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DIGITAL GEOLOGICAL MAPS OF INSULAR NEWFOUNDLAND

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ABSTRACT

The most recent published bedrock geology maps for insular Newfoundland are being digitized at their full levels of detail. Data are organized into linework files and a relational database containing map-unit information. The linework files are further subdivided into sets of files for individual maps and a set of files, in which maps are joined together to provide continuous coverage.

Geological maps produced from the digital files have consistent unit labelling and legend schemes. They can be produced in a number of formats, including:

1. *Paper maps, which can be created for geographic areas irrespective of geological map boundaries and can have customized levels of detail.*
2. *Digital files, which can be imported into a geographic information system to create a geological database that is searchable and can produce customized maps.*
3. *ArcView™ files, in which digital maps are packaged with other geoscientific information in user-friendly viewing software that runs on personal computers.*

As of November 1996, full map-unit data had been compiled for about 20 percent of insular Newfoundland. Preliminary digitizing had been completed for a further 30 percent of the island. The objectives of the project include completing map-unit coverage and compiling a parallel database of point data to provide structural symbols and other information.

INTRODUCTION

Digital bedrock geology maps are being prepared from the most recent published maps for the Island of Newfoundland (*see* Colman-Sadd and Gillespie, 1996, for index). The source maps range in scale from 1:10 000 to 1:250 000, but are mostly at 1:50 000. At present only linework is being digitized, including map-unit contacts, faults, fold axes and isograds. Unit labels and legends are standardized for all maps using *GeoLegend*, a relational database, whose structure is described by Colman-Sadd *et al.* (1996). Point data, such as station locations and structural symbols, are available for some maps but will not be organized into a systematic data file linked to the linework until some time in the future.

DATA ORGANIZATION

LINEWORK

Linework is digitized exactly as shown on the original published maps with no editing of line types or changes of position. Lines are coded to reflect the kind of geological feature represented and whether the feature is defined, approximate or assumed.

Two general categories of lines are distinguished, those that depict the distribution of map units and those that indicate some geological feature that is independent of map units. In the first category are: a) geological contacts enclosing the outcrop areas of map units and forming polygons, b) lines representing narrow unit outcrops, such as dykes, whose length, but not width, can be shown at the scale of the map, and c) points representing single-exposure units, for which neither width nor length can be shown at the scale of the map. The three kinds of unit outcrops are stored in separate CARIS™ files for polygon units, line units and point units respectively. The polygons, lines and points in all these files have identifying numbers that refer to the *GeoLegend* database for geological information about the map unit each represents (Colman-Sadd *et al.*, 1996).

Geological features independent of map units include faults, isograds, and fold axes. Separate CARIS™ files are created for each kind of feature. Faults represent a special case in that many also form the boundaries of map units.

Where a fault is a map-unit boundary, it is represented on the polygon-unit file by a special line type, which serves merely to close the polygon. Any fault or part of a fault that does not separate two units is omitted from this file. Faults are only stored in full on the file dedicated to them, where different types of faults are distinguished by line codes. When a map is created, geological features independent of map units are superimposed on the map-unit layer after various procedures for labelling and amalgamating units have been completed. All the necessary geological information for these features is contained in CARIS™ and is identified by line codes.

MAP-UNIT DATA

Outcrops of map units, distinguished by polygons, lines or points, have to be labelled and referred to a legend. The amount of information involved is far more than can be carried by a simple attribute within CARIS™. Unit outcrops therefore have only one attribute, which is a unique identifier in the form NF005_0347. The first part of the identifier indicates map 5 on the Island of Newfoundland and the second part indicates polygon 347 within that map. The identifier is keyed to the *GeoLegend* database, where the geological information for the unit is stored.

GeoLegend contains sufficient data to label the units on a map, generate a unit legend and produce a list of references for sources of the geological data (Colman-Sadd *et al.*, 1996). The data in *GeoLegend* are structured in such a way that a map can be produced from a given set of linework using either the generalized labels and legend schemes found on lithofacies maps (e.g., Colman-Sadd *et al.*, 1990) or the standard stratigraphic schemes commonly used for more detailed maps. The amount of detail on stratigraphic maps can be varied for the whole map or for selected units on the map and the level of detail is reflected in the labels, legend and reference list.

INDIVIDUAL AND INTEGRATED MAPS

Published maps are digitized individually and the linework is archived as separate datasets for each map. Most maps are digitized in their entirety but, in a few cases, only part of a map is digitized if the other part has been supplanted by a more recent publication and has clearly defined limits. Map-unit data are entered into a single *GeoLegend* database file for all of insular Newfoundland The classification and labelling of units on all maps is compatible, and all maps use the same set of legend descriptions. When an individual map is generated, *GeoLegend* compiles a legend that contains only those unit descriptions relevant to that particular map.

As well as being stored as individual datasets, the linework for maps is also used to create a dataset which integrates all the digitized maps into a single continuous map. This single map will eventually provide coverage for the whole of the Island of Newfoundland. Many maps, particularly those for specific NTS areas, adjoin each other without overlap and can simply be joined edge to edge. In these cases, there are commonly mismatches of contacts across map joins because contacts are never altered from the original published versions. These mismatches may reflect differing densities of field observations or differing geological opinions. No attempt is made to remove them.

Where there is overlap between published geological maps, only one map can represent the geology for any given location on the integrated map. The map chosen is the one deemed to be most accurate for that particular location. If there is no preference in quality between maps, the join is made where it will minimize mismatches of the linework from one map to the other. Commonly this results in parts of both overlapping maps being discarded.

The polygons, lines and points representing outcrops of map units on the integrated map have the same identifiers as those on the individual maps. The integrated map therefore uses the same *GeoLegend* file as the individual maps to determine unit labels and compile legends. The fact that some map-unit outcrops and even complete map units are discarded in the integration process means that there are records in the *GeoLegend* database that have no counterparts on the integrated map. This is not a concern because data are always derived by the map from *GeoLegend* and never the other way around.

PRODUCTS

The flexibility introduced by storing map-unit information in a database allows a wide variety of maps to be produced from a single set of digitized linework. Currently products are published as paper maps, raw data files for importing into a GIS, and as files for use with GIS viewing software.

PAPER MAPS

Two published geological maps serve as examples of this type of product.

1. *Open File 012H/1367 (Swinden and Sacks, 1996).* This is a 1:50 000 map showing the geology of the Roberts Arm belt between Halls Bay and Lake Bond in the northern part of the Dunnage Zone, central Newfoundland. It has been produced from one of the individual digitized datasets and is published because there is no previously published version of this map at a suitable scale on a controlled topographic base. The map was digitized from a single copy of an unpublished hand-drawn version, which had been used to prepare figures at a much smaller scale for two manuscripts (Swinden and

Sacks, 1986; Swinden, 1987). The open file reproduces the entire map as originally digitized and archived in an individual dataset. The map has also been incorporated into the integrated map (Davenport *et al.*, 1996; Ash and Colman-Sadd, 1996) but in this form, parts of it have been discarded in favour of other maps with which it overlaps.

The unit labels and legend for the open file are derived from *GeoLegend* and are generated at the maximum level of detail, which corresponds to the level of detail on the original map. The labels are alphanumeric (e.g., ORvf) and are compatible with labels that would be created by *GeoLegend* for adjacent maps; they replace numeric labels that existed on the the published small-scale versions of the map (Swinden and Sacks, 1986; Swinden, 1987). The legend descriptions are mostly derived from these versions but some come from adjacent maps (e.g., Bostock, 1988), where some of the same units occur and are more fully described. A reference list generated by *GeoLegend* cites the papers in which small-scale versions of the map are published and other publications that have contributed legend descriptions.

The content of the map was completed by the addition of structural symbols, which were digitized from the hand-drawn version, and mineral occurrences, which were extracted from the MODS database (Stapleton and Parsons, 1991). Final cartography was done using IslandDraw™.

2. *Open File NFLD/2513 (Liverman* et al., *1995).* The bedrock geology map in this open file serves as a base map to surficial geochemical data. The area of the map was defined independently of the boundaries of published geological maps, so the map was extracted from the integrated dataset in which the various geological maps are joined together. For the area in question, parts of five digitized maps provide full coverage.

   The main unit of interest in the open file is the Roberts Arm Group. Consequently, the map was customized to show as much detail as possible in this unit and as little detail as possible in all the others. This was achieved by instructing *GeoLegend* to produce unit labels at maximum and minimum levels of detail respectively, and a legend and reference list to match. The map was then generated in CARIS™ and the various elements were combined together for final cartography in IslandDraw™.

RAW-DATA FILES

Digitized maps are published as raw-data files so that users can import them into their own GIS. There has been one release of this type, Open File NFLD/2616 (Ash and Colman-Sadd, 1996), which provides data for all areas that had been incorporated into the integrated map at the time of publication in November 1996 (Figure 1). The coverage of the open file is about 23 000 km^2, equivalent to 20 percent of insular Newfoundland. Only the integrated map has been published in this format but similar datasets can be released for individual maps, if there is demand for them.

Linework in Open File NFLD/2616 is formatted as three .dxf files for polygon units, line units and faults, and a .xyz data table for point units. In subsequent versions of the open file, .dxf files will be added for isograds, fold axes and other geological features.

Geological information for the units is contained in six text files. The principal one of these contains essential unit information downloaded from *GeoLegend.* The information is formatted as a single table and individual records are keyed to the identifiers for the outcrops of polygon, line and point units. The table can be used with almost any database software; it is formatted in dBase™ style but this style can be changed in a text editor if necessary. Each record contains three unit labels, which refer to legends in three of the other text files and allows generation of geological maps at three different levels of detail. Other information includes unit names, ages and rock types, as well as a reference to the published source map from which the unit outcrop was digitized (*see* Appendix for a list and explanation of fields in the data table). The other text files consist of a legend that subdivides units at the same level as the source maps, a legend that combines units into their major stratigraphic divisions, a legend based on the lithofacies divisions of the 1:1-million-scale map of the Island of Newfoundland (Colman-Sadd *et al.*, 1990), a timescale, and a reference list.

The six text files represent a selection of information from the *GeoLegend* database and have the advantage of being usable on any computer with a wide variety of software. Although the full relational *GeoLegend* database contains more data and is more versatile, it has not been released because it requires the Helix Express™ database package running on a Macintosh™ computer, neither of which are widely distributed. It can, however, be made available if there is demand for it.

ARCVIEW™ FILES

Raw data files presuppose that the user has a GIS into which to load them. In order to reach a wider audience, selected data files have been imported into GIS viewing software that is usable on a personal computer. Open File NFLD/2611 (Davenport *et al.*, 1996) presents a variety of geoscientific data for the Buchans–Roberts Arm belt on CD-ROM. It uses ArcView™ 1.0, which is a viewing software package in the public domain, and includes a bedrock geology map and accompanying unit data that are a subset of the raw

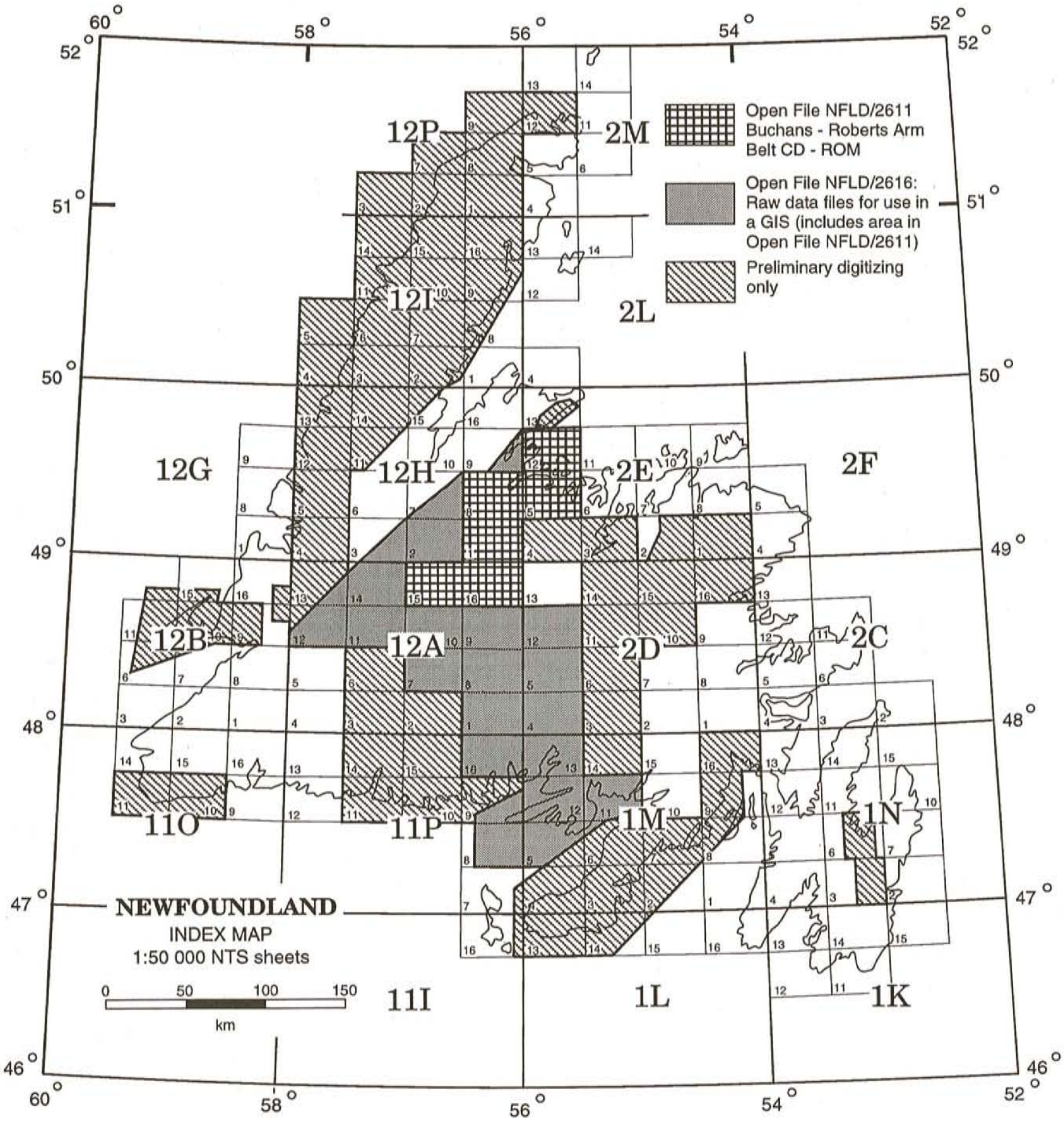

Figure 1. *Digitized bedrock geology maps for the Island of Newfoundland, November 1996.*

data files published as Open File NFLD/2616. Other publications of this type are planned in the future, especially as viewing software becomes available that is more suitable for this particular application.

FUTURE DIRECTIONS

At the time of going to press (February, 1997), geological map units and linework have been digitized and integrated into continuous coverage for about 20 percent of the area of insular Newfoundland. Digitizing has also been done for another 30 percent of the island, but still awaits checking and the compilation of geological data. When coverage is complete for the island, it will be kept current by incorporating new maps as they are published, usually at the rate of five to ten per year, and revising unit data as necessary.

A major task still to be addressed is the compilation of point data, which include station locations, structural measurements, sample locations and related data, and field notes. Much of these data are already in digital form or can be easily digitized. The first problem is gathering them together in a single, consistent database, which is linked to the map unit coverage. Once this is done, a further challenge is to design software that allows the data to be presented in a usable fashion on maps. On many maps, more structural symbols are available for plotting than can actually be displayed. The software should allow the user to select or priorize the types of symbols to be shown. If there are still too many symbols, their number should be reduced according to criteria that are geologically rational and reflect the judgement of the geologist who made the map. The amount of reduction also needs to be compatible with the scale at which a map is plotted because smaller scale maps can show fewer symbols than larger scale ones. In this respect, the reduction process should be analogous to the generalization of map units by *GeoLegend*, which allows the amount of information displayed on a map to be varied so that it is appropriate for any given scale.

Many decisions about how the data are published are made by anticipating how they will be used. This is particularly so for the fields that are selected from *GeoLegend* for inclusion in the data lists and the legends. There is information in the *GeoLegend* database that could be included in these files, but is not, because it is considered to be of low priority for the uses that are envisaged. The information contained in the files could also be redistributed between them, if this improved the usefulness of the dataset. For instance, legend descriptions, which are presently included only in the traditionally organized legend files, could be included in the data list for each polygon, line or point representing a unit. Users of these data are therefore invited to comment on how improvements could be made for their particular situation. Where possible, future releases will incorporate suggested changes that seem to address general concerns, and it may be possible to accommodate more specific needs on an individual basis.

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APPENDIX

Descriptions of fields (1 to 30) in the data listings in Open Files NFLD/2611 and NFLD/2616 (Davenport *et al.*, 1996; Ash and Colman-Sadd, 1996, respectively) are as follows:

POLYGON KEYS

1. *Alphanumeric key (not included in Open File NFLD/2611).* This is the identifier attached to each map unit. Most map units are represented by polygons and have identifiers of the form NFxxx_yyyy, where xxx is a number representing the source map from which the polygon was digitized, and yyyy is a number from 0001 to 1999 representing a particular polygon within a map. Map units with a narrow outcrop area, such as dykes, are represented by lines; for them yyyy is a number from 2000 to 2999. Map units consisting of single exposures may be depicted as points; they have yyyy ranging from 3000 upward. In the following field explanations, polygons, lines and points that represent map units are referred to collectively as polygons.

2. *Numeric key (replaced in Open File NFLD/2611 by a numeric key from 1 upward).* A numeric version of the alphanumeric key is provided for easier handling in certain situations. The number simply consists of the alphanumeric key with the non-numeric characters stripped out, e.g., NF037_0456 becomes 0370456.

GENERALIZED GEOLOGY FIELDS

Six variables provide names, labels and ages of units for a generalized geological map, subdivided at the highest level of the stratigraphic hierarchy, usually by Group or Formation.

3. *Unit name (top rank).* The field contains the name of the highest ranking stratigraphic division to which the polygon belongs (e.g., Springdale Group). The field is the same as the first of Supergroup, Group or Formation to have an entry in the more detailed classification (see fields 15 to 18). Unnamed units are represented by the character appearing in the Sub1-unit field (19). This character is only unique for a unit when it is combined with characters indicating age to produce a complete unit label (fields 4 and 5) so searches for unnamed units should be conducted using the unit labels.

4 and 5. *Unit labels (top rank).* Labels are composed of one or two characters indicating the age of a unit, followed by a character representing the stratigraphic division to which the unit belongs (e.g., eSS stands for "early (e) Silurian (S) Springdale Group (S)").

Most polygons on a geological map have a simple label, indicating a single unit within the polygon; for these polygons the 'Label of the dominant unit (top rank)' and the 'Full polygon label (top rank)' are the same. However, some polygons have complex labels that list two or more unseparated units. For these polygons, the dominant unit is the most important unit in the polygon (e.g., eSS) and on most maps would be used to determine the colour of the polygon; this is the unit named in field 4. The 'Full polygon label...' shows the complete list of unseparated units (e.g., eSS, eST).

6. *Age range of unit (top rank).* The field provides the age range of the stratigraphic division in 'Unit name' in terms of periods and subperiods of the geological timescale. The range is based on the numerical values for the ages of the base and top of the unit (fields 7 and 8).

7. *Age of the base of unit (top rank).* This is the oldest age, expressed in millions of years, that might reasonably be assigned to the base of the stratigraphic division in 'Unit name'. It may be derived from either radiometric or paleontological dating. Radiometric dates are adjusted for errors and paleontological dates are converted to absolute ages using the geological timescale.

8. *Age of the top of unit (top rank).* This is the youngest age that might reasonably be assigned to the top of the stratigraphic division in 'Unit name'.

DETAILED GEOLOGY FIELDS

Fourteen variables provide names, labels, rock types and ages of units for displaying a map at the maximum level of detail. This is the same level of detail as is shown on the source maps from which the linework was digitized; most of these maps were produced at the 1:50 000 scale.

9 and 10. *Unit labels.* As for top rank units, one field shows the label for just the dominant unit and the other shows the full label. The first one or two characters indicate the age of the unit and the succeeding characters represent the stratigraphic divisions of the unit in descending order (e.g., eSSvf stands for "early (e) Silurian (S) Springdale Group (S) volcanic (v) felsic (f)").

Note that the generalized and detailed labels are consistent. The characters indicating age are only different if the detailed subdivision has a more restricted age range than the general division. The character indicating the top rank unit is always the same and the characters indicating lower rank subdivisions are simply omitted from the generalized label.

11. *Summary rock type.* The entry comes from a standard list of rock types. The field is filled with the phrase that most accurately describes the lithology of the dominant unit in a polygon. Note that the description is of a unit, not of a particular polygon, so it may not be accurate for some polygons. Descriptions are structured with the most general term first, followed by more specific terms, e.g., 'volcanic, felsic marine'; this allows searches at various levels of lithological detail.

12. *Age range of unit.* The field provides the age range of the unit in terms of periods and subperiods of the geological timescale. The range is based on the numerical values for the ages of the base and top of the unit (fields 13 and 14).

13. *Age of the base of unit.* This is the oldest age, expressed in millions of years, that might reasonably be assigned to the base of the unit. In most cases, a junior unit is not dated directly and what is actually shown is the age of a more senior unit to which it belongs.

14. *Age of the top of unit.* This is the youngest age that might reasonably be assigned to the top of the unit.

15 to 18. *Supergroup, Group, Formation, Member.* These four fields give the names of the stratigraphic divisions to which a unit belongs. Formal and informal names are used.

19 to 22. *Sub1-unit, Sub2-unit, Sub3-unit, Sub4-unit (Sub4-unit is not included on Open File NFLD/2611).* These four fields are used for unnamed subdivisions below the Member level. Subunits are usually indicated by a single, lower case character, which is also used in the unit label. They are structured hierarchically to allow maps to be generalized at several different levels. For example, units may be divided into volcanic (v) and sedimentary (s) in Sub1-unit, and the volcanic units may be further subdivided into felsic (f) and mafic (m) in Sub2-unit. The felsic units can then be split again into flows (f) and pyroclastics (p) in Sub3-unit, and the pyroclastics into tuffs (t) and breccias (x) in Sub4-unit.

LITHOFACIES MAP FIELDS

Two fields allow the map to be displayed in the same format as the 1:1 million-scale Map 90-01, "Geology of the Island of Newfoundland" (Colman-Sadd *et al.*, 1990). This map uses a tectonic lithofacies classification for units rather than a stratigraphic classification. Note that, although the unit classification is generalized to about the same level as on the printed 1:1-million-scale map, the linework is not. As a result, a map derived from the digital files shows the distribution of units in much more detail and with much more accuracy than the printed map.

23. *Lithofacies label.* The labels are similar to those used on Map 90-01.

24. *Zone ± Subzone.* The field contains the name of the tectonostratigraphic zone to which the polygon belongs, together with the subzone where appropriate. Zones and subzones are adapted from the classification of Williams *et al.* (1988).

SOURCE MAP FIELDS

25. *Map ID.* Each polygon has been digitized from an existing hard-copy map. This field gives the Newfoundland Geological Survey Geofiles number for the map. Note that linework has not been changed from that shown on the original maps.

26. *Map reference.* This is the short-form reference to the map from which the polygon was digitized.

ORDERING NUMBER FIELDS

These four fields are the same as fields 4, 9, 23 and 24, except that they have numeric prefixes that allow them to be sorted in a specific order. They are provided for use in GIS viewing software that creates screen legends of values in selected fields. Such software could use field 4 to make a screen legend of all the labels for top ranking units. However, it would have no means of sorting the labels in a geologically sensible way. If field 27 is used instead, the numeric prefix ensures that the labels are sorted with the oldest units at the bottom of the list and the youngest ones at the top. Once the labels are sorted, the prefixes can be deleted.

27. *Label of dominant unit ordering number (top rank).* Equivalent to field 4. Sorting is by age and older units have higher numbers.

28. *Label of dominant unit ordering number.* Equivalent to field 9. Sorting is by age and older units have higher numbers.

29. *Lithofacies label ordering number.* Equivalent to field 23. Sorting is by tectonostratigraphic zone, rock class and age, and the order of units matches that on Map 90-01.

30. *Zone ± Subzone ordering number.* Equivalent to field 24.