GEOLOGICAL SURVEY OF CANADA
OPEN FILE 7469

Geo-mapping Frontiers: Compilation and Interpretation of Geologic structures North of 60^{o}, Canada

P. Behnia, J.R. Harris, J.C. Harrison, M.R. St-Onge, A. Okulitch, D. Irwin and S.P. Gordey

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Publications in this series have not been edited; they are released as submitted by the author.

ABSTRACT

The Geo-mapping Frontiers project was initiated to improve geoscience knowledge in the least understood parts of Canada's north. This publication presents a compilation and interpretation of geologic structures derived from both high and low resolution enhanced magnetic data (available from the GSC), enhanced LANDSAT imagery and topographic (DEM) data. The data sets included in this OPEN FILE include low resolution airborne magnetic data, a CDED DEM, legacy geological data (IPY map) and structural data compiled by the Yukon and Northwest Territories Geological Surveys as well as a newly interpreted dataset of geologic structures for the entire area of Canada's Arctic north of 60^{o}.

This is the second of a series of reports for the Geo-mapping Frontiers project, and is intended to provide structural information for mapping and exploration in Canada's Arctic.

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INTRODUCTION

In the final phase of the Geomapping for Energy and Minerals (GEM) Program, a project entitled Geo-mapping Frontiers (http://www.nrcan.gc.ca/earth-sciences/about/current-program/geomapping/minerals/11975) (originally called Operation GEM) was initiated to improve geoscience knowledge in the least understood parts of Canada's north. An inventory was first conducted to evaluate the state of knowledge in parts of Nunavut, NWT and Yukon shown as having insufficient knowledge to support decision-making. Criteria included: 1) mapped at 250K scale or coarser; 2) mapped prior to aeromagnetic coverage; 3) lacking modern U-Pb age information on major units; 4) lacking Nd-Sm model age data; 5) lacking thermochronological data; 6) lacking a stratigraphic framework for supracrustal rocks; 7) lacking subdivision of granitic rocks; and 8) mineral potential unconfirmed. Eleven areas identified during a preliminary scan were discussed with territorial geological surveys in the spirit of the Intergovernmental Geoscience Accord.

The project activities include consolidating and improving existing information (data mining, compilation and remote predictive mapping), acquiring new data (e.g. geophysical, geochemical surveys), testing emerging models through targeted field work, contributing to completion of the Tri-territorial database, and advancing planning with regard to future work. Activities are aimed at stimulating direct industry interest through timely delivery of maps, reports, compilations and datasets.

For this Open File, the Geo-mapping Frontiers project in concert with the Remote Predictive Mapping (RPM) project, also part of GEM, has produced a compilation of existing and previously published structures of the Arctic Islands, Yukon and NWT as well as a new and comprehensive interpretation of geologic structures for the entire mainland and islands north of 60^0 as shown in Figure 1.

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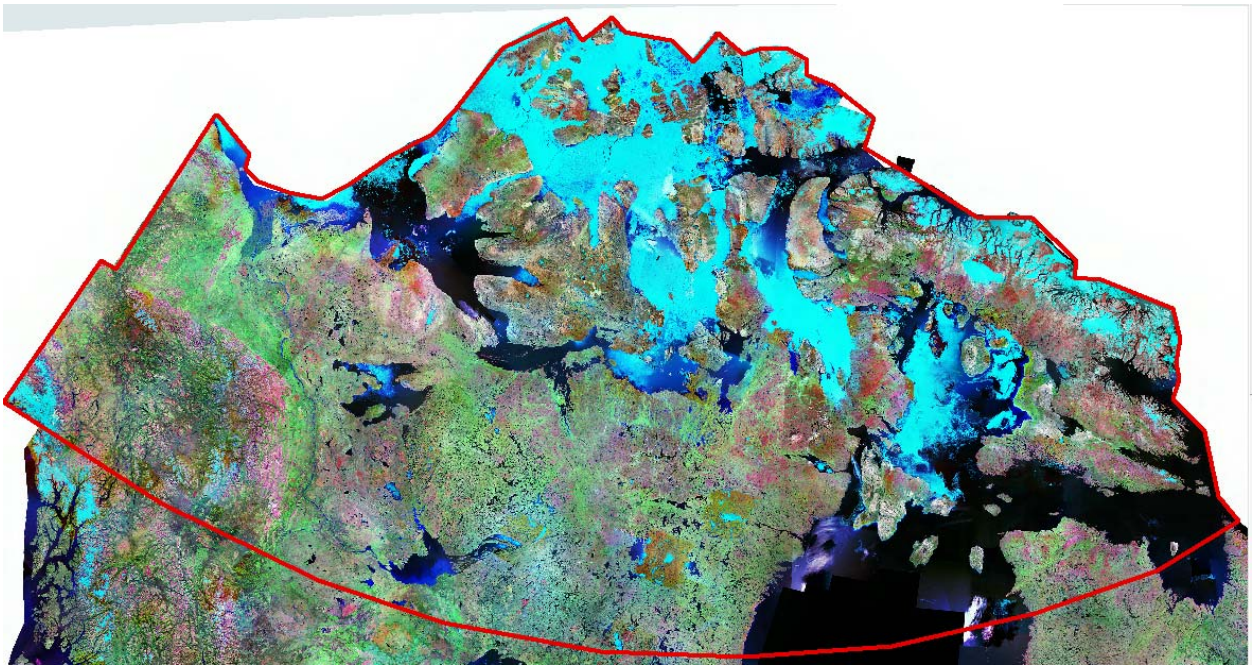
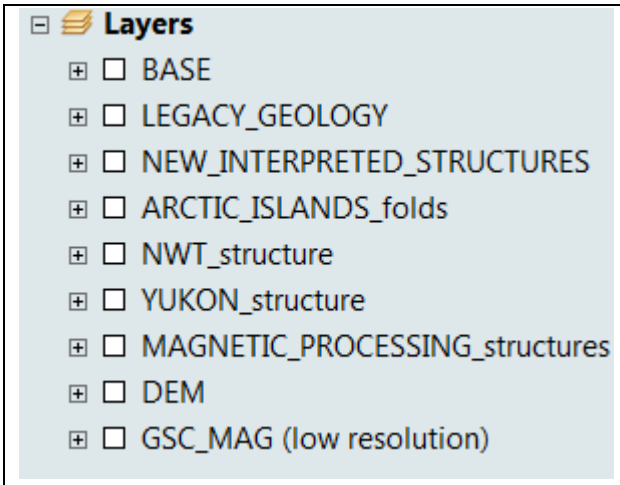


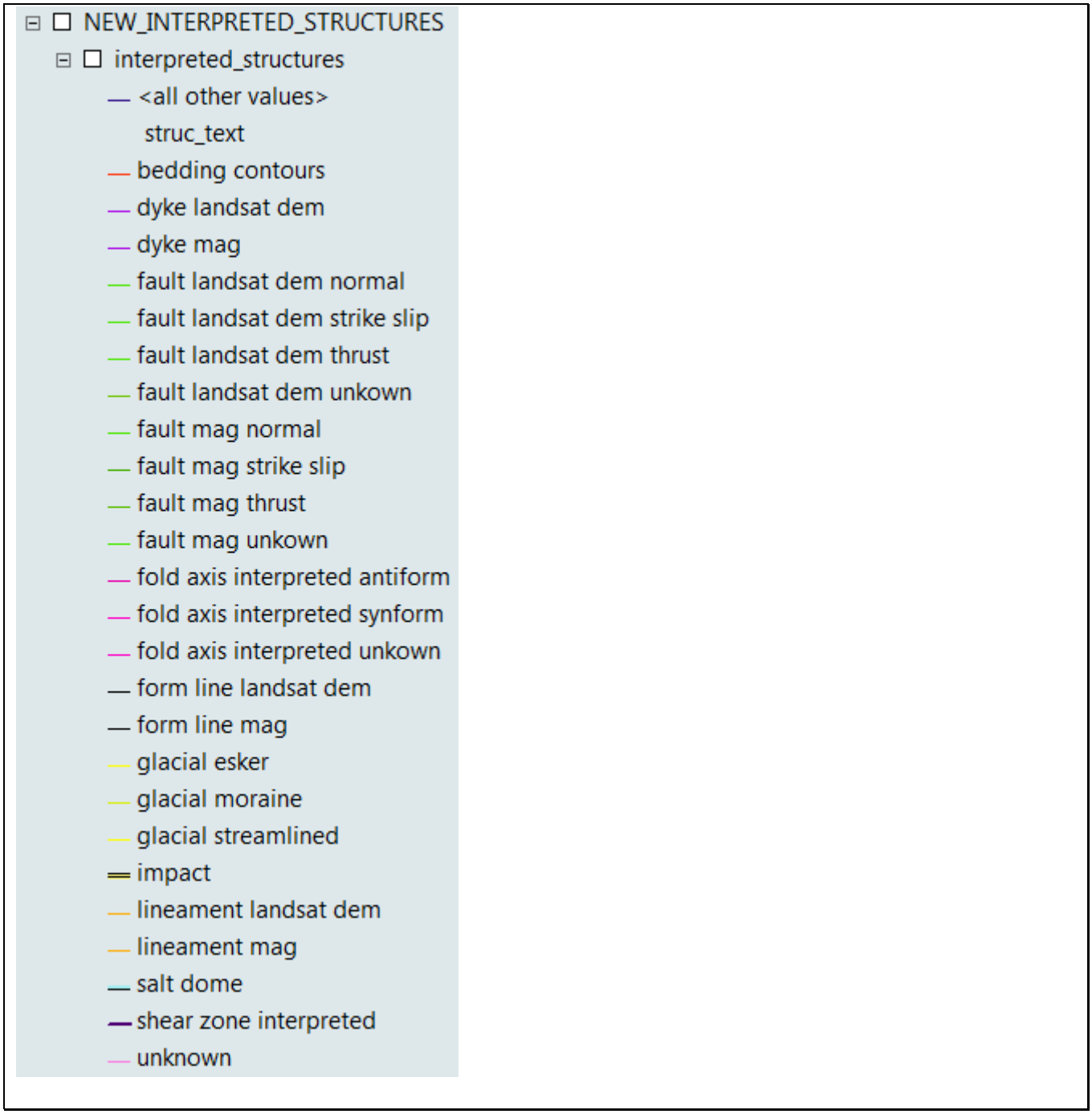
Figure 1. Coverage area shown in red

The following data area included in this Open File all of which have been included in the mxd files (version 10.0 and 10.1) provided in the *data*/*mxd* directory. These files can simply be opened with ArcGIS and all data is displayed and available in grouped layers. The table of contents (TOC) for the ArcGIS mxd is shown in Figure 2 and the data directory structure is shown in Figure 3. A readme and a license file are also included in the downloadable data package. Non ArcGIS users can simply import the shape and raster tiff files into their GIS of choice.



EXPLODED GROUP LAYERS


BASE
Hydrology_arc
Hydrology_poly
<all other values>
HYD_SYM
0
990
LEGACY_GEOLOGY
IPY
Map_2159A_faults
ipy_proj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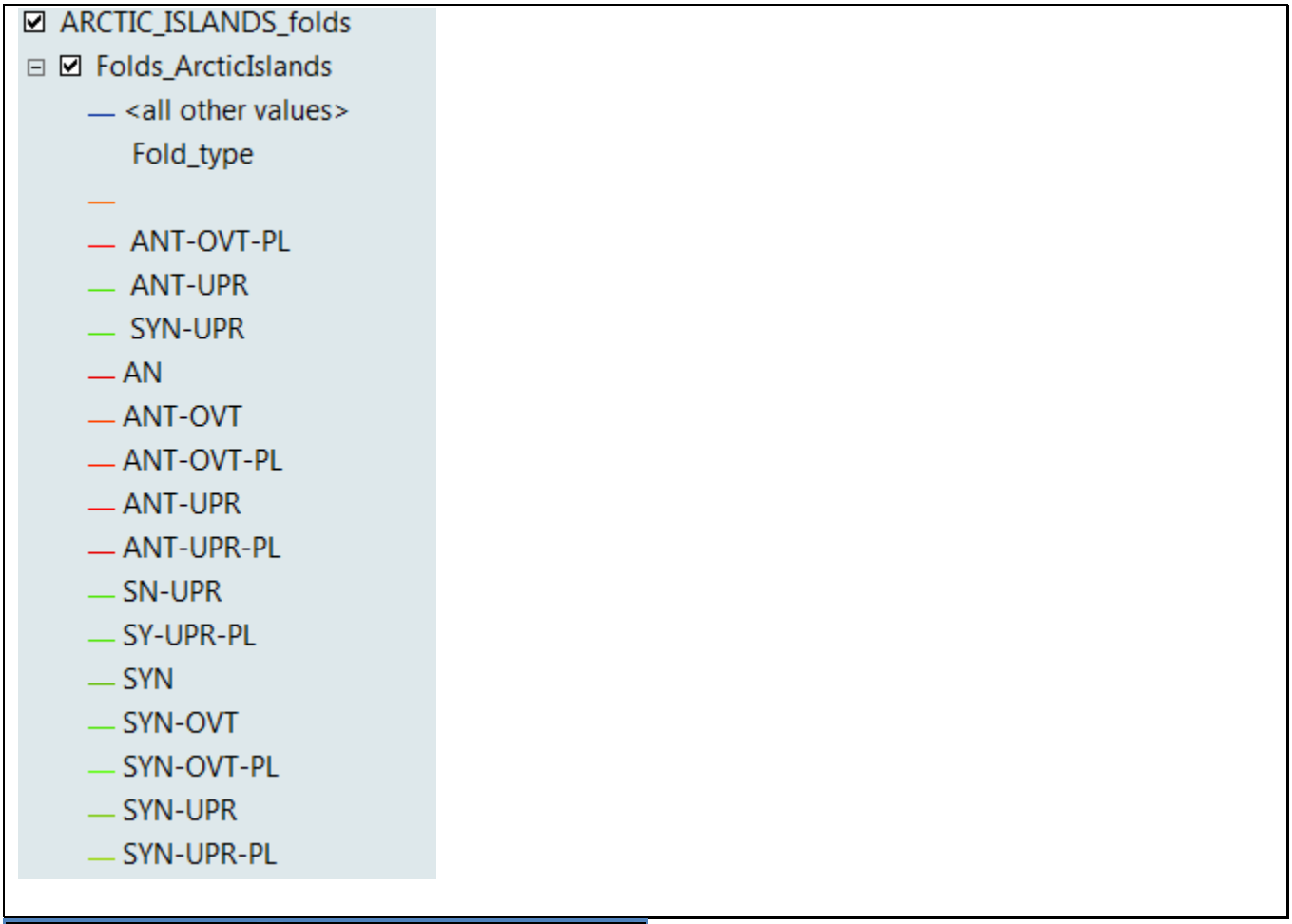
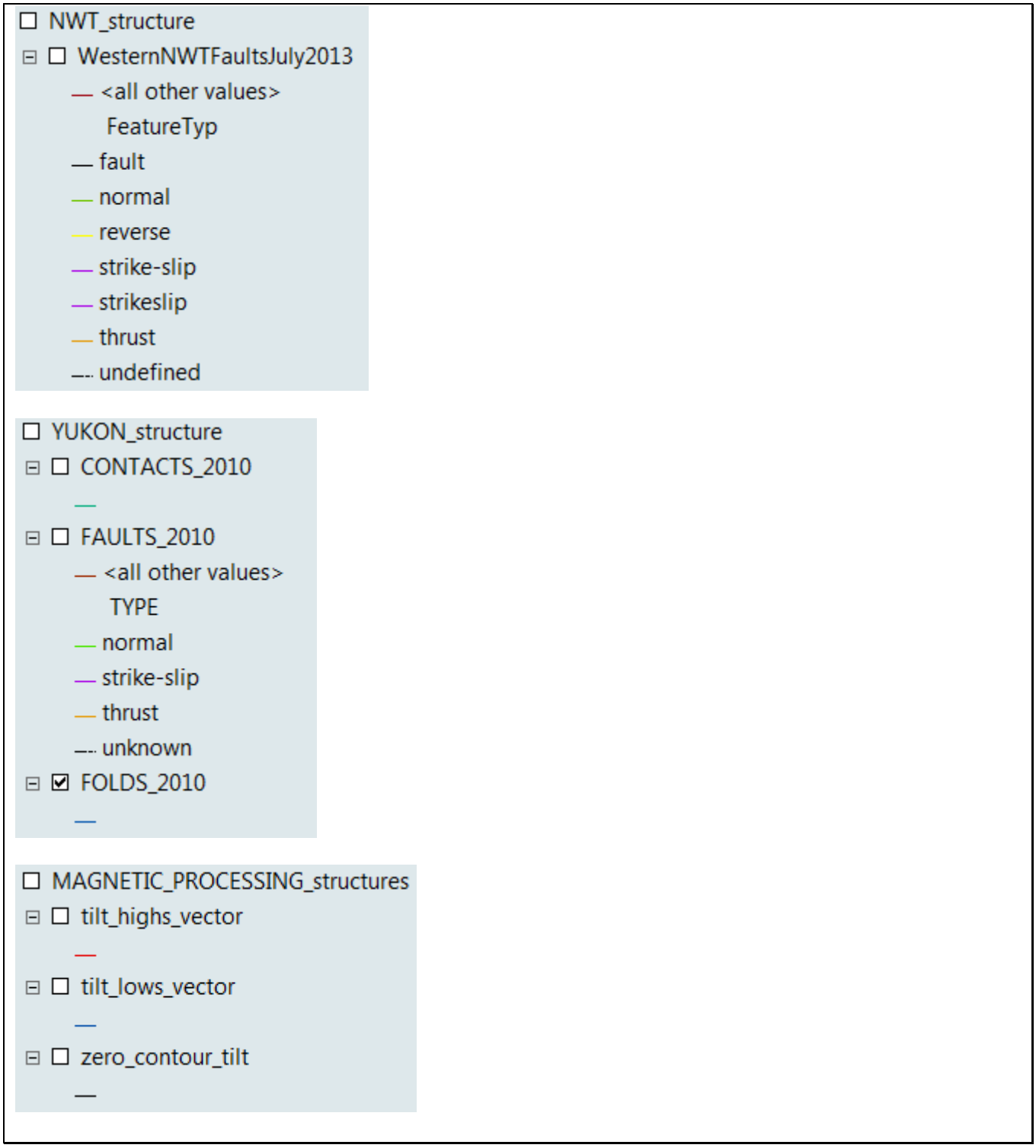
dyke mag
fault landsat dem normal
fault landsat dem strike slip
fault landsat dem thrust
fault landsat dem unkown
fault mag normal
fault mag strike slip
fault mag thrust
fault mag unkown
fold axis interpreted antiform
fold axis interpreted synform
fold axis interpreted unkown
form line landsat dem
form line mag
glacial esker
glacial moraine
glacial streamlined
impact
lineament landsat dem
lineament mag
salt dome
shear zone interpreted
unknown



LABEL	DESCRIPTION
AN	Anticline
SYN	Syncline
ANT-UPR	Anticline Upright
ANT-OVT	Anticline Overturned
ANT-OVR-PL	Anticline Overturned Plunging
ANT-UPR-PL	Anticline Upright Plunging
SYN-UPR	Syncline Upright
SYN-OVT	Syncline Overturned
SYN-OVT-PL	Syncline Overturned Plunging
SYN-UPR-PL	Syncline Upright Plunging
SYN-UPR	Syncline Upright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WesternNWTFaultsJuly2013
<all other values>
FeatureTyp
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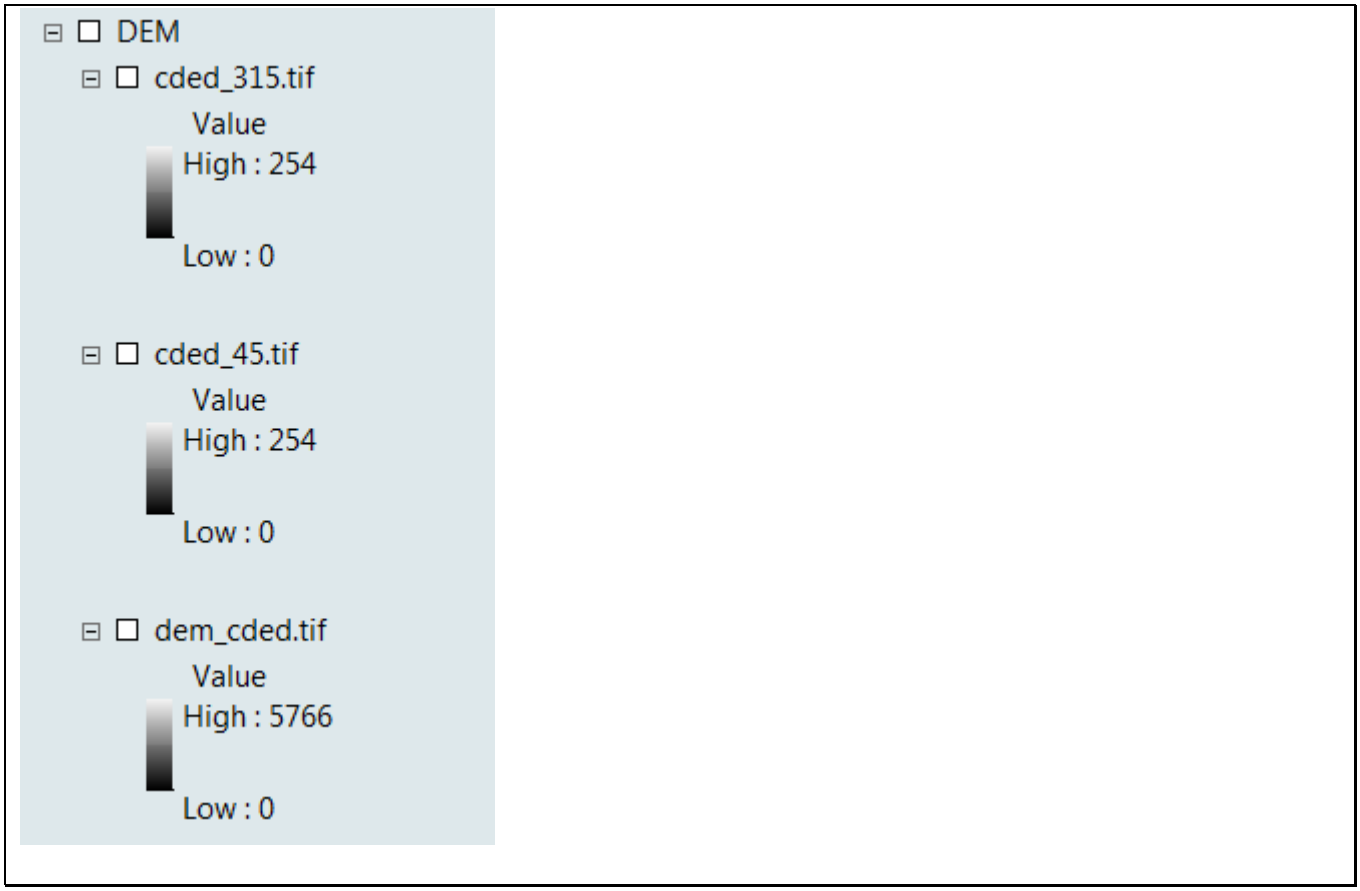
normal
reverse
strike-slip
strikeslip
thrust
undefined
YUKON_structure
CONTACTS_2010
FAULTS_2010
<all other values>
TYPE
normal
strike-slip
thrust
unknown
FOLDS_2010
MAGNETIC_PROCESSING_structures
tilt_highs_vector
tilt_lows_vector
zero_contour_tilt


DEM
cded_315.tif
Value
High : 254
Low : 0
cded_45.tif
Value
High : 254
Low : 0
dem_cded.tif
Value
High : 5766
Low : 0

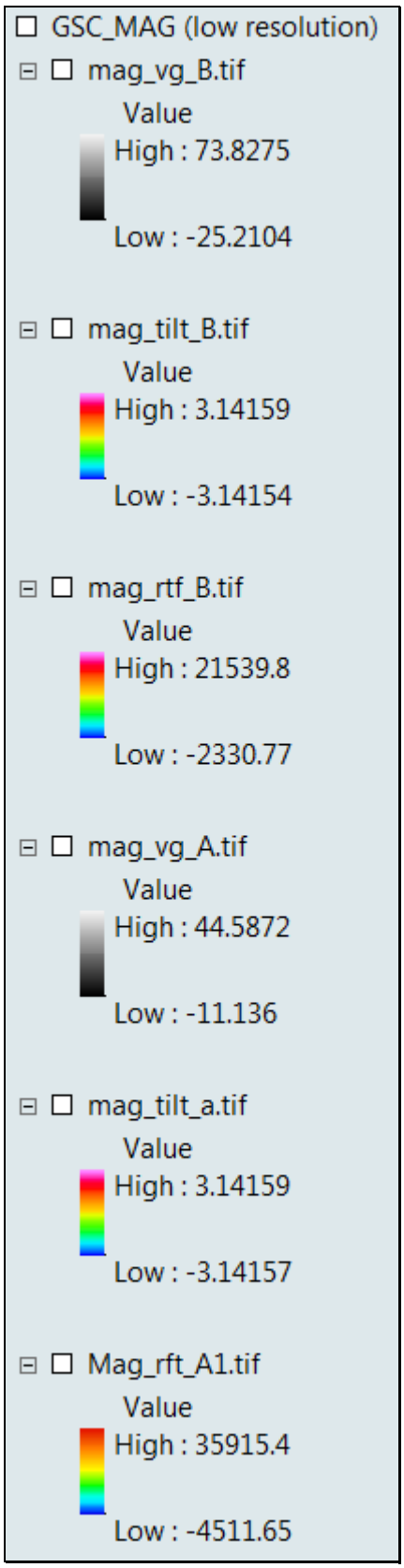


Fig. 2 –ARCGIS mxd groups and layers

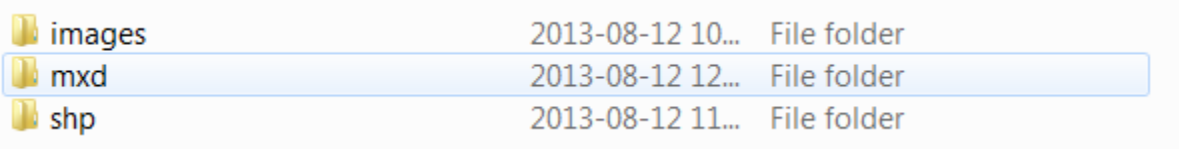


Fig. 3 – Data directory structure

The mxd data frame uses a Lambert Conformal Conic projection with the following parameters:

Projection: Lambert_Conformal_Conic
False_Easting: 0.0
False_Northing: 0.0
Central_Meridian: -96.0
Standard_Parallel_1: 50.0
Standard_Parallel_2: 70.0
Latitude_Of_Origin: 40.0
Linear Unit: Meter (1.0)

Geographic Coordinate System: GCS_North_American_1983
Angular Unit: Degree (0.0174532925199433)
Prime Meridian: Greenwich (0.0)
Datum: D_North_American_1983
Spheroid: GRS_1980
Semimajor Axis: 6378137.0
Semiminor Axis: 6356752.314140356
Inverse Flattening: 298.257222101

DIGITAL DATA

This Open File is the second of a series of reports for the Geo-mapping Frontiers project. It provides the following data and interpretations:

- legacy geological map (IPY) (Harrison et al., 2011) and structural compilations of the Northwest (Okulitch and Irwin, 2013) and Yukon (Gordey and Makepeace, 2003) Territories and fold axes from the Acrtic Islands
- CDED DEM – raw data and shaded relief
- raw and enhanced airborne magnetic low-resolution GSC magnetic data
- High resolution magnetic data have not been included but is available for download from the Geological of Survey geophysical data centre (http://gdr.agg.nrcan.gc.ca/gdrdap/dap/search-eng.php)
- structural data automatically extracted from the GSC airborne magnetic data
- a new interpretation of geologic structures based on magnetic, LANDSAT and topographic data
- base data – ocean and lakes for north of 60^{o}

The LANDSAT data used for interpretation of geologic structures have not been included in this Open File due to size restrictions but can be downloaded for free at the following web-site: http://www.geobase.ca/geobase/en/index.html

DESCRIPTION of DATA LAYERS

A. Base layers

Base data have also been included in group layers as part of the mxd file as follows:

- includes *hydrology_arc* and hydrology_poly in the group layer *BASE* in the mxd file- these layers are derived from the GSC IPY map 2159A. (Harrison et al., 2011).

B. Regional published geology map

- includes the Geology_of_the_Arctic – GSC Map 2159A (IPY – Harrison et al., 2011). This includes lithologic unit polygons and faults. – found in IPY map layer in the *LEGACY_GEOLOGY* group layer in the mxd file and in the *data/shp/Geology_legacy* directory

C. Legacy structural compilations of geologic structures

- a compilation of geologic structures including contacts, faults and fold axes published previously by the Yukon Geological Survey (Gordey and Makepeace, 2003)
- a compilation of faults for the Northwest Territories (Okulitch and Irwin, 2013)
- a compilation of fold axes of the Artic Islands (C. Harrision - GSC)

C. Airborne Magnetic Data

These data are included as separate tiff files (in *data\images*) and are included in the ArcGIS mxd file. Under *GSC_MAG (low resolution)* group layer. The raster images are found in the *data\images\magnetics* directory in *tiff* format. They include low resolution magnetic data flown and processed by the Geological Survey of Canada (Canadian Aeromagnetic Data Base, Airborne Geophysics Section, GSC - Central Canada Division, Geological Survey of Canada, Earth Sciences Sector, Natural Resources Canada Contact: http://gdcinfo.agg.nrcan.gc.ca/contact_e.html#DataCentre). These data described below formed one of the primary data sources for the interpretation of geologic structures as well as the source for the automatically derived structures, discussed below. In addition various high resolution airborne magnetic GSC data (not included in this Open File but available from (http://gdr.agg.nrcan.gc.ca/gdrdap/dap/search-eng.php) were also interpreted.

Total field

This image of the magnetic total field, produced by the Geological Survey of Canada covers a large area of Canada north of 60°. A histogram equalization look-up-table (LUT) has been applied to the data which has been displayed in a colours ranging from blue through green to red. The patterns of colours depicted on the map show the strength of the measured magnetic field and hence reflect how magnetic the rocks are. Trends in the anomalies, therefore, represent trends caused by the distribution of magnetic minerals which reflect the geological make-up of the area.

Vertical gradient

This images of the magnetic vertical gradient, produced by the Geological Survey of Canada, covers the same area as the total field. A standard deviation stretch has been applied to the data using a black and white LUT. The image shows the 1st vertical derivative of the magnetic field and serves to enhance near-surface geologic structure.

Tilt

The tilt (which is related to the instantaneous phase) black and white images are defined as the arctangent of the ratio of the vertical gradient to the magnitude of horizontal gradient of the magnetic field. The horizontal gradient achieves a maximum near or over source edges and tends to zero elsewhere. The vertical gradient is positive over the source, zero over or near source edges, and negative elsewhere. As a result, the instantaneous phase of the magnetic field tends to be positive over sources bodies, zero over source edges, and negative elsewhere. One advantage of the use of the tilt is that, being a ratio, anomalies due to both weak and strongly magnetized sources are given equal weight. Hence, subtle (and often short-wavelength) anomalies are enhanced. Linear and quasi-linear geological features, such as faults, appear as lows whereas dykes often appear as maxima in the tilt map. The disadvantage is that, since the tilt is based on a ratio, all the original amplitude information in the magnetic field is lost, so strongly magnetized sources may produce the same tilt response as weakly magnetized sources. More information on magnetic tilt can be found in Pilkington et al. (2008)

C. Digital Elevation Model (DEM)

A 1:250,000 mosaic of Canadian Digital Elevation Data CDED data showing elevation values for the area north of 60° along with 2 shaded relief images (45 and 315 directions – 45° elevation) is included in the DEM group layer and *\data\images\DEM* data directory. The DEM data is available from the following web-site: http://www.geobase.ca/

D. Structures automatically extracted from airborne magnetic data

These layers are found in the *MAGNETIC_PROCESSING_structures* group layer and in the *data/shp/magnetic_processing* data directory.

Magnetic contacts

Mapping the locations of lateral magnetization contrasts (*zero_contour_tilt*), i.e. the edges of magnetic sources, is one of the most basic and useful applications of magnetic survey data in geological mapping. Delineating the extent of units with similar magnetic properties follows the geological mapping approach of dividing the surface into rocks having similar properties. Whether or not the magnetization changes exactly mimic lithological ones, mapping such contrasts provides valuable information on deformation styles and trends. The potential contacts have been extracted from the magnetic tilt data (tilt horizontal gradient magnitude (TI-hgm)) and represent zones of significant contrast in magnetic susceptibility and represent structures (i.e dykes, faults) and possible lithologic contacts. Further details on this method can be found in Pilkington et al, 2008.

Magnetic lineaments

Magnetic linear highs (form lines, dykes) (*tilt_high_vector*) and lows (form lines, faults) (*tilt_lows_vector*) where automatically extracted from the magnetic data using a combination of histogram thresholding followed by line-thinning and a raster-vector conversion within a GIS environment. These lineaments help to define and map the surface geologic fabric of north of 60^{o}.

E. Interpreted Geologic Structures

A geological structural layer (*interpreted_structures* under the *NE*W_INTERPRETED_STRUCTURES *group layer*) visually interpreted from enhanced airborne magnetic, LANDSAT and topographic data within ArcGIS (ESRI™) using a heads-up interpretation process employing a touch sensitive screen and pen is provided that covers the entire Canadian landmass and islands north of 60^{0} (Fig. 1). The nominal scale of interpretation was 1:500,000 but in many areas characterized by complicated structural regimes and in areas covered by higher resolution airborne magnetic surveys, interpretation was undertaken at 1:250,000 to 1:100,000 scales. A description of the interpretation process can be found in Harris (2012). The primary geologic structures captured include form lines characterizing bedding/foliation/folds, faults, dykes, lineaments, fold axes, glacial features (eskers, moraines , stream-lined landforms, potential impact and salt dome structures and a category was left for unknown structures (Table 1). The structures have been attributed (*stuc_text* in the *interpreted_structures* shape file) according to what the feature represents and the data source from which the structure was derived (Table 1). The sense of displacement of interpreted faults was determined through photogeologic interpretation principles and/ or by using the sense of displacement recorded on legacy geologic maps The shape file attribute, *struc_text*, (Table 1) can be queried and selected separately and/or merged to allow the user to create a structural map that highlights individual or grouped structures. This dataset is useful for not only defining the structural fabric but also provides useful structural information for mineral exploration activity in Canada's Arctic.

Structures interpreted – *struct_text attribute*	**Description**
Form Lines	
form line landsat dem	form lines interpreted from LANDSAT and/or DEM data
form line mag	form line interpreted from enhanced magnetic data
Faults	
fault landsat dem normal	normal fault interpreted from LANDSAT and/or DEM data
fault landsat dem thrust	thrust fault interpreted from LANDSAT and/or DEM data
fault_landsat dem strike slip	
fault landsat dem unkown	fault with unkown displacement interpreted from LANDSAT and/or DEM
fault mag normal	normal fault interpreted from enhanced magnetic data
fault mag strike slip	strike slip fault interpreted from enhanced magnetic data
fault mag thrust	thrust fault interpreted from enhanced magnetic data
fault mag unkown	fault with unkown displacement interpreted from enhance magnetic data
Dyke	
dyke landsat dem	dyke interpreted from LANDSAT and/or DEM
dyke mag	dyke interpreted from enhanced magnetic data
Lineaments	
lineament landsat dem	lineament interpreted from LANDSAT and/or DEM
lineament mag	lineament interpreted from enhanced magnetic data
Shear zone	
shear zone interpreted	Shear zone interpreted from LANDSAT and/or DEM and/or enhanced magnetic data
Bedding contour	
Bedding contour	Bedding contour in flat-lying sedimentary rocks interpreted from primarily LANDSAT data
Interpreted fold axes	
fold axis interpreted antiform	interpreted from LANDSAT,DEM and enhanced magnetic data with support from legacy geology maps
fold axis interpreted synform	interpreted from LANDSAT,DEM and enhanced magnetic data with support from legacy geology

	maps
fold axis interpreted unkown	interpreted from LANDSAT,DEM and enhanced magnetic data with support from legacy geology maps
Possible Impact crater	
impact	circular feature interpreted from LANDSAT and/or DEM and/or enhanced magnetic data
Possible Salt dome	
salt dome	Circular feature interpreted from LANDSAT and/or DEM and or enhanced magnetic data
Glacial features	
glacial esker	esker interpreted from primarily LANDSAT and to a lesser extent DEM data
glacial moraine	moraine interpreted from primarily LANDSAT and to a lesser extent DEM data
glacial streamlined	streamlined landform interpreted from primarily LANDSAT and to a lesser extent DEM data

Table 1 – Summary of interpreted geologic structures

SUMMARY

This publication presents a basic compilation and new interpretation of geologic structures from enhanced magnetic, LANDSAT and topographic data, all of which are available for free to the public. Visual interpretation, using simple photogeologic principles, supported by legacy geological maps and databases where available, was utilized to produce the structural interpretation. The interpretation was undertaken in ARCGIS by "heads-up" digitization using a touch-sensitive screen and pen within a geo-database environment

This interpretation\compilation is the second of a series of reports for the Geo-mapping Frontiers project, to provide a basis of geo-science knowledge for Canada's North.

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Harris, J.R., Schetselaar, E., and P. Behnia, 2012. Remote Predictive Mapping: An Approach for the Geological Mapping of Canada's Arctic (Ch. 20), *in* Earth Sciences, *ed.* by Imran, Ajhmad Dar, InTeCH, Croatia, 648. p

Harrison, J C; St-Onge, M R; Petrov, O V; Strelnikov, S I; Lopatin, B G; Wilson, F H; Tella, S; Paul, D; Lynds, T; Shokalsky, S P; Hults, C K; Bergman, S; Jepsen, H F; Solli, A., 2011. Geological map of the Arctic; Geological Survey of Canada, "A" Series Map 2159A, 9 sheets; 1 DVD.

Gordey, S.P. and Makepeace, A.J. (comp.), 2003. Yukon digital geology (version 2); Geological Survey of Canada, Open File 1749; Yukon Geological Survey, Open File 2003-9(D), 2 CD-ROMs, scale 1:1 000 000.

Pilkington, M., 2008. Chapter 3. Geophysics, *in* Remote predictive mapping: an aid for northern mapping, *ed.* J.R. Harris - GSC Open File 5643; 306 p, 1 DVD.