YUKON GEOPROCESS FILE

(An inventory of geological processes and terrain hazards)

USER GUIDE

Indian and Northern Affairs Canada
Exploration and Geological Services Division
#345-300 Main Street
Whitehorse, Yukon
Y1A 2B5

INTRODUCTION AND USER GUIDE

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INTRODUCTION

This CD-ROM is a digital re-release of data collected and published as the Yukon GEOPROCESS FILE between 1994-1996. The data set is a compilation of information and knowledge on geological processes and terrain hazards in the Yukon Territory.

The original work was carried out in three phases from 1992 to 1995. Contractors performed the work under the supervision of the Environmental Geologist, Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada. The following individuals and companies were involved in carrying out the project: Mougeot GeoAnalysis, Aurum Geological Consultants Inc., L. Walton and C. Hart.

This inventory is available to industry, government and other agencies as a tool for preliminary evaluation of geological processes and potential terrain hazards near proposed development projects. It provides baseline information on geological processes for environmental reviews required under the Canadian Environmental Assessment Act (CEAA). **The GEOPROCESS File should never replace an on-site investigation by qualified professionals.**

GEOPROCESS File Contents

The new **Digital GEOPROCESS File** release is a CD-ROM containing the following:

- Individual 1:250 000 map sheets in portable document format (.pdf).
- AutoCAD™ Map 2000 (.dwg) drawings of maps, legends and notes, coordinates, hatches, linework, and structural geology.
- Text files for each individual map sheet describing the bedrock and surficial geology, mineral occurrences, and geological processes and terrain hazards
- Readme File (.doc) containing information on technical requirements.
- User Guide containing background information.

User Guide

This User Guide gives background information on the GEOPROCESS File project and provides brief descriptions of the contents of the CD-ROM. It also includes appendices to help the user interpret the maps and summary reports:

Appendix A. "Geological Famework of the Yukon Territory" by C. Hart

An overall summary of Yukon geology, "The Geological Framework of Yukon Territory" was prepared as part of the original GEOPROCESS File project, and is included as Appendix A in this Introduction and User Guide. The purpose of the summary is to provide GEOPROCESS File users, who may not have geological training, with a broad understanding of the geology of Yukon. This will assist the GEOPROCESS File user in interpreting the bedrock geology summaries for each NTS map sheet and the GEOPROCESS File maps themselves.

The paper briefly describes the geological framework of Yukon south of 65 degrees N and, with some exceptions, uses the Tectonic Assemblage Map of the Canadian Cordillera (Wheeler and McFeely, 1991) and the Terrane Map of the Canadian Cordillera (Wheeler *et al.,* 1991) as a foundation. Some of the names used on the tectonic assemblage and terrane maps have been superseded by new terminology; the new terminology is included in the summary. Recent brief syntheses of Yukon physiography and geology are rare (Tempelman-Kluit, 1979; 1981) although geological compilations of Cordilleran geology are numerous and contain useful information about Yukon geology (Monger *et al.,* 1982; Monger, 1989; Gabrielse and Yorath, 1992). **Please keep in mind the maps were produced and summaries were written prior to the release of the Yukon Digital Geology (S. Gordey and A. Makepeace, 1999, EGSD Open File 1999-1(D)), thus in some cases more recent information on the bedrock geology is now available.**

Appendix B. Summary of the Glacial History of Yukon by T. Fuller and L. Jackson

The report and figures are excerpts from the Yukon Ecoregions Report (in prep., Department of Renewable Resources, Government of Yukon).

Appendix C. Report and Map of Permafrost in Yukon by C. Burn

The report and map are excerpts from the Yukon Ecoregions Report (in prep., Department of Renewable Resources, Government of Yukon).

Appendix D Comprehesive General List of References

The methodology used for gathering references is described in the Reference List section. Two sets of references were generated for the GEOPROCESS File project. Those references pertaining to large areas of Yukon or of Canada are in the general reference list (Appendix D). References that are more NTS-specific are in the reference lists for the appropriate NTS map sheets. A thorough reference search will involve checking both the General Reference List in Appendix D and the Reference List for specific NTS map sheets.

Geological Processes and Terrain Hazard Compilation Maps

Information on each 1:250 000-scale GEOPROCESS File map is compiled almost entirely from published reports and maps. Plots of terrain hazards/geological processes, faults and recent volcanism on mylar overlays were digitized in AutoCad release 12 and drafted by Geological Drafting Services and Underhill & Underhill. Information on seismic activity was transferred to the GEOPROCESS File maps from a digital spreadsheet provided by the Pacific Geoscience Centre.

The compilation maps have a confidence level reflecting the original source material. All materials used to produce the maps are noted with an asterisk in the list of references on each map. A file containing much of the documentation used to construct these maps is available at the Library, Indian and Northern Affairs Canada in Whitehorse, Yukon. Information from small scale (e.g., 1:1 000 000 scale) maps was used for the summary reports, but not redrafted onto the 1:250 000 GEOPROCESS File maps.

Each 1:250 000-scale compilation map contains four types of geological information:

- Terrain Hazards and Geological Processes
- Faults
- Recent Volcanism
- Seismic Activity

a. Terrain Hazards

Terrain hazards are naturally occurring geologic and geomorphic processes and unstable conditions that present a risk to life and property within a specific area (Ryder and McLean, 1980). Terrain hazards are classified into the following general categories:

1. Hazards caused by mass movement process such as landslides, debris flows, avalanches and rock slides;

2. Hazards related to frozen soil or ground ice, such as solifluction, permafrost and thermokarst;

3. Hazards related to fluvial processes such as flooding either by seasonal discharge variation or by other catastrophic natural phenomena (i.e., ice-dammed lake).

Terrain hazards can be triggered by natural events such as heavy rain, seismic activity or a change in glacial equilibrium. Degradation of permafrost, which is a slow process, can cause sheet flow, mud flow or thermokarst collapse. Heavily fractured rock can shed small to large volumes of rock regularly as weathering takes place. Although hazards such as floods and avalanches are closely related to storm activity or seasonal patterns, it is very difficult to predict with accuracy the extent and timing of such hazards. These compilation maps simply attempt to identify which hazards are likely to occur or which processes are likely to take place - they do not comment on the intensity, frequency or extent of future occurrences.

Risk level, whether high, moderate or low, relates to the expected degree of loss due to a particular natural phenomenon. It may be expressed as directly proportional to the magnitude and severity of the specified hazard and the vulnerability of the specified area (potential loss of a set of elements such as housing, roads, etc.). All risk levels attached to the map units refer to hazards affecting human activity and properties such as major roads, housing developments and public areas such as campgrounds. The severity of risk to human life is often unrelated to the probability of the hazard occurring. For example, the probability that thermokarst will develop when the vegetation is removed from some types of material containing permafrost is great, but the risk to human life is usually low. It could constitute a significant risk if poor road design or maintenance allowed a portion of a road to eventually become dangerous. The risk of rock fall, although less probable and predictable, would put human life at much greater risk.

Terrain Hazard Map Legend

The legend for the Geological Processes and Terrain Hazard maps is standard for all maps. Consequently, units identified in the legend will not be present on every map. The legend is divided into two main categories to reflect the two dominant types of information available. The first category lists terrain hazards and is represented on the map by a capital letter or group of capital letters. This category is based on the terrain hazards legend developed by Thurber (1989) and applies to information compiled directly from terrain hazard maps, or from Quaternary geology map units with specific hazards identified on the source map. The units in this category are described in the following section. The second portion of the legend identifies landforms and Quaternary deposits associated with specific hazards. These map units are identified by lower case letters. An example of such a feature is a flood plain on which flooding is a probable hazard.

Terrain Hazards Map Units

Mass Movement Processes

A Snow avalanched.
Avalanches are considered a high risk.

F Slow to moderate rates of failure in soil or bedrock.
This includes soils creep, rock creep, soil slump, earth flow, some debris slide types and rock slides. Although these may involve large volumes of material, they may occur on fairly gentle slopes and at considerably lower speeds than processes classified as R. This category is considered to be a low to moderate risk.

R Moderate to rapid rates of failure in soil or bedrock.

This category includes rock slump, debris slide, rock slide, debris flow, debris torrent, debris avalanche, rockfall and rock avalanche. This category is considered high risk because of the possible rapid rate of failure and large volume of material involved.

Arctic Alpine and Periglacial Processes

X Permafrost present.

The presence of permanently frozen soil is common at Yukon's latitudes. Frozen ground can contain ice crystals, ice-wedges, ice lenses or large tabular bodies of ice. Patterned ground, pingos, and solifluction landforms are good indicators that permafrost is present. Areas with poor drainage and thick surface vegetation covers, such as thick moss or organic mats, are commonly sites underlain by permafrost. North-facing slopes normally have more permafrost than south-facing slopes, but the larger amount of solar radiation received by south-facing slope is not always sufficient to eliminate the possibility of permafrost-rich soil given similar conditions (thick organic mat and fine-grained soils with poor drainage). Although the presence of permafrost can be inferred, the type, volume and distribution of ice within the unconsolidated material can only be determined by a site investigation. Permafrost is considered to be a low risk to human life, but surface disturbance of permafrost landforms can trigger slope or collapse processes, which may cause problems and high maintenance costs to roads and structures. Appendix C describes types of permafrost commonly encountered in Yukon.

K Thermokarst.

The irregular topography of such units is due to the melting of underlying permafrost. Active thermokarst will cause collapse and subsidence of the ground, resulting in steep-sided ponds, unstable walls and surface ground fractures. The pond walls may recede rapidly and infringe on roads or other structures. Thermokarst collapse is most likely to occur in fine-grained sediments with large inclusions of massive ice and can be initiated by the disturbance of ground insulation (removal of vegetation) commonly by natural causes such as forest fires. Although considered as low risk to human life, thermokarst collapse can have a negative impact on roads and other structures.

S Soliflucted.

Solifluction or gelifluction, when it applies to an area where permafrost is present, refers to the downward motion of the thawed saturated soil layer over a surface of frozen ground. It can involve large surfaces on fairly gentle slopes, called solifluction sheets, or smaller surfaces creating lobes, stripes, terraces. Although considered as low risk to human life, solifluction features can have a negative impact on roads and other structures. It is classified as low to intermediate risk, especially to roads, air strips, etc. because of the large surfaces involved.

Z Grouped.

This describes an area where a combination of permafrost related features are present, including nivation, solifluction and cryoturbation. This map unit is classified as low to intermediate risk.

Fluvial Processes

B Braided.

A braided fluvial environment is one where many diverging and converging channels are separated by non-vegetated and temporary sand or gravel bars and islands. During peak-flow periods, the entire channel area may be flooded. It is considered an intermediate to high risk to human life and structures.

E Fluvial erosion and deposition.

This refers to normal stream erosion and deposition, and is commonly attached to low-level flood plain terraces and active fluvial landforms. It is considered as low to intermediate risk.

J Anastamosing.

An anastamosing fluvial system is one where channels diverge and converge around several, relatively stable islands. Channels may be dry at low flow periods and flooded during peak flow periods. It is considered an intermediate to high risk to human life and structures.

U Flooded.

The lowest terraces of some streams are regularly flooded on a seasonal basis. They are considered as unsuitable for development and represent an intermediate to high risk.

Miscellaneous Processes

T Karst.

Process associated with the solution of carbonates (e.g., limestone) and other soluble rocks resulting in underground weathering, collapse and subsidence. Although not a life threatening phenomena, these disturbances can damage buildings, structures and are considered as intermediate risk.

P Piping.

Subterranean erosion of unconsolidated materials by flowing water, which results in the formation of tubular underground conduits or pipes. Piping is most common in fine-grained sediments, such as alluvial or glaciolacustrine sediments. They are considered as intermediate to high risk to buildings and other structures because these failures take place in unconsolidated sediment and may involve local changes in the water table.

V Gullied.

Gullies or deep, long ravines may disturb established roads. They also provide a path for other geological processes such as debris torrents, avalanches, etc. This category is considered as low to intermediate risk because, although slope erosion is gradual over large periods of time, large volumes of material and rapid failure rates may be involved.

b. Faults

Faults were compiled using Wheeler and McFeely (1991) and the most recent 1:250 000-scale and 1:50 000-scale bedrock geology maps (current to 1994). For some map sheets the only structural information available was on Wheeler and McFeely (1991) at a scale of 1:1 000 000. On other map sheets there were large discrepancies between Wheeler and McFeely (1991) and the latest 1:250 000 map and more detailed 1:50 000-scale maps. Government geologists familiar with the structural geology in specific NTS map sheets were consulted which sometimes resulted in structures plotted differently than those shown on either Wheeler and McFeely (1991) or other published government geology maps.

Faults were classified according to relative motion. A fault forms when rocks on either side of a fault plane are carried past one another. It is rare to have a single fault plane; fault zones consisting of a series of fault planes and fractures are more common. Fault traces on the map legend are shown as defined, approximate and assumed. Where possible, the relative displacement of the fault is shown. Thrust faults, as shown on the legend, are shallow-dipping faults, usually around 30 degrees, where the hanging wall of the fault moves upwards relative to the footwall. Structural indicators, such as landslides and air photo lineaments shown on published geology maps, were also plotted.

The selection and plotting of faults is very subjective and fault location, as plotted on the GEOPROCESS File maps, may be misleading. Interpretation of fault location should not be attempted by anyone without training in structural geology. This is especially true when doing site-specific studies.

No interpretation was made as to the relation of the mapped faults to seismic and/or volcanic activity.

Discussion on the nature of faulting in the Yukon is located in the “Summary Reports for each NTS Map Sheet” section of this User Guide and in "Geological Framework of the Yukon Territory" in Appendix A. Additional information on faulting is contained in the bedrock geology sections of the summary reports for each NTS map sheet.

c. Quaternary Volcanism

The Yukon is a tectonically active region in which volcanic eruptions and earthquakes are a certainty. A felsic volcanic eruption can expel small to large amounts of pyroclastic material, which may result in a blanket of ash. Basaltic eruptions in regions of heavy snow may produce debris flows or floods from rapidly melting snow.

Quaternary volcanism shown on 1:250 000-scale published geology maps was transferred to the GEOPROCESS FILE maps. In general, there are two important areas:

> *White River Ash Vent*
> The most recent large explosive eruption in the Canadian Cordillera occurred 1300 years ago from a volcanic vent just on the Alaska side of the Yukon-Alaska border near the White River, Yukon. This catastrophic event ejected an estimated 30 cubic kilometres of pyroclastic material and covered large areas of Yukon with a blanket of ash (Lerbeckmo and Campbell, 1969). This ash is often mixed with uppermost soil horizons and can be as thick as 40 cm in some areas. The vent is situated in the 25 million year old Wrangell volcanic belt. The belt built up as a result of subduction, and later on, strike-slip related movement between plate margins.
>
> *Volcano Mountain*
> Volcano Mountain, a cinder cone on the Carmacks sheet (NTS 115I), has erupted several times during its history, most recently in the early 19th century. The volcanism may be related to the intersection of nearby deep-seated faults, and it is therefore likely that eruptions will occur again (Jackson and Stevens, 1992).

Once again, the GEOPROCESS File maps and references are meant to guide the user to more detailed information, in this case the "General References" list of references for volcanism in the Canadian Cordillera, in addition to the NTS specific references.

d. Seismic Activity

The Earthquake Studies Subdivision of the Pacific Geoscience Centre, Natural Resources Canada, Sydney, B.C. maintains and manages seismic stations located throughout British Columbia, Northwest Territories and Yukon. Research scientists locate earthquake epicentres, and calculate their depths, magnitudes, and the mechanisms of fault motion.

Diskettes containing seismic activity information for the GEOPROCESS File project were purchased from the Pacific Geoscience Centre. The seismic activity data was translated and plotted on the digital 1:250 000-scale maps (Autocad 12).

There are two broad areas of intense seismic activity in the (Rogers and Horner, 1991):

> *Southwestern Yukon near the Denali Fault*
> Seismic activity in southwestern Yukon is generated by convergence of the Pacific and North American plates in the eastern Gulf of Alaska. The Denali Fault zone, which passes through NTS map sheets 115A, 115F/G, 115J/K, is the focus of significant seismic activity.
>
> *Mackenzie and Richardson Mountains*
> Large earthquakes generated in the Nahanni (105I) map sheet in 1985 (magnitude 6.6) and 1988 (magnitude 6.0) may have been the result of thrust faulting on shallow-dipping planes in the MacKenzie Mountains. Recent seismic activity in the Richardson Mountains may also be related to reactivation of faults.

Summary Reports for each NTS Map Sheet

a. Bedrock Geology Summary

Each 1:250 000 NTS map area is described according to morphogeological belts and terranes defined by Gabrielse *et al.* (1991) and Wheeler *et al.* (1991). A summary paper ("A Geological Framework for the Yukon Territory") is provided in Appendix A to provide a framework and context for each of the bedrock summaries.

Bedrock geology, geological structures and mineral occurrences are briefly described and taken largely from the referenced, most recent 1:250 000 geological map (up to 1994) with additional contributions from Wheeler and McFeely (1991), and Yukon MINFILE (1993). Please note that there are now more recent geology maps available in the new Yukon Digital Geology compilation (S. Gordey and A. Makepeace, EGSD Open File 1999-1(D)), and more recent MINFILE summaries than those used in this compilation (Yukon MINFILE, 2001). Many of the names, ages and terrane affinities of several of the rock units are now considered to be incorrect as they appear on the most recent 1:250,000 geological map. Although much of the information reflects the knowledge at the time that the source map was published, additional information has been inserted whenever possible to assist the user in merging the information with current geological maps, concepts and understanding.

In addition to the differing sources of information between the map areas, the age ranges for similar packages of rocks vary between map areas since the actual rocks, or at least the constraints on their age, vary between map areas.

There are several generally reliable descriptors of Yukon geology:

C Rock units and major faults strike (trend) towards the northwest.

C Faults occur throughout most of the Yukon, particularly in the accreted terranes. Thrust faults are common in the thick sedimentary rock packages of Ancient North America.
C Rock units older than 120 million years old have been folded at least once.
C Many northwest-trending faults likely have some right-handed strike-slip motion along them. This motion is coincident with displacements along the Tintina and Denali faults.
C The Tintina Trench is the surface expression of the Tintina Fault, which was active mainly between 100 and 50 million years ago.
C The Shakwak Trench formed (for the most part) along the Denali Fault, which was active between 50 and 15 million years ago. Most of its motion has been transferred to the Duke River fault, which is still active today.

Particular rock packages throughout the Yukon are recognized as having characteristics which predispose them to gravitational failure (i.e., slides). These include:

C columnar-jointed volcanic rocks which locally form unstable cliff faces; serpentinized ultramafic rocks which contain talc and are therefore extremely slippery (i.e., have no internal friction).
C clay-altered acid volcanic rocks, which when saturated or wet are extremely slippery. The clays also expand in volume to create further instability.
C poorly indurated, clastic sedimentary rocks such as those of the Amphitheatre Formation which are unstable yet typically form steep slopes (badlands), which periodically fail.
C hornfelsed sedimentary rocks that surround plutons tend to be extremely brittle and highly fractured.
C Hyland Group sedimentary rocks are locally unstable and susceptible to landslides.

Additional descriptions of the physiography and Quaternary geology of Yukon can be found in Bostock (1948), Clague (1989) and Matthews (1991).

b. Surficial Geology Summary

Surficial geology summaries are based on published reports and professional papers, and in a few cases, on regional maps or reports from surrounding map sheets. The summaries provide a general description of the unlithified, unconsolidated deposits of each particular map sheet. Ice limits and relative age of surfaces are discussed in relation to the overall Quaternary history of the Yukon (Appendix B). Surficial geology source materials used to compile the summaries and the GEOPROCESS File compilation maps are in the reference list and were revised with new work up to 1996.

c. Terrain Hazards Summary

The terrain hazards summary is based on the GEOPROCESS File terrain hazards compilation maps. For each section (seismicity, mass movement, permafrost, flooding risks), there is a brief description of the extent and distribution of the most severe hazards likely to affect development. In some cases, when map information was unavailable, the summary was based on information from adjacent maps or from regional scale maps.

Reference Lists

References were compiled by searching computer databases, catalogues, bibliographies, compilations and talking to geoscientists. The GEOREF database search for Phase I was carried out at Yukon and subsequent database searches were carried out at the DIAND library on the third floor of the Elijah Smith Building in Whitehorse.

References were of two types: NTS-specific or general references pertaining to more than one NTS map sheet.

The databases were searched using two methods:

1. By NTS map sheet

This method was particularly useful with the Geological Survey of Canada databases.

2. By keyword

Keywords used included:

mass movement
ground ice
permafrost
solifluction (solifluxion)
slope movement
slope stability
slope processes
thermokarst
floods-flooding
volcanic ash
volcanic activity
volcanic eruption
tephra
glacial geology
quaternary geology
terrain hazards
surficial geology
earthquake
seismic
geologic hazards

landslide
mudslide
gravity slide
avalanches
terrain mapping
terrain modeling
landforms
stream dynamics

Reference Sources

a. **VLTS**

VLTS is an on-line listing of the publications in all DIAND departmental libraries, including thesis publications, 'in-house' government reports and interdepartmental or joint government/industry publications. It is now possible to search these publications online at http://www.yukia.yk.net/.

b. **Geological Survey of Canada Databases**

The GEOSCAN database is managed by the Canadian Geoscience Information Centre of the Geological Survey of Canada. It contains references to geoscience literature concerning the Canadian landmass and offshore regions supplied by fifteen federal, provincial, academic and professional geoscience organizations located throughout Canada. There are over 190,000 records including serials, books, theses, maps, open files and mineral assessment reports. It is possible to retrieve information by author, title, source, keywords, geographic areas and NTS map sheet.

c. **GEOREF**

The CD-ROM version of the American Geological Institute's database contains over 1.5 million records on geology journal articles, conference papers and theses. The DIAND library has a workstation where a client can search GEOREF directly on CD-ROM.

d. **Yukon Geology Bibliography**

This bibliography is now available digitally (EGSD Open File 2001-29(D)) and contains listings of all reports that have a bearing on Yukon's Mineral Industry. It excludes actual geology reports, maps and assessment reports. The CD can be purchased through Geoscience Information and Sales, Whitehorse Mining Recorder, DIAND.

e. **Exploration and Geological Services Division, DIAND Publications List**

This publications list can be viewed on the Yukon Geology Program website (http://www.geology.gov.yk.ca). It includes a complete listing of geological reports, maps, open-file reports and other publications available for sale through Geoscience Information and Sales, Whitehorse Mining Recorder, DIAND.

f. **Economic Development Library, Yukon Government**

This library is located on the fourth floor of the Shoppers Drug Mart building on the corner of 3rd and Main Street, Whitehorse, Yukon.

g. **Current Contents**

Current Contents, available in print, or on diskette at the DIAND library, contains the titles of recently published papers.

The most useful resource is the DIAND library with its professional staff and extensive resources, including GEOREF and the Geological Survey of Canada databases on CD-ROM.

For information on Yukon mineral deposits, the user is referred to "Yukon MINFILE" which is available for viewing on the Yukon Geology Program website (http://www.geology.gov.yk.ca). The Yukon MINFILE 2001 CD-ROM can also be purchased through Geoscience Information and Sales and is available in three main formats:

1) Access Database
2) Portable Document Format (PDF) and Word format - Text Files
3) Portable Document Format (PDF) - Maps

Geological Survey of Canada stream sediment surveys for each NTS map sheet are listed in the references. These surveys are in the EGSD Publications List and are available for purchase through Geoscience Information and Sales or for viewing in the DIAND library.

The decision to include particular references in the GEOPROCESS File inventory is somewhat subjective. The most up-to-date geological maps, reports and open-files were included, especially those which would be easy to find in Yukon libraries. Historical geology reports and maps, assessment reports and deposit-specific papers on ore deposits and coal deposits were, in general, beyond the scope of this project.

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APPENDIX A – The Geological Framework of the Yukon Territory

by C. Hart

The Yukon Territory occupies the northern portion of a large geologic (and physiographic) province known as the Cordillera. This province is composed of relatively young mountain belts that range from Alaska to Mexico. Like most of the Cordillera, Yukon is composed of a diverse array of rock types that record more than a billion years of geological history. Most of the rocks have been affected by folding, faulting, metamorphism and uplift during various deformation events over at least the last 190 million years. This deformation has resulted in a complex arrangement of rock units and the mountainous terrain we see today. In Yukon, there are two main geological components which are largely separated by a major, northwest-trending fault (the Tintina): 1) the northeastern region is composed of a thick, older sequence of sedimentary rocks which was deposited upon a stable geological basement; and 2) the southwestern region is composed of a younger, complex mosaic of varying rock types that amalgamated and accreted to the stable sedimentary package.

This paper briefly describes the geological framework of Yukon south of 65 degrees N and, with some exceptions, uses the Tectonic Assemblage Map of the Canadian Cordillera (Wheeler and McFeely 1991) and the Terrane Map of the Canadian Cordillera (Wheeler *et al.* 1991) as a foundation. However, some of the names used on these maps have been superseded by new terminology and they are included in this paper. Recent brief syntheses of Yukon physiography and geology are rare (Tempelman-Kluit, 1979; 1981), although geological compilations of Cordilleran geology are numerous and contain useful information about Yukon geology (Monger *et al.*, 1982; Monger, 1989; Gabrielse and Yorath, 1992).

MORPHOGEOLOGICAL BELTS

The Canadian Cordillera is composed of five northwest-trending morphogeological belts that are parallel to the continental margin: from west to east they are the Insular, Coast, Intermontane, Omineca and Foreland belts (Figure 1). Together these five belts form the Cordilleran continental crust, which varies from less than 3 km thick in the west to 50 km thick in the east. These belts reflect the sum of geological processes, which interacted over the past billion years to produce the geological framework of Yukon. Each belt is different due to the different rock types contained and the different geological history, as well as the varied effects of climate and glaciation. The close ties between geology and physiography has led some to call these morphogeological belts. Generally speaking, younger mountain belts are more topographically extreme. The age of a mountain belt refers to the timing of its uplift and not the age of the rocks.

The ***Insular Belt*** comprises very high, huge and craggy mountain ranges that are composed of mainly volcanic and sedimentary rocks of oceanic origin. Much of the Insular Belt has been tectonically uplifted during the last 15 million years at a rate of approximately 3 cm/year, or 3 km every million years. Rapid uplift combined with several periods of extensive glaciation, as well as erosion in the past 1.6 million years resulted in the extreme topography we see today.

The rugged, high-relief, steep-sided mountains of the ***Coast Belt*** are mainly composed of granitic rocks. These rocks are rich in silica, which is resistant to weathering, however well-developed fractures, or joints which are typical of granitic rocks result in steep or vertical mountain sides. Like the Insular Belt, the Coast Belt has also experienced dramatic tectonic uplift, but about 50 million years ago. Coast Belt topography has been modified by numerous glacial events, and more recently by excessive precipitation causing intensive gully erosion, which has made the mountain sides steepen.

The ***Intermontane Belt*** is characterized by subdued relief, and rounded or flat-topped mountains with long, straight slopes. This character is largely the result of the recessive nature of the sedimentary rocks composing this belt, and slow and continuous erosion over most of the past 100 million years. This region has also not experienced the tectonic uplift that affected the Insular and Coast Belts.

The ***Omineca Belt*** is the most complex and varied in Yukon, and is composed of variably metamorphosed sedimentary rocks and granites. Most of this belt contains large mountain ranges with localized centres of high mountains called massifs. However, the northwestern part of this belt is characterized by low, rolling, heavily vegetated hills. This area was not reached by northward-advancing glaciers. Consequently, millions of years of erosion established a thick cover of soil and weathered bedrock. Where glaciated, this cover has been scoured away and exposed craggy bedrock. Massifs in the glaciated portion are usually centred on granitic intrusions whose heat cooked and hardened the surrounding sedimentary rocks. The boundary between the Omineca and the Foreland Belts is defined by the easternmost exposures of granitic rocks.

The ***Foreland Belt*** contains long, linear ranges of mountains composed entirely of sedimentary rocks. Unlike the Intermontane Belt, the Foreland Belt rocks have been affected by a period of deformation that stacked and thickened the sedimentary rocks along numerous, generally northwest-trending, folds and thrust faults. The larger faults constitute zones of weakness in the rock, which easily erode and give rise to long linear valleys (e.g., upper Hess, Stewart, Bonnet Plume, Wind and Snake rivers) between the mountain ranges.

GEOLOGY

Yukon's geology divides into two essential components that are, for the most part, separated by the Tintina Trench. Rocks northeast of the Tintina Trench are old (>1000 to 300 million years), mainly sedimentary and represent the *Ancient North American* margin. Rocks southwest of the Tintina Trench are mostly young (350 to 20 million years old), mainly igneous and metamorphic, and represent numerous crustal fragments called *accreted terranes* whose place of origin is uncertain. During most of the Yukon's geological history, the terranes were not attached to North America, but were accreted to the western margin of Ancient North American between 190 and 120 million years ago. Rocks in the zone between the accreted terranes and Ancient North America have been extensively deformed and form a belt known as the *Teslin Suture Zone*. This belt has subsequently been cut by the Tintina Fault, which has caused some complexity in this region.

Ancient North America

Prior to 190 million years ago, the western edge of the Ancient North American continental craton extended far out into the ancient Pacific Ocean. This submerged continental shelf is composed of crystalline basement rocks (akin to the Canadian Shield) that are at least 1.7 billion years old. These rocks provided a stable continental *platform* upon which sediments, dominantly limestone and sandstone accumulated for over a billion years. Shale, sandstone and chert accumulated in regions of deeper water known as *basins*. These two different depositional environments (platforms and basins) gave rise to differing packages of rocks characterized mainly by limestone and shale, respectively. Today, millions of years later, these limestone and shale packages are largely in fault contact with each other.

Sediments deposited on the platform formed a thick succession of rocks that are now exposed in the Mackenzie and Cassiar mountain ranges. The Mackenzie and Cassiar platforms (Figure 2) accumulated between 5 and 25 kilometres of mainly limestone and sandstone over a one billion year period. The limestone accumulated during quiescent periods in warm, shallow and clear water. The sandstone accumulated from detritus that eroded from exposed rocks of the Canadian Shield craton, which were carried west by ocean currents. Each platform is composed of rocks of the Wernecke Supergroup and the Mackenzie Mountains Supergroup. These two thick stratigraphic packages include the Mackenzie, Purcell, Wernecke, Windemere, Rapitan, Pinguicula and Gog assemblages. Although parts of the Cassiar Platform are west of the Tintina Trench, the rocks there are so similar to those on Ancient North America margin that it is certain they are North American in origin, but have been displaced along the Tintina Fault. On some maps the displaced fragments of North American continental margin are called the Cassiar and Dorsey terranes (Figure 3).

The Selwyn Basin and Richardson Trough were two major basins that formed within the platforms. Limestone growth is impossible in these basins due to the depth of water. Instead these basins slowly accumulated muds and biogenic silica that later formed successions of black shale and chert. These shale basins existed from about 800 to 320 million years ago. Rock units in the basins are dominated by sandstone, maroon and green shales and rare marble of the Hyland Group; the chert and black shales of the Road River/Rocky Mountain Group; and the black shale and chert-pebble conglomerate of the

Earn and Imperial Groups. The black shales host numerous deposits of zinc-lead-silver and barite such as those at Faro and Macmillan Pass.

Accreted Terranes

Southwest of the Tintina Trench there exists a mosaic of rock packages that are different from each other and are separated by faults. Individual rock packages or crustal fragments are known as *terranes*. Most terranes are different from rocks of the Ancient North American margin and their place of origin is uncertain. These are called *suspect* terranes. Some terranes are similar to Ancient North American rocks but cannot be absolutely correlated -- these are called *pericratonic* terranes. Other terranes have features that indicate that they formed in an environment totally unlike that of Ancient North America -- these are called *exotic* terranes. The one thing that all of these terranes have in common is that they were accreted to the ancient western margin of ancient North America - consequently they are all called *accreted* terranes. The Yukon is composed of ten of these terranes (Figures 2 and 3). Geological evidence further suggests that several of these terranes may have amalgamated with each other prior to their accretion to Ancient North America. These groups of terranes constitute *composite* and *superterranes* -- three of these are found in Yukon.

Yukon-Tanana Composite Terrane

The Yukon-Tanana Terrane is a name that was not included on recent compilation maps but is preserved here because of its common and continued usage in Yukon. The Yukon-Tanana Terrane is the largest of Yukon's terranes, covering a large portion of the Omineca Belt, and extending into adjacent Alaska and British Columbia (Figure 3). The Yukon-Tanana Terrane is composed of several metamorphic rock assemblages -- from oldest to youngest they are the Nisling assemblage (or Terrane), the Nasina assemblage, the Pelly Gneiss and the Nisutlin assemblage. Each of these components appear to have been deposited upon one another during this Terrane's 500 million year long history.

The Nisling assemblage is a metasedimentary package composed of quartzite, quartz-mica schist and marble that is at least 400 million years old but may be as old as a billion years old. The 400-320 million year old Nasina assemblage rocks are also dominated by quartzite and schist, but contain large amounts of carbon that makes these rocks black, or graphitic. The Pelly Gneiss and Nisutlin assemblage are composed of 350 to 250 million year old granitic and volcanic rocks, respectively, that have been subjected to heat and pressure which has deformed and metamorphosed them. The Pelly Gneiss still retains its granitic composition but is strongly foliated and locally displays mineral banding. The metamorphism has turned the Nisutlin assemblage into a light green quartz-mica schist package that underlies the Klondike goldfields and is known as the Klondike schist. The complexity of the Yukon-Tanana Terrane largely results from the diversity of rock types and the numerous metamorphic events it has undergone throughout its long history. The metamorphism is locally of extremely high temperature (650°C) and high pressures that correspond to crustal depths of approximately 25 kilometres.

Most of the metamorphic rocks that comprise Yukon-Tanana Terrane were originally sedimentary rocks. The stratigraphy, or the order in which the different sediments were deposited, is similar to that of rocks on Ancient North America. This has resulted in the Yukon-Tanana Terrane's assignment as a pericratonic terrane. However, the Yukon-Tanana Terrane encloses, and is amalgamated with the terranes that comprise the Intermontane Superterrane. This has led many geologists to include the Yukon-Tanana Terrane as part of the Intermontane Superterrane.

Intermontane Superterrane

The Intermontane Superterrane is composed of five dissimilar terranes that were amalgamated approximately 180 million years ago, including Stikinia, Quesnellia, Slide Mountain, Cache Creek and Windy-McKinley.

Stikinia is the largest terrane in the Cordillera but in Yukon is restricted to the area of the Intermontane Belt. Stikinia is composed of a linear belt of 220 million year old volcanic rocks of the Lewes River Group. The volcanoes formed in an oceanic setting called an island arc that is similar to present-day Japan. A 7-km-thick sequence called the Whitehorse Trough consisting of slightly younger (210-160 million years) sedimentary rocks was deposited in a marine basin adjacent to the Lewes River arc. These rocks are mainly sandstone, conglomerate and limestone of the Laberge and Lewes River Groups. These rocks are exposed between Whitehorse and Carmacks, and include the limestone of Grey Mountain and the conglomerates near Braeburn. The limestone unit hosts the copper deposits of the Whitehorse Copper Belt.

Quesnellia in Yukon is composed of volcanic rocks known as Nikolai Group that are the same age and similar to those in Stikinia. Although they cover a large area in British Columbia, Quesnellia in the Yukon is represented by only a few small fragments east of the Teslin River.

Slide Mountain, Cache Creek and Windy-McKinley Terranes are composed of volcanic rocks that formed on the oceanic sea floor, as well as overlying successions of chert, limestone and shale. These terranes are similar in age and range from 320 to 190 million years old. Both Slide Mountain and Cache Creek Terranes are thought to represent ancient oceans that existed between other terranes. Slide Mountain Terrane represents the up-thrusted remains of the ocean floor that once separated Quesnellia from North America, whereas the Cache Creek Terrane represents the ocean floor that existed between Stikinia and Quesnellia/Yukon-Tanana. Locally, Slide Mountain, Cache Creek and Windy-McKinley Terranes have outcrops of ultramafic rocks. These are rocks that are rich in iron and magnesium and originally formed the base of the oceanic crust. Ultramafic rocks that are faulted up and exposed on the land surface contain the Clinton Creek and Cassiar asbestos deposits, as well as forming the Midnight Dome at Dawson City. Sedimentary rocks of the Cache Creek Terrane contain a particular assemblage of fossils that are found in Asia and not in Ancient North American rocks. This suggests that the Cache Creek Terrane likely originated far from North America and may have existed on the other side of the Pacific Ocean. It is therefore considered *exotic*. These

Cache Creek limestones form the large white mountain across from Jakes Corner and Bove Island.

Insular Superterrane

The Insular Superterrane is mainly composed of two older terranes that were amalgamated by 320 million years ago -- they are Wrangellia and Alexander Terrane. Both of these terranes are composed of island arc and ocean floor volcanic rocks with thick assemblages of overlying oceanic sedimentary rocks that range in age from 400 to 220 million years old. Wrangellia in particular, has a several-kilometre-thick package of platform-type limestones. The Insular Superterrane hosts a 230 million year old package of volcanic rocks (the Nikolai Group) that contains the Windy Craggy copper-cobalt-gold deposit in northernmost British Columbia and the Wellgreen nickel-copper-platinum deposit near Burwash. The Chugach and Yakutat Terranes are not part of the Insular Superterrane, but are within the Insular Belt. These two terranes are composed of young (20-90 million year old) sedimentary rocks that were originally deposited on the floor of the Pacific Ocean. These sedimentary rocks were subsequently scraped off of the ocean floor by tectonic processes and accreted onto the western margin of North America.

Overlapping Assemblages

Numerous rock packages were deposited for the large part after all the terranes were amalgamated and accreted to North America. These *overlapping assemblages* of rocks are not specific to one terrane but are found on or in two or more terranes, or on Ancient North America. These post-accretionary assemblages could be felsic plutonic (igneous) rocks that intrude two or more terranes, or volcanic or sedimentary rocks that are deposited on, or across two or more terranes.

Felsic Plutonic Rocks

Many felsic plutons intrude into Yukon's basement rocks (the assembled terranes and Ancient North America) in all morphogeological belts, except for the Foreland Belt. These rocks vary in composition from granite to granodiorite, to quartz monzonite to diorite to syenite, but in this summary are coined as ‘granites’. The largest concentration of plutons occurs in the Coast and Omineca belts.

The Coast Plutonic Complex takes up most of the Coast Belt. It is not a terrane, but rather a linear belt composed almost entirely of felsic plutons. The plutons of this vast granitic region are bounded to the east by western margins of Stikinia and the Yukon-Tanana Terrane, which they intrude, and are truncated on their western margin by the Denali Fault. The Coast Plutonic Complex ranges in age from 185 to 55 million years with most of the older rocks along its eastern margin. The western margin of the Coast Plutonic Complex experienced a tremendous amount of uplift about 50 million years ago that has exposed rocks that were previously 20 km deep in the crust. These rocks are exposed near Haines Junction and Skagway, Alaska.

The remaining felsic plutonic rocks are grouped into suites according to their age and composition. Granitic plutons of the Klotassin suite are approximately 210-180 million years old and intrude the Yukon-Tanana Terrane and western Stikinia. Granitic plutons of the St. Elias suite are approximately 130 million years old and underlie parts of the St. Elias and Icefield Ranges in the extreme southwestern part of the territory. Granitic rocks of approximately 120-65 million years of age comprise several plutonic suites that range from the Kluane Mountains across all the terranes of the Yukon into Ancient North American rocks, as far east as the Northwest Territories. This most widespread and voluminous age of granite pluton formation includes the Kluane, Whitehorse, Cassiar, Surprise Lake Tombstone and Selwyn plutonic suites. These plutons are important since they are responsible for the formation of numerous deposits of copper, gold, molybdenum, tungsten and tin including Mactung, Logtung and Cantung tungsten deposits, Red Mountain molybdenum deposit, Casino Copper, Brewery Creek and Dublin Gulch gold deposits as well as the deposits of the Whitehorse Copper Belt. Plutons of approximately 55 million years in age are common in the Coast Plutonic Complex and western Yukon-Tanana Terrane, and locally host copper-molybdenum mineralization, but are rare in eastern Yukon.

Volcanic Rocks

There are four main packages of post-accretionary volcanic rocks. Mount Nansen Group rocks are about 100 million years old and are sporadically located across Stikinia and the western Yukon-Tanana Terrane. Rocks of the similar aged South Fork volcanics form huge caldera complexes on Ancient North America north of Ross River. The younger Carmacks Group (75 million years old) forms numerous thick successions of volcanic rocks along the contact between Stikinia and Yukon-Tanana Terrane and through the Dawson Range northwest of Carmacks. This volcanic event is responsible for much of the mineralization in the Dawson Range including the Laforma gold veins and the huge Casino copper-molybdenum-gold deposit. The 55 million year old Skukum Group forms discreet volcanic calderas that occur in a linear array from the south end of Atlin Lake (in British Columbia) to Bennett Lake then to Aishihik Lake. This group of rocks hosts the Mount Skukum gold deposit southwest of Whitehorse.

The Yukon's youngest volcanic rocks are the less than 10 million year old Fort Selkirk, Miles Canyon and Tuya basaltic lavas that occur near Fort Selkirk, Whitehorse and Watson Lake, respectively. One of the youngest volcanic events represented in the Yukon is so young that it is not even a rock yet. The thin strip of white ash that is common near the top of road-cuts in western Yukon is the White River Ash. This ash resulted from a volcanic explosion in the St. Elias Range near the Yukon-Alaska border about 1250 years ago. Lavas near Fort Selkirk were formed even more recently, during the early 19th century.

Sedimentary Rocks

There are few occurrences of young (<150 million years old) sedimentary rocks in the southern Yukon. The Dezadeash Formation is composed of a thick succession of muddy sandstone called greywacke that was deposited in a huge submarine fan about 150-100 million years ago. The Front Ranges, as seen from Haines Junction, are composed of these rocks. These rocks stretch from north of Haines, Alaska, northerly to Dezadeash Lake and Haines Junction, and were deposited on the Insular Superterrane and the

Yukon-Tanana Terrane. The Tantalus Formation occurs in small isolated exposures that range from south of Whitehorse to Carmacks and to just south of Dawson. These exposures are mainly of quartz-rich sandstone and conglomerate and host the Whitehorse, Division Mountain, Tantalus Butte and Haystack Mountain coal deposits. Tantalus Formation rocks range in age from 140 to 60 million years old and are deposited on Stikinia, Quesnellia and Yukon-Tanana Terrane. Unnamed, localized deposits of conglomerate were deposited within the Tintina Trench about 55 million years ago. These deposits also host coal deposits most notably near Dawson and Ross River. The youngest package of sedimentary rocks in the Yukon is the Amphitheater Formation conglomerates and sandstones that occurs in three main areas: near the upper White River, Burwash and Dalton Post. These 25 million year old rocks also contain deposits of coal but because of their youthful age the coal is low-grade lignite.

Faults

There are two major faults that extend across the Yukon (Figures 2, 3).

Tintina Fault

The long, linear depression that extends northwesterly across the Yukon from Watson Lake along to Ross River, Faro and Dawson, and then into Alaska is the Tintina Trench. It is the northern continuation of the Northern Rocky Mountain Trench in British Columbia. The Tintina Trench is the physiographic expression of the Tintina Fault. Tectonic forces caused the block of rocks southwest of the fault to grind up against the stable North American block and, during a history of innumerable earthquakes, moved the southwestern block northwest towards Alaska. The grinding along the fault caused the rock to break up and become less resistant which, with erosion led to the formation of the trench. Most geological evidence suggests that there was at least 450 km of right-lateral displacement (area southwest of the fault moved northwest) along the Tintina Fault, although there may have been as much as 1200 km offset. Volcanic rocks were deposited in the trench about 55 million years ago - probably at the same time as some of the motion along the Tintina Fault. These volcanic rocks host the Grew Creek gold deposit.

Denali Fault

The Denali Fault originates (on land) at Haines, Alaska and continues north into the Yukon to the south end of Kluane Lake, and further northwest into eastern Alaska. This fault, and the associated Duke River Fault, are still active and cause a steady stream of small earthquakes. The Denali Fault separates the very high mountains of the Insular Belt from the lower mountains east of the fault. The tectonic forces that are causing uplift in the Insular Belt are also responsible for displacement along the Denali Fault. This transfer of force along the fault prevents the region east of the fault from being affected by the tectonic forces that form the high mountains. There has been at least 350 km of right-lateral offset along the Denali Fault.

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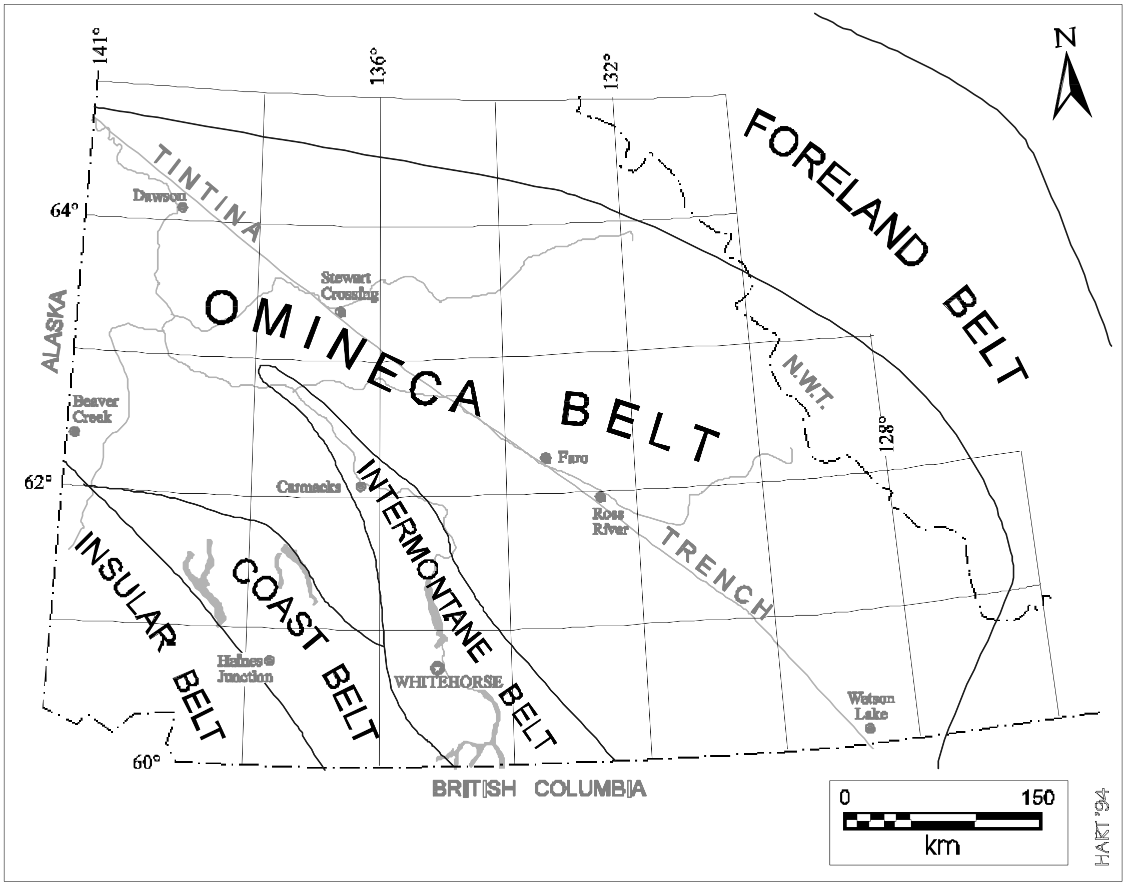

Figure 1. Location of the five physiographic or morphogeological belts of the Yukon. The belts underlie regions that have similar geology or have undergone similar geological histories. The Yukon north of 65 degrees is underlain by the Foreland Belt. The lines of latitude and longitude define the 1:250 000 NTS grid.

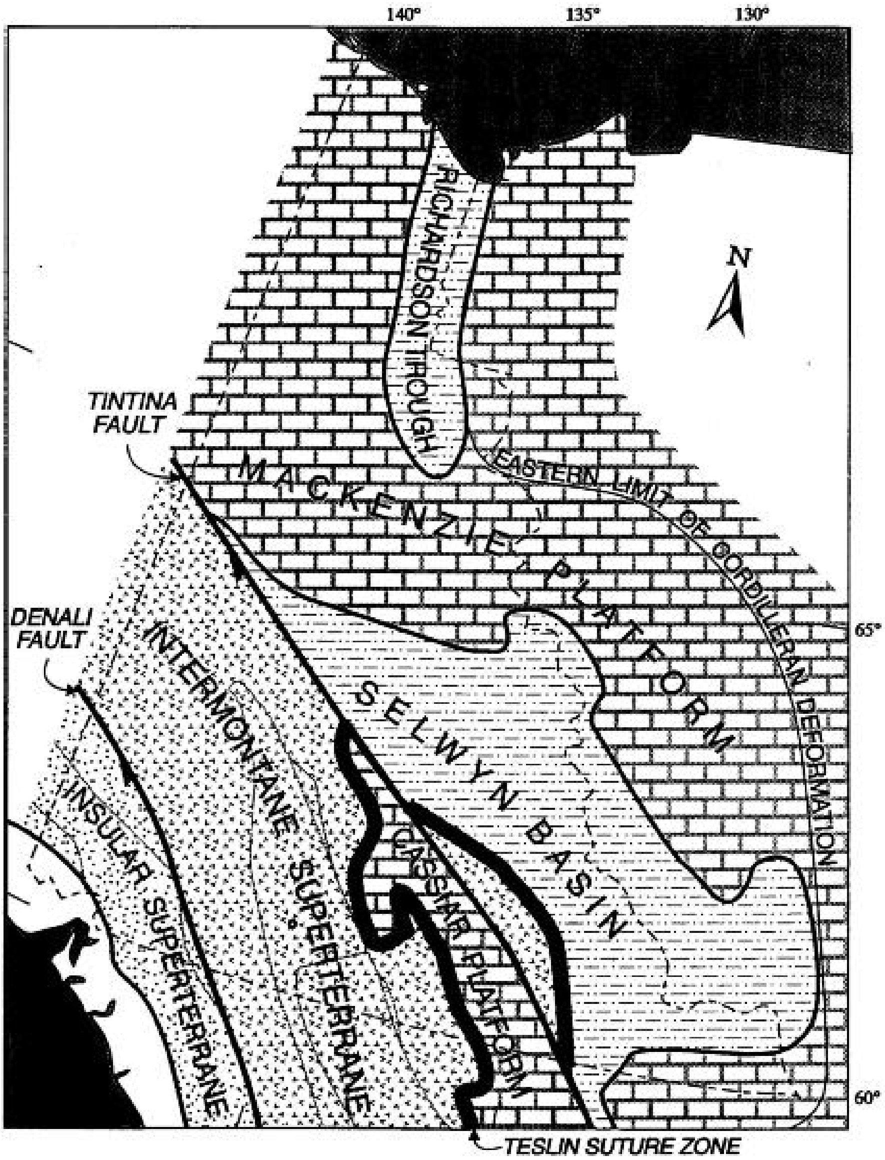

Figure 2. The Yukon's major tectonic elements indicate that the territory is underlain by two dominant rock packages. Northeast of the Tintina Fault are a thick assemblage of sedimentary rocks that belong to the Ancient North American continental margin. They are platformal (mainly limestones) and basinal (mainly shale) in origin. Southwest of the Tintina Fault are numerous dissimilar crustal fragments called Terranes. The terranes were amalgamated into the Insular and Intermontane Superterranes prior to their accretion to the Ancient North American margin. The zone of deformation between the accreted terranes and Ancient North America is represented by the Teslin Suture Zone.

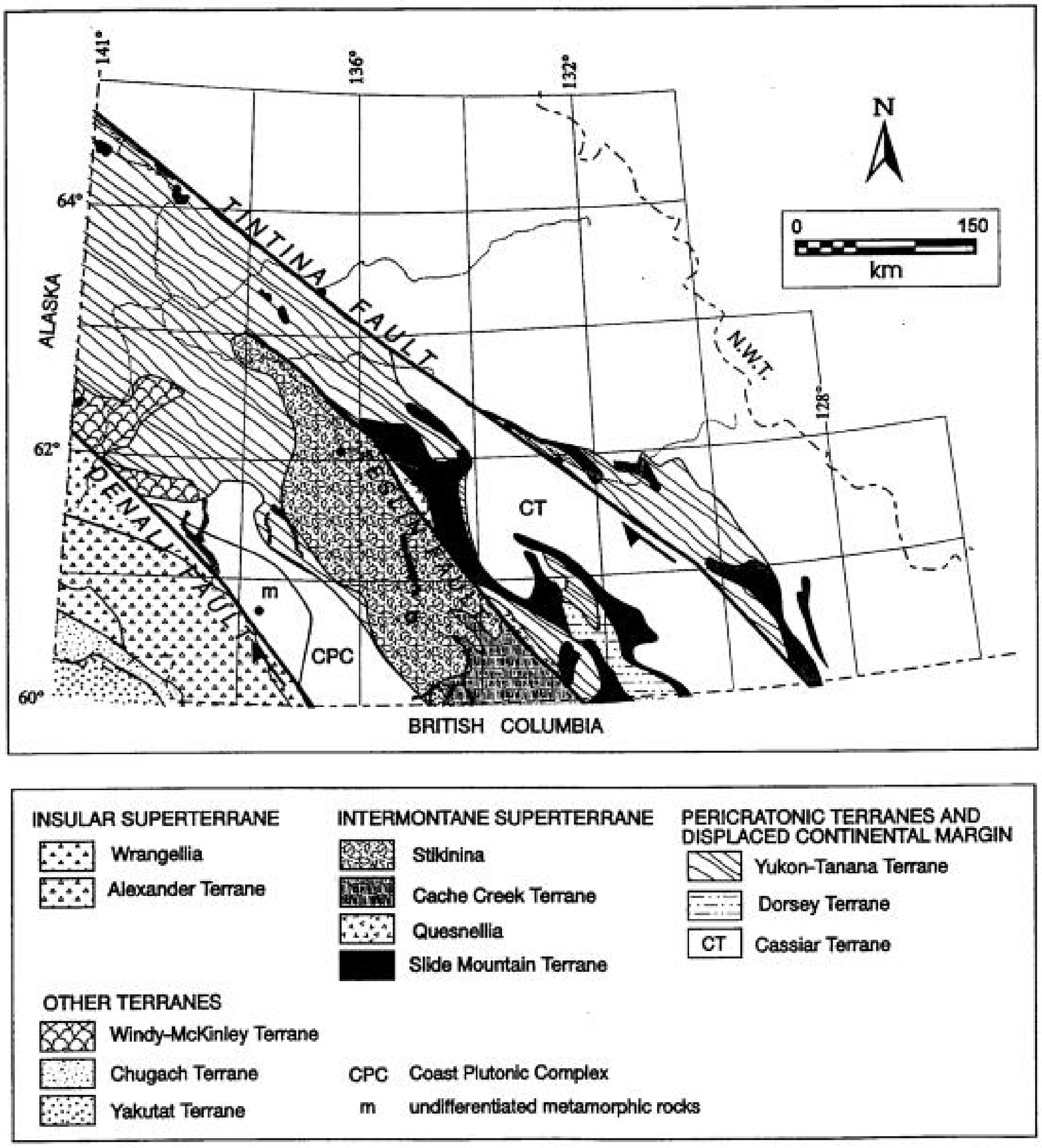

Figure 3. The numerous terranes that comprise the accreted terrane portion of the Yukon include fragments of oceanic floor, volcanic island arcs, oceanic basins and old metamorphosed crust. Since their accretion to North America over 120 million years ago, their positions have been complicated by displacements along numerous faults.

APPENDIX B - Quaternary Geology Summary

Extract from Yukon Ecoregion Report (in prep.)

BY T. FULLER AND L. JACKSON

The glacial history of Yukon Territory is unique in Canada. The rest of Canada was almost entirely covered by glacial ice during the last (Late Wisconsin- 25,000 to 10,000 years B.P.) ice age but much of the Yukon was free of ice (Figure 1). The region extending from the central and northern Yukon across Alaska and westward to northern Asia was a vast ice-free wilderness across which herds of now extinct grazing mammals and their predators roamed. Horses, camels, lions, mammoths, to name a few, survived in this ice-free area more correctly called a refugium. The Bering Sea did not exist at that time because sea level was more than 100 metres lower than that of today. This lower sea level was caused by the fact that great quantities of water were tied up on the land as continental ice sheets. This ecological ice-free region is called Beringia after the now submerged Bering land bridge between Asia and North America. The first people to enter the Americas entered through Beringia.

Although the earliest known glaciation in the Yukon occurred about one billion years ago, during the late Precambrian Era, it was the events of the past 65 million years, the Cenozoic era, that shaped the landscape of the Yukon.

During this period, prolonged weathering and erosion defined the plateau areas of central Yukon. A well-developed system of smooth rounded summits and valleys formed as a mature landscape, with streams draining in a southerly direction. In late Cenozoic, after this period of geologic stability, the region was slowly uplifted and this continued into the Quaternary time period (2 million years to present). Drainage systems carved extensive valley systems. While the plateau region of central Yukon was being gently elevated (millimetres per thousands of years), the St. Elias Mountains in the west were being rapidly uplifted (metres per thousands of years). By about 8 million years ago, they were high enough for glaciers to form. These left distinctive deposits in what is now the White River valley.

During Pleistocene epoch (about the last 1.65 Ma), an ice sheet called the Cordilleran Ice Sheet advanced from the mountains into central Yukon at least six times. These glaciations were separated by tens of thousands of years during which the climate was similar to the one we are experiencing now or even milder. Soils developed during the warmer periods. These soils are locally preserved between glacial deposits. They are easy to recognize because they are thicker and redder than the soils that formed since the last ice age. These soils are used to subdivide and correlate glacial deposits across central Yukon. This climatic roller coaster of cold glacial periods alternating with warmer interglacial periods is caused by variations in the earth's orbit and its angle of rotation with time. Each major warm-cold cycle lasted about 100,000 years.

Till underlies many of the valley deposits in the glaciated regions. Subsequent to the disappearance of the glaciers, river and slope processes modify the variety of deposits. Rivers flowing away from glaciers leave thick and broad expanses of gravel. Ice sheets dam drainage and create huge lakes. The white cliffs around Whitehorse are composed of silts from such a lake, called glacial lake Champagne. Debris melting directly from ice forms sediment called till with boulders set in mud much like fruit in fruitcake. This paraglacial period is marked by an abundance of unconsolidated material available for erosion and redeposition. Wind blown deposits (loess and sand dunes) derived from the rock flour produced by glaciation occur over some valley bottoms and terraces.

Besides eroding the rocks and leaving distinctive deposits, glaciers have changed the landscape in other ways. In many places, the flow of glacial ice was in a direction opposite to that of the flow of major rivers such as the Yukon. The original flow of the Yukon River was to the south. Glacial diversion caused it to reverse flow direction and it now flows northwest and west through Alaska.

The chronology of Pleistocene Cordilleran Ice Sheet advances are reconstructed based on fragmentary evidence. For example, at Fort Selkirk in central Yukon, lava beds as old as 1 million years have unconsolidated glacial deposits both above and below them.

The most recent widely distributed volcanic ash is the White River Ash. It actually occurs as two ash beds (Figure 2), an older north-trending lobe (1400 yr.) and a younger (1250 yr.) east-trending lobe. Other tephras of Pleistocene age include the Old Crow tephra approximately 150,000 years old, the Mosquito Gulch tephra (1.22 million years old) in the Bonanza Creek drainage, and the Sheep Creek Tephra from Ash Bend, Stewart River also about 150,000 years old. A recently dated tephra in the Klondike area dates the White Channel gravel, an important gold bearing formation, at 2.7 million years.

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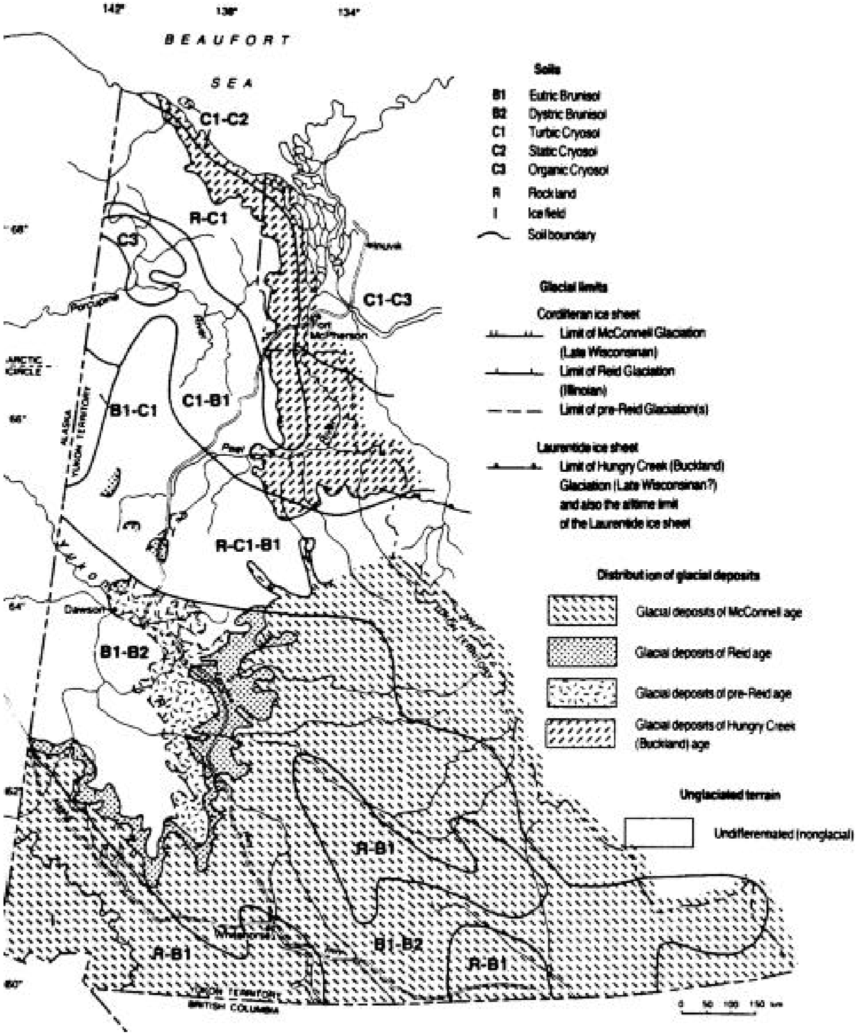

Figure 1. Distribution of recent soils and glacial limits in the Yukon (Morison and Smith, 1987).

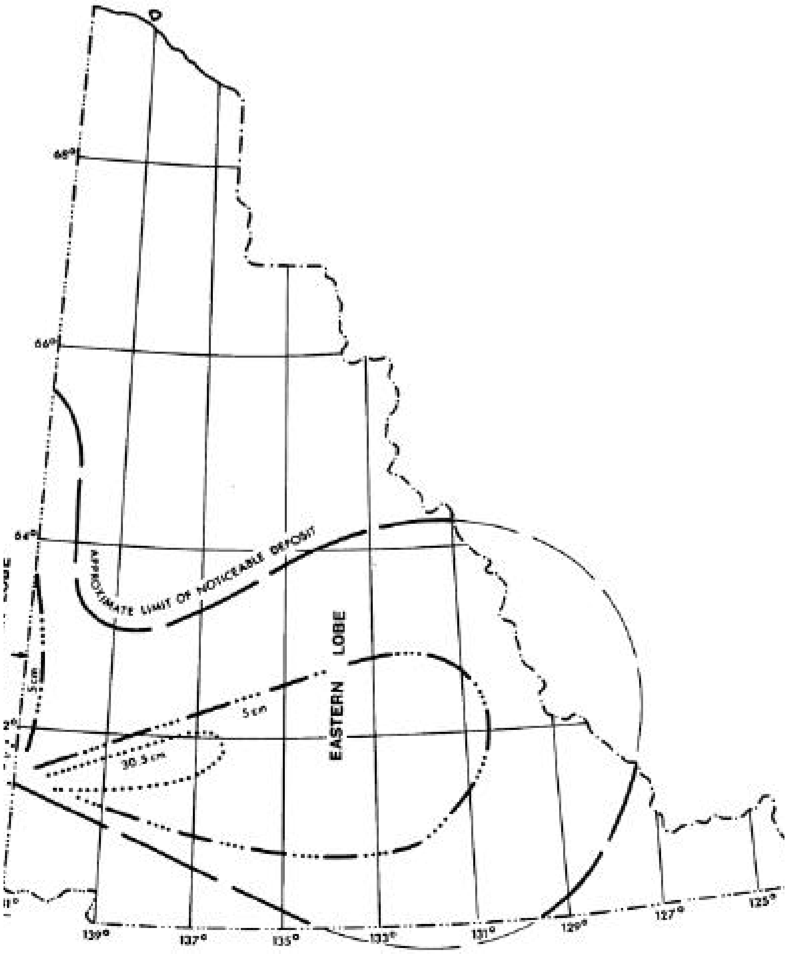

Figure 2. Approximate extent and depth of White River volcanic ash (Oswald and Senyk, 1977).

APPENDIX C - Permafrost

by C. Burn (Excerpt from: Burn, C., in prep., Permafrost, *in:* Yukon Ecoregions Report, Renewable Resources, Yukon Territorial Government)

Introduction

Permafrost is "ground (soil or rock) that remains at or below 0^oC for two or more years" (ACGR, 1988); permafrost terrain comprises a seasonally thawed active layer, underlain by perennially-frozen ground. Permafrost occurs in all of Yukon, but its thickness, and the proportion of ground it underlies, increases northwards (Fig. 1). All terrain, except rivers and lakes, is underlain by perennially frozen ground in north Yukon, but the scattered permafrost of southern Yukon is found under less than 25% of the ground surface.

Thickness

Permafrost may be well over 300 m thick in the more westerly, unglaciated portions of the Yukon Coastal Plain (Rampton 1982), but it thins rapidly to the south, and is usually absent beneath glacial ice and lakes. At Old Crow it is only 63 m thick (EBA, 1982). In areas underlain by coarse glacial deposits, convective heat from groundwater circulation may also locally raise the base of permafrost. Thicknesses between 20 and 60 m have been reported from valley-bottom sites in the Klondike Plateau near Dawson, and between 25 and 40 m near Mayo (Burn, 1991). Drilling in the Takhini valley near Whitehorse has revealed 16 m of frozen sediments, while municipal excavations near Teslin intersected 2 m.

Very thin permafrost may degrade or be established in years or decades, while the time scale for thicknesses of over 15 m is on the order of centuries (Burn, 1993a). Permafrost in Yukon Coastal Plain has formed over millennia. The permafrost zones are, therefore temporal, as well as spatial units.

Distribution

Mean annual near-surface ground temperatures below 0^oC lead to permafrost growth. At macroscale, these are a function of air temperature, modified by the insulation of snow. In Yukon, physiographic factors are responsible for the presence of permafrost, particularly blocking of maritime air by St. Elias Mountains, and topographic enhancement of winter inversions within the dissected Yukon Plateaus (Harris, 1983; Burn, 1994). Permafrost in uplands of central and southern Yukon is a result of short, cool summers; in winter the ground is protected by a thick snow cover. In valleys, summer is commonly hot, but the winter cold may be extreme (Burn, 1993b). Within the boreal forest, interception of snow by the canopy and reduced wind speeds mean that there is little snow drifting, and a uniform snowpack, but above or north of treeline snow effects may be considerable, even leading to absence of permafrost (e.g., Smith, 1975).

Within discontinuous permafrost, the specific location of frozen ground depends mainly on the thickness of the organic horizon, whose low thermal diffusivity restricts penetration of the summer temperature wave (Harris, 1987; Riseborough and Burn, 1988), and on the moisture content of the active layer, which maintains evapo-transpiration to reduce ground surface temperatures (Brown and Williams, 1972).

The combination of factors at various scales that lead to permafrost imply that its response to climate change is complex (Smith and Riseborough, 1983). Changes in surface conditions, such as wrought by forest fire, can alter the ground thermal regime more rapidly than fluctuations in climate, and are currently causing permafrost degradation in Takhini valley (Burn, 1993a). However, climate changes over decades, particularly if they involve changes in snow accumulation, may also warm permafrost (Burn, 1992).

Ground ice

The practical significance of permafrost largely derives from the growth and decay of ground ice. There is commonly an ice-rich zone at the base of the active layer, which forms by ice segregation during downward migration of water into permafrost at the end of summer (Mackay, 1983; Burn,1988; Burn and Michel, 1988; Harris et al., 1992). Water may be injected into near-surface permafrost in autumn (Pollard and French, 1984), and the growth of ice wedges by snowmelt infiltrating winter thermal contraction cracks also contributes to high ice contents in the uppermost 10 m of the ground (Pollard and French, 1980). Ice-wedge polygons are most easily seen in lowlands of northern Yukon, but individual wedges have been reported further south (Burn, 1990; Yukon Territorial Government, Transportation Engineering Branch, 1993).

Accumulation of ground ice leads to heaving of the ground surface. Thick, laterally extensive bodies of massive, near-surface ice, probably formed by ice segregation during permafrost growth, occur in Yukon Coastal Plain (Harry et al., 1988; Pollard and Dallimore, 1988) and also in the Klondike District (French and Pollard, 1986). Glaciolacustrine sediments in central and southern Yukon commonly contain beds of segregated ice (Burn et al., 1986), which may comprise over 80% ice by volume in the upper 10 m of the ground. Over 400 open-system pingos have been identified in central Yukon, mostly in unglaciated valleys, where coarse materials do not impede groundwater movement downslope (Hughes, 1969). Numerous palsas, which are peat mounds with a core of segregated ice, have been identified in wet lands (Kershaw and Gill, 1979; Harris, 1993). Buried glacier ice is abundant near the termini of glaciers throughout southern Yukon, and rock glaciers are also widespread in the alpine zone (Johnson, 1978).

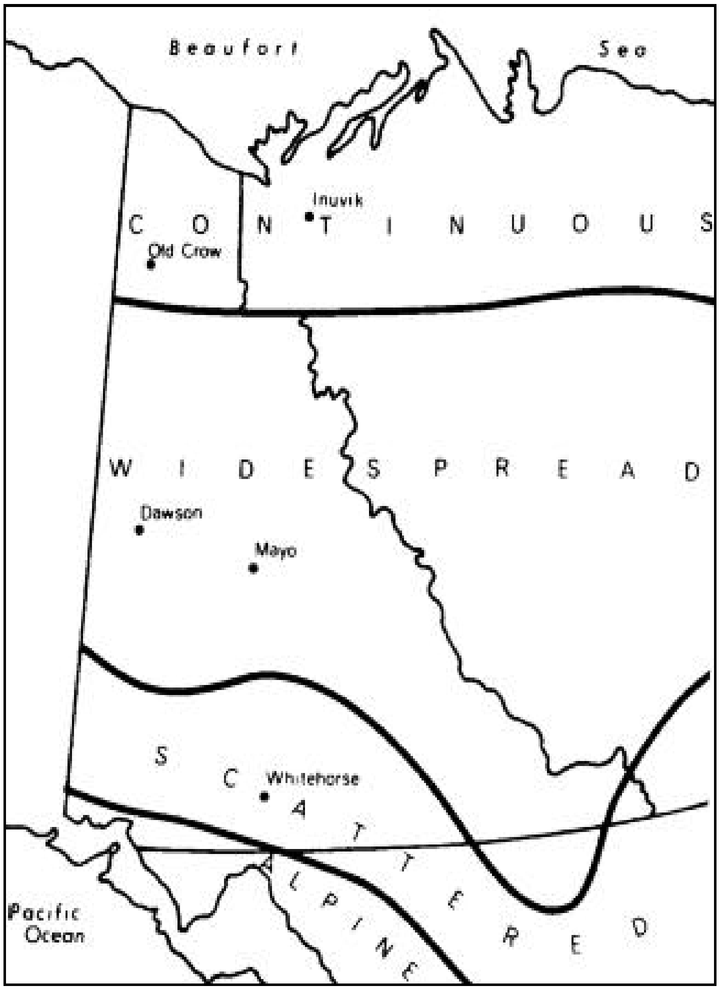

Figure 1. Permafrost distribution in the Yukon Territory (after Brown, 1978).

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ORE DEPOSITS, PLACER DEPOSITS, COAL DEPOSITS

There are many sources of information on Yukon's ore, placer gold and coal deposits. A listing of all the references available is beyond the scope of this project. Most pertinent information is available for sale through DIAND’s Geoscience Information and Sales or for viewing on the Yukon Geology Program website (http://www.geology.gov.yk.ca), or in the DIAND library. The DIAND building is located at 300 Main Street, Whitehorse, Yukon.

For any particular NTS sheet, the following sources may supply useful information on ore deposits, placer deposits and coal deposits:

1. **Yukon MINFILE**
   -summaries of all known mineral occurrences on each NTS sheet (includes 1:250 000-scale map showing occurrence location)

2. **Yukon Exploration and Geology, Yukon Geology series**

-papers on Yukon geology, exploration and ore deposits

3. **Open File Reports and Maps**

4. **Placer Mining Industry Reports and Maps**

5. **Geological Survey of Canada Publications.**

6. **GEOREF CD-ROM (available at the DIAND library only)**

7. **DIAND Publication List**

8. **Yukon Geology Bibliography (CD-ROM)**

9. **Graduate Research (copies of M.Sc. or Ph.D. theses done on Yukon geology and ore deposits).**

All of the above are available for viewing in the DIAND library.