to cracking of ceramic products. The large-volume changes associated with wet-dry cycles are partly responsible for foundation cracking in buildings constructed on such material. The chemistry of montmorillonites is complex because the clay's structure can accommodate a variety of foreign ions. The variable chemistry and large drying shrinkage associated with montmorillonites make them undesirable for many ceramic applications. Bentonite, a type of montmorillonite, is found in western Kansas. Rural roads made from this material become extremely slick when wet. This feature allows montmorillonite to be used in drilling mud.

Between the kaolinite and montmorillonite types of clay are the illites. They range from plastic to almost non-plastic and also have variable drying shrinkages. Many clays that are used for ceramic production are actually a mixture of kaolinite and illite. The latter imparts the desired plasticity to the mixture but also increases the drying shrinkage. To prevent the increased drying shrinkage from causing cracking in bricks, a non-plastic material (called grog) is added to the mixture before extrusion of the brick. As drying proceeds and shrinkage occurs, particles of the grog begin making contact with each other, thus minimizing further shrinkage. The grog may be a natural material such as sand or may also be scrap brick that has been crushed into relatively small particles.

From this simplified discussion of clay minerals and their related properties it should be clear that clays are complex minerals. Further general information about clays with respect to their use for pottery making can be found in Grisafe and Bauleke (1977).

Mining and Production Methods

Although the vast majority of industrial mineral operations in Kansas are surface mines, some underground mining occurs throughout the state. Underground mining of limestone for crushed rock occurs from relatively thick limestone members near Kansas City and Atchison on the eastern edge of the state. Underground mining of gypsum occurs in Barber and Marshall counties, and rock salt is produced from underground mines in Rice, Reno, and Ellsworth counties. Conventional methods used to mine the different minerals include drilling, blasting, and crushing to the desired sizes. Another underground mining method is solution mining. Salt brine from solution wells is used for evaporative salt production in Rice and Reno counties. The basic operation involves drilling a well into the salt bed, injecting water into the salt to dissolve it, and using recovery wells to bring up the brine that is then evaporated for uses such as table salt and food products. The method has the advantage of separating out the insoluble impurities such as shale and anhydrite seams in the original salt bed. A similar system is used to produce salt brine for industrial use in Sedgwick County. The operation utilizes electrolysis to decompose the salt solution into sodium hydroxide (also known as caustic), chlorine, and hydrogen. All the products are sold, although a portion of the chlorine is used at the plant to form certain organic compounds that are called chlorinated hydrocarbons.

The majority of gypsum from Barber County is produced by a surface operation whose production in some years has ranked it as one of the 10 largest gypsum mines in the United States. However, there are two underground gypsum mines in Kansas, one in Marshall County and one adjacent to the open-pit mine in Barber County. They also use conventional mining methods to produce the raw material. In Barber County, the gypsum is hauled by rail to the processing plant located in Medicine Lodge, whereas in Marshall County the mine and plant are adjacent. Most of the gypsum is heated in kilns (ovens) to the plaster of Paris state ($CaSO_4 \cdot 0.5\ H_2O$) and then water is added to make a slurry for production of the product we know as wallboard, plasterboard, or sheetrock ($CaSO_4 \cdot 2H_2O$). It takes less than an hour to produce the finished sheetrock or plasterboard once the slurry has been formed. It is a highly automated, high-volume operation in order to be competitive, and trimming seconds off of the process translates into significant savings for the company. Although the bulk of the gypsum is fabricated into board products, smaller amounts also are used for the production of specialty plasters. A review of this mineral commodity is given in Kulstad et al. (1956).

Sand and gravel are produced by conventional methods. Many small pits in western Kansas simply use a front-end loader to fill trucks, crushing and/or screening the product when necessary before delivering to a job site. A smaller number of operators produce the majority of the state's sand and gravel tonnage from dredge operations in or along the larger rivers, most notably the Kansas and Arkansas rivers.

River dredges operate in the river and literally suck the sand and gravel from the bed of the river. The dredge is kept in place by two cables, one anchored along each bank of the river and also by the submerged device used to break up the sand. The dredge lowers one of its cables whenever necessary to allow the passage of boats. The slurry of sand and water is pumped to the plant located along the shoreline where it passes through a series of screens to separate out undesirable material and collect all particles within certain size ranges. Sorting by size is necessary because certain applications require certain size fractions. Because no overburden removal is necessary, the river dredge has a major cost advantage over a dredge in the floodplain. Another advantage to river dredging is that the resulting pit in the river bed is gradually filled in by sand and silt being transported downstream by the river. Approximately 10 acres of land are required for the sand-processing plant and stockpiles of sized material.

Floodplain dredges, also called pit dredges, operate within the floodplain along the river. Because water is necessary for a dredge operation, sufficient overburden must be removed until the water table is encountered before the dredge can be put into place and begin operating. The floodplain dredge requires a large amount of land for the pit being dredged, and for overburden stockpiles that must have a sufficiently shallow slope to avoid collapse. These requirements, including the sand-processing facility and stockpile storage, mean that approximately 100 acres is necessary for an average floodplain dredge operation along much of the Kansas River. By contrast, most of the Arkansas River floodplain has a relatively shallow water table and little overburden. Thus, less land is required for a floodplain dredge along the Arkansas River. A floodplain dredge leaves a pit in the floodplain whose surroundings require some degree of reclamation.

Both construction and industrial sand are produced in Kansas, the latter only along the Kansas River. The amount of industrial sand produced is much smaller in tonnage and is sometimes further processed to remove magnetic minerals in order to make it a suitable raw material for fiberglass production. A small amount of industrial sand also is used for sandblasting applications.

In general, crushed limestone rock is produced in the eastern one-third of the state (Permian and Pennsylvanian age) by drilling, blasting, and crushing typical of most such operations. Many quarries use selective mining.

Because of the specifications required by the Kansas Department of Transportation, only certain layers of stone within the quarry are suitable for highway construction, especially for use in concrete. Layers that do not meet such specifications are used for other purposes or may be discarded. Fine-sized particles from the crushing operation are often saved for local, agricultural lime usage. A lesser amount of crushed stone is also produced from Cretaceous-age material, including dolomite and a calcite-cemented sandstone in central Kansas and limestone from the Fort Hays Limestone and Smoky Hill Chalk Members of the Niobrara Chalk in northwestern Kansas. In addition, a small amount of crushed stone is produced in northwestern Kansas from the Ogallala Formation of Tertiary age. The latter deposits often vary greatly over small distances with respect to thickness and properties. In eastern Kansas they would likely be ignored as a source of crushed stone but are used in northwestern Kansas because they are the only hard rock available.

Drilling, blasting, and crushing also are used in the surface mining of limestone, clay or shale, and sandstone that are blended and fired in rotary kilns to produce cement clinker, a calcium silicate-rich material. The finished clinker is ground, often with the addition of gypsum that acts as a retarding agent to prevent the cement from setting too rapidly, and bagged. The raw materials must be of just the right composition to impart the desired properties to the cement. In some cases, it is necessary to add materials. For example, sources of iron are often added to form a particular phase known as brownmillerite, a calcium, iron, aluminum oxide structure that has been found necessary for good portland cement.

Commodities such as clay/shale may or may not require more than crushing; the deposits are often sufficiently soft to be loaded via shovel to truck and then hauled to the processing plant. In some cases, selective mining may be used to avoid or minimize the amount of undesirable minerals present in the deposit, such as seams or beds of pyrite (iron sulfide), gypsum, and carbonate minerals. Other methods may be used to separate undesirable iron minerals. Water is then added to the clay and mixed to produce a stiff mud that is first treated by using a vacuum system to remove air pockets and then extruded through dies to form green brick, tile, and sewer pipe that are dried and then fired in kilns. In recent years, conventional firebrick used to line the kilns has been at least partially replaced by refractory fiber lining. Available as either rigid board or flexible blanket and composed of high-temperature ceramic material, refractory fiber lining absorbs little heat and is therefore an excellent insulating

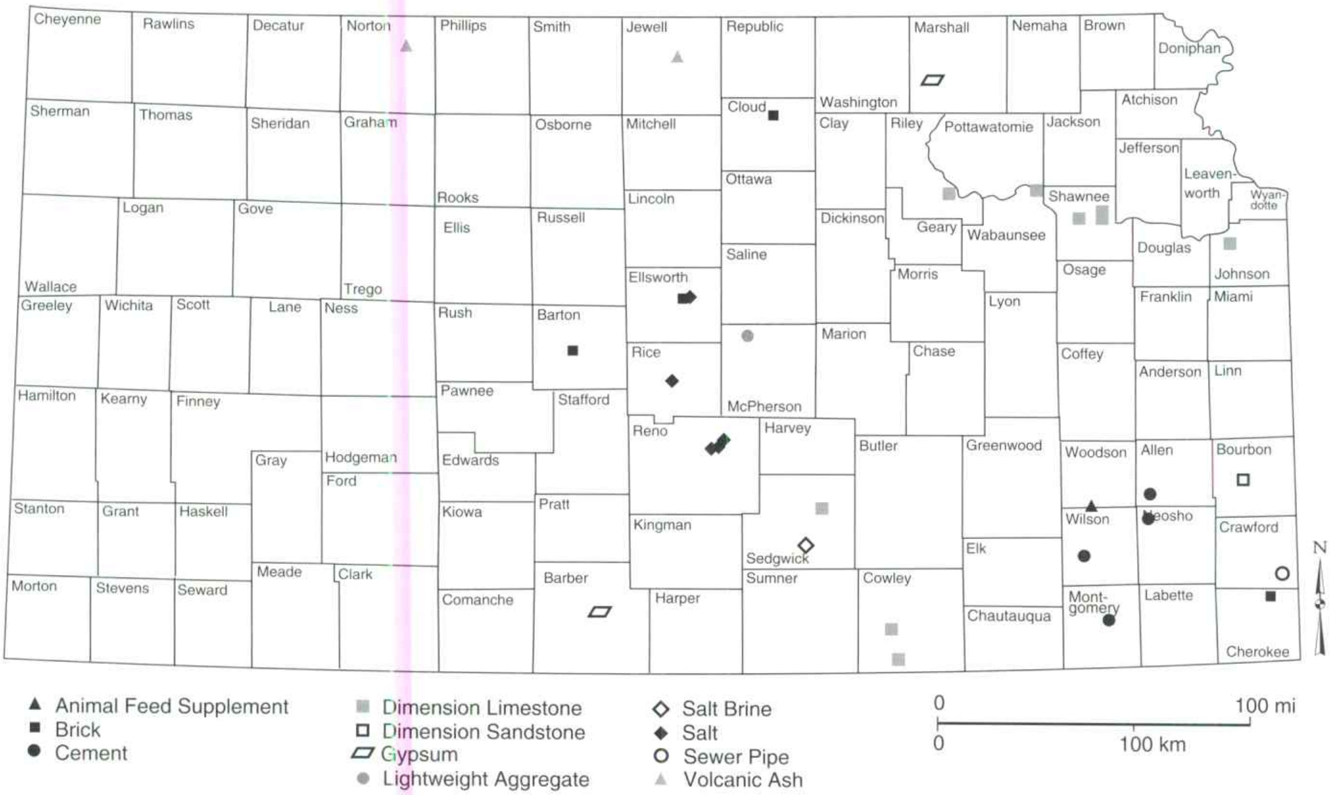
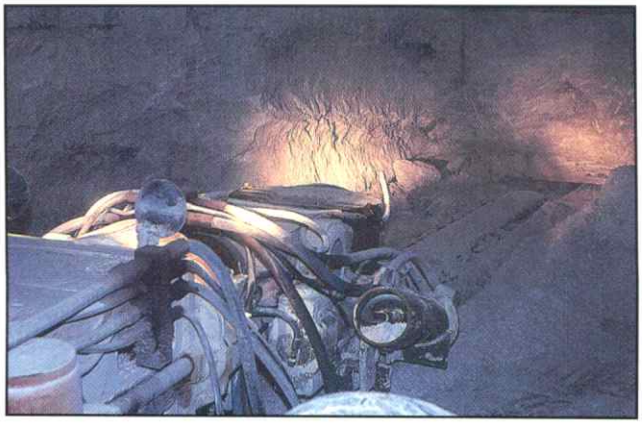
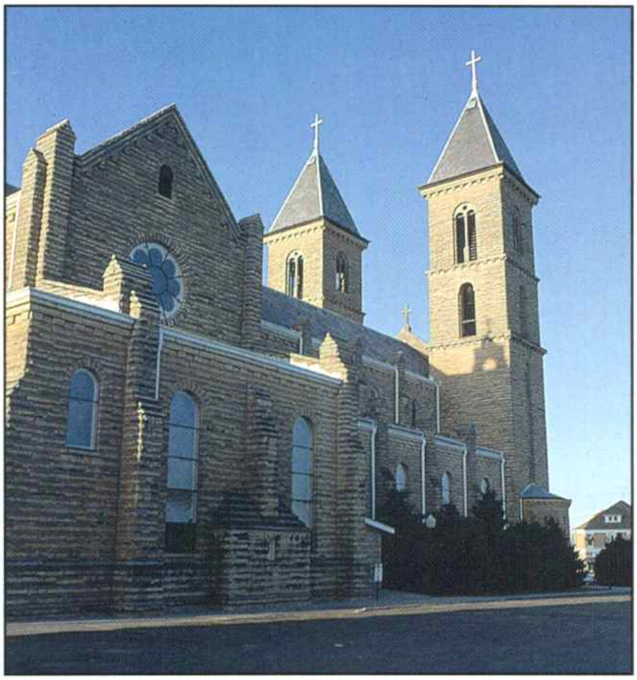


FIGURE 4—Map of Kansas showing location of processing/manufacturing facilities for industrial-mineral products, excluding natural aggregates.

The Bandera sandstone quarry, Bourbon County, produces rock used as building stone.



Gypsum production from the underground mine near Blue Rapids, Marshall County.

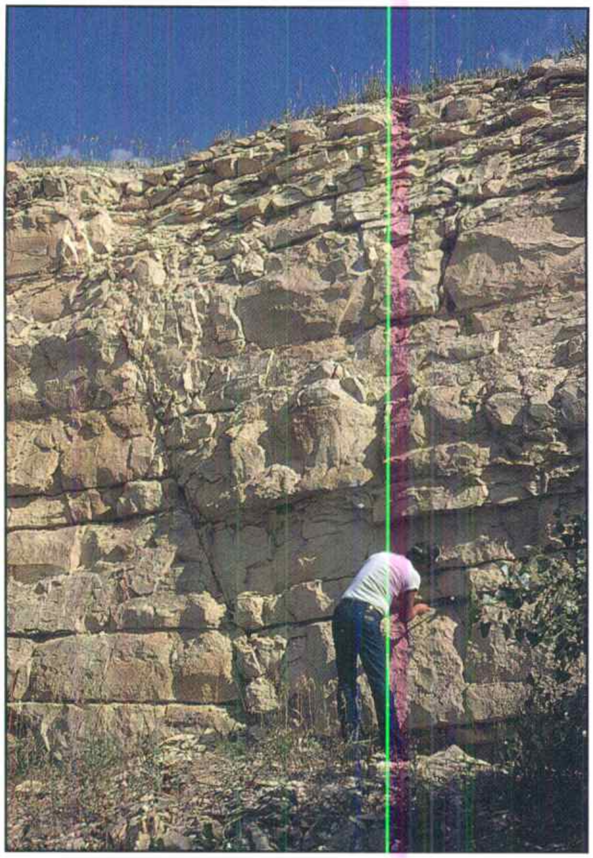


St. Fidelis Church (Cathedral of the Plains), Victoria, is built of Greenhorn Limestone, a common building stone in north-central Kansas.

Monument Rocks, Gove County, are composed of Niobrara Chalk, which is occasionally used as a building stone in west-central Kansas.

Cottonwood Ranch near Studley (Sheridan County), built of rock from the Ogallala Formation and Niobrara Chalk.

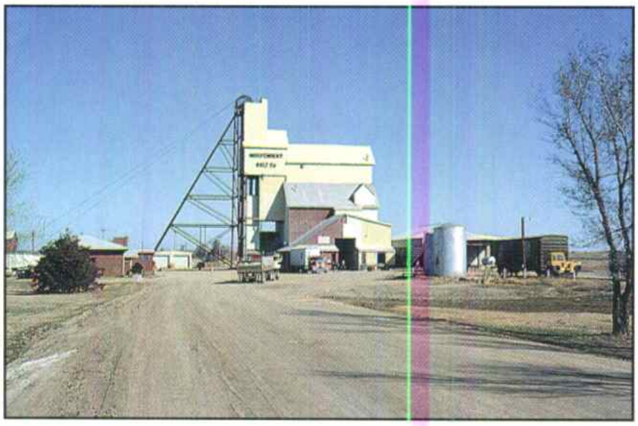
Water tower at Paradise (Russell County) built of Greenhorn Limestone.



The Fort Hays limestone is used for building in western Kansas. This roadcut is in Jewell County.

Salt mine, Hutchinson (Reno County).

Brick plant in Kanopolis (Ellsworth County).

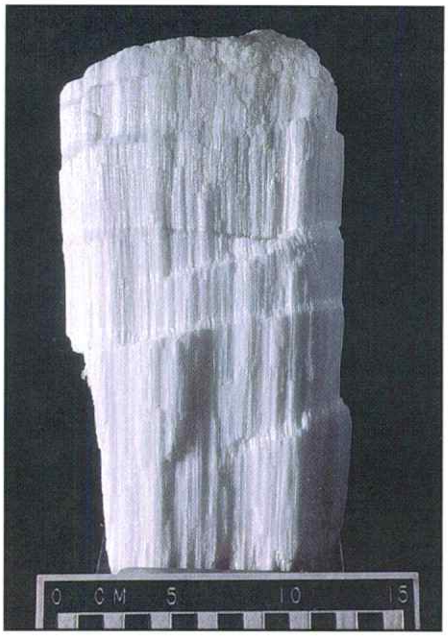


Salt mine near Kanopolis (Ellsworth County).

This pit produces volcanic ash near Calvert, Norton County.

House built of Niobrara Chalk, Phillips County.

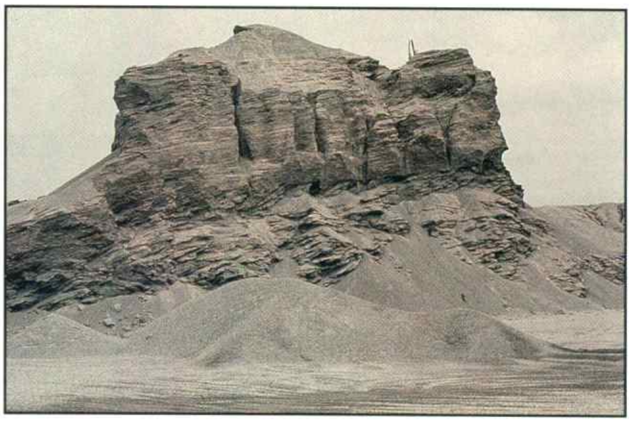
Helium plant at Otis, Rush County.



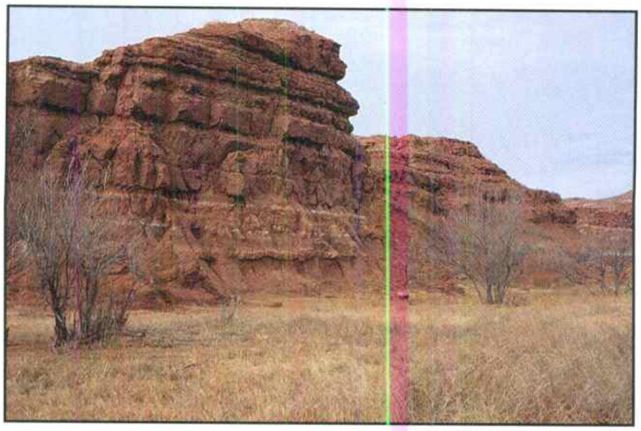
Satin spar, a form of gypsum from the mine at Blue Rapids, Marshall County.

Cement plant near Humboldt, Allen County.

The Dakota Formation near Wilson Lake, Lincoln County. Sandstone from the Dakota is occasionally used for building and clays are used in brick production.

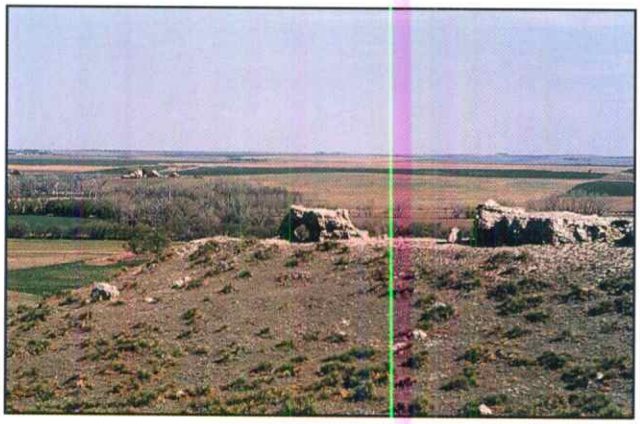


Chat pile from lead and zinc mining, Cherokee County.



Gypsum forms the thin white layers in the rocks of the Red Hills, Clark County.

Bridge built of Cottonwood limestone near Elmdale, Chase County.



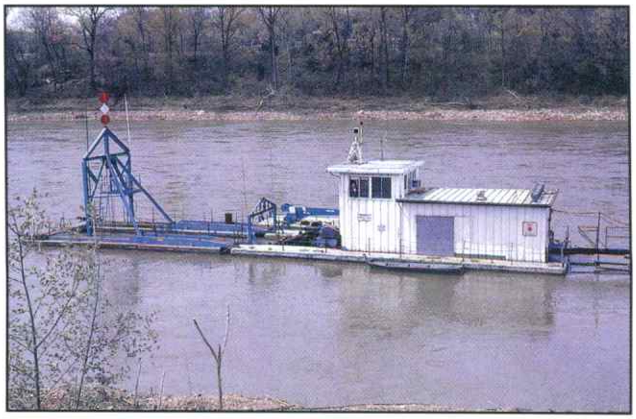
Outcrop of Ogallala Formation "mortarbeds" near Traer, Decatur County.

Mississippian rocks in the lead and zinc mining area of Cherokee County.

The Fort Hays limestone at Cedar Bluff, Trego County.

The Greenhorn Limestone as a fence post and as it originally occurred, Russell County.

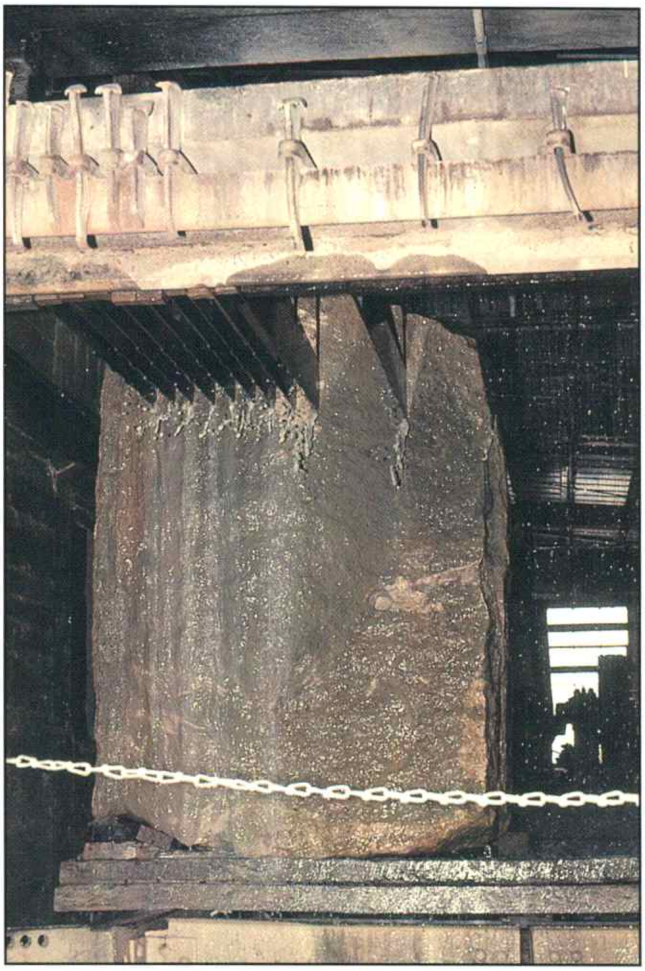
Reclaimed quarry east of Topeka, Shawnee County.



Dredge on the Kansas River near Holliday, Johnson County.

Circular saw cutting stone at the Bayer Stone Company, St. Marys.

The concretions at Mushroom Rocks State Park, Ellsworth County, are formed of sandstone from the Dakota Formation.



Gang saw slicing stone at the Bayer Stone Company, St. Marys.

This unique map of Cowley County was made from the Fort Riley Limestone.

Weathering on Capitol building in Topeka. The presence of a thin seam of clay-rich limestone is responsible for the differential weathering shown on the surface of the limestone block in the foreground. No such zone is present in the adjacent block.

material. The fiber lining allows the bulk of the heat to be absorbed by the product being formed instead of by the firebrick, resulting in faster firing cycles and decreased fuel bills that more than offset the cost of the fiber lining.

Another ceramic product produced from shale is lightweight aggregate, also called expanded shale. Crushed shale is rapidly heated in rotary kilns to produce the expanded product, mostly used as an aggregate in lightweight concrete. A smaller amount of this aggregate is used for landscaping purposes. The only current manufacturer in Kansas, in McPherson County, uses the Kiowa Shale. Using a different firing treatment, the plant also produces a calcined clay that is added to cement. This new additive is reported to reduce concrete cracking compared to the normal portland cement concrete.

Volcanic-ash deposits are more or less unconsolidated and require no drilling, blasting, or crushing. Screening is normally used for abrasive product applications while some is fired rapidly to produce bloated particles for filtering applications. Despite large reserves in the state, only two small operations exist now, one each in Norton and Jewell counties. A good review of this industrial mineral including locations, reserves, chemical analyses, and particle-size distributions is given in Carey et al. (1952).

Dimension-limestone blocks are usually drilled and blasted from the quarry face and hauled to the plant where the thicker blocks are usually sawed into slabs using gang saws. Further processing uses diamond-coated circular saws, splitters, lathes, and planers, depending on the desired product. One plant has an apparatus to produce a smooth finish on large slabs such as 4 foot by 8 foot (1.3 × 2.4 m) panels. Reviews of this commodity are given in Risser (1952) and Grisafe (1976). The Bandera Quarry sandstone is highly laminated into horizontal layers that range from a few to several inches thick. As a result, blasting is not used; portable saws are used to cut the desired slab size at the quarry face. The resulting slab is lifted from the quarry face and taken to the adjacent plant for further processing if necessary.

A map showing the location of various processing or manufacturing facilities is shown in fig. 4.

Industrial Minerals—Production Data

Figure 5 shows the historical values of all non-fuel mineral commodities. While totals may fluctuate from year to year, depending on economic conditions, the long-term trend is obviously upward. Table 1 gives the quantities and value of various mineral commodities produced during the last three years in Kansas. The dollar values for certain commodities are lumped together so that proprietary information voluntarily supplied to the U.S. Geological Survey about commodities produced by only one or two companies is not revealed.

A look at the table shows that aggregates (crushed stone combined with sand and gravel) and dimension stone are the major industrial-mineral categories from the standpoint of tonnage. The increases registered for these commodities since 1992 reflect increased construction activity, including road construction, in Kansas. In terms of value, helium, salt, crushed stone, and cement generate the most revenue. The total value of $547 million during 1997 represents an all-time high for industrial minerals in Kansas.

Figures 6–8 show where industrial minerals are quarried in the state. With respect to the number of operations, sand and gravel (fig. 6) and crushed stone (fig. 7) constitute about 95% of the state's industrial-mineral operations. Figure 8 shows the locations of the remaining industrial-mineral operations.

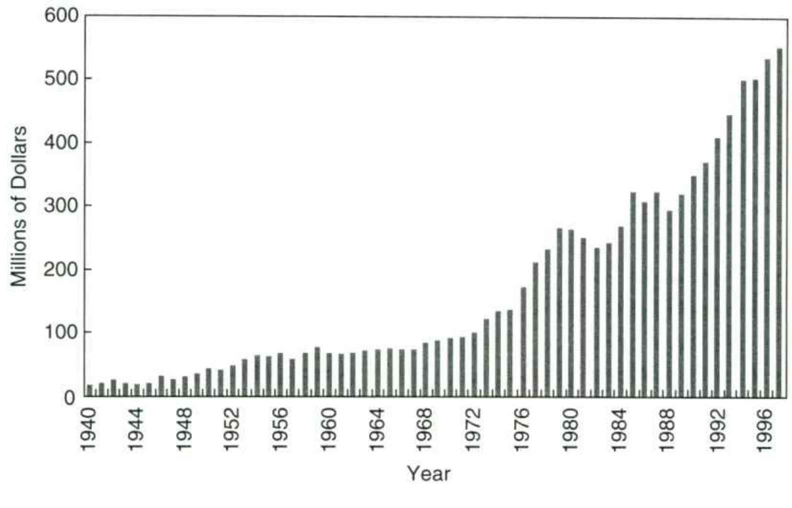


FIGURE 5—Value of industrial minerals in Kansas: 1940–1997. The 1997 value of $547 million is a preliminary figure subject to revision.

TABLE 1—Industrial mineral production and value in Kansas: 1995-1997, thousand metric tons and thousand dollars unless otherwise specified. One metric ton is equivalent to 1.1 short tons.

	1995		1996		1997 p/	
Mineral	**Quantity**	**Value**	**Quantity**	**Value**	**Quantity**	**Value**
Cement:						
Masonry	31	2,650	24	2,240 e/	25	2,330 e/
Portland	1,730	109,000	1,730	120,000 e/	1,760	124,000 e/
Clays:						
Common	573	2,390	548	2,250	376	1,270
Fuller's earth	48	W	64	W	W	W
Gemstones	NA	W	NA	621	NA	1,000
Helium:						
Crude (million m^3)	30	26,600	W	W	W	W
Grade A (million m^3)	53	105,000	53	104,000	54	108,000
Salt	2,770	113,000	2,950	118,000	3,100	121,000
Sand and Gravel (construction)	11,100	29,400	11,500	31,300	10,800	30,100
Stone:						
Crushed	20,400	95,800	22,100	110,000	23,600	118,000
Dimension 5/ (metric tons)	19,800	1,810	21,400	2,100	21,500	2,110
Combined value of gypsum (crude), pumice and pumicite, sand and gravel (industrial), stone (dimension sandstone), and values indicated by W	XX	12,200	XX	40,600	XX	39,300
TOTAL	XX	498,000	XX	530,000	XX	547,000

e/ estimated
p/ preliminary
NA not available
W withheld to avoid disclosing company proprietary data; value included with Combined value data
5/ excludes certain stones that are included with combined value data

Source: Annual Mineral Yearbook Chapters for Kansas, U.S. Geological Survey

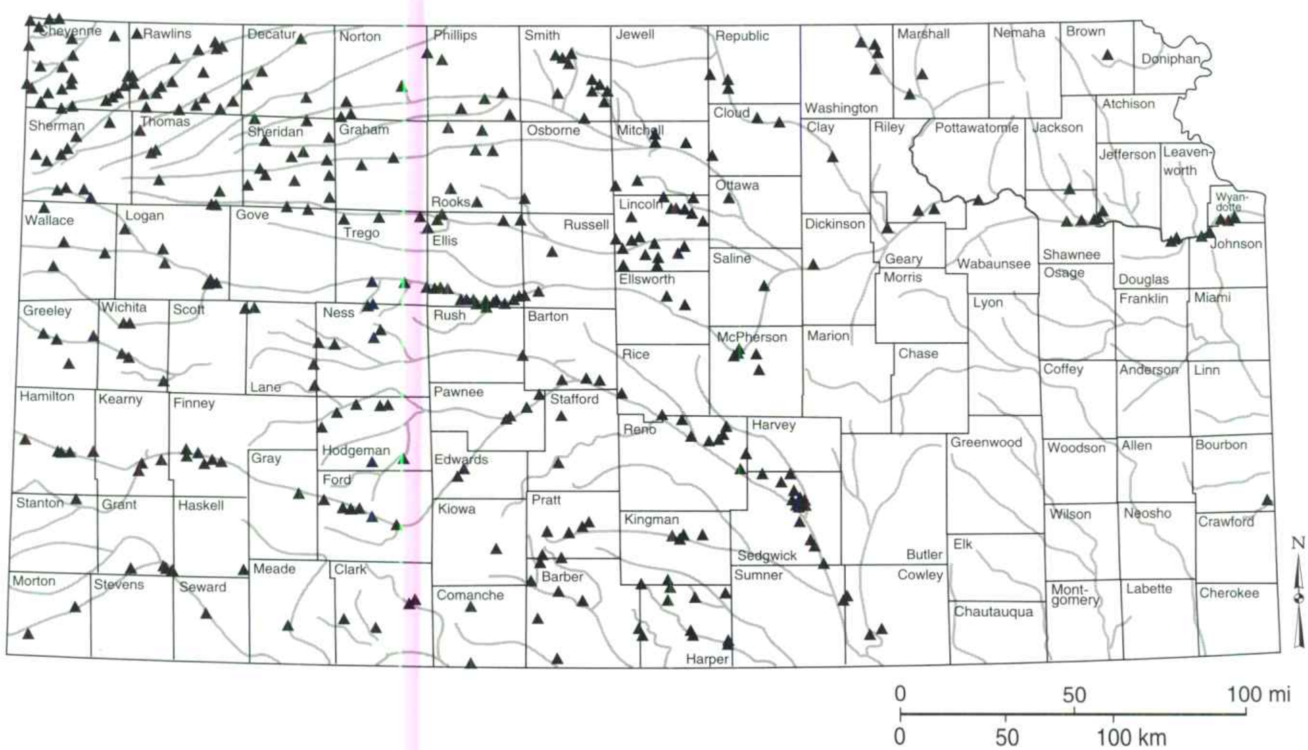


FIGURE 6—Location of sand and gravel operations in Kansas.

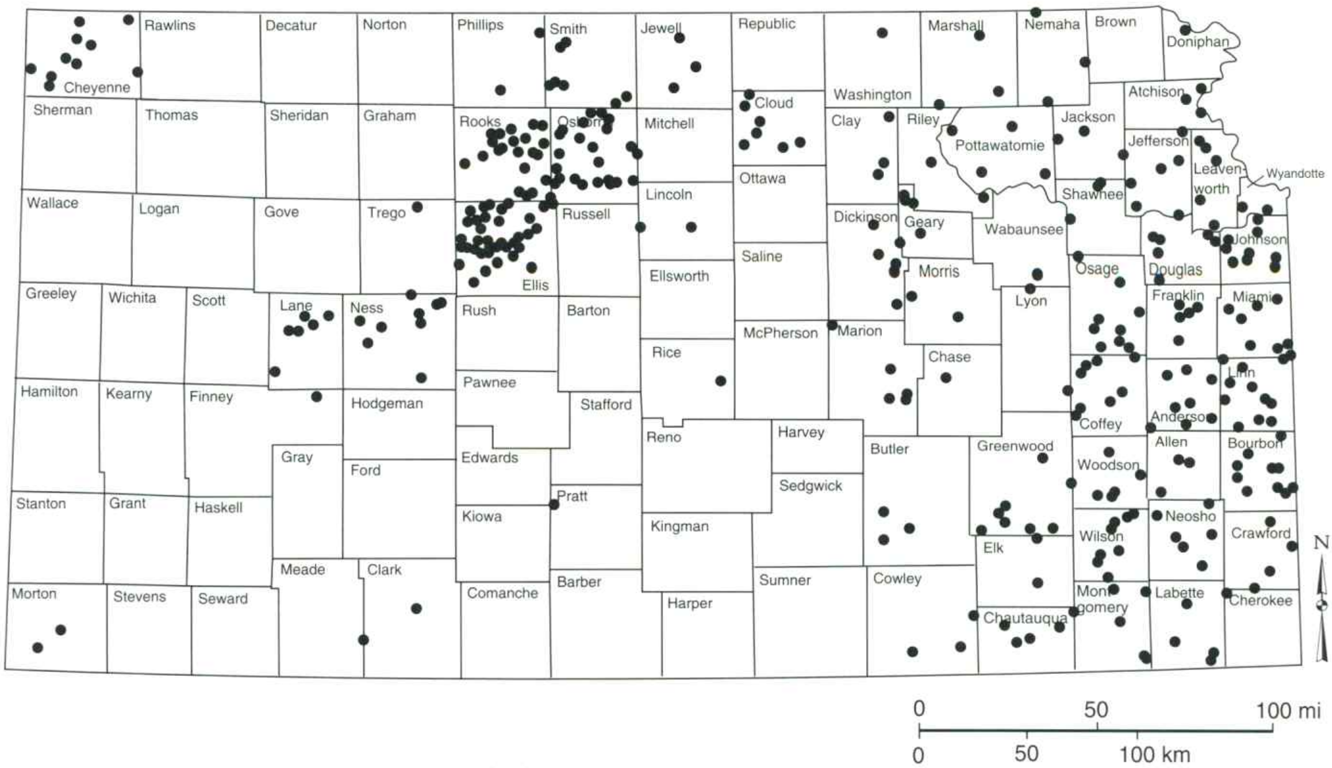


FIGURE 7—Location of crushed-stone quarries in Kansas.

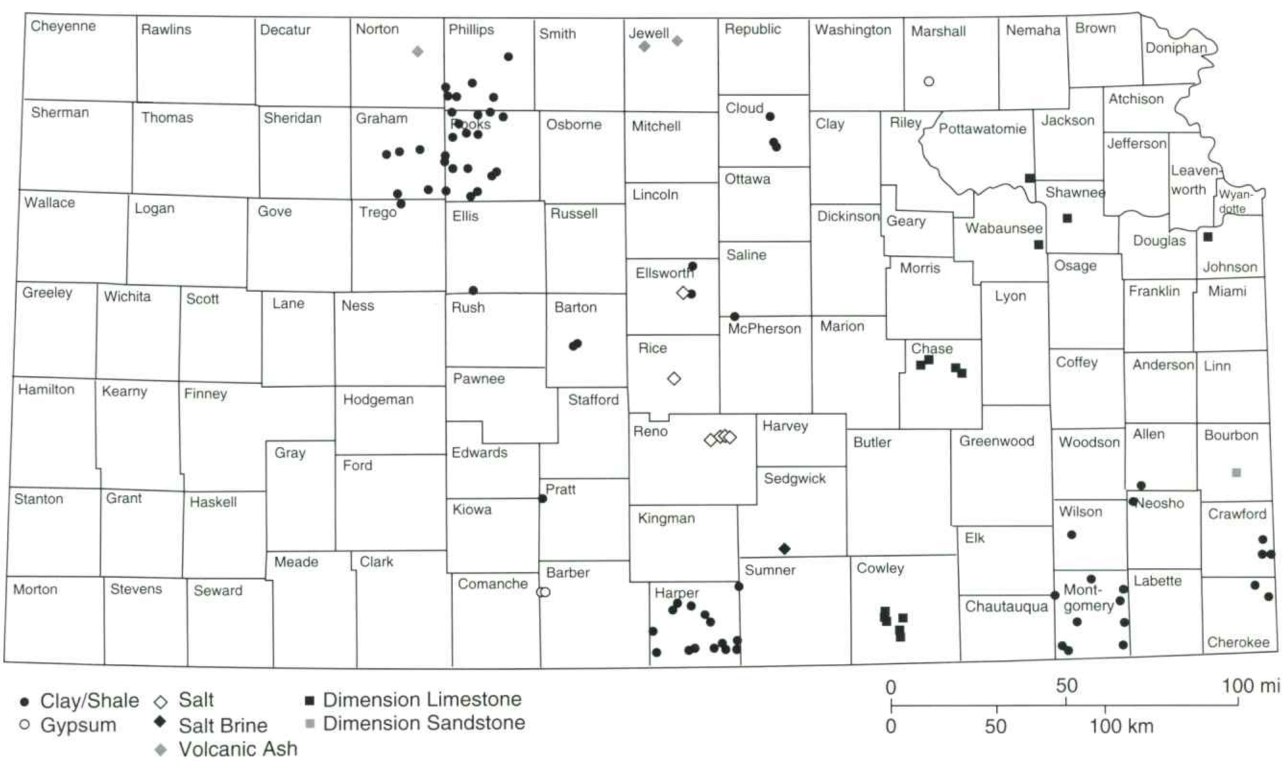


FIGURE 8—Location of industrial-mineral mines, other than aggregates, in Kansas.

Health, Safety, and Environmental Issues

The mining industry faces a number of health, safety, and environmental issues. Since 1980, U.S. businesses (including mining companies) have spent over a trillion dollars for environmental clean-up. According to the National Mining Association, the annual amount expended has grown rapidly in recent years and is now about $250 billion annually. In addition, Federal regulations under the jurisdiction of such agencies as the Mine Safety and Health Administration (MSHA), the Occupational Safety and Health Administration (OSHA), and the Kansas Department of Health and Environment have had a pronounced effect upon health, safety, and environmental hazards associated with the mining industry. Total deaths from all types of mining have decreased nationwide, with low records being set during the past two years. During 1996 and 1997, 90 or fewer deaths per year were attributed to mining-related accidents in the United States. This figure is in marked contrast to the hundreds of deaths recorded in some countries each year.

Many feel the United States has led the way, relative to the rest of the world, in safety, health, and environmental concerns related to the mining industry. Ironically, leading the way has cost American mining and mineral-producing companies their competitive edge. American companies compete for sales with most countries that do not have the stringent health, safety, and environmental standards of the United States. In other words, the cost of American industrial minerals and products are higher than most other countries, in part because of the costs associated with safety, health, and environmental concerns and regulations.

For the most part, non-fuel, non-metal mining has produced few health and safety impacts in Kansas. In a few isolated instances in underground mines, roof falls have caused injury or death. The chemicals associated with most commodities currently mined have little serious health impact. However, in recent years, concern has been expressed regarding the presence of free or crystalline quartz that is often present in deposits being mined and crushed. Initially, the danger of silicosis (massive fibrosis of the lungs resulting in shortness of breath caused by breathing in of particulates) led to the installation of sprayers in crushers of limestone rock to hold dust levels to a minimum, even when the limestone had so much moisture in it that no dust was formed during crushing. In time, this rule was modified so that it applied only to crushing equipment used for silica-type material. At present, operations involving free silica are carefully monitored because of the potential for silicosis. Plant workers are equipped with air-quality monitors that detect fine particulates in the air at the mining and processing facilities.

Nuisance factors such as traffic, noise, and dust occur whenever a crushing operation is located in or near a city. These factors are probably the major objections most people have to locating a new stone quarry near their residential areas.

The nature of quarry blasting has changed greatly in recent years. At one time, quarry blasting involved large charges that threw debris and sometimes sent shock waves for a considerable distance. Thanks to advances in blasting technology, quarry operators now use smaller charges in series or sequence to obtain the desired quantity and size of rock from the quarry face, while minimizing the chances of rock being thrown from the quarry area. These improved techniques also reduce the chances of damage to structures from the resulting shock wave.

Subsidence is sometimes a result of abandoned underground mines, particularly with salt mines. For example, at Kanopolis (Ellsworth County), an improperly filled salt-mine shaft, combined with continued dissolution and rotting timbers, suddenly gave way and rapidly formed a large sink that is partly filled with water. A similar incident occurred in Hutchinson.

Far more serious, from safety, health, and environmental standpoints, are the abandoned lead and zinc mines in extreme southeastern Kansas. Until recently, hundreds of abandoned mine shafts dotted the area. Many had partially collapsed and filled to varying depths with water, yet many remained open. In numerous areas, subsidence is a potential hazard. Thanks to cleanup efforts paid for by the United States Environmental Protection Agency's National Priorities List (Superfund), a Federal program to clean up hazardous sites, many of the open shafts have been filled or plugged, particularly in the vicinity of Galena where the mines were most common.

Because galena (lead) and sphalerite (zinc) are sulfides, they react with water and produce the acid water present in the mines and ground-water system. Also, some acid drainage from mine-waste piles can find its way to stream systems. In Cherokee County, an estimated 2,200 acres of underground workings exist, and another 2,300 acres were occupied by surface workings. The highly acidic, metal-laden water has undoubtedly contaminated both surface and subsurface water. The extent of ground-water contamination is not well known. Much of the mined area supports only limited vegetation and some areas are still considered wastelands. Some of the mine waste was in the form of chat or chert piles that, at one time, approached 200 feet (60 m) in height. The large quantities of mine waste have diminished greatly over the past 20 years as the material has been used to some extent for roads and a large amount for railroad ballast.

Although most of the mines were underground, some were open pits that continue to be a source of pollution for both water and air. Mine wastes are another source of pollution. At one time, smelting operations provided a large quantity of airborne contamination, while tailings ponds and smelter residues were a source of water contamination.

Among the non-fuel, non-metal commodities, salt has probably had the greatest environmental impact. Salt is widely used as a road de-icer, but it also kills the adjacent vegetation. Its gradual penetration into the road surface allows it to reach the reinforcing rods where the chloride ion attacks the iron and leads to volume expansion and eventual road failure. State highway departments throughout the country have spent large amounts of time and money in an attempt to solve this problem. One alternative is using reinforcing rod that has been coated with an epoxy material, although it is very difficult to put the reinforcing rod into place without chipping or scraping off a portion of the protective coating.

Salt is toxic to vegetation, and several years ago a group of farmers filed suit against a salt company whose operations contaminated a shallow aquifer that supplied the croplands of the area farmers. Broken salt blocks and possibly other salt were stockpiled at the surface or buried at the plant site. In time, the salt was dissolved by rain and subsurface water and the salt began migrating along the shallow water aquifer. Eventually, a multi-million dollar fine was levied against the responsible company. The company has since taken steps to minimize the contamination.

Salt contamination of ground water is not only caused by mining activities. Natural salt deposits can also be the origin of contamination (Buddemeier et al., 1995). Normally, the denser saltwater zone lies below the freshwater, but fault zones, improperly abandoned wells or boreholes, and excessive pumping of wells are examples of factors that may cause upward movement of the saline water from its normal depth to the point that it enters domestic- or irrigation-water supplies

While any mining operation has some degree of environmental impact, it is likely that all non-fuel, non-metal operations lumped together have not had as great an environmental impact as the lead-zinc mines or coal mines in southeastern Kansas.

Laws and Regulations

Until recently, only fuel commodities were regulated by the State of Kansas. Drilling for oil and gas are regulated by the Kansas Corporation Commission. The permitting and reclamation of coal mines was first regulated by the Mined Land Conservation and Reclamation Board, associated with the old Kansas Department of Labor, beginning in 1969. Through a reorganization in 1988, all activity related to coal mining and reclamation is now regulated by the Surface Mining Section of the Kansas Department of Health and Environment.

Until recently, permitting and reclamation of non-fuel, industrial minerals (except for river dredging) resided with county governments. River dredging is regulated by the U.S. Army, Corps of Engineers, and the chief engineer of the Division of Water Resources, Kansas Department of Agriculture. In recent years, county planners and commissions have become more restrictive about allowing new quarries near city areas. Several proposed quarries and dredge sites in Kansas have been hotly contested during recent years, particularly in areas of growth, largely related to the feelings of nearby neighbors.

In 1994, an industry-supported bill regulating the permitting, operation, and reclamation of all industrial mineral pits and quarries was passed by the State legislature. The State Conservation Commission was given the jurisdiction for all permitting and reclamation. All sites larger than two acres are required to be registered with the Commission. Permits are granted only after public hearings have been held, approval by the county commissioners has been obtained, and bonds have been issued to insure reclamation is completed after mining ceases. The reclamation regulations require the area be returned to its approximate natural state with respect to grading, appropriate vegetation (native vegetation is recommended), and shallow slopes to minimize potential hazards associated with landslides. The State finally has a uniform set of rules to govern the mining activities of industrial minerals. It is important to note that these regulations have largely been supported by the mining industry.

Reclamation Efforts

Prior to 1994, most of the reclamation of the non-fuel, non-metal industrial mineral operations had been done by producers as a result of county requirements. Hundreds of pits and quarries are scattered throughout the state for which no reclamation is planned at present; most were abandoned long ago. The majority are stone quarries or sand and gravel pits, but many of the latter sites tend to "heal" themselves.

A small amount of volunteer reclamation was done at coal mines before regulations took effect, and some abandoned surface coal mines where significant danger to humans is present have been reclaimed using Federal funds. However, these efforts are miniscule compared to the total acres of disturbed land. The same can be said for the abandoned lead-zinc mines; in some cases, cities have provided funds for limited reclamation efforts. The Federal government has provided funds to study and assess the environmental and safety aspects of this area as well as a demonstration project aimed at plugging some of the abandoned mine shafts with an inverted pyramid type of plug.

How Regulations Affect Aggregrates Business

Most of the state's industrial-mineral producers are involved in the production of aggregrates (crushed stone as well as sand and gravel). Aggregrates are vital to the growth of our communities and the repair of the state's infrastructure. Because the profit margin in aggregates is low, businesses cannot survive without reasonable volume and certainly cannot afford large hauling costs associated with long distances to the market areas. That is why one must carefully consider zoning restrictions. If a county decides that they do not want a crushed stone operation within 10 or 20 miles of a city's limits, what are the consequences of that decision? Such decisions can have large economic consequences for a community. Are the communities ready or able to pay increased transportation costs? It is very expensive to haul industrial minerals for any significant distance, particularly for a low-cost item like aggregates. These are problems that city-planning staffs and zoners must consider when working to arrive at satisfactory solutions.

For example, consider a hypothetical situation where a city decides not to allow any quarry operations within 20 miles (32 km). A construction company has a quarry located 20 miles (32 km) from a proposed housing development within the city. Because of a scarcity of sand and gravel, the company is using only various sizes of crushed stone for the aggregate. (While this sole use of crushed stone for aggregate is not likely today, it could become common in the future as the available or accessible supplies of good sand deposits are exhausted.) The Kansas Aggregate Producers Association estimates that it takes approximately 400 tons of aggregate to build one single-family house in a new housing development. This figure includes all uses, such as concrete aggregate for the house, driveway, street, bedding for drainage features associated with the house and street. Suppose that the average hauling cost for the aggregate is \$0.22 per ton mile in the area. The transportation costs for a single house would be 400 tons × \$0.22 per ton mile × 20 miles, or \$1,760. In a 20-house development, the increased transportation raises aggregate costs over \$35,000. The example shows how important the transportation issue is to an industrial-mineral producer, especially an aggregate producer.

The U.S. Army, Corps of Engineers (1991) established limits on the amount of sand and gravel dredged from the Kansas River along the Topeka to Kansas City corridor. The limits were created to stabilize the level of the river bed and prevent damage to structures along the river as a result of a continual lowering of the bed. This had a substantial impact on the sand and gravel producers. The Topeka–Kansas City corridor is a high-demand area for sand and gravel and the restrictions have lowered production and sent producers scrambling for other sources. Unfortunately, sand from the Missouri River has disadvantages. Much of the sand from the Missouri is fine-sized and lacks the desired coarser size ranges. In addition, the sand contains lignite (a low-grade coal) that must be minimized or removed before the sand can be used for many applications, thus making the sand more expensive. Furthermore, the remaining lignite may float to the surface of the concrete where it causes discoloration and also allows accelerated weathering of the concrete surface.

Future of Industrial Minerals

Many variables affect the future of industrial minerals in Kansas. What are we using now, and what will we need in 5, 10, or 25 years? What are the known reserves of the different mineral commodities now mined and processed? What sort of population growth can we expect? What type of environmental and zoning restrictions can we expect in the future?

As the previous discussion pointed out, sand and gravel producers have some of the most difficult issues to face. The impact of restricted river dredging on the Kansas River has been reported by Brady et al. (1998). The report showed how the population growth in Kansas is primarily within the 10 counties bordering the Kansas River. Presently, about 40% of the state's population lives in these counties, and population projections indicate close to half of the state's population will occupy these counties by 2025. This area will obviously need large amounts of aggregates to support the high demand for the construction of highways, roads, streets, buildings, and residences.

Sand and gravel resources within the lower portion of the Kansas River floodplain are limited. According to one company, drilling along the floodplain of the Kansas River from Kansas City to Lawrence has shown limited resources to support the industry. Limited potential floodplain dredge sites for this portion of the river were also reported by Blechinger (1997). Even if a site were known to have a substantial amount of sand and gravel, it might be unavailable. Most of the floodplain land is prime farmland. Not only would the land be expensive, it would usually not be available because a farmer whose livelihood depends on the land is simply not interested in selling it. Furthermore, some land is not available because of commercial uses or structures such as roads, rail lines, pipelines, and bridges that eliminate dredging activity due to regulations.

River dredges in the Kansas River also face reduced recharge supplies of sand and gravel, particularly the recharge of coarse-sized material. The problem is caused by the construction of 18 flood-control reservoirs along the drainage system of the Kansas River. These reservoirs act like holding ponds; sand and gravel settle out in the reservoirs and are thus removed from the river flow. As a result, the amount of sand recharge into the Kansas River and the floodplain during periods of high water has been reduced. The reservoir system has had a large overall effect on lowering the Kansas River bed and certainly has greatly limited the recharge of coarse sand and gravel.

The demand for sand and gravel in south-central and southwestern Kansas is primarily met by floodplain operations along the Arkansas River. There are no conventional river dredges in the Arkansas River. The characteristics of the Arkansas are quite different than those of the Kansas River. A combination of little overburden, shallow water table, available and inexpensive land, and the lack of thick river-bed deposits make floodplain operations more viable along the Arkansas River. In addition, Arkansas River sand is important because there is very little limestone in this part of the state, and rural roads depend upon sand and gravel for road cover.

Although all dredging operations have common problems, dredgers along the Arkansas River face some different issues than those along the Kansas River system. Probably the most important issue is water. Rainfall in western Kansas is low, with some areas being only a step away from a desert environment. Under these conditions, water is a precious commodity. The low humidity, windy conditions, and high evaporation rate make water conservation essential. Floodplain dredges with pits full of water are considered by many as detrimental to water conservation because of evaporation and subsequent effects on the water-table elevation. A related issue is the shallow water table and the shallow Equus Beds aquifer that supplies water to communities. Concern has been expressed that floodplain dredges can lead to possible contamination of these beds. Representatives from the Kansas Aggregate Producers Association and the Equus Beds Groundwater Management District #2 have conducted monthly, day-long meetings for over a year in an attempt to define the extent of the problem and come up with a solution that satisfies all parties, a goal that is expected to be attained by year's end (1998). A related major problem is how to handle applications for dredging permits in areas where all the ground water is already appropriated. The task force hopes to draft legislation that would enable aggregate producers to acquire water rights.

In northwestern Kansas, sand and gravel producers, including county road departments, face a different problem, namely the lack of substantial resources. There is an obvious lack of river deposits, and much of the product is obtained from pits associated with terrace deposits as mentioned earlier. Frequently, these pits are small and inconsistent. Unless other reserves are found, the day may come when reserves will be depleted, and counties will be forced to "import" sand from other areas or use a graded crushed stone product for aggregate. Because little hard rock is found in this part of the state, an aggregate shortage could occur. Again, transportation costs associated with bringing in such resources could become a major factor affecting construction in this part of the state.

As mentioned previously, most of the crushed stone aggregate is produced in the eastern one-third of the state from Pennsylvanian and Permian rocks. While resources seem to be adequate in most of eastern Kansas at present, the continual upgrading of specifications for aggregate by the Kansas Department of Transportation will continue to eliminate certain beds of stone for use in highway construction. These upgraded specifications may prevent many potential quarry sites from opening, because there may not be sufficient rock of good quality at the site to justify opening a quarry. In addition, concrete in the Kansas City area is deteriorating more rapidly than expected and limestone aggregate has been mentioned as a possible cause. Certain beds of limestone may contain varying amounts of reactive silica that lower the durability of the concrete. Ready-mix producers may need to use more sand and gravel and less limestone in the aggregate mixture. Because a cubic yard of concrete for road construction contains about 3,000 pounds of aggregate, such a shift in the aggregate mixture would have an appreciable impact on both types of aggregate producers.

Much of what applies to the future of the aggregate industry also applies to other industrial minerals used for construction purposes. Like aggregate producers, the cement, gypsum, and building-stone producers are doing well in the current scenario of low interest rates and economic prosperity.

Cement is used to make concrete that will always be needed for new roads, repair of existing roads, and residential and non-residential buildings. Although affected by economic conditions, the overall demand for this commodity is expected to remain strong into the next century.

Board products made from gypsum should continue to remain in demand as long as interest rates remain relatively low and building construction remains strong. However, as the population growth slows, there will be a time in the next century when demand for board products will decline.

Although the building-stone industry is affected by economic conditions, it also depends on customer preferences such as the availability of color or whiteness of the stone. In some areas, shortages of stonemasons may discourage prospective customers. The cost of a skilled stone mason is great, even if one is available, and it becomes greater if one must "import" a mason to the job site. The increased cost associated with a stone exterior is due more to the stone mason than the stone.

Although salt is essential for food applications and road de-icing, the overall growth in the industry is not expected to be large. For the short term, weather is responsible for the feast or famine years associated with road de-icing. Mixtures of salts, such as a combination of sodium and calcium chloride, have often been used in recent years instead of 100% salt. The toxicity of salt to vegetation and the detrimental effect salt has on roads are other reasons to search for an alternative product. Salt is inexpensive, and thus has a cost advantage over other products that might be used.

The demand for evaporative salt used in and on foods is expected to remain stable. Increases in population that would cause an increase in salt consumption may be offset by lower per capita consumption due to health considerations related to high blood pressure.

Summary

Beginning with a discussion of the early mining history of Kansas, this primer has covered the basic geology, location, composition, properties, uses, and mining and production methods associated with industrial minerals in Kansas. Additionally, the primer has discussed the various health, safety and environmental issues, laws and regulations including their impact on business, reclamation efforts, and future of industrial minerals.

One important point should be emphasized: a modern society cannot exist without industrial minerals. They are necessary for nearly all buildings and roads. They contributed an estimated $547 million to the state's economy during 1997; this number is based on the raw materials' value and not the finished product. If one converts the price of common clay to the price of finished brick or sewer pipe, cement to concrete, gypsum to board products and plasters and so forth, the $547 million becomes finished products worth billions of dollars. Preserving adequate resources to support our society is essential.

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Appendix A—

Annual Production and Value for Individual Commodities

Sand and Gravel Production in Kansas

YEAR	QUANTITY (thousand short tons)	VALUE (thousands of dollars)
1905	71	$22
1906	294	67
1907	557	117
1908	320	64
1909	978	189
1910	777	166
1911	735	164
1912	1,382	287
1913	1,120	272
1914	1,347	381
1915	1,285	378
1916	1,165	304
1917	823	196
1918	761	264
1919	954	508
1920	1,275	906
1921	1,084	648
1922	1,399	791
1923	1,950	1,039
1924	1,883	1,223
1925	2,199	1,303
1926	2,489	1,491
1927	2,255	1,456
1928	2,760	1,532
1929	3,390	1,880
1930	3,233	1,649
1931	2,893	1,333
1932	1,851	879
1933	2,016	734
1934	1,682	698
1935	1,571	667
1936	2,454	921
1937	2,495	1,017
1938	2,963	1,117
1939	1,935	833
1940	2,265	894
1941	2,928	1,289
1942	5,201	2,773
1943	3,616	2,103
1944	2,786	1,603
1945	3,082	1,675
1946	4,443	2,506
1947	4,352	2,330
1948	5,083	2,749
1949	6,187	3,328
1950	9,781	6,782
1951	7,677	4,748
1952	8,380	5,024
1953	8,728	5,668
1954	10,422	7,194
1955	10,665	6,910
1956	12,515	8,022
1957	9,345	6,175
1958	10,317	6,769
1959	11,334	7,937
1960	9,710	6,808
1961	11,366	7,781
1962	11,552	8,039
1963	12,062	8,676
1964	12,968	9,108
1965	12,544	8,473
1966	11,627	8,374
1967	12,066	8,650
1968	12,427	10,559
1969	12,029	10,061
1970	12,968	12,351
1971	11,862	11,351
1972	11,591	10,920
1973	13,261	12,663
1974	11,687	13,388
1975	10,866	13,467
1976	12,291**	14,940
1977	13,973	23,299
1978	14,260	24,330
1979	14,280	26,490
1980	12,124	23,817
1981*	10,500	21,000
1982	9,720	20,612
1983*	12,400	26,600
1984	11,796	26,358
1985*	13,200	31,800
1986	15,609	33,721
1987*	15,600	37,800
1988	10,760	25,329
1989*	13,000***	33,200
1990	10,737	23,771
1991*	9,600****	22,100
1992	11,954	27,289
1993*	13,090	30,700
1994	12,316	29,589
1995	12,210	29,400
1996	12,650	31,300
1997	11,880	30,100

(continued next column)

* Denotes estimated amounts by USBM (odd-numbered years beginning in 1981 through 1993).

** USBM began excluding industrial sand from the total production in 1976.

*** USBM began excluding crushed sandstone and quartzite in 1989.

****U.S. Army, Corps of Engineers, restrictions on dredge production from the Kansas River went into effect on February 21, 1991.

Cement Production in Kansas

YEAR	QUANTITY (thousands of short tons)	VALUE (thousands of dollars)
1928	1,276	$10,091
1929	1,289	10,041
1930	1,059	8,254
1931	842	4,113
1932	822	1,881
1933	411	2,882
1934	456	3,734
1935	468	3,778
1936	671	5,550
1937	658	5,489
1938	605	4,949
1939	704	5,614
1940	647	5,192
1941	890	7,137
1942	1,453	11,415
1943	997	8,036
1944	539	4,454
1945	620	5,158
1946	1,296	11,574
1947	1,355	13,017
1948	1,491	16,188
1949	1,436	16,880
1950	1,647	19,400
1951	1,535	19,413
1952	1,657	20,957
1953	1,607	21,429
1954	1,706	23,874
1955	1,777	25,854
1956	1,992	30,696
1957	1,537	24,814
1958	1,805	30,048
1959	1,956	32,282
1960	1,534	26,373
1961	1,509	25,605
1962	1,515	25,134
1963	1,542	25,372
1964	1,595	25,959
1965	1,655	26,972
1966	1,688	27,246
1967	1,661	25,545
1968	1,820	29,898
1969	1,835	29,365
1970	1,729	28,177
1971	1,731	29,961
1972	1,889	35,432
1973	2,026	42,172
1974	1,940	46,940
1975	1,832	55,033
1976	2,005	66,478
1977	2,020	72,815
1978	2,083	78,717
1979	2,086	88,619
1980	1,835	86,103
1981	1,641	81,792
1982	1,549	79,558
1983	Not Published —	—
1984	Not Published —	—
1985	Not Published —	—
1986	1,763	91,110
1987	1,697	81,045
1988	1,569	72,805
1989	1,505	69,390
1990	1,707	76,564
1991	1,466	65,970 (est.)
1992	1,710	79,464
1993	1,521	73,914
1994	1,804	101,000
1995	1,903	109,000
1996	1,903	120,000
1997	1,936	124,000

(continued next column)

From 1928 through 1960, data represent a combination of portland and masonry cement. Figures for 1961 through 1997 represent only portland cement. Natural cement is not included in these figures.

Clay Production in Kansas

YEAR	QUANTITY (thousand short tons)	VALUE (thousands of dollars)
1945	255	$197
1946	464	283
1947	269	243
1948	289	240
1949	302	260
1950	725	601
1951	732	729
1952	666	789
1953	671	750
1954	—	—
1955	768	873
1956	977	1,169
1957	909	1,240
1958	875	1,145
1959	1,021	1,271
1960	894	1,224
1961	954	1,225
1962	895	1,091
1963	893	1,104
1964	785	935
1965	789	953
1966	847	1,006
1967	935	1,339
1968	932	1,433
1969	797	1,070
1970	713	946
1971	879	1,151

(continued next page)

YEAR	QUANTITY (thousand short tons)	VALUE (thousands of dollars)
1972	1,170	1,457
1973	1,169	1,490
1974	1,311	1,785
1975	1,178	1,604
1976	1,064	1,869
1977	1,117	1,965
1978	1,161	2,314
1979	1,061	2,636
1980	886	2,325
1981	915	4,756
1982	664	3,656
1983	718	3,921
1984	918	5,537
1985	878	5,326
1986	903	5,295
1987	604	2,576
1988	613	2,632
1989	588	2,700
1990	690	4,056
1991	670	2,828
1992	600	3,921
1993	572	1,970
1994	613	2,150
1995	632	2,390
1996	604	2,250
1997	414	1,270

Before 1945, the value of finished products made from clay was reported but not tons of clay mined. Between 1946 and 1949, figures exclude clay used in cement production. No values were published in 1954. Between 1950 to the present, tons produced for all uses are given except for certain years that excluded bentonite production or certain clays.

Salt Production in Kansas

YEAR	QUANTITY (thousand short tons)	VALUE (thousands of dollars)
1928	822	$3,574
1929	840	3,762
1930	760	3,149
1931	691	3,004
1932	688	2,876
1933	733	3,039
1934	768	2,950
1935	608	2,309
1936	704	2,580
1937	654	2,759
1938	598	2,565
1939	642	2,592
1940	684	2,711
1941	781	3,255
1942	860	3,809
1943	945	4,198
1944	932	4,357
1945	856	3,838
1946	815	4,015
1947	904	4,534
1948	832	4,961
1949	832	5,218
1950	846	5,915
1951	901	6,640
1952	912	6,850
1953	905	7,481
1954	877	7,778
1955	911	8,432
1956	1,004	9,167
1957	1,018	10,353
1958	1,073	11,348
1959	1,123	13,670
1960	1,213	14,109
1961	913	11,409
1962	944	11,654
1963	924	11,993
1964	930	11,799
1965	1,053	12,376
1966	969	13,388
1967	1,069	14,686
1968	1,128	15,520
1969	1,270	17,090
1970	1,230	18,206
1971	1,240	18,712
1972	1,369	20,562
1973	1,397	23,460
1974	1,367	27,007
1975	1,446	31,214
1976	1,310	35,291
1977	1,430	41,154
1978	1,661	48,097
1979	1,900	61,184
1980	1,572	64,276
1981	1,410	60,148
1982	1,601	72,146
1983	1,719	67,195
1984	1,712	71,558
1985	1,790	71,970
1986	1,656	68,887
1987	1,689	70,148
1988	1,284	55,753
1989	1,948	82,212
1990	2,390	92,119
1991	2,316	97,713
1992	2,037	98,620
1993	2,548	103,019
1994	2,926	108,000
1995	3,047	103,000
1996	3,245	118,000
1997	3,410	121,000

(continued next column)

Beginning in 1961, salt in brines was excluded.

Crushed Stone Production in Kansas

YEAR	QUANTITY (thousand short tons)	VALUE (thousands of dollars)
1928	1,203	$1,213
1929	1,420	1,461
1930	1,249	1,245
1931	1,099	1,036
1932	733	651
1933	1,053	957
1934	1,371	1,350
1935	1,852	1,834
1936	4,935	5,747
1937	3,541	4,763
1938	3,676	4,959
1939	3,407	4,551
1940	2,881	3,673
1941	2,727	3,172
1942	2,588	3,031
1943	2,075	2,291
1944	2,121	2,070
1945	3,666	2,847
1946	3,654	3,909
1947	4,793	4,868
1948	5,316	5,481
1949	5,978	7,951
1950	7,630	8,920
1951	7,191	9,059
1952	8,831	12,052
1953	8,769	11,304
1954	10,377	12,942
1955	12,483	15,946
1956	13,434	15,703
1957	10,412	11,926
1958	12,424	15,036
1959	13,999	17,108
1960	11,814	15,031
1961	12,328	16,411
1962	13,527	17,274
1963	13,558	18,483
1964	14,138	18,912
1965	15,270	20,538
1966	14,027	18,789
1967	13,551	17,806
1968	14,372	20,650
1969	15,828	22,645
1970	15,161	22,406
1971	14,908	23,697
1972	14,547	23,899
1973	18,334	33,601
1974	17,869	34,869
1975	15,907	35,050
1976	16,348	38,228
1977	17,229	41,807
1978	18,578	48,803
1979	19,308	56,038
1980	17,398	54,731
1981	14,143	45,738
1982	14,400	41,100
1983	12,687	45,121
1984	13,600	48,500
1985	15,653	57,155
1986	16,600	60,300
1987	19,319	69,628
1988	17,300	72,700
1989	15,850	56,976
1990	20,800	79,200
1991	16,802	67,249
1992	16,864	69,600
1993	20,732	90,663
1994	23,650	103,000
1995	22,400	95,800
1996	24,310	110,000
1997	25,960	118,000

(continued next column)

Quantity and value have been influenced by inconsistent treatment of dimension limestone, dimension sandstone, crushed limestone for cement, and crushed sandstone. One or more of these categories may be included in some years but not others. Dimension stone has been excluded from these figures since 1971. Also, in 1982–1992, figures were estimated for every even-numbered year by the U.S. Bureau of Mines.

Additional KGS Educational Series Publications

Ancient Life Found in Kansas Rocks (Common Fossils of Kansas), Educational Series 1, by R. B. Williams
An introduction to many of the common fossils found in Kansas. The geologic history of Kansas, the formation and classification of fossils, and definitions for difficult terminology also are included. Color illustrations accompany the text.
44 p. • 1975 • **$5.00**

Kansas Rocks and Minerals, Educational Series 2, by L. L. Tolsted and A. Swineford
Descriptions of Kansas rocks and minerals are accompanied by illustrations for identification. The discussion of rocks is broken into igneous and sedimentary types. The geological history of Kansas and sedimentary structures also are described.
64 p. • 1957, revised and reprinted 1998 • **$3.00**

Kansas Clays for the Ceramic Hobbyist, Educational Series 3, by D. A. Grisafe and M. Bauleke
Written in dialogue format, this publication answers common questions about finding, testing, and using clays for sculpting. Illustrations and a glossary are also included.
35 p. • 1977 • **$5.00**

Kansas Geomaps, Educational Series 4, by D. W. Steeples and R. Buchanan
A compilation of Kansas maps illustrating geology, physiology, oil and gas fields, availability of ground water, coal and mineral products, microearthquakes and faults, the geologic timetable, and more. Text accompanies each of the fourteen maps.
30 p. • 1983, revised and reprinted 1984 • **$5.00**

Kansas Landscapes: A Geologic Diary, Educational Series 5, by F. W. Wilson
A sequential discussion of the Kansas landscapes. The Mississippian, Pennsylvanian, Permian, Cretaceous, and Quaternary rock systems are discussed along with their locations in the state of Kansas.
50 p. • 1978 • **$5.00**

From Sea to Prairie: A Primer of Kansas Geology, Educational Series 6, by C. S. Evans
A general discussion of the changing Kansas landscape, geologic time, rocks and minerals, and fossils of Kansas is undertaken. The state is broken into eleven regions, and the book addresses the rock type, age, and landscape of each. This publication contains a glossary; excellent for children.
60 p. • 1988, reprinted 1995 • **$5.00**

Educational Series also available online at:
http://www.kgs.ukans.edu/

Petroleum: A Primer for Kansas, Educational Series 7, by D. L. Baars, W. L. Watney, D. W. Steeples, and E. A. Brostuen
This publication discusses the geology of petroleum, exploration for oil and gas fields, and subsurface and petroleum geology of Kansas. Mineral rights and leasing, drilling, and production also are addressed. A glossary of technical terms is included.
40 p. • 1989, reprinted 1993 • **$5.00**

A Guide to Finding Kansas Maps, Educational Series 8, by C. S. Evans
Comprehensive digest arranged by category to aid in locating sources of Kansas maps. Source agencies, their addresses, and phone numbers are included.
80 p. • 1990 • **$5.00**

Caves in Kansas, Educational Series 9, by J. Young and J. Beard
A discussion of cave formations and speleogenesis is followed by profiles and descriptions of caves from six regions in Kansas. Exact cave locations are not provided.
48 p. • 1993 • **$7.50**

Kansas Ground Water, Educational Series 10, comp. by R. Buchanan and R. W. Buddemeier
A general overview of ground-water occurrence, the hydrologic cycle, water quality, well construction and ground-water production, and ground-water management. Specific aquifers of Kansas are identified and discussed briefly. A glossary of technical terms and a list of water agencies and their responsibilities are included.
44 p. • 1993 • **$ 5.00**

Wichita's Building Blocks: A Guide to Building Stones and Geologic Features, Educational Series 11, by L. Skelton
The stones used in Wichita's downtown buildings are a sampler of rocks, fossils, and minerals from around the world. This book introduces the reader to some of the geologic features visible in downtown Wichita and describes features that can be seen outside downtown.
28 p. • 1997 • **$7.50**

Climate and Weather Atlas of Kansas, Educational Series 12, by D. G. Goodin, J. E. Mitchell, M. Knapp, and R. E. Bivens
This book discusses common terms and measurements encountered in recording weather and climate. Information is derived from data collected across the state and compiled at the State Weather Library at Kansas State University. Includes tables, charts, and maps depicting general patterns of weather behavior across the state.
28 p. • 1995 • **$7.50**

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