Chapter 6

GEOLOGIC MAPPING AND DOCUMENTATION

Geologic mapping is defined as the examination of natural and manmade exposures of rock or unconsolidated materials, the systematic recording of geologic data from these exposures, and the analysis and interpretation of these data in two- or three-dimensional format (maps, cross sections, and perspective [block] diagrams). The maps and cross sections generated from these data: (1) serve as a record of the location of factual data; (2) present a graphic picture of the conceptual model of the study area based on the available factual data; and (3) serve as tools for solving three-dimensional problems related to the design, construction, and/or maintenance of engineered structures or site characterization. This chapter presents guidelines for the collection and documentation of surface and subsurface geologic field data for use in the design, specifications, construc-tion, or maintenance of engineered structures and site characterization studies.

Responsibilities of the Engineering Geologist

An engineering geologist defines, evaluates, and documents site-specific geologic conditions relating to the design, construction, maintenance, and remediation of engineered structures or other sites. This responsibility also may include more regionally based geologic studies, such as materials investigations or regional reconnaissance mapping. An engineering geologist engaged in geologic mapping is responsible for:

- Recognizing the key geologic conditions in a study area that will or could significantly affect hazardous and toxic waste sites or a proposed or existing structure;

- Integrating all the available, pertinent geologic data into a rational, interpretive, three-dimensional conceptual model of the study area and presenting this conceptual model to design and construction engineers, other geologists, hydrologists, site managers, and contractors in a form that can be understood.

The process and responsibilities of engineering geology mapping are illustrated in figure 6-1.

The engineering geologist needs to realize that geologic mapping for site characterization is a dynamic process of gathering, evaluating, and revising geologic data and that the significance of these data, both to the structure and to further exploration, must be continually assessed. The initial exploration program for a structure is always based on incomplete data and must be modified continuously as the site geology becomes better understood. The key to understanding the site geology is through interpretive geologic drawings such as geologic maps, cross sections, isopachs, and contour maps of surfaces. These working drawings, periodically revised and re-interpreted as new data become available, are continuously used to assess the effects of the site geology and to delineate areas where additional exploration is needed. These drawings are used in designs, specifica-tions, and modeling and maintained in the technical record of the project.

Development of a Study Plan

Prior to mapping any project, a study plan must be developed. Depending on the complexity of the site geology, the nature of the engineered structure, and the level of

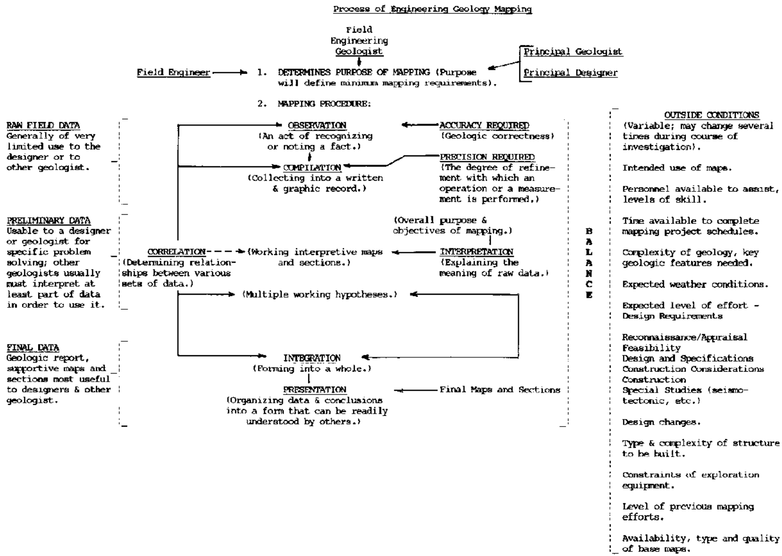

Figure 6-1.—Process of engineering geology mapping.

previous studies, the study plan may be preliminary or comprehensive. Although elements of the plan may be modified, expanded, or deleted as geologic data become available, the primary purpose of the study plan—coordination among all geologists and engineers working on the project—should be retained. Early study plan development and agreement to this plan by those involved in the project are necessary to prevent the collection of unneeded, possibly costly data and ensure needed data are available at the correct time in the analysis, design, and construction process.

Scope of Study

The purpose and scope of the mapping project are strongly influenced by the primary engineering and geologic considerations, the level of previous studies, and overall job schedules. The purpose and scope are formulated jointly by the geologists and engineers on the project. Time of year and critical dates for needed information also will have a great impact on the pace of data collection and the personnel needed to handle a mapping project. Discussion of these factors prior to initiating the mapping program is essential so that only necessary data are obtained and the work can be completed on schedule. Items to consider when defining the scope of a mapping program are:

1. Study limits.—Set general regional and site study limits based on engineering and geologic needs.

2. Critical features and properties.—Determine the critical geologic features and physical properties of site materials that will need to be defined and discuss the difficulties in collecting data on these features.

3. Schedules.—Determine schedules under which the work will be performed and define key data due dates. Prioritize work to be done. The time of year the mapping is to be performed, the type of mapping required, available personnel and their skills, the availability of support personnel such as drill crews and surveyors, and budget constraints will influence the work schedule and must be carefully evaluated.

4. Extent of previous studies.—Collect and study all available geologic literature for the study area. The extent and adequacy of previous studies helps to define the types of mapping required and how data will be collected, i.e., based on analyses, design, or construction needs.

5. Photography.—Aerial and terrestrial photography should be considered for any project. As a minimum, aerial photographs of the site should be reviewed. Aerial photographs reveal features that are difficult to recognize from the ground or at small scales. Extensive use of terrestrial or aerial photography will require a different approach to the mapping program. Define areas where terrestrial photogrammetry could aid mapping progress. Terrestrial photography of various types is an integral part of the final study record.

Specific Mapping Requirements

This section provides the basic considerations an engineering geologist should evaluate prior to starting any mapping project or portion of a mapping project.

Map Type

Define the types of mapping required and how data are to be collected, including special equipment needed for data collection. The types of mapping required depend on the study purpose or the type of structure or site that is to be built or rehabilitated, structure size, the phase of study (planning through operation and maintenance), and the specific design needs.

Scales and Controls

Define the required scales for design or construction needs. Although finished maps can be enlarged or reduced photographically or by Computer-Aided Drafting Design (CADD)-generated drawings to any desired scale, in most cases map text and symbols will have to be redone for legibility. Selection of an adequate map scale at the beginning of a mapping project will save time and energy as well as help ensure that the types of data needed can be portrayed adequately on the final drawings. Suggested map scales for various types of investigations are listed under specific mapping techniques.

The horizontal and vertical accuracy and precision of locations on a map depend on the spatial control of the base map. General base map controls are listed in decreasing significance: (1) Survey Control or Controlled Terrestrial Photogrammetry—geology mapped from survey controlled observation points or by plane table or stadia; (2) Existing Topographic Maps—control for these maps vary with scale. The most accurate are large-scale photogrammetric topographic maps generated from aerial photographs for specific site studies; (3) Uncontrolled Aerial/Terrestrial Photogrammetry—Camera lens distor-tion is the chief source of error; (4) Brunton Compass/Tape Surveys—can be reasonably accurate if measure-ments are taken with care; and (5) Sketch Mapping— Practice is needed to make reasonably accurate sketch maps. The Global Positioning System can provide adequate position locations depending on the required accuracy or precision.

Global Positioning System

The Global Positioning System (GPS) is a system of satellites that provides positioning data to receivers on earth. The receiver uses the positioning data to calculate the location of the receiver on earth. Accuracy and type of data output depends on many factors that must be evaluated before using the system. The factors that must be evaluated are: (1) the needs of the project, (2) the capabilities of the GPS equipment, and (3) the parameters necessary for collecting the data in an appropriate form.

Project Requirements

The location accuracy or precision needed by the project is a controlling factor whether GPS is appropriate for the project. The actual needs of the project should be determined, being careful to differentiate with "what would be nice." Costs should be compared between traditional surveying and GPS.

GPS Equipment

Different GPS receiver/systems have different accuracies. Accuracies can range from 300 ft to inches (100 m to cm) depending on the GPS system. Costs increase exponen-tially with the increase in accuracy. A realistic evalua-tion of the typical accuracy of the equipment to be used is necessary, and a realistic evaluation of the needed, not "what would be nice," accuracy is important. Possible accuracy and typical accuracy are often not the same.

Datums

The datum or theoretical reference surface to be used for the project must be determined at the start. U.S. Geologi-cal Survey (USGS) topographic maps commonly use North American Datum (NAD) 27, but most new surveys use NAD 83. Changing from one datum to another can result in apparent location differences of several hundred feet or meters if not done properly.

Map Projections

The map projection is the projection used to depict the round shape of the earth on a flat plane or map. The most common projections used in the United States are the Transverse Mercator and the Lambert Conformal Conic. State plane coordinate systems almost exclusively use one or the other. To use these state plane projections, location and definition parameters are necessary. Table 6-1 has the types of projections and the projection parameters for each state in the United States. A discussion of map projections and coordinate systems is in *Map Projections - A Working Manual*, USGS Profes-sional Paper 1395[1].

Transverse Mercator.—The Transverse Mercator projection requires a central meridian, scale reduction, and origin for each state or state zone.

Lambert Conformal Conic.—The Lambert Conformal Conic projection requires two standard parallels and an origin for each state or state zone.

Coordinate System.—The coordinate system is the grid system that is to be used on the project. The state plane

Table 6-1.—U.S. State plane coordinate systems – 1927 datum

(T indicates Transverse Mercator: L. Lambert Conformal Conic: H. Hotine Oblique Mercator. Modified slightly and updated from Mitchell and Simmons, 1945, p. 45-47)

Area	Projec-tion	Zones	Area	Projec-tion	Zones
Alabama_______	T	2	Nevada _______	T	3
Alaska ________	T	8	New		
	L	1	Hampshire __	T	1
	H	1	New Jersey ___	T	1
Arizona _______	T	3	New Mexico ___	T	3
Arkansas ______	L	2	New York _____	T	3
California _____	L	7		L	1
Colorado ______	L	3	North		
Connecticut____	L	1	Carolina	L	1
Deleware ______	T	1	North Dakota _	L	2
Florida ________	T	2	Ohio __________	L	2
	L	1	Oklahoma _____	L	2
Georgia _______	T	2	Oregon _______	L	2
Hawaii ________	T	5	Pennsylvania __	L	2
Idaho _________	T	3	Puerto Rico &		
Illinois ________	T	2	Virgin		
Indiana _______	T	2	Islands _____	L	2
Iowa __________	L	2	Rhode Island __	T	1
Kansas ________	L	2	Samoa ________	L	1
Kentucky______	L	2	South		
Louisiana _____	L	3	Carolina ____	L	2
Maine_________	T	2	South Dakota _	L	2
Maryland _____	L	1	Tennessee ____	L	1
Massachusetts _	L	2	Texas ________	L	5
Michigan[1]			Utah _________	L	3
obsolete_____	T	3	Vermont ______	T	1
current _____	L	3	Virginia ______	L	2
Minnesota _____	L	3	Washington ___	L	2
Mississippi ____	T	2	West Virginia _	L	2
Missouri ______	T	3	Wisconsin ____	L	3
Montana ______	L	3	Wyoming _____	T	4
Nebraska _____	L	2			

Table 6-1.—U.S. State plane coordinate systems – 1927 datum (continued)

Transverse Mercator Projection			
Zone	Central meridian	Scale reduction[2]	Origin[3] (latitude)
Alabama			
East	85° 50' W.	1:25,000	30° 30' N.
West	87 30	1:15,000	30 00
Alaska[4]			
2	142 00	1:10,000	54 00
3	146 00	1:10,000	54 00
4	150 00	1:10,000	54 00
5	154 00	1:10,000	54 00
6	158 00	1:10,000	54 00
7	162 00	1:10,000	54 00
8	166 00	1:10,000	54 00
9	170 00	1:10,000	54 00
Arizona			
East	110 10	1:10,000	31 00
Central	111 55	1:10,000	31 00
West	113 45	1:15,000	31 00
Delaware	75 25	1:200,000	38 00
Florida[4]			
East	81 00	1:17,000	24 20
West	82 00	1:17,000	24 20
Georgia			
East	82 10	1:10,000	30 00
West	84 10	1:10,000	30 00
Hawaii			
1	155 30	1:30,000	18 50
2	156 40	1:30,000	20 20
3	158 00	1:100,000	21 10
4	159 30	1:100,000	21 50
5	160 10	0	21 40
Idaho			
East	112 10	1:19,000	41 40
Central	114 00	1:19,000	41 40
West	115 45	1:15,000	41 40
Illinois			
East	88 20	1:40,000	36 40
West	90 10	1:17,000	36 40
Indiana			
East	85 40	1:30,000	37 30
West	87 05	1:30,000	37 30

Table 6-1.—U.S. State plane coordinate systems – 1927 datum (continued)

Transverse Mercator Projection			
Zone	**Central meridian**	**Scale reduction[2]**	**Origin[3] (latitude)**
Maine			
East	68° 30' W.	1:10,000	43° 50' N.
West	70 10	1:30,000	42 50
Michigan (old)[4]			
East	83 40	1:17,500	41 30
Central	85 45	1:11,000	41 30
West	88 45	1:11,000	41 30
Mississippi			
East	88 50	1:25,000	29 40
West	90 20	1:17,000	30 30
Missouri			
East	90 30	1:15,000	35 50
Central	92 30	1:15,000	35 50
West	94 30	1:17,000	36 10
Nevada			
East	115 35	1:10,000	34 45
Central	116 40	1:10,000	34 45
West	118 35	1:10,000	34 45
New Hampshire	71 40	1:30,000	42 30
New Jersey	74 40	1:40,000	38 50
New Mexico			
East	104 20	1:11,000	31 00
Central	106 15	1:10,000	31 00
West	107 50	1:12,000	31 00
New York[4]			
East	74 20	1:30,000	40 00
Central	76 35	1:16,000	40 00
West	78 35	1:16,000	40 00
Rhode Island	71 30	1:160,000	41 05
Vermont	72 30	1:28,000	42 30
Wyoming			
East	105 10	1:17,000	40 40
East Central	107 20	1:17,000	40 40
West Central	108 45	1:17,000	40 40
West	110 05	1:17,000	40 40

Table 6-1.—U.S. State plane coordinate systems – 1927 datum (continued)

Lambert Conformal Conic projection				
Zone	Standard parallels		Origin[5] Longitude	Origin[5] Latitude
Alaska[4]				
10	51°50' N.	53° 50' N.	176°00' W.[5a]	51° 00' N.
Arkansas				
North	34 56	36 14	92 00	34 20
South	33 18	34 46	92 00	32 40
California				
I	40 00	41 40	122 00	39 20
II	38 20	39 50	122 00	37 40
III	37 04	38 26	120 30	36 30
IV	36 00	37 15	119 00	35 20
V	34 02	35 28	118 00	33 30
VI	32 47	33 53	116 15	32 10
VII	33 52	34 25	118 20	34 08[5b]
Colorado				
North	39 43	40 47	105 30	39 20
Central	38 27	39 45	105 30	37 50
South	37 14	38 26	105 30	36 40
Connecticut	41 12	41 52	72 45	40 50[5d]
Florida[4]				
North	29 35	30 45	84 30	29 00
Iowa				
North	42 04	43 16	93 30	41 30
South	40 37	41 47	93 30	40 00
Kansas				
North	38 43	39 47	98 00	38 20
South	37 16	38 34	98 30	36 40
Kentucky				
North	37 58	38 58	84 15	37 30
South	36 44	37 56	85 45	36 20
Louisiana				
North	31 10	32 40	92 30	30 40
South	29 18	30 42	91 20	28 40
Offshore	26 10	27 50	91 20	25 40
Maryland	38 18	39 27	77 00	37 50[5c]
Massachusetts				
Mainland	41 43	42 41	71 30	41 00[5d]
Island	41 17	41 29	70 30	41 00[5c]

Table 6-1.—U.S. State plane coordinate systems – 1927 datum (continued)

Lambert Conformal Conic projection (continued)				
Zone	Standard parallels		Origin[5] Longitude	Origin[5] Latitude
Michigan (current)[4]				
North	45°29' N.	47° 05' N.	87°00' W.	44° 47' N.
Central	44 11	45 42	84 20	43 19
South	42 06	43 40	84 20	41 30
Minnesota				
North	47 02	48 38	93 06	46 30
Central	45 37	47 03	94 15	45 00
South	43 47	45 13	94 00	43 00
Montana				
North	47 51	48 43	109 30	47 00
Central	46 27	47 53	109 30	45 50
South	44 52	46 24	109 30	44 00
Nebraska				
North	41 51	42 49	100 00	41 20
South	40 17	41 43	99 30	39 40
New York[4]				
Long Island	40 40	41 02	74 00	40 30[5f]
North Carolina	34 20	36 10	79 00	33 45
North Dakota				
North	47 26	48 44	100 30	47 00
South	46 11	47 29	100 30	45 40
Ohio				
North	40 26	41 42	82 30	39 40
South	38 44	40 02	82 30	38 00
Oklahoma				
North	35 34	36 46	98 00	35 00
South	33 56	35 14	98 00	33 20
Oregon				
North	44 20	46 00	120 30	43 40
South	42 20	44 00	120 30	41 40
Pennsylvania				
North	40 53	41 57	77 45	40 10
South	39 56	40 58	77 45	39 20
Puerto Rico and Virgin Islands				
1	18° 02' N.	18° 26' N.	66° 26' W.	17° 50' N.[5g]
2 (St. Croix)	18 02	18 26	66 26	17 50[5f, g]

Table 6-1.—U.S. State plane coordinate systems – 1927 datum (continued)

Lambert Conformal Conic projection (continued)				
			Origin[5]	
Zone	Standard parallels		Longitude	Latitude
Samoa	14°16' S.	(single)	170 00[5h]	— —
South Carolina				
North	33°46' N.	34 58	81 00	33 00
South	32 20	33 40	81 00	31 50
South Dakota				
North	44 25	45 41	100 00	43 50
South	42 50	44 24	100 20	42 20
Tennessee	35 15	36 25	86 00	34 40[5f]

Note: All these systems are based on the Clarke 1866 ellipsoid and are based on the 1927 datum. Origin refers to rectangular coordinates.

[1] The major and minor axes of the ellipsoid are taken at exactly 1.0000382 times those of the Clarke 1866, for Michigan only. This incorporates an average elevation throughout the State of about 800 ft, with limited variation.

[2] Along the central meridian.

[3] At origin, x = 500,000 ft, y = 0 ft, except for Alaska zone 7, x = 700,000 ft; Alaska zone 9, x = 600,000 ft; and New Jersey, x = 2,000,000 ft.

[4] Additional zones listed in this table under other projection(s).

[5] At origin, x = 2,000,000 ft, 7 = 0 ft, except (a) x = 3,000,000 ft, (b) x = 4,186,692.58, y = 4,160,926.74 ft, (c) x = 800,000 ft, (d) x = 600,000 ft, (e) x = 200,000 ft, (f) y = 100,000 ft, (g) x = 500,000 ft, (h) x = 500,000 ft, y = 0, but radius to latitude of origin = -82,000,000 ft.

system is used by most projects, but latitude/longitude, universal transverse mercator, or a local coordinate system may be used.

State Plane Coordinate Systems-changes for 1983 datum.—This listing indicates changes for the NAD 1983 datum from projections, parameters, and origins of zones for the NAD 1927 datum. State plane coordinates based on the 1927 datum *cannot* be correctly converted to coordinates on the 1983 datum merely by using inverse formulas to convert from 1927 rectangular coordinates to latitude and longitude, and then using forward formulas with this latitude and longitude to convert to 1983 rectangular coordinates. Due to readjustment of the survey control networks and to the change of ellipsoid, the latitude and longitude also change slightly from one datum to the other.

These changes are given in the same order as the entries in the 1927 table, except that *only the changes are shown*. All parameters not listed remain as before, except for the different ellipsoid and datum. Because all coordinates at the origin have been changed, and because they vary considerably, the coordinates are presented in the body of the table rather than as footnotes. Somoa is not being changed to the new datum.

Table 6-2.—U.S. State plane coordinate systems – 1983 datum

[*L indicates Lambert Conformal Conic*]

Area	Projection	Zones
California	L	6
Montana	L	1
Nebraska	L	1
Puerto Rico and Virgin Islands	L	1
South Carolina	L	1
Wyoming	Unresolved	

Transverse Mercator projection

	Coordinates of origin (meters)		
Zone	*x*	*y*	*Other Changes*
Alabama			
East	200,000	0	
West	600,000	0	
Alaska, 2-9	500,000	0	
Arizona, all	213,360	0	Origin in Intl. feet[1]

Table 6-2.—U.S. State plane coordinate systems – 1983 datum (continued)

Transverse Mercator projection (continued)			
	Coordinates of origin (meters)		
Zone	*x*	*y*	*Other Changes*
Delaware	200,000	0	
Florida			
East, West	200,000	0	
Georgia			
East	200,000	0	
West	700,000	0	
Hawaii, all	500,000	0	
Idaho			
East	200,000	0	
Central	500,000	0	
West	800,000	0	
Illinois			
East	300,000	0	
West	700,000	0	
Indiana			
East	100,000	250,000	
West	900,000	250,000	
Maine			Lat. of origin 43°40' N.
East	300,000	0	
West	900,000	0	
Mississippi			
East	300,000	0	Scale reduction 1:20,000, Lat. of origin 29°30' N.
West	700,000	0	Scale reduction 1:20,000, Lat. of origin 29°30' N.
Missouri			
East	250,000	0	
Central	500,000	0	
West	850,000	0	
Nevada			
East	200,000	8,000,000	
Central	500,000	6,000,000	
West	800,000	4,000,000	
New Hampshire	300,000	0	

Table 6-2.—U.S. State plane coordinate systems – 1983 datum (continued)

Transverse Mercator projection (continued)			
	Coordinates of origin (meters)		
Zone	*x*	*y*	*Other Changes*
New Jersey	150,000	0	Central meridian 74°30'W. Scale reduction 1:10,000.
New Mexico			
East	165,000	0	
Central	500,000	0	
West	830,000	0	
New York			
East	All parameters identical with above New Jersey zone.		
Central	250,000	0	
West	350,000	0	
Rhode Island	100,000	0	
Vermont	500,000	0	
Wyoming	Unresolved		

Lambert Conformal Conic projection			
	Coordinates of origin (meters)		
Zone	*x*	*y*	*Other Changes*
Alaska, 10	1,000,000	0	
Arkansas			
North	400,000	0	
South	400,000	400,000	
California			Zone 7 deleted.
1-6	2,000,000	500,000	
Colorado, all	914,401.8289	304,800.6096	
Connecticut	304,800.6096	152,400.3048	
Florida, North	600,000	0	
Iowa			
North	1,500,000	1,000,000	
South	500,000	0	
Kansas			
North	400,000	0	
South	400,000	400,000	
Kentucky			
North	500,000	0	
South	500,000	500,000	

Table 6-2.—U.S. State plane coordinate systems – 1983 datum (continued)

Lambert Conformal Conic projection (continued)			
	Coordinates of origin (meters)		
Zone	*x*	*y*	*Other Changes*
Kansas			
North	400,000	0	
South	400,000	400,000	
Kentucky			
North	500,000	0	
South	500,000	500,000	
Louisiana			
North	1,000,000	0	Lat. of origin 30°30' N.
South	1,000,000	0	Lat. of origin 28°30' N.
Offshore	1,000,000	0	Lat of origin 25°30' N.
Maryland	400,000	0	Lat. of origin 37°40' N.
Massachusetts			
Mainland	200,000	750,000	
Island	500,000	0	
Michigan			GRS 80 ellipsoid used without alteration.
North	8,000,000	0	
Central	6,000,000	0	Long. of origin 84°22'W.
South	4,000,000	0	Long. of origin 84°22'W.
Minnesota, all	800,000	100,000	
Montana (single zone)	600,000	0	Standard parallels, 45°00' and 49°00' N. Long. of origin 109°30' W. Lat. of origin 44°15' N.
Nebraska (single zone)	500,000	0	Standard parallels, 40°00' and 43°00' N. Long. of origin 100°00' W. Lat. of origin 39°50' N.
New York			
Long Island	300,000	0	Lat. of origin 40°10' N.
North Carolina	609,621.22	0	
North Dakota, all	600,000	0	
Ohio, all	600,000	0	

Table 6-2.—U.S. State plane coordinate systems – 1983 datum (continued)

Lambert Conformal Conic projection (continued)			
	Coordinates of origin (meters)		
Zone	*x*	*y*	*Other Changes*
Oklahoma, all	600,000	0	
Oregon			
North	2,500,000	0	
South	1,500,000	0	
Pennsylvania, all	600,000	0	
Puerto Rico and Virgin Islands	200,000	200,000	(Two previous zones identical except for *x* and *y* or origin.)
South Carolina (single zone)	609,600	0	Standard parallels, 32°30' and 34°50' N. Long. of origin 81°00' W. Lat. of origin 31°50' N.
South Dakota, all	600,000	0	
Tennessee	600,000	0	Lat. of origin 34°20' N.
Texas			
North	200,000	1,000,000	
North Central	600,000	2,000,000	Central meridian 98°30' W.
Central	700,000	3,000,000	
South Central	600,000	4,000,000	
South	300,000	5,000,000	
Utah			
North	500,000	1,000,000	
Central	500,000	2,000,000	
South	500,000	3,000,000	
Virginia			
North	3,500,000	2,000,000	
South	3,500,000	1,000,000	
Washington, all	500,000	0	
West Virginia, all	600,000	0	
Wisconsin, all	600,000	0	

NOTE: All these systems are based on the GRS 80 ellipsoid.

[1] For the International foot, 1 in = 2.54 cm, or 1 ft = 30.48 cm.

Units

English or metric units should be selected as early in the project as possible. Conversions are possible, but convert-ing a large 1-foot contour map to meters is no trivial matter.

Remember that when using several sources of location data, the reference datum must be known. Systematic differences in location data are generally due to mixing datums.

Specific Nomenclature and Definitions

Establish a uniform nomenclature system with written definitions for rock types, map units, and map symbols used. The American Geologic Institute *Glossary of Geology* [2] is the standard for geologic terms except where Reclamation has established definitions for its own needs. These definitions and nomenclature are discussed in chapters 2 through 5.

Field Equipment and Techniques

General geologic mapping equipment and techniques are discussed in field geology manuals such as Lahee (1961) [3] and Compton (1985) [4]. Refer to these texts for discussions of suggested field equipment and general geologic mapping techniques.

Use of Computers

Computers are used during a mapping program in four basic ways: (1) to process and analyze voluminous numerical data (e.g., joint data), (2) as a tool in the analysis of basic geologic data (e.g., construction of preliminary or final plan and section views which incorporate previously entered geologic data), (3) Computer Aided Drafting and Design (CADD) of section and plan views, and (4) in modeling geologic conditions. How computers will be used in the reduction, analysis, and drafting of the geologic data generated during a mapping program needs to be decided early because records of field data will depend on whether data are to be stored in digital format and restructuring these data at a later date is costly, time consuming, and introduces transcription errors.

Right-of-Way

Right-of-way is needed for any mapping of non-Reclamation land and should be obtained early to prevent work delays. Although "walk on" permission usually is obtained easily, permission for trenching and drilling may take several months, especially if archeological or environmental assessment is necessary.

Records

Systematic methods of recording field observations, traverse data, outcrop data, and trench logs are important. Suggested sample field book formats are shown under each section below dealing with specific mapping procedures, but any format should allow clear representation of the field data.

Geologic Considerations

The following are some key items that should be evaluated during a mapping project. The degree of importance varies with the project but the factors are common to most.

Lithology.—Differentiation between the various geologic deposits and lithologies in a study area is basic to geologic mapping. However, an engineering geologist is more concerned with the engineering characteristics of the unit than with its geologic definition, and these characteristics should be the controlling factor in how geologic units are subdivided. For some engineering geologic purposes, it may be reasonable to consolidate geologic units with similar engineering properties into a single engineering geologic map unit. Depending on the needs of the project, lithologic subunits may be defined jointly between the engineers and the geologists working on the job.

After the basic geologic subdivisions for a mapping job have been agreed upon, detailed descriptions of each subunit should be compiled and mapping symbols selected. Map unit definitions usually will apply specifically to the job or project area and normally will be modified as additional data are collected. Map symbols fall into several categories. American Geological Institute data sheets have a comprehensive tabulation of symbols.

Geologic contacts.—Two different line types normally are used on geologic maps to denote the precision and accuracy of geologic contacts. These are solid and broken (dashed or dotted) lines. Solid lines usually are used where exposures are excellent, such as a cleaned foundation or an area with nearly continuous outcrops. Solid lines indicate that the contacts are located with a prescribed degree of accuracy. Broken contacts are used when unsure of the accurate location of the contact, i.e., when the contact is covered by thin slopewash deposits (dashed line) or where the contact is buried by deep surficial deposits (dotted line). Confidence levels, expressed in feet or meters, for both types of contacts should be stated clearly in the definition of the contact line. The mapper should keep in mind the type of geologic data being compiled and use the appropriate line.

Discontinuities.—Discontinuities separate geological materials into discrete blocks that can control the stability and bearing capacity of a foundation or slope. Intersecting discontinuities in cut slopes can form unstable wedges. Because of the destabilizing or weakening effects, mapping and adequately describing discontinuities is critical in engineering geology studies. The various types of discontinuities and the terminology for describing their engineering properties are discussed in chapter 5.

Weathering and alteration.—The mechanical and chemical alteration of geological materials can significantly affect stability and bearing strengths. Adequately determining weathering depths, extent of altered materials and the engineering properties of these weathered and altered materials is critical in engineering geologic mapping. Refer to chapter 4 for definitions of weathering and alteration descriptors.

Water.—The location and amount of groundwater to be expected in an excavation and how it can be controlled is critical to the overall success of a project.

Geomorphology.—Study of landforms is often the key to interpreting the geologic history, structure, lithology, and materials at a site. Exploration programs can be better designed and implemented using landforms as a basis. The geomorphic history is important in determining the relative age of faults.

Vegetation indicators.—Differences in vegetation types and patterns can provide indirect data on lithologies, dis-continuities, weathering, groundwater, and mineralization. The water holding capacity of soil developed on one rock (e.g., shale) may differ considerably from the water holding capacity of soil developed on another type of rock (e.g., sandstone); consequently, the types of vegetation that grow in these soils can vary considerably. Minerals present in the parent rock may affect soil chemistry and may limit vegetation to types tolerant of highly acidic or alkaline soils or high concentrations of trace elements. Vegetation seeking groundwater moving up major joints and faults will form vegetation lineations that are highly visible on aerial photographs, particularly color infrared photo-graphs. In most locations, local conditions have to be assessed to use vegetative indicators effectively.

Cultural features (manmade).—Cultural features, such as water, gas or oil wells, road cuts or foundation excavations, can provide surface and subsurface data and should be reviewed early in the mapping project. When data collection through trenching and core drilling programs is considered, buried utility lines (water, gas, electrical, sewage, or specialized lines) can be hazardous or embarrassing when broken. Usually the utility or owners will locate their lines.

Field checking.—Field checking by both mapper and independent reviewer is a critical part of the mapping process. Field checking after a map is complete allows the mapper to check the interpretations at a given location with the geologic concepts developed on the map as a whole. Field checking by the independent reviewer ensures that the basic field data are correct and conform to project standards. Periodic field checking of previously mapped areas can be useful as the mapper's concept of the site geology changes with the addition of new surface and subsurface data.

MAPPING

Site Mapping

Engineering geologic mapping has two phases—mapping prior to construction and mapping during construction. In general, the following guidelines are for: (1) general mapping requirements, (2) suggested equipment, (3) specific preparations needed for the job, (4) type of documentation needed, and (5) special considerations that the mapping may require.

General

Detailed site geologic mapping studies generally are done for most structures or sites. Site mapping requirements are controlled by numerous factors, the most important of which are the type and size of structure to be built or rehabilitated or site to be remediated, the phase of study (planning through operation and maintenance), and the specific design needs.

Site mapping studies for major engineering features should be performed within an approximate 5-mile (8-km) radius of the feature, with smaller areas mapped for less critical structures. These studies consist of detailed mapping and a study of the immediate site, with more generalized studies of the surrounding area. This approach allows an integration of the detailed site geology with the regional geology. The overall process of site mapping is a progression from preliminary, highly interpretive concepts based on limited data to final concepts based on detailed, reasonably well-defined data and interpretation. This progression builds on each previous step using more detailed methods of data collection to acquire better defined geologic information. Typically, site mapping is performed in two phases: (1) preliminary surface geologic mapping and (2) detailed surface geologic mapping. All site mapping studies begin with preparation of a preliminary surface geologic map which delineates surficial deposits and existing bedrock exposures. The preliminary surface geologic map is then used to select sites for dozer trenches, backhoe trenches, and drill holes. Surface geologic maps are then re-interpreted based on the detailed surface and subsurface data. If required, detailed subsurface geologic data are also obtained from exploratory shafts and adits.

Suggested Equipment

The following list of basic equipment should meet most needs. Not all listed equipment is necessary for every project, but a Brunton Compass, geologist's pick, (2-pound hammer may be necessary for rock sampling), maps, map board, aerial photographs, notebook, scale, tape measure, protractor, knife, hand lens, various pens and pencils, and a GPS should meet most needs.

Preparation

Whether a site mapping program is completed in one field season or over several years, the overall project schedule and budget are critical. A critical assessment should be made of the time available for the mapping program, the skills and availability of personnel to accomplish the work, weather conditions, and budget constraints.

Documentation

Site data are documented on drawings (and associated notes) generated during the study. The drawings fall into two general categories—working drawings and final drawings. Working drawings serve as tools to evaluate and analyze data as it is collected and to define areas where additional data are needed. Analysis of data in a three-dimensional format is the only way the geologist can understand the site geology. Drawings should be generated early in the study and continuously updated as the work progresses. These drawings are used for pre-liminary data transmittals. Scales used for working drawings may permit more detailed descriptions and collection of data that are not as significant to the final drawings. Final drawings are generated late in the mapping program, after the basic geology is well understood. Many times new maps and cross sections are generated to illustrate specific data that were not available or well understood when the working drawings were made. Final drawings serve as a record of the investigations for special studies, specifications, or technical record reports.

Preliminary Surface Geologic Mapping.—The purpose of preliminary surface geologic mapping is to define the major geologic units and structures in the site area and the general engineering properties of the units. Suggested basic geologic maps are a regional reconnaissance map at scales between 1 inch = 2,000 feet and 1 inch = 5,280 feet (1:24,000 to 1:62,500), and a site geology map at scales between 1 inch = 20 feet and 1 inch = 1,000 feet (1:250 to 1:12,000). Scale selection depends on the size of the engineered structure and the complexity of the geology. Maps of smaller areas may be generated at scales larger than the base map to illustrate critical conditions. Cross sections should be made at a natural scale (equal horizontal and vertical) as the base maps unless specific data are better illustrated at an exaggerated scale. Exaggerated scale cross sections are generally not suited for geologic analysis because the distortion makes projection and interpretation of geologic data difficult.

Initial studies generally are a reconnaissance-level effort, and the time available to do the work usually is limited.

Initially, previous geologic studies in the general site area are used. These studies should be reviewed and field checked for adequacy and new data added. Initial base maps usually are generated from existing topographic maps, but because most readily available topography is unsuitable for detailed studies, site topography at a suitable scale should be obtained if possible. Existing aerial photographs can be used as temporary base maps if topographic maps are not available. Sketch maps and Brunton/tape surveys or GPS location of surface geologic data can be done if survey accuracy or control is not available or necessary. Good notes and records of outcrop locations and data are important to minimize re-examination of previously mapped areas. Aerial photo-graphy is useful at this stage in the investigation, as photos can be studied in the office for additional data. Only after reasonably accurate surface geology maps have been compiled can other investigative techniques, such as trenching and core drilling, be used to full advantage. For some levels of study, this phase may be all that is required.

Detailed Surface Geologic Mapping.— The purpose of detailed surface geologic mapping is to define the regional geology and site geology in sufficient detail so geologic questions critical to the structure can be answered and addressed. Specific geologic features critical to this assessment are identified and studied, and detailed descriptions of the engineering properties of the site geologic units are compiled. Project nomenclature should be systematized and standard definitions used. Suggested basic geologic maps are similar to those for preliminary studies, although drawing scales may be changed based on the results of the initial mapping program. Maps of smaller areas may be generated to illustrate critical data at scales larger than the base map.

The preliminary surface geology maps are used to select sites for dozer trenches, backhoe trenches, and drill core holes. As the surface geology is better defined, drill hole locations can be selected to help clarify multiple geologic problems. Detailed topography of the study site should be obtained, if not obtained during the initial investigations. Data collected during the preliminary investigations should be transferred to the new base maps, if possible, to save drafting time. Field mapping control is provided primarily by the detailed topographic maps and/or GPS, supplemented by survey control if available or Brunton/ tape survey. If not, large scale aerial photographs of a site area flown to obtain detailed topography are useful in geologic mapping.

Dozer Trench Mapping

General

Dozer trenches are cut to expose rock or unconsolidated materials below the surface and major surface creep. Walls normally should be excavated vertically, free of narrow benches and loose debris. Upon completion of excavation, floors must be cleaned below any depth of ripping, loose rubble should be removed, and a new surface exposed. Structures such as contacts and shear zones must be traceable from wall into floor for optimum determination of their nature and attitude. The geologist is responsible to ensure the dozer operator produces a safe finished trench that meets Reclamation and Occupational Safety and Health Administration (OSHA) safety standards. If livestock are present, fencing of the trench with four strands of barbed wire may be required. After trench logging is completed, decide whether to leave the trench open or to backfill. At sites with complex geology, it is desirable to leave the trench open for reinterpretation of the trench in light of newly acquired data. Backfilling of the dozer trench may be necessary where an open trench would be a safety hazard. Generally, all trenches should be backfilled and com-pacted prior to abandonment.

Suggested Equipment

Additional equipment needed may include hard hat, scraper or putty knife, square-nosed shovel, plastic flagging, nails, wooden stakes, surveyors chain or tape measure (feet or meters) and log book. Use putty knife, shovel, and whisk broom for cleaning trench exposures and a Brunton tripod for more accurate trench bearings.

Preparation

Prior to working in a dozer trench, the geologist should inspect the excavation trench walls for failure planes (obvious or incipient) or loose materials. These should be removed before mapping starts. An examination of the whole trench should be made at the start of each work period. A baseline should be laid out along the toe of the trench wall or at the top of the excavation. Because dozer trenches often are not straight, the trench should be divided into a series of straight segments with stations established at each point where the trench changes direction. Each station should be marked by a stake, tied with flagging, and marked with the trench number and station letter (e.g., DT-12A). Flagging strips should be nailed to the wall approximately 6 feet (2 meters [m]) vertically above or below the station for another reference point in case minor sloughing buries or dislodges the stake.

Documentation

The scale and format selected for logging a backhoe trench depends on the type of data needed and the amount of detail to be illustrated. Typical dozer trench log scales are between 1 inch (in) = 5 feet (ft) (1:100) and 1 in = 10 ft (1 : 200), but scales of 1 in = 1 ft (1: 50) may be required in critical areas to adequately show structural and stratigraphic details. If trench geology is not complex, record trench logs, along with names of the field party and date in a field book. Determine and record the bearing, slope distance, and slope angle between each station. Survey the coordinates and elevations of each station. Orient the log book so the sketch and description may be viewed together (see figure 6-2). Sketch the walls and floors across the top page of the open log book. Mark the baseline at 5-foot (1.5-m) intervals and draw a single "hinge line"; wall above, floor below. Determine the vertical heights of the trench walls at each station and between stations, if the profile or thickness of surficial materials changes between stations.

Sketches should be accurate and illustrate the field relationship of soil and geologic units and structures. Use nails and flagging strips to mark obscure contacts or other features for ready reference during logging. Designate geologic units by name and symbol. Accurately plot the attitude of contacts, bedding, foliation or cleavage, faults, shear zones, and joints where they are determined using standard symbols, and write a description. If attitudes are determined from the wall, they may be projected along strike into the floor, if no change is apparent in the floor. Note and show the bedding or foliation wherever relationships are complex and differ from the recorded attitude (i.e., where surface creep, drag folds, or disturbed zones are exposed in the wall). Record unit attitudes that may have been affected

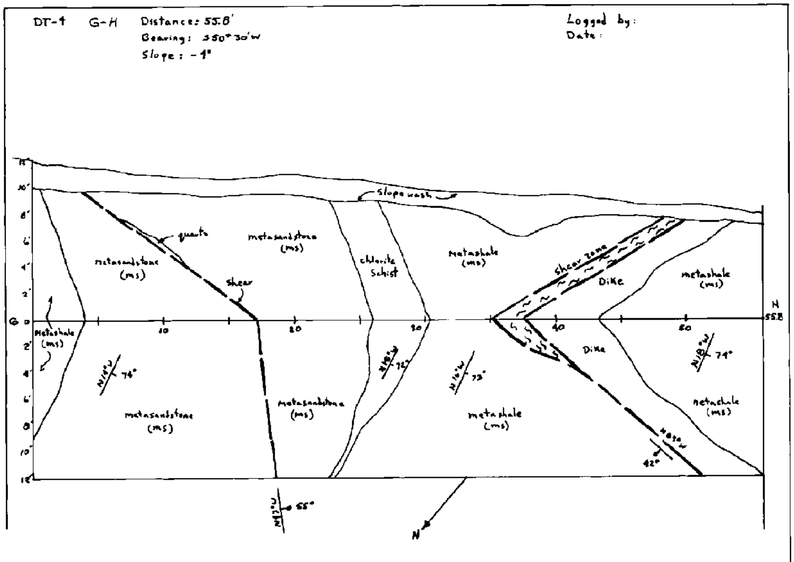

Figure 6-2.—Sample trench log.

by surface creep or slumping. Written descriptions of soil and rock units and structural zones should be restricted to the page below the sketch and should not be written over the sketch. Main heading for written descriptions are restricted to mappable geologic units. Intervals are noted where the contacts intersect the baseline. Indent subheadings within text to describe lithologic or structural variations within the mappable unit. An example of heading order is as follows:

DT-58, Sta. B-C, Distance - 27.5', Bearing - S. 45° W.,
Slope + 2

22.5-50.0': Metasediments	(description)
39.9-41.0': Chlorite Schist B	(description)
47.5-49.0': Talc Schist	(description)
48.2-48.4': Shear Zone	(description)

Stratigraphic units should be colored to complete the log. Photograph the trench to complement the log or to record specific details within the trench.

Backhoe Trench Mapping

General

Backhoe trenches are excavated to expose rock or unconsolidated materials below surficial deposits and major surface creep. Generally, backhoe trenches are excavated at sites which must be returned to near-original conditions and where dozer trenching would produce unacceptable damage. Backhoe trenches often are excavated in the floor of an existing dozer trench to deepen the excavation. Walls should be excavated vertically and free of narrow benches and loose debris. In most cases, the trench should be about 3 to 3-1/2 feet wide (1 m) (width of standard backhoe bucket), 10 to 12 feet (3 to 3.6 m) deep, and slope at one end for easy access. Upon excavation completion, hydraulic trench shores are placed and pressurized or wooden shores constructed to support the trench walls. Shore construction and spacing must meet OSHA standards and standards outlined in Reclamation's *Construction Safety and Health Standards* manual. At no time should personnel enter unshored portions of the trench over 5 feet deep. The geologist who oversees the excavation of the backhoe trench is respon-sible for the construction of a safe, stable trench.

After trench logging is completed, decide whether to leave the trench open or to backfill. At sites with complex geology, leave the trench open, if possible, as this allows reinterpretation of the trench in light of newly acquired data. However, backhoe trenches are prone to sloughing with time, even when supported, and backfilling of the trench may be necessary for safety reasons. The coordi-nates and elevation of each end of the backhoe trench should be surveyed prior to backfilling.

Suggested Equipment

Standard field equipment is used during backhoe trench mapping. Additional equipment may include a hard hat, large knife, flat-blade pick or army trenching tool to clean off trench walls, putty knife, whisk broom, nails, flagging, twine, small string level, 100-foot (30-m) long surveyor's chain or tape, and map board or log book. The type of backhoe needed depends on how consolidated or cemented the material is, site accessibility, and depth to be excavated. Most of the larger, rubber-tired backhoes are suitable for excavation of typical trenches, but well consolidated or cemented material, steep site terrain, or trench depths over about 12 feet (3.6 m) may require a larger track-mounted hydraulic excavator.

Preparation

Each day prior to working in a backhoe trench, the trench along both sides and the trench walls should be examined for incipient fractures or loose materials, particularly within the surficial materials. These loose materials should be removed before work starts. Hydraulic trench shores should be checked visually for leakage and for loss of pressure by pushing on them with a foot. Re-pressure any loose shores and replace leaking shores. The stability of each shore should be checked before the mapper's weight is put on it, particularly if the shore is to be used to examine the upper trench wall or to climb out of the trench.

A backhoe trench must be cleaned prior to logging. During excavation, the backhoe bucket may smear clay and silt along the walls, obscuring structural and stratigraphic relationships. This smeared zone may be anywhere from a fraction of an inch thick to several inches thick, depending on the amount of fines and moisture in the material excavated. The smeared material can be removed by chipping or scraping with a large knife, flat-bladed pick, or army trenching tool. If the trench is excavated in reasonably consolidated material and the trench is free draining, a high pressure water and/or air jet will remove this material. Both walls should be spot cleaned and examined prior to major cleaning to determine which wall exposes the best geologic data. Usually only one wall is completely cleaned; the other wall is spot cleaned during trench logging to expose another view of critical features or relationships. After a wall is cleaned, a horizontal base line is established. The baseline is run at about eye level and constructed by stringing twine between nails driven into the cleaned trench wall. The twine can be leveled using a small string level (available in most hardware stores) prior to driving nails. When the baseline becomes either too high or too low for comfort-able measurements, a vertical offset of the string line is made and the baseline continued at the new horizon. In complex, critical areas where accurately located contacts are needed, a string grid with horizontal and vertical elements can be constructed off the baseline to assist in mapping.

Documentation

The scale and format selected for logging a backhoe trench depends on the type of data needed and the amount of detail to be illustrated. Typical backhoe trench log scales are between 1 in = 5 ft (1:100) and 1 in = 10 ft (1 : 200), but scales of 1 in = 1 ft (1 : 50) may be required in critical areas to adequately show structural and stratigraphic details. If trench geology is not complex, a notebook is suggested. The log book should be oriented so the sketch and description may be viewed together. The names of the field party, date, trench number, location, and other pertinent data should be recorded. If trench geology is complex and a larger scale is desired, cut sheets of grid paper attached to a map board may be used. These sheets are usually redrafted after trench logging is completed. If the backhoe trench is wet or wall material is sloughing down onto the map board, a blank grid sheet can be taped to the map board and overlain by sheets of mylar. Trench data sketched onto the mylar will not be smeared as easily, and the sheets can be erased without tearing. Prints of the sheets can be made for use in preliminary data transmittal or as check prints for field checking. Figure 6-3 shows a completed trench log.

Because the log sheets are separated easily, each sheet should be marked with the names of the field party, date, trench number, location, and other pertinent data.

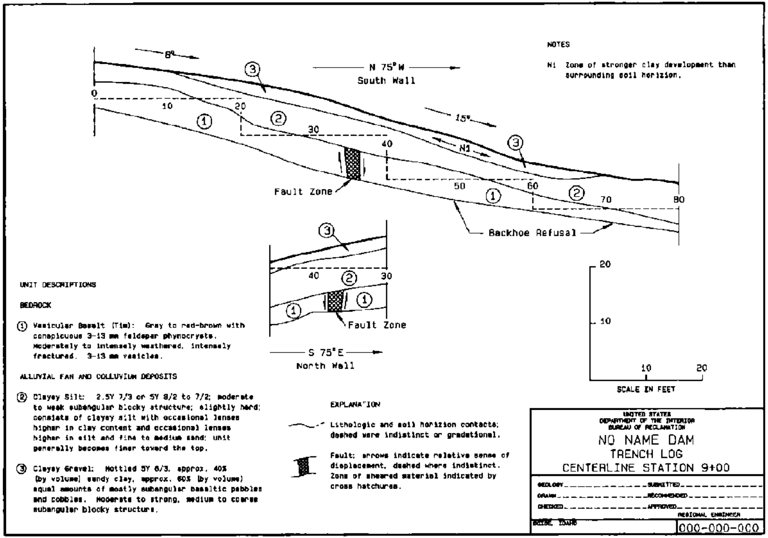

Figure 6-3.—Sample completed trench log.

Begin trench logging by recording the trench bearing. Begin at one end of the trench; place a surveyors chain or tape along the horizontal base line string. Vertical distance of the trench wall above and below the base line should be measured every 10 feet (3 m) or so and the trench outlines sketched. Sketches must be as accurate as possible to illustrate the field relationships of soil, geologic units, and structures. Use flagging to mark obscure contacts or other features for easier logging.

Intervals for the various geologic units and features are to be noted where the contacts intersect the baseline. Contacts above and below the baseline are located by two measurements—the vertical distance from the baseline and baseline distance—and sketched onto the log. Geologic units should be designated by name or symbol. Symbols to illustrate the attitude of contacts, bedding, fol-iation or cleavage, faults, shear zones, and joints should be drawn at the point where determined and also re-corded in the written description. Bedding or foliation should be depicted and noted wherever relationships are complex and differ from the recorded attitude (i.e., where surface creep, drag folds, or disturbed zones are exposed in the wall). Attitudes on units that may have been affected by surface creep or slumping should also be so noted.

Written descriptions of soil and rock units and structural zones should be restricted to the area below the sketch. Main headings for written descriptions are restricted to mappable geologic units. Description format is similar to that discussed for dozer trench mapping. After trench logging is completed, geologic units should be colored to complete the log and the trench field checked. Photograph the trench to complement the trench log or to record specific details within the trench. The limited space and poor lighting conditions in a backhoe trench many times make it difficult to obtain satisfactory photos. Generally, cameras capable of closeup focusing and loaded with fast film work best. Photographs taken while standing at the top of the trench generally are marginal because of poor lighting and perspective. The ends of the trench should be located by GPS or survey.

Construction Geologic Mapping

Geologic mapping during construction is to: (1) identify and delineate potential or actual construction-related needs and problems; (2) verify and better define geologic interpretations made during design studies, particularly for critical geologic features and properties; (3) determine if the geologic conditions are as interpreted during the design phase and ensure that the actual conditions revealed are as interpreted. If those conditions are not as interpreted, design modifications may be required; and (4) provide a record of as-built conditions in the event of litigation or operational problems.

To obtain meaningful data for mapping during construction, cooperation and coordination between the Contractor and the construction staff is required. The field geologist prioritizes mapping; and when the specific area is ready for mapping and approval, the staff and surveyors (if required) should accomplish the work as quickly as possible. Photographs should be taken using appropriate photographic equipment. All photographs should be captioned and dated.

Possible safety hazards that might occur during mapping should be evaluated, and appropriate precautions should be taken.

Large Excavation Mapping

General

Construction considerations prepared before construction begins should contain guidelines for the mapping of specific features. The scope and detail of mapping required at each portion of the site should be determined and suitable mapping scales determined. Suggested scales for detailed foundation mapping are 1 in = 5 ft to 1 in = 50 ft (1:50 to 1: 600), generalized foundation invert map scale 1 in = 20 ft to 1 in = 100 ft (1:20 to 1:1,000). Detailed, as-built foundation geology maps are used in final design modification, as a final record, and for use in possible future operation and maintenance problems. Mapping can be done on detailed topographic base maps generated from survey control, GPS, or plane table. Preferably, geology points are flagged and surveyed by a survey crew. Terrestrial photography, photogrammetry, and GPS can also be used to supplement mapping. Detailed photo-graphy of the entire foundation is important for inclusion in the final construction geology report and as a part of the construction record. Use standard nomenclature and symbols both on maps and photographs, but be consistent with those used in earlier studies and specifications. Use a systematic method of collecting mapping data, then compile these data into a useful and accurate geologic map.

Detailed, as-built geology maps of cutslopes are required in delineating and solving major slope stability problems and in selecting general slope support systems. Recommended scale selection for detailed cut-slope geology maps are 1 inch = 10 feet to 1 inch = 50 feet (1:100 to 1:600), generalized cutslope geology maps use a scale 1 inch = 20 feet to 1 inch = 100 feet (1:200 to 1:1,000). Generally, maps are on detailed topographic base maps generated from survey control. Geologic points may be flagged for survey by survey crews. Detailed photographs of the slopes are important.

Steep Slope Mapping

General

Define the purpose and goal for mapping and research the stratigraphy and structural geology prior to starting. Select scaling and safety equipment for specific areas.

Preparation

Special training is required for scaling. While scaling and mapping, a pocket tape recorder and camera are useful for documentation.

Suggested Equipment

Use the appropriate scaling equipment and systems. Standard mapping equipment needs to be reviewed and modified for scaling operations.

Documentation

Establish ground control for mapping including terrestrial photo mapping. Data collected while scaling should be based on the purpose of mapping and detail required. Establish general map controls such as grid controls.

Special Considerations

Select specific portions of an exposure to be mapped.

Canal and Pipeline Mapping

General

In reconnaissance investigations, surface geologic mapping is used to determine the most feasible alignment, which may be representative of the geologic conditions to be encountered, the lining requirements, and construction materials available. Design data investigations along canal alignments must be detailed enough to determine the final alignment and all associated requirements for specifications and construction.

Preconstruction investigations for canals and pipelines are less detailed because of the long distances involved. Consequently, geologic construction mapping is necessary to verify preconstruction assumptions, document changes from original assumptions, and provide data for potential design changes or claim analyses.

Preparation

General field mapping requirements.

Documentation

Pertinent geologic data that should be shown on the base maps include: soil and geologic units, all natural and manmade exposures, geologic structures, springs and seepage, surface channels, and potentially unstable areas. Where appropriate, photographs with overlays or detailed site-specific drawings should be used to show surface conditions in relation to the canal prism or associated canal structures. Base maps should be plan strip topo-graphy or orthophotography with scales of 1 in = 20 ft (1:400) to 1 in = 100 ft (1:2,000) with associated topographic profiles.

Underground Geologic Mapping

General

This is a general guide for recording tunnel geology and describes mapping requirements and procedures. This guide and the field geologist's judgement and experience should permit development of geologic data which adequately document geologic factors that are significant to design, construction, and stability of tunnels and shafts. Some of the necessary data may be obtained from other project personnel such as engineers, surveyors, and inspectors. The following items are of primary impor-tance during the construction or exploration for a wide range of tunnel and shaft types, excavation problems, geologic conditions, and contract administration require-ments. The data recorded and the emphasis given each item should be determined for each specific tunnel. (Note: references to tunnels apply equally to shafts)

Three principal objectives are to:

- Acquire progressive, timely mapping of all significant geologic features as exposed during the advance of the tunnel or shaft. These initial features are important for subsequent identification of changes which may take place, such as water flow, rock slaking, or support behavior, as the heading progresses and before lining or other completion measures are undertaken.

- Facilitate periodic transmittal of these data in preliminary form to the office so that conditions being encountered and their effect on the excavation can be used in immediate evaluation of current construction activities and anticipation of future excavation conditions.

- Assure that a systematic, clear, record of geologic conditions is compiled for design reviews and use by the project and contractor. These data should be included in the final construction geology report. These records may prove invaluable during subsequent operation and maintenance and in the planning and design of future tunnels and shafts. If geologically related problems occur, these data will be essential in evaluating the conditions.

Accuracy is essential, and consistency of data shown on tunnel maps is vital. If the maps are used in contract claim negotiations or in litigation, even a few errors or inconsistencies may compromise the entire map.

The preparation of an adequate tunnel or shaft geologic map requires a careful study of geologic structure, lithology, mineralogy, groundwater, and their effects on rock quality and behavior, tunneling methods, stability, and support. The preparation of a tunnel or shaft geologic map is a geologic mapping process; geologic data should be recorded directly on the map while making the observations and not described in notes for subsequent drafting in the office. An appropriately scaled tunnel or shaft mapping form, prepared prior to starting the mapping, is essential to systematic data collection. One-matte-sided mylar tunnel forms should be used in wet excavations and are recommended as a standard for all tunnel and shaft mapping. Figures 6-4 and 6-5 are examples of field mapping forms. The use of mylars in all tunnels facili-tates copying and immediate use. The extent or amount of mapping detail for a specific tunnel or shaft will depend on the driving method, geologic conditions, and design considerations. For example, tunnel face (head-ing) maps can be obtained under most conditions when conventional excavation (drill/blast) methods are used but are difficult to obtain in tunnels excavated by tunnel

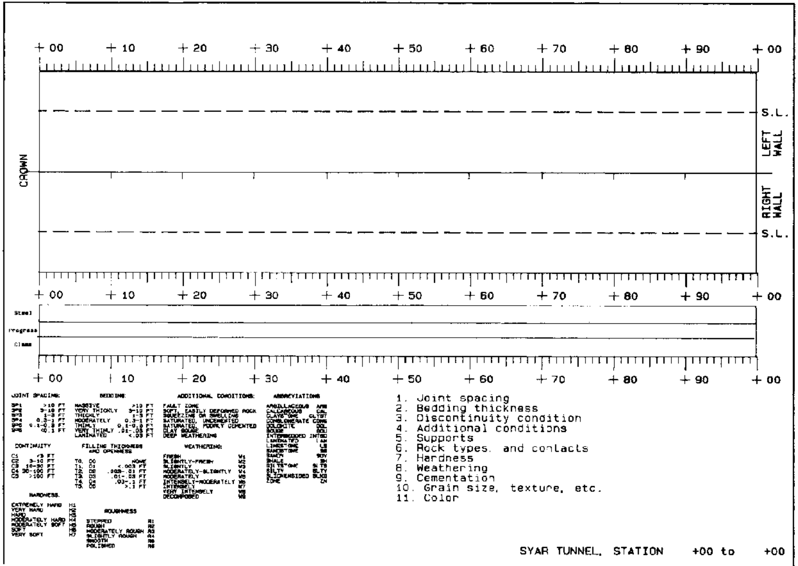

Figure 6-4.—Tunnel mapping form with key alphanumeric descriptors and mapping data.

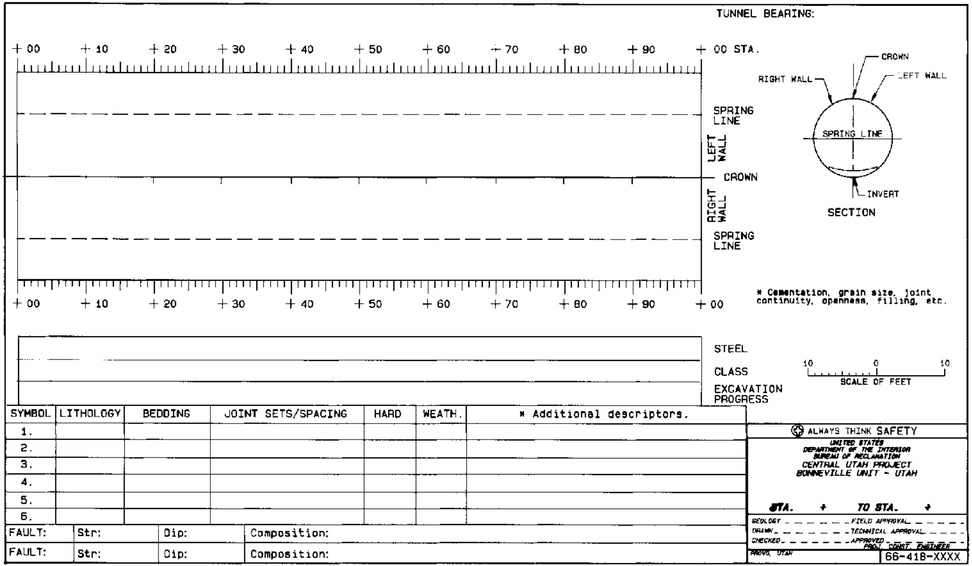

Figure 6-5.—Tunnel mapping form with blocks for title and geologic data.

boring machine (TBM). TBM excavated tunnels may be more difficult to map than conventionally excavated tunnels, depending on the level of detail required, machine configuration, and the support method. However, the key rock characteristics relative to tunnel stability must be mapped. In tunnels where shotcrete or precast segments are used for support, detailed mapping may be impossible; this does not cancel the requirement for mapping and recording of important data on the geologic conditions. The geologist must obtain required data with the available resources and under the specific conditions. These guidelines apply to all tunnel or shaft excavations regardless of whether the mapping is performed during project planning, design data acquisition, or construction.

Safety

Underground construction activities are inherently more hazardous than surface construction. Before working underground, the specific safety requirements for the particular tunnel should be determined. Self-rescuer training commonly is required, and the safety requirements as described in the *Reclamation Safety and Health Standards* [5] should be reviewed. Additional training or additional requirements may exist under special circumstances such as gassy conditions. Before beginning work, a familiarization tour of the work site (including the underground workings) should be made with project personnel, such as an inspector, intimately familiar with the job. Also, assume that every piece of equipment and worker is out to get you; you should always maintain an awareness of what the workers and equipment are doing around you.

General Preparation

Tunnel construction is essentially a linear activity. All access, equipment haulage, and work activities take place in a line. The mapping process should be planned such that a minimum number of trips to the heading are required and a minimum amount of time is spent at the heading. Geologic mapping can usually be integrated into an optimum part of the construction cycle. Unnecessarily spending time at the heading is not only inefficient but can interfere with the construction process by adding to an already congested situation.

Available geologic data should be reviewed and established nomenclature used as appropriate. Geologic features described in the available literature should be specifically investigated while mapping, especially those described in specifications documents. Forms should be designed to expedite the work as much as possible (figures 6-4 and 6-5), required mapping equipment must be available, and the construction cycle should be analyzed to determine the best and safest time to map. Tunnel map sheets should be a convenient size such as 8.5 x 11 inches (A4) or 11 x 18 inches (A3). This permits 100 feet (30 m) of tunnel on a scale of 1 inch = 10 feet (1:200) with sufficient space for concise explanations and a title block. The geology should be mapped in the tunnel directly on the matt side of mylar film. This map, developed in the tunnel, can be edited and copied for quick transmittal to the office. The value of current data cannot be overemphasized. Except under very special conditions, the recording of geologic data in a notebook without mapping for subsequent preparation of a graphic tunnel map is unacceptable. Without a graphic represen-tation during data acquisition, the interrelationships of geologic data cannot be properly evaluated, and data are missed or errors are introduced. Some items listed above will not apply to every tunnel, and some items may be shown more appropriately in a summary tunnel map (figure 6-6). This map presents a summary of essential engineering and geologic relationships. Plotting engi-neering and geologic data as a time line permits direct comparison of geologic conditions, supports installed, overbreak, excavation rate, etc., for correlation. Sum-mary sheet scales may range from 1 inch = 10 to 100 feet (1:100 to 1:1,000) depending on amount of data and complexity of the geology. Ongoing maintenance of these data avoids excessive compilation time after construction is completed. A summary tunnel map is required on tunnels for construction records.

When several individuals are mapping and/or contract requirements hinge on geologic data, e.g., payment based on ground classification, a project or specific mapping manual may be necessary. A manual provides an easy reference for data requirements and format, reduces inconsistency between geologists, and sets a specific mapping standard.

Excavation Configuration

Conventionally excavated tunnels are usually a modified horseshoe shape. Departures from this shape are usually for a special configuration or when ground conditions
dictate a circular shape for optimizing support effective-ness. Machine-excavated tunnels are round if bored unless a road-header type machine is used. Road-header excavated tunnels are usually horseshoe shaped for con-struction convenience. Shafts are almost always round for optimizing support effectiveness and because most are drilled or bored either from the surface or raise-bored from the bottom. Exploratory shafts may be sunk conven-tionally if shallow. Whatever the shape, the map format should be designed to minimize the amount of projection

and interpretation required. Whenever possible, the full periphery mapping method should be employed.

Data Requirements

The relationship of the geology to the engineering aspects of the tunnel or shaft is of primary importance. If geologi-cally related problems occur, the recorded data will be valuable to the geologist and engineer in evaluating the conditions, the cause(s), and in devising remedial measures. In most cases, geologic discontinuities, such as joints, faults, bedding, etc., are the most important factors affecting excavation stability; and these data are of primary importance. Also, the rock strength is important in high cover tunnels, and water is important in many situations. The following data are most important:

1. Rock Classification.— Lithology and related features such as foliation, schistosity, and flow structure. Rock descriptions should be concise; use standard descriptors.

- **Formation boundaries —** describe bedding thick-ness and attitude, areas of soft, or unstable rock. Give dip and strike unless otherwise noted. Dips of planes (not necessarily true dip) into tunnel are desirable in cases where they may influence excavation stability.

- **Physical properties of the rock —** determine hardness by comparison with common or familiar materials, brittleness, reaction to pick or knife, and color.

- **Alteration —** describe degree, type, extent, and effects on construction. Differentiate between wea-thering, other alteration, and cementation.

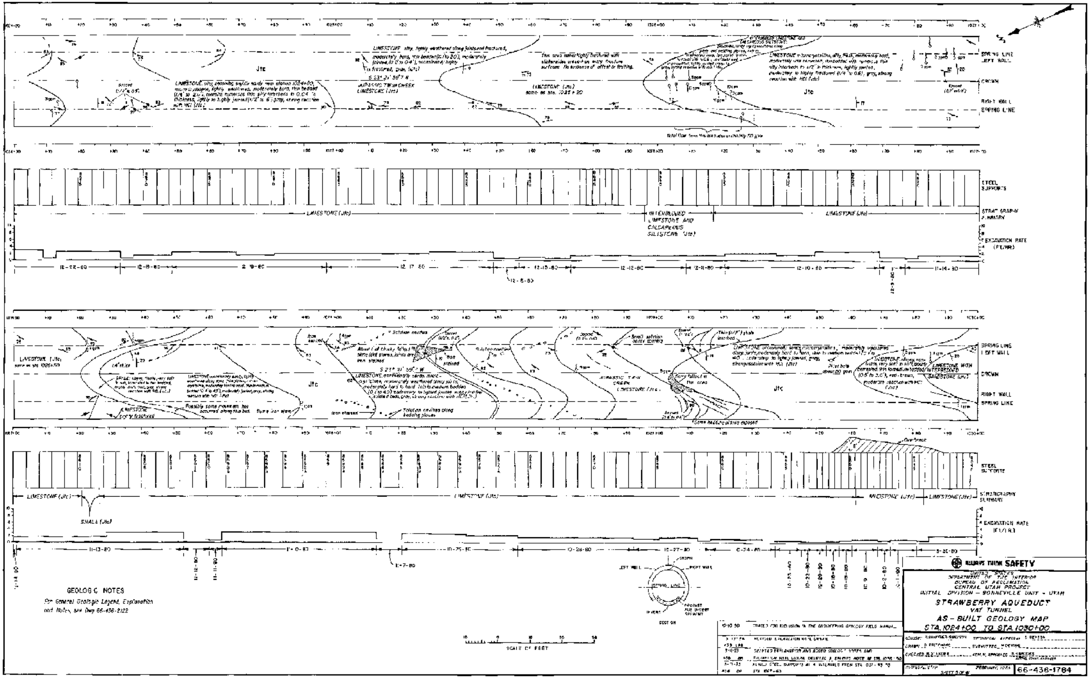

Figure 6-6.—As-built summary geology tunnel map.

- **Features —** describe the size, form (tabular, irregular), contacts (sharp, gradational, sheared), and mineralization, if any.

2. Conditions Which Affect Stability of the Rock.—

- **Joints or joint systems —** describe spacing, conti-nuity, length, whether open or tight, slickensides, planarity, waviness, cementation, fillings, dip and strike, and water.

- **Shear zones —** describe severity of shearing and physical condition of rock in and adjacent to the zone, whether material is crushed or composed of breccia, gouge, or mylonite; describe gouge thickness, physi-cal properties, mineralogy and alteration; dip and strike, and water.

- **Faults —** give dimensions of fault breccia and/or gouge and adjacent disturbed or fractured zones, amount of displacement, if determinable, and the fault's effect on stability of rock.

3. Effects of Tunneling on Rock.— Comment on: the condition of rock after excavation, rate of air slaking or other deterioration of rock where appropriate, rock bursts, fallouts, development of squeezing or heavy ground, and time interval between first exposure and the beginning of these effects. Include the evidence used in evaluation, and the reaction of different rock types to conventional blasting or mechanical excavation method.

Periodic re-examination of the tunnel and comparison of originally mapped conditions with those existing later is recommended.

4. Tunnel Excavation Methods.—

Blast pattern **—** Give example of typical blast round pattern, type of explosive and quantity per yard (powder factor) of rock blasted, size of rock fragments, ease or difficulty of rock breakage and condition of the walls of the tunnel such as whether half-rounds (half of peripheral shot holes) are visible. Some of this infor-mation should be obtainable from the inspectors.

Overbreak **—** Overbreak and fallout should be measured as a peripheral average from "B" line (excavation pay line), where practical, and maximum at specific stations. Plot average overbreak on the section along tunnel alignment. Relate this to geologic conditions and construction methods, particularly blasting procedure.

Ground behavior **—** Blockiness, caving, swelling, and/ or squeezing should be described with evidence and effects.

Supports **—** Give size and spacing of ribs, size and types of struts, and behavior of supports in reaches of bad ground. Where supports show distress or have failed, give reason for failure, time after installation for load to develop, the remedial measures undertaken, and size and spacing of replaced supports or jump sets. If a ground classification system is being used, relate to geologic conditions and support used. Incorporate some reference to the actual need for support versus that installed. Use the proper terminology when describing supports. A good reference for tunnel supports (and conventional tunneling) is *Rock Tunneling with Steel Supports* [6].

Indicate where special supports such as mats, spiling, or breast boards are required and geologic reason. Where rock bolts (or split sets) are used, give spacing, size, length, type, anchor type, torque loading values, and quantities used. Note retorquing, if performed. Locations of rock bolts should be plotted on the geologic maps.

Machine excavation **—** In machine-type excavations (in addition to appropriate items above) give: rate of advance, pressures used, and description of cuttings or rock breakage. Describe the effect of cutters and grippers on rock walls, or other geologically related problems such as abrasive rock wearing cutters.

5. Hydrogeology .—Water flows should be mapped and quantities estimated. Daily heading and portal measurements should be recorded. The location of all significant flows should be plotted on the tunnel map and changes in rate or duration of flow recorded. If the water is highly mineralized, obtain chemical analyses of water for pos-sible effect on concrete or steel linings or contamination of water being discharged or to be conveyed by the tunnel.

6. Gas.—The following should be done:

- Determine type, quantity, occurrence, geologic associations, and points of discharge should be mapped.

- Samples should be taken. This is usually done by safety personnel.

- Record actions taken.

7. Instrumentation, Special Tests, Grout, and Feeler Holes.—Locations and logs (if available) should be shown on the tunnel maps.

8. Miscellaneous Excavations.—Geologic maps and sections of related excavations such as surge tanks, gate shafts, inlet and outlet portal open cuts are necessary.

Tunnel maps should include brief comments on the geologic conditions being encountered and their possible effects.

9. Sampling.—A systematic sampling program of the tunnel rock is essential to adequately record tunnel geology. These samples may be 2 in x 3 in (5 cm x 8 cm) or larger and should be secured in a labeled sample bag showing station, date, and wall position with an appropriate description. Rock that easily deteriorates should be protected with wax or plastic. Sampling at irregular (and locally close) intervals may be required to ensure that all important rock, geologic, and physical conditions are adequately represented. A representative stratigraphic series of samples should be collected. The judgement of the geologist who is familiar with the geology is the best guide in determining the most appropriate sampling interval.

Thorough photographic coverage provides a visual record of construction and geologic conditions. Postconstruction evaluations use construction photographs extensively and are an important part of the construction record. A camera should be part of the mapping equipment and routinely used. Photographs that show typical, as well as atypical, geologic conditions should be taken routinely. Identify photographs of significant features by number on the appropriate map sheet.

Underground Geologic Mapping Methods

Full Periphery Mapping

The full periphery (or developed surface) mapping method is widely used in engineering practice and involves creating a map of the surface of the underground excavation regardless of shape. The method produces a map which is virtually free from distortion and interpretation present in other methods where geologic features are projected onto a plane or section. The method has been used successfully in various types and shapes of excavations (Hatheway, 1982 [7]; U.S. Army Corps of Engineers, 1970 [8]; Proctor, 1971 [9]) and on numerous Reclamation projects.

The method uses a developed surface created by "unrolling" or "flattening out" the circumference of the tunnel or shaft to form a "plan" of the entire wall surface (figure 6-7). The geologic features are plotted on this plan. The method is especially effective in that geologic features of all types can be plotted directly onto the map regardless of orientation or location with no projection required. The method is useful for plotting curving or irregular discontinuities which are difficult to project to a flat plane as in other methods.

Procedure.—Full periphery mapping generally requires the assembly of field sheets prior to the actual start of mapping. This is done for drifts and tunnels by first drawing in the crown centerline of the plan (figure 6-7). The bases of the walls or the invert are then plotted at a circumferential distance from the crown centerline on the plan. For instance, if the tunnel is 10 feet (3.048 m) in excavated diameter, the invert centerline will be plotted 15.71 feet (4.79 m) (in scale) from the crown centerline. Plot springline at the appropriate circumferential

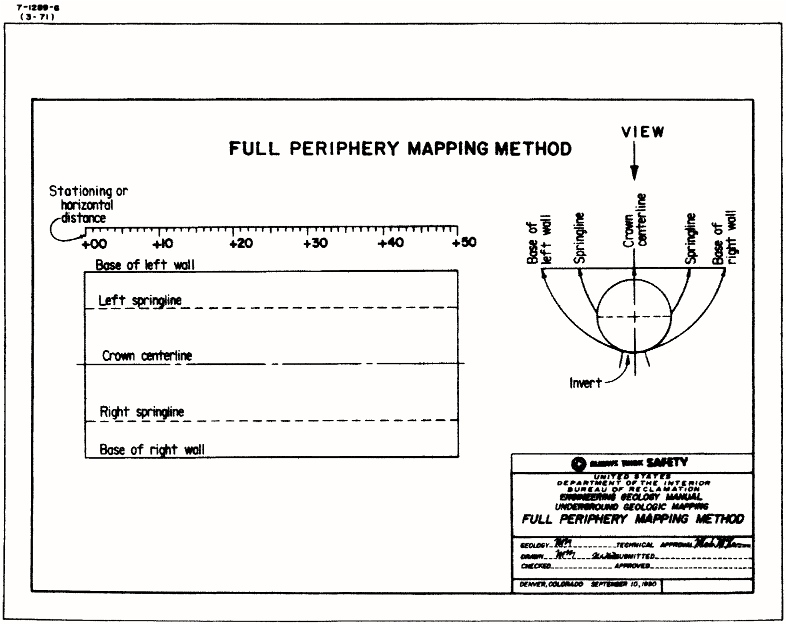

Figure 6-7.--Full periphery mapping method layout.

distance from the crown centerline. This process is done for both walls and produces a plan which represents the actual wall surface of the excavation. The map layout is designed to be viewed from above the tunnel. Shaft data are plotted as viewed from inside the excavation. The tunnel invert is not mapped because rock surfaces usually are covered with muck or invert segments. Plot scales on either side of the plan to provide distance control while mapping. A longitudinal section view of the excavation may be added alongside the plan to provide a space to record types and locations of support, overbreak, etc. Plot geologic features on the field sheets (figures 6-4 and 6-5) by noting where the features intercept known lines, such as where a particular joint intercepts the crown centerline, the spring line on both walls, or the base of either wall. The trace of the joint is sketched to scale between these known points. The strike and dip of the discontinuity are recorded directly on the field sheet adjacent to the trace. The locations of samples, photographs, water seeps, and flows are plotted on the map (figure 6-8).

The Brunton compass is used to measure dips on the various discontinuities; but due to the presence of support steel, rock bolts, utilities, and any natural magnetism of the wall rock, a Brunton may not be reliable for deter-mining the strike of the feature. In this case, the strike may be determined by one of several methods. The first method is to align the map parallel to the tunnel where the feature is exposed in the wall and plot the strike by eye on the sheet parallel to the strike of the feature in the wall. The second method is to observe the strike of the feature on the map where it intersects the crown centerline. At this point, the crown is essentially hori-zontal, and the trace of the feature at this point represents the strike. The third method is slightly more complex but is the most accurate method of the three.

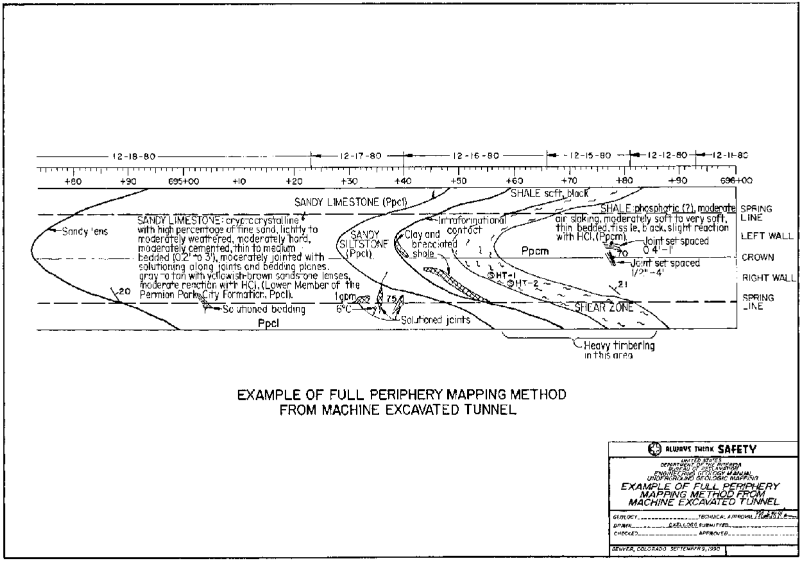

Figure 6-8.—Full periphery geologic map example.

This method requires locating where the feature intersects springline on each wall of the full periphery map. These points are projected to the corrected springline. A line drawn between the projected points represents the strike of the feature. Note that these methods assume that the tunnel or drift is relatively horizontal. In some cases, if the excavation is inclined, the apparent strike can be corrected for the amount of inclination. A fourth method is to use a gyroscopic compass.

Other Applications.—With minor variations in the method described above, the full periphery method can be used equally well in vertical or inclined shafts, horseshoe shaped drifts and tunnels, and other regular shaped excavations.

Advantages.—The full periphery method:

- Involves plotting the actual traces of geologic features as they are exposed in the tunnel. This eliminates the distortion and interpretation introduced by other methods where the traces are projected back to a plane tangent to the tunnel.

- Allows the geologist to observe and plot irregularities in geologic features and make accurate three-dimensional interpretations of the features.

- Allows rapid and easy plotting of the locations of samples and photographs.

- Allows easy and rapid recording of the locations of rock bolts and other types of rock reinforcement.

Disadvantages.—

- Since the surface of the excavation is generally a curved surface, the trace of planar features, such as fractures, faults, and bedding planes, produce curves when plotted on the map.

- The full periphery method requires that the points at which features intersect springline be projected to the original tunnel diameter in order to compute the true strike of the discontinuity (figure 6-7).

Plan and Section

The plan and section method has been used in engineering practice but has generally been replaced by the full periphery mapping method. The plan and section method is still used where data interpretation is facilitated by the flat plan and sections. The method creates vertical sections commonly coincident with a wall or walls of a tunnel or shaft, through centerline, or is tangent to a curving surface commonly at springline or an edge of a shaft (figure 6-9). Geologic features are projected to the sections and plotted as they are mapped.

The method produces a map which is a combination of direct trace and projection or a projection of the walls except where the map is tangent to the excavation (figure 6-10). The plan through tunnel springline and centerline or shaft centerline is a projection of the geologic features exposed in the excavation.

Procedure.—The plan and section method generally requires the assembly of field sheets prior to the actual start of mapping. This is done for drifts and tunnels by drawing vertical sections the height of the excavation.

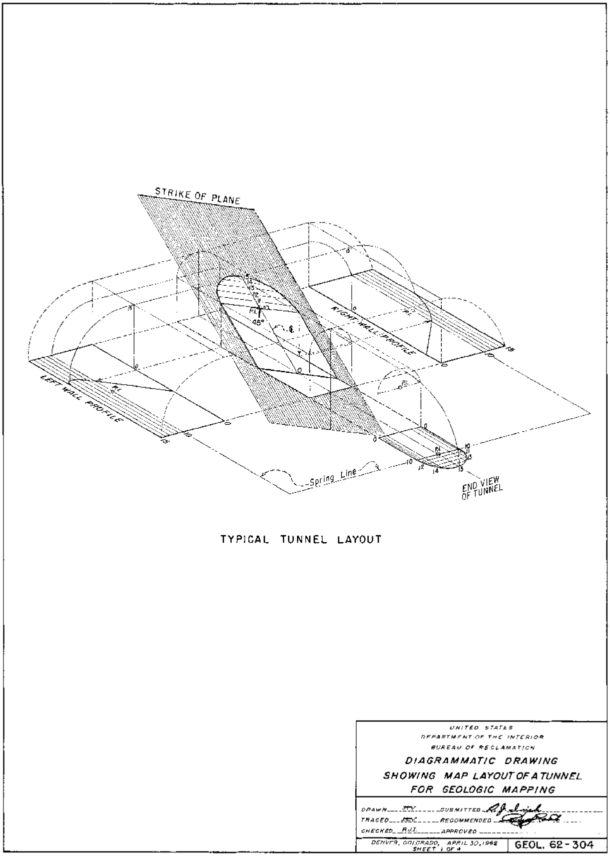

Figure 6-9.—Map layout of a tunnel for geologic mapping.

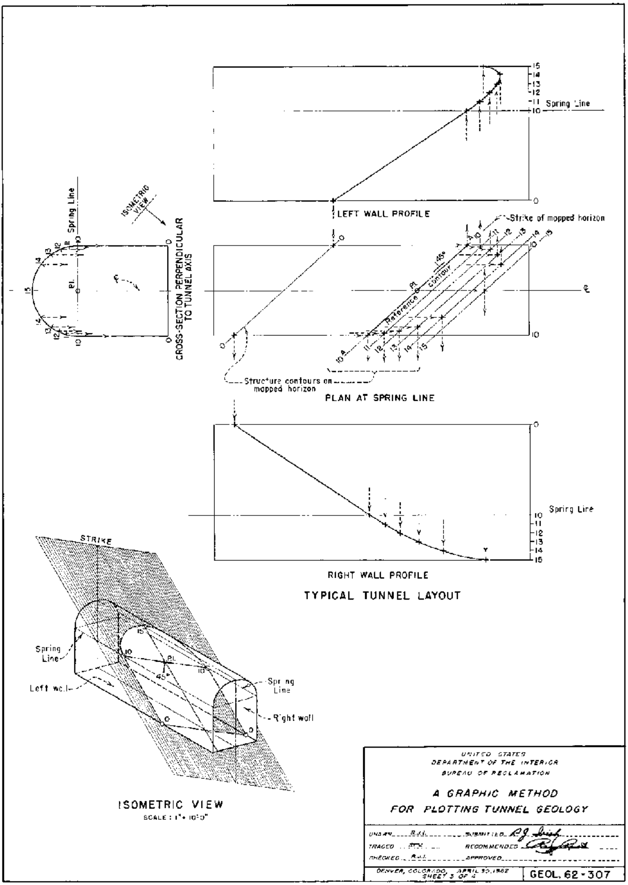

Figure 6-10.—Relationship of planar feature trace to map projections.

The bases of the walls or the invert form the base of the section with springline plotted and the crown forming the top of the section. For instance, if the tunnel is 20 feet (6 m) high, the crown will be 20 feet (6 m) from the invert. Springline is plotted the appropriate vertical distance from the crown or invert (figure 6-10). This process may be done for one or both walls, producing one or two vertical representations of the wall/arch exposure. Shafts are similar, but the section corresponds to the wall of a rectangular shaft or is tangent to the shaft wall at a point, and the map is a projection of the shaft of one diameter.

A section through tunnel springlines produces a plan projection of the arch except at the plan intersection with the wall at springline. The corresponding section through a shaft produces a vertical projection of the wall(s) through a shaft or along a diameter. The map represents the actual wall surface of the excavation only where the projection intersects the wall.

Scales are added on either side of the sections to provide distance control while plotting. An additional longitudinal section view of the excavation may be added to provide a space to record types and locations of support or overbreak. Geologic features are then plotted on the field sheets by noting where the features intercept known lines, such as where a particular joint intercepts the crown centerline, the spring line on both walls, or the base of either wall. The trace of the joint is then projected to the section between these known points. The attitudes of features are recorded on the field sheet adjacent to the trace. The location of samples, photographs, water seeps, and flows can be recorded by finding their location on the wall and projecting that location to the map.

Advantages.—The plan and section method:

- Produces two-dimensional sections and plans that do not require conversion. The sections and plans can be integrated directly with other plans and sections. The sections and plans are easily understood by individuals not familiar with full periphery mapping or individuals who have difficulty visualizing structural features in three-dimensions.

- Permits direct determination of strikes by spring-line intersections.

Disadvantages.—Since the surface of the excavation is generally a curved surface, the trace of planar features, such as fractures, faults, and bedding planes, are projections to a plane. The only objective data is where the map is coincident or tangent to the excavation surface.

The plan and section method requires:

- Plotting and observing geologic features and making accurate three-dimensional interpretations of the features by projecting locations to a plane.

- Plotting locations of samples and photographs by projection.

- Recording locations of rock bolts and other types of rock reinforcement by projection.

- Plotting is done after data collection and re-examination of the site is difficult or not practical.

Face Maps

The geology exposed in an excavation face is plotted directly on a map. The purpose of the face map is to provide a quick appraisal of rock conditions and provide data for special detailed studies. The combination of wall and face maps will usually give an adequate and clear permanent record of any complex tunnel geology. Natural scales such as 1 inch = 1 to 2 feet (1:50) are the most satisfactory. All significant geologic features which may affect the stability of the tunnel must be mapped.

Photogrammetric Mapping

Photogrammetric geologic mapping is a specialized method consisting of the interpretation of close-range stereophotography of excavation walls. Photogrammetric control is provided by surveyed targets or by a gnomon or scale in the photographs. The stereophotos are interpreted using photogrammetric software or an analytical plotter. Feature location accuracy can vary from a few inches (cm) to one-eighth of an inch (3mm) depending on equipment and survey control accuracy. The photogrammetric mapping can be combined with detail line surveys for small-scale data collection and control.

Exploration Mapping Method Selection

The geologic mapping format for exploratory drifts and shafts should be determined by data uses. Direct integra-tion of excavation maps into composite maps of a dam foundation is much easier if undistorted sections are available. The maps can be treated in the same manner as drill hole logs. The disadvantages of plan and section mapping may be offset by the advantages of easy inter-pretation and integration into other data bases.

Construction Mapping.—Full periphery geologic mapping should be used for routine construction activities. The advantages of increased speed and accuracy in production mapping and the reduction of interpretation offsets the disadvantages.

Summary

This guide to tunnel geologic mapping during construction has been developed for general use and serves to standardize procedures and data collection. Items of primary significance are included, but some are not adaptable to all tunnels or methods of tunnel excavation. The judgment of an experienced geologist is the best guide to the specific items and amount of detail required to provide pertinent, informative data. To ensure reliable and useful tunnel geologic studies, all important geology and related engineering construction data which may be significant to tunnel construction as well as in the planning, designing, and constructing of future tunnels should be considered for inclusion in the tunnel map and report.

Photogeologic Mapping

General

Aerial photographs generally are used in reconnaissance geologic mapping, geologic field mapping, and in generation of photo-interpretive geologic maps. Various scales of airphotos are valuable for regional and site studies, for both detection and mapping of a wide variety of geologic features important to engineering geology.

Types of Aerial Photographs

Panchromatic (Black and White).—Panchromatic photography records images essentially across the entire visible spectrum, and with proper film and filters also can record into the near-infrared. In aerial photography, blue is generally filtered out to reduce the effects of atmospheric haze.

Natural Color.—Images are recorded in the natural colors seen by the human eye in the visible portion of the spectrum.

False-Color Infrared.—Images are recorded using part of the visible spectrum and part of the near-infrared, but the colors in the resultant photographs are not natural (false-color). Infrared film is commonly used and is less affected by haze than other types. False-color photography is not the same as thermal-infrared imaging which uses the thermal part of the infrared spectrum.

Multispectral.—Photographs acquired by multiple cameras simultaneously recording different portions of the spectrum can aid interpretation.

Photogrammetry and Equipment

Use stereoscopes to view aerial photographs for maximum utility and ease of interpretation. Pocket stereoscopes are useful in the field or office. Large mirror stereoscopes are useful for viewing large quantities of photos or photos in rolls. Know the photo scale, resolution, and exaggeration. Be aware of the types of distortions inherent in airphotos.

Compilation of Photogeologic Map Data

Mapping should be done on transparent one-side-matte mylar overlays and not on the photographs. Any lines, even if erased, can confuse later interpretations using the photos. The mapping is then transferred to base maps minimizing the effects of distortions in photos due to the camera optics. Orthophoto quadrangles can help reduce this distortion.

Analysis of Aerial Photographs

General Interpretive Factors

Analysis of aerial photographs involves interpreting indirect data. In most cases, several factors are used to interpret geologic conditions. Interpretive factors usually used in the analysis of aerial photographs are:

Sun Angle.—High or low illumination angles may be desired, depending on the nature of the features to be detected.

Photographic Tone.—Variations in color, intensity, shade and shadows.

Texture.—Frequency of change in tone, evident as roughness, smoothness.

Color.—True and false-color imagery may be easier to interpret than panchromatic photographs, depending on features being observed. For some applications (e.g., low sun angle photography), panchromatic photography is better.

Geomorphic Shape and Pattern.—Geologic conditions can be identified by mapping various types of geomorphic features related to drainage, bedding, and structure.

Vegetation.—Some types of vegetation and vegetal patterns can assist in interpreting geology. Vegetation may indicate depth of soil, type of soil, available moisture, and type of bedrock.

Photoanalysis for Reconnaissance Geologic Mapping

Photo-reconnaissance geologic mapping can be done to produce a preliminary geologic map of the study area prior to going into the field to check and verify the interpreted geologic data or to produce a finished geologic map with little or no field checking. These maps are called photo-reconnaissance geologic maps and photo-interpretive geologic maps, respectively.

Photo-Reconnaissance Geologic Mapping

Photo-analysis prior to field work allows the mapper to form a preliminary concept of the geology of the study area and to select areas for detailed examination. Prior photo-analysis is critical if available field time is limited, especially when a large area is involved, as in regional studies, reservoir area mapping, and pipeline or canal alignment studies.

Photo-Interpretive Geologic Mapping

Geologic maps produced solely from aerial photographs with little or no field checking are useful when time, funds, or access are limited or when adverse weather prevents a more detailed field mapping program. The limitations of this form of geologic map are dependent on outcrop density and degree of exposure, amount of vegetative cover, contrast of the geologic units, and the skills of the photogeologic mapper. This type of map is useful for preliminary or reconnaissance level evaluations but should never be used for design level work.

Photoanalysis During Geologic Field Mapping

The location and verification of geologic features in the field can usually be expedited by using aerial photographs. Photographs often reveal landforms that are difficult to see or interpret from the ground, such as land-slides. Photographs can be used to clarify and speed up field mapping by allowing a comprehensive view of the study site and the relationships of the various geologic features exposed. Alternately viewing photos and exam-ining outcrops can greatly facilitate mapping.

Availability of Imagery

Aerial photography is available, commonly in a variety of scales and types, for essentially the entire conterminous United States. The principal repositories of publicly owned airphotos is the EROS Data Center, operated by the U.S. Geological Survey and the Agricultural Stabilization and Conservation Service (ASCS) of the U.S. Department of Agriculture. The USGS has several regional offices of the Earth Science Information Center (ESIC). The ESIC operates the Aerial Photography Summary Record System (APSRS), which is a standard reference data base for users of aerial photographs. The APSRS lists aerial photography available from a large number of government agencies and commercial companies. The lists are comprehensive and categorized by state and by latitude and longitude. APSRS data are available on request from ESIC. ESIC also provides information about cartographic products other than imagery.

Some important addresses and telephone numbers are:

USDA-ASCS (801) 524-5856
Aerial Photography Field Office
Customer Services
2222 West 2300 South
P.O. Box 30010
Salt Lake City, UT 84130-0010

USGS (605) 594-6151
EROS Data Center
Sioux Falls, SD 57198

USGS (303) 202-4200
ESIC
Denver Federal Center
Denver, CO 80225

USGS (650) 329-4309
ESIC
345 Middlefield Road
Menlo Park, CA 94025

Aerial Photography Flight Planning

If air photos are not available at the right scale, or of the right type for an area, specific flights can be made. Successful airphoto mission planning requires considera-tion of several factors, including film type, scale, time of day (sun-angle), time of year, and the size of the area to be covered. Mission planning should not be done by someone unfamiliar with the process without assistance. Specifications should be written to ensure that the result-ing photographs will be appropriate for the intended purpose. Information critical to mission planning is available from the references listed below.

Time and Cost Estimating

The cost of data acquisition is relatively easy to estimate. The cost of interpretation is much harder to estimate, being a function of the time required, which is related to the size and complexity of the study area and the skill of the interpreter. The cost of a single drill hole will pay for a lot of aerial photography and interpretation.

References

A classic text on the use of airphotos in geology was reprinted in 1985 and should be readily available. Some of the equipment described is obsolete and it is essentially limited to discussion of panchromatic photography. The publication contains numerous stereopairs with geologic descriptions and is one of the best works on airphoto interpretation for geologists:

Ray, R.G., Aerial photographs in geologic interpretation and mapping, USGS Professional Paper 373, 230 p., 1960.

Other useful references are:

Lattman, L.H., and Ray, R.G., *Aerial photographs in field geology*, Holt, Rinehart and Winston, New York, NY 221 p., 1965.

Miller, V.C., *Photogeology*, McGraw-Hill, New York, NY, 248 p., 1961.

A reference containing no general discussion of principles, but with excellent examples of stereopairs of geologic features, associated topographic maps, and geologic annotations is:

Scovel, J.L., et al., *Atlas of Landforms,* Wiley & Sons, New York, NY, 164 p., 1965.

A broad and lengthy reference covering remote sensing in general, including much information about aerial photography of all types, is:

Colwell, R.N., editor, *Manual of remote sensing,* 2nd edition, American Society of Photogrammetry, Falls Church, VA, 272 p., 1983.

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