Geology and Concern for the Environment

PAUL L. HILPMAN and GARY F. STEWART,
Respectively, Chief of Environmental Geology Section, and Geologist, State Geological Survey of Kansas

CONCERN for the physical environment is intensifying at all levels of our society. Americans seem to believe that this concern is a new phenomenon, but for centuries enlightened men have warned us of the consequences of desecrating the environment. The seemingly unique quality of our time is that nearly everyone realizes the necessity for conservative and efficient use of our land and its resources. One manifestation of our interest is the creation of new specialties within established professions—specialties like environmental health, environmental engineering, environmental architecture, and, redundant as it may seem, environmental geology. Obviously, no single discipline includes all aspects of what can be called environmental science. Consequently, the growth of these new specialties has generated a high level of communication among professions that heretofore have operated almost independently.

In the past, geologists were basically indifferent to the needs of planners, engineers, architects and contractors. They often failed to explain some of the simple geologic facts that would have been of great assistance to these other professions. Today many geologists are vigorously adapting their work for greater usefulness in other fields. It is safe to predict that geologists will provide their share of leadership in creating communities that are in balance with the environment.

FACTOR MAPS AND SUITABILITY MAPS

Geologists are well-prepared to contribute to land-use planning by making inventories of the natural factors that must be taken into account in planning. If we are to perform this task properly, we must create and publish documents that will lead to the layman's understanding of the physical environment and, at the same time, contain data that will be useful to engineers, planners, and contractors in their day-to-day work. In order to meet the needs of the engineer and planner most effectively, the geologist must know (a) what data should be collected, and (b) in what form they should be presented. Table 1 lists those factors that are the most important in land-use planning. To determine the most useful form in which to present the data regarding these factors, the geologist must turn to information-users for help. In a pilot study of land-use planning in Kansas, we established categories for factor mapping by interviewing engineers, architects, planners, builders, and contractors. Figure 1 shows categories of grade limitations in the Kansas City area for several common construction activities. By means of such an illustration the obvious groups of grade limitations can be delineated and used as mapping categories. Similarly, Figure 2 shows minimum depth requirements for various urban installations. An illustration of this type facilitates establishment of categories for mapping the thickness of common excavation material. It should be apparent to the reader that mapping categories established in a given region will not be useful everywhere. For example, burial of water lines at a depth of about 3 feet is adequate in Kansas but might prove to be risky in areas where the climate is colder. We emphasize, however, that such a limitation is related to the provincial nature of the categories, and is not a limitation of the technique. All the physical factors given in Table 1 do not lend themselves to the type of analysis just discussed. Where the

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technique is applicable, however, it enables the geologist to prepare inventory-planning maps (factor maps) that are very useful to engineers and planners.

Urban activities that are strongly dependent on the natural-resource base are listed in Table 2. It should be apparent that the planning of each of these activities requires information from an inventory of several physical factors. For example, foundation design and construction involves knowledge of soil types, slopes, bedrock geology, and drainage of surface water and groundwater. By the use of factor maps in combination, suitability maps can be prepared that show areas that are well-suited or poorly suited for a given activity. Figure 3 is a suitability map of one square mile in eastern Kansas that delineates areas satisfactory for construction of one- or two-story residences with basements. Factor maps that were used to construct this suitability map are shown in Figures 4 through 7. It should be clearly understood that even though suitability maps

TABLE 1

FACTORS USED IN MAKING GEOLOGIC MAPS FOR PLANNING

Elevation	Hardness and rippability	Soil moisture
Slope	Soil types	Swell-shrink characteristics
Surface water	Groundwater	Atterberg limits
Bedrock geology and structure	Natural resources	Compaction characteristics
Soil-mantle thickness	Drainage basin factors	pH
Faults, joints, and other rock defects	Land use	Resistivity
	Vegetation	Grain size
	Precipitation	Porosity
		Permeability
		Mineralogy

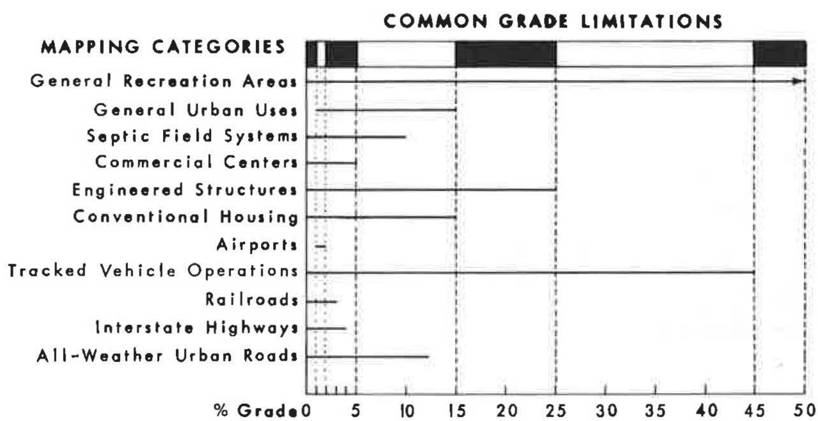


Figure 1. Ranges of slopes (grades) commonly suited for the various urban installations and activities shown, Kansas City region (3).

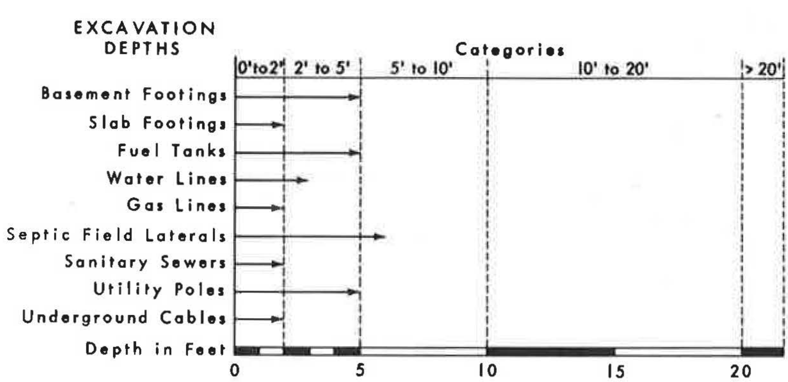


Figure 2. Minimum depth requirements for various urban installations in the Kansas City region (3).

TABLE 2

URBAN ACTIVITIES AND INSTALLATIONS STRONGLY DEPENDENT ON NATURAL RESOURCE BASE*

Waste disposal: solids, liquids, gases	Design and construction of foundations
Transportation: land (surface and subsurface), water, air	Extraction of mineral resources
Flood control	Open-space and recreation
Water supply: surface, subsurface	Underground utility networks
	Land reclamation and urban renewal

*From Ref. 3.

are highly useful in urban planning, geology should not be the ultimate basis of planning. Residences can be built successfully in areas that are poorly suited for such use, but the costs of overcoming the physical inadequacies of building sites may be very high. A suitability map merely forewarns planners and builders of this possibility and they are then free to examine the component factor maps and to use them as aids in their calculations of costs.

So far, this paper has dealt with generalities that relate geology to land-use planning, and we have shown a few of the techniques that have been developed to make geologic reports more intelligible, and hence more useful, to non-geologists. Most of the re-

Figure 3. Suitability map showing parts suitable (no pattern) and not suitable (stippled pattern) for residences with basements (3).

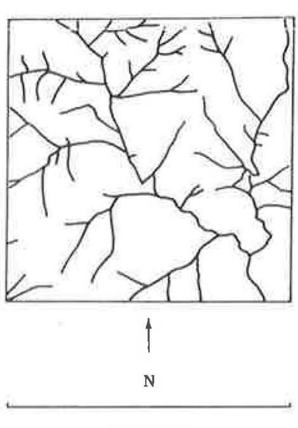


Figure 4. Pattern of streams in area shown in Figure 3. Flooding may occur during rainy weather, and at some places building of residences in proximity to streams is ill-advised (3).

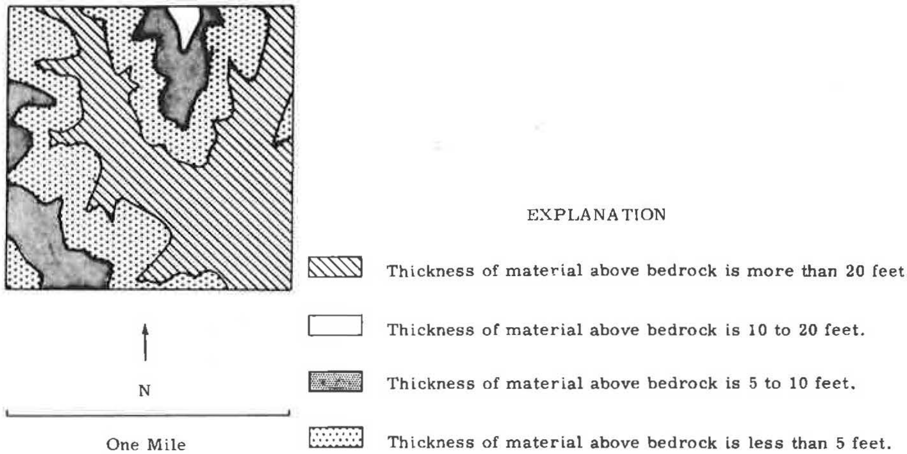


Figure 5. Patterns indicate depths to limestone or hard, unweathered shale in area shown in Figure 3 (3).

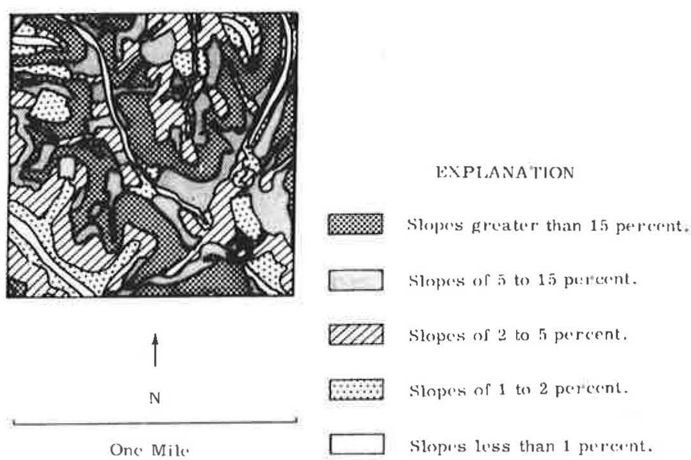


Figure 6. Simplified map of slopes in area shown in Figure 3. Slopes are mapped in percent grade (3).

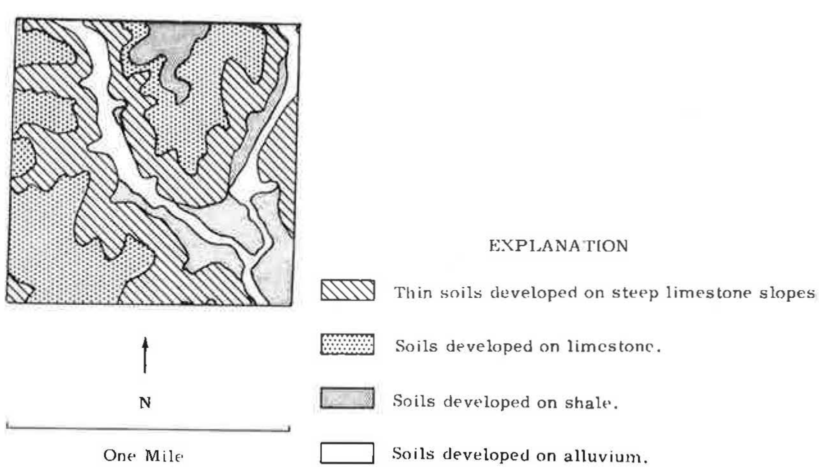


Figure 7. Simplified classification of soils in area shown in Figure 3. Classification is based on engineering properties, which in this instance can be correlated with the patterns of bedrock outcrop (3).

mainder of the paper discusses case histories that show the need for greater understanding of the physical environment and that illustrate some of the benefits to be realized by inventories of the natural-resource base.

SOME APPLICATIONS OF GEOLOGY TO URBAN PROBLEMS

There are probably few cities in the United States in which storm-water drainage always takes place as the original design intended. Engineers and engineering geologists have established algorithms for calculation of volumes and rates of discharge of storm water and these algorithms work most of the time because their bases are empirical as well as rational. In the last two decades we have begun to make detailed quantified analyses of non-urbanized drainage basins, but we are still not able to predict exactly how urbanization will affect these basins. One of our limitations is the fact that all the kinds of structures that will be built in a drainage basin cannot be anticipated at the time the storm-sewer system is designed. It is difficult to estimate how much of a drainage basin will eventually be made into paved parking lots, recreational areas, residential areas, and so forth.

For example, the upstream area of a small drainage basin in Lawrence, Kansas, was first developed as open space on the campus of The University of Kansas (Fig. 8). The downstream area of the basin subsequently became a residential district. The main line of the storm-sewer system is an open grass-and-concrete waterway that passes through the residential area and that is crossed by culverts at five places. In recent years the University of Kansas has built parking lots, large buildings, and dormitories in areas that had been open space. This construction and other urbanization of the basin has increased runoff so much that storm water backs up be hind culverts in the storm sewer and streets are flooded extensively at some places. Replacement of the storm sewers is out of the question, of course, but it is hoped that modification of this system will alleviate the problem.

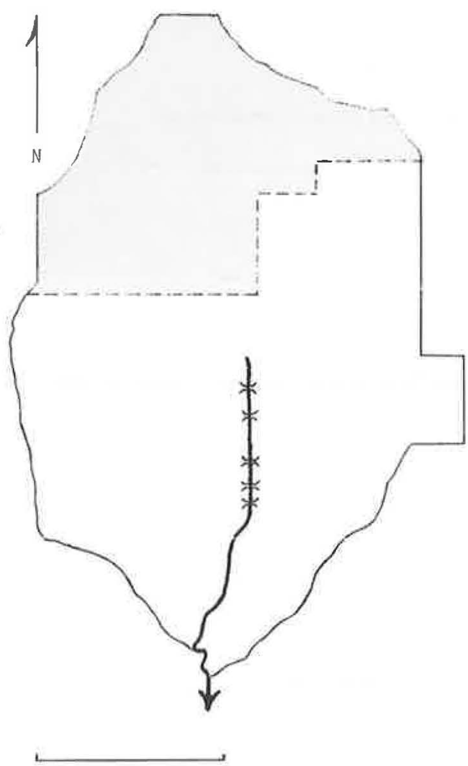


Figure 8. Small drainage basin in Lawrence, Kansas. Stippled pattern shows part of basin originally developed as grassland and sparsely wooded slopes on campus of The University of Kansas. Main line of the storm-sewer system is shown with locations of culverts.

The purpose of a highly efficient storm-sewer system need not be limited just to moving storm waters out of a city. These waters might be stored and used during periods of little rain fall, assuming, of course, that the water is so little polluted that its use is safe. Figure 9 shows diagrammatic quantity and quality hydrographs based on data collected from the drainage basin just described. At a specific level of pollution, water is rejected as being too contaminated for use, and the curves show clearly that part of the runoff from this basin is, in fact, highly contaminated. However, the data also show that most of the water is relatively uncontaminated and could be stored and used. Perhaps the planning of our future storm-sewer networks could even include design of systems to separate contaminated and uncontaminated water and to shunt usable water to reservoirs located within urban areas.

Because we are beginning to realize that we cannot take our resources for granted, the accelerated growth of our 200-plus metropolitan

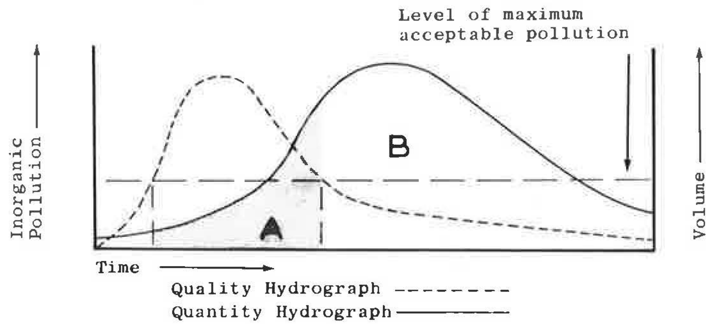


Figure 9. Diagrammatic quantity and quality hydrographs based on data compiled in drainage basin shown in Figure 8. Level of maximum acceptable pollution refers to quality hydrograph, and stippled pattern shows the relative volume of water that is not acceptable for storage and use, as based on quantity hydrograph (1).

areas is a subject of increasing concern (even apprehension) at many levels in our government. We truly are on a land-and-resources budget that has no provision for deficit spending, and therefore we cannot afford to have significantly large mineral deposits preempted by urban development. Nevertheless, our cities will continue to occupy more and more land each year. Ideally, a city has rural area entirely around its periphery and has close-in deposits of sand and gravel and stone suitable for use as

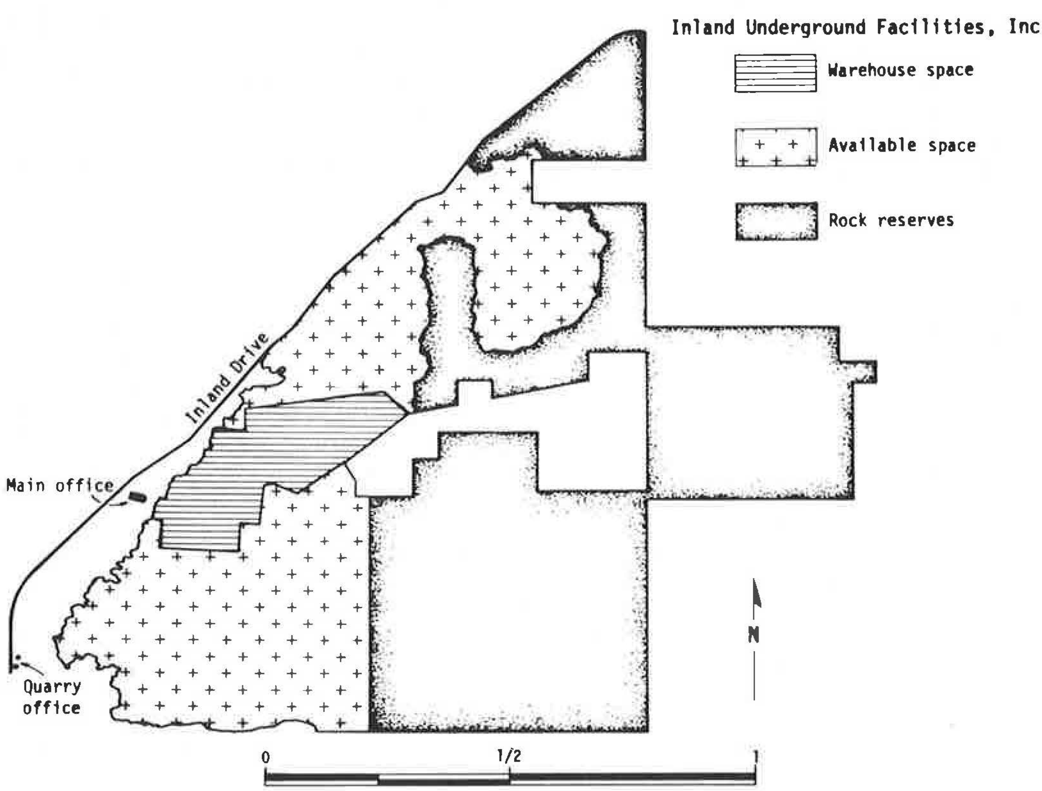


Figure 10. Plan of limestone mine near Kansas City, Kansas, showing warehouse space, mined-out areas, and areas of rock reserves (2).

Figure 11. Cross sections along line A-A′ shown on topographic map above. Contour interval of topographic map is 10 feet; area shown in one section, above one square mile. Upper cross section shows a "classical" representation of bedrock geology and boundaries of soil types as mapped by Soil Conservation Service, U.S. Department of Agriculture. Lower cross section is adapted for land-use planning. Some of the most important properties of the rock and soil are described in the following and keyed to the lower cross section by number. Horizontal exaggeration of cross sections, 3:1; vertical exaggeration 13:1 (3).

1. Kereford Limestone: Weathers easily and joints and bedding planes are widened by solution at some places. Near the outcrop, the Kereford may be so weathered as to be common excavation material. Approximate thickness: 2.5 to 9 feet.

2. Plattsmouth Limestone: Fresh rock where covered by Heumader Shale, and can be quarried or mined if rock meets standard tests and economic conditions are favorable. Thickness: about 18 feet.

3. Soils developed on limestone: Generally tend to swell and shrink and can cause foundation problems. These soils have low permeability and are poorly suited for septic systems.

4. Plattsmouth Limestone: Solution cavities may be present along joints and bedding planes at places where limestone is covered only by soil and mantle. Openings may be filled with clay and may be large enough to cause problems in construction of foundations. Weathered rock generally unsuited for industrial use. Near edge of outcrop, rock may be so deeply weathered as to be common excavation material.

5. Toronto Limestone: Fresh rock where covered by Snyderville Shale. The Toronto is used as dimension stone and crushed stone. Thickness: about 10 feet.

6. Heebner Shale: Seasonal seeps and springs may be present at Plattsmouth-Heebner contact. Groundwater moves through joints and bedding planes in lower part of Heebner, causing seeps and small springs at some places. Heebner should be excavated and foundation footings constructed on the Leavenworth Limestone, especially in construction of large buildings. Thickness: 5 to 8 feet.

7. Leavenworth Limestone: Solution cavities may be present along the closely spaced joints in this unit. Seeps and small springs from joints and at Leavenworth-Heebner contact are common. In some places near the outcrop, joint-blocks of Leavenworth can be excavated without blasting. Thickness: about 2 feet.

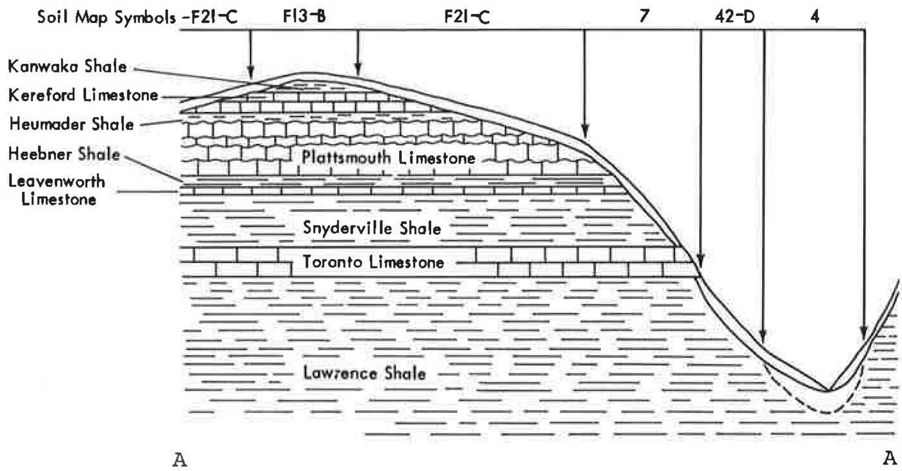
8. Snyderville Shale: Weathers to clayey soil that swells when wetted and shrinks when dried. Thickness: 10 to 15 feet.

9. Toronto Limestone: Joints are abundant and closely spaced and may be enlarged by solution in some areas, facts that should be considered in design of foundations.

10. Lawrence Shale: Seasonal seeps and springs from beds of siltstone below Toronto Limestone are common. In some areas, enough water reaches the surface through these beds to require diversion ditches. Thickness: about 150 feet.

11. Lawrence Shale: Locally, much groundwater moves along contact of mantle and shale during wet seasons. Unless this water is handled properly it can cause undue maintenance of foundations and streets. Perched water tables may be present at some places. The Lawrence Shale weathers to thick soil and mantle that swells and shrinks and causes many problems in construction and maintenance of foundations of buildings and subcourses of streets. Thickness of mantle varies considerably.

12. Lawrence Shale: Beds of siltstone included in shale carry considerable quantities of water at some places in wet seasons, and design of deep foundations should allow for this possibility.



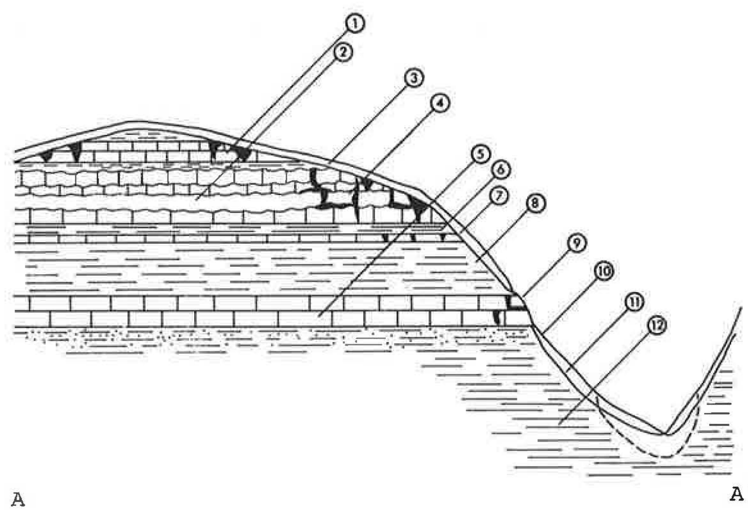


Figure 11. See legend on facing page.

concrete aggregate. Because these "ideal" conditions do not exist in every city, we are motivated to increased study and practice of multiple land use, since it has been shown that mining of resources and urban development need not be mutually exclusive. For example, greater Kansas City is built on terrain made up of sequences of limestone and shale formations. Several of the limestone units contain rock that is excellent for use as construction material. A 20-foot-thick limestone unit that makes the best crushed aggregate in the metropolitan area is mined underground near Kansas City, Kansas (Fig. 10), about 100 feet beneath a residential district. The limestone is almost horizontal and is well-suited for excavation of rooms that have stable roofs and floors. Cold-storage warehouses that include more than a million cubic feet of space and a factory for fabrication of wire cable have been built in this mine, complete with offices and a railroad siding. This development is just one of many underground complexes in metropolitan Kansas City; in fact, one-seventh of Kansas City's warehouse space has been constructed in limestone mines and more than 200 acres are mined each year for use as offices, factories, and warehouses. The value of limestone actually is a secondary consideration in some of this mining.

The four stages of development of the site of the Denver Coliseum are another good example of multiple land use (6). The coliseum is located on land that first was used for agriculture and then was exploited for gravel. By 1948 the site was being used for sanitary landfill, and today the coliseum, its parking lot, and the overhead ramps of Interstate-70 are developed on the landfill.

These examples of multiple land use point out the kinds of benefits that can be realized if we commit our land to use in a deliberate and farsighted manner. At this point we can emphasize appropriately that the appeal of multiple land use should not be limited to those of us who are interested in conservation and planning and who find great satisfaction in witnessing multiphase, efficient, and logical disposition of tracts of land. The benefits of multiple land use include such tangibles as maximum income from the land and a higher net tax revenue, which should be subjects of general interest. This point can be illustrated by planning that is under way and that could lead to a freeway beneath Kansas City, Missouri. The highway would be built entirely underground within a thick limestone unit and construction therefore would produce much limestone aggregate. About $35 million could be saved in right-of-way costs, and an enormous saving could be made by leaving in place the taxable businesses of downtown Kansas City.

COMMUNICATION BETWEEN GEOLOGISTS AND LAYMEN

If an author intends to write for a specific audience with the objective of furnishing useful information and communicating it effectively, he must know that audience—he must know its needs and its "language." It seems reasonable to assume that the environmental geologist's audience, the general public, knows little about soils and less about bedrock—but soils and shallow bedrock are, or should be, two of the chief determinants of land use. Therefore, geologists must publish data concerning soils and bedrock in such a fasion that use of these data in planning will be assured. This statement essentially means (a) that the information must be disseminated widely so that it reaches planners of all kinds, and (b) that it must be worded in such a way that readers can bridge the expanse between the geologists' knowledge and the practical application of this knowledge. Figure 11 is an illustration of a type that should be both informative and useful to the lay reader. This illustration is especially designed for land-use planning and it synthesizes data that commonly are shown on soils maps in one kind of publication and geologic maps in another. It overrides some of the limitations of both and it also shows the makeup of the subsurface, a concept that generally is foreign to laymen. In addition, engineering and economic properties of the rock units are described in such a manner as to stress the characteristics that are definite assets or definite liabilities, according to the uses that will be made of the land. We consider this illustration to be an example of the type of change that geologists can make in some of their publications, in order to transmit geological information to non-geologists in a manner that will lead to its use.

We emphasize that we still hold sound geological reports in the high esteem that they deserve, but these reports simply are not used to the fullest. Consider, for example, the fact that several years before the disastrous earthquake of 1964 at Anchorage, Alaska, a geologic report (5) clearly discussed the possibility that landslides could be triggered by seismic shock, but the public did not comprehend the warning. Basically, there are only two real stimuli for the layman's using the information that geologists publish: (a) he recognizes that he can make some type of profit from the information, or (b) he recognizes that it may keep him out of trouble. Unless geologists adopt a different approach in specific instances (namely, to make the appropriate audience recognize the worth of their work) many of the most admirable geologic reports—like the one cited—will go unused.

THE FUTURE

We estimate that at least 1,000 environmental geologists are needed in urban areas of the United States, and the need will become greater. As to their potential contribution to the economy, Kaye (4) stated that the proper application of geology in urban areas could result in savings of about $300 million each year in costs of building foundations alone. In several respects, the state of environmental geology today is similar to the state of highway geology a few decades ago, when the need for geological advice in highway construction was first being recognized. However, highway geologists formed their profession at a time when the public at large generally was not attentive to their efforts. In contrast, the public now seems to be awakening to the need for geologists in evaluating our environment and planning for its conservation and improvement.

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