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Digitization of a Geologic Map for the Quebec-Maine-Gulf of Maine Global Geoscience Transect

By BRUCE E. WRIGHT and DAVID B. STEWART

U.S. GEOLOGICAL SURVEY CIRCULAR 1041

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Digitization of a Geologic Map for the Quebec-Maine-Gulf of Maine Global Geoscience Transect

By Bruce E. Wright *and* David B. Stewart

Abstract

The Bedrock Geologic Map of Maine was digitized and combined with digital geologic data for Quebec and the Gulf of Maine for the Quebec-Maine-Gulf of Maine Geologic Transect Project. This map is being combined with digital geophysical data to produce three-dimensional depictions of the subsurface geology and to produce cross sections of the Earth's crust. It is an essential component of a transect that stretches from the craton near Quebec City, Quebec, to the Atlantic Ocean Basin south of Georges Bank. The transect is part of the Global Geosciences Transect Project of the International Lithosphere Program.

The Digital Line Graph format is used for storage of the digitized data. A coding scheme similar to that used for base category planimetric data was developed to assign numeric codes to the digitized geologic data. These codes were used to assign attributes to polygon and line features to describe rock type, age, name, tectonic setting of original deposition, mineralogy, and composition of igneous plutonic rocks, as well as faults and other linear features.

The digital geologic data can be readily edited, rescaled, and reprojected. The attribute codes allow generalization and selective retrieval of the geologic features. The codes allow assignment of map colors based on age, lithology, or other attribute. The Digital Line Graph format is a general transfer format that is supported by many software vendors and is easily transferred between systems.

INTRODUCTION

Geologic maps display a wide range of information that is tied to a geographic/cartographic base. Maps may contain topographic, hydrographic, and political, as well as other geological or geophysical, information. In conventional maps this information is inextricably linked unless the separates used to prepare the map can be obtained. However, extraction of one or more kinds of geologic data from a map can allow these data to be combined with geologic data from other sources or with other kinds of data. Editing to incorporate corrections to existing data and to make additions of new data is also possible. Changes in map scales or projections are frequently desirable for either regional compilations or detailed studies of specific locations. It may be necessary to combine and simplify geologic formations, or separate them into members of different rank, for the purposes of the new maps. Map colors may need to be changed to meet new conventions for geologic ages or to emphasize different geologic aspects of the region. The digitization of geologic maps, combined with automated analysis and display, permits rapid and low cost achievement of all of these purposes, as well as others.

Geologic and geophysical maps and cross sections are essential components of geologic transects such as the Centennial Continent-Ocean Transects of the Decade of North American Geology (Speed and others, 1982; Speed, 1982) and of the Global Geosciences Transect Project (CC-7) of the International Lithosphere Program (Monger, 1986). The U.S. Geological Survey is digitizing all of the geological and geophysical data sets required to prepare the Quebec-Maine-Gulf of Maine transect (fig. 1), which has been accepted into the Global Geosciences Transect Project. The several kinds of maps and cross sections derived from these maps that are required for each transect use different combinations of the various geological and geophysical data sets (fig. 2). These products can most readily be produced if available in digital form.

METHODS

This paper describes some of the problems addressed, and methods used to resolve them, in preparing the digital geologic map and in assigning attributes to describe geologic data such as rock type, age, name, and tectonic setting of original deposition, as well as faults and other linear features. The digital data were structured into a common exchange format that permits rapid transfer between networked computers. This exchange format will be used for public distribution.

Digitizing Methods

A number of digitizing methods were available for use in this project. The U.S. Geological Survey 7.5-minute topographic map series is currently being digitized by using both manual and automated digitizing techniques. The recently completed digitization of 1:100,000-scale base maps, prepared in cooperation with the Bureau of the

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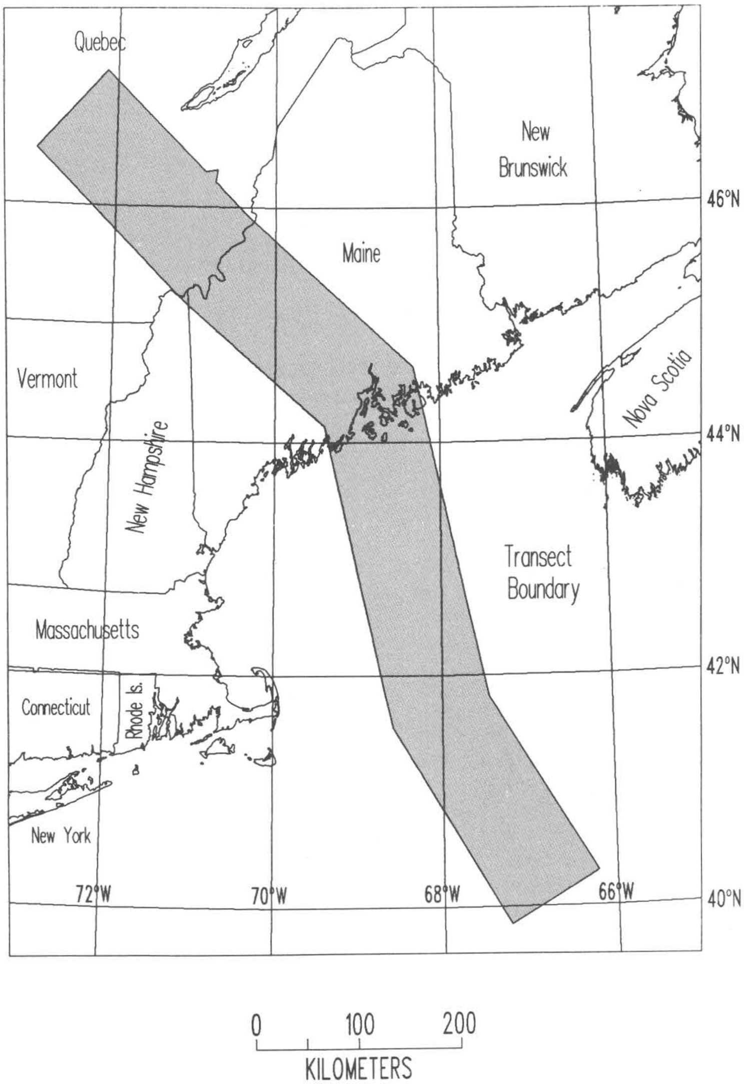

Figure 1. Location of the Quebec-Maine-Gulf of Maine Transect.

Census, relied almost exclusively on scanning technology (Callahan, 1983).

The Bedrock Geologic Map of Maine (Osberg and others, 1985) contains detailed geologic information at a scale of 1:500,000. For example, a large number of steeply dipping stratified layers have widths of less than 1 mm on the map (approximately 0.5 km on the surface) and are linear in shape. The State map contains approximately 2,400 areas and 9,000 lines, and within the study area there are over 900 areas and over 3,000 lines that are either area boundaries or faults. The most efficient method of digitizing was to scan digitize the stable-base separates by using existing scanning facilities and then to attach attribute codes manually after the raw data were edited and converted to line data.

The primary reason for digitizing the Maine map was to convert the bedrock geology information from analog to digital form for subsequent computer analysis in combination with seismic and geophysical data. The digital data will also be used to produce the printed geologic map that is one of several maps that are required in the final publication (fig. 2). The Maine Geological Survey is interested in the digitized data for the State, even though only the area within the transect boundary contains attribute codes. Other U.S. Geological Survey studies in Maine are currently underway or are being planned that will use the digital geologic data. Because of these reasons, the bedrock geology base for the entire State was digitized. Attribute codes were assigned to only that portion of the map that lies within the transect study area,

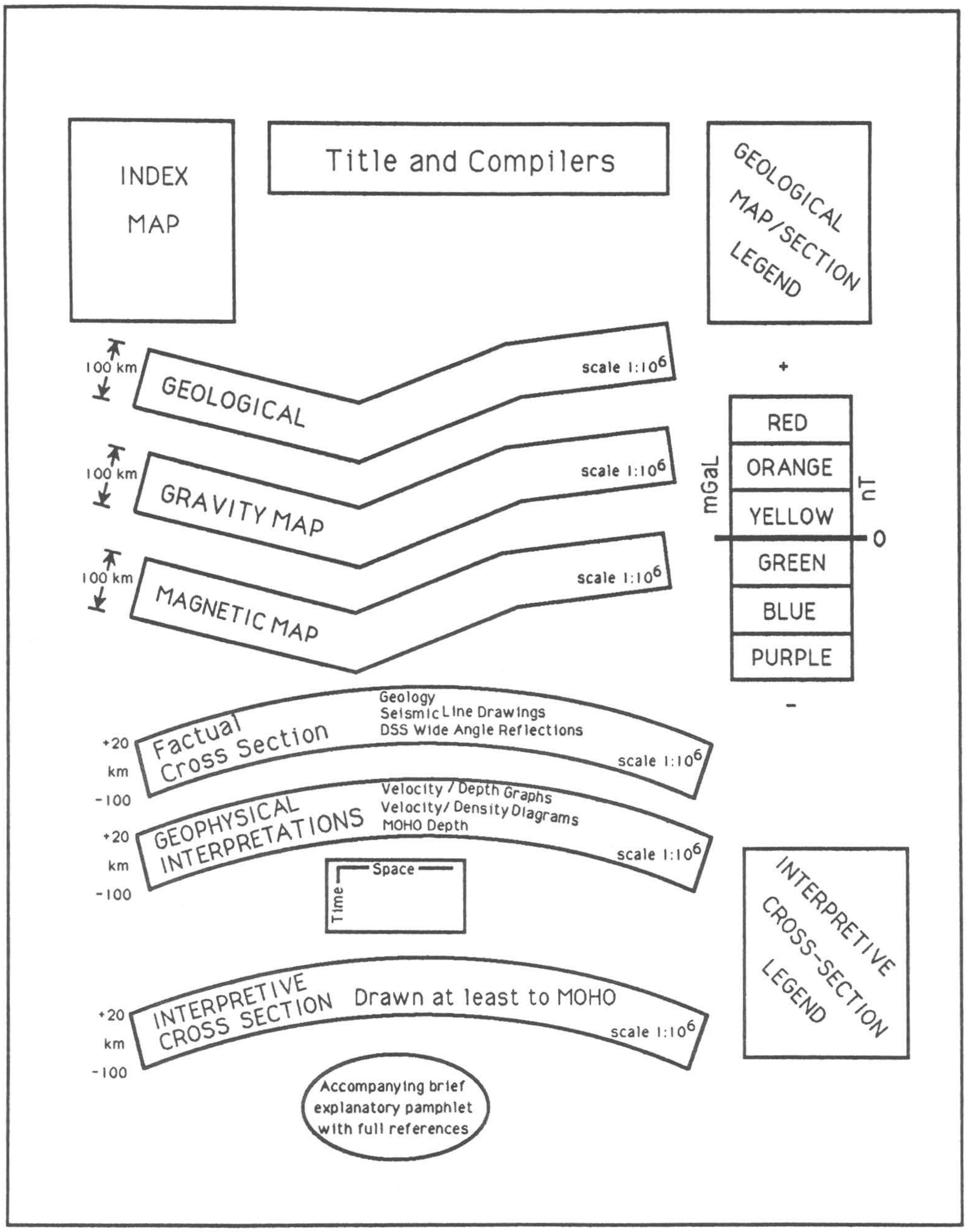

Figure 2. Layout of global geoscience transect publication.

with the rest of the map to be coded at a later time possibly by other users.

As with most geologic maps, a number of ancillary layers of data are also depicted on the original map graphic to add geographic reference. Hydrographic features are present in the form of lakes and rivers. The minimum size for inclusion was approximately 0.25 km^2 or 1 by 1 mm at the map scale of 1:500,000. Political boundaries shown are county boundaries. Railroads are the only transportation feature shown. City and town names are present, as are the names of the larger lakes and rivers (fig. 3).

Three layers of information from the original map were captured during the digitization process: bedrock geology, major hydrographic features (major lakes and double line streams), and county boundaries. The source material used for scanning consisted of blue lines on translucent stable-base material. Copies of the original printing

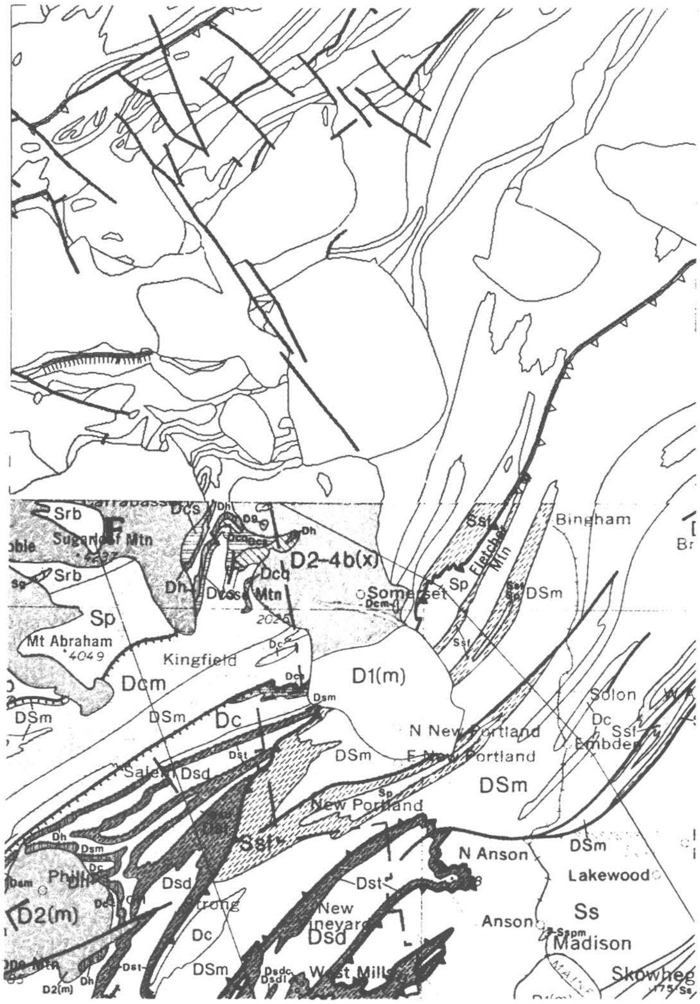

Figure 3. Portion of the Bedrock Geologic Map of Maine (Osberg and others, 1985) showing the original printed map below a plot of the digitized data.

separates were purchased from the publisher with the prior permission of the Geological Survey of Maine. The materials consisted of one separate for each of the layers. Because the State boundary was needed to close areas along the border of Maine and Canada, the county boundary file was also scanned. The shoreline was also necessary for inclusion in the final graphics for reference purposes and was digitized from the hydrography separate.

The system used for scanning was the Scitex Response 250 scanning and editing system. The procedure entails placement of the stable-base source material onto a drum that rotates beneath the scanning head. The width of the scanning increment can be varied from 4 to 48 pixels per mm (101 to 1,219 lines per inch). Digital Line Graph (DLG) data at 1:24,000 and 1:100,000 scales are digitized by using 30 pixels per mm (762 lines per inch). Thematic data are generally digitized by using 17 or 18 pixels per mm (431 to 457 lines per inch). The geologic map was scanned by using 17 pixels per mm. The resulting digital raster file contains either on or off pixels that indicate the presence or absence of a line or other map feature. The line features in the raster file are skeletonized to a width of one pixel and converted to a vector format. The vector file is then rerasterized and compared with the original scanned file to check the vectorization process. The file is then edited to correct alignment errors, to close breaks in the linework, and to split lines along which the attribute values change (Lee, 1985).

Attaching Geologic Attributes

The file is then topologically structured, and final editing and attribute tagging are conducted on the vector files. For the bedrock geologic map, two menus were created for attribute tagging: one for stratified rock types, which included sedimentary and volcanic extrusive rocks and their metamorphic equivalents, and one for intrusive igneous rocks. Two attribute tagging passes were made on the area features shown on the map. During the first pass, the printed paper copy of the map was used for the tagging of the stratified rock units. The menu item used for tagging stratified rocks was the upper/lower case formation letter code, which directly relates to the minor code for the formation name. Each formation, member, or lentil represented by the formation name code consists of a unique set of major and minor attribute codes. In this way the operator can identify the letter code for each feature on the map and point to the same code on the menu (fig. 4), and then the appropriate major and minor codes are assigned to the features.

STATIFIED ROCK FEATURE CODES

Ch	DSus	Dst	OZce	Oqv	Ss
Cha	DSuss	Dt	OZceq	Ous	Ssa
Chmg	DSuv	Dtm	OZcev	Ouss	Ssal
Chpx	DSvh	Dtmc	OZcg	Oussp	Ssc
Chq	DZar	Dto	OZcl	Ouvm	Ssf
Chqw	Db	Dtokc	OZcq	Ouvs	Ssl
Chr	Dc	Dtokg	OZcr	Sc	Sspm
CJ	Dcm	Dtokm	OZe	SOf	Stf
CJf	Dcq	Durg	OZef	SOfc	Suc
CJg	Dcs	Dus	OZev	SOup	Sul
CJk	Dh	Ocb	OZpg	SOur	Sur
CJp	Dhb	OCd	OZpgl	SOus	Suvm
CJq	Dhm	OCdp	OZpgs	SOv	Sw
Cuvm	Dhmd	OCdq	Obh	Sak	Swl
DCus	Dlm	OCme	Obhg	Sg	Zcb
DOb	Dpk	OCmec	Ok	Shm	Zl
DOup	Ds	OCmel	Okmg	Sp	Zil
DSbh	Dsc	OCp	Okms	Sr	Znh
DSca	Dsd	OCpg	Olm	Sra	Zop
DScd	Dsdc	OCpmig	Oq	Srac	Zrk
DSm	Dsdl	OCuv	Oqg	Srb	pCc
DStf	Dsm	OZc	Oqs	Src	590.46
590.10	590.21	590.22	590.41	590.42	590.45

Figure 4. Digitizing menu used for attaching stratified rock codes to the digital line data.

The igneous bodies were coded by using a separate overlay. First, the areas identifying the igneous rock units were sketched onto a clear plastic overlay, and the polygons were numbered to correspond to the minor code for the rock name. The alphanumeric intrusive code on the map is not a unique representation for the names of bodies of igneous rocks. For instance, the code D1 (Devonian granite) applies to many plutons without naming any of them uniquely. The minor code for the igneous rock name, a unique identifier, was used for the digitizing menu look-up item.

The attribute codes for linear features were also attached during this stage. Only one major/minor code pair was assigned to each line type, and this was keyed in manually by the operator instead of using a menu. Some linear features require that the direction of the line be known. Listric and thrust fault lines contain symbology on only one side of the line, depicting the direction of fault movement (fig. 5). To properly attach a code to such lines, it was necessary to know the direction of the line before a left or right code could be attached. The data production staff developed a routine that labeled and depicted graphically the beginning and ending nodes of each line. The direction of the line is determined along the line from its beginning. This procedure allows the operator to attach a code that indicates to which side of the line (left or right) the symbol belongs.

EXPLANATION FOR MAP AND CROSS SECTIONS

Stratigraphic or intrusive contact; queried where location is uncertain.

Fault, interpreted as a high angle normal or reverse fault; queried where location is uncertain. Inferred motion on cross sections is based largely on separation of contacts and is indicated by arrows or T (Towards) and A (Away).

Fault, interpreted as a thrust fault; barbs on upper plate. Inferred motion on cross sections is based largely on separation of contacts and is indicated by arrows.

Fault, interpreted as a listric fault; hachures on upper plate. Inferred motion on cross sections is based largely on separation of contacts and is indicated by arrows.

Figure 5. Line symbols used for the Bedrock Geologic Map of Maine (Osberg and others, 1985).

Color-coded plots of the tagged data were used for the quality control process, followed by successive iterations of the coding and quality control process. The final step in the process involved conversion of the tagged data sets to DLG formatted files using the PROSYS software developed by the U.S. Geological Survey for production of base category digital data. The data were structured, and logical checks were performed on the attribute codes and the topology. If inconsistencies in the data were found at this stage, additional quality control cycles were required. Once through this final phase, the data were written to magnetic tape in the DLG format.

Digital Line Graph Format

The storage format that was chosen for use with the transect geologic map was the DLG format developed by the U.S. Geological Survey. The format consists of ASCII data in a fixed length format. Several lines of header information precede the topologically structured graphic data. The header data are followed by sections containing nodes (intersections of two or more arcs), areas (regions surrounded by connecting arcs), and lines (arcs with beginning and ending nodes). Each of the three types of data can be accompanied by descriptive attributes. For planimetric data, the U.S. Geological Survey has developed specific attribute codes, which are contained in a series of publications describing the various scales of DLG data (U.S. Geological Survey, 1986, 1987, 1989). Major codes for base category data are:

020 Hypsography
050 Hydrography
070 Surface cover
080 Nonvegetative surface features
090 Boundaries
150 Survey control and markers
170 Transportation--Roads and trails
180 Transportation--Railroads
190 Transportation systems--Pipelines, transmission lines, miscellaneous transportation features
200 Other significant manmade structures
300 U.S. Public Land Survey System

No standard DLG coding scheme for geologic data has been adopted. In the past, unique codes were assigned to geologic units primarily for cartographic purposes (for example, assigning color codes for use in a final printed map) (McCulloch and others, 1987). A standard attribute scheme would alleviate the need for unique codes and would create a much more usable digital data file, which would provide the capability for producing a color coded geologic map. Development of a standardized coding scheme for geologic features was identified as one of the long-term goals of the U.S. Geological Survey Thematic Mapping Program.

DEVELOPMENT OF A GEOLOGIC ATTRIBUTE CODING SCHEME

The various kinds of geologic data on geologic maps may be represented by color and pattern symbols, by combinations of upper and lower case letters that are mnemonics for stratified formations, or by numeric or alphanumeric combinations in the case of intrusive rocks. Whatever symbols are used, the principal categories of geologic information presented include the geologic system or age, lithology or rock composition, name of the rock, tectonic setting in which the rock originated, and various types of data observed at specific points or along linear features, such as contacts or faults. In some cases, rock units may be subdivided into several lesser ranks or categories, and additional details about characteristic minerals or textures may be included. A useful code for geologic attributes should be expandable and flexible and must also be capable of categorizing rocks where properties may vary, such as in composition or in time of origin.

Capturing each of these physical properties with a numeric code was vital for the digitization of the geologic maps. A DLG code was used that is similar to the codes for planimetric features developed by the U.S. Geological Survey (U.S. Geological Survey, 1986, 1987, 1989). This code consists of a three-digit major code and a four-digit minor code. Each rock unit on the geologic map is assigned several coded attributes that include age, rock type, and name as a minimum. Many additional attributes can also be assigned by using this method.

Major Code

The three-digit major code defines the general category of each attribute. The first digit is 5, to denote that geologic units are to be described. The choice of this digit is compatible with the DLG code for planimetric features.

The second digit specifies what kind of geologic data are to be described. The third digit is used to add additional capacity to the same specific category of data denoted by the second digit. As used in the planimetric DLG, 9 as the third digit designates that two (or more) attributes refer to the same feature. The major codes assigned or contemplated to date are shown in table 1.

Minor Code

The four-digit minor code enumerates specific elements of the individual features designated by the major code. The minor codes deal with the range, variations, or uncertainties within the same category that are so common for geologic units. Rocks may range in age from one geological series to another, such as from Silurian to Devonian, and vary in composition, protolith, or other characteristics. Uncertainty can also exist about one property or another, such as age, which may be approximate, unknown, or queried. These problems are addressed by conventions for the first digit of the minor code. Except in codes that describe names, which are unique and not coincident with another property, the first digit of the minor code is zero if that code is a unique property within the category. The first digit of the minor code also can be used as a modifier

Table 1. Digital Line Graph major codes assigned to geologic features

Code	Feature
510	Geologic system (geologic age)
520	Protoliths of stratified sedimentary and extrusive igneous rocks
521	Protoliths identified on Bedrock Geologic Map of Maine[1]
524	Inferred tectonic setting of deposition
525	Basement and mantle rocks
530	Names of stratified bedrocks (group, formation, member, lentil)
540,550	Not assigned. Could be used for surficial deposits and names
560	Intrusive rock composition
561	Additional characteristics of igneous rocks (phenocysts, textures)
562	Names of igneous rock bodies
570	Not assigned
580	Geologic point symbols (strike and dip of beds, foliation, cleavage, lineation, and so on)
590	Linear geologic features (contacts, faults, folds, and so on)

[1] Osberg and others (1985).

to describe ranges, bounds, or uncertainties **within the same category.** If the first digit is 1, a bound of a property, such as geologic age or composition, is implied. By convention, the younger geologic age or most siliceous composition is given first. If the first digit is 2, both (or all) of the codes within this category apply. If the first digit is 3, the property is one value among the range of properties that are specified by the codes within this category. If the first digit is 4, the property is queried, approximate, or unknown (see fig. 6).

The second and third digits of the minor codes have principal value in enumerating items within the category specified by the major code. The fourth digit has principal value in delineating subvariants of a unit enumerated by the second or third digit.

In digitizing the geologic map of Maine, each attribute was captured as it was expressed on that map. Some of the results, specifically for protoliths of stratified rocks, have turned out to be not as general or fundamental as was shown to be desirable when contiguous maps were digitized. The specific list of protoliths given on the Bedrock Geologic Map of Maine (Osberg and others, 1985) was encoded by numbering the published sequence as a look-up table from 1 to 28 on the second and third digits of the minor code. This sequence was inadequate to encode all of the kinds of stratified rocks encountered along the transect in Quebec, such as olistostromes or several different combinations of sedimentary and extrusive igneous rock compositions. This matter was easily remedied by assigning a new third digit to the major code, which made the specific data for Maine a subset within the more general category.

Geologic Age

This category is denoted by major code 510 (table 1). The first digit of the minor code is zero unless a modifying digit is required to denote range, bounds, or other qualifications. If these are required, the convention for digits 1 to 4 is applied as discussed above. Coding for digits 2 to 4 of the minor code is taken from the numeric code devised for geologic names by Swanson and others (1981), as shown in table 2 (see fig. 6).

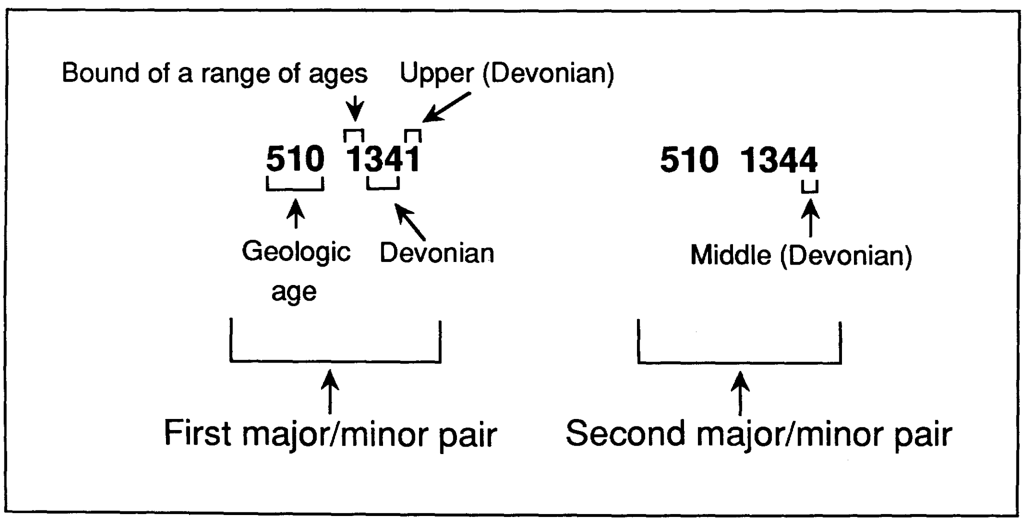

Figure 6. Major and minor codes used to describe a geologic unit that ranges in age from Upper Devonian to Middle Devonian. The code 510 is used to designate geologic age, and the first minor code indicates Middle Devonian (341). The 1 in the first digit indicates that the first minor code is a bound of a range of ages (Upper Devonian to Middle Devonian).

Table 2. DLG codes for geologic age of rocks, digits 2 to 4 of minor code

Era	System	Series	DLG minor code
Cenozoic			100
upper			101
middle			104
lower			107
	Quaternary		110
		Holocene	111
		Pleistocene	112
	Tertiary		120
		Pliocene	121
		Miocene	122
		Oligocene	123
		Eocene	124
		Paleocene	125
Mesozoic			200
upper			201
middle			204
lower			207
	Cretaceous		210
		Upper	211
		Lower	217
	Jurassic		220
		Upper	221
		Middle	224
		Lower	227
	Triassic		230
		Upper	231
		Middle	234
		Lower	237
Paleozoic			300
upper			301
middle			304
lower			307
	Permian		310
		Upper	311
		Lower	317
	Pennsylvanian[1]		320
		Upper	321
		Middle	324
		Lower	327
	Missippian[1]		330
		Upper	331
		Lower	337
	Devonian		340
		Upper	341
		Middle	344
		Lower	347
	Silurian		350
		Upper	351
		Middle	354
		Lower	357
	Ordovician		360
		Upper	361
		Middle	364
		Lower	367
	Cambrian		370
		Upper	371
		Middle	374
		Lower	377
Precambrian			400
Z (570-800 m.y.)			410
Y (800-1,600 m.y.)			420
X (1,600-2,500 m.y.)			430
W (>2,500 m.y.)			440

[1] Carboniferous would be 2320, 2330.

Lithology of Stratified Rocks

The lithology or protolith of stratified sedimentary and extrusive igneous rocks is denoted by major code 520. The first digit of the minor code is zero unless the rock consists of a mixture of sizes or compositions of constituents. The second and third digits of the minor code are taken from the genetic series of protoliths given in table 3 for either sedimentary or extrusive volcanic rocks. The fourth digit for stratified sedimentary rocks may be taken from the list of common modifiers also given in table 3 (fig. 7). While this list may not include all possible kinds of lithologies, the remaining unassigned numbers will surely suffice. The description of formations that are composed of several different lithologies is readily achieved by use of the convention for the first digit of the

Table 3. Generic genetic DLG codes for protoliths of stratified rocks

Major code	Minor code	Rock type
		Stratified sedimentary rocks
520	0010	Conglomerate
520	0020	Sandstone, psammite
520	0030	Shale, pelite
520	0040	Limestone
520	0050	Dolostone
520	0060	Evaporite
520	0070	Gypsum or anhydrite
520	0080	Salt
520	0090	Potassic salts
520	0100	Iron formation
520	0110	Chert
520	0120	Melange
520	0130	Olistostrome
520	0140	Diamictite
		Stratified extrusive rocks
520	0500	Rhyolite
520	0530	Dacite
520	0550	Quartz andesite
520	0560	Quartz basalt
520	0570	Trachyte
520	0580	Andesite
520	0590	Basalt
520	0600	Phonolite
520	0610	Leucite-nepheline basalt
520	0620	Leucite-olivine basalt
520	0660	Komatiite
520	0700	Felsic volcanic rock
520	0750	Intermediate volcanic rock
520	0800	Mafic volcanic rock
520	0810	Ophiolite
520	0900	Undetermined volcanic rocks

Table 3. Generic genetic DLG codes for protoliths of stratifed rocks--Continued

Major code	Minor code	Rock type
	Modifiers for stratified rocks	
520	0XX1	Lithic
520	0XX2	Sandy
520	0XX3	Silty
520	0XX4	Calcareous
520	0XX5	Sulfidic
520	0XX6	Carbonaceous
520	0XX7	Manganiferous
520	0XX8	Feldspathic
520	0XX9	Nonmarine

minor code described above. Thus a formation consisting of limestone and dolostone would be described by two minor codes, each with 2 as the first digit. The minor codes for stratified extrusive rocks are arbitrarily arranged. Volcanic rocks with a range of compositions are described with 3 in the first digit, and the limits of the compositional range are given by the second and third digits.

Inferred Tectonic Setting for Deposition

A critical interpretive cross section required for each Global Geoscience Transect displays the inferred tectonic setting in which the rocks were deposited. This category was assigned major code 524. The minor codes are shown in table 4.

Table 4*A*. DLG codes for inferred tectonic setting

Major code	Minor code	Tectonic settings
524	0000	Continental platform or shelf (GGT1a, light blue)
524	0100	Continental slope or rise (GGT1b, dark blue)
524	0200	Magmatic arc (GGT2, red or pink)
524	0300	Rift/transform related deposits within continental crust (GGT3, yellow)
524	0400	Oceanic (GGT4, purple)
524	0500	Orogenic and related sedimentary rocks, clastic wedges of foreland and successor basins (GGT5, green)
524	0600	Anorogenic magmatic rocks (GGT6, orange)
524	0700	Cratonic basement (GGT7, brown)
524	0800	Indeterminate (GGT8, gray)
524	0900	Continent-continent collision (new, brick red)

Note: Different ages within same tectonic setting shown by usual geologic age symbols. Darker shades of same color used to show younger rocks.

Table 4*B*. Modifiers for inferred tectonic setting DLG codes

Major code	Minor code	Tectonic setting modifiers
524	0X00	Melange
524	0X11	Molasse
524	0X1-	
524	0X20	Paralic clastic (nonmarine)
524	0X25	Nonmarine clastic
524	0X2-	
524	0X30	Marine fan sequence and turbidite
524	0X31	Flysch
524	0X32	Marine clastic
524	0X33	Basin floor and trench turbidite
524	0X40	Marine clastic black shale, and sandstone
524	0X41	Pelagic sediment
524	0X4-	
524	0X50	Calcareous shale, carbonate, shale, and sandstone
524	0X51	Calcareous shale and siltstone
524	0X5-	
524	0X60	Carbonate
524	0X61	Carbonate bank
524	0X62	Deep marine carbonate
524	0X6-	
524	0X70	Evaporite
524	0X71	Evaporite and synrift sediments
524	0X80	Volcanic rocks of magmatic arcs
524	0X84	Volcanic rocks of rifts and transforms in continental crust
524	0X88	Volcanic rocks of ocean ridge or seafloor
524	0X89	Anorogenic pluton
524	0X90	Undifferentiated stratified rocks

Basement and Mantle Rocks

Major code 525 is used for rocks from the deeper parts of the Earth's crust or even the mantle (table 5). Usually basement rocks have experienced such a long and complex geologic history that their original nature cannot be clearly determined. These rocks may have been more or less homogenized because of extreme deformation or they may have been partly remelted with the addition or loss of substantial portions of the material initially present. Some of these rocks were recrystallized under extreme pressure conditions and were brought to the surface in such a way that the mineral assemblages characteristic of extreme pressures were preserved. Rocks that formed in the Earth's mantle beneath the crust were brought to the surface in rare instances. Such rocks could also be classified within major code 525. The minor codes shown in table 5 are used to denote broad ranges of bulk chemical composition of basement and mantle rocks.

Names of Stratified Bedrocks or Basement Rocks

The major codes 530 to 538 are used for stratified sedimentary or extrusive igneous bedrocks. The names of

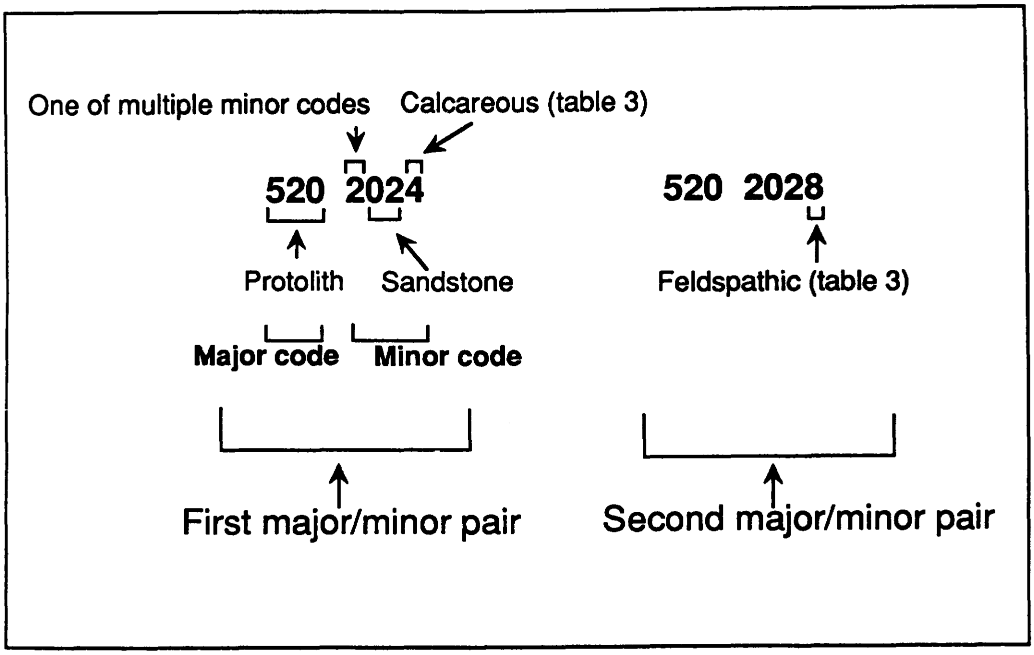

Figure 7. Major and minor codes used to describe the lithology of a calcareous feldspathic sandstone geologic unit. The code 520 is used to designate lithology, and the first minor code indicates that it is one of multiple minor codes (2000) of calcareous (0004) sandstone (0020). The second minor code adds the modifier feldspathic (0008).

Table 5. DLG codes for basement and mantle rocks

Major code	Minor code	Rock composition
525	0011	Granitic bulk composition
525	0090	Mafic granulite
525	0091	Dioritic granulite
525	0092	Gabbroic granulite
525	0093	Anorthositic granulite
525	0094	Amphibolite or hornblendite
525	0095	Eclogite

mapped stratified rocks are unique so the first digit of the minor code is not used as a modifier. The first and second digits of the minor code are used to enumerate fundamental rock-stratigraphic units on the geologic map. Depending on the stratigraphy of the region and the map scale, the fundamental unit may be a formation or the higher ranked unit, a group. Units of lesser rank, such as formation, member, or lentil, are described by using the third or fourth digit of the minor code. Some of the stratigraphic names for Maine are shown in table 6 as an example. The major/minor code for each stratigraphic unit, the letter code, and its full name are listed. The minor code is used to relate colors to areas on the map on the basis of age and rock type.

The coding scheme developed above was satisfactory to describe hundreds of stratigraphic units. Up to 99

Table 6. DLG codes for some stratified rocks in Maine [From Osberg and others (1985)]

Major code	Minor code	Geologic mnemonic	Name of stratified rock
531	0100	Dto	Tomhegan Formation
531	0110	Dtok	Kineo rhyolite member
531	0111	Dtokc	Tuffs and volcaniclastic rocks
531	0112	Dtokg	Garnet rhyolite
531	0113	Dtokm	Massive felsite
530	6500	Sr	Rangeley Formation
530	6540	Sra	"A" member
530	6541	Srac	Lithic sandstone
530	6530	Srb	"B" member
530	6520	Src	"C" Member

fundamental units can be described with one major code, along with hundreds of lesser ranked units. Each regional stratigraphic sequence is designated from top to base by an increasing closely grouped sequence of numbers for the fundamental units, such as 0100, 0200, 0400, 0700, and so on. The numbers omitted may be assigned to fundamental units that are facies equivalents in contiguous regions or may be used for later expansion. The regional sequence for the adjacent region is then taken as a sequence of numbers a decade or two from the last regional sequence. The stratified rocks of Maine, New Hampshire, and southeastern Quebec, where there are many fundamental stratigraphic units that differ little in age, were successfully encoded. Some fundamental units were subdivided into as many as 20 units of lesser rank.

Lithology and Names of Surficial Deposits

Surficial rocks are not shown in the Global Geoscience Transects, so no attempt was made to establish major/minor codes for them. The lithology of surficial deposits should be assigned major code 540, and these units should be assigned names under major code 550.

Composition, Mineralogy, Textures, and Names of Igneous Intrusive Rocks

The properties and names of intrusive rocks are denoted within major codes 560 to 568. The major code for the composition of an igneous intrusive rock is 560 (table 7). The minor codes were developed by adapting the scheme used in the Bedrock Geologic Map of Maine (Osberg and others, 1985), which in turn is a modification of the classification proposed by Streckeisen (1973) (fig. 8). The second and third digits of the minor code are used to enumerate the compositional fields on the diagram of Streckeisen (1973), on which modal quartz, alkali feldspar, and plagioclase are recalculated to 100 percent. According to the convention described above, the first digit can be used for modifiers to describe variations and ranges. The fourth digit of the minor code is used to describe variants or alternative petrographic names like gabbro and diorite that depend on the composition of the plagioclase and to accommodate the present inability of the DLG code to accept alphanumeric nomenclature (fig. 9).

The secondary characteristics of igneous rocks are denoted by major code 561. Specific minor codes associated with this category use the second and third digits to designate one characteristic from the list given in table 8, compiled from those listed on several recent maps. Frequently this characteristic identifies abundant phenocrysts or inclusions but may also identify a prominent texture (porphyritic, for example) or indicate other important details, such as brecciation or migmatization. The first digit is used according to the convention described above to indicate that two secondary characteristics apply, and so forth. The fourth digit of the minor code is used for more exact identification of specific minerals within families of rock-forming minerals, such as the amphiboles or micas, or to indicate additional details about inclusions of foreign materials.

Major code 562 is used to designate names of igneous rock bodies or of separately mapped bodies of the same intrusive rock. Modifiers are not used in the first digit, as each named body is unique. Thus 999 igneous bodies could be designated within this major code, and each could have nine subunits or equivalent adjacent bodies. No category has been assigned to major code 570.

Table 7. DLG codes for intrusive rock types

Major code	Minor code	Rock type
560	0010	Alkali feldspar granite (1a)[1]
560	0011	Granite (1b)[1]
560	0020	Granodiorite (2)[1]
560	0030	Tonalite (3a)[1]
560	0031	Trondhjemite (3b)[1]
560	0040	Quartz syenite clan (4)[1]
560	0041	Alkali feldspar quartz syenite (4a)[1]
560	0042	Quartz syenite (4b)[1]
560	0043	Quartz monzonite (4c)[1]
560	0050	Quartz monzodiorite (5)[1]
560	0060	Quartz diorite (6)[1]
560	0070	Syenite clan (7)[1]
560	0071	Alkali feldspar syenite (7a)[1]
560	0072	Syenite (7b)[1]
560	0073	Monzonite (7c)[1]
560	0080	Monzodiorite (8)[1]
560	0090	Gabbro and diorite (9)[1]
560	0091	Diorite (9a)[1]
560	0092	Gabbro (9b)[1]
560	0093	Anorthosite
560	0100	Foid-bearing syenite (10)[1]
560	0110	Foid-bearing monzodiorite
560	0120	Foid-bearing gabbro diorite
560	0160	Ultramafic rock, serpentinite, and soapstone (9c)[1]

[1]Codes used on the Maine Bedrock Geologic Map.

Point Geologic Symbols

Hundreds of symbols are used to describe the different kinds of geologic observations that are made at a single outcrop or point. These observations may be for all the planar or linear features that can be measured, such as the attitude of bedding, schistosity, joints, or lineations. Some features may be present in several generations, sets, or kinds, and many different features can be measured at a point. Each such observation has a strike (or azimuth) and inclination (dip or plunge). Geologic point symbols are not usually displayed on small-scale maps (1:500,000 or smaller), such as our Global Geoscience Transect, and so they will not be used.

However, a set of codes under major code 580, which is included here for completeness, was devised (table 9). The symbols for outcrops, points, or other small features are distinguished from those for long linear geologic features, such as contacts, faults, and the axes of large folds, for which major code 590 is used (table 10).

The suggested list of minor codes for geologic point symbols (table 9) is incomplete but has the capacity for expansion to 99 possible symbols using only the second and third digits. The first digit can be used according to the convention defined earlier, especially using 2 as the first digit to indicate that two or more features are coincident, such as when cleavage is parallel to bedding (580 2010, 580 2020). Point symbols shown with a common

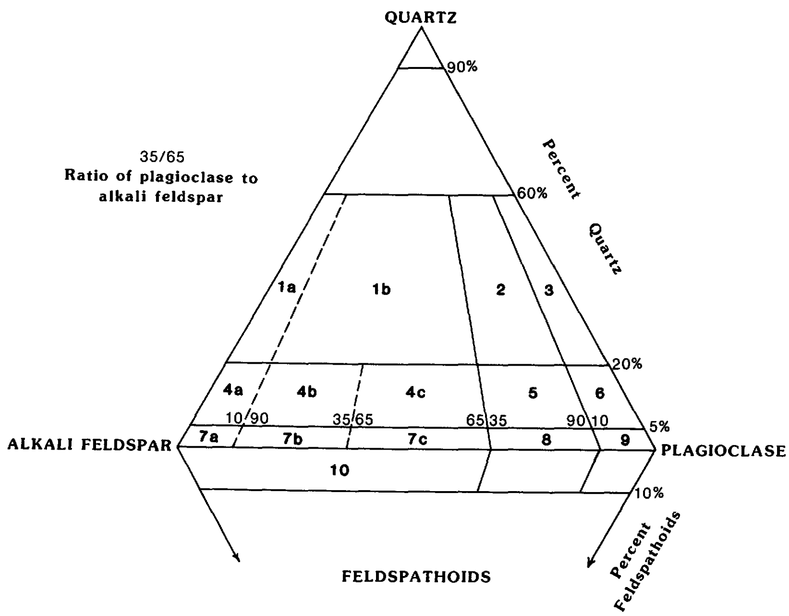

Figure 8. Classification of igneous rock compositions according to Streckeisen (1973).

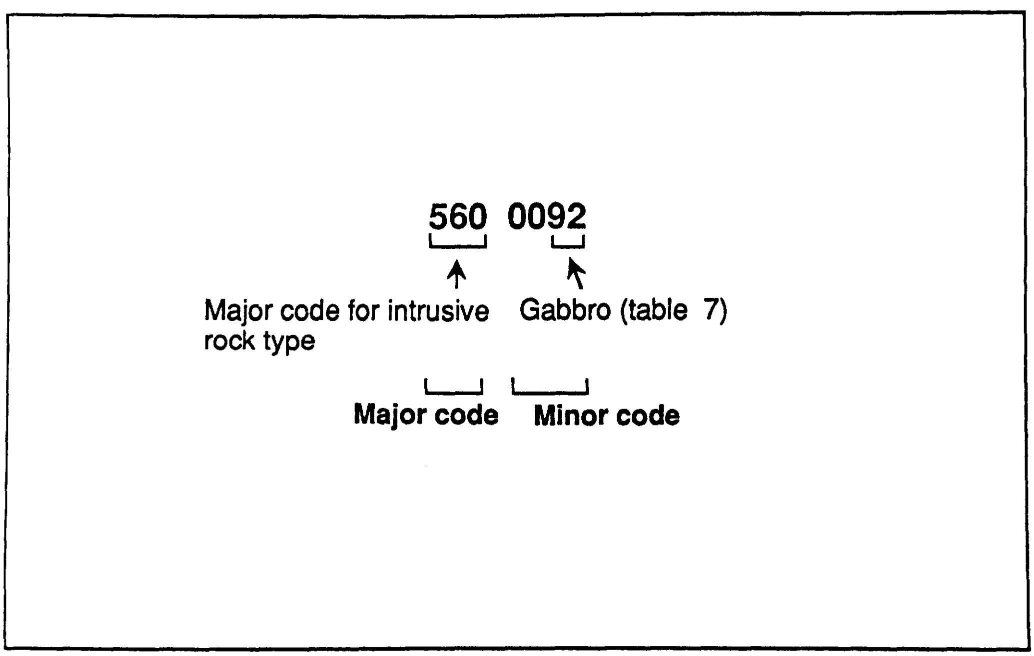

Figure 9. Major and minor codes used to describe intrusive rock characteristics. The code 560 is used to designate intrusive rock type, and the minor code indicates that it is a gabbro (0092).

origin, such as cleavage and lineation measured at the same place, can be conveniently combined by using this convention for the first digit, for example, 580 2020 and 580 2140. The fourth digit could be used for successive generations of the same kind of feature, such as a first cleavage (580 0021) and a second cleavage (580 0022) where a different cartographic symbol could be used for each cleavage. In a similar way, different kinds of cleavage (spaced or fracture, for example) could be identified by different second or third digits, and different generations of each could be described with the fourth digit. Successive generations of minor folds could be numbered with the fourth digit of the minor code, for example, 580 0161, 580 0162, 580 0163. If all of these kinds of folds were observed at a single locality, 2 could be used as the first digit of the minor code.

Table 8. DLG codes for additional characteristics of igneous rock

Major code	Minor code	Rock attribute
561	0010	Contains biotite (b)[1]
561	0020	Contains muscovite (m)
561	0030	Contains amphibole (h)
561	0031	Contains hornblende
561	0032	Contains riebeckite (r)
561	0040	Contains pyroxene (p)
561	0071	Contains fayalite
561	0080	Contains garnet, andalusite, sillimanite, or cordierite (peraluminous)
561	0100	Porphyritic (x)
561	0200	Granophyric (y)
561	0300	Aphanitic or fine-grained (a)
561	0400	Foliated or gneissic
561	0500	Leucocratic (l)
561	0600	Melanocratic
561	0700	Abundant pegmatite >50%
561	0800	Abundant inclusions >50%
561	0801	Abundant xenoliths
561	0802	Abundant metasedimentary inclusion
561	0803	Intrusive breccia
561	0900	Migmatized (z)

[1]Letters in parentheses are mnemonics for rock characteristics.

Table 9. Suggested DLG codes for point geologic symbols

Major code	Minor code	Point features
580	0010	Bedding
580	0020	Cleavage (in slaty rocks)
580	0050	Schistosity (in medium- to high-grade metamorphic rocks)
580	0060	Foliation (planar-oriented minerals in igneous rocks)
580	0090	Layering (in gneisses or layered igneous rocks)
580	0100	Joints
580	0120	Shear or cataclastic surfaces
580	0140	Lineations
580	0160	Axes of minor folds

Table 10. DLG codes for linear geologic symbols

Major code	Minor code	Linear features
590	0010	Contact exactly located or assumed to be
590	0011	Contact approximately located
590	0012	Contact inferred
590	0013	Contact concealed
590	0020	Fault exactly located or assumed to be
590	0021	Fault approximately located
590	0022	Fault inferred
590	0023	Fault concealed
590	0030	Normal fault
590	0037	Normal fault, downthrown on left side of to-from arc
590	0038	Normal fault, downthrown on right side of to-from arc
590	0047	Thrust fault, teeth on upper plate, left side of arc
590	0048	Thrust fault, teeth on upper plate, right side of arc
590	0057	Listric fault, ticks on downthrown side, left side of arc
590	0058	Listric fault, ticks on downthrown side, right side of arc
590	0067	Strike slip fault, left lateral transport
590	0068	Strike slip fault, right lateral transport
590	0070	Reverse fault
590	0100	Axial trace of syncline
590	0110	Axial trace of synform
590	0120	Axial trace of anticline
590	0130	Axial trace of antiform
590	0140	Axial trace of monocline
590	0180	Trace of lineament
590	0200	Metamorphic isograd
590	0210	Zeolite facies
590	0220	Greenschist facies
590	0230	Biotite isograd in pelites
590	0240	Garnet isograd in pelites
590	0250	Staurolite isograd in pelites
590	0260	Sillimanite isograd in pelites
590	0270	Sillimanite-orthoclase isograd in pelites
590	0400	Dike
590	0401	Rhyolite or granite dike
590	0409	Basalt dike
590	0500	Sill
590	0600	Vein

The attribute of a point feature could be shown by using 581 for the major code and a convention like 1xxx for the minor code to denote the azimuth (strike or bearing), in degrees clockwise from north. The dip (or plunge) could be shown by minor code 2xxx, with xxx in degrees and 000 equal to horizontal, 090 equal to vertical, and an overturned planar feature (like bedding) at values between 090 and 179. Another useful convention would be to use 3 in the first digit of the minor code for the average azimuth of crumpled, plicated, and crenulated or otherwise irregular planar features, and 4 in the first digit to indicate average dip or plunge of irregular or variable features. The gamut of symbols used for geologic points like quarries, mines, gravel pits, gas (oil) wells, springs, geysers, and so on, could be placed in major code 582.

Linear Geologic Symbols

Linear geologic symbols are grouped under major code 590 (table 10) and are distinguished and further characterized by digits 2 to 4 of the minor code. The different kinds of linear symbols, faults, folds, dikes, and so on, are separately numbered in digits 2 and 3, and so 99 kinds of linear features, can be readily described by these two digits. Two in the first digit of the minor code indicates coincident linear features, and no other use is made of this digit. The fourth digit of the minor code can be used to specify the certainty with which a linear feature can be located, but this cartographic refinement is falling into disuse. Possibly a superior use of the fourth digit is to indicate successive generations of the same kind of linear features.

The fourth digit of the minor code also could be used to indicate composition of dikes or sills (using the numbers for igneous rock composition in the major code 560, table 7), but it is probably as convenient on a small map to assign a different second or third digit number in the minor code to each kind of dike. These distinctions were not made on the map for this transect.

The symbols used to represent several kinds of faults and various other geologic features have sawteeth, bar-and-ball, or other decorations to indicate the relative directions in which the fault blocks moved. The convention was established to use the first digit of the minor code to indicate which side of the linear symbol carries the symbol. As the coordinates of linear symbols are ordered from beginning node to ending node, the code is assigned accordingly. For symbols on the left side of the linear feature, 7 is used as the fourth digit of the minor code, and for symbols on the right, 8 is used.

The azimuth and the dip of a linear geological feature is described by major code 591. The format for the minor code for azimuth is 1xxx, with the direction in degrees clockwise from north providing the last three digits. The dip is shown by a minor code beginning with 2, and the last three digits represent the value, in degrees from the horizontal position (taken to be 000).

PROGRESS TO DATE

The Maine Bedrock Geologic Map was entered into a vector-based geographic information system and is being modified on the basis of new interpretations of the geology within the transect. The geology in the Quebec and Gulf of Maine portions of the study area have also been digitized, coded with the above attribute codes described in this paper, and merged with the Maine map. The Quebec portion consisted of parts of two 1:250,000-scale maps. The majority of the information was contained on the map by St-Julien and Slivitsky (1987). The published map consisted of four photocomposited 1:100,000 maps in two different Universal Transverse Mercator zones; consequently, the two maps did not join precisely. The map was redrafted by the Geological Survey of Canada onto stable-based material by using the Lambert Conic Conformal projection, and the redrafted map was scanned by using a Scitex scanner, vectorized, and edited on the Scitex. ARC/INFO was used to assign attributes to each of the geologic units. A single code was used for this tagging, and at a later time major/minor attribute codes were assigned on the basis of this value.

Similar problems were encountered in the small portion of the Quebec geology map that extended north of the L'Estrie-Beauce map. Instead of redrafting the geology data, the map was divided into two separate zones and digitized separately. These zones were then projected on the Lambert Conic Conformal projection and joined. A numeric code was assigned to each area feature, and major/minor codes were added.

The offshore portion of the transect map consisted of interpretations of tectonic features based on gravity and magnetic data. The data were converted from geographic coordinates to the Lambert Conic Conformal projection, and each of the major tectonic features was appended. These features were then assigned codes and merged with the onshore geology data.

In the early stages of the project, a small portion of the Maine map was digitized by hand, and attributes were assigned to this subset of the larger map. This procedure brought out many requirements for an adequate geologic attribute code and verified the proposed code prior to assigning it to the large regional data set. Several changes were made to the codes during this development phase.

PROBLEMS ENCOUNTERED

The Maine Bedrock Geology Map at a scale of 21:500,000 is approximately 105 cm long by 70 cm wide. The scanner used for digitizing requires that source materials be smaller than 99 cm by 90 cm. To accommodate the large size, the map was scanned in two parts, which were later digitally merged.

The skeletonization process, in which the raster image of the line data is reduced to a single-cell representation of the lines, introduced a number of errors. At the intersection of two arcs, incorrect depictions of the intersection were produced. Instead of producing intersecting arcs at right angles, the arcs were prematurely snapped, producing what are termed "saddles" (fig. 10).

These saddles were particularly evident at intersections of approximately 45° and 135° to the horizontal. The transect boundary on the original source material transects the State at approximately 135°, and the strike of stratigraphic units is about 45°. This coincidence created a large number of these saddle artifacts where the two transect boundaries intersected the stratigraphic units. By using automated techniques, the artifacts were located and

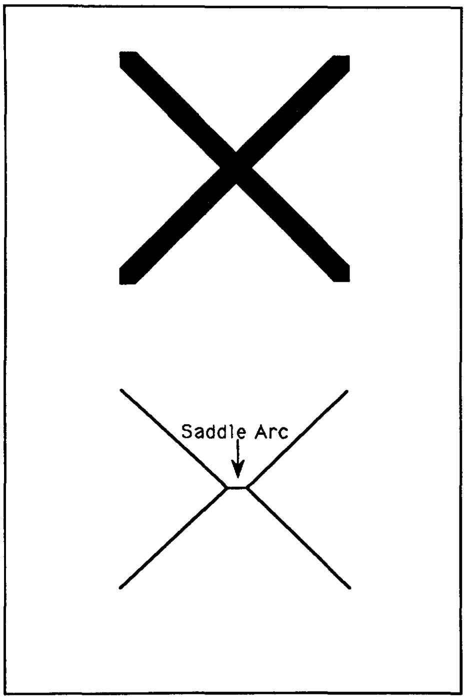

Figure 10. Example of the formation of a spurious saddle arc.

displayed on the interactive editing station, and the operator was given the choice of either changing the arcs in the case of an error or leaving them unchanged if the saddle was a natural occurrence.

The DLG coding scheme has a number of limitations because the codes must be numeric in either three or four digit fields. This limitation precludes the use of more descriptive and self-explanatory text and number strings. As a result, to decipher the codes, a look-up table must accompany the numeric codes either in textual form, as in the DLG Users Guides, or as digital files. The U.S. Geological Survey is currently developing an enhanced DLG format that will provide the capability for including text strings with the digital data.

Another problem with the codes is that a variable number of codes is needed for each feature. Therefore, to use the codes in a relational data base system, they must be sorted and rearranged to place common items in the proper tabular format, or the table must be searched extensively to extract the proper codes.

In the initial scanning stage, a reference grid was created for the control points. These control points (in the Lambert Conic Conformal projection) did not agree with those contained on the original stable base of the Maine Bedrock Geologic Map. To eliminate any future confusion and to produce a more geographically correct digital file, the scanned map was scaled to fit the calculated control points. The result is that the digital file, when plotted at a scale of 1:500,000, will not agree exactly with the original source materials. It is not uncommon that the manually drafted grid of some older maps does not agree with a theoretical calculated grid created by computer techniques. This problem will be reduced as newer, more accurate maps using computer-generated grids replace older maps, but it can be a cause for concern and confusion when first encountered.

The time required to digitize and attach attribute codes was much greater than the time required for manipulations of the data. The coding scheme had to be developed and tested, and new utilities were required to facilitate the attribute tagging phase. In the future, as these techniques become more routine, the amount of time required for the digitizing process should decrease. Nevertheless, the initial capture of the digital data will always be the most time-consuming and labor-intensive process for most projects when compared to the amount of time required to analyze and use the digital data.

CONCLUSIONS

The successful digitizing, coding, and merging of the bedrock geologic map data for the Quebec-Maine-Gulf of Maine Transect has prompted geologists to propose the use of a standard format and coding scheme for geologic features. As more and more digital geologic data are gathered, the need for a common storage format and coding scheme becomes increasingly important for the exchange, merging, and editing of geologic data. DLG coding provides the capability for capturing the original contents of a map graphic. Such a coding scheme is useful for extracting selected kinds of information from the geologic map, for generalization of features, and for assigning different color codes to areas for different purposes, such as displaying age or original tectonic setting. The coding scheme and digitizing techniques developed for this project will continue to be modified by others. Such methods will become nearly universal in the future because of the ease with which the data can be manipulated, once captured.

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