Experimental Engineering-Geologic and Environmental-Geologic Maps of the Conterminous United States

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Experimental Engineering-Geologic and Environmental-Geologic Maps of the Conterminous United States

By Dorothy H. Radbruch–Hall, Kathleen Edwards, *and* Raymond M. Batson

Abstract

The accompanying set of experimental engineering-geologic and environmental-geologic maps of the conterminous United States consists of four maps at a scale of 1:7,500,000. The set includes: (1) a geologic map showing generalized geologic units differentiated by criteria related to the physical properties of the rocks and soils; (2) an engineering-geologic map showing by colors the intensity of certain geologic conditions that might pose constraints to construction; (3) a map showing by colors and patterns the distribution of various geologic conditions or processes that might cause difficulties in construction, such as landslides or volcanic hazards; and (4) an environmental-geologic map showing where construction or land development may intensify existing hazards and (or) introduce secondary adverse environmental effects.

The geologic map was compiled in conventional fashion, using tectonic, geologic, and physiographic data from several sources. Deformational complexity of the rocks is shown by pattern. The engineering-geologic and environmental-geologic maps were generated by computer. The engineering-geologic map was compiled by evaluating data from environmental overview maps of landslides, karst, and volcanic hazards, as well as from maps of seismic probability, areas of standing water, steep slopes, and expansive materials. The same data that were used for the engineering-geologic map were stored in the computer and reevaluated in a different manner to produce the environmental-geologic map.

The colors or patterns for all maps were generated by computer. The computer techniques developed during the compilation can be used for black-and-white or color presentation of any comparisons or overlays of numerous maps or other data. Map units outlined in digital form are converted to raster format for all manipulation and display. After digitizing, a value code is given to the area enclosed by each outline. A program called FILLIN fills each area with the value code assigned to that area. A program called ZIP writes patterns within the windows created by FILLIN. A program called COLOR was developed to assign colors to density numbers assigned by FILLIN.

The engineering-geologic map indicated that the physical subdivisions of the United States with geologic conditions and processes that may be the most troublesome in construction are the Pacific Mountain Division, the Rocky Mountain Division, the Ozark-Ouachita Highlands, and the Appalachian Highlands. Areas where geologic factors may cause environmental problems are not everywhere the same as the areas where they cause engineering problems.

INTRODUCTION

The accompanying set of engineering-geologic and environmental-geologic maps of the conterminous United States comprises four maps at a scale of 1:7,500,000. The set was prepared as part of a program to compile a series of national environmental overview maps of the United States. Other overview maps showing various individual geologic hazards, including landslides, karst, and volcanic hazards, were used in the preparation of these engineering and environmental maps. The data used were those that were available on a uniform scale and at a consistent level of reliability for the entire conterminous United States.

The set of four maps is shown on plates 1, 3, 4, and 5 in the pocket of this report. Plate 1 is a geologic map of the United States; it shows in color generalized geologic units selected on the basis of criteria that are related to the physical properties of the rocks and soils. The engineering-geologic map comprises plates 3A and 3B, each using a different base. Plate 3A shows by color pattern the intensity of certain geologic conditions and processes that might pose constraints to construction; the colors are overprinted on a black-and-white base consisting of the outlines of the geologic units from plate 1, so that the relation of the contraints to the generalized geology of the conterminous United States can be seen clearly. Plate 3B consists of the same color overprint as plate 3A, but superposed on a screened black base that consists of simplified drainage, state lines, and major cities, as well as young faults (Howard and others, 1978). The faults are shown on this map rather than on plate 3A so that they can be seen more clearly. (They would be obscured by the other geologic data on the geologic base map for plate 3A.) Plate 4 shows, by a combination of color and black patterns, which of the restrictive conditions and processes, or combinations of them, exist at any given point on the map; this information is displayed on the same base as that used for plate 3B. Plate 5 is a map showing by color the areas where construction or land development might cause environmental damage by worsening existing restrictive geologic conditions or processes or by introducing secondary adverse environmental effects, or by both—for example, an area where draining of standing water might destroy wildlife habitats.

The geologic data for plate 1 were compiled in the conventional manner; the color or black patterns for all maps were generated by computer.

For the purpose of making these maps, two assumptions were made: (1) engineering geology deals with the effects of geologic conditions and processes on construction and land development, and (2) environmental geology deals with the effects of construction and land development on the physical environment.

COMPUTER TECHNIQUES USED TO GENERATE THE MAPS

The computer techniques developed during the compilation of the accompanying maps not only facilitated the data presentation, but also provided a method that can hereafter be used for the rapid—and economical—simultaneous presentation, in black and white or color, of numerous map overlays. These compilations were made by means of digital image-processing techniques originally developed for use with the multispectral images returned by Earth-orbiting and interplanetary spacecraft. Much of the conventional time-consuming drafting (such as the making of peelcoats or other color separations) and photography for color maps was thus automated or eliminated. A set of algorithms and software for displaying digital map data was developed that uses an Electrack (Trak 100)[1] table digitizer, a PDP 11-45 computer with 28K words core storage, and an Optronic P-1500 Photowrite film output device.

The first stage in making a digital map requires that map units be outlined in digital form. For example, to make a geologic map the contacts around geologic units are traced manually on a table digitizer, and the contacts are converted to raster format (a regular array of numbers in rows and columns). The software includes a program for assigning a specific attribute code to all image elements enclosed by lines (such as an area of a given geologic formation), so that the resulting data base (in this case, a geologic map) can be manipulated by means of a digital image-processing system. Given these techniques, one map can be added to another, projections of the original map can be modified, and distinctions or correlations between attributes can be enhanced or subdued in the film image output. Map units are encoded for computer processing in terms of 256 "shades of gray"; colors and patterns can be generated in the computer and combined for making the final film images to be used for printing in traditional map form. An impressively large number of color and pattern combinations is available.

After the map units are digitized, a code value is given to the area enclosed by each outline. A value of 1 is assigned to all boundary lines, and a specific value other than 1 or 0 is assigned to a single point inside each of the units. All other points in the array are called equal to 0. A program called FILLIN fills each area with the code value assigned to that area.

Several maps can be combined in various ways, so that the resulting image contains a wide range of units. Since shades of gray—represented by the density numbers assigned by FILLIN—are difficult to interpret, two new programs to produce more conventional portrayals were developed. The first of these new programs, called ZIP, writes patterns within the windows created by FILLIN. The second program, called COLOR, assigns specific colors to particular density numbers, and then the Photowrite output device produces halftone color-separation plates. A more detailed description of these computer techniques appears in an article by Edwards and Batson (1980).

The cost of preparing for printing a typical colored geologic map of the type presented in this report, using the programs now developed, is estimated to be one-tenth the cost of using conventional peelcoat methods—roughly $2,000 using computer techniques, but $20,000 or more for peelcoat methods.

Because of irregularities inherent in the manual digitizing process, map colors do not everywhere correspond precisely to shorelines and political boundaries shown on the accompanying plates. Also, because the map explanations were prepared at different times than the maps, and because the computer-generated color separations for the maps had to be photographically enlarged for printing, the colors on the maps do not exactly match those in the explanations.

GEOLOGIC MAP

The geologic map, which is also the base map for one plate (pl. 3A) of the engineering-geologic map of the conterminous United States, first was compiled by conventional methods and then was digitized and prepared for color printing by the methods described above. The map comprises tectonic, geologic, and physiographic data compiled from the following sources: "Tectonic Features" (King, 1967) from "The National Atlas of the United States of America"; "Geologic Map of the United States" (King and Beikman, 1974); "Surficial Geology of the United States" (Hunt, 1977); "Physical Subdivisions" (Hammond, 1970a) and "Classes of Land-Surface Form" (Hammond, 1970b), both from the National Atlas; and unpublished data on geologic complexity by Walter White and Bradley Meyers (written commun., 1977).

Boundaries of major tectonic provinces are shown on the geologic map by heavy black lines. The boundaries were selected by referring to the tectonic-features map of the National Atlas. Boundaries are shown for the Cordilleran foldbelt, the Appalachian foldbelt, and the central part of the Ouachita foldbelt. The boundary of the Cordilleran foldbelt was

[1]Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey.

arbitrarily drawn to include most folds and faults at the eastern front of the Rocky Mountains, as well as most of the Paleozoic rocks of the mountainous area. Clusters of intrusive rocks of Tertiary age in Montana and the Black Hills are included as part of the Cordilleran tectonic area. Paleozoic rocks of the Ouachita foldbelt and the numerous anticlines north of them were included in the Ouachita foldbelt. The boundary of the Appalachian foldbelt was drawn to include the areas of Precambrian, Paleozoic, and Mesozoic bedrock as well as the band of closely compressed anticlines northwest of these areas. Wherever feasible, the boundaries of the tectonic provinces were slightly adjusted to coincide with the boundaries of physical subdivisions.

Physical subdivisions are shown by moderately heavy lines. The regions used are slightly modified from the physical subdivisions of Hammond (1970a), shown on sheet 61 of the National Atlas.

Geologic units shown on the geologic map are adapted from the "Geologic Map of the United States" (King and Beikman, 1974) and from the map "Surficial Geology of the United States" (Hunt, 1977). Because of the small scale of the geologic map, specific formations and rock types could not be shown. Sedimentary, plutonic, and volcanic rocks are delineated, as is Quaternary alluvium. Colluvium and saprolite are shown in the Appalachian region, where underlying rocks are indicated by symbol, because the thick surficial deposits in that area are probably as critical for engineering construction as are the underlying rocks. Rocks wholly or partly covered by continental glacial deposits, in the northern part of the United States, are also indicated by symbol. The southern extent of glacial deposits is indicated by a heavy dashed line. Sedimentary rocks are divided by age, inasmuch as the engineering geologic properties of the rocks generally are different for rocks of different ages, the younger rocks commonly being less consolidated and less deformed than the older. Tertiary and Quaternary volcanic rocks are also differentiated. In places where geologic units of two or more types are too intimately mixed to be indicated separately, they are shown as mixed rocks.

Deformational complexity of the rocks is taken from unpublished data by Walter W. White and Bradley W. Meyers (written commun., 1977), who classified it in four grades: A, undeformed or mildly deformed; B, moderately deformed; C, severely deformed; and D, regionally metamorphosed (so greatly modified that original structure is lost). For grades B, C, and D, deformational complexity is shown by pattern. Undeformed units have no pattern, nor do mixed rocks, which vary in complexity. Units of mixed complexity (other than mixed rocks) are indicated by a combination of patterns. Patterns within areas covered by glacial deposits, saprolite, or colluvium indicate the deformational complexity of the underlying bedrock. Patterns were generated by computer techniques; the line showing the southern extent of continental glaciation, as well as the boundaries of physical subdivisions, tectonic provinces, and geologic units (where shown under surficial deposits), was drafted by conventional methods, because computer techniques had not been developed to produce dashed lines or lines of different weights.

ENGINEERING-GEOLOGIC MAP

After the geologic map was prepared, the areas affected by geologic and topographic conditions that pose constraints to construction were compiled by means of the computer techniques described above. The following maps were used for basic data to determine these areas:

1. "Landslide Overview Map of the Conterminous United States" (Radbruch-Hall and others, 1982);
2. "Map showing Engineering Aspects of Karst in the United States" (Davies and others, 1976);
3. "Preliminary Overview Map of Volcanic Hazards in the 48 Conterminous United States" (Mullineaux, 1976);
4. "Preliminary Map of Horizontal Acceleration in Rock in the Contiguous United States" (Algermissen and Perkins, 1976);
5. Map showing areas of standing water (modified from Hammond, 1970b);
6. Map of steep slopes (modified from Hammond, 1970b);
7. Map of expansive materials in the United States (Patrick and Snethen, 1976).

These seven maps are presented on plate 2 as figures 1-7.

Additional data such as depth of seasonal freezing, flood hazard, thickness of overburden over rock, areas having high potential for liquefaction, places particularly susceptible to erosion, and regions where rebound or rockbursting are prevalent would have been desirable inclusions. However, maps with these data were not available when the engineering-geologic map was compiled, or they were available only for small areas.

The possibility of superposing the seven maps so that as many as seven data factors would overlay any given point was rejected as unreasonable. This method would have implied that each factor possessed constraints to construction of equal severity; that implication would be false. Moreover, the severity of the different constraints represented varies within individual maps; the landslide map, for example, shows three degrees of incidence (that is, amount) of landslides and three degrees of susceptibility to landsliding. Therefore, an evaluation and comparison of the data were necessary before the maps could be superposed; this presented the classic problem of trying to compare apples and oranges.

To enable the comparison of one map with another, three criteria were selected by which the constraining factors could be evaluated. These criteria were severity, permanence or recurrence, and difficulty of amelioration. Severity refers to the amount of possible damage to property or loss of life that can be caused by a given condition or process. Permanence or recurrence refers to the difference between conditions that are continuing with little change, such as the presence of certain formations susceptible to landsliding, and those that are sporadic, such as volcanic eruptions or earthquakes. Amelioration refers to the degree of difficulty of correcting the condition. Bases for evaluating each of these criteria were worked out, and specific numerical values were assigned to the various criteria, as follows:

Severity

1. Can cause some engineering problems; property damage is likely to be rare or minor.
2. Definite engineering problems; some property damage is likely, as is rare loss of life.
3. Can cause severe engineering problems; property damage is likely to be extensive; some loss of life is possible.
4 and 5. Much extensive property damage and loss of life is likely. (These values occur only on the map of seismic probability.)

Permanence or recurrence

1. Considered to be rare or sporadic (not known to occur within historical time, which is arbitrarily set at 4,000 years).
2. Intermittent (has been known to occur during historical time).
3. Permanent or continuing.

Amelioration

1. Could probably be ameliorated at reasonable cost during the course of construction.
2. Might be ameliorated, but with great difficulty or great expense.
3. Can probably be handled only by avoidance.

Evaluation of the individual maps by means of these criteria produced the figures that are displayed on table 1. Each numerically evaluated area on each component map was digitized and converted to raster format, using an array of numbers that contained approximately 3,000 numbers in rows (east-west) and approximately 2,200 numbers in columns (north-south) across the map of the United States. Areas were then converted to color by computer, using the techniques described in the preceding section. The resulting individual maps are at a scale of approximately 1:21,000,000 (figs. 1 to 7, pl. 2).

All the individual maps were superposed by combining, for each point in the array, the data already stored in the computer. On the final combined map, colors were assigned to the resulting numbers. The highest numbers are shown in red; they then range downward through orange, yellow, green, blue, and violet. Areas in which restrictive conditions are minor or absent remain white. The resulting engineering-geologic map (pl. 3) shows immediately and graphically the areas of the United States where geologic conditions are most restrictive for construction (within the limits of the data used). It also shows the relations of these restrictive conditions to the tectonic provinces, the physical subdivisions, the geologic complexity of the rocks, and the rocks and soils, which are delineated in color on plate 1 and in black-outline form as a base for plate 3A.

BASIC DATA AND ENVIRONMENTAL-GEOLOGIC MAPS

When reading the engineering-geologic map, the specific problems that exist for any given spot are not possible to tell. To present that information, the third map of the set—the basic data map (pl. 4)—was prepared. In a combination of black patterns and color, it shows the extent of the various individual problem conditions and processes that are shown on the component maps; it gives no information about the gradations of the intensity of these constraints to construction. The data from which this basic data map was prepared had been stored in the computer, so the map was easily generated. The color and patterns are overprinted on a simplified base.

A fourth map—the environmental-geologic map (pl. 5)--was prepared from the same data by reevaluating the component maps in a different manner. This procedure produced from the stored data a map that shows where construction might cause damage to the environment--either directly, by worsening the condition or process shown on the component map, or indirectly, by causing damage to other aspects of the environment. For example, volcanic hazards were not evaluated for environmental damage potential because construction on or near a volcano would have no influence on its activity, although eruptions could indirectly cause damage to structures, such as by flooding if reservoirs were to fill with ash. All the categories of landslide incidence and susceptibility were given a high rating for potential environmental damage, inasmuch as construction could both increase the amount of sliding and cause secondary effects, such as the clogging of streams with debris. Areas of standing water were given a low rating because the draining of such an area for development would not increase the amount of standing water, although it could have secondary effects such as land subsidence or the elimination of nesting places for waterfowl.

The map areas were given environmental evaluation ratings as follows:
1. If they were thought to have potential for either direct or indirect damage to the environment as a result of construction.
2. If they were thought to have a potential for both kinds of damage. The environmental evaluation for all component maps is shown on table 1. These reevaluated maps were combined to produce the final environmental-geologic map.

DISCUSSION

The engineering-geologic map of this series (pl. 3) indicates which areas of the conterminous United States have geologic conditions and processes that may cause problems in construction. A comparison with the small map of Hammond's physical subdivisions of the United States, printed on the plate with the engineering-geologic map (pl. 3A), shows that the most troublesome areas are the Pacific Mountain Division, the Rocky Mountain Division, the Ozark-Ouachita Highlands in the Interior Division, and the Appalachian Highlands in the Eastern Highland Division.

By referring to plates 2 and 4, the kinds of geologic conditions and processes that characterize each physical subdivision can be seen. On the west coast (the Pacific Mountain Division of Hammond's physical subdivisions), landslides, volcanism, steep slopes, seismic activity (the highest in the United

Table 1. Evaluation of component maps for the engineering-geologic and environmental-geologic maps of the conterminous United States

[See subsection "Engineering-Geologic Map" in text for explanation of constraint-evaluation categories and values, and subsection "Basic Data and Environmental-Geologic Maps" for environmental evaluation ratings]

Unit on component map	Constraint-evaluation category				Environmental evaluation
	Severity	Amelioration	Recurrence	Total	
Landslide [I, incidence; S, susceptibility; H, high; M, moderate; L, low]					
I-H, S-H	3	3	3	9	2
I-M, S-H	2-1/2	2-1/2	3	8	2
I-M, S-M	2	2	3	7	2
I-L, S-H	1-1/2	1-1/2	3	6	2
I-L, S-M	1	1	3	5	2
I-L, S-L	0	0	0	0	0
Seismic probability					
5	5	3	2	10	--
4	4	2	2	8	--
3	3	2	2	7	--
2	2	2	2	6	--
1	1	1	2	4	--
Volcanic hazard					
Recent flows:					
Subject to ash, mudflows, and hot avalanches	3	3	2	8	--
Subject to ash from large eruption	2	3	1	6	--
Subject to ash from very large eruption	1	3	1	5	--
Karst					
Large sink holes, much subsidence	3	3	3	9	2
Do.	3	2	3	8	2
Small sink holes, minor subsidence	2	3	3	8	2
Do.	2	2	3	7	2
Do.	1	1	3	5	2
No subsidence	1	1	3	5	1
Expansive materials					
Highly expansive	3	1	3	7	--
Moderately expansive	2	1	3	6	--
Slightly expansive	1	1	3	5	--
Standing water					
Percentage of land area:					
Over 50 percent	2	2	3	7	1
10-50 percent	1	1	3	5	1
Steep slopes					
Only one category	1	2	3	6	1

States), and a moderate amount of expansive clays all constitute geologic hazards to structures. In the Rocky Mountain Division, landslides, expansive soils, and steep slopes, in addition to some karst, seismic activity, volcanism, and standing water cause problems, particularly in the southern Rocky Mountains. In the Ozark-Ouachita Uplands, seismic activity, steep slopes, landslides, karst, and expansive soil are troublesome. In the Appalachian Highlands, landslides, karst, seismic activity, steep slopes, and some expansive clays cause difficulties. An area of lesser but still substantial problems is the Gulf-Atlantic Coastal Flats, which are plagued with karst, standing water, expansive soil, and seismic activity.

Boundaries of these physical divisions and subdivisions are shown by medium-weight lines on the geologic map and on the base for the engineering-geologic map (pls. 1 and 3A). Although the boundaries are not everywhere covariant, the correspondence of physiographic boundaries with geologic boundaries is apparent in many places. In these places, both physiographic expression and engineering problems associated with geology are intimately related to geologic conditions. For example, hilly or mountainous areas with their steep slopes, sheared or fractured rocks of diverse types, and active geologic processes, including seismicity, landsliding, and volcanism, have in general more engineering problems than parts of the country that are flatter, more uniform, and less active, although these flatter areas may have other types of problems, such as karst, standing water, or swelling clay.

The environmental-geologic map (pl. 5), indicates where environmental problems related to geology can be expected as a result of land development. The areas where geologic factors may cause environmental problems are not everywhere the same as the areas where they may cause engineering problems; thus, whereas the engineering-geologic map shows areas where geologic conditions or processes may cause difficulties in construction or may damage structures, the environmental-geologic map shows places where works of man may damage the land.

In many places the same geologic processes that can damage structures, such as landslides and karst, can also be activated by construction so that they may cause environmental damage to large areas of formerly undisturbed terrain. Where these kinds of processes are widespread--such as in the Appalachian Highlands, the Rocky Mountains, and the Ozark-Ouachita Highlands--both the hazards to construction and the potential for environmental damage are great. However, some areas that are very hazardous to structures have no more potential for environmental damage than do some other areas of the country where construction problems are less severe; this relationship can be seen by comparing plates 3 and 5. For example, the volcanoes, seismic activity, landslides, and steep slopes on the west coast constitute numerous hazards to construction, but in many places these factors add up to less potential for environmental damage than do the standing water, steep slopes, scattered landslides, and karst in the northeastern part of the United States. One reason for this apparent inconsistency is that the seismic activity and volcanoes on the west coast are ever-present hazards to human use of the land, but construction and land use do not cause major earthquakes, nor do they activate volcanoes. Conversely, the draining of swamps may make land relatively safe for development, but the environmental damage to water supply, wildlife, and scenic areas may be immense.

CONCLUSION

Engineering- and environmental-geologic maps of the type and scale presented here clearly show areas where geologic factors pose constraints or possible hazards to construction, and where environmental damage may result from construction. These maps cannot be used for specific site selection, but they are useful for preliminary planning of large-scale national construction programs such as major highways or hydroelectric projects.

The same methods used to prepare these maps of the entire United States at the scale of 1:7,500,000 can also be used to prepare maps at a larger scale for regional or local use. The computer techniques used to compile these maps provide many shortcuts and monetary savings over traditional methods of map preparation.

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