Chapter 4
Surface Investigations

4-1. Description of Operation

This chapter describes field operations that do not involve significant disturbance of the ground at the time the investigation is conducted. This type of investigation typically occurs at a preliminary stage of projects and supplies generalized information. However, these investigations can involve mapping specific locations in great detail during construction. The end product is commonly a pictorial rendering of conditions at the site. The degree of accuracy and precision required in such a rendering varies with the application and purpose for which the information is to be used. Some leeway in the degree of accuracy is required because of the inherent difficulty in presenting a 3-D subject in two dimensions. With computer-aided design and drafting (CADD) systems and specialized engineering application software packages, it is possible to portray 3-D information of greater complexity more effectively.

This chapter and the next describe in detail elements necessary for completion of a successful field investigation program for large civil and military projects. Several elements are applicable for refinement of regional geology investigations discussed in Chapter 3. Many civil works projects are, however, too small to afford complete onsite field investigations as outlined in the next two chapters. For smaller projects, emphasis should be placed on compilation and analysis of existing data, remote sensing imagery, and surface and subsurface information derived from onsite drilling and construction excavations. The following discussion can serve as a guide to the types of critical geotechnical information needed to support design and construction decisions.

Section I
Geologic Field Mapping

4-2. Areal Mapping

The purpose of areal mapping is to develop an accurate picture of the geologic framework of the project area. The area and the degree of detail to be mapped can vary widely depending on the type and size of the project and on the complexity of the regional geology. In general, the area to be mapped should include the project site(s) as well as the surrounding area that could influence or could be influenced by the project. The information available from other sources should have been identified and collected during preliminary investigations (Chapter 3). If this was not done, or if for any reason it appears that additional useful information may be available, this information should be obtained and evaluated before expensive field investigations are begun. Only if existing geologic studies of an area have been combined with current geologic mapping and appropriate remote sensing techniques can an areal mapping program be considered complete. Such analysis is best carried out in a GIS. Utilization of GPS is a low cost and efficient alternative for providing precise horizontal and vertical measures to establish ground control points for georeferencing remote sensing images and for locating monitoring wells and other geologic sampling stations. GPS procedures are described in EM 1110-2-1003. For initial surface mapping, hand-held electronic distance measuring instruments are commonly sufficiently accurate and are efficient.

a. Reservoir projects. Geologic and environmental features within the reservoir and adjacent areas that should be studied and mapped include the following:

(1) Faults, joints, stratigraphy, and other significant geologic features.

(2) Karst topography or other features that indicate high reservoir leakage potential.

(3) Water well levels, springs, surface water, water-sensitive vegetation, or other evidence of the ground water regime.

(4) Soluble or swelling rocks such as gypsum or anhydrite.

(5) Potential landslide areas around the reservoir rim.

(6) Valuable mineral resources.

(7) Mine shafts, tunnels, and gas and oil wells.

(8) Potential borrow and quarry areas and sources of construction materials.

(9) Shoreline erosion potential.

(10) Landfills, dumps, underground storage tanks, surface impoundments, and other potential environmental hazards.

b. Other projects. The geologic features listed above are applicable in part to navigation locks and dams, main-line levees, coastal and harbor protection projects, and large or complex military projects. However, the scope and detail of the area mapped depend on the type and size of the project. Environmental engineering aspects of site investigations are covered in EM 1110-2-1202, -1204, -1205, and -1206 and Keller (1992). Procedures to investigate sedimentation in river and reservoir sites are discussed in EM 1110-2-4000.

4-3. Site Mapping

Large-scale and detailed geologic maps should be prepared for specific sites of interest within the project area and should include proposed structure areas and borrow and quarry sites. Investigation of the geologic features of overburden and rock materials is essential in site mapping and subsequent explorations. Determination of the subsurface features should be derived from a coordinated, cooperative study by geotechnical engineers and geologists. The geologist should contribute information on origin, distribution, and manner of deposition of the overburden and rock. The geotechnical engineer or engineering geologist should determine the engineering properties of the site foundation and potential construction materials, potential problem materials or conditions, application of geologic conditions to design, and the adaptation of proposed structures to foundation conditions.

a. Structure sites. A good preliminary geologic map should be prepared prior to making any subsurface borings to provide an approximate picture of the geologic conditions and hazards at a site. Such a map permits borings to be strategically located. For each proposed boring, an estimate should be made of the subsurface conditions that will be encountered, such as depths to critical contacts and to the water table. This estimate is possible, at least in an approximate manner, if geologic mapping has been performed to determine the geologic structure, lithology, and stratigraphy. The process of progressively refining the model of the geologic structure and stratigraphy by comparison with boring information is the most efficient and cost-effective means to develop a complete understanding of the geologic site conditions. A digital format, such as CADD, provides a cost- and time-effective way to refine the model as new information becomes available.

b. Borrow and quarry sites. Sources of materials for embankment construction, riprap protection, and aggregates for concrete or road construction can often be located and evaluated during the course of regional mapping. It is sometimes necessary to expand the field area to locate suitable types and quantities of construction materials. In these instances, remote sensing techniques including analysis of aerial photography may be useful. Alternate plans that would make use of materials nearer to the project but lower in quality should be tentatively formulated and evaluated. A complete borrow and quarry source map should include all soil types encountered and all rock types with adequate descriptions of surficial weathering, hardness, and joint spacings.

(1) Processed rock products are usually most economically acquired from commercial sources. Test results are often available on these sources through state or Federal offices. The procedures for approval of construction materials sources are outlined in EM 1110-2-2301.

(2) Evaluation of soil and/or rock sources should be based upon sampling and laboratory analysis. By making field estimates of the thicknesses of various deposits, a geologic map may be used to estimate quantities available. Geologic maps can also be used to make a preliminary layout of haul and access roads and to estimate haul distances. A GIS is ideally suited to evaluate the quality and quantity of available quarry material, cost of excavation, and optimal transport routes.

4-4. Construction Mapping

Construction maps record in detail geologic conditions encountered during construction. Traditionally, a foundation map is a geologic map with details on structural, lithologic, and hydrologic features. It can represent structure foundations, cut slopes, and geologic features in tunnels or large chambers. The map should be prepared for soil and rock areas and show any feature installed to improve, modify, or control geologic conditions. Some examples are rock reinforcing systems, permanent dewatering systems, and special treatment areas. The mapping of foundations is usually performed after the foundation has been cleaned just prior to the placement of concrete or backfill. The surface cleanup at this time is generally sufficient to permit the observation and recording of all geologic details in the foundation. An extensive photographic and videographic record should be made during foundation mapping.

a. The person in charge of foundation mapping should be familiar with design intent via careful examination of design memoranda and discussion with design personnel. The actual geology should be compared with the geologic model developed during the design phase to evaluate whether or not there are any significant differences and how these differences may affect structural integrity. The person in charge of foundation mapping should be involved in all decisions regarding foundation modifications or additional foundation treatment considered advisable based on conditions observed after preliminary cleanup. Design personnel should be consulted during excavation work whenever differences between the actual geology and the design phase geological model require clarification or change in foundation design. Mapping records should include details of all foundation modifications and treatment performed.

b. Geologic maps and sections of the project which relate to construction and postconstruction procedures, hazards, or problems should be prepared for the Construction Foundation Report. Also, an edited video recording of excavation procedures, final foundation surfaces, treatment, etc. should be an integral part of the final report. The various geological data layers and video information are best compiled, analyzed, and prepared for presentation in a GIS.

c. Appendix B provides detailed guidance on technical procedures for mapping foundations. Mapping of tunnels and other underground openings must be planned differently from foundation mapping. Design requirements for support of the openings may require installation of support before an adequate cleanup can be made for mapping purposes. Consequently, mapping should be performed as the heading or opening is advanced and during the installation of support features. This requires a well trained geologist, engineering geologist, or geological engineer at the excavation at all times. Specifications should be included in construction plans for periodic cleaning of exposure surfaces and to allow a reasonable length of time for mapping to be carried out. Technical procedures for mapping tunnels are outlined in Appendix C and can be modified for large chambers.

Section II
Surface Geophysical Explorations

4-5. Background

Geophysical exploration consists of making indirect measurements from the earth's surface or in boreholes to obtain subsurface information. Geologic information is obtained through analysis or interpretation of these measurements. Boreholes or other subsurface explorations are needed to calibrate geophysical measurements. Geophysical explorations are of greatest value when performed early in the field exploration program in combination with limited subsurface exploration. They are appropriate for a rapid location and correlation of geologic features such as stratigraphy, lithology, discontinuities, ground water, and the in situ measurement of elastic moduli and densities. The cost of geophysical explorations is generally low compared with the cost of core borings or test pits, and considerable savings may be realized by judicious use of these methods.

4-6. Methods

The six major geophysical exploration methods are seismic, electrical resistivity, sonic, magnetic, radar, and gravity. Of these, the seismic and electrical resistivity methods have found the most practical application to the engineering problems of the Corps of Engineers (Steeples and Miller 1990, Society of Exploration Geophysicists 1990). Potential applications of selected geophysical methods are summarized in Tables 4-1 and 4-2. EM 1110-1-1802, Society of Exploration Geophysicists (1990), and Annan (1992) provide detailed guidance on the use and interpretation of geophysical methods. Special applications of microgravimetric techniques for sites with faults, fracture zones, cavities, and other rock irregularities have been made (Butler 1980).

Table 4-1
Applications of Selected Geophysical and Other Methods for Determination of Engineering Parameters[1]

Method	Basic Measurement	Application	Advantages	Limitations
		Surface		
Refraction seismic	Travel time of compressional waves through subsurface layers	Velocity determination of compression wave through subsurface. Depths to contrasting interfaces and geologic correlation of horizontal layers	Rapid, accurate, and relatively economical technique. Interpretation theory generally straightforward and equipment readily available	Incapable of detecting material of lower velocity underlying higher velocity. Thin stratum sometimes not detectable. Interpretation is not unique
Reflection seismic	Travel time of compressional waves reflected from subsurface layers	Mapping of selected reflector horizons. Depth determinations, fault detection, discontinuities, and other anomalous features	Rapid, thorough coverage of given site area. Data displays highly effective	Even with recent advances in high-resolution, seismic technology applicable to civil works projects is limited in area of resolution
Rayleigh wave dispersion	Travel time and period of surface Rayleigh waves	Inference of shear wave velocity in near-surface materials	Rapid technique which uses conventional refraction seismographs	Requires long line (large site). Requires high-intensity seismic source rich in low-frequency energy. Interpretation complex
Vibratory (seismic)	Travel time or wavelength of surface Rayleigh waves	Inference of shear wave velocity in near-surface materials	Controlled vibratory source allows selection of frequency, hence wavelength and depth of penetration (up to 200 ft). Detects low-velocity zones underlying strata of higher velocity. Accepted method	Requires large vibratory source, specialized instrumentation, and interpretation
Reflection profiling (seismic-acoustic)	Travel times of compressional waves through water and subsurface materials and amplitude of reflected signal	Mapping of various lithologic horizons; detection of faults, buried stream channels, and salt domes, location of buried man-made objects; and depth determination of bedrock or other reflecting horizons	Surveys of large areas at minimal time and cost; continuity of recorded data allows direct correlation of lithologic and geologic changes; correlative drilling and coring can be kept to a minimum	Data resolution and penetration capability are frequency-dependent; sediment layer thickness and/or depth to reflection horizons must be considered approximate unless true velocities are known; some bottom conditions (e.g., organic sediments) prevent penetration; water depth should be at least 15 to 20 ft for proper system operation

[1] From EM 1110-1-1802.

(Sheet 1 of 5)

Table 4-1 (Continued)

Method	Basic Measurement	Application	Advantages	Limitations
		Surface (Continued)		
Electrical resistivity	Electrical resistance of a volume of material between probes	Complementary to refraction seis-mic. Quarry rock, ground water, sand and gravel prospecting. River bottom studies and cavity detection	Economical nondestructive technique. Can detect large bodies of "soft" materials	Lateral changes in calculated resistance often interpreted incorrectly as depth related; hence, for this and other reasons, depth determinations can be grossly in error. Should be used in conjunction with other methods, e.g., seismic
Acoustic (resonance)	Amplitude of acoustically coupled sound waves originat-ing in an air-filled cavity	Traces (on ground surface) lateral extent of cavities	Rapid and reliable method. Interpretation relatively straightforward. Equipment readily available	Still in experimental stage - limits not fully established. Must have access to some cavity opening
Ground Penetrating Radar	Travel time and amplitude of a reflect signal microwave	Rapidly profiles layering conditions. Stratification, dip, water table, and presence of many types of anomalies can be determined	Very rapid method for shallow site investigations. Online digital data processing can yield "onsite" look. Variable density display highly effective	Transmitted signal rapidly attenuated by water. Severely limits depth of penetration. Multiple reflections can complicate data interpretation
Gravity	Variations in gravitational field	Detects anticlinal structures, buried ridges, salt domes, faults, and cavities	Reasonably accurate results can be obtained, provided extreme care is exercised in establishing gravitational references	Equipment very costly. Requires specialized personnel. Anything having mass can influence data (buildings, automobiles, etc). Data reduction and interpretation are complex. Topography and strata density influence data
Magnetic	Variations of earth's magnetic field	Determines presence and location of magnetic materials in the subsurface. Locates ore bodies	Minute quantities of magnetic materials are detectable	Only useful for locating magnetic materials. Interpretation highly specialized. Calibration on site extremely critical. Presence of any metallic objects influences data
		Borehole		
Uphole/downhole (seismic)	Vertical travel time of com-pressional and/or shear waves	Velocity determination of vertical P- and/or S-waves. Identification of low-velocity zones	Rapid technique useful to define low-velocity strata. Interpretation straightforward	Care must be exercised to prevent undesirable influence of grouting or casing

(Sheet 2 of 5)

Table 4-1
(Continued)

Method	Basic Measurement	Application	Advantages	Limitations
		Borehole (Continued)		
Crosshole (seismic)	Horizontal travel time of compressional and/or shear waves	Velocity determination of horizontal P- and/or S-waves. Elastic characteristics of subsurface strata can be calculated	Generally accepted as producing reliable results. Detects low-velocity zones provided borehole spacing not excessive	Careful planning with regard to borehole spacing based upon geologic and other seismic data an absolute necessity. Snell's law of refraction must be applied to establish zoning. A borehole deviation survey must be run. Highly experienced personnel required. Repeatable source required
Borehole spontaneous potential	Natural earth potential	Correlates deposits, locates water resources, studies rock deformation, assesses permeability, and determines ground water salinity	Widely used, economical tool. Particularly useful in the identification of highly porous strata (sand, etc.)	Log must be run in a fluid filled, uncased boring. Not all influences on potentials are known
Single-point resistivity	Strata electrical resistance adjacent to a single electrode	In conjunction with spontaneous potential, correlates strata and locates porous materials	Widely used, economical tool. Log obtained simultaneous with spontaneous potential	Strata resistivity difficult to obtain. Log must be run in a fluid filled, uncased boring. Influenced by drill fluid
Long and short normal resistivity	Near-hole electrical resistance	Measures resistivity within a radius of 16 and 64 in.	Widely used, economical tool	Influenced by drill fluid invasion. Log must be run in a fluid filled, uncased boring
Lateral resistivity	Far-hole electrical resistance	Measures resistivity within a radius of 18.7 ft	Less drill fluid invasion influence	Log must be run in a fluid filled, uncased boring. Investigation radius limited in low-moisture strata
Induction resistivity	Far-hole electrical resistance	Measures resistivity in air- or oil-filled holes	Log can be run in a nonconductive casing	Large, heavy tool
Borehole imagery (acoustic)	Sonic image of borehole wall	Detects cavities, joints, fractures in borehole wall. Determine attitude (strike and dip) of structures	Useful in examining casing interior. Graphic display of images. Fluid clarity immaterial	Highly experienced operator required. Slow log to obtain. Probe awkward and delicate. Borehole must be less than a 6-in. diam

(Sheet 3 of 5)

Table 4-1 (Continued)

Method	Basic Measurement	Application	Advantages	Limitations
		Borehole (Continued)		
Continuous sonic (3-D) velocity	Time of arrival of P- and S-waves in high-velocity materials	Determines velocity of P- and S-waves in near vicinity of borehole. Potentially useful for cavity and fracture detection. Modulus determinations. Sometimes S-wave velocities are inferred from P-wave velocity and concurrently run nuclear logs through empirical correlations	Widely used method. Rapid and relatively economical. Variable density display generally impressive. Discontinuities in strata detectable	Shear wave velocity definition questionable in unconsolidated materials and soft sedimentary rocks. Only P-wave velocities greater than 5,000 fps can be determined
Natural gamma radiation	Natural radioactivity	Lithology, correlation of strata, may be used to infer permeability. Locates clay strata and radioactive minerals	Widely used, technically simple to operate and interpret	Borehole effects, slow logging speed, cannot directly identify fluid, rock type, or porosity. Assumes clay minerals contain potassium 40 isotope
Gamma-gamma density	Electron density	Determines rock density of subsurface strata	Widely used. Can be applied to quantitative analyses of engineering properties. Can provide porosity	Borehole effects, calibration, source intensity, and chemical variation in strata affect measurement precision. Radioactive source hazard
Neutron porosity	Hydrogen content	Moisture content (above water table) Total porosity (below water table)	Continuous measurement of porosity. Useful in hydrology and engineering property determinations. Widely used	Borehole effects, calibration, source intensity, and bound water all affect measurement precision. Radioactive source hazard
Neutron activation	Neutron capture	Concentration of selected radioactive materials in strata	Detects elements such as U, Na, Mn. Used to determine oil-water contact (oil industry) and in prospecting for minerals (Al, Cu)	Source intensity, presence of two or more elements having similar radiation energy affect data
Borehole magnetic	Nuclear precession	Deposition, sequence, and age of strata	Distinguishes ages of lithologically identical strata	Earth field reversal intervals under study. Still subject of research
Mechanical caliper	Diameter of borehole	Measures borehole diameter	Useful in a wet or dry hole	Must be recalibrated for each run. Averages three diameters
Acoustic caliper	Sonic ranging	Measures borehole diameter	Large range. Useful with highly irregular shapes	Requires fluid filled hole and accurate positioning

(Sheet 4 of 5)

Table 4-1 (Concluded)

Method	Basic Measurement	Application	Advantages	Limitations
		Borehole (Continued)		
Temperature	Temperature	Measures temperature of fluids and borehole sidewalls. Detects zones of inflow or fluid loss	Rapid, economical, and generally accurate	None of importance
Fluid resistivity	Fluid electrical resistance	Water-quality determinations and auxiliary log for rock resistivity	Economical tool	Borehole fluid must be same as ground water
Tracers	Direction of fluid flow	Determines direction of fluid flow	Economical	Environmental considerations often preclude use of radioactive tracers
Flowmeter	Fluid velocity and quantity	Determines velocity of subsurface fluid flow and, in most cases, quantity of flow	--	--
Sidewall sampling	--	--	--	--
Fluid sampling	--	--	--	--
Borehole dipmeter	--	--	--	--
Borehole surveying	Azimuth and declination of borehole drift	Determines the amount and direction of borehole deviation from the vertical normal	A reasonably reliable technique. Method must be used during the conduct of crosshole surveys to determine distance between seismic source and receivers	Errors are cumulative, so care must be taken at each measurement point to achieve precise data
Downhole flow meter	Flow across the borehole	Determines the rate and direction of ground water flow	A reliable, cost-effective method to determine lateral foundation leakage under concrete structures	Assumes flow not influenced by emplacement of borehole

Note: Blanks indicate no data.

(Sheet 5 of 5)

Table 4-2
Numerical Rating of Geophysical Methods to Provide Specific Engineering Parameters[1] Engineering Application

Geophysical Method	Depth to Rock	P-Wave Velocity	S-Wave Velocity	Shear Modulus	Young's Modulus	Poisson's Ratio	Lithology	Material Boundaries Stratigraphy	Dip of Strata	Density	In Situ State of Stress	Temperature	Permeability	Percent Saturation	Ground water Table	Ground water Quality	Ground water Aquifers	Flow Rate and/or Direction	Borehole Diameter	Obstructions	Rippability	Fault Detection	Cavity Detection	Cavity Delineation	Location of Ore Bodies	Borehole Azimuth and Inclination
Surface																										
Refraction (seismic)	4	4	4	4	4	4	1	3	4	2	1	0	0	2	2	0	2	0	0	2	4	3	2	2	3	0
Reflection (seismic)	4	0	0	0	0	0	1	4	4	0	0	0	0	0	2	0	1	0	0	2	0	4	3	3	3	0
Rayleigh wave dispersion	1	0	2	2	0	0	1	3	0	2	1	0	0	0	0	0	0	0	0	1	0	0	0	1	2	0
Vibratory (seismic)	2	0	4	4	4	0	1	3	0	2	1	0	0	0	0	0	0	0	0	2	2	1	2	2	3	0
Reflection profiling (seismic-acoustic)	4	0	0	0	0	0	1	4	4	0	0	0	0	0	0	0	0	0	0	3	0	4	3	3	4	0
Electrical potential[2]	0	0	0	0	0	0	0	1	0	0	0	0	1	1	2	3	3	3	0	0	0	3	3	3	4	0
Electrical resistivity	3	0	0	0	0	0	1	3	2	0	0	0	2	1	4	0	4	2	0	3	2	0	4	4	4	0
Acoustic (resonance)[2]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	4	0	0
Radar[2,3]	3	0	0	0	0	0	1	3	2	0	0	0	2	3	3	0	0	2	0	3	0	3	3	3	3	0
Electromagnetic[2]	4	0	0	0	0	0	3	4	1	0	0	0	1	2	3	1	2	0	0	0	0	3	0	0	4	0
Gravity	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	4	0	1	3	3	3	0
Magnetic[2,3]	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	4	0
Borehole																										
Uphole/downhole (seismic)	4	4	4	4	4	4	1	4	0	2	1	0	0	2	2	0	2	0	0	1	2	3	0	2	2	0
Crosshole (seismic)	4	4	4	4	4	4	1	4	2	2	1	0	0	2	2	0	2	0	0	3	2	3	3	2	3	0

(Continued)

[1] Numerical rating refers to applicability of method in terms of current use and future potential:
- 0 = Not considered applicable
- 1 = Limited
- 2 = Used or could be used, but not best approach
- 3 = Excellent potential but not fully developed
- 4 = Generally considered as excellent approach; state of art well developed
- A = In conjunction with other electrical and nuclear logs

[2] Methods not included in EM 1110-1-1802.

[3] Airborne or inhole survey capability not considered.

Table 4-2 (Concluded)

Geophysical Method	Depth to Rock	P-Wave Velocity	S-Wave Velocity	Shear Modulus	Young's Modulus	Poisson's Ratio	Lithology	Material Boundaries Stratigraphy	Dip of Strata	Density	In Situ State of Stress	Temperature	Permeability	Percent Saturation	Ground water Table	Ground water Quality	Ground water Aquifers	Flow Rate and/or Direction	Borehole Diameter	Obstructions	Rippability	Fault Detection	Cavity Detection	Cavity Delineation	Location of Ore Bodies	Borehole Azimuth and Inclination
Borehole (Continued)																										
Crosshole acoustic[2]	4	4	4	4	4	0	1	3	4	0	0	0	1	0	3	0	0	0	0	1	3	3	3	3	0	0
Crosshole resistivity[2]	3	0	0	0	0	0	1	3	1	0	0	0	1	0	3	0	3	0	0	1	0	2	3	3	0	0
Borehole spontaneous potential	2	0	0	0	0	0	4	4	4	2	0	0	0	0	4	2	4	0	0	1	0	2	2	1	3	0
Single-point resistivity	2	0	0	0	0	0	4	4	1	0	0	0	0	1	4	2	4	0	0	1	0	1	1	1	2	0
Long and short normal resistivity	2	0	0	0	0	0	4	4	1	1	0	0	0	4	3	0	2	0	0	0	0	1	1	2	4	0
Lateral resistivity	2	0	0	0	0	0	3	4	1	1	0	0	0	4	3	0	2	0	0	0	0	1	1	2	4	0
Induction-resistivity[2]	2	0	0	0	0	0	4	4	1	1	0	0	0	4	3	0	2	0	0	0	0	1	1	2	4	0
Borehole imagery acoustic	4	0	0	0	0	0	2	3	1	0	1	0	2	0	2	0	0	0	0	1	0	2	2	3	0	0
Interval (3-D) velocity	2	4	2	2	2	2	2	3	1	2	1	0	0	1	1	0	0	0	0	1	0	3	2	2	2	0
Natural gamma radiation	2	0	0	0	0	0	4	4	1	2	0	0	3A	1A	3A	2	2A	1	0	0	0	3A	1	1	4	0
Gamma-gamma density	3A	0	0	0	0	0	4	4	1	3A	0	0	2A	3A	2A	0	0	0	0	0	3	3A	2	1	4	0
Neutron porosity	2A	0	0	0	0	0	4	4	1	3A	0	0	2	3A	3A	0	0	0	0	0	0	3A	2	1	4	0
Neutron activation[2]	2A	0	0	0	0	0	3	1	1	0	0	0	2A	2	3A	0	0	2	0	1	0	1	0	0	4	0
Borehole gravity[2]	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2	4	0	0
Mechanical caliper	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
Acoustic caliper	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0
Temperature	0	0	0	0	0	0	0	0	0	0	1	4	1	0	2	4	4	2	0	0	0	0	1	2	1	0
Fluid resistivity	0	0	0	0	0	0	0	1	0	1	0	0	1	4	4	4	4	0	0	0	0	0	3	1	1	0
Tracers[2]	0	0	0	0	0	0	1	0	0	0	0	0	1	0	2	0	4	4	0	1	0	0	0	3	0	0
Flowmeter[2]	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	0	4	4	0	2	0	0	0	2	0	0
Sidewall sampling[2]	4	0	0	0	0	0	4	4	1	4	2	0	4	4	2	0	0	0	0	2	2	2	1	0	4	0
Fluid sampling[2]	0	0	0	0	0	0	0	0	0	0	0	4	1	0	4	4	4	2	0	0	0	0	0	0	0	0
Borehole dipmeter[2]	0	0	0	0	0	0	2	1	4	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	2
Borehole surveying	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4