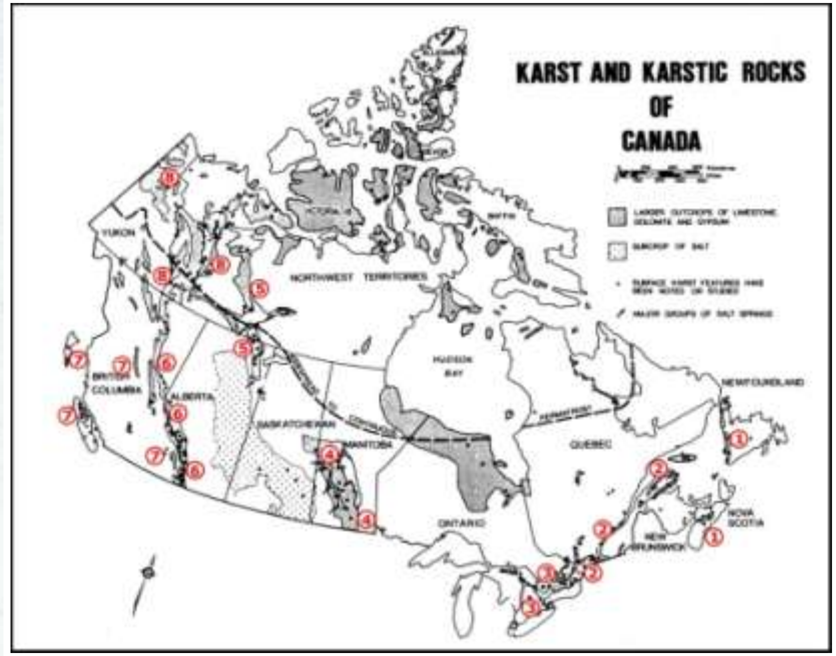
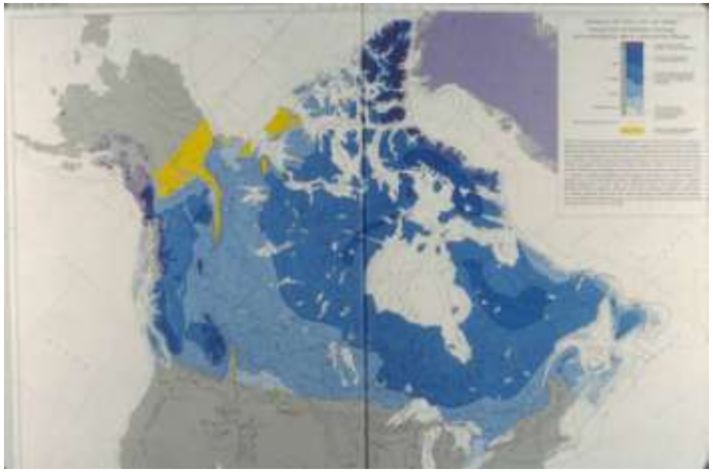

LANDFORMS and PHYSICAL REGIONS
HUDSON BAY LOWLAND
PUGET SOUND LOWLAND
CALIFORNIA CENTRAL VALLEY
ATLANTIC COASTAL
MEXICAN HIGHLANDS
Elevation in feet
Elevation in meters
more than 13123
6562 to 13123
3281 to 6562
656 to 3281
sea level to 656
below sea level
more than 4000
2000 to 4000
1000 to 2000
200 to 1000
sea level to 200
below sea level


KARST AND KARSTIC ROCKS OF CANADA
YUKON
NORTHWEST TERRITORIES
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANITOBA
ONTARIO
QUEBEC
NEW BRUNSWICK
NOVA SCOTIA
NEWFOUNDLAND



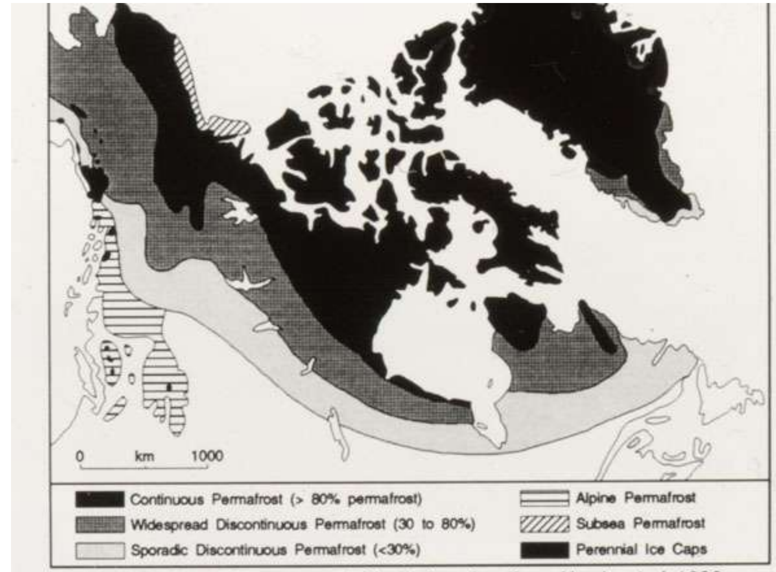
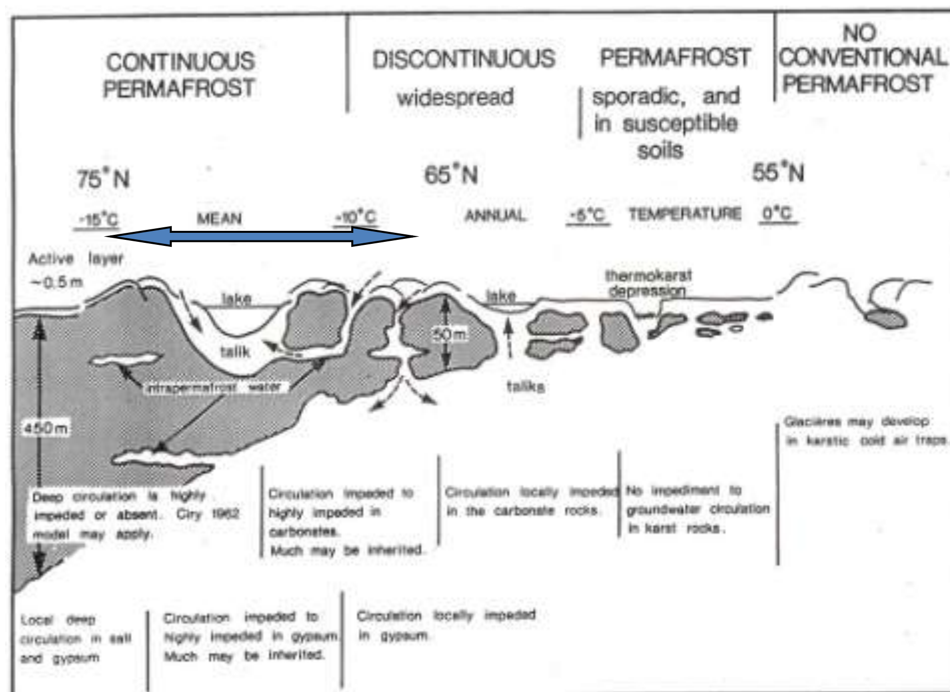
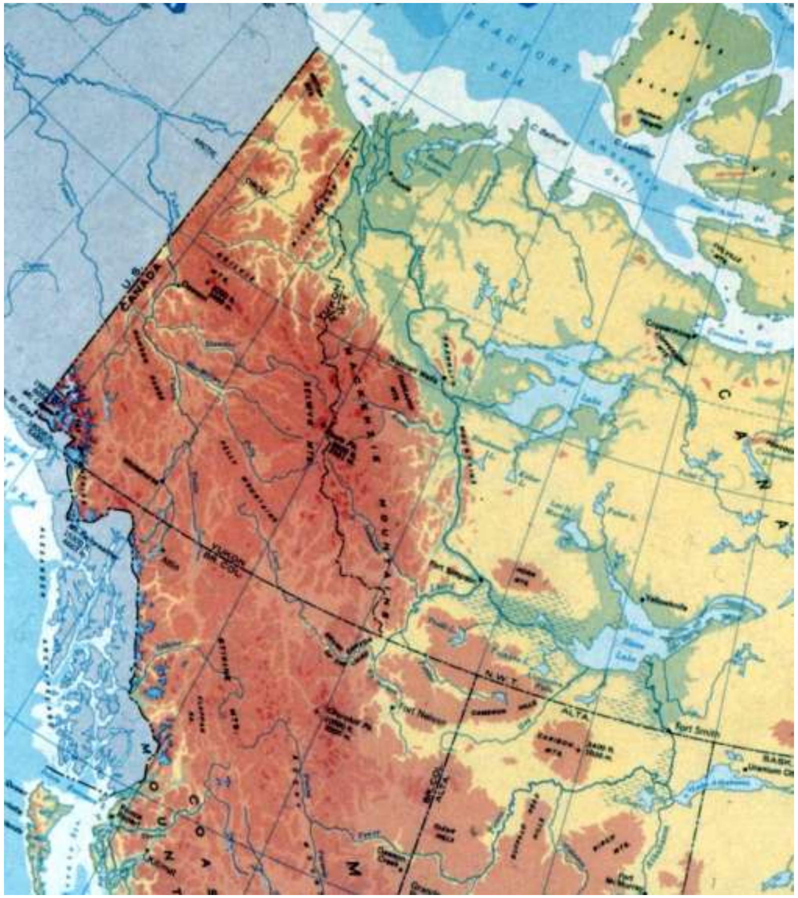
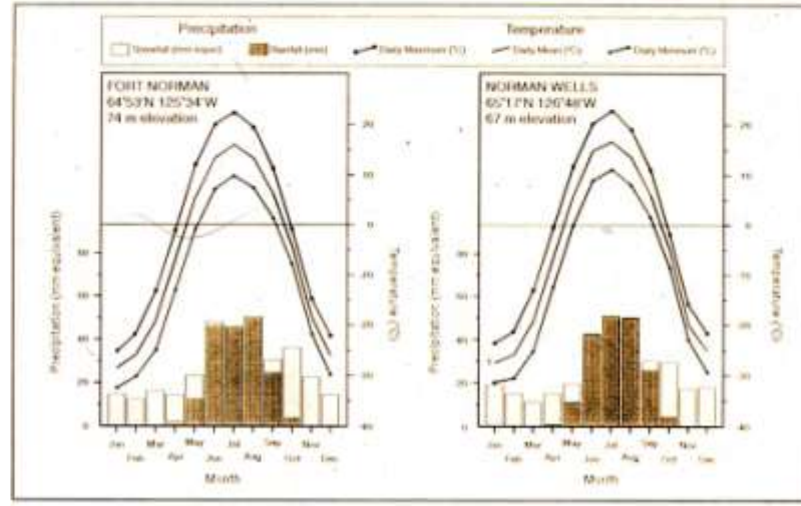


Figure 2.7: Permafrost zones in North America (from Harris *et al*, 1988; after Harris, 1986; Heginbottom, 1984; Johnston, 1981).

The Laurentide Continental Icesheet covered the lowlands, Franklins and eastern edge of the Mackenzie Mtns several times. The western Mackenzies were filled by valley glaciers. A narrow ice-free corridor survived between. There are no glaciers today but the region is cold – see the climate statistics for Ft Norman (Tulita) and Norman Wells (next frame). Frozen ground phenomena are seen everywhere. The karsts range from 220 m to 1900 m asl, straddling a range of permafrost conditions as shown <u>on the right</u>.







Karst around Norman Wells.

There are at least 14 geographically distinct areas of karst around Norman Wells. Bob van Everdingen (1981) studied six of them in and east of the Franklin Mountains in varying detail. Jim Hamilton (1995) studied five to the west, following a 1981 reconnaissance by Ford.

Figure 6.1: Distribution of karst in the northern Franklin and Mackenzie Mountains. The shaded regions are characterized by internal drainage and/or a frequency of dolines and closed depressions greater than 2 km². Karst data are from aerial photographic interpretation, van Everdingen (1981), and Duk-Rodkin (personal communication, 1990). Also indicated are spring locations sampled by Michel (1986) in a hydrogeological study of the Mackenzie Valley, and the position of the southern Mackenzie Mountain Nahanni Karst (Brook, 1976).

The youngest rocks are unconsolidated deposits of gravels, sands, silts and clays laid down by glaciers, rivers and past lakes during and after the last Quaternary ice age.
The Tertiary, Cretaceous and Upper Devonian strata are all consolidated clastic (fragmental) rocks such as sandstones, siltstones and shales (clay rocks) that are insoluble and so will not develop karst features. They re also mechanically weak in most places and so do not support big cliffs.

The karst develops in strata of Cambrian to Middle Devonian age. At base, the Saline River Fm is a mixture of salt, anhydrite and red beds (clays). Salt is the most soluble karst rock and so can be attacked by groundwater even deep beneath the surface, generating collapse of overlying rocks upwards. The redbeds are very prominent at the head of Dodo Canyon (above).

The Franklin Mountain and Mt. Kindle Fms are varied dolomites separated by an erosion surface displaying paleokarst (e.g. in Dodo Canyon).

The Bear Rock Fm consists of interbedded anhydrite and dolomite and minor limestone in deep wells but is always a breccia variably cemented by calcite when seen in outcrop. The Hume Fm is a limestone, often brecciated at the base by collapse into Bear Rock karst. Ramparts Fm is a thinner, less pure limestone, separated from the
Hume Fm by the Hare Indian Fm, shaly rocks (insoluble) with minor limestone; it blocks any extension of karst groundwater circulation from the Ramparts to the Hume and *vice versa*.

Dolomites are the least soluble of the standard karst rocks. Karst landforms and ground water flow are surprisingly well developed in them in this region, especially given the permafrost climate: e.g. superior to those on the famed Niagara dolomites of Ontario.

Above - The top of the Mt Kindle dolomite at Dodo Canyon. Below – the contact between the Franklin Mountain dolomite (orange) and the Mt Kindle (grey) dolomite in Dodo Canyon.

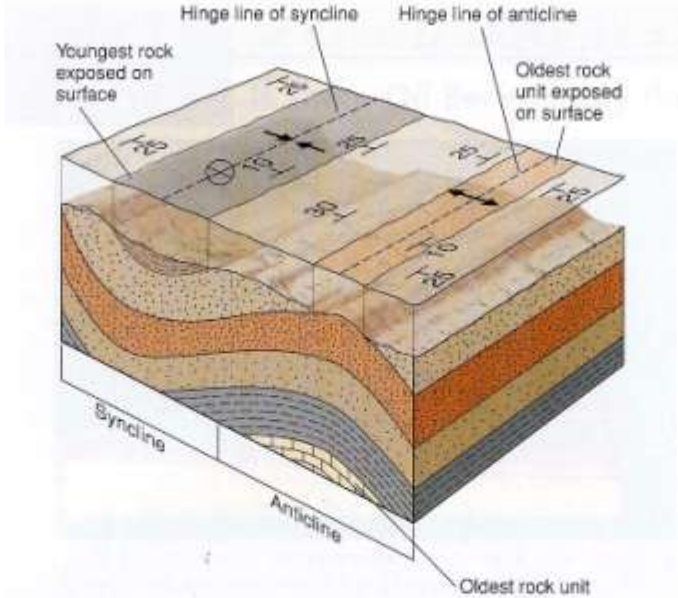
Both formations are 'cyclic' – contain sequences of thicker and thinner beds, the thicker being stronger. East of Norman Wells the Franklin Fm is divided into three 'members' – the lowest member (Of2) is impure, the top member (Of4) has prominent nodules of chert (flint – insoluble)

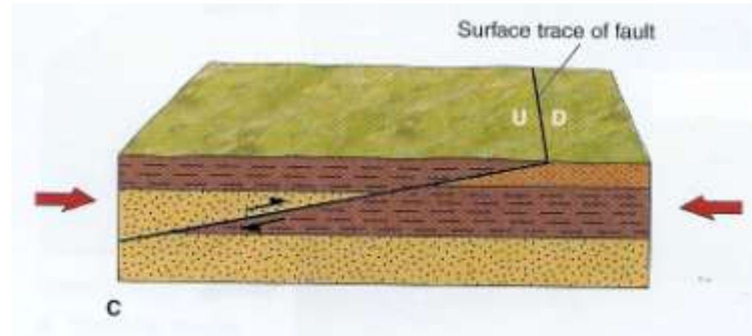
The Bear Rock Formation is one of the two most remarkable solution breccias I have seen (the other is in Belize). Deep beneath Norman Wells cores reveal that it consists of sequences of beds of dolomite and gypsum. Nearer the surface the much more soluble gypsum is progressively dissolved, collapsing the dolomite above into broken fragments, termed ‘breccia’. The breccia is now re-cemented by calcite precipitated from the circulating ground waters. The strength of cementation varies considerably, so the Formation displays very variable responses to solution and other erosion processes. Locally, a layer a few metres thick is particularly strongly cemented – the ‘Landry Member’ seen in the lower photo here.

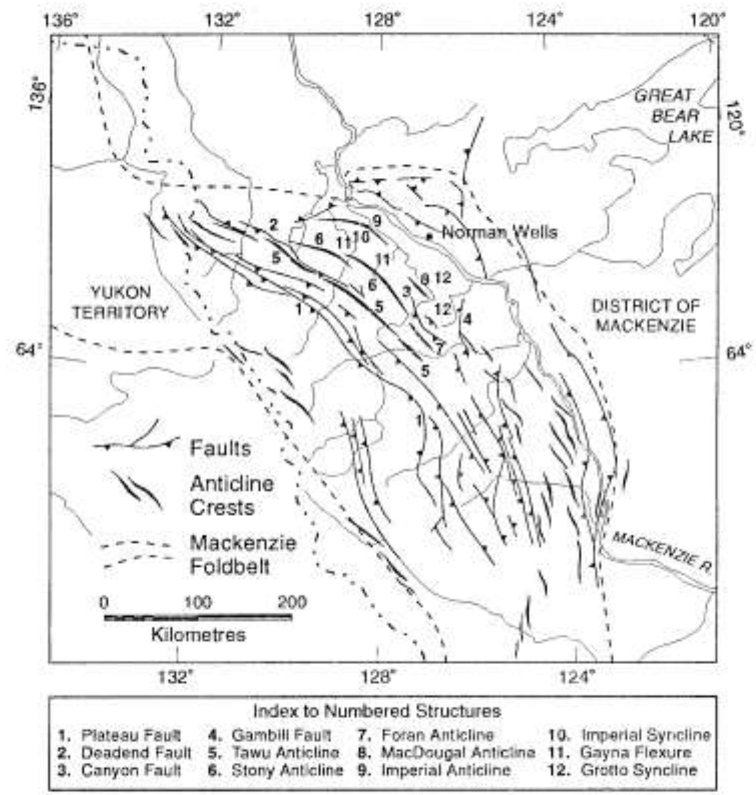
Above – the contact between the Mt Kindle dolomite and Bear Rock breccia is usually sharp.

Below- details of the Bear Rock breccia, a very remarkable formation.

Above – the rugged, chaotic karst topography on the Bear Rock breccia in the foreground contrasts with the regular cliff line of the Hume limestone formation seen behind it. Bear Rock itself is in the far background.
Right – the Hume Formation is a more conventional, regularly bedded platformal limestone that takes good glacial scour and polish.





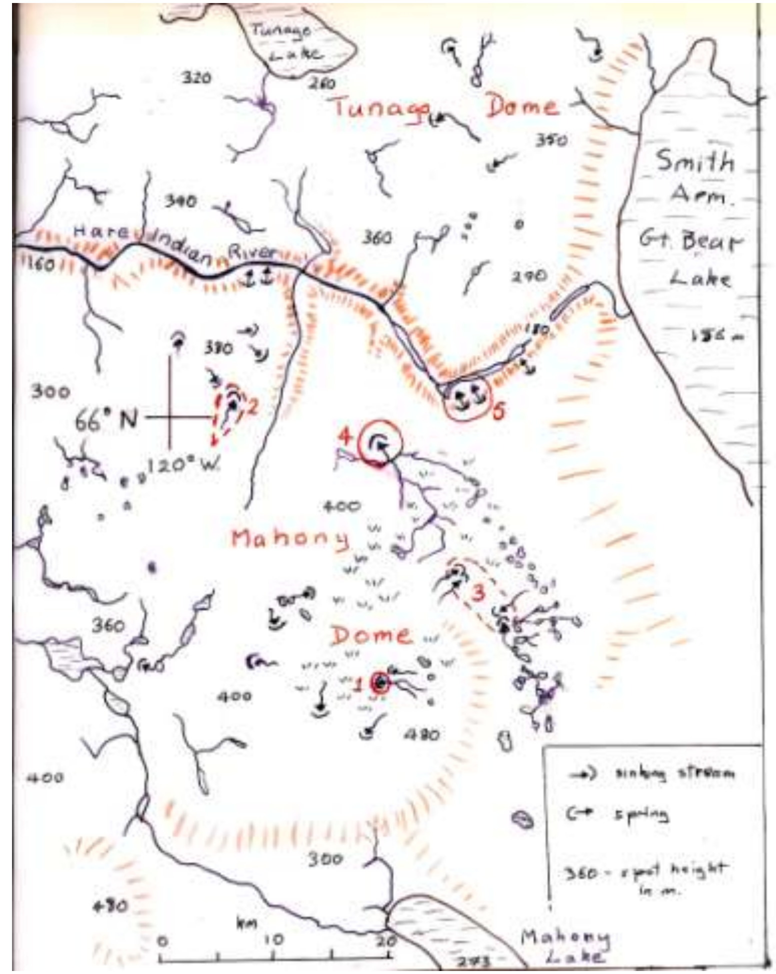


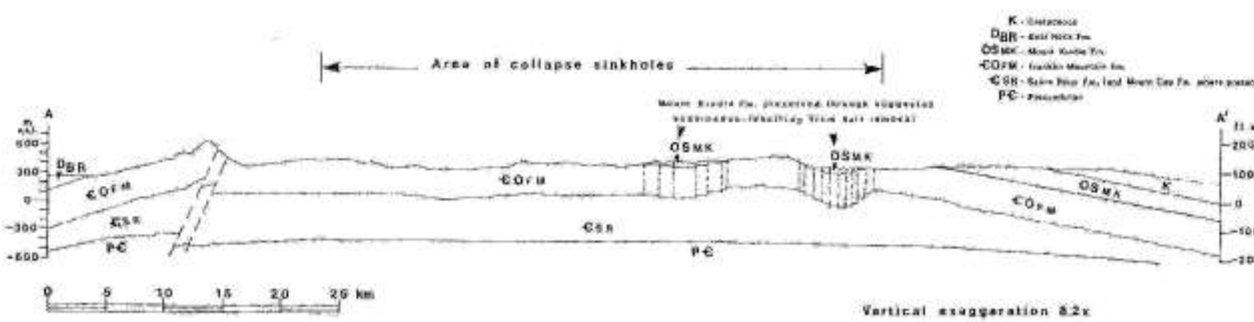
In some parts of the study region the sedimentary strata remain horizontal and little disturbed although they have been uplifted thousands of metres from their burial positions. But in the Canyon Ranges and the Norman Range they display tilting or anticlinal and synclinal folding (above). Most important is the overthrusting (above right) by force from the west. On right the surface fault traces of the many thrusts. Thrusting is usually accompanied by some folding of the displaced strata.

The Hare Indian eastern plateaus
(the Mahony Lake and Tunago Lake 'domes')

71 In his 1981 report R. van Everdingen adopted the names, Mahony and Tunago Lake 'domes' for two shallow plateaus east of the Norman Range. The sketch map on right shows their locations. The two separate features have been created by the deep entrenchment of the Hare Indian River Valley, a major glacial spillway.

Geologically, the region lies east of the zone of intensive thrust faulting and folding that created the Franklin Mountains. As shown in the section below (from Van Everdingen) the bedrocks are the Franklin Mtn dolomites, underlain by the Saline River Fm and with some Mt Kindle Fm dolomite possibly preserved on top in down-dropped areas.





This very shallow depression east of Bracket Lake drains underground into the small sinkhole seen as a separate small pond on the right.

In the southeastern foothills of the Range a closed depression occupied by Yakeleva Lake is a fine example of a turlough at a young stage of development such that it retains a (probably) permanent, shallow lake. All drainage is into the sinkhole seen in the upper right quarter of the photo. The feature is in the Of4 cherty Franklin dolomites.

Yakeleva Turlough is located at 65 10.185 N, 125 42.486 W.
Elevation = 1400’ asl.
The feature is in the Of4 cherty dolomites.
The floor is of flood clays on glacial till. Most erratics noted were small, angular clasts of Hume-type limestone. There were very few true, well-rounded erratics from further away (i.e. from the Shield around Great Bear Lake). The sinking stream was flowing at 1-2 l/s during our visit. Water temperature was 21 C, SpC = 198.
Karst processes are very active in the channel, as shown by fresh collapses 1-2 m in diameter along it.

Ground Stop #2, Mahony Dome. R. van Everdingen's Sinkhole #142. Location – N 66 00.86', W 125 52.86'. Elevation at lowest sinkpoint ~300 m asl. The feature is ~3 km in length, 1.5 km maximum width. It is clear that it has a few permanent ponds and an extensive area subject to frequent flooding. Van Everdingen showed that flooding occurred in the Spring thaw and lasted for a few weeks most years. It is the finest example of a mature turlough I have seen in the entire region.

Aerial views of the downstream sinks. There is a main stream into bedrock at left centre in the upper photo, with an overspill pond on the right that drains to a separate sinkhole.

The lower photo shows both sinks and a small permanent pond that is perched on two metres of till above them.

Turlough # 142, looking upstream from the main sink. This feature floods to the forest trim line in most years. Van Everdingen recorded flooding from mid-May to mid-July in 1977. The maximum volume of water sinking (all sinks combined) was estimated at about three cubic metres per second.

<u>#142 is recommended for protection as an outstanding example of a mature turlough.</u>

Two more overviews of Turlough #110. Above – shallow sinkholes in the central sector of the depression; the forest is encroaching on ground that rarely floods today. Right – overhead view of a cluster of sinks in the north.

Aerial view of a major upstream (SE) sinkhole where Ground Stop 3(1) was made in 2007. The sink is in the cherty member of the Franklin Mountain Fm. A dry stream channel is seen at bottom right.
Location is N 65 51.07’, W 125 23.27’. Elevation is 370 m above sea level.

There was no water flowing into this sinkhole during our visit on July 31 2007 but the dry channel entering it from the southern end has a bedload of pebbles, cobblestone-sized boulders and larger, all ‘imbricated’ (wedged together and tipped upwards in the downstream direction) that indicates a flood flow of more than one cubic metre per second.

The southerly large sinkhole at Ground Stop 3(2). It is about ten metres deep. Dissolution first segregates large blocks along vertical joint faces. The blocks then topple into the sink and disintegrate along bedding planes.

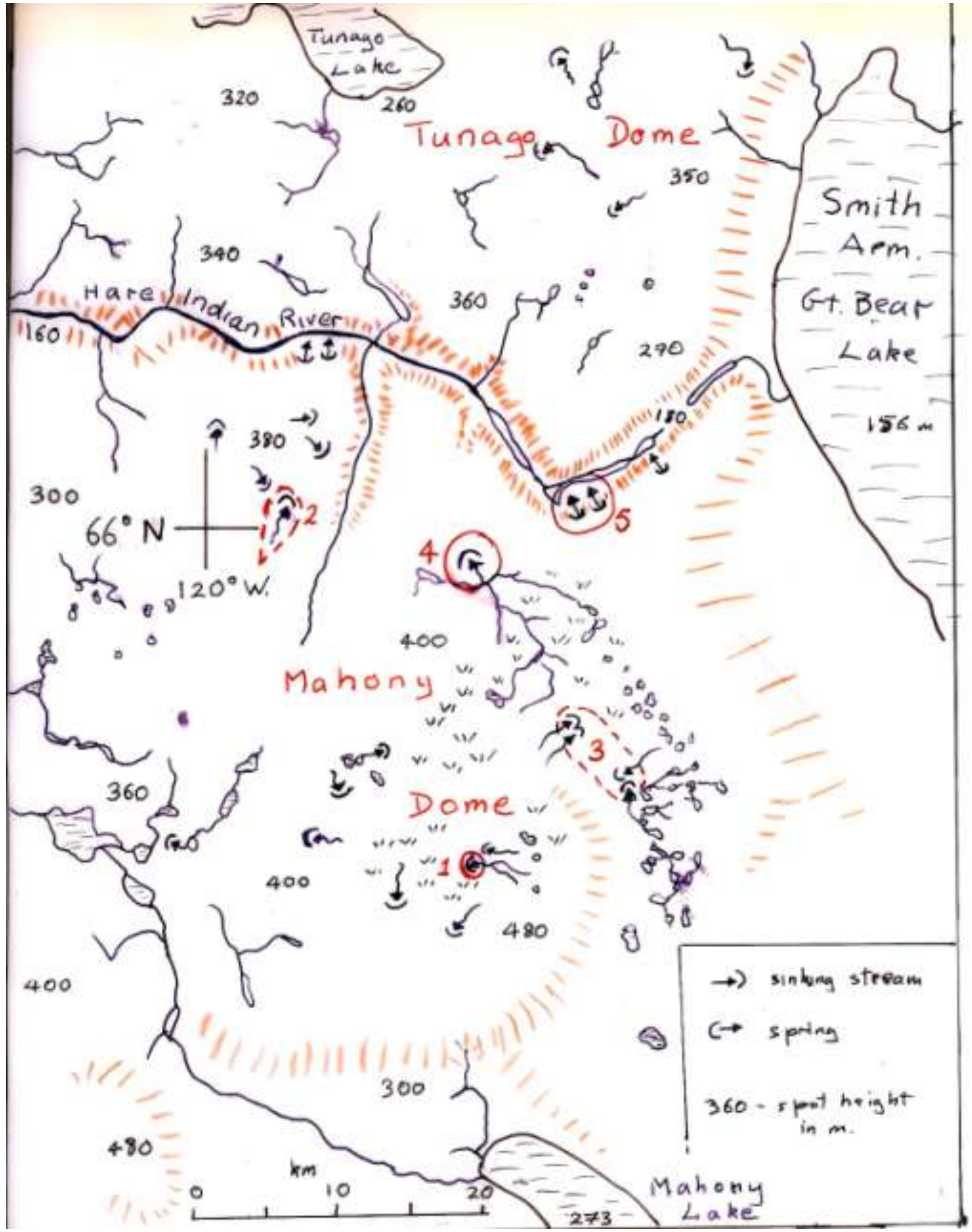
The northerly large sinkhole at Ground Stop 3(2) is a dramatically narrow shaft that appears to be younger than the others but is now evolving rapidly.

A second aerial view of the Disappearing River, looking northeast. The overspill Sink, 86A, is in the foreground. The River sinks at the NE end of the central sink and there is a smaller collapse sink behind it along the same joint fracture trend. Beyond it is a permanent pond. Muskeg in the foreground and rear appears to be suffering some desiccation, probably due to the development of karst drainage.

Ground Stop #4 – “The Disappearing River” of van Everdingen (1981). The location is N 65 58.76’, W 125 35.64’. Elevation of the rim of the sinkhole is 332 metres above sea level. The river sinks into van Everdingen’s Sink 86B, with occasional overspill via a meandering channel into Sink 86A in the foreground.

The principal sinkhole, #86B, is approximately 100 m in length, 40 m wide and 25-30 m deep from the rim to the water sink.

Entering it, the River first drops down a small waterfall (<u>above</u>) and then builds a detrital fan (<u>right</u>) out into the depression.


Tunago Lake
320
260
Tunago Dome
350
Smith Arm.
Gt. Bear Lake
156 m
340
360
Hare Indian River
160
290
180
380
300
66° N
120° W.
2
4
5
400
Mahony
3
360
Dome
1
400
480
400
300
480
km
0
10
20
273
Mahony Lake
sinking stream
spring
360 - spot height in m.

The Hare Indian River Valley

The valley is a glacial spillway formed by melt waters pouring out of the Laurentide continental ice sheet over Smith Arm. In its eastern parts the valley is a straight-walled entrenchment into the dolomites, 120-150 m deep and 1200-1500 m wide. Its nearly flat floor is an infilling of glacial and proglacial sediments. In the eastern sector these pond up a series of elongated, shallow lakes, shown above looking east towards Smith Arm, Great Bear Lake.

Location of spring #144 was N 66 0.86’, W 125 26.98’. Elevation was 165 m above sea level.

Van Everdingen (1981) mapped three groups of springs in the Valley. The central group (Nos. 143-5) were the largest and are shown above emerging from the southern wall. Ground Stop #5 was made on the principal stream (<u>on right</u>, #144, viewed upstream and downstream). The Volume of flow on 31 July 2007 was ~1.0 - 1.5 cubic metres per second (or 100-150 times greater than the flow in the Disappearing River that day). Water temperature was 4.1 C. The specific conductivity was 390 microsiemens, suggesting a dissolved load of dolomite of about 150 mg/l.

109 Karst features on the Tunago Lake Dome

A view northwest across the Dome, with Tunago Lake in the background.

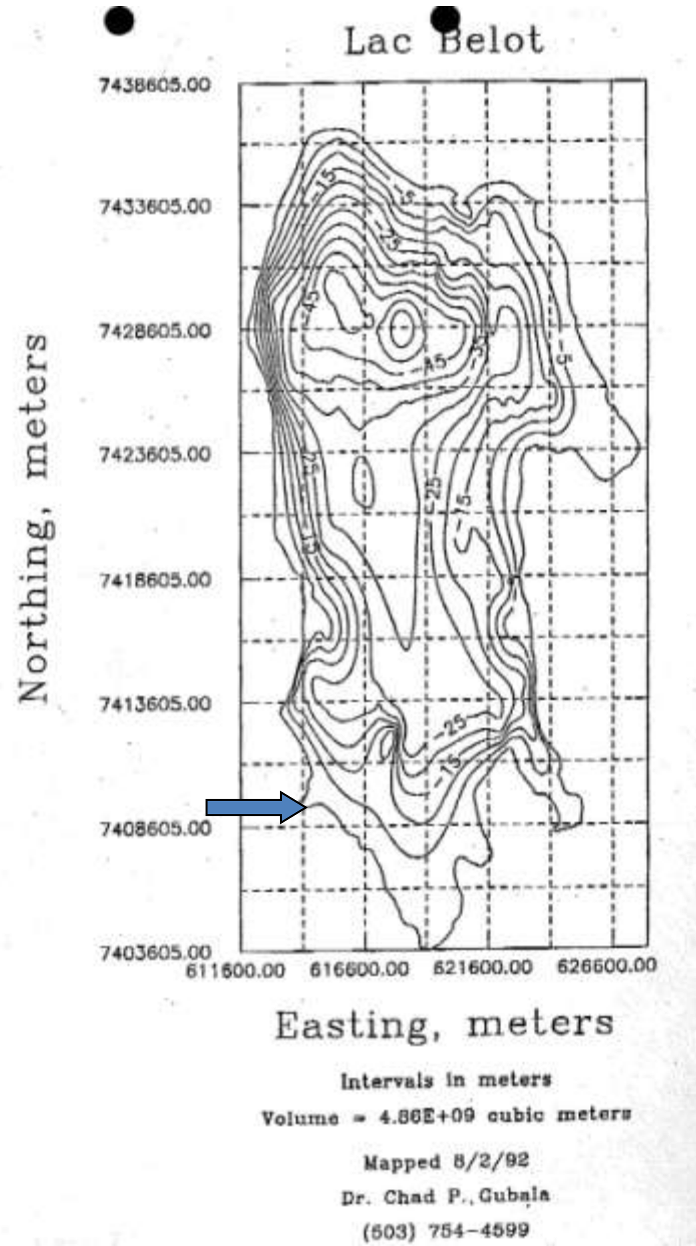
On the Tunago Lake dome there are patches of rectilinear corridor terrain reminiscent of the Nahanni karst but much shallower. This suggests that, in contrast to the Mahony Lake dome, this area experienced sub-glacial mega-flood erosion which disrupted the earlier patterns of karst drainage. The deeper sinkholes are scattered widely apart, draining into local cliffs, as seen in these pictures and the upper one on page 110.

Lac Belot and its underground river,
Lac Belot Ridge, Tunago Ridge and the Belot Karst.

Lac Belot Ridge, looking south. The southern end of Lac Belot is seen to the left.

Above – another view of Lac Belot, seen from above the Ridge.

Right – the bathymetry of the lake. It has an area of 300+ km square kms and is estimated to store nearly five billion cubic metres of water. The arrow indicates where, according to the Neyadalin map on page 115, the outflow passes underground via a sinkhole. The water will pass beneath the Ridge or perhaps flow along it underground for some distance.



Site Description

As told by an elder from Fort Good Hope, this story from an ancient time describes how the people from the Colville area found the people from the Good Hope area:

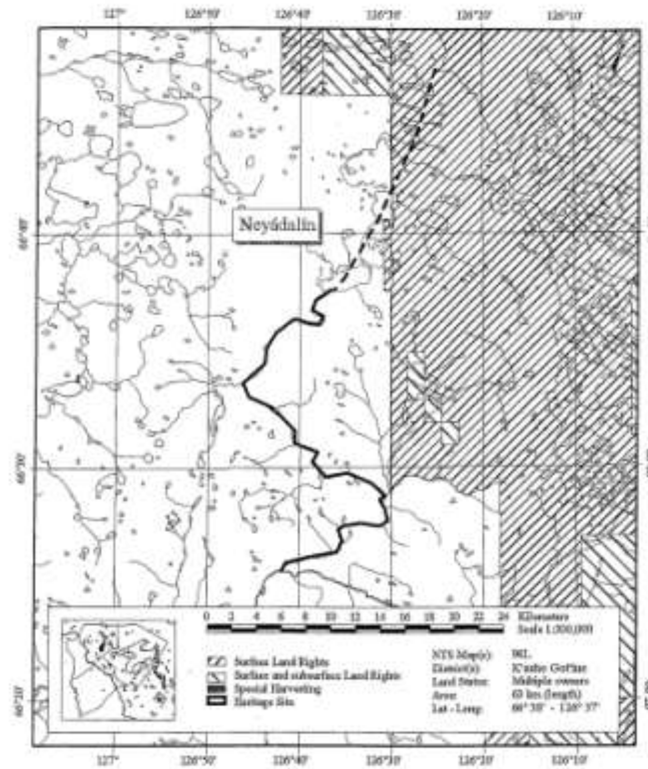
I'll tell you the story Neyádalin—the river that runs underground and how two brothers went through it. There was once a Dene that always lived alone with his family. He made his living at Odarah Tué [near Belot Lake]. People would say that he lived alone with his family because he was jealous of his wife. He had two grown sons that were old enough to take wives. But how could they since they were always alone? One day the brothers were hunting ducks along the shores of the lake. They each had their own canoe, and they were chasing a goose with two chicks. They were very close to them when the goose ran ashore with one chick. The other kept going and the brothers continued to chase it. The chick went into a creek then suddenly disappeared. The older brother was wondering what happened to the chick when suddenly he too went underground in that creek! His younger brother also went underground. The creek became very swift as the older brother shot through it. As he went thrashing around in the underground creek he came upon a giant pike. He went into his mouth and passed right through it. Next he came upon a giant Loche that he also passed through. On and on he went until he saw a small light. He yelled out in joy because he thought he might have a slight chance of surviving. Then suddenly he came shooting out from the side of a cliff where the creek was gushing out. His whole canoe flew in the air, and then landed on Kasó Niyué [Hare Indian River]. He was waiting there hoping that his younger brother would show up, when suddenly he came shooting out of the cliff. The older brother said, "So this is the reason why when I was coming to my mother before I was born, I saw flying canoes that carried me into her."

It was a good thing these boys were able to handle things with their medicine. This was a strange land for the two boys because they have never gone farther south from where they were raised at Odarah Tué. They paddled along the Hare Indian River until they could see signs of people. They talked about the signs and wondered if they would be able to understand their language. They paddled on and on until they suddenly came out into the Deho [Mackenzie River]. They had never seen such a big muddy river before. They stopped on the shore and noticed smoke rising from Kogojeré Du [Manitou Island: p. 52]. They crossed the river and found that the people spoke the same language. They were very thankful but they weren't feeling good because they had been underground. They had medicine in their bodies so they weren't feeling good. They decided that they were going to go to the Ramparts. There they went through the cliffs. These are the two lines that run through the cliffs that can still be seen today. These are the marks that these two brothers left. After they did this they felt much better and they lived with people in the Good Hope area for two years.

They both took wives and probably even had children when they decided to return to their parents who were still searching the shores of Niyé Tué [Belot Lake] with a raft. The parents had been searching the shores of that great big lake and had given them up for dead, when one day they saw two canoes coming to their camp. They waited on the shore and the family was overjoyed to see one another. Their family lived with other groups from then on. It is said that this is how the groups from around Colville area became aware of the people who lived further south. This is a very ancient story.

Recommendations for Protection

- Identify for special consideration in the land use planning process.



The legend of Neyadalin, the underground river. From the Report of the Sahtu Heritage Places and Sites Joint Working Group, pages 56 -7.

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Area A

This Google Earth image shows the Norman Range between Norman Wells and Kelly Lake (to North), extending down to Bear Rock and the mouth of the Great Bear River (southeast). The circular lake on the eastern boundary is Bracket Lake.

The Norman Range is formed by an eastwards overthrusting of the carbonate rocks, chiefly the Franklin Mountain dolomites. Overall, this creates an escarpment landform with a steep 'scarp' face on the east side and a longer, gentler 'dip' slope on the west side. Bear Rock, Hume, Hare Indian and Ramparts strata outcrop on the dip slope. The Mt Kindle dolomites are absent in the Range.

The differing erodibility of these formations, plus multiple overthrusts, has created lesser escarpments on both the main scarp and dip slopes.

Above. The eastern, scarp face of the Norman Range viewed from NE across Kelly Lake.

Right. A view down the dip slope towards the Mackenzie River on an afternoon when the air is thick with smoke from forest fires.

All parts of the Norman Range were overriden by glacier ice of the Laurentide Continental Ice Sheet flowing from the east and northeast.

Effects of glacial scour of the rocks are best seen along the crest of the Range, shown here. Strata are the Franklin Mountain dolomites

Karst landforms on the strongly ice-scoured upper slopes are composite features, topographically closed depressions created partly by water sinking underground and dissolving the rock along its course, and partly by basal glacier scour. Such ‘glaciokarstic’ landforms pose a chicken and egg problem. Do glaciers enlarge earlier sinkholes, or do groundwaters adapt prior ice scour depressions?
Shown above are two superb examples that may overflow seasonally but are drained perenially down dip into bedding plane micro-caves in the rock.

Lower down on both scarp and dip slopes ice scour was often less intensive.

Larger closed depressions that are now drained karstically are common.

The scarp face depression (<u>above</u>) is developed on a thrust plane in the Franklin Mountain dolomites.

The dip slope feature (<u>right</u>) is at the contact between Hume limestone (cliffs to the left) and Bear Rock breccia (eroding slopes on the right).

Bear Rock towers over voyagers on the Mackenzie River. The tributary flow from Great Bear River is easily distinguished at the foot of the Rock.

In contrast to the main sector of the Range to the north, in the southern Franklins and Bear Rock itself the Bear Rock Fm (Db) and overlying Hume limestone (Dh) are preserved at the crest line on top of the Franklin Mtn Fm (COf). This forms a series of east-facing, dissected scarplands at lower elevations than in the main Range. This scene is north of Bear Rock, which is in the background left.

In the pinnacle country of northern Bear Rock

Right – a ridge descending towards the River.

Below – steep dry valleys with fragile pinnacles that somehow endure, and many caves that quickly become impassably small.

Striking solifluction features such as stone stripes and lobate flows in the talus below a pinnacle ridge on northern Bear Rock.

The crest of southern Bear Rock.
Above – the Long Lake karst depression with the River and Mackay Range behind
Right – Long Lake in rear with Round Lake in the foreground. The two lakes are aligned along a depression scoured in the crest of an anticline with Franklin Mtn dolomite in the floor and Db breccia forming the cliffs.

The Bear Rock Springs Area is the prominent tree-less apron seen above. Ground water emerges at many different points (detail on right). Jim Hamilton estimated summer discharge at around 20 litres/second. T =3.7 C. SpC~1400.Total dissolved solids ~1000 mg/l, indicating that there is much dissolved gypsum in the water. There is some discharge throughout the winter.

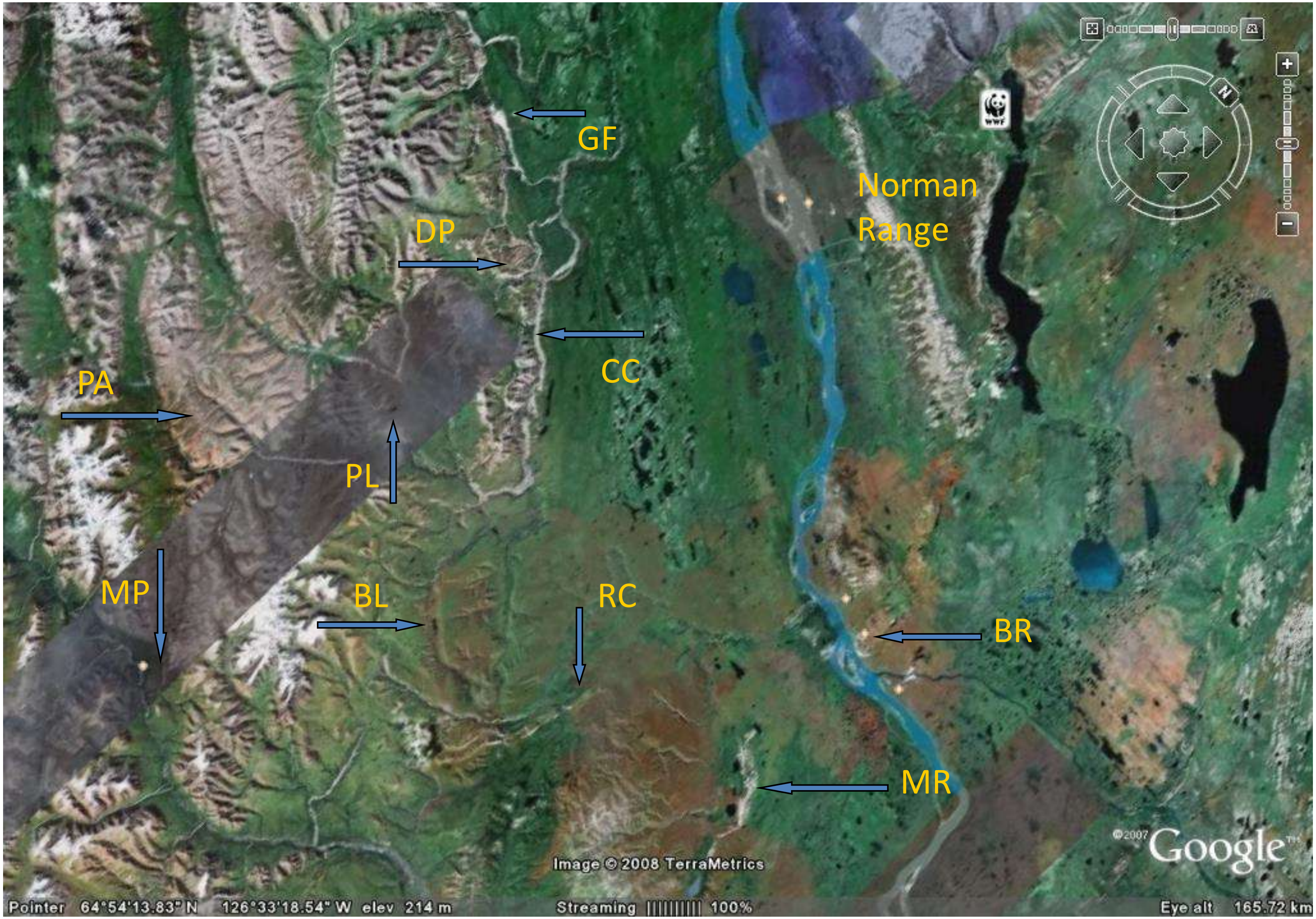
Vermillion Creek Collapse Sinkhole

Photo by R. van Everdingen.

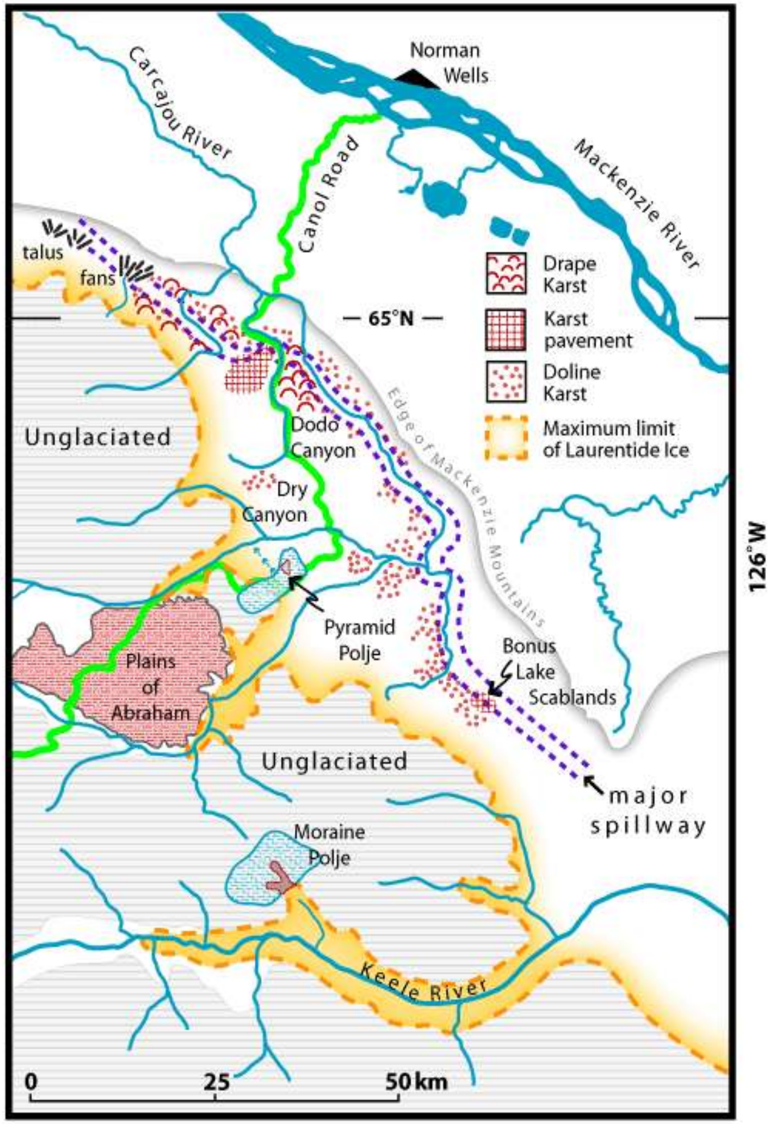
Vermillion Creek Sinkhole is located at 65 08.217 N, 126 05.5 W. Its rim is at an elevation of approximately 270 m (900 feet) above sea level. It measures 120 x 60 m in plan view and is about 40 m deep to the waterline.

The top of the collapse is through shales and shaly limestones of the Canol Fm, with limestones of the upper Ramparts Fm probably being seen in the lower half of the cliffs. This collapse will have been triggered by dissolution of gypsum in the Bear Rock Fm below, or by dissolution of salt in the Saline River Fm, or by both.

The world's shapeliest karst collapse sinkholes are either cylindrical, or elongated along a vertical fracture to create an ellipse such as is seen here. The walls are vertical. Vermillion Creek Sinkhole is the finest example of a fresh collapse that I have seen anywhere in Canada or the United States. <u>It is strongly recommended for protection.</u>



PA = Plains of Abraham; MP = Moraine Polje; BL = Bonus Lake; PL = Pyramid Lake; DP = Dodo Pavements;
GF = Great Fan; CC = Carcajou Canyon; RC = Ration Creek Sinkhole; MR = Mackay Range; BR = Bear Rock



Norman
Wells
Carcajou River
Canol Road
Mackenzie River
talus
fans
Drape
Karst
Karst
pavement
Doline
Karst
Maximum limit
of Laurentide Ice
65°N
Unglaciated
Dodo
Canyon
Dry
Canyon
Edge of Mackenzie Mountains
128°W
126°W
Pyramid
Polje
Plains
of
Abraham
Bonus
Lake
Scablands
Unglaciated
major
spillway
Moraine
Polje
Keele River
0
25
50 km

Looking down into the central closed depression from a point on the southeastern ridge. The depression was created by dissolution of Bear Rock breccia, and possibly by underlying solution of salt in the Saline River Fm as suggested by Hamilton. It and all other interior areas of the Range are drained karstically to small springs around the perimeter of the Range.

Above – very steeply dipping Bear Rock strata along part of the east face produce these beautiful talus fans with torrential debris flow channels in some of them. Below – accumulation of ground ice in the base of this fan has converted it into a rock glacier.

Ration Creek Sinkhole

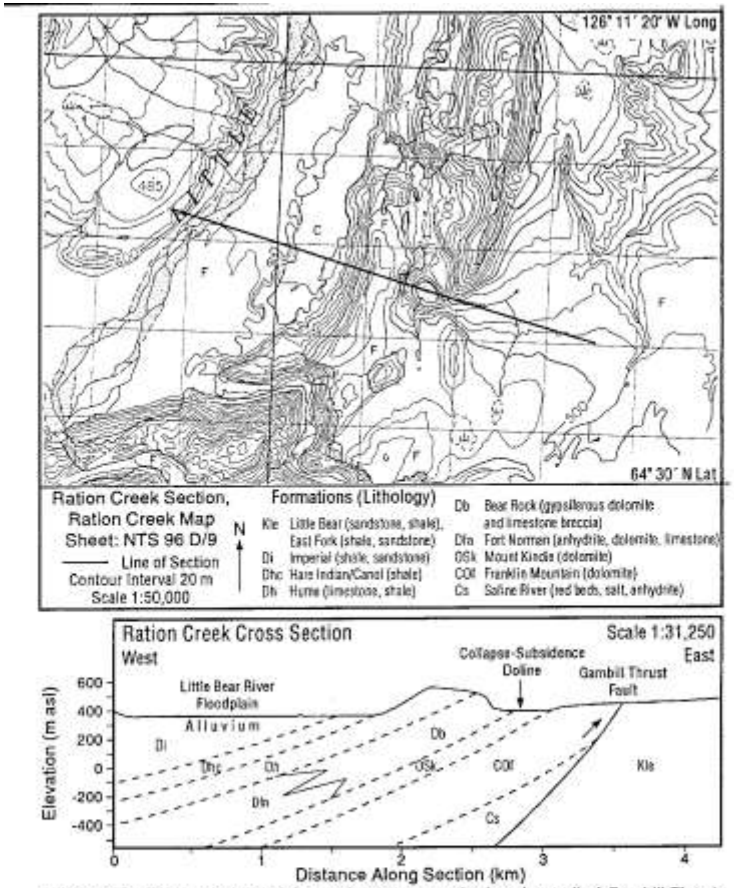


Figure 6.14: Dolines and linear depressions occur on the hanging wall of Gambill Thrust, east of Little Bear River. The largest feature, Ration Creek Doline, is an oval shaped, steep walled sink located within a linear trough. The trough is in the Bear Rock Formation, its axis is parallel to strike. The doline extends into the Mount Kindle Formation. The morphology suggests a collapse-subsidence origin. Subrosion originates in the Saline River Formation which subcrops 500 to 600 m below the feature (after Aitken and Cook, 1974; Pugh, 1993).

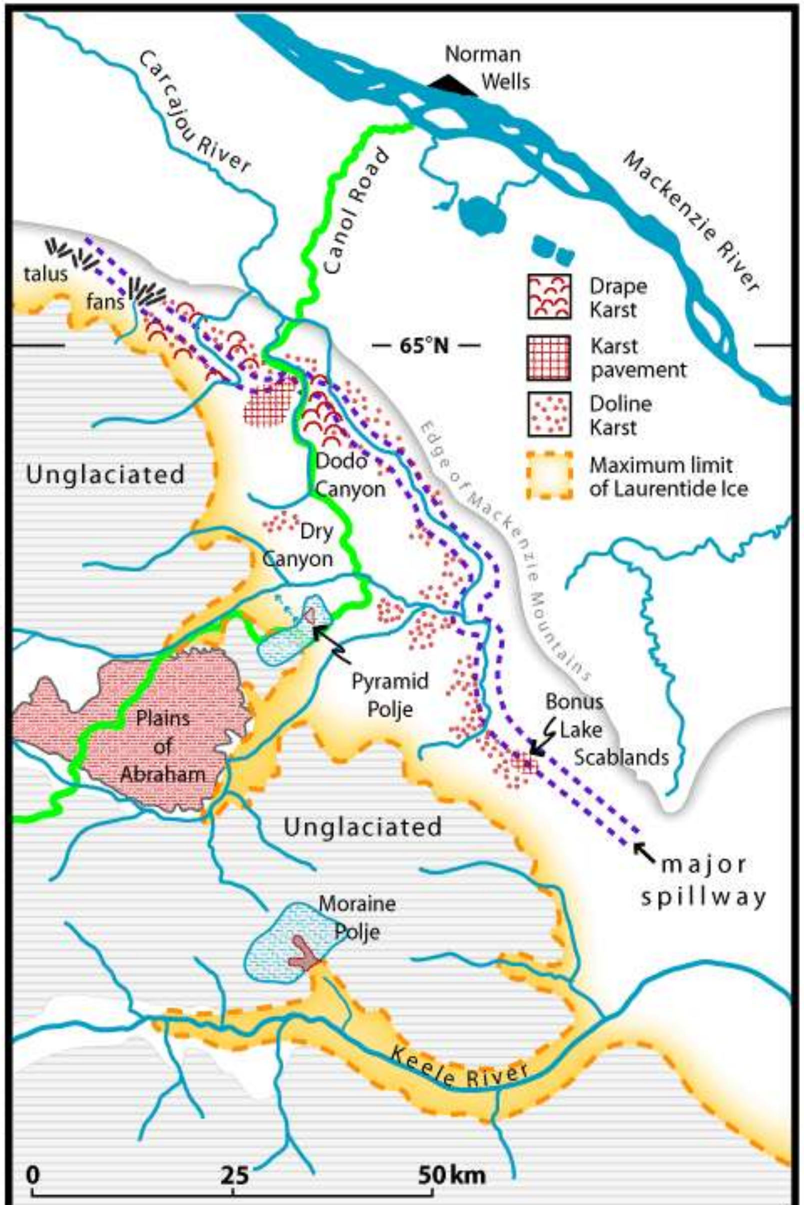
West of the Mackay Range a shallow ridge of steeply dipping Bear Rock and Hume strata rises
above the general level of the Mackenzie Valley. It is well rounded by glacial action. A large

Three further perspectives flying around the sinkhole. We have not visited it on the ground. A small stream flows in at the east end and two possible sink points are seen towards the west end.

The ground water probably drains to the Little Bear River valley, which is two km to the west at 360 m asl. In the past geologists have suggested that the collapse was caused by dissolution of the Saline River salt far below but it is considered as likely to be due to the local stream dissolving the Breccia.

Ration Creek Sinkhole is one of the finest examples known in Canada and offers an excellent morphological contrast to Vermillion Creek Sinkhole.

Recommendation - that Ration Creek be considered for protection with Vermillion Creek as a truly spectacular pair of karst depressions.



Norman
Wells
Carcajou River
Canol Road
Mackenzie River
Drape
Karst
Karst
pavement
Doline
Karst
Maximum limit
of Laurentide Ice
65°N
talus
fans
Unglaciated
Dodo
Canyon
Dry
Canyon
Edge of Mackenzie Mountains
128°W
126°W
Pyramid
Polje
Plains
of
Abraham
Bonus
Lake
Scablands
Unglaciated
major
spillway
Moraine
Polje
Keele River
0
25
50 km

The Plains of Abraham

The Plains of Abraham are an extensive plateau in the central unglaciated zone, formed of horizontally bedded dolomites of the Mt Kindle and Franklin formations. Elevations are generally between 1500 -1700 m asl, placing the Plains in the arctic tundra biozone. In this view we are approaching them from the south, with Carcajou River at their foot 500 m below them.

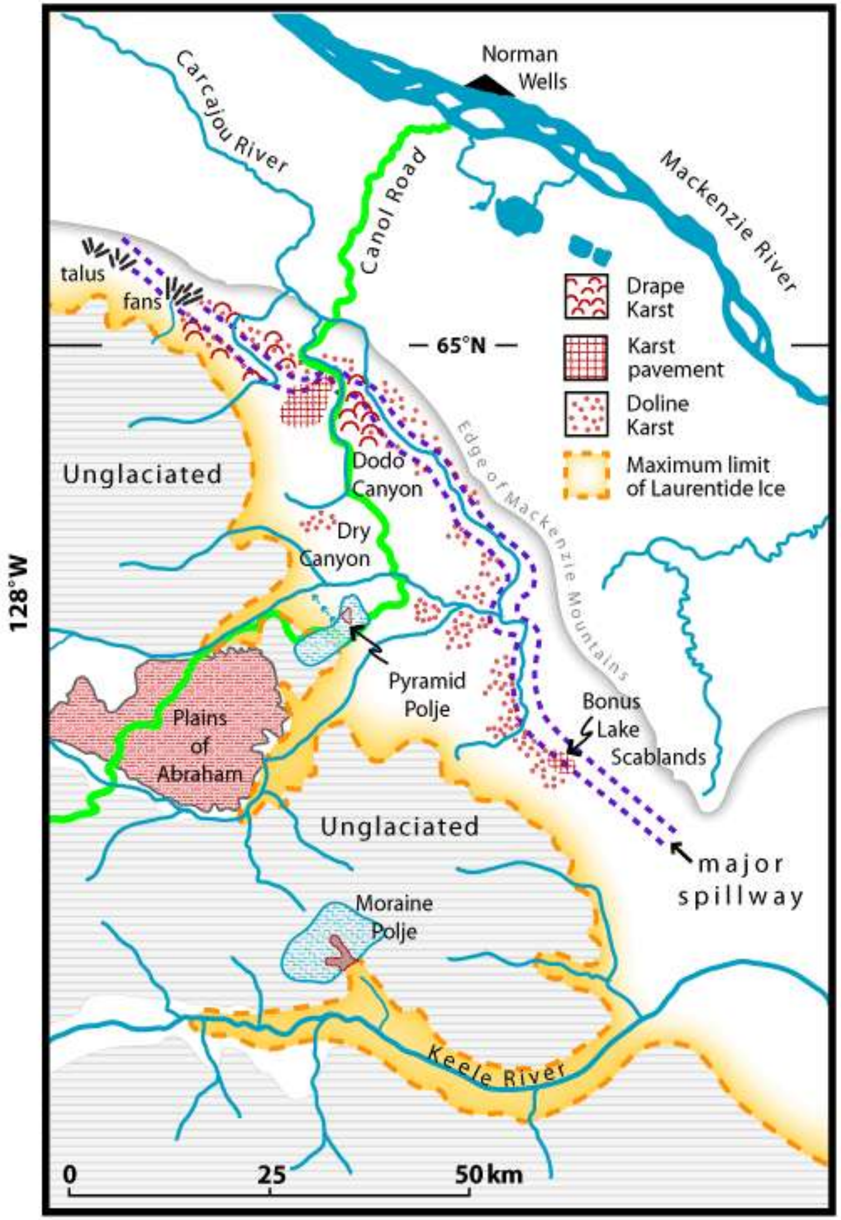
Varieties of patterned ground above an elevation of 1600 m where growth of grasses is very limited.

A superb display of stone stripes

This is the finest steephead I have seen in any alpine or periglacial region. Water seeps out along the foot of the arcuate cliff in massive, resistant dolomite, sapping it back by a combination of solution and frost shattering. The water surfaces from springs at the base of the talus below, creating an oasis.
The Canol Road passes by the crest.

The oasis is at N 64 33.7’, W 127 18.6’. Its floor is at an elevation of 1450 m.

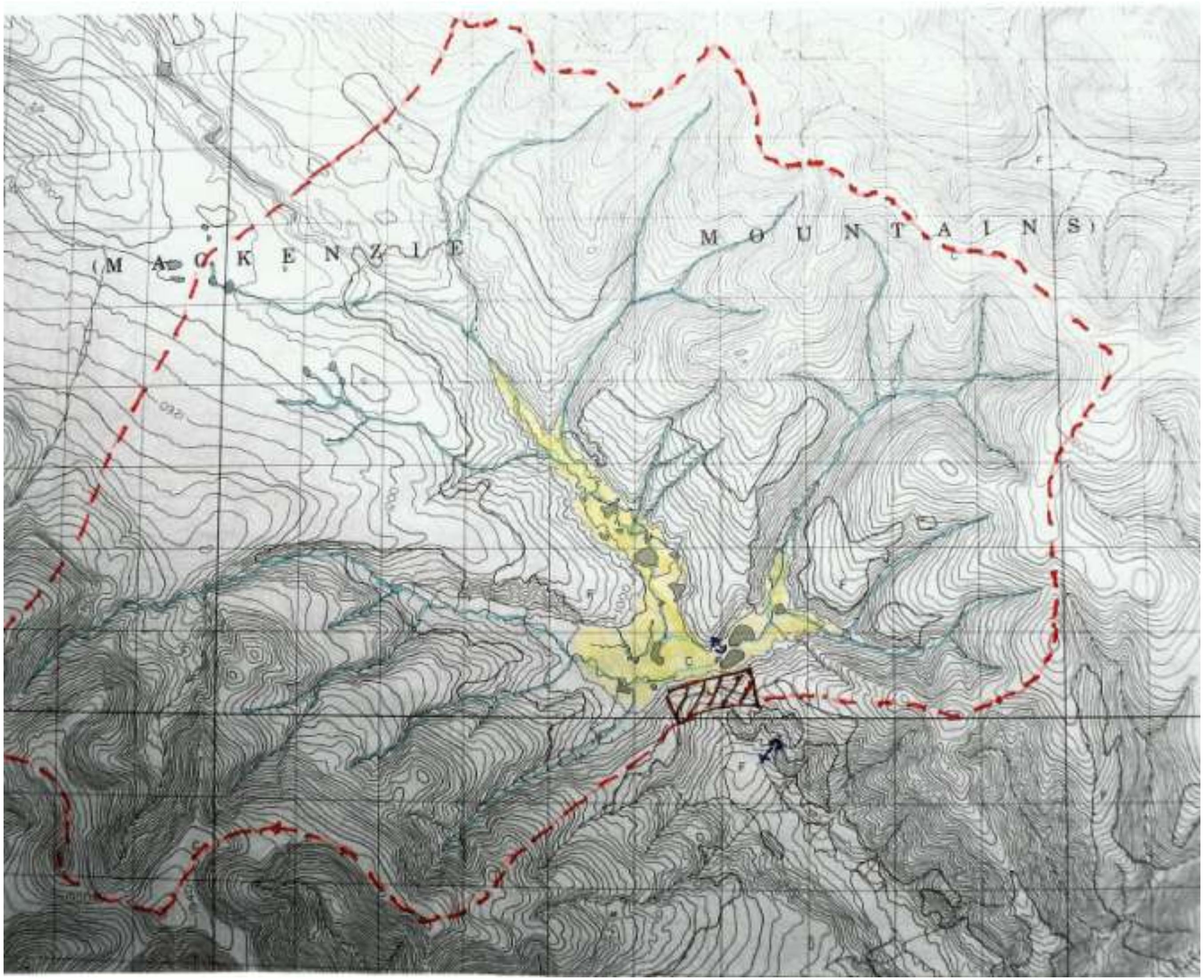
On right – a line of tiny caves can be seen in the prominent bedding plane at the base of the massive dolomite bed. These caves are now abandoned as the groundwater has moved down to another exit plane masked by the top of the talus.



Norman Wells
Carcajou River
Canol Road
Mackenzie River
talus
fans
Drape Karst
Karst pavement
Doline Karst
Maximum limit of Laurentide Ice
65°N
Unglaciated
Dodo Canyon
Dry Canyon
Edge of Mackenzie Mountains
128°W
126°W
Pyramid Polje
Plains of Abraham
Bonus Lake Scablands
Unglaciated
major spillway
Moraine Polje
Keele River
0
25
50 km

(B) Moraine Polje

An astonishing feature! – in its furthest incursion into the Keele River valley the Laurentide Glacier front reached the position between the arrows in the rear of the picture and built a terminal moraine there. This blocked surface stream flow out of the valley in the foreground, which has never been glaciated. The valley became partly filled with alluvial debris and the water developed an underground karst exit through the



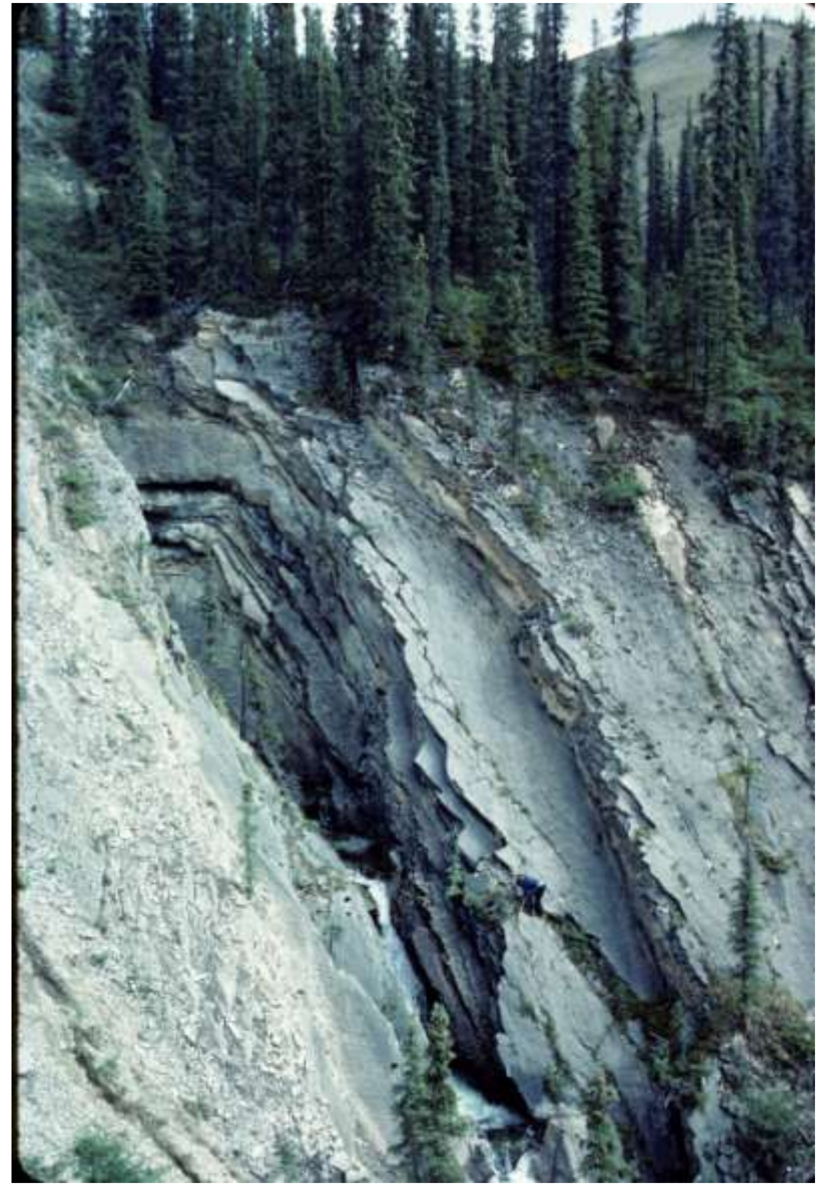
Topographic map of the Moraine Polje basin. The grid has one km squares. Contour interval is 20 m. Red = topographic watershed. Yellow = the alluvial floor (infilling). Brown quadrangle = approximate extent of the moraine dam. Northern blue arrow = stream sink. Southern blue arrow = the spring. The area of the basin is ~90 square km.

Left – the stream sink of Moraine Polje viewed from the crest of the moraine in 1983. Below – viewed in 2007. The sink point and the shallow ponds on the alluvium have been very stable over this time period.

The polje has developed in a steep, V-form syncline (downfold). Curiously, the stream has sunk into the rock north of the alluvial flat in the pictures instead of into the same strata on the south side (shown by horizontal arrow), which are much closer to the spring outlet.

The stream sinks into a cave of enterable dimensions. Top left – the author injecting fluorescein tracer dye on the first visit, August 1983. The water had warmed in the shallow approach channels and was a pleasant 14 C. Top right – the entrance in August 2007. There has been one fall of roof rock in the centre of the entrance arch; otherwise the scene is unchanged from 1983.

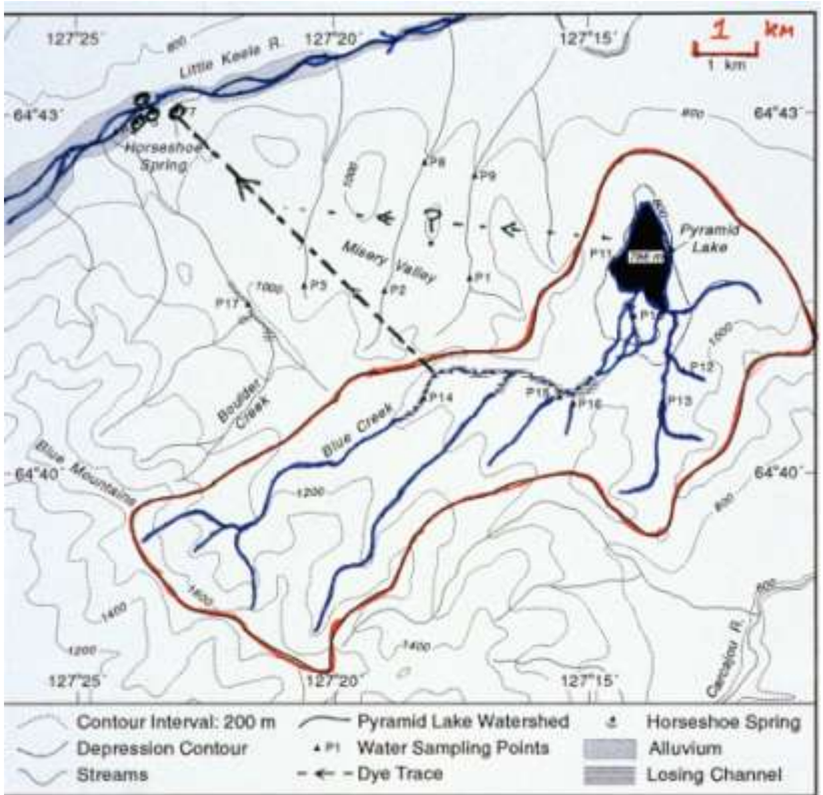
From the entrance the cave opens up into a substantial chamber formed by rockfall (‘breakdown chamber’) and plunges down a small waterfall. Beyond it is the wet and constricted passage shown above. This may be explorable in winter when there is no water flow but I do not believe that it will be enjoyable! The cave is a very raw, young feature formed as a consequence of the Moraine blockage. There are no sediments or speleothems of interest, and no faunal remains were seen.



The spring is a truly astonishing feature, appearing as if a giant fist had punched out from inside the rock to release the pent-up water.

The Pyramid Lake Polje

Pyramid Lake is located at N 64 42’, W 127 15’. The lake surface is at 786+/- m above sea level, fluctuating a little seasonally. It occupies an alluvial lowland, is drained underground karstically, and thus functions as a karst polje. This view looks south across it towards the Plains of Abraham. The Canol Road is at the foot of the hills behind the lake.



Above – Jim Hamilton's map of Pyramid Lake Polje. It has a catchment basin area of 34.4 sq kms. Water sinks in the Blue Creek channel bed upstream of the lake, where it was dye traced to 'Horseshoe Springs' (unofficial name) with a flow time of four days or ~1500+ m/day. The underground flow broadly follows a synclinal downfold in Franklin Mountain dolomites, i.e. this is a polje determined chiefly by geological structure

The middle section of Dodo Dry Canyon shown looking upstream (south) <u>on left</u> and downstream <u>above</u>.
An outstanding feature of the canyon is the manner in which great aprons and fans of dolomite talus sweep in from either side.

A further feature of the middle canyon is the apparent occurrence of paleokarst depressions and deposits in the cliffs. After deposition of the Franklin Mountain dolomite there was a long period of surficial erosion before deposition of the Mt Kindle dolomites began. Karst sinkholes formed and filled with terrestrial sediments, the buff, orange and yellow patches shown in these photographs.

The climax of Dodo Dry Canyon is the northern (downstream) end where it is more than 350 metres deep. The lake is at N 64 49’, W 127 14’, at 600 m asl. Dodo Creek at the head of its canyon is in the background.

Dodo Creek Canyon

Dodo Creek has entrenched its course across the flank of a major anticline (upfold) in the strata. As a consequence it first passes down through progressively older rocks to the crest of the anticline and then back up through them to its mouth. It is a very colourful journey, as this picture from the southern (upstream) end suggests.

The start of the lower canyon where strata dip in the downstream direction and the cliffs become higher.Here the top of the redbeds is beautifully exposed. Note that one block has settled below the others, probably due to salt dissolution below. Inset – the ruins of a Canol camp glimpsed in the main picture.

A further scene in the redbeds sector of Dodo Canyon. Another differentially settled block is seen where a tributary stream enters.

This is one of the finest scenes in Dodo Canyon. The orange Franklin Mountain dolomites dip into the canyon floor and the more massive, dark grey and steeper cliffs of the Mt Kindle Formation appear behind them. This is the deepest part of the canyon, the walls being more than 400 m in height.

In Dodo Canyon the Franklin Mountain dolomites display some attractive pinnacles and bright reddish orange patches of paleokarst sinkhole fillings.

Upper left – the Franklin Mtn dolomites pass below the Canyon floor. Upper right – the Mt Kindle dolomites have also dipped below the floor and a prominent ‘gatepost’ marks entry int Bear Rock breccia sector of the Canyon. Lower right- a surviving remnant of the Canol Road he

The Dodo West Karst Pavements

These two pictures both show the upper beds of the resistant Mt Kindle dolomites. On left – on the never-glaciated Plains of Abraham, where periglacial frost shatter processes predominate. On right – on Dodo West where the last Laurentide glacier scoured all loose debris away, exposing fresh bedrock to karst solutional attack.

The Mt Kindle dolomites were ‘cyclic’ deposits of thick and strong beds, succeeded by weak thin beds like meat in a sandwich (above). Glacier ice bulldozed the rock away along the weaker beds, creating a staircase-like topography (upper right). Each strong bed surface that was exposed tends to have slightly different properties with the consequence that the detailed solutional landforms (karren) are never quite alike on any two beds.

Looking North across the pavements with the Breccia karst beyond and the confluence of Dodo Creek and Carcajou River in the background. The West Dodo dolomite karst pavements are amongst the finest known anywhere in the arctic regions.

The Dodo Breccia Drape Karst

Between Dodo Canyon and Carcajou Canyon the Bear Rock Breccia is dissected by karst processes into a fantastical landscape unknown in any other part of the world. It was its dramatic appearance on air photos that first drew the author to reconnoitre the regional geomorphology in 1983. Meltwaters from the Laurentide Ice Sheet and then thousands of years of rain and snow melt have scoured corridors and sinkholes into the Breccia, destroying its softer parts and leaving more resistant, hardened surface crusts such as the Landry Member draped on ridges and sliding into the solutional depressions, as shown here

Further scenes in the upper belts. Lower photos show an example of hardened breccia crust tipped on end and sliding downslope, and some of the superb patterned ground, both evidences of the vigour of periglacial processes on the Breccia.

This aerial photograph of a very beautiful sinkhole with its pond perched on permafrost but leaking slowly into the groundwater aquifer underneath has delighted fellow geomorphologist worldwide when they have seen it. It is an ideal example of periglacial karst.

A general view from east to west along the ‘Carcadodo Valley’. The aircraft is over the steep drop off into Carcajou Canyon. This was an important section of The Great Spillway at the end of the last glaciation, when meltwater flowed along it from east to west. Today its stream is fe by springs from the Drape Karst belts (on left) and flows from west to east until sinking again i left centre

Above – the Carcadodo stream flowing east to its sinkpoint (arrow); July 2007. In rear, the Carcajou River flows from the mouth of its canyon. On right – a detail from the 1989 field study season; the sinkhole ponds were very similar in extent to 2007.

Three views of springs at the mouth of Carcajou Canyon. Above left – the arrow shows the stream sink in Carcadodo Valley. The springs are in the foreground. Above right – the flow from the springs is bright but peaty, readily distinguished from the turbid, silty water of Carcajou River.
Below – measuring temperature and conductivity in the springs. They were at 10.7 C and carrying about 4000 mg/l of salt, plus dissolved dolomite and gypsum.

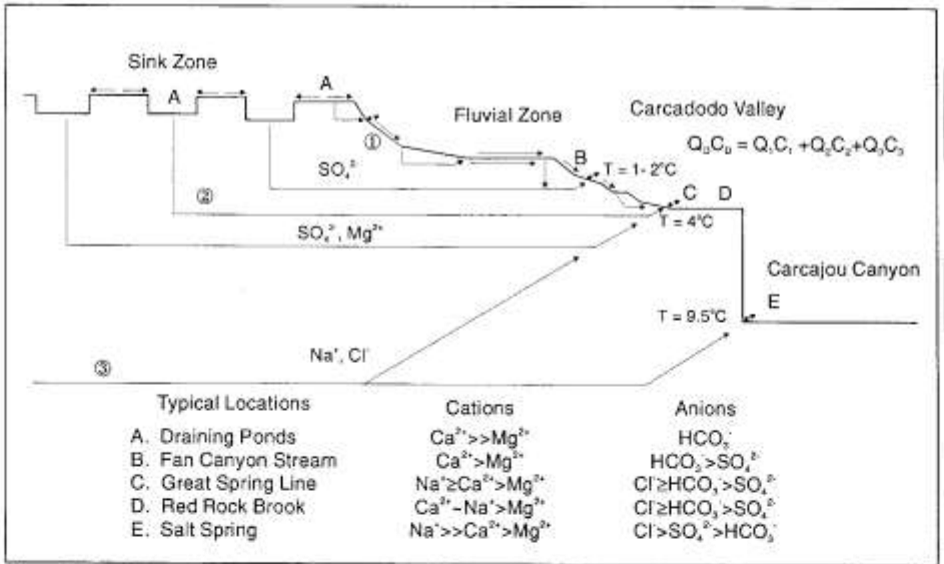
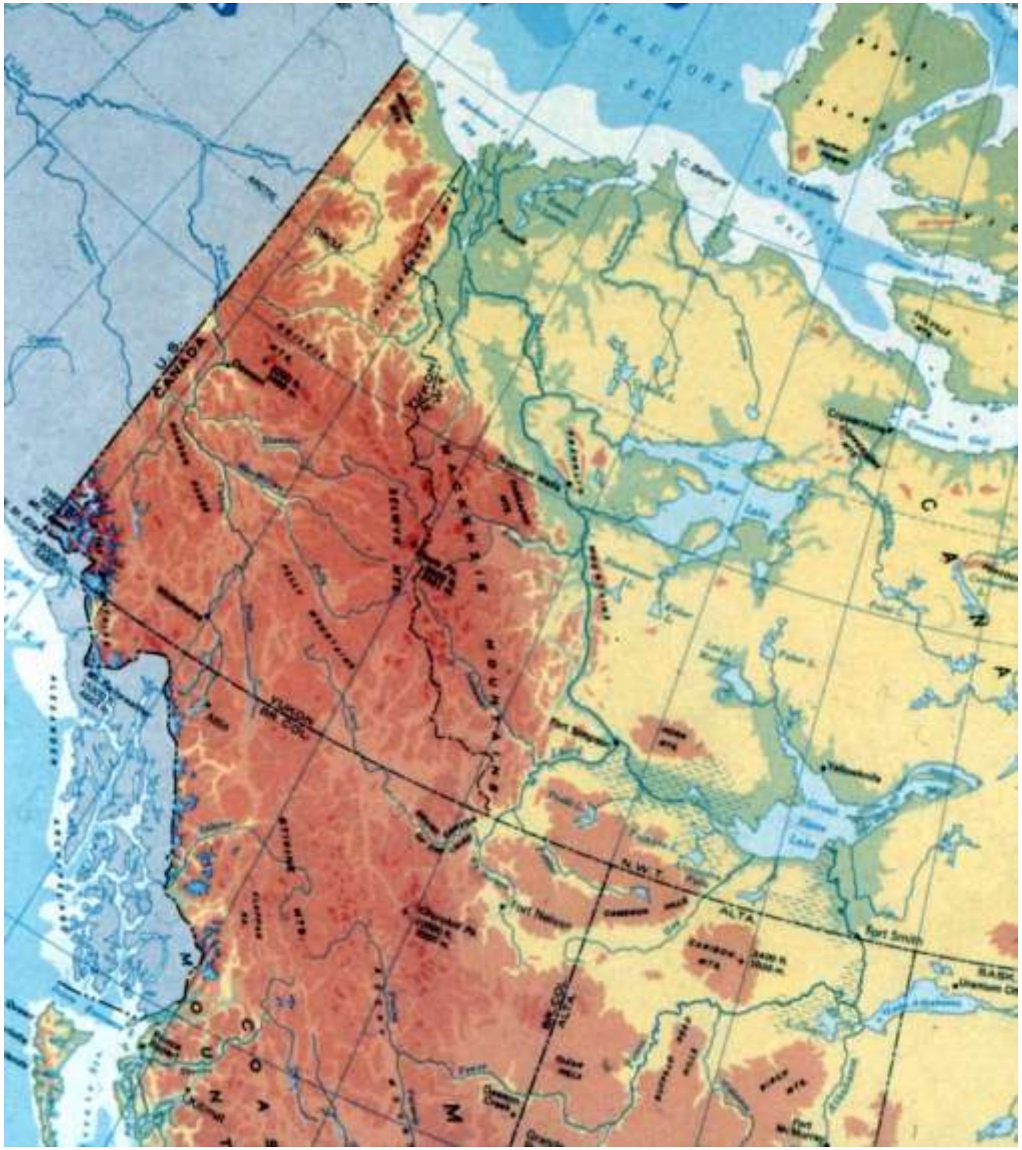


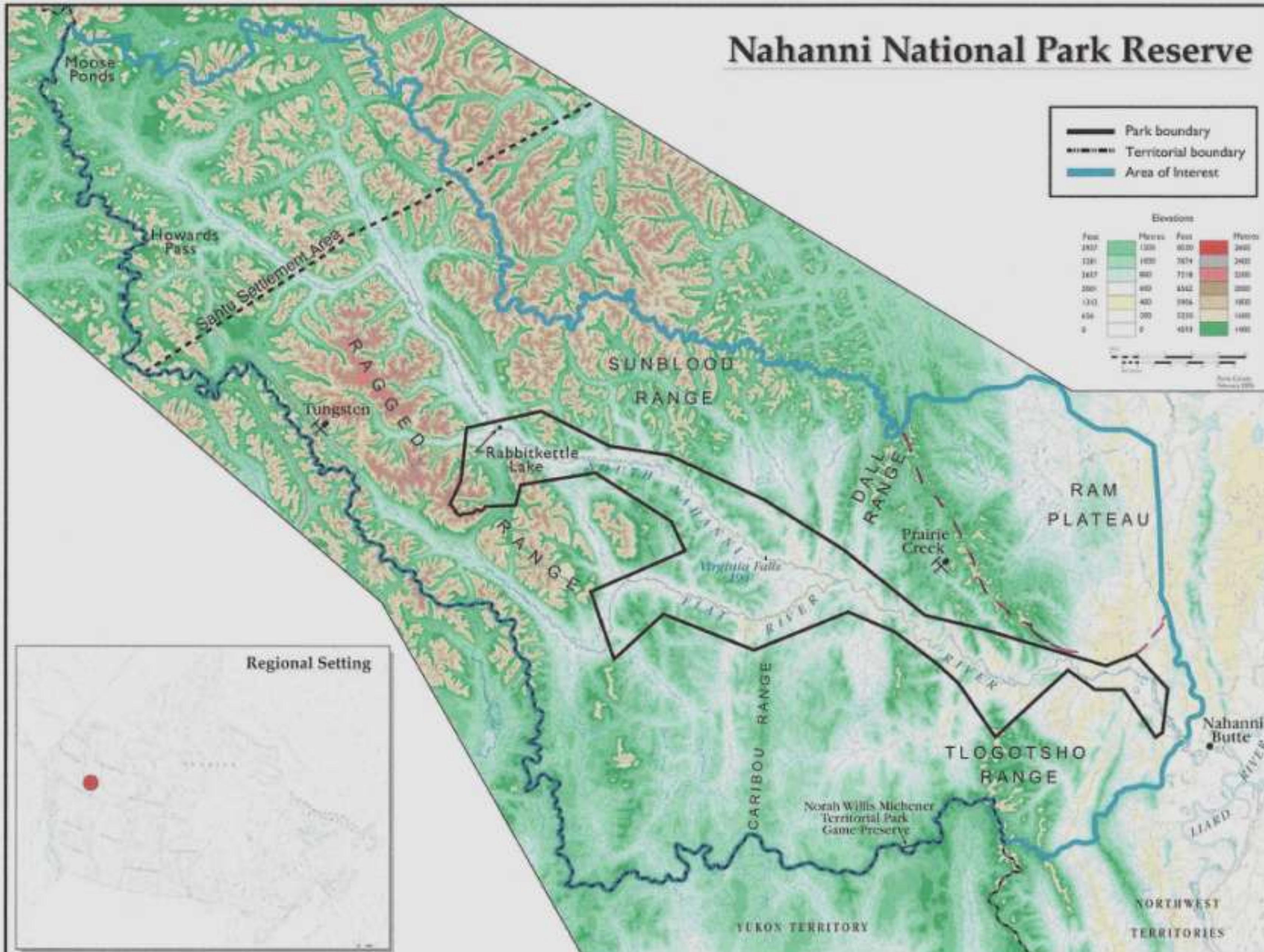
Figure 7.32: Schematic diagram of groundwater circulation in the Dodo Canyon Karst. The figure is not to scale. Changes in ion abundance are indicated for five locations that are typical of the data set. Spring temperatures are shown for the Fluvial Zone, Carcadodo Valley, and along Carca-Spring Stream. Red Rock Brook takes flow from shallow, intermediate, and deep groundwater components. The latter has high concentrations of Na^+ and Cl^-. Much of the SO_4^{2-} and Mg^{2+} is from the intermediate Bear Rock and Mount Kindle Formations aquifer.

Above – Jim Hamilton's model for the chemistry of karst groundwaters in the Breccia. Type (1), intrapermafrost, water is dissolving chiefly gypsum. Type (2) water reaches the base of the permafrost and dissolves both gypsum and dolomite. It takes 40 – 50 days to travel to the springs in Carcadodo Valley. Type (3) water is warmed by long distance, deep flow into the salt of the Saline River Formation. On right – salt-tolerant lichens and slimes in a young salt spring



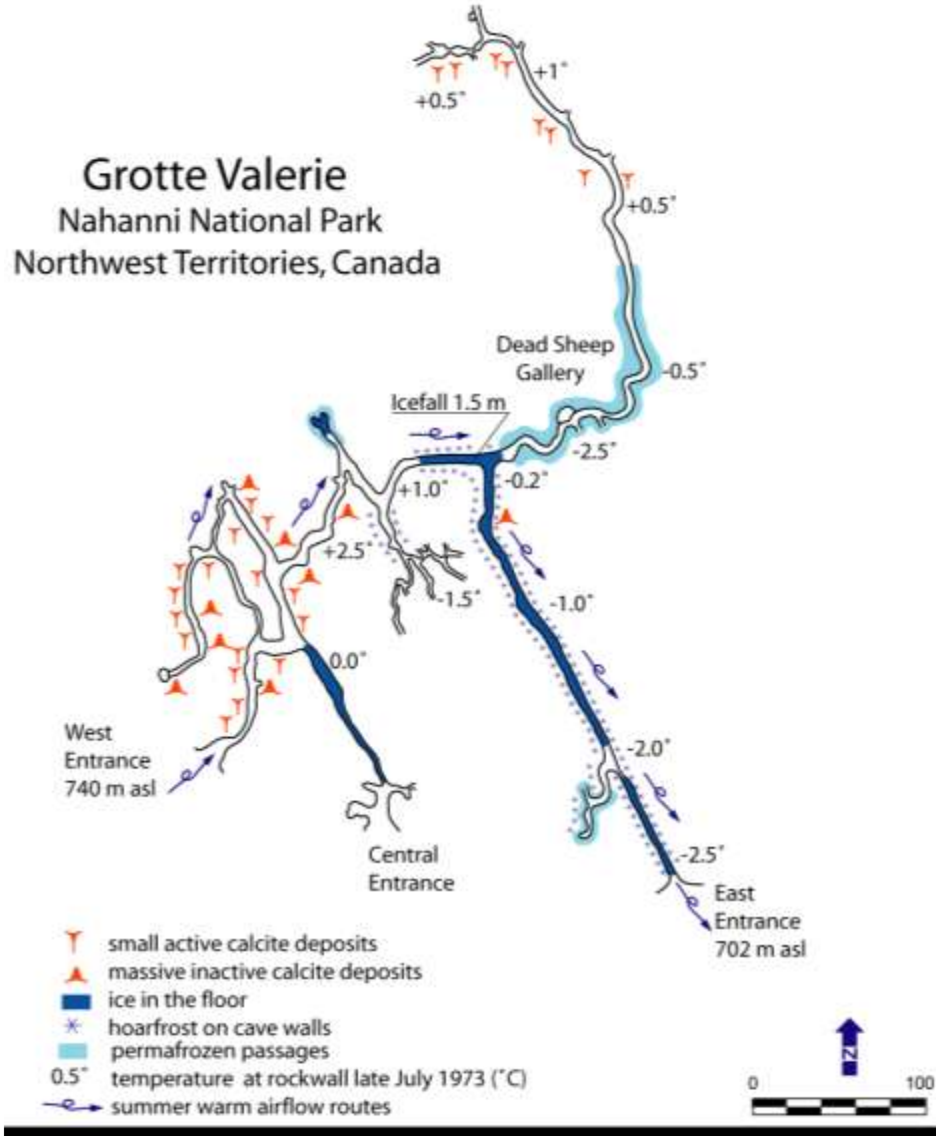
Nahanni National Park Reserve was established by Prime Minister P.-E. Trudeau in 1971 to protect three river canyons and a great waterfall from proposed hydro-electric dams. That year I was asked to evaluate newly discovered caves in the downstream (First) canyon and enlarged the task to study the geology, geomorphology and hydrology of the Reserve, and explore a major karst area to the north of it. My reports (1974, 1975) provided the basis for the Reserve being one of the first two UNESCO World Heritage natural sites to be declared, in 1978 (Yellowstone National Park in the United States was the other).

It was always the intention to enlarge the Park but many political problems have arisen. In June 2009 an incomplete enlargement was announced.



Nahanni National Park Reserve
Park boundary
Territorial boundary
Area of Interest
Elevations
Moose Ponds
Howards Pass
Sahtu Settlement Area
RAGGED RANGE
SUNBLOOD RANGE
Tungsten
Rabbitkettle Lake
DALL RANGE
RAM PLATEAU
Prairie Creek
Virginia Falls
FLAT RIVER
RIVER
CARIBOU RANGE
TLOGOTSHO RANGE
Nahanni Butte
LIARD RIVER
Norah Willis Michener Territorial Park Game Preserve
YUKON TERRITORY
NORTHWEST TERRITORIES
Regional Setting

We cannot get into the modern underground river caves but there are plenty of relict ones high and dry in the canyon walls



Grotte Valerie, overlooking First Canyon, is the finest

The cave has three climatic zones – warm, cold and permafrozen

Brightly coloured speleothems in the warm cave

In the largest chamber

In ‘the cold cave’ – 300 m of skating

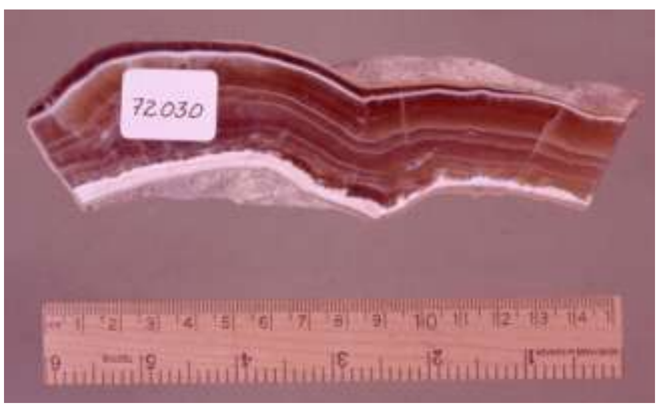
Hexagonal crystals of hoarfrost in a recess

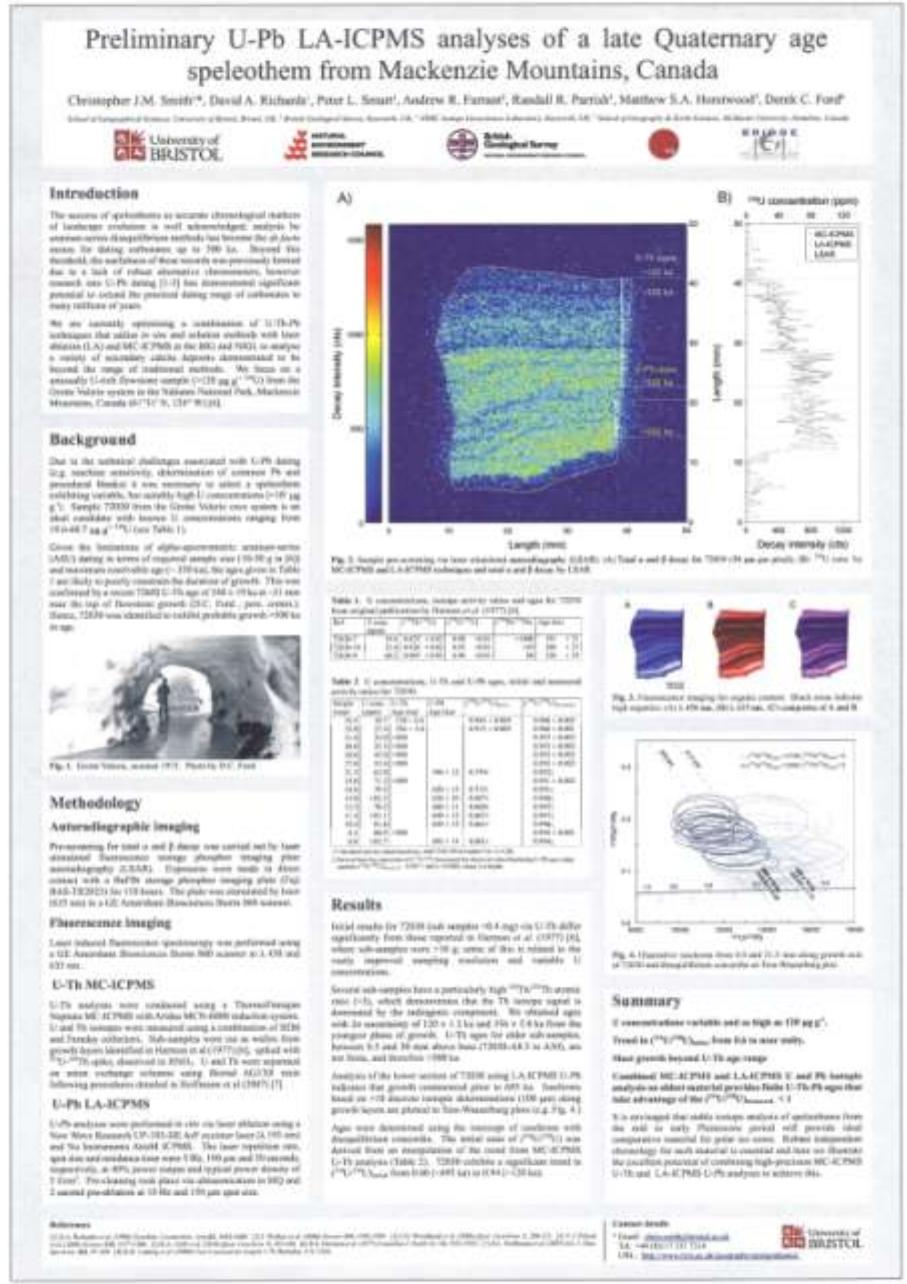
Looking down into ‘the permafrozen cave’

The cold cave is an ossuary

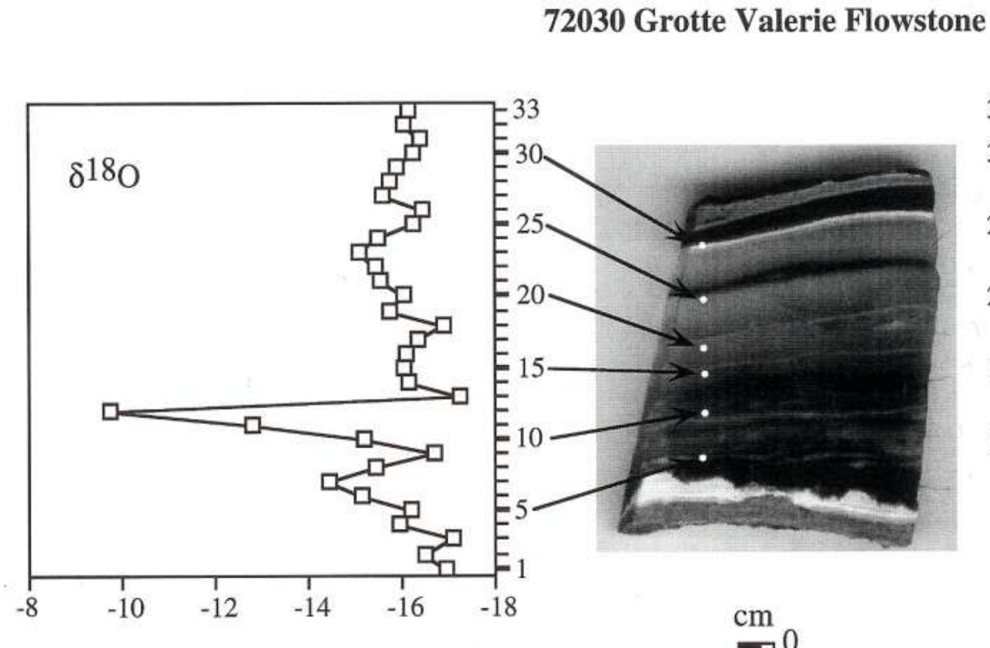
Twenty-two hundred years old

Grotte Valerie, Nahanni; Lat 63 N

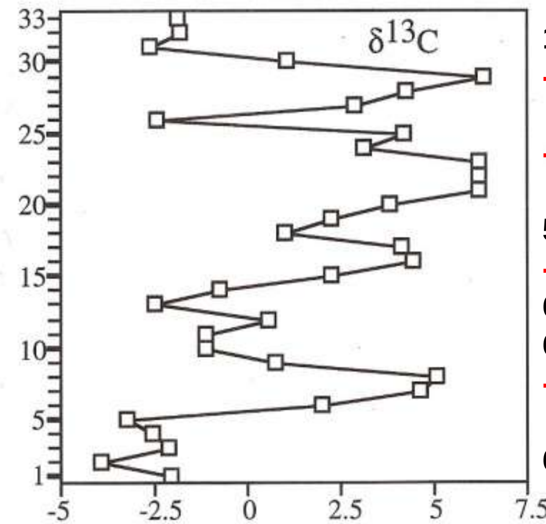




Karst Record 6 conference, June 2011



2011 - Bristol Th/U and U/Pb ages



120+/-0.6 ka BP

356+/-6

596+/-12

620+/-15

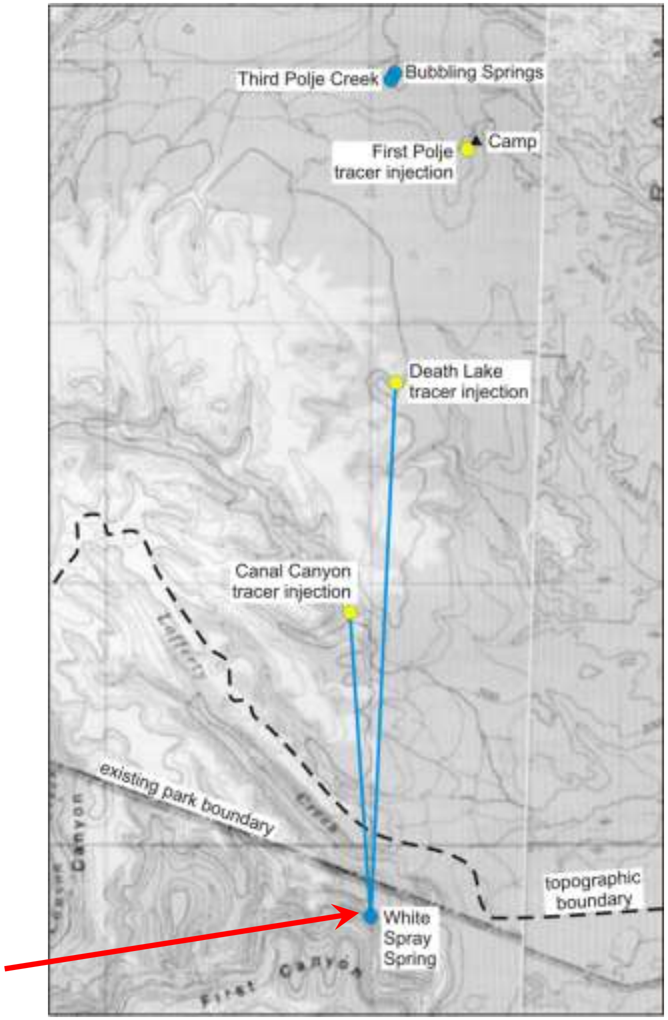
650+/-15

696+/-14

1694 - Valvasor

North of Death Lake lies the spectacular Labyrinth Karst, draining via Bubbling Springs into the Ram River basin. To incorporate all of the karst in an expanded Nahanni National Park it is necessary to include the Ram basin to the mouth of Ram Canyon in Ram Plateau.

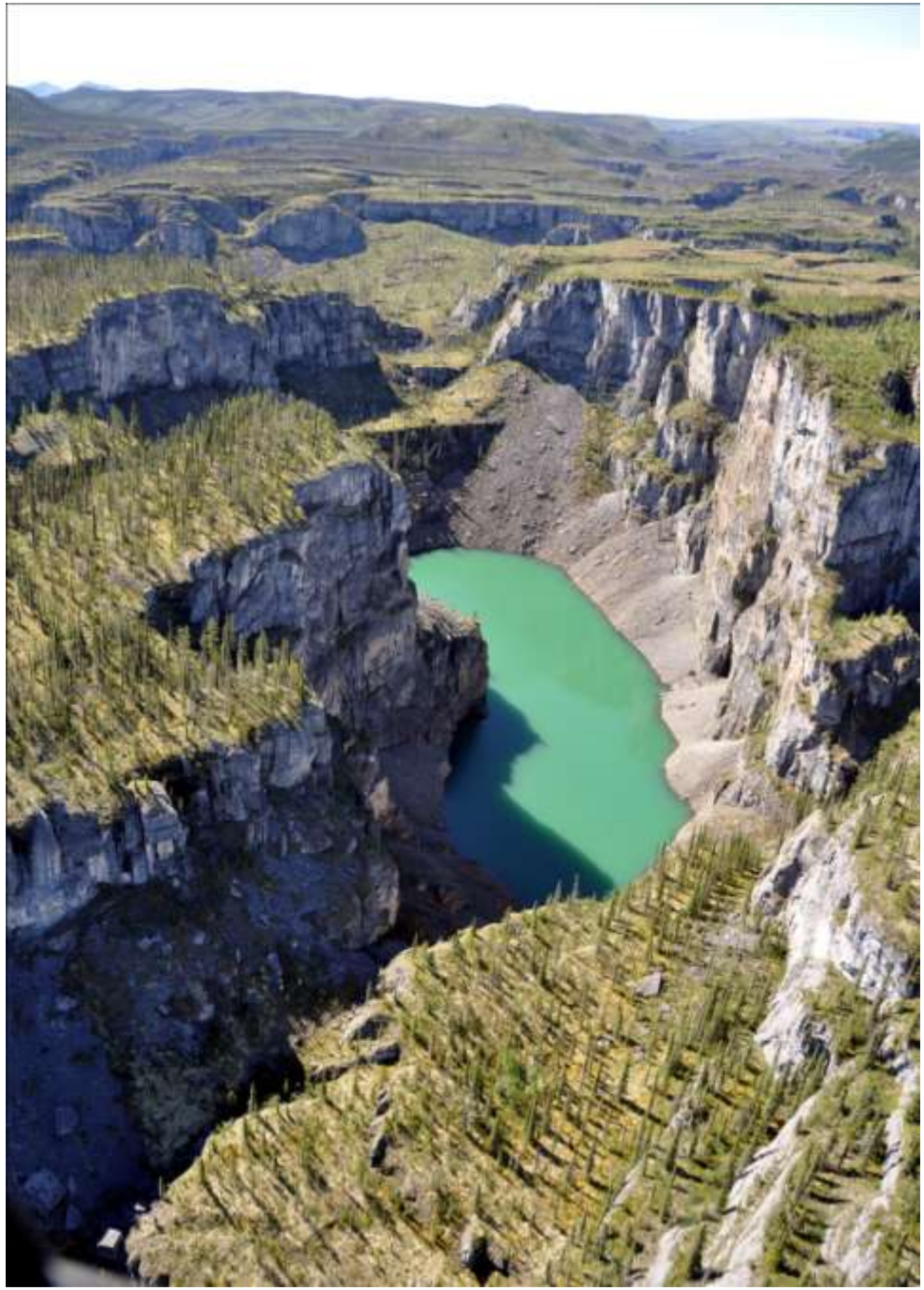
The geomorphic case for extending the Park into the Ram River basin



Death Lake

Canal Canyon

Karst features extend far to the north of the topographic divide on the east flank of First Canyon. Major stream sinks at Death Lake and Canal Canyon have been dye-traced to White Spray Springs in the bottom of First Canyon, >460 m below the stratigraphic top of the dolomites.



There are three small but perfectly formed karst poljes.
Some historic pictures.

Third Polje is seen dry on the occasion of my first visit, in June 1972.

The high water dissolution notch seen in a cliff on the right bank that day.

Third Polje fully flooded after eight days of rain in July 1972 that also filled the other poljes and Raven Lake.

‘Bubbling Springs’ (~10 cumecs) are the northern drain of the main karst belt. They are also perennial.

Global warming is melting permafrost rapidly in northern Canada.
I have noted a big increase between 1971-78 and 2006 -10 in Nahanni.

<u>Left</u> – Second Polje in August 2007

<u>Right</u> – the same scene in September 2009 after a landslide in glacial silts due to permafrost melting

The End