Implications of Geology in City and Regional Planning

by

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> When planning starts, for urban community or region, the area to be developed is not the equivalent, therfore, of a blank piece of paper ready for the free materialization of the ideas of the designer, but it is rather an environment that has been exposed for a very long period to the effects of many natural modifying factors. ... Development of new communities and the charting of regional development must, therefore, take account of this fundemental organic and dynamic character of Nature so that the works of man may fit as harmoniously as possible into the environment and not disturb its biological equilibrium any more than is essential.
>
> Robert F. Legget
> Cities and Geology, 1973

INTRODUCTION

"On the evening of June, 9, 1972, a strong easterly flow of moist low-level warm air collided with a cold front over the Black Hills." (Rahn, 1975) So begins the narrative of one of the most tragic natural disasters in the history of the United States: the 1972 flooding of Rapid Creek in Rapid City, South Dakota. In less than 6 hours, nearly 15 inches of rain fell on the basin of this stream, which threads its way sinuously through an historic frontier town, causing flooding which left 238 dead and some $128 million in damages in its wake. (Rahn, 1975) If such appalling statistics weren't tragedy enough for the residents who survived that terrible night, worse yet was the later realization that it could have all been avoided. Geologists knew for years the risk city fathers were taking by allowing residents to build homes on the flood plain. In fact, Quaternary alluvium mapped years before the flood matched almost perfectly the area inundated in 1972. (Rahn, 1972) So why did Rapid City develop residential communities on a potentially dangerous area such as this? "No one paid attention to the maps; people thought that because Pactola Reservoir had reduced the annual or 20 year flood, that the flood plain was safe from any flood. Now Rapid City residents know differently." (Rahn, 1972) But what a way to gain knowledge of the flood plain!

Were Rapid City planners so avaricious in their expansion of the area that they willfully ignored sound geologic advice and built anyway? Probably not, in fact, the sad truth of the matter is they probably never really considered it very important; and this is hardly an isolated incident. Not only American cities, but cities all over the world have historically been planned with practically no consideration of the local and regional geology of the very land upon which they stand. As one author put it:

> Until fairly recently, natural resources were considered inexaustible, the effects of natural hazards were viewed as "acts of God", and governmental bodies tended to place the rights of the private property owner above those of the public at large. (Spangle,et al, 1976)

Today, nearly all large-scale urban and regional projects are planned with the aid of sound earth science information, and most towns like Rapid City avoid geologic hazards in their development; yet, ignorance on a smaller scale is more prevalent and costly than ever. With the ever growing population and sprawl of cities out into the surrounding countryside, small private developers and landowners have begun cramming people, businesses, and industrial sites onto land previously supportive only of cows and crabgrass. Since most of this land falls under fairly archaic county and village jurisdiction, the development with respect to geology usually goes partially or wholly unchecked; and what's worse, it sells! As a result, the land is overburdened in many cases and fails; hillsides erode and slump, wells foul or dry up, and homes collapse into the earth from subsidence of mineshafts the developer probably never knew existed. Every day new stories such as these crop up, and usually they involve extensive repair costs, or even abandonment of the effected land. And when projected over the entire world, the loss of time and money is horrendous.

It is the purpose of this paper to examine the way geologic information is incorporated, (or not incorporated), in the planning of urban and regional development. Some space will be given to evaluating past actions, but most of the material will involve the present interaction between geologists and planners. What the reader will gain is an appreciation for just how complex is the process by which geologists and planners collaborate to use the land underneath us to its fullest potential. As the poet, Burns put it in that well-known verse, "the best laid plans o' mice and men gang aft agley," but with careful consideration of geology in the planning process, our plans in the future need not result in "sorrow and pain" nearly as often.

> Therefore whosoever heareth these sayings of mine, and doeth them, I will liken him unto a wise man, which built his house upon a rock:
> And the rain descended, and the floods came, and the winds blew, and beat upon that house; and it fell not: for it was founded upon a rock.
> And every one that heareth these sayings of mine, and doeth them not, shall be likened unto a foolish man, which built his house upon the sand:
> And the rain descended, and the floods came, and the winds blew, and beat upon that house; and it fell: and great was the fall of it.
>
> St. Matthew, 7:24-27

These words were written two thousand years ago by a man more concerned with the souls of men than with geology, but they illustrate the kind of basic geologic thinking that has been a part of civilized thought from ancient times on. What made this parable so effective was its reference to something so ordinary, and yet sensible, that everyone who read it could immediately see the logic of it. This type of common sense approach to geology and building was typical of men in the past. Yet often, the logic held true only for the most obvious and immediate of geologic concerns, and all but the most superficial hazards were completely ignored. As Legget noted in <u>Cities and Geology</u>, 1973, "Ancient cities can be seen to have grown from small settlements founded for some clearly recognizable reason. The crossings of rivers at convenient fords, ...ports at the mouths of rivers or on coasts... a good source of drinking water... the summit of a rocky crag or at the entrance to a pass through mountainous country.", and later, " ... the rule being that geology is a factor in planning generally neglected. In all too many cases, it has been given due recognition only when trouble has developed and has been found to be due to some previously neglected aspect of subsurface conditions."

One of my earliest memories of a geologic catastrophe involves the flooding of a small lowland tributary of Island creek in southeastern Ohio. After a particularly heavy rainfall in late spring, the tiny bubbling stream where generations of my family had played as children became a raging torrent, washing tons of rocks, sand, and debris over its banks and into the yards of families living on the floodplain. My own mother was nearly swept away as this once quiet brook topped the bridge she drove over, some six feet above the normal water level. As I helped remove the sediment from my neighbors' yards, I remember wondering what possessed men to live in such a hazardous spot. In fact, one man's garage, (part of which was washed away), was built only inches from the stream bank. Looking back, I realize that the only real reason people built their homes there in the first place was that they were looking for a nice level spot with a good water supply; the floodplain surely fit that. But judging from the size of some of the boulders in that channel, it is obvious they were concerned with little else. Geology just wasn't important to them until after their neglect of it proved their undoing.

In another instance, I recall a road that was built

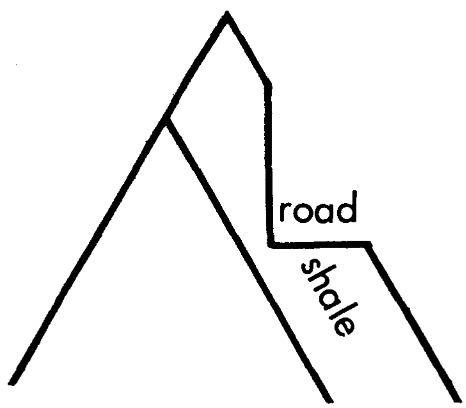

FIG 1a

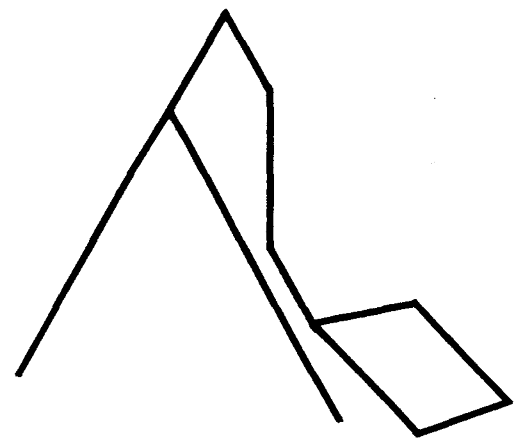

FIG 1b

Figure 1a shows a profile of the mountainside just after the road was cut into it; Figure 1b shows the same profile after failure: the block containing the road has slumped some twenty feet down the slope.

along a mountainside, parallel to the strike of some fairly fissile Paleozoic shale which dipped gently over the hill. (Figure 1a)

For years, I rode back and forth over this road in a school bus, oblivious to the potential hazard which existed. Then, one year after a heavy rain the block below the road slid down the slope of the hill, along the bedding plane of the shale, and ruined the road; luckily, no one was traveling over it when it failed. (Figure 1b)

I use these examples from my own experience to illustrate how universal the neglect of geology in planning really is. Everyone can recollect some instance from his lifetime such as these: failed roads, poisoned streams, toppled houses. No one will ever write about them in textbooks, most will be forgotten, but throughout history such events have continually plagued mankind.

Volumes have been written about how geologic conditions have led to cataclysmic destructions of cities, from the accounts of the burial of Pompei, to the records of the horror of the great San Francisco earthquake, yet, references to geology in the planning of cities is nearly non-existant. (Legget, 1973) It seemed, sadly enough, hardly worthy of mention.

Rather than dwell on neglect any longer, suffice it to say that planners and geologists have not cooperated satisfactorily in the past to ensure that cities were well located. Numerous factors have contributed to this rift of the two sciences, not the least of which has been the very nature of the geologist's and planner's approach to problem solving:

> ...planning is a public undertaking usually culminating in decisions made by political bodies. (The earth scientist), is often uncomfortable when faced with the reality of political compromise and dismayed when a recommendation supported by exacting earth-science analysis is rejected by decisionmakers on political, social, or economic grounds. (Spangle, et al, 1976)

The blame can also be placed upon the institutions of higher learning which have produced these professionals:

> ...planning curriculums frequently offer little or no exposure to the earth sciences. Earth scientists, although conversant with related scientific fields,

> typically are not required to draw upon the extensive range of subject matters drawn upon by planners. (Spangle, et al, 1976)

Also, there is a language barrier, to some extent, between planners and geologists; earth scientists use a specific language - planners use everyday vocabulary in specific senses, or borrow words from other disciplines, often altering their meanings. (Spangle, et al, 1976)

Whatever the cause for neglect has been, geology is a vital consideration in planning everything from country roads to condominiums. Without knowledge of the geology of an area, planning there is incomplete. Historically, most city and regional planning has been faulty by this criterion.

> For all engaged in the practice of planning, a general understanding of geology, its methods and its achievements, should become as second nature so that physical characteristics of the environment will be considered at the outset of looking into the development of every new area to be used for community purposes. (Legget, 1973)

Essentials of Geologic Planning

In order to properly plan for the development of an area, a thorough knowledge of the underlying geology of the site is essential. Everything from slope stability to drainage must be considered, and the information must be presented such that planners with a marginal background in geology can make full use of it. Geologic investigation of a construction site involves three steps: initial investigation of the region, detailed study of the building sites, and follow-up inspection of the subsurface as it is exposed during construction. (Legget, 1973)

The obvious first source of information for a geologist evaluating a proposed building site is first-hand inspection. Field investigation of the surface can yield information such as the location of exposed bedrock, or the evidence of hillside creep. The presence of certain water-loving plants is a good indicator that drainage in an area is poor. Even observing the cracked walls of other buildings already standing on the site can tell a geologist there might be soft clay or sand underlying the surface. In conjunction with field inspection, a geologist will use previously prepared topographic maps, or geologic maps, noting any changes which may have occured since their printings.

Special engineering geologic maps may be available to show not only the scientific information compiled about the area, but also the interpretation of that information based in terms of the use to which it may be put. Such maps are relatively new in North America, but have been in use in Europe for some time. (Legget, 1973) Such maps have greatly aided geologists and planners in the Denver, San Francisco, and Los Angeles areas. For a detailed description of engineering geologic maps, see: <u>Engineering Geologic Maps for Regional Planning</u>, Gardener and Johnson, 1971, referenced at the end of this paper.

Soil maps are another tool available to the geologist, yielding information on nearly every aspect of the upper subsurface: drainage, physical and chemical characteristics, even its suitability for certain practical uses. For a description of how valuable soil maps can be, see: <u>Mapping of Mountain Soils West of Denver, Colorado for Landuse Planning</u>, Schmidt and Pierce, 1976, also referenced later.

Once a geologist has inspected the region and reported his findings, in-depth planning may begin; this is when the second phase of geologic investigation starts. Now the geologist must inspect each building site and conduct a detailed study of, "small areas that are to be used for specific purposes in civic development." (Legget, 1973) Limitations can now be assessed in terms of how actual structures will effect, or are effected by, the underlying ground.

To say that the geologic situations encountered in this stage of investigation are numerous is to underestimate all the Earth. Each area will have its own group of unique structural, lithologic, and hydrologic conditions, as well as differing climatic controls, degree and type of development, etc... It is the job of the geologist to look at all aspects of the plan in a geologic sense, noting hazards and restrictions that may develop through time. A description of some of the more common concerns when evaluating an actual site follows. While by no means a complete list, it offers examples of geologic conditions often encountered.

Floodplains

The term floodplain is commonly used to describe the large, flat area, subject to occasional flooding, around a river or stream. Because of their broad, flat topography and proximity to water, they they are often looked at as ideal spots for building, however, the converse may be true. Streams usually have the capacity for flooding; in the case of the Nile River, annual flooding was greatly anticipated to bring mineral-rich silt to fields on the floodplain.

Here, an entire culture depended upon flooding for its existance. But in urban settings, flooding can be a nuisance, or worse, a disaster, as in the case of Rapid City already mentioned. Whatever the case, floodplains present special conditions to the planner, not only because of their capacity for flooding, but also due to their inherent hydrological and sedimentary characteristics. Usually, the water table is very near the surface on the floodplain and may make the ground swampy and unsuitable for use. I recall a golf course built on the floodplain of the Ohio River that was usually partially filled with puddles of standing water in the spring. While this may have allowed for a unique style of golfing, it was certainly not an example of well planned construction. Another problem with floodplains is their tendency to be misty and foggy, restricting vision for motorists and enhancing corrosion of structural materials. Also, floodplains typically are underlain by alluvial material, such as sand and silt. These may be too soft for constructing foundations upon, and consequently, unfit for development. Planners of ancient cities often excluded floodplains altogether from development, prefering to leave them in their natural state; this idea may be well on its way back. (Legget, 1973)

Sloping Ground

Slopes are not static features, they are dynamic systems. Gravity provides the energy to move materials down them, thus anything on a slope will be perpetually pulled towards its bottom; this is only common sense. Landslides, slumping, hillside creep, and rapid erosion from running water are some of the developmental problems that may be present, depending on the nature of the individual slope. Geologic study of the area can can allow one to predict whether sloping ground is suitable for the designs of the planner, taking into consideration such factors as the pitch of the slope, the material constituting it, and the runoff of surface and ground water. Since it is a dynamic landform, development which would change conditions on the slope may have adverse effects in the longrun on its stability. Downspouts of houses built on slopes take rainwater which would normally fall on a large area and concentrate its runoff. Concentrating runoff concentrates the erosive force of the rainfall; what was once a very stable area may become the ~~sight~~ site of intense erosion. Problems such as this may be anticipated by the geologist and compensated for by the planner. Many times, the slope may be underlain by incompetant materials, such as shale or alluvium, which could limit the degree of excavation possible on it. To examine the material under the surface, the geologist may make borings into the ground. In any case, building on sloping ground not only requires engineering structures to withstand the incline, but also, adapting them to the geology of a dynamic system.

Clay Soils

Montmorillonite is a clay mineral capable of expanding up to fifteen times its normal volume when saturated with water, conversely, saturated montmorillonite can shrink in volume fifteen times when dried. (Mathewson, 1981) These volume changes make montmorillonitic clays a potential hazard when foundations or roads are built on top of them. "In the United States, expansive soils are responsible for 2.3 billion dollars damage annually, with more than a billion dollars damage to highways and streets. Expansive clays are, in fact, the single most costly natural disaster; the average yearly loss from earthquakes, hurricanes, tornadoes, and floods combined amounts to only half that caused by expansive soils." (Mathewson, 1981)

In humid areas, expansive clays may be perennially saturated and undergo little change with time; in arid regions, expansive clays may never be close enough to the water table to become saturated. But in semiarid regions, where there is an annual cycle of dry and wet conditions, expansive clays are most destructive. Figure 2 shows the areas in the United States where rocks containing expansive clays are most heavily distributed.

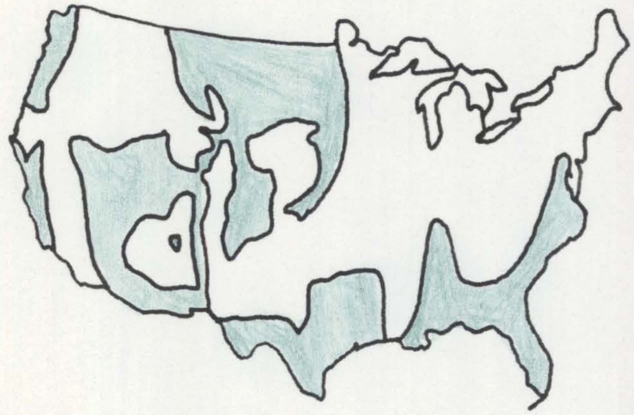

FIG 2

Shaded areas in figure 2 are areas of expansive clay-bearing rocks, (after Mathewson, 1981).

> Though several visual methods for identification of potentially swelling clays exist, only a competant, professional soil engineer and engineering geologist should be relied upon to identify this potential hazard. Some warning signs include: a)soft, puffy, "popcorn" appearance of the soil when dry; b)surface soil that is very sticky when wet; c)open cracks(desiccation polygons) in dry heavy clay soils; d)soils that are very plastic and weak when wet but are "rock-hard" when dry. (Mathewson, 1981)

Hydrocompaction and liquefaction are other problems associated with clay soils. Hydrocompaction is the rapid loss in volume of certain soils when they are saturated. It is commonly associated with fine-sand-silt-clay materials, (loess), deposited along the base of mountains in semiarid environments. (Mathewson, 1981) Quick clays, or sensitive clays, are clay-sized glacial deposits in the Scandinavian countries and along the St. Lawrence River valley that are susceptible to liquefaction when subjected to a vibrating load. If conditions are right, these liquefying quick clays may behave as a liquid and present a hazard to development. (Mathewson, 1981)

Subsidence

Subsidence of the ground has long been a problem in the older cities of the world. (Legget, 1973) Overpumping of water from the aquifer beneath Mexico City has caused a total settlement of the general ground level of more than 7 meters since the turn of the century. (Legget, 1973) Generally, subsidence can be attributed to overdrawing large quantities of pressurized fluids from beneath the ground, mining of solids, or dissoution of carbonate rocks and salts by ground water. In each of these cases, a "void" is created underground after material is removed; to fill the void the ground subsides. Hydrocompaction, though previously included under clay soils, is a cause of subsidence.

Subsidence can be avoided through knowledge of the geology beneath the area. If fluids underground merely fill the pore spaces in the rocks, withdrawing them may not cause appreciable collapse, but when fluids exist in artesian conditions under hydrostatic pressure, their removal results in a release of that pressure and subsequent subsidence. (figure 3a and 3b)

"Sink holes" develop when carbonate rocks like limestone

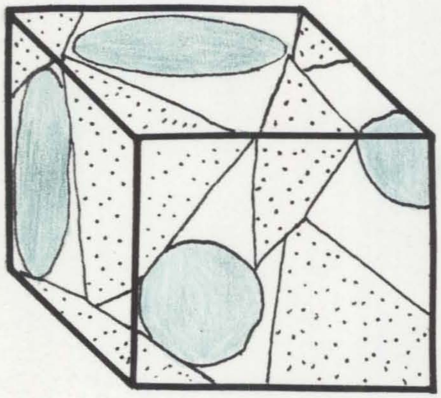

FIG 3a

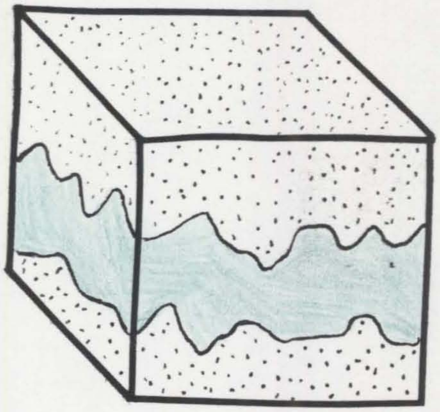

FIG 3b

Figure 3a shows a cube of rock fabric in which water(shaded) fills pore spaces between grains(stippled); figure 3b shows water under confining pressure of the rock surrounding it. Removal of water from 3b would cause subsidence; removal of water from 3a probably would not cause subsidence.

or salts like gypsum are dissolved by percolating groundwater. The spectacular limestone caverns of Kentucky were formed in this way. The ceiling of the void collapses and the overlying material is "sucked" down into a sink hole.

In areas of extensive subsurface mining, records of tunneling are often poor for old mines, (if they were ever kept at all), and problems of mine subsidence plague developers. The recent advent of low frequency ground penetrating radar allows geologic engineers to locate abandoned mineshafts from aerial reconnaissance.(Association of Engineering Geologists Newsletter, January, 1986)

Recoverable Resources

Once construction at a site begins, it may be difficult, if not impossible, to recover mineral resources there. In some cases, actual building materials, such as building stone and aggregate, may be obtained from the site itself. Geologic investigation of the underlying materials can make it possible to extract these before actual building starts and avoid losing them forever. (Legget, 1973)

Other Considerations

Seismic conditions at a site may make it necessary to modify structures to withstand earthquake shocks. Special foundations and construction techniques are often used where intense seismic activity can be expected. The United States Geological Survey National Earthquake Hazard Reduction Program, (NEHRP), uses a series of "strong-motion devices", (seismoscopes), to record such information for evaluating seismic hazard zoning and building design. (Association of Engineering Geologists Newsletter, January,1986)

Permafrost regions,(where the ground is frozen throughout the year), present special problems for development, especially if the previously frozen ground is thawed by the warmth of buildings above it. (Linell and Johnston, 1973)

Special geologic features such as rare fossils or unique structures may need to be preserved for posterity. Many of these may be of interest not only to the scientific community, but to the general public as well. The dinosaur footprint trackway unearthed during construction in Hartford, Connecticutt is a good example. (Legget, 1973).

These are but a few of the many considerations involved in the second phase of geologic evaluation. All or several may apply to any given area for planned landuse, but, only after careful scrutiny by geologists can construction begin.

The third phase of geologic evaluation begins after actual construction commences. Geologists may then observe the actual excavations and determine the validity of their predictions. It cannot be overemphasized that this is a progressive process; the second phase is dependent on the first, and the third is likewise dependent on the first two. In this step-wise manner, geologic evaluation starts with the initial planning for an area and proceeds through to the actual completion of construction.

Conclusion

Good urban and regional planning must involve a close interaction between planners and geologists. The complex geologic controls on an area must not be ignored, rather they must be evaluated and incorporated into the overall plan. Good cities don't happen by accident, they are the result of good city plans; these plans are only as valuable as the land beneath them dictates.

In the past, disregard of geology in the planning process has led to innumerable problems. Both disciplines concerned have been at fault; planners have regarded geology as unimportant, and geologists have failed to state the importance of their own case. It is the challenge of planners and geologists today to pool their efforts, so that we may have truly great cities in the future.

> The needs of our growing population require that we conscientiously plan for the use of the land, not only to protect its resources and aesthetic values, but also to reduce the exposure of urban development to natural hazards by giving explicit consideration to natural conditions and processes in land-use decisions. In this task, the work of the planner and the earth scientist can be mutually reinforcing. (Spangle, et al, 1976)

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