Genesis-Lithology-Qualifier System of Engineering Geology Mapping Symbols: Applications to Terrain Analysis For Transportation Systems

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The genesis-lithology-qualifier (GLQ) system of engineering geology mapping symbols provides a convenient and widely applicable means of documenting geologic and soils information in descriptive terms that have direct engineering significance. The purpose of this paper is to broaden the awareness in the engineering community of the existence of this relatively new system, which appears to provide an excellent basis for standardization. Unconsolidated surficial materials are documented by a series of capital and lower-case letters that represent material genesis and lithology. Qualifying information, thickness, and modifying information may be added if understanding of engineering significance will be enhanced. Bedrock materials are documented by conventional geologic shorthand. Stratigraphic sequence can be shown by simply stacking symbols. The GLQ system may be applied to terrain analysis for transportation systems in the areas of (a) planning exploratory programs, (b) predicting foundation conditions, (c) predicting engineering problems, and (d) evaluating construction materials. A conventional geologic map and an engineering geologic (GLQ) map of the same part of the Draper Quadrangle, Utah, are presented to permit engineers and geologists to assess the utility of the GLQ system for their own applications.

The genesis-lithology-qualifier (GLQ) system of engineering geology mapping symbols provides a convenient and widely applicable means for documenting geologic and soils information in a manner readily usable by engineers responsible for the design of transportation systems and other facilities. This relatively new system uses descriptive combinations of capital and lower-case letters to represent geologic materials.

Engineering geology maps traditionally have been produced in two ways. First, conventional time-rock symbols are used in the usual geologic manner (e.g., Tfu for Tertiary-aged Fort Union Formation or Qal for Quaternary-aged alluvium), and a tabulation is provided of selected engineering characteristics. Second, special symbols, which consist of Roman or Arabic numerals, letters, and combinations of numerals and letters, are used to portray the distribution of geologic materials in terms of engineering character. Examples of engineering geology mapping symbols are contained in publications by Varnes (1), the United Nations Educational, Scientific, and Cultural Organization (UNESCO) (2), and Nichols and Campbell (3).

A major deficiency with these two traditional methods is that constant reference to an explanation is needed to understand the engineering significance of the symbol. A symbol such as IIb3 has no significance without reference to its explanation. Furthermore, a different symbol would be assigned to identical material in another region.

The GLQ system consists of symbols that have engineering significance. In addition, the same material in different regions will be represented by the same symbol. It is very desirable to have a system of engineering geology mapping symbols that is standardized; the GLQ system appears to provide an excellent basis for standardization. In most engineering applications, the geologic age of materials is either not important or so important that conventional time-rock mapping is insufficient. Age is not included in the GLQ system; hence, GLQ symbols would not be appropriate for fault evaluation projects.

One notable system of engineering geology mapping was developed by Gardner and described in terms of regional planning by Gardner and Johnson (4). Gardner's system and the GLQ system are very similar in many respects. The most significant difference is that Gardner's system has no term for genesis of surficial materials.

The purpose of this paper is to broaden the awareness in the engineering community of the existence of this relatively new system of descriptive engineering geology mapping symbols. This purpose is accomplished in two ways. First, the elements of the GLQ system are described, and second, applications of the GLQ system to terrain analysis for transportation systems are outlined.

GLQ SYSTEM

The elements of the GLQ system were first described by the originator, Galster, in 1975 (5) and subsequently published in 1977 (6). The name genesis-lithology-qualifier system and the GLQ acronym were proposed in 1980 by Keaton (7) to provide a convenient and descriptive identification of the system.

The GLQ system consists of a set of symbols that are easy to memorize and meaningful at a glance without constant reference to the explanation on a map. The majority of symbols pertains to unconsolidated or surficial materials; bedrock materials are designated by conventional geologic shorthand for rock type.

Surficial Materials

The GLQ name is derived from the principal elements of the symbol for surficial materials. Typical symbols for surficial materials consist of a single capital letter, which identifies the genesis or origin of the material, followed by one or more lower-case letters, which represent the lithology or texture of the material constituents.

Commonly, additional qualifying information that pertains to the topographic expression (geomorphology) of the materials is desirable. Such information may be designated by one or more lower-case letters in parentheses. In some cases, thickness and modifying symbols may be added if they are applicable.

The general formula for symbols that represent surficial materials can be stated as follows:

$$eAb(c)(d) \tag{1}$$

where

- A = genetic symbol; usually a single capital letter;
- b = lithologic symbol; one or more lower-case letters;
- (c) = qualifier symbol, if desirable; one or more lower-case letters in parentheses;
- (d) = thickness, if applicable; Arabic number with feet or meter symbol in parentheses; and
- e = modifier symbol, if applicable; one or more lower-case letters.

All symbols for surficial materials must have a genetic symbol and a lithologic symbol. Qualifier, thickness, and modifier symbols may be included if they enhance understanding of engineering significance.

Genetic Symbols

The genetic symbol is the initial symbol because it identifies the process by which the material arrived at its present location. Frequently, a knowledge of material genesis provides insight into engineering properties and material behavior. As Galster (6) states, there is a fundamental engineering and geologic difference between a clayey gravel of residual origin and one deposited as glacial till. In many cases, the process of formation is still active and must be accommodated in the design of engineering works.

Virtually all surficial materials may be classified by one of 10 genetic symbols; these 10 symbols are follows: A = alluvial, C = colluvial, E = eolian, F = fill (man-made), G = glacial, L = lacustrine, M = marine, R = residual, S = slide, and V = volcanic. In some instances, materials of two origins may be interlayered or interbedded, such as alluvial and colluvial deposits or glacial and lacustrine deposits. In these cases, interbedded materials can be designated by the two genetic symbols separated by a slash: A/C or G/L.

Occasionally, some uncertainty of material genesis may exist. Uncertainty of genesis can be designated by the two genetic symbols separated by a hyphen: A-C, G-L, or R-C. Generally, material genesis is sufficiently clear so that only a single symbol is required.

The most significant difference between Gardner's system (4) and the GLQ system is in the genesis of unconsolidated materials. Gardner's symbol for bouldery sand, silt, and clay is SCb, regardless of its origin. The GLQ symbol would have the textural components identified as smcb, which would mean silty and clayey sand (smc) with boulders (b). The GLQ symbol would also identify the origin of the material because the process of deposition influences the engineering behavior. For example, bouldery sand, silt, and clay of glacial (G) origin would have different character than the same materials formed by residual (R) processes: Gsmcb versus Rsmcb.

Lithologic Symbols

The most commonly used lithologic symbols pertain to material texture and are adapted from the Unified Soil Classification System. Additional terms are needed for textural sizes larger than gravel and for materials such as peat and trash. Lithologic symbols consist of the following 12 terms: c = clay, m = silt, s = sand, g = gravel, k = cobbles, b = boulders, r = rock rubble, e = erratic blocks, p = peat, o = organic material, and d = diatomaceous material. The most abundant or significant lithologic constituent symbol should appear adjacent to the genetic symbol. For example, Asm signifies alluvial silty sand.

Interbedded lithologies can be designated by the two symbols separated by a slash: cm/ms signifies interbedded silty clay and sandy silt. Commonly, a number of grain sizes are present in a single deposit. Listing each grain size creates a lengthy symbol, which can be abbreviated with the use of a hyphen: m-b signifies that all textural constituents from silt to boulders are present. Some deposits consist of a principal constituent in a matrix of other textures: rm-g signifies rock rubble in a matrix composed of silt, sand, and gravel.

Qualifier Symbols

Qualifier symbols may be used if noteworthy qualities are present. For example, an alluvial deposit that consists of silt, sand, and gravel will require different design measures if it is a flood plain than if it is an alluvial fan. The GLQ symbol for the first condition is Am-g(fp); the symbol for the second condition is Am-g(f).

Qualifier symbols are generally unique for each genetic classification. The qualifiers proposed below consist of 39 symbols; no two symbols consist of the same combination of letters.

1. Alluvial deposits: (f) = fan morphology, (te) = terrace, (s) = stream deposits, (fp) = present flood plain, (p) = pediment deposits, and (df) = debris flow.
2. Colluvial deposits: (sw) = slope wash, (ra) = rock avalanche, (ta) = talus, and (cr) = creep deposits.
3. Eolian deposits: (d) = dune morphology and (l) = loess.
4. Fill deposits: (u) = uncompacted and (e) = engineered.
5. Glacial deposits: (t) = till, (es) = esker, (ic) = ice contact, (m) = moraine, (k) = kame, and (o) = outwash.
6. Lacustrine and/or marine deposits: (b) = beach, (et) = estuary, (sp) = swamp, (de) = delta, (ma) = marsh, and (ti) = tide lands.
7. Residual deposits: (sa) = saprolite and (wp) = weathering profile.
8. Slide deposits: (ro) = rotational, (ls) = lateral spread, (fa) = fall, (fl) = flow, (tr) = translational, (sl) = slump, and (to) = topple.
9. Volcanic deposits: (a) = ash, (cl) = clinker, (pu) = pumice, and (ci) = cinders.

Thickness

The thickness and stratigraphic sequence of materials can be shown by simply placing the thickness value at the end of the symbol and stacking symbols. For example, if it is known that a certain location has 10 ft or 3 m of eolian silty sand over basalt, the symbols would be written as follows:

$$\frac{\mathrm{Esm(10')}}{\mathrm{BA}} \text{ or } \frac{\mathrm{Esm(3m)}}{\mathrm{BA}}.$$

Modifier Symbols

Occasionally, an extremely important characteristic should be noted in a symbol. Three modifier symbols are proposed for surficial materials: c = cemented, e = expansive, and h = hydrocompactible. As indicated in Equation 1, these symbols precede the genetic symbol. Cemented alluvial sandy and silty gravel would have the symbol cAgsm, expansive residual silty clay would be eRcm, and hydrocompactible alluvial sandy and clayey silt would be hAmsc.

Bedrock Materials

Typical symbols for bedrock materials consist of two capital letters, which represent rock type in conventional geologic shorthand. In some cases, thickness and modifying symbols may be added if they are applicable. The general formula for symbols that represent bedrock materials can be stated as follows:

$$\mathrm{cAA(b)} \qquad (2)$$

where

AA = conventional geologic shorthand for bedrock type; usually one set of two capital letters;
(b) = thickness, if applicable; Arabic number with feet or meter symbol in parentheses; and
c = modifier symbol, if applicable; one or more lower-case letters.

All symbols for bedrock materials must have, at a minimum, the two-capital-letter notation for rock type. Thickness and modifier symbols may be added if they enhance understanding.

Rock Symbols

The GLQ symbols for rock materials consist of conventional two-letter abbreviations of rock type. The symbols for sedimentary, igneous, and metamorphic rock types that are given below are modified only slightly from Galster (6).

1. Sedimentary rock types: SS = sandstone, ST = siltstone, CG = conglomerate, CH = chert, DT = diatomite, SH = shale, CS = claystone, DO = dolomite, CK = chalk, and LS = limestone.
2. Igneous rock types: GR = granite (granitic), GA = gabbro, FE = felsite, AN = andesite, VO = volcanic, BA = basalt, SY = syenite, RH = rhyolite, IG = igneous, TU = tuff, and DI = diorite.
3. Metamorphic rock types: QT = quartzite, SC = schist, GN = gneiss, SL = slate, AR = argillite, GS = greenstone, MA = marble, SE = serpentine, PH = phyllite, ME = metamprophic, and HO = hornfels.

Galster (6) also suggested symbols for man-made rock equivalents: CC for portland cement concrete, AC for asphalt concrete, and PA for undifferentiated pavement.

Sedimentary rocks are commonly interbedded to some degree. Interbedded rocks can be designated by the two symbols separated by a slash: SS/SH signifies interbedded sandstone and shale. If the interbeds are sufficiently thick, they should be mapped as separate units.

Occasionally, a rock will require a dual classification similar to some soils. In the Unified Soil Classification System, ML-SM is used to signify that the soil is sandy silt to silty sand. In the GLQ system, SS-ST denotes silty sandstone to sandy siltstone.

Thickness and Modifier Symbols

Thickness and stratigraphic sequence of bedrock materials can be shown in the manner described for surficial materials. Occasionally, an extremely important charactertistic should be noted in a symbol. The modifier symbol "e" for expansive may be used for rock materials as well as soils. Additional characteristics that may be important in denoting rock materials are degree of weathering and degree of fracturing. These symbols are as follows: xw = extremely weathered, hw = highly weathered, mw = moderately weathered, sw = slightly weathered, uw = unweathered, xf = extremely fractured, hf = highly fractured, mf = moderately fractured, sf = slightly fractured, and uf = unfractured. In addition, the use of k for karstic as a modifier for limestone bedrock may be informative in some locations.

Greater use of the GLQ system will likely generate the need for additional symbols, particularly modifier symbols. It is likely that additional symbols will have regional application only.

Explanations and Miscellaneous Symbols

No matter how clear and descriptive a system of symbols is, each map should have an explanation of symbols to be complete. Explanations on GLQ maps can be presented in two ways. If only a few symbols are used (less than about 10), each symbol may be shown and described in detail. Alternatively, if many symbols are required on a single map, then the elements of the GLQ system may be outlined in a manner similar to that presented above. Only those specific symbols used on the map should be included in the explanation. A few representative examples should be included to clearly identify the use of numbers for thickness values and the concept of stacking symbols to portray stratigraphic sequence.

Many conventional geologic symbols are necessary in engineering geology evaluations. These symbols include strikes and dips, contacts and faults, landslides, test pits and borings, and springs and seeps. These symbols are represented on GLQ maps in the same fashion as on conventional geologic maps.

Formation name and age of rock materials can be included in explanatory descriptions of GLQ symbols. In addition, texts that accompany GLQ maps should contain at least a brief discussion of local geology in time-rock terms. The value of the GLQ system is that symbols on a map have direct engineering significance, which reduces the need for reference to an explanation. It must be emphasized that the GLQ system is intended for special-purpose engineering geology mapping. No map can retain readability and contain sufficient information to qualify as a general-purpose engineering geology map.

The GLQ system and the Unified Soil Classification System have only two common combinations of letters. These two are SC, which means schist in the GLQ system and clayey sand in the Unified Soil Classification System, and CH, which means chert and high plasticity clay, respectively. Confusion is not likely to result from this duplication of symbols.

APPLICATIONS TO TERRAIN ANALYSIS FOR TRANSPORTATION SYSTEMS

Engineering geology applications to terrain analysis for transportation systems have been discussed by Bean (8), Krynine and Judd (9, pp. 501-543), Hofmann and Fleckenstein (10), McCauley (11), and Thornburn (12). The engineering geologist can provide assistance in the planning, design, construction, and maintenance phases of highway engineering. Principal opportunities for terrain analysis will occur in the planning and design phases. Early recognition of geologic constraints will permit them to be accommodated in the planning and design of transportation systems; this will tend to minimize emergencies caused by geologic conditions that occur during the construction and maintenance phases.

Route selection appears to be done primarily on the basis of nongeologic considerations. Maximum grades, minimum radius curves, number of bridge structures, and existing land use factors frequently outweigh geologic factors in route alignment decisions. Detailed knowledge of engineering geology conditions along a given right-of-way permits transportation engineers to make more realistic estimates of construction costs. Economic evaluation of alternatives can be more realistic also.

As Thornburn (12) discusses, the engineering geologist can make significant contributions to transportation projects in the areas of (a) planning exploratory programs, (b) predicting foundation conditions for structures, (c) predicting engineering problems, and (d) evaluating construction materials. Some applications of the GLQ system in these areas are presented in the remaining sections of this paper.

Thornburn (12) also states that the engineering geologist can contribute significantly in evaluating slope stability. The GLQ system is not particularly useful in quantitative assessments; however, it may be used conveniently in conjunction with slope stability evaluations.

Exploratory Programs

Knowledge of the areal geology along a given right-of-way can aid greatly in making an exploration program efficient. Because GLQ maps present geologic data in terms of engineering significance, they form a very good basis for minimizing the cost of an exploratory program by differentiating units that can be grouped for preliminary design purposes.

The GLQ system is well suited for documenting veneers of surficial materials over rock. Conventional geologic mapping would portray an area as exposed bedrock even if up to several feet of surficial deposits were present. Most engineers have learned from experience that surficial deposits exist to some extent virtually everywhere. The GLQ system provides a way for the engineer to have some knowledge of the character and thickness of such materials at an early stage in a project. Such knowledge should be of value in planning exploratory programs.

GLQ maps can be constructed to provide a basis for exploratory programs in two ways. They can be produced in the office by relatively straightforward interpretation of conventional geologic mapping. Alternatively, GLQ maps can be produced in the field by direct observation. My experience with the GLQ system is that engineering geologic maps can be produced in the field as quickly as conventional geologic maps. Some laboratory analyses may be used to confirm field interpretations of textural constituents of map units.

Foundation Conditions

Specific foundation conditions can be evaluated adequately only with subsurface exploration and subsequent laboratory testing. For design purposes, engineering geology interpretations must be verified by well-placed (and sufficiently deep) borings. The

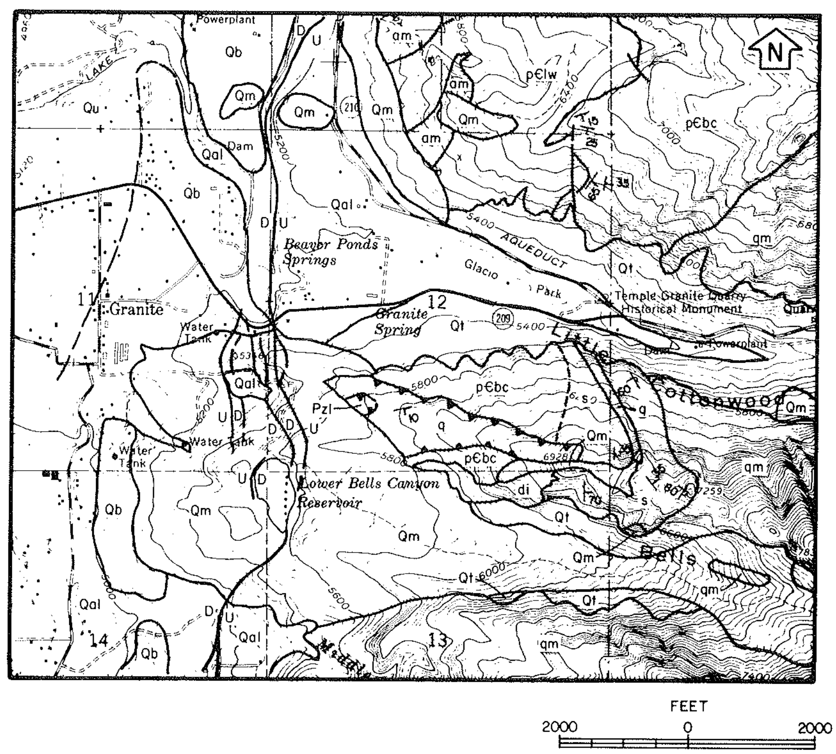


Figure 1. Conventional geologic map of part of Draper Quadrangle, Utah.

EXPLANATION

QUATERNARY DEPOSITS

Qal — Stream gravel and valley fill.
Qt — Talus and high-angle alluvial cones.
Qb — Depsits of Lake Bonneville.
Qu — Undifferentiated alluvium.
Qm — Glacial moraine.

CRETACEOUS OR TERTIARY PLUTONIC ROCKS

qm — Quartz monzonite of Little Cottonwood stock.
di — Diorite in Bells Canyon.

PALEOZOIC

Pzl — Gray crinoidal limestone.

PRECAMBRIAN

pЄbc — Big Cottonwood Formation quartzite interbedded with shales and siltstones.
q — Quartzite unit.
s — Shale or siltstone unit.
pЄlw — Little Willow Formation quartz schist interbedded with biotite schist.
am — Lenses of chlorite amphibole schist.

SYMBOLS

Contact, dashed where approximate, dotted where concealed.
U/D Fault, dashed where approximate, dotted where concealed, U, up thrown side.
Thrust fault, sawteeth on upper plate.
35 Strike and Dip of beds, 60 overturned beds.

GLQ system provides a simple means of recording surficial and near-surface engineering geology data in a way that may be able to increase the degree of confidence in projecting anticipated foundation conditions between boring locations.

Engineering Problems

The GLQ system is intended to permit documentation of geologic data with descriptive symbols that have engineering significance. As such, many engineering problems may be anticipated early in a project. Engineering problems usually mean unanticipated geologic conditions.

Examples presented in earlier sections of this paper pertained to documenting conditions of expansive, cemented, and hydrocompactible surficial materials. Each of these three conditions can be accommodated by conventional design measures and/or anticipating additional costs related to construction.

Dynamic processes, such as debris flows and flooding, can be documented by the GLQ system. Am-b(df) in an area where alluvial fans are present would indicate that debris flow activity could be a potential problem to a highway. Amcs(fp) would indicate that the surface is susceptible to flooding.

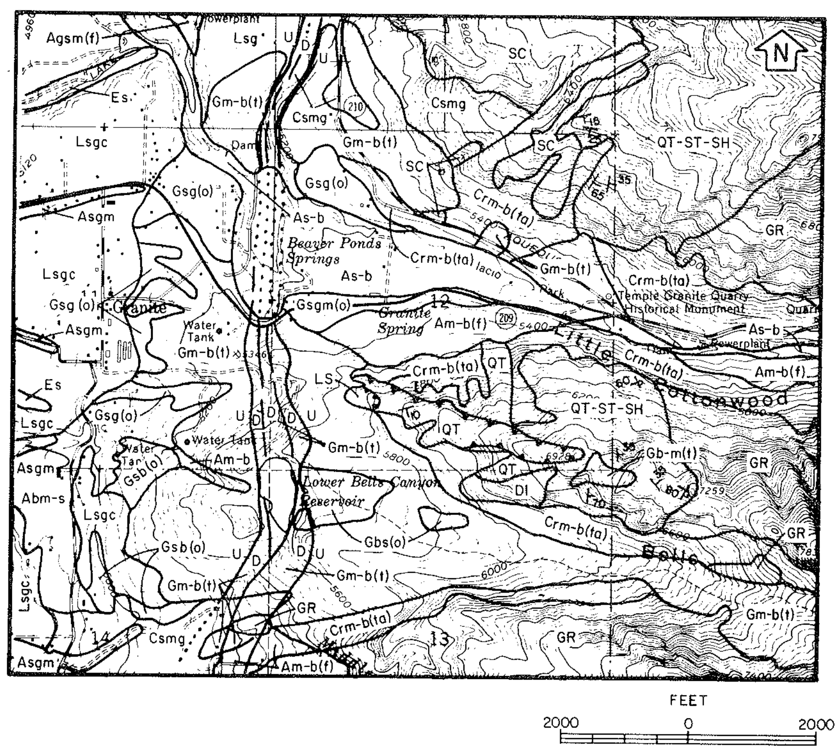
Peat and organic sediments commonly require special design considerations or expensive construction measures. The GLQ system includes specific lithologic symbols for these materials. Landslide deposits frequently require stabilization measures to reduce the risk of damage to transportation systems. The GLQ system includes a specific genetic symbol for slide materials.

Construction Materials

The location of adequate amounts of suitable construction materials is one of the most important tasks related to the planning and construction of transportation systems. The GLQ system is particularly well suited for documentation of information pertinent to assessment of potential sources of construction materials.

Construction materials of prime importance are

Figure 2. Engineering geologic map of part of Draper Quadrangle, Utah.



EXPLANATION

UNCONSOLIDATED MATERIALS

GENERAL SYMBOL : Ab(c)

A — Genetic symbol.
b — Lithologic symbol.
(c) — Qualifier symbol.

GENETIC SYMBOLS

A — Alluvial. G — Glacial.
C — Colluvial. L — Lacustrine.
E — Eolian.

LITHOLOGIC SYMBOLS

b — Boulders. m — Silt.
c — Clay. r — Rock rubble.
g — Gravel. s — Sand.

QUALIFIER SYMBOLS

(f) — Fan. (t) — Till.
(o) — Outwash. (ta) — Talus.

EXAMPLES

Agsm(f) - Alluvial material composed of gravel, sand, and silt forming an alluvial fan.
Crm-b(ta) - Colluvial deposits composed of rock rubble, in a matrix of silt to boulders forming talus.
Gm-b(t) - Glacial till composed of silt to boulders.

BEDROCK MATERIALS

DI — Diorite. LS — Limestone.
GR — Granitic rock (chiefly quartz monzonite).
QT — Quartzite. SC — Schist.
SH — Shale. QT-ST-SH-Interbedded.
ST — Siltstone.

SYMBOLS

Contact
U/D Fault, dashed where approximate, dotted where concealed, U on up thrown side.
Thrust fault in bedrock, sawteeth on upper plate.
35 Strike and Dip of beds, 60 overturned beds.

granular fill material and aggregate suitable for use in concrete. A significant difference can be seen easily in the following two symbols: As-k(GR) and As-k(SS). The genesis and lithology (texture) of the materials represented by these two symbols are the same, yet most engineers would avoid using sandstone fragments as aggregate in concrete. Either material would be suitable for use as granular borrow material. A similar deposit, which contains predominantly chert fragments [As-k(ČH)], would be unsuitable for use in concrete.

The quality of construction materials at potential sites would have to be evaluated by a thorough laboratory testing program. The GLQ system provides the initial information to assist in the identification of sites where suitable material might be present in adequate amounts.

CONCLUSION

The GLQ system of engineering geology mapping symbols provides a convenient and widely applicable means of documenting geologic information in terms that have direct engineering significance. For comparison purposes, a portion of the Draper Quadrangle, Utah, is presented in Figures 1 and 2. Conventional geologic symbols shown in Figure 1 are taken from a publication by Crittenden (13). The same area is shown in Figure 2, but the GLQ symbols are used in lieu of conventional geologic symbols. The GLQ symbols are derived from publications by Richmond (14) and Morrison (15) in addition to that by Crittenden (13).

The example area contains several types of bedrock materials and several types of surficial materials. The surficial materials are all Quaternary in age and consist of materials deposited in alluvial, colluvial, eolian, glacial, and lacustrine environments. Engineers and geologists who study the two examples of the same area will be able to assess the utility of the GLQ system for their own applications.

The GLQ system appears to provide an excellent basis for standardization of engineering geology mapping symbols. The system has great utility because (a) it is simple and easy to memorize, (b) it is a means of documenting basic geologic data in terms of direct engineering significance, and (c) it is universally applicable.

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