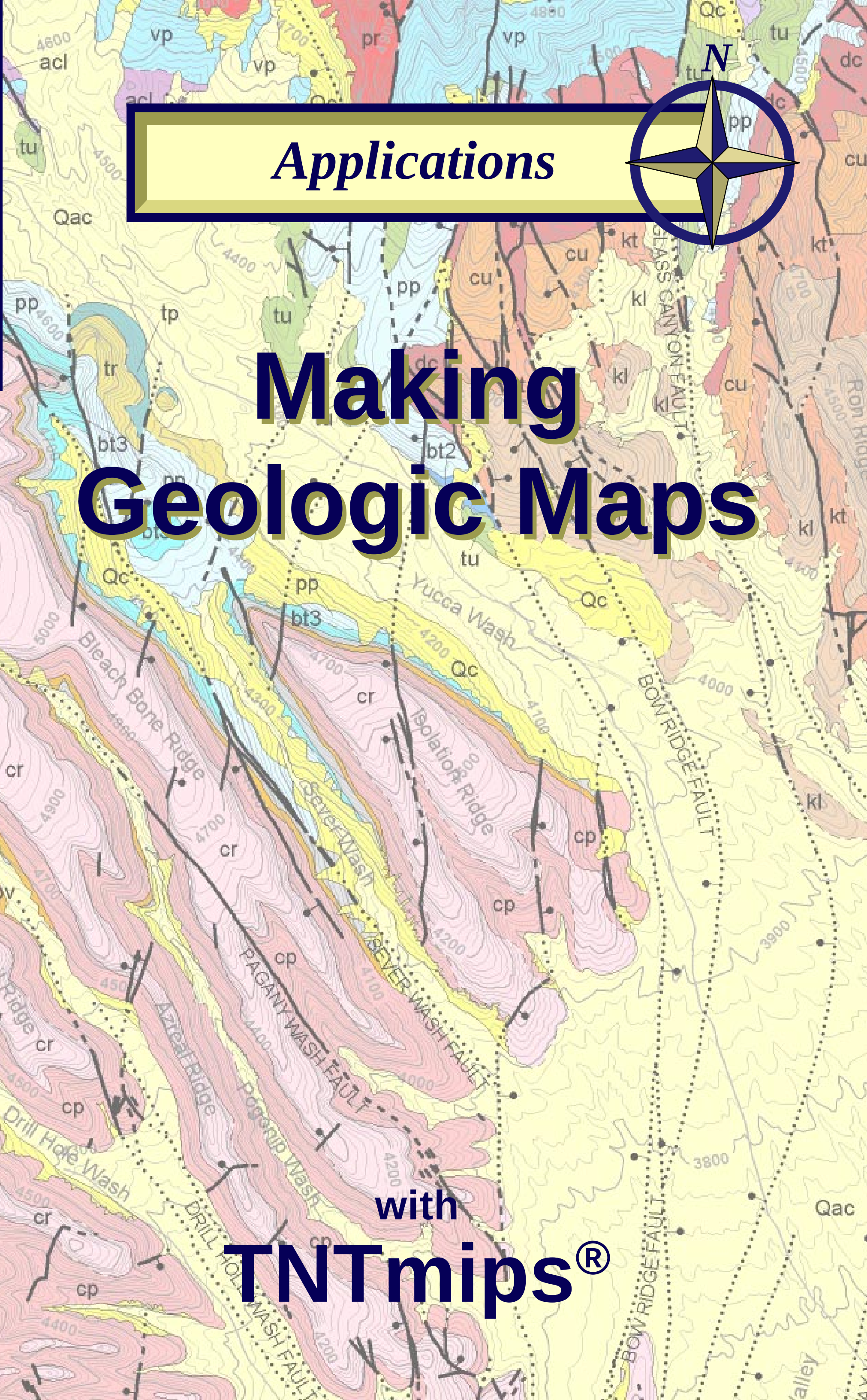
GEOLOGIC MAPS

Applications

Making Geologic Maps

with TNTmips®



Before Getting Started

TNTmips provides a variety of tools for working with geologic data and making geologic maps that can be printed or distributed as an electronic atlas. This booklet is intended as a general guide to making geologic maps in TNTmips. Using a sample geologic map layout, it discusses how the different data layers were prepared and assembled, and illustrates the type of results you can achieve with your own data using TNTmips.

Prerequisite Skills This booklet assumes that you have completed the exercises in the tutorial booklets *Displaying Geospatial Data* and *Navigating*. Those exercises introduce essential skills and basic techniques that are not covered again here. Please consult those booklets and the TNTmips reference manual for any review you need.

Sample Data The data used to prepare the map shown in this booklet are distributed as sample data with the TNT products. Although this booklet does not include exercises with step-by-step instructions on how to use this data, you may wish to view the different data layers and experiment with them before you begin working with your own geologic map data. In particular, this booklet refers to sample files in the GEOLMAP data collection.

More Documentation This booklet is intended only as an overview of useful strategies for preparing and assembling geospatial data layers to make geologic maps. As different tasks and procedures are discussed in the text, references are provided to appropriate tutorial booklets that provide exercises introducing the tools for performing those tasks in TNTmips.

TNTmips and TNTlite® TNTmips comes in two versions: the professional version and the free TNTlite version. This booklet refers to both versions as “TNTmips.” If you did not purchase the professional version (which requires a software license key), TNTmips operates in TNTlite mode, which limits object size and enables data sharing only with other copies of TNTlite.

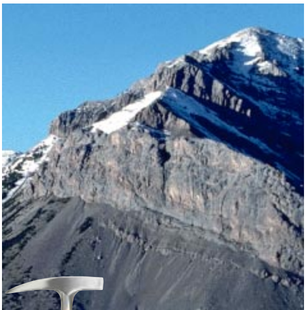
The individual spatial data objects in the sample GEOLMAP Project File are useable in TNTlite, but opening the saved layout requires TNTmips.

Randall B. Smith, Ph.D., 12 July 2002

It may be difficult to identify the important points in some illustrations without a color copy of this booklet. You can print or read this booklet in color from MicroImages’ Web site. The Web site is also your source for the newest Getting Started booklets on other topics. You can download an installation guide, sample data, and the latest version of TNTlite.

http://www.microimages.com

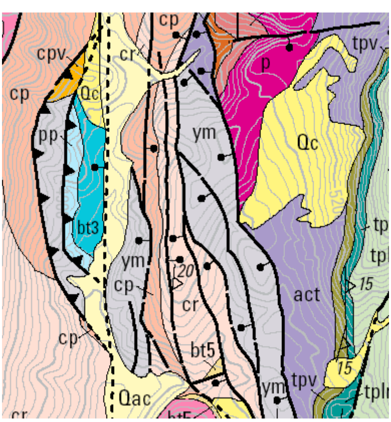
Welcome to Making Geologic Maps



Geological data plays a key role in the discovery and development of new sources of minerals and energy, evaluation of water resources, engineering assessment for construction projects, evaluation of risks from natural hazards, and environmental monitoring and remediation, among other applications. The starting point for all such studies is usually a geologic map of the relevant area.

A geologic map depicts the geologist's observations and inferences about the surface distribution, geometry, and structure of the various rocks and sediments in the area. The geologist usually gathers much of the information shown in a geologic map by examining rock outcrops in the field. The field data may be supplemented by interpretation of aerial photographs or satellite images and in some cases by analysis of geochemical samples or geophysical surveys.

In the past, manual methods were used for recording geological map data and preparing the final map. But modern computer software tools such as TNTmips can be used to streamline both of those tasks. And once the map data is in digital form, it can be interactively queried, readily combined with imagery or with map data from adjoining areas to aid interpretation, or distributed as an electronic atlas.

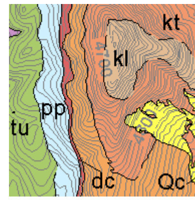


TNTmips provides a set of software tools that is uniquely suited to the tasks of recording and compiling varied types of geological map data and preparing the final geologic map layout. This booklet discusses general strategies you can use to record, organize, and format your own geologic data so that it can be easily assembled into a layout for printing or for distribution as part of an electronic atlas.

Components of a Geologic Map

Map Units

In making a geologic map, the geologist must recognize or define units or rock or surficial sediment that can be differentiated and mapped. The areas underlain by each unit are indicated on geologic maps by polygonal areas with distinctive fill colors and patterns. Each unit is also labeled with a text symbol that commonly encodes age information and an abbreviation for the unit name. If a particular unit polygon is too small for the text label to fit inside, it should be placed outside the polygon with a leader line connecting the two.

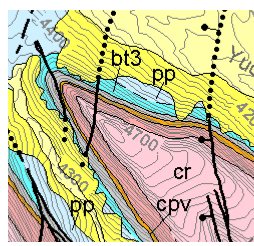


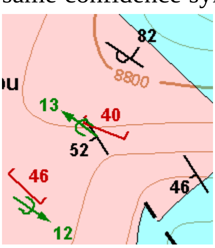
Contacts

The boundary lines between the map unit polygons represent the surface traces of geologic contacts. In many places contacts may be obscured by soil cover or younger sediment, so different line styles are used to indicate the geologist's degree of confidence in the contact location. Typically a solid line represents an exposed contact, a dashed line indicates an obscured (approximately located) contact, and a dotted line shows a contact covered by surficial sediments.

Structures

Mappable structures such as folds and faults are shown by line symbols on geologic maps. Different symbols are used for different varieties of folds (anticlines and synclines) and faults (normal, reverse, thrust, and strike-slip). Faults may coincide with unit contacts, and the same confidence symbology used for contact lines is commonly applied to line symbols for faults.





Measurements of the attitude of rock layers or other outcrop-scale structures can be shown on large-scale maps by special point symbols. The symbol indicates the type of structure and its orientation and numerical label show the measured attitude.

Other Elements

The base map information included in a geologic map usually includes labeled topographic contours (for large-scale maps), hydrographic features, and cultural features such as roads. A legend provides an explanation for the area, line, and point symbols and often an abbreviated description of the geologic units and their ages. A printed geologic map also requires standard cartographic elements such as scale information, map grid ticks with labels, and coordinate information.

Data Models for Geologic Maps

> Unlike some other GIS and mapping software, an individual vector object in TNTmips can include any or all types of vector element: points, lines, polygons, nodes, and labels. When you display vector objects in TNTmips, you can independently set up styling for each type of element. You can apply one style for all elements of that type, or base styles on attributes in related database tables.
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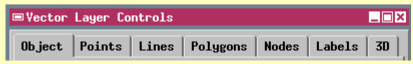
> 
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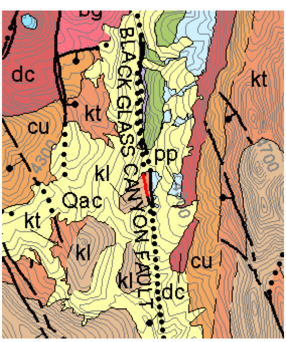
The geologic information shown on a geologic map can be represented most conveniently using the vector data format in TNTmips. Individual areas of map units can be represented as polygon elements with polygon labels; contacts, faults, and other linear structures can be represented as line elements; and observations at individual map locations can be represented as point elements.

Although the computer representation of the spatial elements of a geologic map is straight-forward, the relationships between the spatial elements and the associated geologic attribute information is commonly quite complex. As a relatively simple example, consider a line element that forms the boundary between two map unit polygons (red line in the illustration below). This line represents a contact located with some degree of accuracy. It might also be a particular type of contact, such as a normal fault with the west side downthrown. And that fault might be regionally significant and thus have a name. To convey all of this information, the line needs to have attributes for positional accuracy, fault type, and fault name. To reduce redundancy in the database, these attributes might be in different attribute tables related directly to the map elements or to each other. To avoid assigning attributes for upthrown and downthrown sides of dip-slip faults altogether, these faults might be digitized such that the downthrown side was always on the same side (left or right).



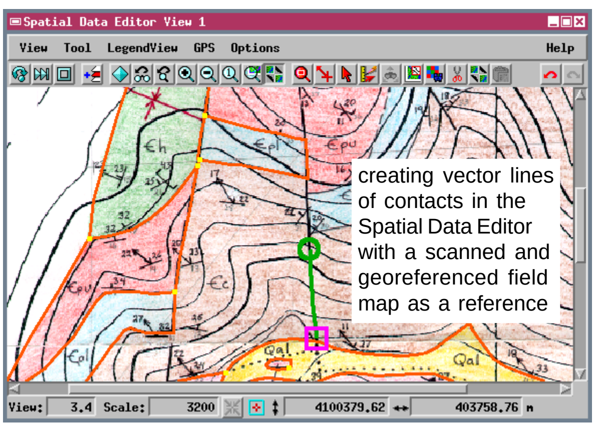
As government agencies around the world have begun the transition to digital geologic maps, they have attempted to develop appropriate relational database models that can efficiently and completely represent geological attributes. One such effort is the Digital Geologic Map Data Model under development by a committee representing the federal, state, and provincial geological surveys of the United States and Canada. A report on the current draft version is available at http://geology.usgs.gov/dm. This problem is not a simple one, and you will need to give considerable thought to the design of the attribute databases for your digital geologic map.

Digitizing Your Field Map

The Midway Valley geologic map included with this booklet was prepared entirely in TNTmips using publicly-available map data produced by the United States Geological Survey (USGS). (The map layout and all relevant data are in the MIDMAP Project File distributed with the booklet.) We will use this map to discuss and illustrate some of the issues and strategies involved in producing a digital geologic map. But let's assume you are working with your own geologic map data. How do you get your map data into digital form?

The method you use depends in part on how you are collecting the data. If you have recorded the map and outcrop data only in paper form (field map and field notebook), you will need to digitize the field map. You could use an external digitizing tablet to trace over and vectorize the contact lines, faults, and station locations, but for more accurate results you should try the heads-up digitizing method.

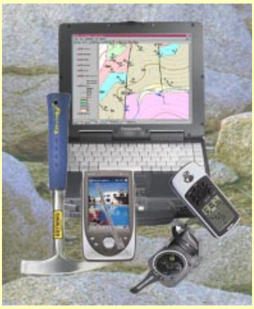
First scan your field map and georeference the resulting raster image of the map. You can then use the raster map as a reference (background) layer in the Spatial Data Editor and use the mouse to trace the map features into new vector objects. Since the new vector elements are displayed over your reference map image, you can visually check your accuracy as you go along. You can assign attributes to the vector elements as you create them in the editor, or later in the Spatial Data Display process. You can consult the tutorial booklets *Editing Vector Geodata*, and *Managing Geoattributes* for more information and sample exercises for these procedures.



creating vector lines of contacts in the Spatial Data Editor with a scanned and georeferenced field map as a reference

The TNTmips vector data structure allows you to represent the geological data in a single vector object, and this provides the most efficient means to digitize and store the data for a large, complex map. Later you may want to separate the data into different thematic layers (such as unit contacts, faults, and outcrop structures) for more flexibility in setting up the map layout. To do so, you can use the Vector Extract process, choose the desired element type(s), and select the desired elements by attribute or by using a script.

Recording Digital Data at the Outcrop



Geologic mapping tools for the digital age.

Computers and other electronic devices have now become small, powerful, and inexpensive enough to be used in the field to collect geologic data directly in digital format. Collecting data in digital format removes the need for later redigitizing of the field data.

The first step in "going digital" at the outcrop is using a Global Positioning System (GPS) receiver to provide map coordinates for each field station at which you record outcrop information. You can record the map coordinates in your field notes and also store them as a "waypoint" in the GPS unit. Most GPS receivers can store hundreds of waypoints and can download a waypoint list to a desktop or laptop computer in ASCII text format. In camp, at the end of each field day or at the end of each week, you can download the current waypoint list to a laptop and import the text file into TNTmips to create a set of point elements in a vector object, with each point representing a station location.

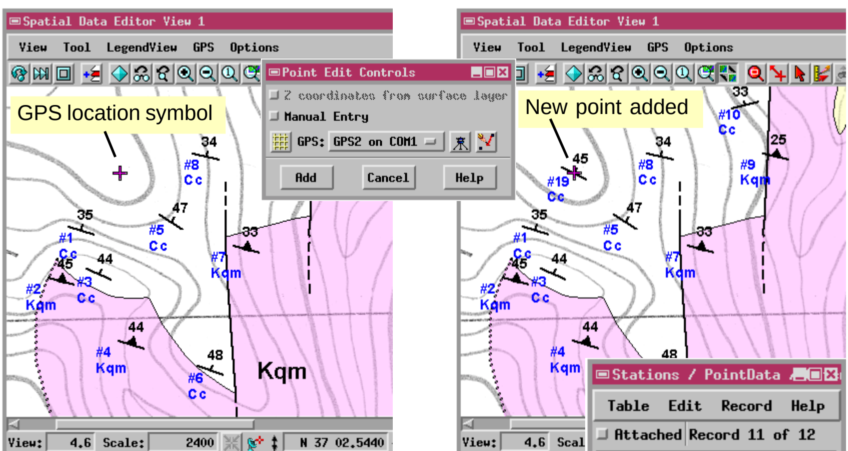
You can further automate data collection by recording essential attribute data in digital form at each station. This can be done in several ways. Some GPS receivers can be linked to a data-logger accessory or to a handheld computer running software that enables attributes to be recorded for each waypoint as it is logged. As an alternative, you can use a handheld computer independently from the GPS to record lithology, rock unit name, structural measurements, and other essential data for each station. You can then download both GPS waypoint and attribute data as text files to a laptop, merge the data using a spreadsheet or database program, then import the data into TNTmips to create attributed vector points.

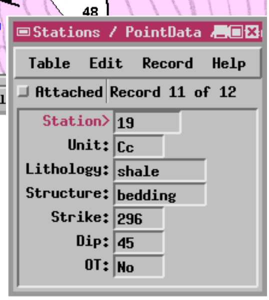
GPS Accuracy

Since the United States government ended the policy of Selective Availability for GPS signals, inexpensive 12-channel GPS units can provide horizontal accuracy of 7 to 15 meters under optimal conditions without differential correction. Newer receivers can provide higher accuracy in the United States using the signal from the Wide Area Augmentation System (WAAS). The WAAS system, in development by the Federal Aviation Administration (FAA), calculates the errors in the satellite GPS signal at ground monitoring stations around the country, then transmits error-correction data to GPS receivers via geostationary satellites. (Similar systems are being developed in Europe and Asia.) The FAA expects horizontal and vertical accuracy to within 7 meters, but testing by several GPS receiver manufacturors indicates accuracy to within 3 meters 95% of the time. This accuracy is sufficient for geological mapping at 1:24,000 or smaller scales.

Making Your Digital Map in the Field

You may also want to try creating your digital geologic map in the field using TNTmips running on a ruggedized laptop computer. View windows in TNTmips can read positions from a GPS receiver and place a location symbol in the view. (You can connect a handheld GPS receiver to the laptop via a serial cable or use a GPS PCMCIA card.) You can use this GPS input when you add elements to vector objects with the Spatial Data Editor, such as points to a vector with station locations and lines to a vector with contact lines. (The Editor lets you have several objects open for editing at the same time.) As you walk long a contact, the Editor can track the changing GPS position and add line vertices automatically, or you can add a new position only when you choose. More information on using GPS with TNTmips is available in the tutorial booklet *Operating with a GPS Unit*.

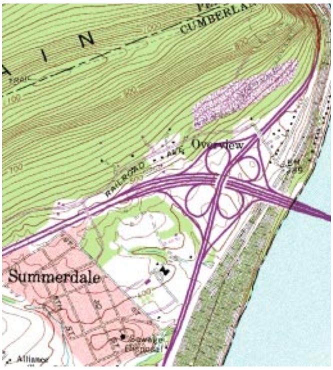




Adding a point element to a vector object of station locations using the current GPS coordinates. The structural attitude symbols are point symbols generated by a CartoScript using data entered in an attached database table (see the tutorial booklet *Using CartoScripts*). The point display controls have also been set to generate a label for each point with the station number and map unit code, each read from the same attached table. A Database Prompt was set up to automatically open a single-record view of this table, allowing the attributes for each new station point to be entered as it is added. Two reference layers are shown: a scanned and georeferenced topographic base map and a vector object with the contacts and map unit polygons mapped on previous days. Contact lines are styled by attribute according to contact type and completed polygons are styled by attribute using the unit code.

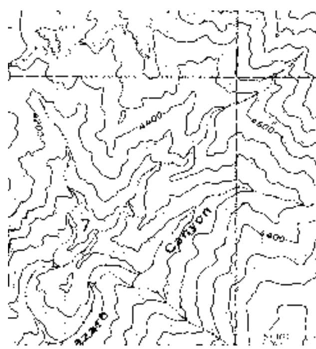
Digital Basemap Data

The influence of topography on the pattern of contact and fault lines provides geologists with information about the three-dimensional orientation of these features. For this reason, geologic maps produced at scales of 1:250,000 or larger typically include a topographic base with labeled elevation contours. In most cases the base map also includes natural water features and any cultural features (roads, trails) that can help provide location information to a map user in the field.



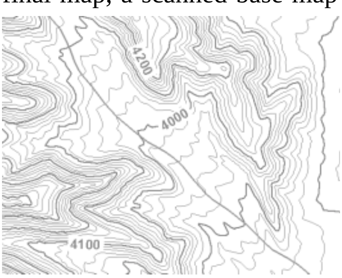
Extract from a DRG raster.

The source for your digital topographic base can be either 1) a scanned (rasterized) image of a published topographic map or 2) one or more vector layers showing the various types of features in the base map (hydrology, contours, etc.). You can scan and georeference paper topographic maps yourself, or purchase scanned images such as the Digital Raster Graphics series (http://mcmcweb.er.usgs.gov/drg) produced by the United States Geological Survey. Vector versions of U.S. topographic map data are available for free download in the Digital Line Graph series (http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html). If DLG contour data are unavailable for your area, you can use the Surface Modeling process in TNTmips to produce contours from raster digital elevation models.



Grayscale version of a scanned topographic map.

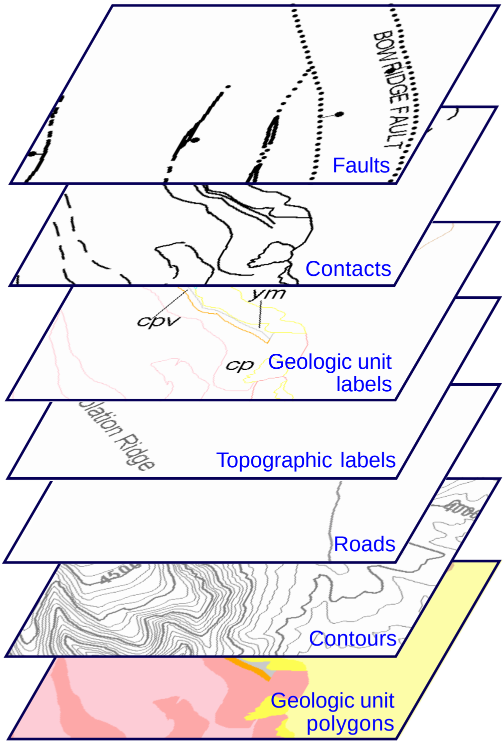
To prevent the various original map colors from distracting from the geologic information on your final map, a scanned base map should be converted to a high-contrast grayscale or binary raster with as much of the background shading (such as green vegetation shading) removed as possible. Using vector layers for the base map gives you more control over color and of the order of layers in the layout.



Vector contour lines with labels and separate road vector.

Map Layers in the Midway Geologic Map

The map group in the Midway Valley geologic map plate is composed of a number of overlaid data layers, plus two map grids (State Plane and Latitude / Longitude) generated from the data. An exploded view of the data layers is shown to the right for a representative area.

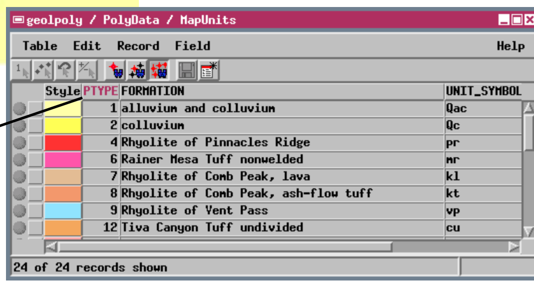


The segregation of the map data into this particular collection of layers was driven in part by the organization of the raw data supplied by the USGS. Faults, contacts, and geologic unit polygons were in different data files. Contours and roads were not provided, so data files for these layer were procured and assembled separately. The layer sequence used for this plate should therefore not be interpreted as an ideal or optimal solution, just one viable solution driven by the nature of the source map data. When you create your own digital geologic map, you have control over the division of data into separate layers and database tables, so you will have to consider the final map presentation in designing your data structure.

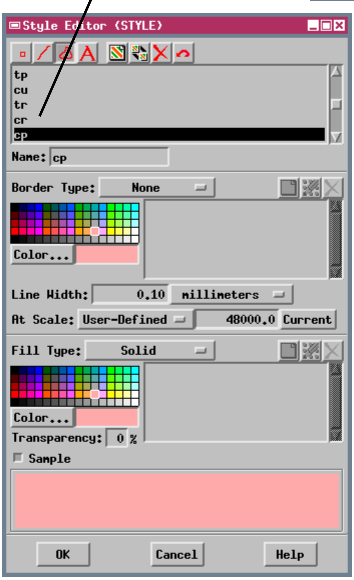
Note that I placed the geologic unit polygon layer on the bottom, below the base map data layers (contours, roads, and topographic feature labels). This order enabled me to use opaque polygon fills for the geologic units, which serve as a background for all of the other data layers. Alternatively, the base map layers could have been placed on the bottom, but this would have required setting a partial transparency value for each of the geologic unit polygon fill styles (one style for each rock unit) so that the underlying base map layers would be visible. Also, note that I used black to style the geologic lines and labels, but a neutral gray for all of the elements in the three base map layers, ensuring that the base map does not distract from the geologic elements of the map.

Geologic Unit Polygons

A portion of the vector object containing the map unit polygons (*geolpoly*) is shown to the right. Each polygon represents an outcrop area of a particular geologic unit. The geologic attribute information is contained in a polygon database table MapUnits, part of which is shown below. This table contains one record for each geologic unit type, with fields for a numeric unit identifier, the formation name, and the unit symbol.



As indicated by the purple color of its field name, field PTYPE is set as the primary key field for the table MapUnits. Styles shown in the table are created in the Style Editor.

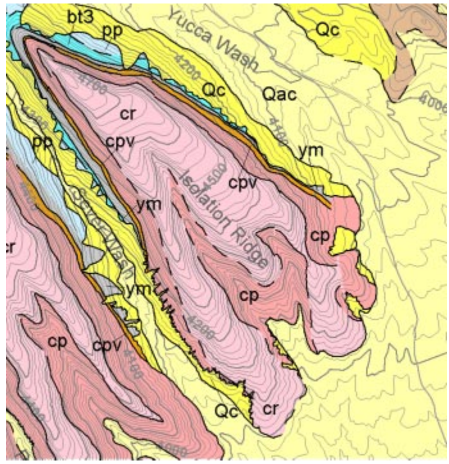


Each record in the table is attached to all of the polygons that represent that unit. The identifier field PTYPE is set as the primary key field for the table. The unique values in this field were then used to set up polygon styles by attribute, with one style for each unit type.

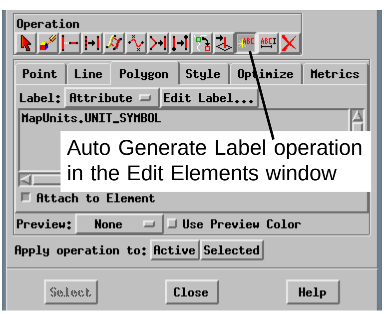
For simplicity, solid fill colors were used for all units. You can also create bitmap fill patterns or hatch patterns for polygon fills, but make sure patterned fills are appropriate for the final scale you have in mind for the map. Since the contacts and faults are shown by other data layers in the layout, lines are not selected for display in this layer, and no polygon border is displayed. For more information on setting up polygon styles, consult the tutorial booklet *Creating and Using Styles*.

Unit Labels and Contacts

If the map unit labels were included in the bottom *geolpoly* layer, they would be partially obscured by the lines in the overlying contour layer. For this reason I included a separate layer for unit labels in the layout. The *geol_labels* layer is a copy of the *geolpoly* vector object to which I added polygon labels. I used the Auto Generate Label operation in the Spatial Data Editor to add the labels and used the Attribute option to read the label text from the UNIT_SYMBOL field in the MapUnits table (illustrated on the preceding page). This operation places the label within the polygon if it will fit. If the polygon is too small, the label is placed inside a neighboring polygon with a leader line stretching to the label's parent polygon. Once the labels are added, you can edit them to change the label position and the position of the leader line. For more information on label auto-generation, consult the tutorial booklet *Advanced Vector Editing*.

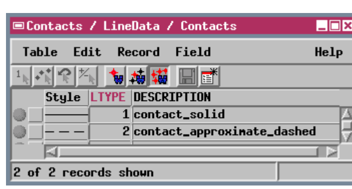


Sample area with unit contact, unit label, and all underlying map layers.

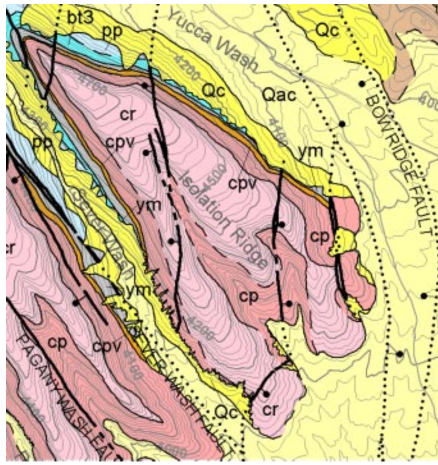


In order for polygon labels to be displayed, polygons must be selected for display and a polygon border or fill must be defined. The polygons in the *geol_labels* layer are styled by attribute with no fill but with solid borders drawn in the unit color. Contact and fault lines in overlying layers are drawn over these polygon borders, so the borders are not evident in the finished map.

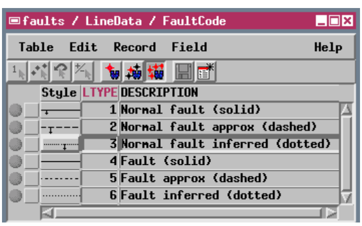
Geologic contacts other than faults are contained in the *Contacts* layer. The contacts are drawn with either solid or dashed lines (by attribute) based on the attached record in the CONTACTS table. You can find more information about setting up line styles in the tutorial booklet *Creating and Using Styles*.



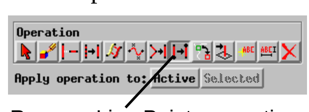
Lines representing the surface traces of faults are contained in the *faults* layer. The lines are styled by attribute to indicate both the fault type (normal or unknown) and the location confidence (solid, dashed, and dotted versions of the fault type style). The barb-and-ball normal fault symbol was created using the Line Style Editor, which lets you create complex line styles using solid or dashed lines, crossing lines, and circles. Line styles requiring other graphic elements (such as the triangular barbs on thrust faults) can be created using CartoScripts (Style by Script option). More information on CartoScripts can be found in the tutorial booklet *Using Cartoscripts*.



Sample area with faults and all underlying map layers.



Dip-slip fault symbols have elements that are drawn on one side of the fault to indicate the downthrown side (normal fault) or upthrown side (reverse and thrust faults). Standard line styles or CartoScript symbols that incorporate such elements must draw them on a topologically consistent side of each line element (either right or left), which is relative to the direction in which the ordered line vertices were recorded. After I created the normal fault line styles and applied them, I compared the result to the published map and noted the lines that had the barb-and-ball symbol on the wrong side. I then edited the *faults* vector and used the Reverse Line Points operation to reverse the directions of these lines to reverse their symbols.



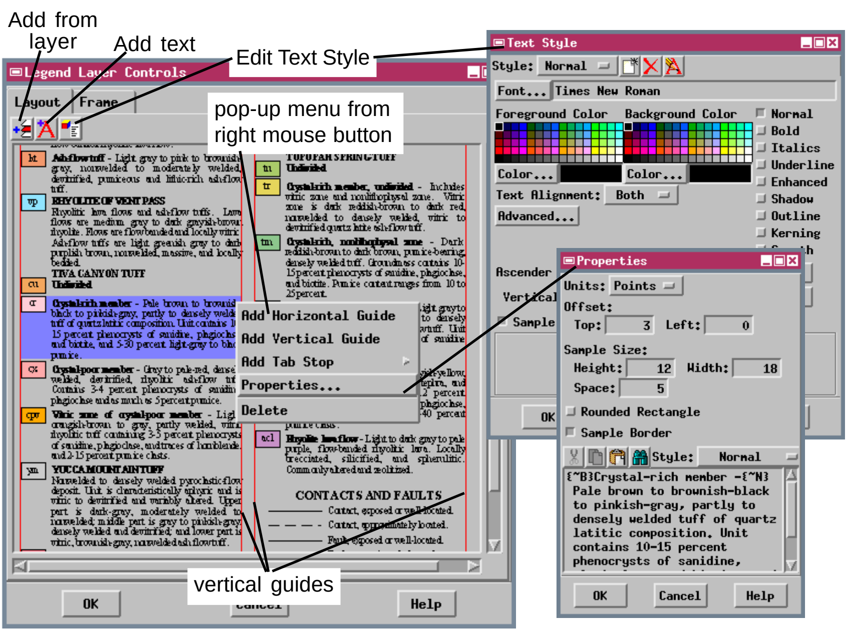
Reverse Line Points operation in the Edit Elements window.

Names for major faults are recorded in a separate FaultNames table (right). I used the Auto Generate Label operation in the Spatial Data Editor again to create labels automatically for these faults using the text in the NAME field. I used the Join Lines by Attribute option to create a single label for connected line elements representing segments of the same fault.

Map Legend

The legend for a geologic map provides an explanation for all of the map unit styles and symbols and for the line and point symbols on the map. For maps of smaller areas (such as a single map quadrangle), the legend also provides a description of the salient lithologic characteristics each rock unit. Normally entries in the map unit legend are arranged by the ages of the units.

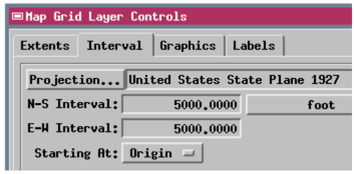
In a map layout you can create legends that automatically use the defined styles to create entries with appropriate samples. Legend labels can be read from a database, or you can enter the text manually. You can add an individual legend object for each object and element type, but the most flexible approach is to create a multi-object legend. In a multi-object legend you can combine legend information for different element types and for different objects in the layout. Creating a multi-object legend is also easier because you use a graphical editor (shown below) that lets you set horizontal and vertical guides to align entries and change the legend order by dragging entries to new positions.

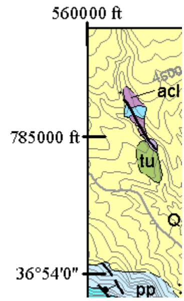


You can also set text styles in a multi-object legend to automatically justify the text in the legend labels (align both right and left), which improves the appearance of the unit descriptions. You can find more information about legends in the tutorial booklet *Making Map Layouts*.

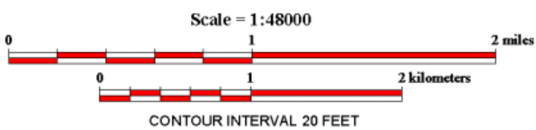
Other Map Components

Other cartographic elements of a good geologic map can be created easily in a map layout using the Layout Controls window. You should consult the tutorial booklet *Making Map Layouts* for instructions on how to create the layout elements shown here.

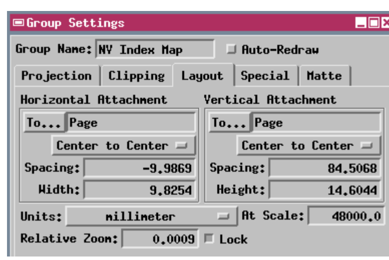




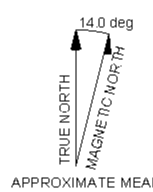
The Midway geologic map includes two map grids as layers in Group 1 (which contains all of the layers for the map itself). The Map Grid Layer Controls let you set up the extents, interval, and graphic elements for a grid. I set up the Midway map grids to show only border tick marks and labels.



You can easily add one or more scale bars to provide graphic scales for the map. You can control the length, intervals, labeling, and bar styles. The verbal scale and contour interval annotation shown here are text elements. You can add any number of text elements to a layout to create titles and other anotations using various fonts and styles. Each element in a map layout is a group that can be positioned separately on the page and is attached to either the page or to another group. I attached the kilometer scale, verbal scale text and contour text to the mile scalebar, so that repositioning that scalebar moves all of the attached elements as well.



The index map for the Midway layout is a map group with several attached text groups. A map layout has a single map scale that applies to all spatial groups (set in the Group Settings window for any group; 1:48,000 for the Midway map). To shrink the index map to a smaller size I set a Relative Zoom value of 0.0009 in its Group Settings window (above).



The declination graphic used in the layout is an SML (Spatial Manipulation Language) script layer. SML display layers are discussed in the tutorial booklet *Writing Scripts with SML*.

Advanced Software for Geospatial Analysis

GEOLOGIC MAPS

MicroImages, Inc. publishes a complete line of professional software for advanced geospatial data visualization, analysis, and publishing. Contact us or visit our web site for detailed product information.

TNTmips TNTmips is a professional system for fully integrated GIS, image analysis, CAD, TIN, desktop cartography, and geospatial database management.

TNTedit TNTedit provides interactive tools to create, georeference, and edit vector, image, CAD, TIN, and relational database project materials in a wide variety of formats.

TNTview TNTview has the same powerful display features as TNTmips and is perfect for those who do not need the technical processing and preparation features of TNTmips.

TNTatlas TNTatlas lets you publish and distribute your spatial project materials on CD-ROM at low cost. TNTatlas CDs can be used on any popular computing platform.

TNTserver TNTserver lets you publish TNTatlases on the Internet or on your intranet. Navigate through geodata atlases with your web browser and the TNTclient Java applet.

TNTlite TNTlite is a free version of TNTmips for students and professionals with small projects. You can download TNTlite from MicroImages' web site, or you can order TNTlite on CD-ROM.

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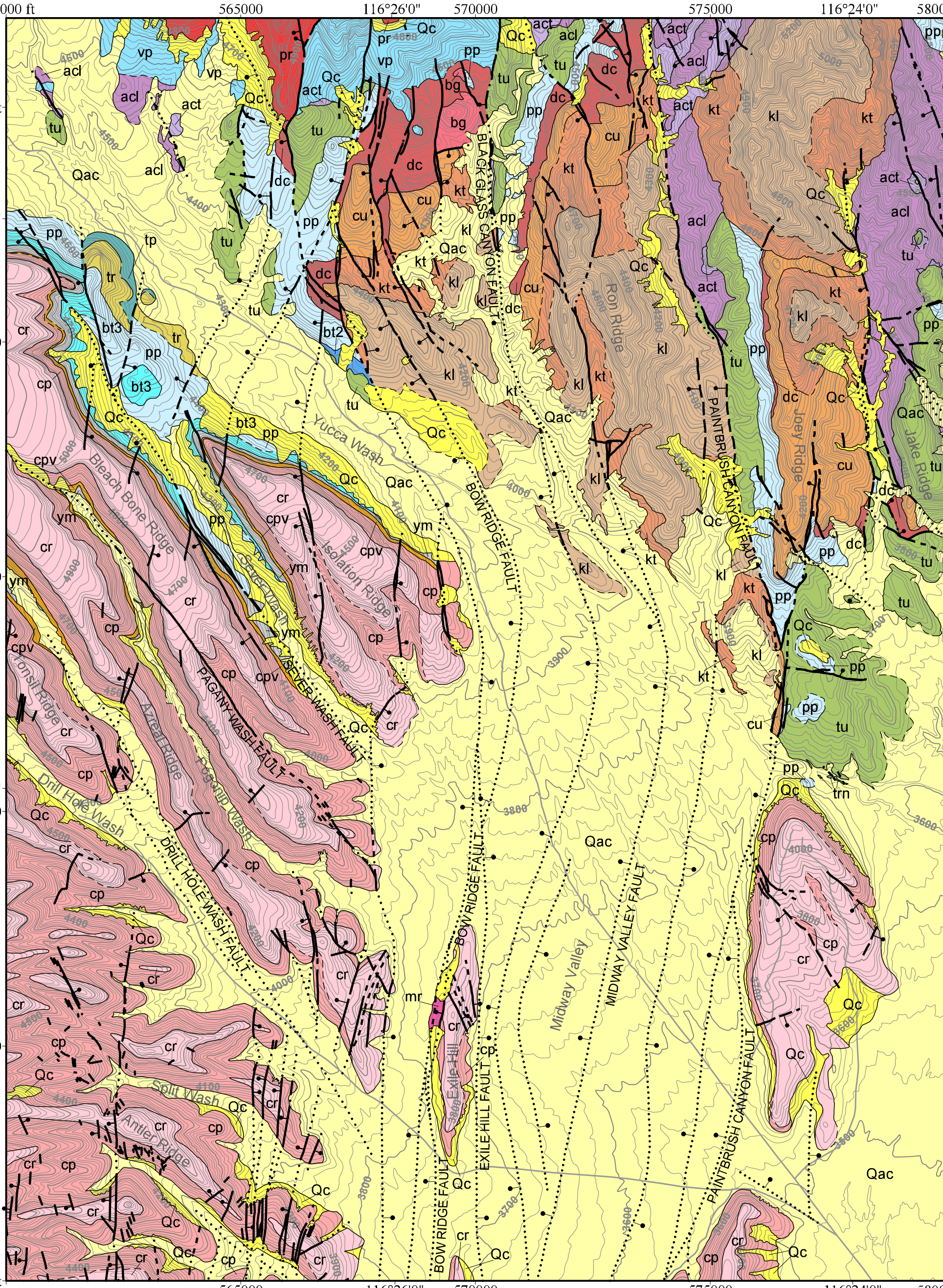
MicroImages, Inc.

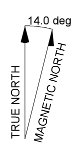
11th Floor - Sharp Tower
206 South 13th Street
Lincoln, Nebraska 68508-2010 USA

Voice: (402) 477-9554
FAX: (402) 477-9559

email: info@microimages.com
internet: www.microimages.com

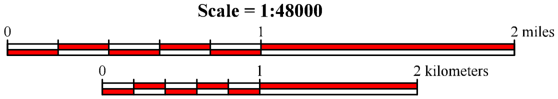


5,000-ft grid ticks based on the Nevada State Plane Coordinate System, Central Zone, 1927 North American datum.



APPROXIMATE MEAN DECLINATION, 1998

Scale = 1:48000



CONTOUR INTERVAL 20 FEET

DESCRIPTION OF MAP UNITS

QUATERNARY SURFICIAL DEPOSITS

- **Qac** — Alluvium and colluvium
- **Qc** — Colluvium

MIOCENE VOLCANIC ROCKS

- **pr** — RHYOLITE OF PINNACLES RIDGE
  Rhyolitic lava flows and ash-flow tuff of a flow-dome complex.

Timber Mountain Group

- **mr** — RAINER MESA TUFF, nonwelded
  Light-gray to pinkish-gray, partly to moderately welded, devitrified, massive, quartz-rich ash-flow tuff.

Paintbrush Group

RHYOLITE OF COMB PEAK

- **kl** — Lava flow - Light gray to pinkish-gray, devitrified, flow-banded rhyolitic lava flow.
- **kt** — Ash-flow tuff - Light gray to pink to brownish-gray, nonwelded to moderately welded, devitrified, pumiceous and lithic-rich ash-flow tuff.
- **vp** — RHYOLITE OF VENT PASS
  Rhyolitic lava flows and ash-flow tuffs. Lava flows are medium gray to dark grayish-brown rhyolite. Flows are flow banded and locally vitric. Ash-flow tuffs are light greenish gray to dark purplish brown, nonwelded, massive, and locally bedded.

TIVA CANYON TUFF

- **cu** — Undivided
- **cr** — Crystal-rich member - Pale brown to brownish-black to pinkish-gray, partly to densely welded tuff of quartz latitic composition. Unit contains 10-15 percent phenocrysts of sanidine, plagioclase, and biotite, and 5-30 percent light-gray to black pumice.
- **cp** — Crystal-poor member - Gray to pale-red, densely welded, devitrified, rhyolitic ash-flow tuff. Contains 3-4 percent phenocrysts of sanidine, plagioclase and as much as 5 percent pumice.
- **cpv** — Vitric zone of crystal-poor member - Light orangish-brown to gray, partly welded, vitric rhyolitic tuff containing 3-5 percent phenocrysts of sanidine, plagioclase, and traces of hornblende, and 2-15 percent pumice clasts.
- **ym** — YUCCA MOUNTAIN TUFF
  Nonwelded to densely welded pyroclastic-flow deposit. Unit is characteristically aphyric and is vitric to devitrified and variably altered. Upper part is dark-gray, moderately welded to nonwelded; middle part is gray to pinkish-gray, densely welded and devitrified; and lower part is vitric, brownish-gray, nonwelded ash flow tuff.
- **bg** — RHYOLITE OF BLACK GLASS CANYON
  Medium gray to purplish-gray flow-banded rhyolite lava flow and tan to brownish-gray nonwelded to part massive ash-flow tuff.
- **bt3** — NONWELDED BEDDED TUFF 3
  White to light brown to light gray pumiceous, vitric, nonwelded pyroclastic flow deposits.
- **dc** — RHYOLITE OF DELIRIUM CANYON
  Light gray to light pinkish-gray to light brown vitric to devitrified, flow-banded rhyolite lava flow with light gray to tan ash-flow tuff. Tuffaceous parts are nonwelded to partly welded, partly vitric to devitrified, and massive to poorly bedded.
- **pp** — PAH CANYON TUFF
  Pyroclastic flow deposit with abundant large pumice clasts. Upper part is pink to lavendar, nonwelded, vitric to devitrified; middle part is light-gray to brown, densely welded; lower part is light purple-gray, partly to nonwelded, and vitric.
- **bt2** — NONWELDED BEDDED TUFF 2
  White to light gray, pale-orange to reddish-brown, nonwelded, vitric to devitrified to altered, massive to crudely stratified fallout tephra and ash-flow tuff. Unit contains 15-85 percent pumice clasts.

TOPOPAH SPRING TUFF

- **tu** — Undivided
- **tr** — Crystal-rich member, undivided - Includes vitric zone and nonlithophysal zone. Vitric zone is dark reddish-brown to dark red, nonwelded to densely welded, vitric to devitrified quartz latite ash-flow tuff.
- **trn** — Crystal-rich, nonlithophysal zone - Dark reddish-brown to dark brown, pumice-bearing, densely welded tuff. Groundmass contains 10-15 percent phenocrysts of sanidine, plagioclase, and biotite. Pumice content ranges from 10 to 25 percent.
- **tp** — Crystal-rich member, undivided - Includes vitric zone and nonlithophysal zone. Vitric zone is dark reddish-brown to dark red, nonwelded to densely welded, vitric to devitrified quartz latite ash-flow tuff.

CALICO HILLS FORMATION

- **act** — Ash-flow tuff - Pale orange and grayish-yellow, nonwelded ash-flow tuff, fallout tephra, and reworked tuff. Contains 1-12 percent phenocrysts of quartz, sanidine, plagioclase, biotite, and hornblende, and 10-40 percent pumice clasts.
- **acl** — Rhyolite lava flow - Light to dark gray to pale purple, flow-banded rhyolitic lava. Locally brecciated, silicified, and spherulitic. Commonly altered and zeolitized.

CONTACTS AND FAULTS

- Contact, exposed or well-located.
- Contact, approximately located.
- Fault, exposed or well-located.
- Fault, approximately located.
- Fault, concealed or poorly exposed.
- Normal fault, exposed or well-located. Bar and ball on downthrown side.
- Normal fault, approximately located.
- Normal fault, concealed.

BEDROCK GEOLOGIC MAP OF THE NORTHERN MIDWAY VALLEY AREA, NYE COUNTY, NEVADA

Data from Bedrock Geologic Map of Yucca Mountain Area, Nye County, Nevada. U.S.G.S. Geological Investigations Series I-2627, by Warren C. Day, Robert P. Dickerson, Christopher J. Potter, Donald S. Sweetkind, Carma A. San Juan, Ronald M. Drake II, and Christopher J. Fridrich.