1. INTRODUCTORY MATERIAL

1.1 OBJECTIVE

This document provides a single national standard for the digital cartographic representation of geologic map features. This standard is intended to support the Nation's producers and users of geologic map information by providing line symbols, point symbols, and colors and patterns that can be used to portray the various features on geologic maps. The objective of this standard is to aid in the production of geologic maps and related products, as well as to help provide geologic maps and products that are more consistent in both their appearance and their underlying database content.

A geologic map is a cartographic product that expresses information about the geology of a particular area. The map uses graphical elements such as line symbols, point symbols, and colored or patterned areas to portray complex geological information such as the composition, age, genesis, and extent of an area's geologic materials, as well as the geometry, orientation, and character of the geologic structures that have deformed them.

Geologic maps generally are intended for use by both the geoscience professional and the general public; however, designing and preparing a geologic map that will inform such an audience can be a daunting task because of the complexity of both the mapping concepts and the geologic information. The imperative for clear communication of geologic map information to a diverse audience was outlined early in the history of the U.S. Geological Survey (USGS) by then-Director John Wesley Powell, who stated that "the maps are designed not so much for the specialist as for the people, who justly look to the official geologist for a classification, nomenclature, and system of convention so simple and expressive as to render his work immediately available alike to the theoretic physicist or astronomer, the practical engineer or miner, and the skilled agriculturist or artisan" (Powell, 1888, p. 229).

The consistent, unambiguous expression of geologic map information is even more critical now because such information increasingly is compiled, stored, manipulated, and exchanged in digital files and geospatial databases. In the digital files, the cartographic representation of each feature on a geologic map must have a unique and explicit meaning, and it also must be compatible with the feature's attributes in the geologic map database. To that end, the preparers of this standard reviewed existing formal and informal USGS geologic map symbolization standards and adapted them for implementation with modern digital mapmaking systems and geospatial databases.

This standard attempts to facilitate geologic map communication and comprehension by providing clear and familiar symbology, thereby ensuring that the lines, points, and areas on the map convey the same meaning to all information producers and users. This standard also endeavors to clarify some of the concepts of geologic mapping, as well as to standardize some of the terminology used to describe the various features on a geologic map.

Although this standard is herein formalized, it is not intended to be used inflexibly or in a manner that will unduly restrict a geologist's ability to communicate the observations and interpretations gained from geologic mapping. On the contrary, this standard recognizes that, in certain situations, an existing symbol or its usage might need to be modified to fit a particular geologic situation or setting. Likewise, this standard recognizes that a new symbol or set of symbols may need to be created to more fully express local geologic conditions or to keep pace with evolving geologic mapping concepts and practices. Accordingly, such new or modified symbols, if found to be of wide applicability, will be incorporated into this standard through planned, periodic revisions.

1.2 SCOPE

This standard contains descriptions, examples, cartographic specifications, and notes on usage for a wide variety of symbols that may be used on typical, general-purpose geologic maps and related products such as cross sections. However, the standard also can be used for different kinds of special-purpose or derivative map products and databases that may be focused on a specific geoscience topic (for example, slope stability) or class of features (for example, a fault map). The standard is scale-independent, meaning that the symbols are appropriate for use with geologic mapping compiled or published at any scale. It is designed for use by anyone who either produces or uses geologic map information, whether in analog or digital form.

1.3 APPLICABILITY

This document establishes standards that are applicable to all geologic map information (in other words, geologic maps and databases) published by the Federal Government and its Federally funded contractors and collaborators. Non-Federal agencies and private firms that produce geologic map information also are urged to adopt the standard.

The standard applies to all forms of geologic map publications, whether they are released as (1) hard-copy products, in either offset-print or plot-on-demand format, or (2) digital products, either as files for spatial analysis in Geographic Information Systems (GIS), as Portable Document Format (PDF) files in online publications, or as browse-graphic files for display on the World Wide Web. In particular, the standard applies to all geologic map products archived within the National Geologic Map Database (NGMDB), which is administered by the USGS: geologic map products submitted to and incorporated within the NGMDB will conform to this standard.

1.4 RELATED STANDARDS

The USGS traditionally has established nationally applicable cartographic standards for the production of geologic map information, both explicitly, through various formal and informal standards documents (see Section 2.1 below, entitled "Relation to Previous U.S. Geological Survey Standards"), and implicitly, through the cartographic content of its publications. This standard supersedes any existing USGS formal or informal cartographic standards for geologic maps.

During preparation of this standard, its relation to other standards or standards-development activities was assessed, and no significant conflicts were found. For example, the International Organization for Standardization (ISO) Standard 710, Parts 1–4, describes a general schema for graphical display of a selected set of geologic map symbols. Although similar to some that are included in this standard, they were found to have limited applicability. In addition, similar standards have been developed in other agencies of the Federal Government, including the U.S. Forest Service (in the geology component of their Terra database), the U.S. Army Corps of Engineers (in the geology component of their Spatial Data Standard for Facilities, Infrastructure, and the Environment [SDSFIE]), and the U.S. Bureau of Reclamation (in their Engineering Geology Office Manual). These were found to be somewhat specialized and limited in their coverage of geologic map features. Conversely, this standard provides comprehensive coverage of symbology for a broad range of geologic map features.

1.5 STANDARDS DEVELOPMENT PROCEDURES

This standards document represents only the latest milestone in a long history of geologic map standards development in the United States, which, within the USGS, began prior to 1881. As then-Director John Wesley Powell noted in 1888, in reference to geologic map standards under development at that time within the USGS, "While it is not professed that this [cartographic] system is final, or even unobjectionable, it represents the present state of knowledge and opinion" (Powell, 1888, p. 230). Although the present standards document draws heavily on previously established formal and informal cartographic standards of the USGS, it has undergone substantial revisions that reflect current geologic mapping practices and modern digital mapmaking methods. Accordingly, the standards-development procedures outlined in this section will address only the most recent development history of this standard (for a more complete historical background, see Section 2.1 below, entitled "Relation to Previous U.S. Geological Survey Standards").

This standards document was developed by members of the USGS Geologic Discipline's Western Publications Group and the National Geologic Map Database (NGMDB), with guidance and contributions from members of the Map Symbol Standards Committee (see below; see also, Section 2.3, entitled "Preparers of This Standard"). In addition, this standards document has benefited from the broad, modern-day perspective gained from the many thoughtful responses from reviewers of the Federal Geographic Data Committee's (FGDC) Public Review Draft of the standard (Federal Geographic Data Committee, 2000; see also, U.S. Geological Survey, 2000). The preparers of this standard gratefully acknowledge all current and prior participants and appreciate their invaluable contributions to the development of both this standards document and all preceding works.

In 1995, a proposed cartographic standard for geologic map information was informally released by the USGS as the "Cartographic and Digital Standard for Geologic Map Information" (U.S. Geological Survey, 1995a, 1995b). In 1996, this proposed standard was formally reviewed by geologists and cartographers from the USGS, as well as from the Association of American State Geologists (AASG), which represents the State geological surveys, and from the FGDC Geologic Data Subcommittee, which is composed of representatives from Federal agencies that produce or use geologic map information. That review (Soller, 1996) indicated the need for some revision to the proposed standard prior to its consideration by the FGDC for formal adoption as a Federal standard.

In 1996, plans were outlined to create a revised and updated Federal standard, and an early standards-development group was formed (see Section 2.3 below, entitled "Preparers of This Standard"). A proposal to develop the revised standard was submitted by the FGDC Geologic Data Subcommittee (see http://ngmdb.usgs.gov/fgdc_gds/mapsymbprop.php), and the FGDC accepted that proposal in 1997. Later that year, the standards-development group produced a preliminary version of the draft standard, which was circulated among selected USGS and State geological survey personnel for review. Comments were incorporated and, in 1999, the revised draft standard was submitted (as the "Working Draft") to the FGDC Geologic Data Subcommittee for consideration. Upon review and subsequent approval by the Subcommittee, the Working Draft was submitted to the FGDC Standards Working Group, which, in 2000, approved the document for public review as the "Public Review Draft" (see below), pending adoption of minor changes.

The Public Review Draft of this standard was finalized and then published in April 2000 (Federal Geographic Data Committee, 2000; see also, U.S. Geological Survey, 2000). In May 2000, the public was invited to review the draft standard and to provide comments and suggestions for revision (see http://ngmdb.usgs.gov/fgdc_gds/geolsymstd/prd/index.php). At the end of the 120–day public review period (May 19 through September 15, 2000), all comments and suggestions pertaining to the Public Review Draft were compiled, and a plan was developed to address the comments and make the necessary changes. Under this plan, a standing Map Symbol Standards Committee was formed to assist in the resolution of the public's review comments and suggestions, as well as in the long-term maintenance of the standard. Committee members were drawn from the geologic mapping community in the State geological surveys, academia, and the USGS (see Section 2.3 below, entitled "Preparers of This Standard").

Revisions to the standards document began in 2001. In July 2005, the revised standard was approved by the Map Symbol Standards Committee, and then it was submitted to the FGDC Geologic Data Subcommittee to begin the final approval process. After review and subsequent approval by the Geologic Data Subcommittee, as well as by the FGDC's Standards Working Group, Coordination Group, and Steering Committee, the final standard (this document) was formally approved as an FGDC standard in August 2006.

This standard will be managed as a "living" standard—that is, it will be maintained and revised as needed to reflect new mapping concepts or evolving usage conventions. The initial release of this FGDC-approved standard is available as an offset-printed document, supplemented by an online (PDF) version. However, all future updates to this standards document will be released online in PDF format only. To help maintain an up-to-date hard-copy version of the standards document, this initial offset-printed release has been designed in a "loose-leaf" format. Subsequent updates to this standards document may be downloaded as PDF files from the FGDC Geologic Data Subcommittee website (http://ngmdb.usgs.gov/fgdc_gds/) and then printed out and inserted where appropriate into a loose-leaf binder. These online updates will be the authoritative reference.

Because this standard is intended for use with digital applications, a PostScript implementation of the Public Review Draft was informally released as a USGS Open-File Report (U.S. Geological Survey, 2000). This early PostScript implementation enabled reviewers to directly apply the standard to geologic maps and illustrations prepared in desktop illustration and (or) publishing software. The PostScript implementation has been updated to reflect changes found in the now-approved standard and has been released as a USGS Techniques and Methods report (U.S. Geological Survey, 2006). Additionally, preliminary work on an ArcGIS implementation may be completed in the future and released as a USGS report. Information regarding these implementation efforts will be posted on the FGDC Geologic Data Subcommittee website (http://ngmdb.usgs.gov/fgdc_gds/).

Questions and comments about, or suggested additions to, this standard may be submitted by email to mapsymbol@flagmail.wr.usgs.gov or mailed to Geologic Map Symbol Standard, c/o David R. Soller, National Geologic Map Database, U.S. Geological Survey, 926A National Center, Reston, Virginia, 20192.

1.6 MAINTENANCE AUTHORITY

On behalf of the FGDC, the USGS will maintain this Federal standard. The responsibility for coordinating Federal geologic mapping information is stipulated by Office of Management and Budget Circular A–16 (see http://www.whitehouse.gov/omb/circulars/a016/a016.html). The Geologic Mapping Act of 1992 (see http://ncgmp.usgs.gov/ncgmpabout/ngmact/ngmact1992 and subsequent reauthorizations) stipulates a requirement for standards development under the auspices of the National Geologic Map Database (NGMDB). Under this authority, the NGMDB will function on behalf of the USGS as coordinator of this maintenance activity (see http://ngmdb.usgs.gov/fgdc_gds/geolsymstd/maintenance.php). Maintenance will be conducted in cooperation with the AASG, which is the USGS's partner in the Geologic Mapping Act. The NGMDB will continue to rely on the Map Symbol Standards Committee to assist in its maintenance efforts. The Committee membership comes from the NGMDB, the USGS scientific staff and Publications Groups, the AASG, and the academic community (see Section 2.3 below, entitled "Preparers of This Standard"). The Committee will, as needed, review comments and suggestions for revisions, additions, and deletions to the standard.

2. BACKGROUND

2.1 RELATION TO PREVIOUS U.S. GEOLOGICAL SURVEY STANDARDS

Soon after the USGS was established in 1879, USGS geologists began to map and assess the Nation's lands, including many areas previously unexplored by Europeans. A new publication series, the Geologic Atlas (or "Folio") series, was created to publish many of these maps. Beginning prior to 1881, the USGS, then under the direction of John Wesley Powell, began to identify geologic and cartographic standards and conventions necessary to uniformly portray the geology in this series: "In providing for the publication of this large body of material, it seemed wise to adopt a common system of general nomenclature, a uniform color scheme for geographic geology, a system of conventional characters for diagrams, and a form for geologic and topographic charts and atlases" (Powell, 1882a, p. XL; see also, Powell, 1882b, for an elaboration on the proposed standards). Following an 1889 Conference on Map Publication, these standards were articulated in more detail and then were published (Powell, 1890).

The standards that were adopted by the USGS in the 1880s served as a strong foundation for the Nation's geological science. Paramount to systematized geologic mapping was the adoption of a standard rock stratigraphic nomenclature, a naming convention for geologic formations, and the subdivisions of geologic time. Another significant contribution was the adoption of a standardized color scheme for displaying geologic map units. This scheme used pure, single-ink colors, usually a different one for each geologic time period; to achieve this, a practical and informative system of overprint patterns also was developed, which served to differentiate the various mapped units within a single time period. Although this single-ink color scheme did not persist intact in the twentieth century because of the emergence of more modern printing technologies (for example, the combining of CMYK—cyan, magenta, yellow, and black—inks to produce a greater variety of colors), many of the overprint patterns that were developed then are still in use today.

In the following decades, as the geological sciences advanced, the concepts of geologic processes and historical geology became more complex, and new insights and refinements required more map symbols and precise scientific cartographic methods to convey details of geology. In 1920, the USGS published a manual on the preparation of illustrations (Ridgway, 1920). By that time, the need for standardization had become urgent: "More than 200 symbols have been used on maps to express 25 different kinds of data, a fact indicating at once a notable lack of uniformity and a need of standardization" (Ridgway, 1920, p. 20). The manual addressed various issues associated with geologic cartography, including standard symbology for geologic maps and cross sections (for example, geologic line and point symbols, water wells, oil and gas wells, coal seams, mine workings, and topographic and other base-category information) and stratigraphic columns (for example, lithologic patterns).

After 1920, and throughout much of the twentieth century, the maintenance of USGS standards for geologic map symbolization and cartography was an internal and somewhat informal process enacted through official USGS policy. For example, USGS Chief Geologist W.H. Bradley (written commun., 1956) adopted recommendations and a list of symbols from the Map Symbol Committee (E.N. Goddard, Chairman), and USGS Chief Geologist D.L. Peck (written commun., 1978) adopted recommendations from the committee for

Standards for General Purpose Geologic Maps (J.C. Reed, Chairman).

In the mid-1970s, the USGS outlined the technical specifications for geologic symbology in its informal "Technical Cartographic Standards" volume (U.S. Geological Survey, ca. 1975). This informal standard, which was maintained until the mid-1980s, was available to USGS cartographers and editors as a set of green, loose-leaf notebooks that allowed pages to be replaced as the standard evolved. The technical specifications at that time were devised to serve the needs of cartographers who prepared maps for offset-print publication using hand-placed type, hand-scribed linework, and peelcoat color-separation techniques. This informal standard served the USGS well, but it was not available to other producers or users of geologic maps, nor was it formally recognized as a standard by the Nation's geoscience community. However, the cartographic details of this standard were clearly displayed on USGS geologic maps. And so, drawing from the cartographic content of USGS maps, others have published manuals on geologic map standards that have (unofficially) incorporated parts of this informal standard: for example, the American Geological Institute's "AGI Data Sheets for Geology in the Field, Laboratory, and Office" (Dietrich and others, 1982 [2nd ed.]; Dutro and others, 1989 [3rd ed.]) includes many symbols commonly shown on USGS geologic maps (see also, "Suggestions to Authors of the Reports of the United States Geological Survey" [7th ed.], Hansen, 1991).

Beginning about the mid-1980s, digital-cartographic and GIS (Geographic Information System) technologies rapidly evolved and became more widely available. The gradual adoption of digitally based mapmaking methods made clear the need to develop new cartographic standards that would satisfy the requirements of the latest technologies for the preparation of digital files, whether they are to be used for geospatial databases, for plot-on-demand or online map publications, or for the production of negatives for offset printing of maps.

In response to this steady increase in digital mapmaking and the accompanying concern about preparing consistent, high-quality, digitally produced geologic maps and geologic map databases, the USGS informally released in 1995 a proposed standard entitled "Cartographic and Digital Standard for Geologic Map Information" (U.S. Geological Survey, 1995a). As noted above, subsequent review of that document by the USGS, the AASG, and the FGDC Geologic Data Subcommittee (Soller, 1996) indicated the need for some revision prior to its consideration by the FGDC for formal adoption as a Federal standard, which led to the development of this standard (see discussion in Section 1.5 above, entitled "Standards Development Procedures").

2.2 CHANGES FROM PREVIOUS STANDARDS

In this new standard (contained in [normative] appendix A), descriptions, examples, cartographic specifications, and notes on usage are provided for a wide variety of symbols that may be used on typical digital geologic maps or related products such as cross sections. In the preparation of this standard, every effort was made to retain the original symbols and their specifications from the 1995 USGS proposed standard (U.S. Geological Survey, 1995a); however, many updates have been incorporated into this new version. The number of symbols has increased significantly, from about 800 to over 2300. Symbols are more logically grouped; some sections have been combined with others, and a few new sections have been added.

Many symbols, particularly lines, have been redesigned slightly so that they would more successfully translate to digital applications. For instance, in the old "Technical Cartographic Standards" volume (U.S. Geological Survey, ca. 1975), as well as in the 1995 USGS proposed standard (U.S. Geological Survey, 1995a), the lineweight for contacts was specified as .005 inches (.125 millimeters). However, experience has shown that .005–inch lines do not always plot well when digitally output by high-resolution imagesetters. Therefore, the minimum lineweight for contacts, as well as for most other stroked-line symbol elements, has been increased to .006 inches (.15 millimeters) in this new standard. In addition, the dash and gap lengths for many line symbols have been adjusted so that their dash-gap templates can be more easily defined electronically.

A chart showing a wide range of CMYK colors ("CMYK Color Chart") has been included; an offset-print version of this chart has been in use at the USGS for many years, and the variety of colors has proved to be sufficient for portraying complex geology shown on most maps, regardless of the output medium. In addition, a chart that shows commonly used geologic patterns ("Pattern Chart") has been added; the patterns themselves are similar to what was in the old "Technical Cartographic Standards" volume (U.S. Geological Survey, ca. 1975), as well as in the 1995 USGS proposed standard (U.S. Geological Survey, 1995a), but most have undergone lineweight changes to facilitate digital output at high resolutions. The old pattern numbers have been revised and the patterns are now organized into seven geologically relevant series. A few new patterns have been added, and some have been eliminated. In addition, each pattern in the Pattern Chart, as well as each color in the CMYK Color Chart, has associated with it a generic lookup-table number that, if desired, may be used to access the pattern (or color) from within digital applications.

Also included in this new standard is a diagram showing suggested ranges of map-unit colors for stratigraphic ages of sedimentary and metamorphic rocks, as well as for volcanic and plutonic rocks. In addition, a new geologic age symbol font ("FGDCGeoAge") has been added. Three new sections that address map marginalia have been included: (1) quadrangle location maps for each of the 50 states (and District of Columbia, Guam, Puerto Rico, and U.S. Virgin Islands), as well as a map of the 48 conterminous states (so that quadrangle locations covering more than one state can be shown); (2) a variety of bar scales, as well as calculation tables that show how to convert between inches, miles, and kilometers; and (3) a series of mean declination arrows, showing magnetic north both east and west of true north.

A few new informational sections have been added to the introductory material in this standard. The section entitled "Guidelines for Map Color and Pattern Selection" provides useful information on color selection and the use of patterns. The section entitled "Guidelines for Map Labeling" provides recommendations on placement of text on a map.

The most significant update to this standard is the addition of two important sections to the introductory material. The section entitled "Geologic Mapping Concepts and Definitions" provides basic information about some of the fundamental concepts of geologic mapping, as well as defines and categorizes the various types of geologic map features. The section entitled "Scientific Confidence and Locational Accuracy of Geologic Features" clarifies the concepts of, and establishes new terminology for, the levels of scientific confidence and locational accuracy of geologic map features.

In response to reviewer's comments (Soller, 1996), much of the first part of the 1995 USGS proposed standard has been abandoned because it was either not pertinent to this standard (for example, the sections on geologic map content, metadata, and geocoding) or not widely applicable to the full range of mapping situations (for example, the specification of a "1.0 mm accuracy standard"). In addition, no attempt has been made in this new standard to provide detailed definitions for the geologic features represented by the various symbols. For such information, please refer to one of a number of reference books available; an excellent source is the American Geological Institute's Glossary of Geology (Jackson, 1997 [4th ed.]; Neuendorf and others, 2005 [5th ed.]).

2.3 PREPARERS OF THIS STANDARD

Principal contributors[1] to the preparation of this FGDC Digital Cartographic Standard for Geologic Map Symbolization include the following individuals:

David R. Soller (USGS; Chief, National Geologic Map Database)—Coordinator, editor, and author, FGDC Digital Cartographic Standard for Geologic Map Symbolization; coordinator, Map Symbol Standards Committee.

Taryn A. Lindquist (USGS; Digital Map Specialist and Geologic Map Editor, Western Publications Group)—Editor, author, and compiler, FGDC Digital Cartographic Standard for Geologic Map Symbolization; designer, line symbols and point symbols, FGDC Digital Cartographic Standard for Geologic Map Symbolization.

Map Symbol Standards Committee: Thomas Berg (State Geologist, Ohio); Jay Parrish (State Geologist, Pennsylvania); Mark Jirsa (Minnesota Geological Survey); Robert Hatcher (University of Tennessee, Knoxville); Steven Reynolds (Arizona State University); and Byron Stone, Jack Reed, Jonathan Matti,

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[1] Unless otherwise noted, persons listed as contributors to the "FGDC Digital Cartographic Standard for Geologic Map Symbolization" participated in the preparation of the following versions of the standard: Working Draft; Public Review Draft (Federal Geographic Data Committee, 2000) and its PostScript implementation (U.S. Geological Survey, 2000); and the now FGDC-approved standard (this document) and its PostScript implementation (U.S. Geological Survey, 2006).

Taryn Lindquist, and David Soller (all USGS)—Referees and reviewers of public comments and subsequent revisions, Public Review Draft (Jonathan Matti is especially noted for his guidance on issues of scientific confidence and locational accuracy).

Sara Boore (USGS; Publication Graphics Specialist, Western Publications Group)—Book designer, FGDC Digital Cartographic Standard for Geologic Map Symbolization; designer, point symbols, line symbols, color charts, and patterns, FGDC Digital Cartographic Standard for Geologic Map Symbolization.

F. Craig Brunstein (USGS; Geologic Map Editor, Central Publications Group)—Technical reviewer, Working Draft.

Alessandro J. Donatich (USGS; Geologic Map Editor, Central Publications Group)—Technical reviewer, Working Draft.

Carolyn Donlin (USGS; Online Publications Specialist and Geologic Map Editor, Western Publications Group)—Preparer, online publication of Public Review Draft (PostScript implementation).

Michael F. Diggles (USGS; CD-ROM Publications Specialist and Online Publications Specialist, Western Publications Group)—Preparer, CD-ROM publications of PostScript implementations; preparer, online publication of FGDC-approved standard (PostScript implementation).

Kevin Ghequiere (USGS; Cartographer, Western Publications Group)—Designer, patterns, FGDC Digital Cartographic Standard for Geologic Map Symbolization.

Richard D. Koch (USGS; Digital Map Specialist, Western Publications Group)—Designer, geologic age symbol font, FGDC Digital Cartographic Standard for Geologic Map Symbolization.

Diane E. Lane (USGS; Geologic Map Editor, Central Publications Group)—Technical reviewer, Working Draft.

Susan E. Mayfield (USGS; Publication Graphics Specialist, Western Publications Group)—Designer, color charts and patterns, FGDC Digital Cartographic Standard for Geologic Map Symbolization.

Kathryn Nimz (USGS; Digital Map Specialist, Western Publications Group)—Designer, patterns, FGDC Digital Cartographic Standard for Geologic Map Symbolization.

Glenn Schumacher (USGS; Publication Graphics Specialist, Western Publications Group)—Designer, bar scales, mean declination arrows, and quadrangle location maps, FGDC Digital Cartographic Standard for Geologic Map Symbolization.

Stephen L. Scott (USGS; Publication Graphics Specialist, Western Publications Group)—Designer, point symbols and line symbols, FGDC Digital Cartographic Standard for Geologic Map Symbolization.

Will Stettner (USGS; Cartographer, Eastern Publications Group)—Technical reviewer, Working Draft.

José F. Vigil (USGS; Motion Graphics Specialist, Western Publications Group)—Designer, geologic age symbol font, FGDC Digital Cartographic Standard for Geologic Map Symbolization.

Jan L. Zigler (USGS; Geologic Map Editor, Western Publications Group)—Technical reviewer, Working Draft.

3. GEOLOGIC MAPPING CONCEPTS AND DEFINITIONS

3.1 GEOLOGIC MAPS

A *geologic map* is a cartographic product that portrays information about the geologic character of a specific geographic area. It is a two-dimensional representation of real-world, three-dimensional geologic features. To achieve this, a geologic map uses graphical elements to express detailed information about the different kinds of earth materials, the boundaries that separate them, and the geologic structures that have subsequently deformed them. For example, a typical general-purpose geologic map may consist of *lines* that trace contacts, faults, and folds; *points* that locate bedding attitudes, minor fold orientations, and sample localities; *areas* that represent geologic units, landslides, and areas of alteration; and *labels* that identify geologic map units, sample-locality numbers, and fault names. Thus, an appropriately symbolized and labeled geologic map can portray comprehensive information about the composition, age, and genesis of the geologic materials and the nature of their boundaries, as well as the character and three-dimensional geometry of the geologic structures that have deformed them. In addition, such geologic map information usually is drawn onto a base map that also uses graphical elements to represent the topography, drainage, and cultural features of an area, and so a geologic map also can depict the spatial relation of the various geologic features to the physical landscape. Other things that may be shown on a geologic map include information about the geomorphology, pedology, paleontology, rock alteration and mineralization, geophysics, geochemistry, or geochronology of an area.

3.2 GEOLOGIC MAP DATABASES

A *geologic map database* is a digitally compiled collection of spatial (geographically referenced) and descriptive geologic information about a specific geographic area. The information in the geologic map database consists of (1) the geographic location and the orientation, length, shape, and (or) area (in other words, the geometry) of each geologic feature or object (for example, an outcrop or a fault), and (2) many different types of descriptive geologic information about each feature or object.

A geologic map database also may contain extensive amounts of additional qualitative and quantitative geologic information. For example, a geologic map database may include geochemical analyses, radiometric ages, soil-horizon information, and geophysical contours, as well as information on the weathering of surface exposures of geologic features, the subsurface geometry of geologic map units, and the glacial landforms or other types of geomorphic features.

Fundamental data elements of a geologic map database are *lines* (for example, contacts and faults), *points* (for example, bedding attitudes and fossil localities), and *areas* or *polygons* (for example, map-unit areas and zones of alteration). In addition, each feature or object in the geologic map database has several associated *feature attributes*. The most basic feature attributes may simply identify the feature (for example, "thrust fault" or "overturned anticline") and express its scientific confidence and locational accuracy (for example, "identity certain" or "location inferred"). Other feature attributes may consist of detailed descriptions of each feature (for example, the lithologic characteristics of a map unit, the dip of a mapped fault, or the identification and age determination of a fossil specimen).

When a geologic map is generated as a cartographic product from a geologic map database, each geologic feature is represented by a specific *geologic map symbol*. The attributes in the database provide the information needed to symbolize each feature. In addition, *annotation* is added to the geologic map wherever necessary to identify the various features (for example, map-unit labels and fault names) and to provide essential quantitative information (for example, dip values and fossil-locality numbers).

3.3 GEOLOGIC MAP UNITS

A *geologic map unit* is a cartographic representation of a volume of geologic materials that share enough characteristics (for example, the composition, areal extent, age, and (or) genesis) to be considered a single entity (a single geologic unit). On a typical geologic map, most geologic units are represented by polygons that are filled with colors and (or) patterns. Geologic units can also be represented by lines (for example, dikes) or points (for example, blueschist blocks).

The *formation*, whether formal or informal, is the lithostratigraphic unit most commonly depicted on a geologic map. A formation can be subdivided into lower rank stratigraphic units (for example, members, tongues, lentils, or beds) or assembled with other formations to make up more generalized, higher rank stratigraphic units (for example, groups or supergroups), depending on the scale of the map or the focus of the geologist (see guidelines for the recognition and naming of geologic units by the North American Commission on Stratigraphic Nomenclature, 1983).

3.3.1 Geologic Time, the Ages of Rock Units, and Geologic Age Symbols

The USGS has published a scheme for the major divisions of *geologic time*, the age estimates of the boundaries, and the specialized *geologic age symbols* to be used on geologic maps (Hansen, 1991). This particular scheme was formally adopted after a 1980 meeting of the Geologic Names Committee of the USGS (Hansen, 1991). In addition, several other schemes of geologic time boundaries have been published (see, for example, Harland and others, 1982, 1989; Palmer, 1983; Snelling, 1985; Berggren and others, 1995; Gradstein and Ogg, 1996; Haq and van Eysinga, 1998; International Union of Geological Sciences, 1998; Palmer and Geissman, 1999), each of which is based on different assumptions, techniques, and (or) data. Any formally published age scheme may be used for a particular map, as long as which scheme was used is specified on the map and in the geologic map database.

3.3.2 Map-Unit Labels

A *map-unit label* is an alphanumeric symbol that identifies the geologic map unit on the map. The map-unit symbol is an abbreviated acronym that usually is made up of, in the following order, (1) either capital letters or geologic age symbols indicating the age of the geologic unit (see Appendix A, Section 32), and (2) lower case letters denoting the name or the lithologic characteristics of the geologic unit. In some cases, numerical subscripts are added to designate different subunits (for example, members or individual lava flows) within a geologic unit.

Map-unit labels are added to the geologic map wherever necessary to clearly identify the various geologic map units. In addition, map-unit labels are included among the feature attributes in the geologic map database, thereby designating each mapped area as belonging to a particular geologic map unit.

3.4 PLANAR GEOLOGIC FEATURES

A *planar geologic feature* is a two-dimensional geologic surface, which may be either a real-world, physical surface (for example, a contact between two geologic units) or a hypothetical surface (for example, an axial surface of a fold). The geometry of the geologic surface may be flat, curved, or crenulated, and its orientation may be horizontal, inclined, vertical, or overturned.

The intersection of a planar geologic feature with the ground surface forms a real or perceived (projected) linear trace. When these linear traces are mapped in the field and then plotted as lines on a base map, they become the most basic and fundamental elements of a typical geologic map: they may delineate simple map-unit areas, or they may define complex patterns of structural deformation. The various types of linear traces are portrayed on a geologic map by unique line symbols (Appendix A), each of which has a different width, pattern, ornamentation, or color; thus, a particular line symbol conveys specific information about the character and (or) geometry of each planar geologic feature.

3.4.1 Contacts

A *contact* is a planar surface that bounds a geologic unit (except where that bounding surface is a fault; see discussion below in Section 3.4.3, entitled "Faults"). A contact is intrinsic to the genesis of each geologic unit; that is, the contact delineates the stratigraphic position where, owing to changing environmental conditions or other genetic factors at the time of origin, the properties and characteristics of one geologic unit change, either abruptly or gradually, to those of another geologic unit.

Discussion of contacts in this standard primarily pertains to those that have been mapped in the field (for example, contacts that bound formations, members, beds, lava flows, or intrusions). Contacts can also exist between higher rank units, although these contacts typically are not mapped in the field; instead, they are concepts that may arise later when lower rank stratigraphic units are combined into higher rank stratigraphic units (see discussion of lithostratigraphic boundaries by the North American Commission on Stratigraphic Nomenclature, 1983, p. 856–58).

Contacts can be classified as one of a number of types, depending on the nature or origin of the contact and the geologic units that it separates. Examples of such contact types include the following: sedimentary (conformable; unconformable, etc.); alluvial; landslide; residual; igneous (intrusive, extrusive, pyroclastic); metamorphic; and high-strain (cataclastic, mylonitic, tectonic). If available, supplemental information about a contact's type is added as a feature attribute to the geologic map database; however, specialized line symbols usually are not used to represent these various contact types. In general, unless otherwise stated on the geologic map or in the geologic map database, contacts should be considered generic; that is, they have no particular type or identity.

The geologic age of a contact also may be specified as a feature attribute in the geologic map database, but rarely is this characteristic symbolized on the geologic map; if desired, such information can be communicated by the addition of geologic point data or annotation placed along the trace of the contact. In addition, specific information collected about a contact's local surface exposure, orientation or character can be added as geologic point data and annotation placed along the trace of the contact where the observation was made.

3.4.1.1 Discrete versus Gradational Contacts

In the field, a contact between two geologic units is a transition zone whose width can range from very narrow to very broad. Examples of transition zones include the following:

- a single surface, as sharply delineated as a knife-edge, between two lithologically distinct geologic units;
- a single surface that zigzags between two intertonguing geologic units;
- a narrow zone, a few centimeters to a few decimeters wide, in which the lithologic character changes from one geologic unit to another;
- a diffuse zone, a few meters to many meters wide, in which the lithologic character of one geologic unit gives way gradually to that of another geologic unit.

Despite the differences inherent in each of these examples, contacts generally can be classified as either one of two types of transition zones: *discrete* or *gradational*. A precise definition of the width of a discrete versus a gradational contact, however, is difficult because of (1) different scales of mapping (for example, a contact that is gradational at a scale of 1:24,000 would probably be considered discrete at a scale of 1:100,000); (2) differing interpretations that can arise between geologists whose mapping primarily focuses on either sedimentary, igneous, or metamorphic rocks (for example, contact relations that are considered gradational by a geologist who maps sedimentary rocks may be viewed as discrete by a geologist who maps plutonic rocks); and (3) differences in individual biases that may arise from different geologic-mapping traditions in geologically dissimilar parts of the Nation. Because of these and other factors, this standard makes no attempt to delimit the precise width of a discrete or a gradational contact. Nevertheless, this standard provides the following general definitions:

A *discrete* contact is a map-unit boundary that is individually distinct; that is, the transition between geologic units is abrupt enough to be recognized and delineated easily on the map. A discrete contact may be a sharp, knife-edged surface, or it may be transitional across a zone as wide as a meter or more, depending on the scale of the map.

A *gradational* contact is a map-unit boundary that is diffuse; that is, the transition between geologic units is gradual enough that it cannot be recognized or delineated easily on the map. A gradational contact is so diffuse across the transition zone (the width of which will vary at different map scales) that delineation of its exact position can be difficult.

The discrete versus gradational character of a contact is specified as a feature attribute in the geologic map database. In addition, if the map scale allows, gradational contacts can be represented on the geologic map by a specialized line symbol (see Appendix A, Section 1). Unless otherwise stated on the map or in the geologic map database, however, a generic contact (that is, one not represented by a specialized line symbol) should be considered discrete at the scale of the map.

3.4.2 Key Beds

A *key bed* is an easily identifiable stratigraphic marker bed within a geologic unit. Although a key bed is a three-dimensional volume rather than a two-dimensional surface, commonly it is too thin to depict as a map-unit area at most map scales, and so it usually is classified as a planar geologic feature.

Key beds are identified on the basis of their lithologic character and, in most cases, their relation to the surrounding rock materials. Examples of various types of key beds include the following:

- a coal bed;
- a fossiliferous horizon;

- a cross-cutting dike;
- a clay bed in a dominantly coarse-grained sedimentary sequence;
- a gravel bed in a dominantly fine-grained sedimentary sequence;
- a marine sedimentary bed in a dominantly nonmarine sedimentary sequence;
- a nonmarine sedimentary bed in a dominantly marine sedimentary sequence;
- a sandstone bed in a dominantly carbonate sedimentary sequence;
- a limestone bed in a dominantly dolomitic sedimentary sequence;
- a volcanic-ash bed or flow in a dominantly nonvolcanic sequence.

The type of key bed can be specified as a feature attribute in the geologic map database. In addition, some types of key beds are portrayed on the geologic map by specialized line symbols (see Appendix A, Section 1). In some cases, if the map scale allows, key beds are represented by colored or patterned areas. Map-unit labels are added to the geologic map to identify the various types of key beds shown on the map. In addition, map-unit labels are included among the feature attributes in the geologic map database to identify each key bed.

3.4.3 Faults

A *fault* is a planar surface of rupture along which geologic units have been fractured and then displaced. Faults can be geometrically complex structures that juxtapose map units over great distances, or they can be simple fracture planes along which the amount of offset is very small.

Discussion of faults in this standard primarily pertains to those that have been mapped in the field. Faults also can be required conceptually when lower rank stratigraphic units are grouped into higher rank units or tectonostratigraphic terranes, although these faults may not have been observed in the field.

Faults can be classified as one of a number of types, depending on the nature of their geometry and (or) sense of offset. Examples of fault types include the following: normal (low-angle, listric); reverse; thrust; overturned thrust; vertical; strike-slip (right-lateral, left-lateral); oblique-slip; detachment; or some combination of the above. Information about a fault's type is specified as a feature attribute in the geologic map database. When the map scale allows, such information also is represented on the geologic map by a specialized line symbol and (or) line-symbol decoration. A particularly robust set of specialized line symbols and line-symbol decorations has evolved to represent the various fault types (see Appendix A, Section 2). In general, unless otherwise stated on the map or in the geologic map database, faults that lack such specialized symbology should be considered generic; that is, their geometry or sense of offset either is not known or has not been specified.

The age of a fault also can be specified as a feature attribute in the geologic map database, but rarely is this characteristic symbolized on the geologic map; if desired, such information can be communicated through the addition of geologic point data or annotation placed along the trace of the fault. In addition, specific information collected about a fault's local orientation can be added as geologic point data and annotation placed along the trace of the fault where the observation was made.

Some faults are relatively minor structures whose traces are mapped within single geologic units until the faults can no longer be observed or they no longer exist. More commonly, faults are mapped as larger, thoroughgoing structures that can produce a significant amount of offset between one or more geologic units, so that the rupture surfaces form new map-unit boundaries. In addition, faulting sometimes can take place at the stratigraphic position where a contact would normally exist between two stratigraphically coherent geologic units. But because faulting is not a process intrinsic to a geologic units' genesis (in these cases, faulting has occurred through already-formed geologic units), these bounding surfaces do not meet the criteria to be called contacts (see discussion above in Section 3.4.1, entitled "Contacts"). Therefore, although they may form boundaries between geologic units, such structures are classified as "faults," not "fault contacts" or "faulted contacts."

3.4.3.1 Discrete Faults versus Fault Zones

In the field, a fault forms a zone of offset whose width can range from very narrow to very broad. Examples of such zones of offset include the following:

- a single offset-fracture surface, as sharply delineated as a knife-edge;
- a narrow zone of offset, a few centimeters to a few decimeters wide;
- a diffuse zone, a few meters to many meters or as much as a kilometer or more wide, within which offset has been distributed among a few or many shear planes.

Despite the differences inherent in each of these examples, faults generally can be described in either one of two ways: as a *discrete fault* or as a *fault zone*. A precise definition of the width of a discrete fault versus a fault zone, however, is difficult for a number of reasons (see related discussion above in Section 3.4.1.1, entitled "Discrete versus Gradational Contacts"), and this standard makes no attempt to do so. Nevertheless, this standard provides the following general definitions:

A *discrete fault* is a zone of offset that is individually distinct; that is, the zone is narrow enough to be recognized and delineated easily on the map. A discrete fault may be a sharp, knife-edged surface of offset, or it may be a zone of offset as wide as a meter or more, depending on the scale of the map.

A *fault zone* (also called a *shear zone*) is a diffuse zone within which offset has been distributed among a few or many shear planes, commonly resulting in a zone of crushed and sheared or ductily deformed rock. In some cases, a fault zone can be mapped as an area bounded by discrete fault planes.

The character of a fault (discrete fault versus fault zone) is specified as a feature attribute in the geologic map database. In addition, a fault zone can be portrayed either by a specialized line symbol or, if the map scale allows, by a colored or patterned area (see Appendix A, Section 2). Unless otherwise stated on the map or in the geologic map database, a generic fault (that is, one not portrayed as an area or by a specialized line symbol) should be considered discrete at the scale of the map.

3.4.4 Folds

In its simplest sense, a *fold* is a geologic structure that results when a flat-lying or otherwise undeformed geologic surface is warped and deformed into an undulating geologic surface. In reality, many fold structures further deform bodies of rock that may already be highly deformed and (or) metamorphosed. Thus, folds may form simple, symmetric structures, or they may form complex, multidimensional and multigenerational fold systems.

The *fold axis* or *hinge line* of a fold is a hypothetical line that traces the locus of maximum curvature of the fold structure. The *axial surface* or *axial plane* of a fold is a hypothetical planar surface that connects the fold axes or hinge lines of folded strata.

Folds can be classified as one of a number of fold types, depending on the geometry of the fold's axial surface and the geometry and the relative ages of the folded strata. Examples of fold types include the following: anticline, syncline, monocline; antiform, synform; symmetrical, asymmetrical, overturned, inverted, isoclinal, recumbent, and plunging.

Information about a fold's type is specified as a feature attribute in the geologic map database. In addition, such information is portrayed on the geologic map by specialized line symbols and line-symbol decorations (see Appendix A, Section 5). On a geologic map, a fold is mapped as a line where the trace of its axial surface intersects the ground surface. In some cases, the trace of a fold's *crest line* (highest point on a fold's crest) or *trough line* (lowest point in a fold's trough) can also be mapped.

The age of a fold also can be specified as a feature attribute in the geologic map database, but rarely is this characteristic symbolized on the geologic map; if desired, such information can be communicated through the addition of geologic point data or annotation placed along the trace of the fold. In addition, specific data collected about a fold's local orientation can be added as geologic point data and annotation placed along the trace of the fold where the observation was made.

3.5 LINEAR GEOLOGIC FEATURES

A *linear geologic feature* is a one-dimensional geologic or geomorphic line, which may be either a real-world, physical line (for example, a moraine, lineament, or outcrop-scale lineation) or a hypothetical line (for example, a hinge line of a fold or a paleocurrent direction). The geometry of the line may be straight, curved, or crenulated, and its orientation may be horizontal, inclined, or vertical.

The orientations of linear geologic features are mapped in the field and then plotted as lines on a base map. Information about the various types of linear geologic features is specified as a feature attribute in the geologic map database. In addition, such information is represented on a geologic map by a unique line symbol (Appendix A), each of which has a different width, pattern, ornamentation, or color; thus, a particular line symbol conveys specific information about the character and (or) geometry of each linear geologic feature.

3.6 GEOLOGIC POINT FEATURES

A *geologic point feature* consists of geologic or geomorphic information that has been collected at a particular point of observation in the field (except when that point feature is a line-symbol decoration; see discussion below in Section 3.6.3.2, entitled "Line-Symbol Decorations"). In some field situations, more than one observation can be taken at a single locality.

Geologic point data may pertain to a planar feature (for example, the orientation of bedded strata), a linear feature (for example, the plunge of a fold axis), or a single locality (for example, a fossil locality). Geologic point data also can be added as line-symbol decorations (for example, anticline arrows) that provide supplemental information about a particular part of a line on a geologic map.

Geologic point data are recorded in the field and then plotted as points on a base map. Information about the various types of geologic point data is specified as a feature attribute in the geologic map database. In addition, such information usually is represented on a geologic map by specialized point symbols and associated annotation (Appendix A).

3.6.1 Planar-Feature Geologic Point Data

Planar-feature geologic point data consist of quantitative information about the character and the orientation of a geologic surface, which may be a physical surface (for example, a fault plane or bedded strata) or a hypothetical surface (for example, an axial surface of a fold or a plane of foliation). The geologic surface may be horizontal, inclined, vertical, or overturned.

Two measurements, the *strike* and the *dip*, define the orientation of a geologic surface in three-dimensional space:

- the *strike* of a surface is the azimuthal direction of a hypothetical line formed by the intersection of the surface with an imaginary horizontal surface, as measured in the direction that the observer is facing when the surface dips down to the right (this method of directional measurement follows the *right-hand rule* convention);
- the *dip* of a surface is the angle of departure of that surface downward from horizontal, as measured perpendicular to the line of strike.

Information about the type of observation, as well as the values of strike and dip, is specified as feature attributes in the geologic map database. Such information also is represented on the geologic map by specialized point symbols and associated annotation: the strike value and the direction of dip are implicit in the orientation of the point symbol; the dip value is added as annotation.

3.6.1.1 Point Symbols for Planar Features, and Their Placement Relative to Point of Observation

The point symbols for inclined or overturned planar features typically are made up of two parts: a long shaft oriented in the strike direction, and a short tick (or ornamentation such as a triangle) pointing in the downdip direction. The point symbol is placed on the map so that the intersection of its long shaft and short tick (or ornamentation) is at the point of observation. When data have been collected about the local orientation of a planar feature that has been represented on the map by a line symbol (for example, the dip of a contact or a fault), the point symbol is placed directly on the line symbol at the point of observation.

The point symbols for vertical planar features are similar to those for inclined surfaces, except that two short ticks (or ornamentations), not one, point away from the long shaft. The point symbol is placed on the map so that the intersection of its long shaft and short ticks (or ornamentations) is at the point of observation.

The point symbols for horizontal planar features, which display no directional information, are simply placed on the map at the point of observation.

3.6.1.2 Specialized Planar-Feature Point Symbols for Multiple Observations at One Locality

In situations where more than one observation has been taken at a single locality, point symbols for planar features can be combined with other point symbols at the point of observation. In these cases, specialized point symbols may be used to avoid the overprinting of information. These specialized point symbols have the short ticks (or ornamentations such as triangles) moved down near the end of the long shafts; the symbols are joined at their endpoints (opposite the ticks or ornamentations) at the point of observation.

3.6.2 Linear-Feature Geologic Point Data

Linear-feature geologic point data consist of quantitative information about the orientation of a geologic or geomorphic linear feature, which may be a physical line (for example, a fault-plane groove or slickenline) or a hypothetical line (for example, the intersection of two surfaces of deformation). The geologic or geomorphic linear feature may be horizontal, inclined, or vertical.

Two measurements, the *bearing* and the *plunge*, define the orientation of a geologic or geomorphic line in three-dimensional space:

- the *bearing* of a line is the azimuthal direction of the trend of that line, as measured in its direction of plunge;
- the *plunge* of a line is the angle of departure of that line downward from horizontal.

Information about the type of observation, as well as the values of bearing and plunge, is specified as attributes in the geologic map database. Such information also is represented on the geologic map by specialized point symbols and associated annotation: the bearing value and the direction of plunge are implicit in the orientation of the point symbol; the plunge value is added as annotation.

3.6.2.1 Point Symbols for Linear Features, and Their Placement Relative to Point of Observation

The point symbols for inclined linear features typically are made up of two parts: a shaft oriented in the bearing direction, and an arrowhead pointing in the plunge direction. The symbol is placed on the map so that the end of its shaft opposite the arrowhead is at the point of observation. When data have been collected about the local orientation of a linear feature that has been represented on the map by a line symbol (for example, a lineation on a fault), the point symbol is placed directly on the line symbol at the point of observation.

The point symbols for horizontal linear features are similar to those for inclined linear features, except that arrowheads are at both ends of the long shaft. The symbol is placed on the map so that the middle of its shaft is at the point of observation.

The point symbols for vertical linear features, which display no directional information, are simply placed on the map at the point of observation.

In situations where more than one observation has been taken at a single locality, point symbols for linear features can be combined with other point symbols at the point of observation. When a single linear-feature observation and a single planar-feature observation are taken at a single locality, the symbols are combined so that the end of the arrow that represents the linear feature is placed at the intersection of the planar-feature point symbol's long shaft and short tick (or ornamentation). When more than two such observations are taken at a single locality, the point symbols for linear features are joined at their endpoints with the specialized point symbols for planar features (see Section 3.6.1.2 above, entitled "Specialized Planar-Feature Point Symbols for Multiple Observations at One Locality") at the point of observation.

3.6.3 Informational Geologic Point Data

Informational geologic point data consist of geologic information that is supplemental to a typical geologic map or its features. Informational geologic point data are divided into two types: *locality-information point data*, and *line-symbol decorations*.

3.6.3.1 Locality-Information Point Data

Locality-information point data record information collected at a particular locality (for example, fossil localities or sample localities). The type of data collected at the locality is specified as a feature attribute in the geologic map database. In addition, such information commonly is represented on the geologic map by a specialized point symbol placed at the point of observation. Sample numbers or other identifying labels are added as annotation near the point symbols.

3.6.3.2 Line-Symbol Decorations

Line-symbol decorations are specialized point symbols that convey qualitative information about the character of a particular line or line segment (for example, anticline arrows or ball-and-bar symbols). The type of line-symbol decoration is specified as a feature attribute in the geologic map database. Line-symbol decorations are not placed at a specific point of observation because they do not represent information collected at a particular locality; instead, they should be placed at a strategic location (or locations) along the trace of a line symbol in order to clearly communicate information about the nature of that line.

4. SCIENTIFIC CONFIDENCE AND LOCATIONAL ACCURACY OF GEOLOGIC FEATURES

Another important concept in geologic mapping is a geologist's level of confidence in the interpretation of features observed in the field. Many factors can adversely affect a geologist's level of confidence when mapping, and field situations often arise in which the interpretation of a feature may be in question, as indicated by the following examples:

- a planar feature is well-exposed in outcrop, but it is not easily identifiable as either a contact or a fault;
- a contact is clearly exposed in a roadcut, but its trace cannot be followed away from that roadcut;
- a fault's trace is obscured by vegetation, and so both its location and its sense of offset cannot be definitively determined;
- a fault's trace is completely concealed beneath valley fill.

As these examples show, uncertainties can exist in either the scientific interpretation or the mapped location of a feature (or in both). Therefore, not only is it important to communicate to the map user the level of confidence in each geologic map feature, but also which type of uncertainty (scientific and (or) locational) may be associated with that feature.

Traditionally, a system of solid, dashed, dotted, or queried line symbol styles (see, for example, Ridgway, 1920, plate 2) has been used on geologic maps to show levels of locational accuracy of planar and linear geologic features observed in the field. This convention followed USGS Director Powell's 1888 policy, which stipulated that "fault lines (particularly when they are formation boundaries) shall be indicated when actually traced by somewhat heavy full lines in black; and when not actually traced, by similar broken lines" (Powell, 1890, p. 76). More guidance was provided in 1956 by USGS Chief Geologist W.H. Bradley, who, in a memorandum to USGS personnel regarding geologic map standards, stated, "The accuracy of location of faults and contacts should be shown by appropriate symbols … Solid lines should be used to indicate accurate locations of features that are geologically identifiable within the plottable limits of the map … Features that are only approximately located should be shown by long dashed lines; those that are indefinite or inferred, by short dashed lines; and those that are concealed, by dotted lines" (W.H. Bradley, written commun., 1956). To further encourage the use of such symbology, Bradley added, "The use of many dashed contacts or faults on a map is not to be construed as a detraction from the quality of the map, and for many maps, it may be undesirable or impossible to achieve sufficiently accurate locations to permit use of solid lines. The quality of the map is not impaired so long as the reader can interpret the accuracy of location" (W.H. Bradley, written commun., 1956).

In conjunction with these traditional line symbol styles, geologists at various times have used terms such as "known," "probable," "certain," "uncertain," "accurately located," "approximately located," "inferred," "projected," "concealed," and "queried" to express the levels of confidence of planar and linear geologic features. However, these terms and their associated line symbol styles have not been used consistently from region to region or from map to map. Also, it has not been always clear whether they reflect uncertainty in a feature's scientific interpretation, its mapped location, or both.

To facilitate the communication of geologic map information, this standard clarifies the concepts of, and establishes the attributes for, the levels of scientific confidence and locational accuracy of geologic map features. In addition, to facilitate the cartographic representation of geologic map information, this standard establishes new terminology that expresses both these concepts.

4.1 SCIENTIFIC CONFIDENCE

Scientific confidence expresses a geologist's level of certainty regarding the nature, origin, geometry, identity, and even the existence of a geologic feature. The characteristics of the geologic materials and structures, the number of outcrops, and the availability of subsurface or geophysical data directly affect the level of scientific confidence in any area. Experience and resources available to a geologist also affect scientific confidence. These fundamental characteristics of geologic features can be grouped into two distinct but related concepts, *identity* and *existence*.

4.1.1 Identity

Identity expresses whether or not the observations and data support the stated nature, origin, or geometry of a mapped geologic feature (for example, a contact versus a fault, or a normal fault versus a thrust fault). The concept of identity is communicated in the following two ways:

- in the geologic map database, the attribute describing the confidence in a feature's identity is specified as either *certain* or *questionable*;
- on the geologic map, the confidence in a feature's identity is communicated in the symbol explanation and (or) the map unit description (see Section 4.1.3 below, entitled "Levels of Scientific Confidence") and also, for some types of geologic map features, conveyed cartographically (see Section 4.1.4 below, entitled "Cartographic Representation of Scientific Confidence").

4.1.2 Existence

Existence expresses whether or not the observations and data support the continuity or existence of a concealed or an otherwise unseen geologic feature (for example, a postulated fault or a subsurface fault). The concept of existence is communicated in the following two ways:

- in the geologic map database, the attribute describing the confidence in a feature's existence is specified as either *certain* or *questionable*;
- on the geologic map, the confidence in a feature's existence is communicated in the symbol explanation and (or) the map unit description (see Section 4.1.3 below, entitled "Levels of Scientific Confidence") and also, for some types of geologic map features, conveyed cartographically (see Section 4.1.4 below, entitled "Cartographic Representation of Scientific Confidence").

4.1.3 Levels of Scientific Confidence

A geologic map must communicate to the map user the level of scientific confidence associated with each mapped feature (both its identity and its existence). In a geologic map database, this information is contained in two attribute fields, identity (*certain*, *questionable*), and existence (*certain*, *questionable*). To facilitate the communication of the two concepts of identity and existence on a geologic map, this standard sets forth the following new terminology, which expresses clearly yet concisely the levels of scientific confidence of geologic features (see Figure 1 for the relation of this new terminology to historically used terminology):

"*Identity and existence certain*"	Both the identity and the existence of a feature can be determined using relevant observations and scientific judgment; therefore, one can be reasonably confident in the scientific credibility of this interpretation. These criteria are met, for example, when a geologist reasons, "*I am*

	certain that the planar feature I see in this outcrop is a fault." This is the default condition for all geologic map features unless otherwise stated on the geologic map or in the geologic map database.
"*Identity or existence questionable*"	Either the identity or the existence of a feature cannot be determined using relevant observations and scientific judgment; therefore, one cannot be reasonably confident in the scientific credibility of this interpretation. These criteria are met, for example, when a geologist reasons, "*I can see some kind of planar feature in this outcrop, but I cannot be certain if it is a contact or a fault*," or, "*My interpretation requires that a thrust fault be present to account for incongruities in the stratigraphy of these rocks, but I can't be certain because I haven't yet seen one here.*"

This new terminology is intended to be used when choosing a particular style of symbol to represent a feature on a geologic map (Fig. 2), as well as when describing that feature in the symbol explanation (see Preface to Appendix A) and (or) the map unit description. If a feature is symbolized or described as "identity or existence questionable," the map user should consult the geologic map database for more complete information.

4.1.4 Cartographic Representation of Scientific Confidence

For most types of geologic map features, queries are used to communicate the lack of scientific confidence in a feature. A queried line symbol indicates that either the identity or the existence of a planar or linear feature may be in question (Figs. 1,2; see also, Appendix A); the map user should consult the geologic map database for more complete information. In contrast, a line symbol without a query most likely indicates that both the identity and the existence of a planar or linear feature are certain, unless otherwise stated in the geologic map database.

For geologic point data, queries are not added to point symbols to indicate that the scientific confidence of a feature may be in question. However, a limited amount of specialized symbology has evolved to express the scientific confidence of certain types of geologic point information; for example, to indicate that the direction of stratigraphic top is known, a small ball may be added to bedding and foliation symbols (see Appendix A, Sections 6 and 8, respectively). In addition, queries may be added to dip or plunge values, both on the geologic map and in the geologic map database, if those measurements are questionable.

A queried map-unit label indicates that either the identity or existence of the geologic map unit may be in question.

4.2 LOCATIONAL ACCURACY

Locational accuracy is based on the relation between a mapped feature's location in the field and its position on the base map. Information about the locational accuracy of mapped features is important to all disciplines, even those in which mapped features commonly are directly observable and can be positioned with a significant degree of accuracy (for example, roads or utilities). It is especially critical in the natural sciences, however, because many mapped features are either interpretive or not directly observable.

The process of locating a feature in the field and then positioning it on a base map is complex, and the locational accuracy of a mapped feature is not easily described or quantified. To evaluate the locational accuracy of a mapped feature, a geologist must consider the following three factors:

- the nature of the feature and its degree of exposure (for example, a contact may be gradational or sharp, and either poorly exposed or well-exposed);
- the quality of the base map (for example, whether the cultural or topographic features on the base map are positioned accurately, according to the geologist’s observations);
- the confidence in accurately positioning the feature relative to the base-map information.

Together, these factors determine a geologist's confidence in the locational accuracy of the features on the map. Locational accuracy is expressed by two distinct but related concepts, *locatability* and *positioning*.

4.2.1 Locatability

Locatability expresses whether or not a geologist can clearly observe a feature *in the field*, as indicated by the following examples:

- a planar or linear feature is observable in several outcrops along its trace;
- a planar or linear feature is not defined by a distinctive physical trace and so is not observable beneath either vegetation, a thin veneer of unmapped geologic material (colluvium, eolian deposits, or residual soil), or man-made features, therefore its location must be inferred by indirect means;
- a planar or linear feature is not observable because it is concealed by an overlying geologic map unit, water, or ice, although it may be observable nearby (for example, a thrust fault is visible on both sides of a glacial valley, but its location within the valley is concealed by glacial deposits), and so its location must be projected beneath the overlying map unit.

As the above examples show, uncertainty in a feature's locatability can arise in a number of geologic situations. The concept of locatability is communicated in the following two ways:

- in the geologic map database, the attribute describing the confidence in a feature's locatability is specified as either *observable*, *inferred*, or *concealed*;
- on the geologic map, the confidence in a feature's locatability is communicated in the symbol explanation and (or) the map unit description (see Section 4.2.3 below, entitled "Levels of Locational Accuracy") and also, for some types of geologic map features, conveyed cartographically (see Section 4.2.4 below, entitled "Cartographic Representation of Locational Accuracy").

4.2.2 Positioning

Positioning expresses the degree of confidence with which a feature is plotted *on the base map*. Commonly, a feature can be accurately plotted on the map because the base-map information is accurate, detailed, and distinctive. However, in some field situations, a feature cannot be confidently plotted on the base map, as indicated by the following examples:

- a feature is observable, but its position on the map cannot be plotted accurately because topographic contours, drainage lines, or cultural information on the base map is insufficiently detailed for the feature to be confidently located relative to the various base-map features (for example, a contact is observable in outcrop, but its location in relatively featureless terrain prevents its position from being plotted accurately on the base map);
- a feature is observable, and its geographic coordinates can be determined in the field by either triangulation or a Global Positioning System (GPS) device or in the laboratory by using a georeferenced aerial photographic stereopair; however, the geographic relation between these coordinates and the topographic or cultural setting shown on the base map is not compatible (for example, a feature was mapped on a hillside, but the GPS-derived coordinates, when plotted on the base map, place its position in a valley bottom).

In such situations, either a feature can be plotted relative to the indistinct or incompatible base-map features, or the locations of topographic contours or other base-map features can be adjusted (the latter approach is not encouraged unless it is done systematically and is well-documented). In either case, the inherent uncertainty in a feature's positioning must be communicated to the map user, both on the geologic map and in the geologic map database (see discussion in Section 4.2.2.1 below, entitled "Specifying Positional Accuracy with the Zone of Confidence").

In the USGS, stringent policies for the accuracy with which an observable feature can be positioned on the base map have been put forth in the past. For example, Chief Geologist W.H. Bradley's 1956 memorandum to the staff advocated a geologic map accuracy standard based on the United States National Map Accuracy Standards (NMAS) for topographic and other types of base maps. The geologic map adaptation of the NMAS stipulated that "features that … can be located from exposures or other evidence [should be positioned] within 1/25 inch [on the map] of their true map position" (W.H. Bradley, written commun., 1956; see also, U.S. Geological Survey, 1995a, Part 1, p. 1.0-4). These earlier efforts to quantify the positional accuracy of geologic features were not widely adopted by the geoscience community, likely in part because of (1) the difficulty in translating to geologic mapping a concept designed for topographic and other types of base maps, (2) the impracticality of requiring that all geologic map information meet the same accuracy criteria uniformly across the Nation, in all types of geologic and topographic settings, and (3) the need to convert ground distance to publication-scale cartographic units before evaluating if a feature is plotted accurately on a base map.

In contrast, this standard advocates a more flexible and conceptually simpler approach in which the accuracy criteria can be defined for each project so that the specified positional accuracy takes into account the character of the geologic setting and other factors (see below). In addition, if the geologic map adaptation of the NMAS (1/25 inch on the map) has been used when mapping, this value can be specified (1/25 inch on the map must first be converted to ground units).

4.2.2.1 Specifying Positional Accuracy with the Zone of Confidence

When a feature is drawn or digitized onto a base map, a geologist commonly has some sense of confidence regarding whether or not the feature is positioned accurately, depending on the quality of the base map and the ability to position features on that base map. This positioning confidence can be characterized as the likelihood that the feature actually occurs within a certain, roughly defined distance from where it is positioned on the base map. This hypothetical distance, which extends outward from a feature’s position on the map, is herein defined as the *zone of confidence*, and its numerical value quantifies a feature’s positional accuracy as follows:

- for planar and linear geologic features, the *zone of confidence* borders the feature along both sides, forming what is described in GIS terminology as a buffer zone, and its numerical value is specified as the approximate distance in ground units (feet or meters) from the feature to the edge of the buffer zone (Fig. 3);
- for geologic point features, the *zone of confidence* is concentric around the feature, forming a circle, and its numerical value is the approximate radius of that circle (Fig. 3).

For any geologic map or mapped area, the numerical value of the zone of confidence will depend on a number of factors: the area's geology, landscape terrain, vegetation cover, and (or) cultural features; the scale of mapping; the quality and nature of the base map used; and (or) a particular project's allotted field-mapping time or other logistical constraints. Because this standard recognizes that the factors affecting the value of the zone of confidence will vary from region to region (and from map to map), and because different agencies have differing mapping needs and mandates, a single, universally applicable value for the zone of confidence is not herein established. Instead, this standard advocates that the responsibility for setting the value of the zone of confidence for a particular geologic map or mapped area lies with each geoscience organization and each mapping geologist.

In the geologic map database, the attributes describing positioning confidence, which are expressed in terms of the zone of confidence, are as follows:

- a numerical value for the zone of confidence is specified (for example, *5 meters*);
- a feature's positioning is specified as being either "*within zone of confidence*" or "*may not be within zone of confidence*" (note that this standard does not stipulate that a feature whose positioning is specified as "may not be within zone of confidence" must *necessarily* be located outside the zone of confidence, but simply that it *may* be).

On the geologic map, positioning confidence is communicated in the symbol explanation and (or) the map unit description (see Section 4.2.3 below, entitled "Levels of Locational Accuracy") and also, for some types of geologic map features, conveyed cartographically (see Section 4.2.4 below, entitled "Cartographic Representation of Locational Accuracy"). In addition, the numerical value of the zone of confidence is indicated, either in a general statement (if one value applies to the entire mapped area) or shown in an index map (if different values apply to different mapped areas; see Section 4.2.2.2 below, entitled "Accommodating Different Values of the Zone of Confidence"). Likewise, if the geologic map adaptation of the NMAS (1/25 inch on the map, converted to ground units) has been used during field mapping as a measure of positioning confidence, or if a zone of confidence was not used during field mapping or map compilation, this also is indicated.

Symbol style[1]	Examples of historically used terminology	Newly revised FGDC standard terminology	Scientific confidence		Locational confidence	
			Identity …	Existence …	Location (in field) …	Position (on map) …
————————	certain; known; accurately located	identity and existence certain, location accurate[2]	certain	certain	observable	within zone of confidence[6]
————?————	[not available for newly defined symbol]	identity or existence questionable, location accurate	may be questionable	may be questionable	observable	within zone of confidence
— — — — — — —	approximately located	identity and existence certain, location approximate[3]	certain	certain	observable	may not be within zone of confidence
— — —?— — —	approximately located, queried	identity or existence questionable, location approximate	may be questionable	may be questionable	observable	may not be within zone of confidence
- - - - - - - - - - - - -	inferred; probable; projected	identity and existence certain, location inferred[4]	certain	certain	inferred (between outcrops or beneath rubble or vegetation)	may not be within zone of confidence
- - -?- - -?- - -?- - -	inferred, queried	identity or existence questionable, location inferred	may be questionable	may be questionable	inferred (between outcrops or beneath rubble or vegetation)	may not be within zone of confidence
······························	concealed; projected	identity and existence certain, location concealed[5]	certain	certain	concealed (beneath overlying map unit, ice, or water)	may not be within zone of confidence
······?······?······?······	concealed, queried	identity or existence questionable, location concealed	may be questionable	may be questionable	concealed (beneath overlying map unit, ice, or water)	may not be within zone of confidence

[1] Queries are added to symbols to indicate that a feature's scientific confidence (that is, either its identity or its existence) may be in question.

[2] The term "location accurate" is used when a feature is observable, and its plotted position on the map is within the zone of confidence.

[3] The term "location approximate" is used when a feature is observable, but its plotted position on the map may not be within the zone of confidence.

[4] The term "location inferred" is used when a feature's location must be inferred between outcrops or beneath rubble or vegetation, and so its plotted position on the map may not be within the zone of confidence.

[5] The term "location concealed" is used when a feature is concealed beneath an overlying map unit, ice, or water, and so its plotted position on the map may not be within the zone of confidence.

[6] The zone of confidence for a particular map or mapped area is specified by the mapping geologists and their agencies.

Figure 1. Diagram showing relation of new FGDC standard terminology to historically used terminology and to traditional line symbol styles.

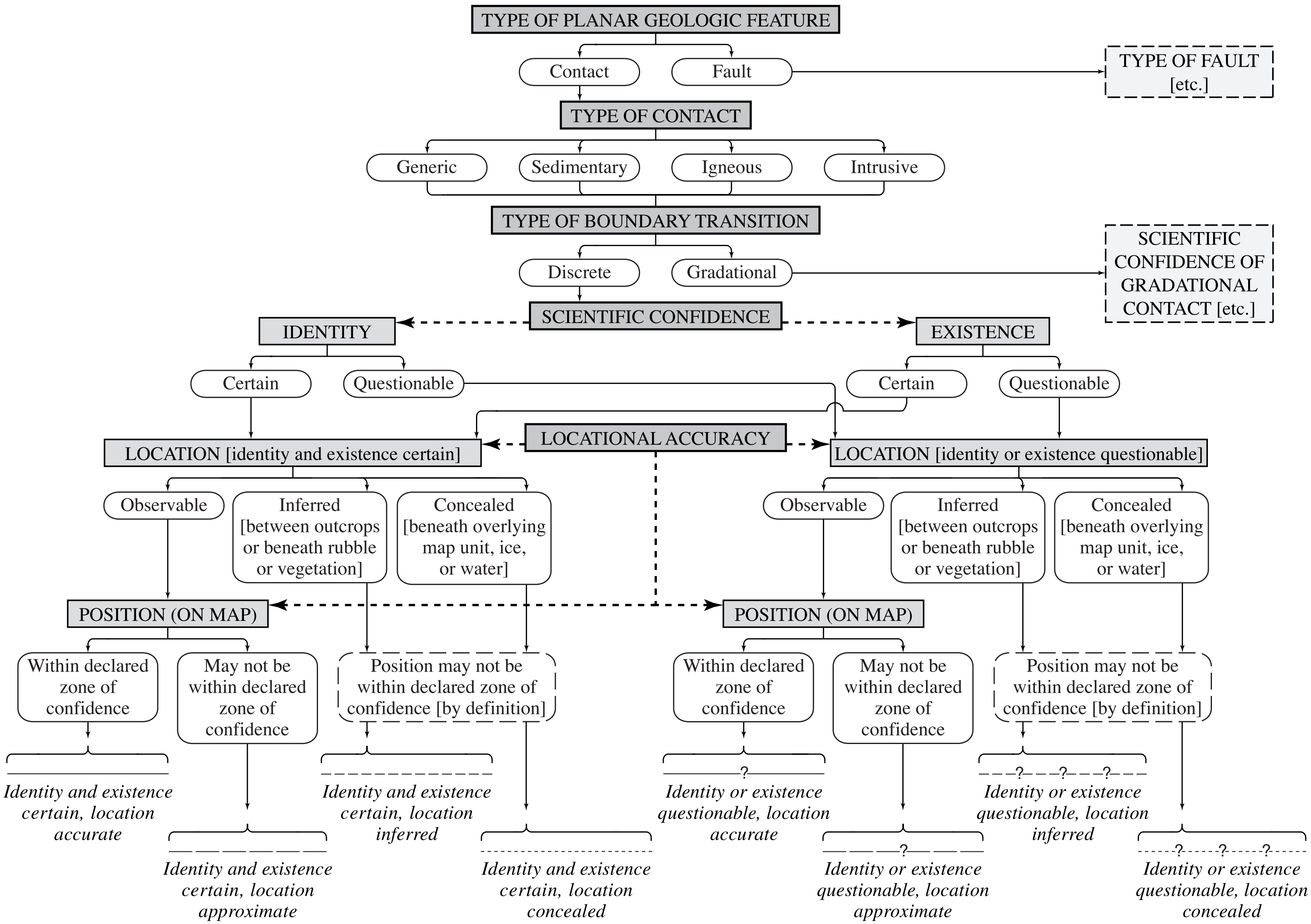

Figure 2. Flowchart showing example of logical steps that might be used to determine appropriate line symbol styles and associated terminology (in italics).

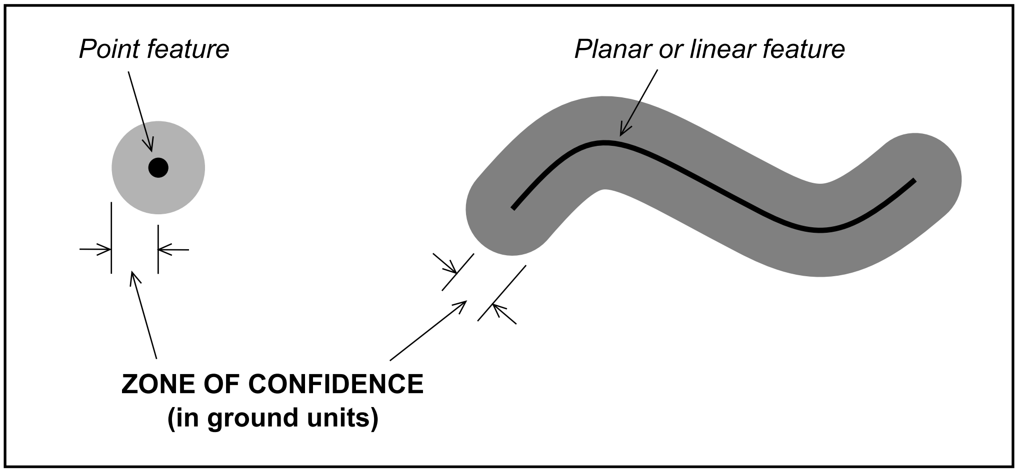

Figure 3. Figure showing examples of the zone of confidence for planar, linear, and point features. The region within which a *point* feature can be considered to be accurately positioned (on a base map) is a circle (light-shaded area above) around the point, and the value of the zone of confidence is the radius of that circle, in ground units. For a *planar* or *linear* feature, the region is a buffer zone (dark-shaded area above) surrounding the line, and the value of the zone of confidence is the distance from the line to the edge of the buffer zone, in ground units.

- a planar or linear feature is observable in only a few outcrops along its trace, but its physical characteristics permit locating it between outcrops by indirect methods;

4.2.2.2 Accommodating Different Values of the Zone of Confidence

For many geologic maps or mapped areas, especially those that are defined by latitude and longitude (for example, quadrangle maps) or political boundaries (for example, state or county maps), one map may contain areas of vastly contrasting geology, topography, vegetation cover, and (or) societal infrastructure, and so different positional accuracy criteria can exist within a single map. For example, a geologic map may include both a mountain range underlain by well-bedded sedimentary rocks and a broad alluvial valley underlain by mostly surficial deposits. In the mountains, clear distinction among the sedimentary rocks, as well as their high relief, may provide a geologist with a significantly higher sense of confidence in the position of contacts than in the adjacent valley, where few topographic landmarks or contours exist and where contacts may be gradational and obscured by vegetation and soil cover. In geologic settings as diverse as these, the levels of confidence in positional accuracy will be different, and so a geologist has the following two choices:

- express the differences in positioning confidence solely by differences in symbology (for example, specify one zone of confidence value for both areas, which might result in mostly solid-line contacts in the mountains and mostly dashed- or dotted-line contacts in the valley);
- express the differences in positioning confidence by specifying different values of the zone of confidence for each area (for example, specify the zone of confidence value as 5 meters in the mountains and 15 meters in the valley).

The choice might depend on the magnitude of the difference between the areas, or on the geologist's level of confidence in the positional accuracy of features across the map area.

Map compilations represent another example where different positional accuracy criteria can exist within a single map. A map compilation is made up of several source maps or mapped areas, each of which may have had a different value specified for the zone of confidence (or perhaps no value had been specified). These variations in the specified value of the zone of confidence should be preserved in the map compilation as well.

In situations in which the numerical values of the zone of confidence are different for different areas across the geologic map, the differences must be communicated to the map user. In the geologic map database, variations in the value of the zone of confidence can be readily accommodated because each feature is assigned (as an attribute in the database) the value of the zone of confidence that has been specified for a particular area. On the geologic map, areas that have different values of the zone of confidence should be shown in an index map.

4.2.3 Levels of Locational Accuracy

A geologic map must communicate to the map user the level of locational accuracy associated with each mapped feature (both its locatability in the field and its positioning on the base map). In the geologic map database, this information is contained in the following three attribute fields: (1) locatability (*observable*, *inferred*, *concealed*); (2) positioning (*within zone of confidence*, *may not be within zone of confidence*); and (3) the numerical value of the zone of confidence (for example, *5 meters*).

To facilitate the communication of the two concepts of locatability and positioning on a geologic map, this standard sets forth the following revised terminology, which expresses clearly yet concisely the levels of locational accuracy of geologic features (see Figure 1 for the relation of this revised terminology to historically used terminology):

"*Location accurate*"	A feature is observable, and its plotted position on the map is within the declared zone of confidence. These criteria are met, for example, when a geologist reasons, "*I can clearly see this contact in outcrop, and I can accurately plot its position on the map.*" This is the default condition for all geologic map features unless otherwise stated on the geologic map or in the geologic map database.
"*Location approximate*"	A feature is observable, but its plotted position on the map may not be within the declared zone of confidence. These criteria are met, for example, when a geologist reasons, "*I can see this contact in outcrop, but I can't tell exactly where it is located because I am surrounded by trees*," or, "*I can see this contact in outcrop, but the poor quality of my base map prohibits me from accurately plotting its position*," or, "*I can see that the width of the gradational contact between these two map units exceeds my value of the zone of confidence, and so, although my base map is of high quality, my confidence in the accuracy of its plotted position is not high.*"
"*Location inferred*"	A feature is not directly observable between outcrops or beneath rubble or vegetation, so its location must be inferred by indirect means; by definition, its plotted position on the map may not be within the declared zone of confidence. These criteria are met, for example, when a geologist reasons, "*I can see by the change in debris materials visible around these gopher holes that a contact runs through here, but I can't locate it very precisely.*"
"*Location concealed*"	A feature is not observable because it is completely concealed beneath an overlying map unit or body of water or ice (although it may be observable nearby); by definition, its plotted position on the map may not be within the declared zone of confidence. These criteria are met, for example, when a geologist reasons, "*I can see that a contact is present on both sides of this lake, but I can't tell where it is located beneath the water.*"

This revised terminology is intended to be used when choosing a particular style of symbol to represent a feature on a geologic map (Fig. 2), as well as when describing that feature in the symbol explanation (see Preface to Appendix A) and (or) the map unit description.

4.2.4 Cartographic Representation of Locational Accuracy

A system of solid, dashed, dotted, and queried line symbols has long been used on geologic maps to convey the uncertainty of planar and linear geologic features (Fig. 1), but it has not always been clear whether these line symbol styles reflect uncertainty in a feature's scientific interpretation, its mapped location, or both. This standard clarifies the use of these line symbols (Figs. 1,2) by applying its revised terminology for locational accuracy (see Section 4.2.3 above, entitled "Levels of Locational Accuracy") to the following line symbol styles[2]:

- a solid, continuous line symbol indicates that the location of a feature is accurate; that is, its location in the field either is readily observable in outcrop or is revealed by the characteristic geomorphic expression of its trace, without extensive cover of thin overlying surficial deposits, and is verifiable by shallow excavations; in addition, it can be accurately plotted because base-map information is accurate, detailed, and distinctive, and so its position on the base map is within the declared zone of confidence.
- a long-dashed line symbol indicates that the location of a feature is approximate; that is, its location in the field either is readily observable in outcrop or is revealed by the characteristic geomorphic expression of its trace, without extensive cover of thin overlying surficial deposits, and is verifiable by shallow excavations; however, it cannot be accurately plotted because base-map information is inaccurate, indistinct, or incompatible with the location of the geologic feature, and so its position on the base map may not be within the declared zone of confidence.
- a short-dashed line symbol indicates that the location of a feature is inferred; that is, its location in the field generally is obscured by overlying (unmapped) surficial deposits, debris materials, or vegetation that may cover exposures and the geomorphic expression of its trace, and has therefore been projected between few outcrops; by definition, its position on the base map may not be within the declared zone of confidence.
- a dotted[3] line symbol indicates that the location of a feature is concealed; that is, its location in the field is covered by a mapped overlying geologic unit or a mapped body of ice or water; by definition, its position on the base map may not be within the declared zone of confidence.

These types of line symbol styles (solid, long-dashed, short-dashed, and dotted) are intended to convey the various levels of locational accuracy of planar geologic features and certain types of linear geologic features.

The locational accuracy of a geologic map unit is not expressed by a specialized symbol but, instead, by the style of line symbols representing the planar features (contacts and faults) that bound it.

In most cases, specialized point symbols are not used to indicate that the locational accuracy of a geologic point feature may be in question. One exception is the specialized symbols that are used to portray bedding attitudes that have been determined using aerial photographs (see Appendix A, Section 6); however, these symbols also may be used to indicate that the scientific confidence (the measurement of dip) is in question, and so, when these types of symbols are used on a geologic map, the map user should consult the geologic map database for more complete information.

5. GUIDELINES FOR MAP COLOR AND PATTERN SELECTION

The goal in color design is to enhance the legibility of the map, as well as to lend meaning to the data presented by helping to focus attention on a particular map feature or group of features. Colors and patterns should not, however, be so visually dominant as to distract from the purpose of the map. A well-balanced color design can greatly improve the presentation of scientific information.

5.1 FACTORS THAT INFLUENCE COLOR AND PATTERN SELECTION

5.1.1 Purpose of Map

Color is used differently on different types of maps. For example, on geologic maps, color is primarily determined by age and type of rock, although other rules may apply for terrane maps or maps that portray only a

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[2] Note that this standard restricts the use of queries to represent the lack of scientific confidence only (see discussion in Section 4.1.4 above, entitled "Cartographic Representation of Scientific Confidence").

[3] In reality, dotted line symbols that are thinner than a certain lineweight are difficult to produce with some software applications; therefore, this standard substitutes a very-short-dashed line symbol as the cartographic standard (see Figures 1,2; see also, Appendix A).

limited range of ages or types of rocks. In addition, some map units, because of their geologic or economic importance, may need to be emphasized by selected colors.

Geophysical maps use several color schemes, depending on the purpose of the data being shown; usually a range of colors from dark to light is used. One such scheme is a graduated set of hues of similar value (for example, purple and magenta to orange and red). Another is a rainbow of hues in which the values alternate between full color and lightly screened color.

On slope-stability maps, the brightest colors are used on areas of highest instability. Similarly, on volcanic- or earthquake-hazard maps, areas of greatest hazard usually are shown in red, whereas areas of lowest hazard are shown in yellow or green.

Data on hydrologic maps are frequently shown in two or three colors. On maps showing depth to water table, color ranges from light blue at the shallowest depths to dark blue at the greatest depths. On maps showing dissolved-solids concentrations, color ranges from dark blue where concentration is lowest to dark red where concentration is highest.

5.1.2 Age and Type of Rock

Whenever possible, colors for ages and rock types on geologic maps should follow the scheme presented in the diagram showing "Suggested Ranges of Map-Unit Colors for Volcanic and Plutonic Rocks and for Stratigraphic Ages of Sedimentary and Metamorphic Rocks" (see Appendix A, Section 33). However, it may not always be feasible to show map units in the suggested color; in these cases, other characteristics should be emphasized with color.

On surficial maps, for example, it may be desirable to show all glacial deposits in one color, landslide deposits in another, lacustrine deposits in another, and alluvial deposits in yet another. On terrane maps, color may be used to show lithotectonic relations between various groups of rocks.

On maps that are mostly one age group, it is best to distinguish sedimentary rocks from volcanic rocks (usually shown in reds or other bright colors) and plutonic rocks (usually shown in pinks). On maps that are mostly one type of rock, differentiation between different rock sequences can be shown through the use of different colors.

On maps that cover a broad range of ages and rock types, relations between rocks within one age group can be shown by using similar colors, whereas relations between the same type of rock in different age groups can be shown by using patterns (for example, all volcanic rocks may have the same "v" pattern). Patterns should be used sparingly, however, as their use can create an overly busy appearance; use them only when the complexity of the map requires the diversity achieved by the use of patterns.

Although it is preferable to follow the aforementioned guidelines, some rock types defy such guidelines because they traditionally have been shown in a particular color. For example, serpentinite and other ultramafic rocks characteristically are shown in purple; limestone usually is shown in bright blue; and glacial till often is shown in light green.

5.1.3 Size of Map-Unit Areas

In general, small map-unit areas should be shown in darker colors and large areas should be shown in lighter colors. An exception to this may be in situations when numerous small bands of map units are shown; in this case it may be best to alternate light and dark colors. In the case of map units that consist of both large and small areas, add labels and leaders to the smaller map units to avoid confusion. For guidelines and recommendations on the placement of map-unit labels and leaders, see Section 6 below, entitled "Guidelines for Map Labeling."

Because it is more difficult to clearly distinguish color in small areas, it is very important to choose as unique a color as possible for map units that are present only in small areas. The minimum size of map-unit area that can show color is about two square millimeters; anything smaller will need to be labeled. In addition, exercise caution when using patterns in small areas because small areas may fail to show enough of the pattern to adequately identify a map unit; about one square centimeter is the minimum size to clearly show patterns. If there can be any ambiguity in a map-unit area's identification, it is safest to add a label and leader.

5.1.4 Contrast

Adequate contrast enhances readability. A key factor is not so much the difference in hue, such as blue or green, but the difference in intensity. Contrast should not, however, be so great as to be glaring, but it should be significant enough for easy legibility. Map units that need to be emphasized should be assigned colors that stand out and contrast well with the colors of less important units. In addition, greater contrast is required for small areas, whereas a more subtle contrast is sufficient for larger areas.

5.2 SPECIFYING COLOR FOR MAP-UNIT AREAS

To maintain control of color output, color on maps and illustrations should always be specified using process-color (CMYK, cyan/magenta/yellow/black) inks, regardless of the intended output medium. If another non-ink color scheme such as RGB (red/green/blue) or HSV (hue/saturation/value) is used, then the output device (be it printer, plotter, or imagesetter) will automatically convert the non-CMYK values to CMYK during output, and unwanted color shifts often will take place. To aid in the selection of color fill for map units, a chart showing a wide variety of CMYK colors ("CMYK Color Chart") has been included herein.

Color values must be high enough to provide adequate contrast but not so great that they prevent the map-unit labels, structure symbols, and topographic base from showing clearly. Except in small areas, magenta and cyan should be used in intensities of 50% or less. A greater intensity of cyan might obscure drainage features (commonly shown in cyan), and a greater intensity of magenta might obscure magenta fold axes and dikes. As a general rule, use a combination of CMYK color values that, when added together, totals 100 or less (for example, 30% cyan/40% magenta/20% yellow; 30/40/20 = 30+40+20 = 90), especially in larger areas.

To maintain enough contrast between two colors, keep at least a 20% difference between the values of one of the CMYK colors (for example, 30% cyan/8% magenta/20% yellow and 30% cyan/8% magenta/40% yellow).

Avoid using 8% yellow because it is too light and cannot easily be distinguished from white. In addition, it may be wise to avoid using 13% or 20% cyan, as these colors may look like a body of water.

On maps that are to be offset printed, it may be best to use a solid (100%) single-ink color such as cyan, magenta, or yellow in very small map-unit areas to avoid misregistration problems. For example, 100% cyan may be used to show small limestone blocks in melange, or 100% magenta may be used to show thin rhyolite intrusions.

5.3 USE OF PATTERNS

Patterns can be printed either in black, in color, or as a dropout. Ideally, patterns should be used sparingly and only when necessary for clarification, as they can add unnecessary complexity to a map. To select appropriate patterns for a map, both the type of rock and the size and (or) orientation of map-unit areas must be considered. To aid in the selection of patterns for map units, a chart showing a wide variety of geologic patterns ("Pattern Chart") has been included herein.

Although some flexibility exists in the use of patterns, some patterns are traditionally and exclusively used for certain rock types: for example, "+" patterns are used for plutonic rocks, and irregular "v" patterns represent volcanic rocks. For map units that are present only in small areas, a tight, random pattern will fit more of the pattern elements into a particular area. Exercise caution, however, when choosing metamorphic patterns that display a strong directionality, as their use may imply a general orientation of metamorphic fabric that in reality is much more varied than the pattern may indicate.

5.3.1 Overprint Patterns

Color overprint patterns are usually specified in either cyan or magenta, but sometimes a spot color such as red is used. For offset printing, it is best to specify only one color for overprint patterns, as using more than one color can cause misregistration problems. Color overprint patterns can be screened to reduce their intensity.

Black overprint patterns are less effective than color in most situations, as they can conceal base-map information or interfere with type or structure symbols. Thus, it may be best to restrict the use of 100% black patterns to small, uncluttered areas; if a map-unit label is needed, it can be placed outside the area and leadered in. Black overprint patterns also can be screened to reduce their intensity.

5.3.2 Dropout Patterns

Dropout patterns cause to be transparent one or more of the CMYK colors that combine to make a map-unit color, thus allowing the remaining color(s) to show through. Their use can be especially effective on a map that has a large amount of labeling or many structure symbols.

For offset printing, only one color should be dropped out, as dropping out more than one might lead to misregistration problems; in general, the most dominant color (the one with the highest value) other than yellow should be the one dropped out. For output to a single-pass inkjet plotter, a dropout pattern may be applied to all of the CMYK colors that make up a map-unit color; the dropout pattern would then show as white. Be aware, however, that doing so may cause that map unit to stand out more than is desired.

5.4 SPECIFYING COLOR FOR LINE AND POINT SYMBOLS

Color commonly is specified for many line and point symbols because it highlights these features. Whenever possible, color for line and point symbols should be specified as either 100% cyan or 100% magenta, two of the standard four process-color (CMYK, cyan/magenta/yellow/black) inks that are used for offset printing and in most inkjet plotters (other non-ink color schemes such as RGB or HSV should be avoided so that unwanted color shifts during output are prevented). In some cases, however, it may not be practical or preferable to specify cyan or magenta; for example, mineral resource assessment areas traditionally have been outlined in red.

Although it is possible to make a non-process color such as red from two or more process-color inks, this should be avoided if the map is to be offset printed because of the difficulties in registering large, CMYK-separated negatives. For maps that are to be offset printed, a Pantone color (single-ink spot color) should be specified. Each Pantone color is imageset onto a separate piece of film, thereby avoiding misregistration problems caused when a color is converted to CMYK and then is color separated onto more than one piece of film.

6. GUIDELINES FOR MAP LABELING

Map-unit labels are the most common labels on geologic maps. Other labels may include base-map information, feature names, and data items such as dip values, gold concentrations, well depths, radiometric ages, and sample locality numbers.

Before the advent of digital technologies for mapmaking, labels were either drawn by hand or applied using stick-up type. Nowadays, using digital mapmaking techniques, labels (and leaders) can be automatically plotted from information in a database; however, this often results in labels overprinting other map features, requiring them to be interactively repositioned or deleted. Regardless of the method employed, effective label placement is an important factor in producing a useful map.

6.1 STRATEGIES FOR MAP LABELING

Enough features on the map should be labeled so that the reader can identify all the various map elements; no unlabeled feature should leave the reader guessing. Labels (and leaders) should not, however, create an overly "busy" or cluttered appearance, which makes recognition of map patterns, shapes, and map-element distribution difficult to discern. For a map to be easily read, labels and leaders should be placed where they are clear and legible, taking care to avoid overprinting of linework, symbols, or other labels. In addition, they should not obscure base-map features that are mentioned in the text or that may be useful in locating places on the map.

Commonly, color or pattern can be used to identify an unlabeled map-unit area if a nearby area of the same map unit is labeled. Therefore, the color and pattern selection is critical when deciding whether or not to label a particular map-unit area, and so it is important to complete the color and pattern design of the map before attempting to place and move map-unit labels, especially for complex maps or those that have many map units.

There are no precise rules for which and how many of the map-unit areas on a map should be labeled, but the following are some general guidelines. If a map unit has a unique and clearly distinguishable color or pattern, it is not necessary to label every area of that map unit. Color and pattern can carry the identification of a group of areas of the same unit as long as some of them are labeled. Use judgment when deciding whether the color for that map unit is distinctive enough and (or) whether a particular unlabeled map-unit area can be visually or logically associated with any nearby labeled areas of the same unit. In small map-unit areas, however, even the most distinctive color or pattern may be difficult to discern. If there might be any doubt, add a label and leader.

At least one area of every map unit within a "normal field of view" should be labeled. This field of view is the area in focus when the map is viewed at a comfortable, readable distance. In uncluttered areas of the map or in areas of relatively simple geology, this field of view might have a radius of about two or three inches; in geologically complex or cluttered areas, however, it may be much smaller. The reader should not need to search across the map trying to find a labeled map-unit area that has a color that matches an unlabeled map-unit area.

In addition, maps that are to be downloaded from the Web will be sent to a plotter of unknown type, and there is no guarantee that colors that appear distinct when plotted on your plotter will also be distinguishable when plotted on other plotters. The more map-unit areas that are labeled, the less chance of ambiguity and confusion.

6.2 FONT SELECTION

For most type on a map (for example, unit labels, dip values, and fault names), a sans-serif font such as Helvetica (or FGDCGeoAge; see Appendix A, Section 32) should be used. Other sans-serif fonts such as Univers or Arial also may be used, but consider that not all fonts will plot correctly on all output devices. Also consider that combining FGDCGeoAge with Univers or Arial will result in odd-looking character strings because the character size and kerning (spacing of letters) of FGDCGeoAge is based on that of Helvetica; therefore, using Helvetica with FGDCGeoAge is recommended. For base-map information, use a combination of sans-serif (for example, Helvetica or Univers) and serif (for example, Times or Times New Roman) fonts; the general rule is to follow the styles used on a published topographic map sheet.

When placing labels digitally, it is important to use the same font that will be used for final publication because the size and kerning of characters are different for different fonts, even those having the same point size. If labels are placed carefully in tight areas using one font, but then another font is used for final publication, the labels may overprint linework or other features because the new font may have longer character heights and string lengths. Therefore, for best results, choose fonts early in a project, and then stay with that choice throughout the project. In addition, the use of PostScript fonts may result in more consistent final output for both print and digital publications.

6.3 TYPE SIZE AND STYLE

The ideal size for map-unit labels is 8 pt, although labels as small as 6 pt may be substituted in places where space is tight. Fractional font sizes may be used if needed, and different sizes can be mixed on the same map. If unit labels contain subscripts or superscripts, the minimum unit-label size should be 7 pt; then the size for the subscript or superscript character would be 5 pt, two point sizes smaller.

Other sizes and styles are used to label different features. In general, use 8 pt type (all caps) for names of faults and major structures, for sample locality numbers and radiometric ages, and for fault (U/D, A/T) and contact (Y/O) ornamentation. Use 6 pt italic type for dip or plunge values. Use 12 pt italic type for cross-section labels. For labels of larger features, type size and (or) kerning (letter spacing) may be increased to improve legibility.

6.4 LABEL PLACEMENT

Map-unit labels and dip values should always be oriented horizontally. They should not overprint other map elements such as linework, point symbols, or any other dip values and labels, nor should they obscure base-map features that are referenced in text or are needed to orient the map in the field. Single labels can be used to identify more than one map-unit area; use multiple leaders where necessary.

Map-unit labels should not be placed in dark-colored map-unit areas or in densely patterned areas, both of which would make the labels hard to read; instead, move labels outside such areas and add leaders. If a label must be placed in a dark-colored or densely patterned map-unit area, it may be necessary to mask out the color or pattern around the label to help make it more legible.

Labels for linear map features should be aligned along those features. Other labels should have a logical or comfortable orientation relative to the map. In rare cases it might be desirable to have labels run parallel to lines of latitude, but in general they should be oriented horizontally.

6.5 LEADER PLACEMENT

Leaders should be drawn as straight lines, not bent or curved. They should cross map-unit area boundaries at as high an angle as possible, and they should not stop at the boundary but should extend well into the map-unit area. Leaders should not cross through other map-unit areas to reach a particular map unit unless absolutely necessary. Multiple leaders emanating from a single label should not be joined at their "label" ends.

7. TECHNICAL SPECIFICATIONS USED IN THE PREPARATION OF THIS STANDARD

This new standard (contained in Appendix A) consists of geologic line and point symbols, geologic map-unit colors and patterns, a geologic age symbol font, and related map marginalia. This section provides some technical discussion regarding preparation of the standard and its implementations.

7.1 UNITS FOR LINEWEIGHTS, LENGTHS, AND DISTANCES

In previous standards, lineweights were specified in thousandths-of-an-inch, which corresponded to the widths of the engraving tools used to scribe the linework. Most lengths and distances also were given in inches. In this standard, the cartographic specifications are given in millimeters, in accordance with the Federal standard for metrification.

When preparing this standard, the old thousandths-of-an-inch specifications were converted to millimeters (Table 1), and then most were rounded to the nearest .05 mm or .025 mm, for ease of use. Whenever possible, cartographic specifications for lengths and distances were given in whole- or half-integer values. However, when designing the symbol graphics in this standard document, as well as the symbols in its PostScript implementation, lineweights, lengths, and distances were specified electronically as points, and the exact conversion values (from inches to points; see Table 1) were retained.

As an example of the unit-conversion process, consider the symbol for faults, which in previous standards had a lineweight of .015" specified. This original lineweight was converted to millimeters (.015" = .381 mm; Table 1) and then rounded to .375 mm, which is the value given as the cartographic specification in this standard (see p. A–2–1, Appendix A). However, when preparing the fault symbol for inclusion in this standard document (and in its PostScript implementation), the exact .015" lineweight was retained and directly converted to points (.015" = 1.08 pt; Table 1), and so the symbol lineweight was defined electronically as 1.08 pt.

Complications from unit conversion can arise not just when designing line symbols but also when creating point symbols and patterns, as most symbols are made of stroked lines. When creating symbols for a particular application, the user should choose the unit of measure most easily used in an application and then use the conversion table (Table 1) to convert to those units.

7.2 TYPE SPECIFICATIONS

Most type in this standard is specified as either Helvetica (sans-serif) or Times (serif), two fonts that are commonly used and widely available (see Table 2 for abbreviations for type faces used in this standard); type sizes are given in points. Other fonts such as Univers, Arial, or Times New Roman may be substituted, but consider that they may not be installed on all common output devices and thus may not plot correctly.

Geologic age characters have been specified as FGDCGeoAge, a specialized sans-serif font designed by the U.S. Geological Survey (see Appendix A, Section 32). The character size and kerning (spacing of letters) of FGDCGeoAge is based on that of Helvetica; therefore, using Helvetica with FGDCGeoAge is recommended.

7.3 COLOR SPECIFICATIONS FOR LINE AND POINT SYMBOLS

Color has been specified as the cartographic standard for many line and point symbols in this standard, either because of adherence to a long-established color convention or because using color for features such as folds and dikes may help them to stand out better from other full-black linework such as contacts and faults. In most cases, another color or black may be substituted if the color specified as the standard would not be visible when printed over an underlying map-unit color.

Whenever possible, color has been specified as either cyan or magenta, two of the four process-color (CMYK, cyan/magenta/yellow/black) inks that are used both in inkjet plotters and for offset printing. However, in some cases it was not practical or preferable to specify cyan or magenta as the standard; for example, mineral resource assessment areas traditionally have been outlined in red (see p. A–19–1, Appendix A).

Although it is possible to make a non-process color such as red from two or more process-color inks, this should be avoided if the map is to be offset printed because of the difficulties in registering large, CMYK-separated negatives. Thus, in some cases a spot color (a single-ink, non-CMYK color) has been specified as the cartographic standard.

As a simple, general way of specifying spot colors, generic color names (for example, "red" and "green") have been used in this standard. Specifying color as these generic color names, however, may not be appropriate for use with certain output media. Therefore, the user must choose a method of specifying color that is appropriate for a particular output device; Table 3 shows suggestions for conversions of spot colors to other color models.

For maps that are to be offset printed, a Pantone color (single-ink spot color) should be specified (Table 3). Each Pantone color is imageset onto a separate piece of film, thereby avoiding misregistration problems caused when a color is converted to CMYK and then is color separated onto more than one piece of film. For output to an inkjet plotter, however, specifying a spot color as one of the generic color names is satisfactory because, during the plotter's RIP[4] of the file, the color will automatically be converted to the proper amounts of CMYK inks that will combine to make the CMYK equivalent of that color. Misregistration is not a problem with single-pass inkjet-plotter output.

If simple, graphical map elements are to be published as part of a web page on the World Wide Web, it may be best to choose colors from a "Web-safe" color palette[5] to avoid unwanted dithering on monitors that display only 256 colors (Weinman, 1996). As an aid in doing so, an attempt was made to provide "Web-safe" color equivalents of the Pantone spot colors used in this standard (Table 3). These "Web-safe" color equivalents are made up of the RGB (red/green/blue) values that are as close as possible to the directly converted RGB-equivalent colors (Table 3). Note, however, that it was impossible to exactly reproduce the directly converted RGB-equivalent colors because, to make "Web-safe" colors, there are only six possible RGB values (000, 051, 102, 153, 204, and 255) from which to choose.

7.4 COLOR SPECIFICATIONS FOR MAP-UNIT AREAS

To aid in the selection of color fill for geologic map units, a chart showing a wide variety of CMYK colors ("CMYK Color Chart") has been included in this standard. The CMYK Color Chart was designed in Adobe Illustrator 8.0.1 to closely replicate the colors on the offset-printed color chart entitled "Printing Colors and Screens in Use by the U.S. Geological Survey for Geologic and Hydrologic Maps" [yellow/magenta/cyan version], which has been in use for many years at the USGS. The new color chart contains the same colors that were in the original offset-printed USGS chart; however, the old color codes indicating the YMC (yellow/magenta/cyan) values have been updated to show CMYK (cyan/magenta/yellow, with K=0) values, to conform to industry standards. In addition, each color in the CMYK Color Chart has associated with it a generic lookup-table number that, if desired, may be used to access the color from within digital applications.

In addition, a diagram showing "Suggested Ranges of Map-Unit Colors for Volcanic and Plutonic Rocks and for Stratigraphic Ages of Sedimentary and Metamorphic Rocks" (see Appendix A, Section 33) has been included in this standard. This diagram was designed in Adobe Illustrator 8.0.1 to reproduce a similar diagram in the old USGS Technical Cartographic Standards volume (U.S. Geological Survey, ca. 1975). In this new version, however, the range of colors was modified slightly, a few new colors were added, and the old color codes were updated to show CMYK (cyan/magenta/yellow, with K=0) values.

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[4] RIP = raster-image processing, a process that runs on all plotters, printers, and imagesetters and converts data (in either raster or vector format) to printer dots to produce an image.

[5] Industry opinions on using "Web-safe" colors (8-bit, 216 colors) are changing, owing to the large number of monitors now in use that can display more than 256 colors; Chris MacGregor (*in* Dennis, 1999) stated that using non–"Web-safe" colors may be acceptable to use in detailed areas, although she still recommends using "Web-safe" colors in large areas.

7.5 PATTERN SPECIFICATIONS

The old USGS Technical Cartographic Standards volume (U.S. Geological Survey, ca. 1975) contained no cartographic specifications (lineweights, dot sizes, or size and spacing of pattern elements) for its patterns. The volume dates back to a time when maps were conventionally prepared using hand-scribed linework and peelcoats. In those days, patterns were preprinted onto large sheets of film, which were photomechanically combined with the various peelcoats to make the CMYK negatives.

For this standard, the patterns (see "Pattern Chart") were recreated by scanning the old pattern sheets and then tracing the pattern elements in Adobe Illustrator 8.0.1. For most patterns, black, cyan, and magenta versions, as well as dropout versions, were created; yellow versions were not created because yellow patterns are not visible over color fill. Also, red and (or) brown versions were created if red or brown patterns were specified as the cartographic standard for a particular feature. Glacial and hydrologic patterns were created only in cyan and black, as it is unlikely that magenta or other colors would be used for these types of patterns.

To facilitate digital output, lineweights and dot sizes were in many cases increased. A few pattern tiles were scaled to accommodate the increased lineweights, and some of the lined patterns were dropped because an increased lineweight would fill in the pattern and because an increase in scale would cause the pattern to be too similar to other patterns. The lineweights and dot sizes for the color and dropout versions were increased even more than for the black versions, to help them show more clearly on maps.

All patterns were renumbered, and suffixes indicating color were added so that all versions of the same pattern are referenced by the same number. In addition, each pattern in the Pattern Chart has associated with it a generic lookup-table number that, if desired, may be used to access the pattern from within digital applications.

7.6 GEOLOGIC AGE SYMBOL FONT

A digital font named FGDCGeoAge (see Appendix A, Section 32) has been created, in which 16 special geologic age characters have been substituted into positions of normal keyboard characters. These characters can be typed either directly or with the Shift key; no Option, Control, or Alt keys are needed to type these characters (they are all in lower-order ASCII positions that have character ID numbers below 128), allowing the same character positioning to work on different computer platforms without interfering with special control key sequences.

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