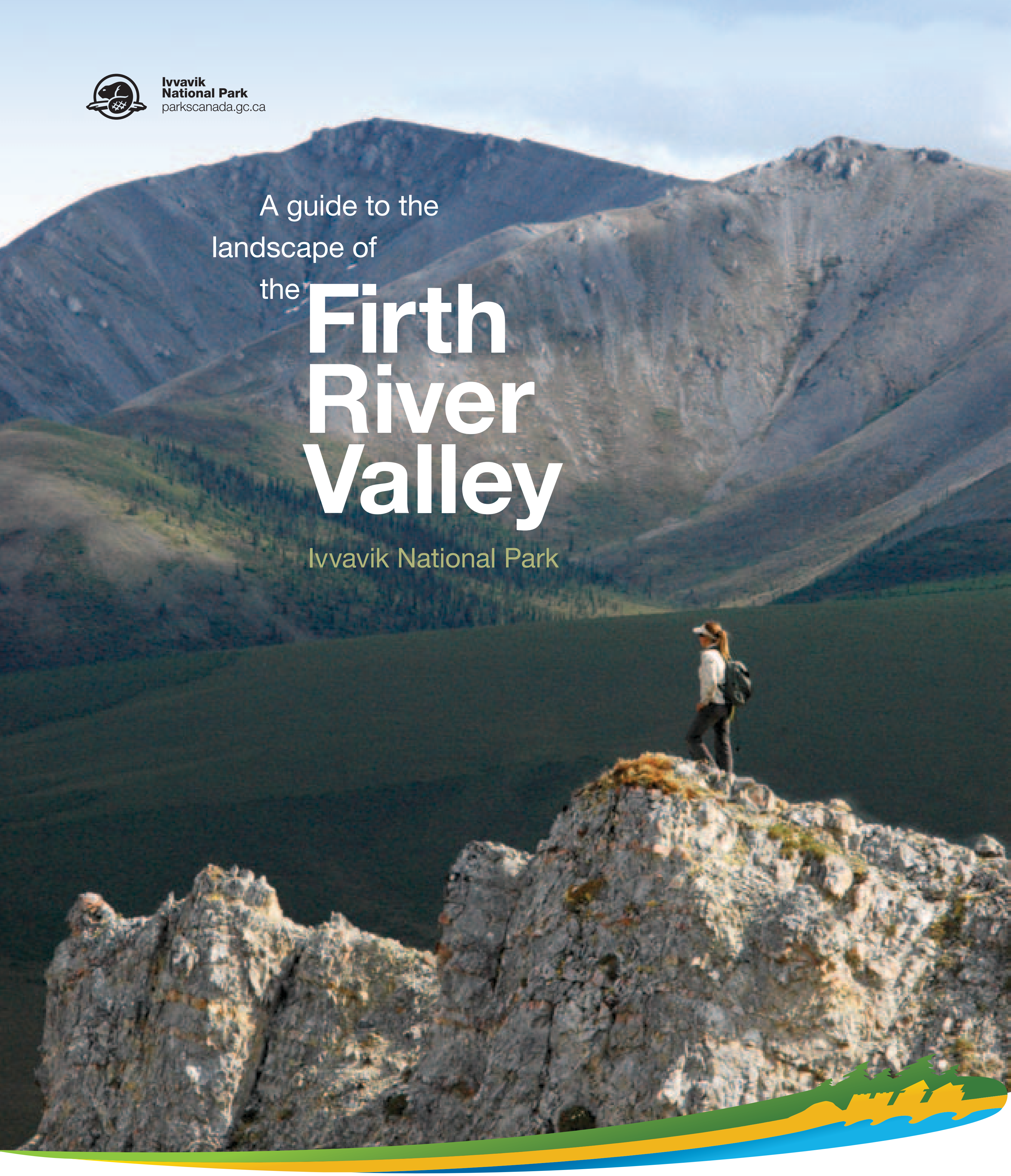
Ivvavik
National Park
parkscanada.gc.ca



A guide to the landscape of the Firth River Valley

Ivvavik National Park

Parks Canada and
Natural Resources Canada

Parcs Canada et
Ressources naturelles Canada

Canada

ISBN:
978-1-100-18115-8

Catalogue Number:
R64-404/2011E

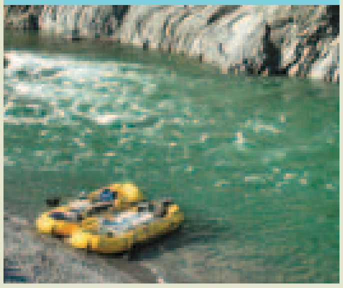
Copies available from
Western Arctic Field
Unit, Parks Canada,
Inuvik, NT X0E 0T0

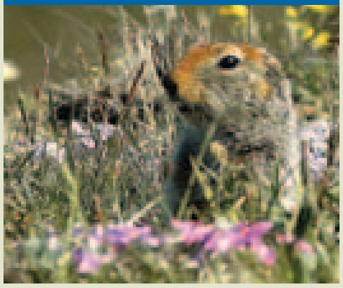
A guide to the landscape of the Firth River Valley

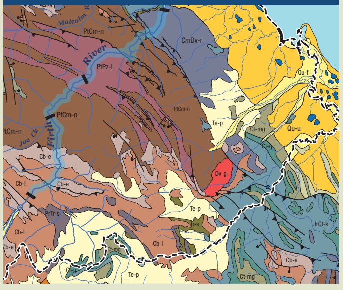
Ivvavik National Park

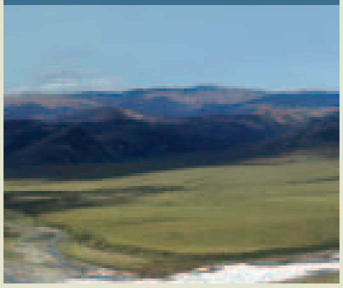
Authors:

Gregory R. Brooks
Larry S. Lane
Geological Survey of Canada
Natural Resources Canada

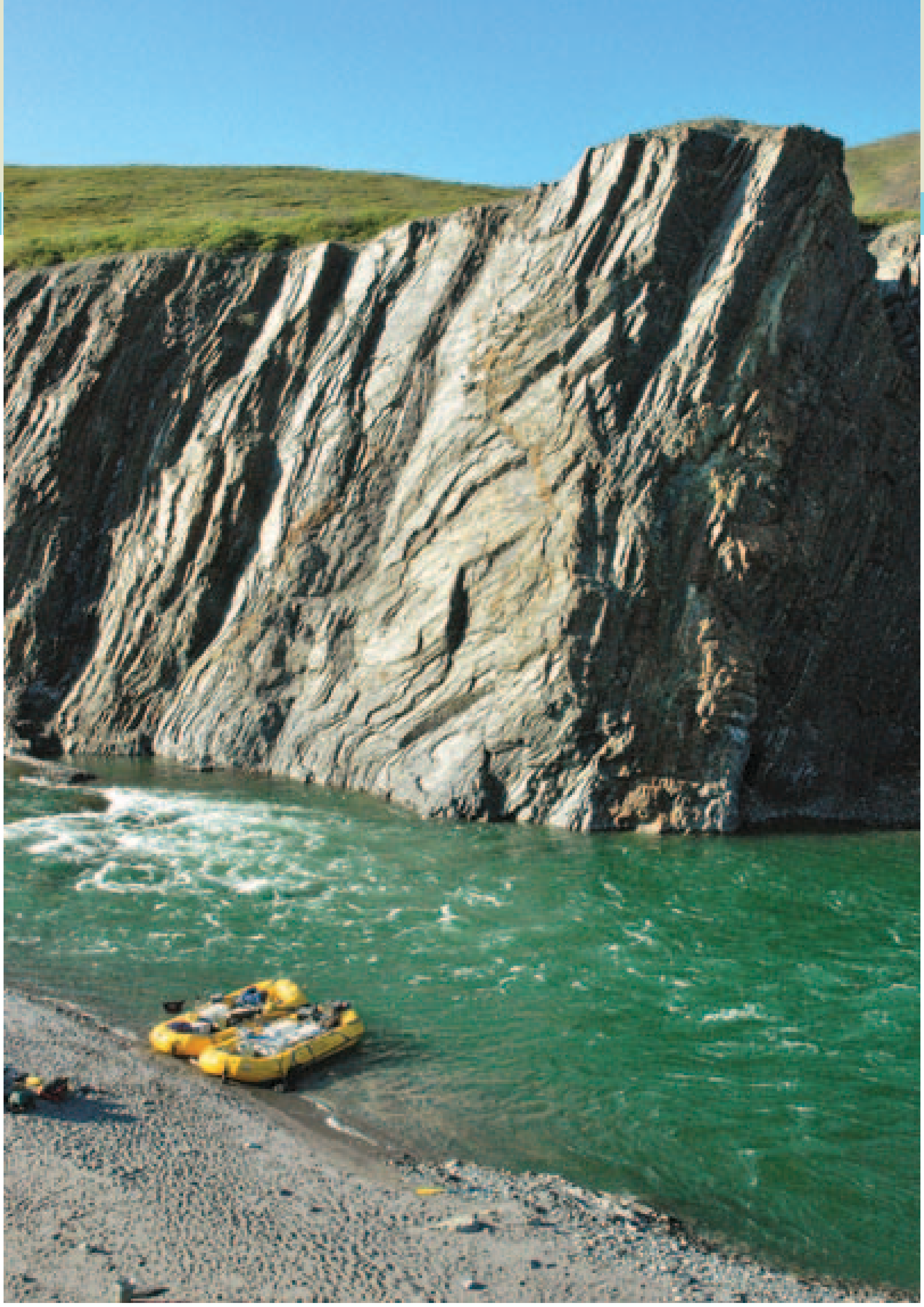








Disclaimer: Natural Resources Canada and Parks Canada, do not warrant or guarantee the accuracy or completeness of the information contained in this Guide Book (*A guide to the landscape of the Firth River valley, Ivvavik National Park*) and do not assume any responsibility or liability with respect to any damage or loss incurred as a result of the use made of the information contained in this Guide Book.



▶ Rafts alongside at Layover Campsite, within the Canyon Reach of the Firth River. (Photograph: Greg Brooks, Natural Resources Canada (NRCan))

INTRODUCTION

Canada offers travellers a remarkable range of landscapes to explore, from dramatic young formations along coastlines to billion year-old bedrock exposed on the Canadian Shield. Despite such diversity, almost all of these settings share a common geological past, bearing the impact of massive glaciers passing repeatedly over their surfaces during the last two million years. One of the few places that completely escaped the effects of glaciation: the northwest corner of the country that is now the Yukon. The geological features found here bear little or no trace of glaciers, distinguishing this particular landscape from any other in the country.

Ivvavik National Park preserves more than 10,000 square km of this landscape in the western portion of Yukon's North Slope. In 1984 this pristine wilderness became the first national park in the country to be established through an aboriginal land claim agreement between the Inuvialuit people and the Government of Canada. Ivvavik is cooperatively managed by Parks Canada and the Inuvialuit to ensure the long-term integrity of the wilderness, the health of wildlife populations, and the preservation of cultural resources. The settlement agreement also ensures that the Inuvialuit can continue to practice their traditional lifestyles, which include hunting, trapping and fishing, within Ivvavik.

In the indigenous language of Inuvialuktun, Ivvavik means "a place for giving birth, a nursery". That name is entirely appropriate, since the Park protects the Canadian portion of calving grounds of the Porcupine caribou herds as well as protecting this biologically and culturally rich area from development.

Despite its national park status, Ivvavik is isolated and devoid of roads and other infrastructure. There are no facilities, services, or established trails and campgrounds. The Parks Canada station at Sheep Creek is only occupied periodically in the summer months. Access is limited to wheeled aircraft landing at a few primitive and unmaintained airstrips, or by float plane on one of the few small lakes of sufficient length for landing. Not surprisingly, Ivvavik Park receives on average 100 visitors a year. Most of these people come to traverse the Firth River by raft or boat over a 132 km distance from Margaret Lake to Nunaluk Spit at the Beaufort Sea coast.

These visitors come for various reasons, including the thrill of rafting the cold, white-water sections of the river, the rare experience of encountering abundant wildlife and diverse Arctic flora, or simply to embrace the natural rhythms of an utterly primitive, less hurried place. Above all, however, travel down the Firth River provides an unrivalled showcase of a Canadian vista that can be found almost nowhere else, a glimpse of what a mountain landscape would look like had glaciers never scoured it.

By any aesthetic measure, the features of this land are impressive. But an appreciation of their exceptional geological qualities elevates them into the realm of the extraordinary. This guide book is intended to convey just such an appreciation of the Firth River valley. It begins with the geologic story of Ivvavik, then outlines in detail some of the most striking features that illustrate that story today. With an understanding of the remarkable geomorphology to be seen at practically every turn, an exceptional trip can likewise be elevated into the realm of the extraordinary.

▲ Raft approaching Sheep Slot rapids at the start of the Canyon Reach of the Firth River. (Photograph: Jean-François Bisaillon, Parks Canada)

Terminology

The terminology of features along the river (e.g., the names of creeks, trails, campsites, rapids, etc.) and the names of river reaches (i.e., the Aufeis, Mountain, Canyon and Delta reaches) follow those in the ***Firth River Map & Guide*** booklet. The map booklet also contains a series of large-scale, shaded relief maps that depict the corridors along the Firth River. These maps are not duplicated in ***A guide to the Landscape of the Firth River valley, Ivvavik National Park***, but an interested reader will find it useful to refer to them. Most of the features and themes found in this guide book reflect a direct experience of the Firth River valley, including the primary elements of most visitors' itineraries.

CONTEXT

Physiography

The Firth River traverses three physiographic regions along its course through Ivvavik National Park: the British Mountains, the Buckland Hills and the Yukon Coastal Plain (see map, on page 7). They represent the topographic expression of the geological processes that have progressively shaped this land—forming, deforming, uplifting, eroding, and weathering its rocks to create the surroundings we find today. These constructive and destructive processes have operated together over many hundreds of millions of years and are still active, as summarized in the *Geological evolution of Ivvavik* section.

Of the three regions, the rugged terrain of the British Mountains covers the largest area of Ivvavik and forms the dominant element of the landscape. These mountains are the eastward extension of the Brooks Range crossing northern Alaska, with ridges exhibiting a distinct NW–SE orientation indicative of the bedrock structure.

A number of large rivers, including the Firth River, cut across these mountains in a northeasterly direction, often spawning tributaries that parallel the orientation of the ridges, perhaps along faults or linear zones of weaker bedrock. The Aufeis, Mountain and Canyon reaches of the Firth River together make up 106 km of the 132 km total distance from Margaret Lake to Nunaluk Spit; they are also situated entirely within the British Mountains.

With the exception of the Malcolm River watershed, these mountains escaped the glaciations of the last two million years, as revealed by some of their particular characteristics (see *A mostly unglaciated landscape* section). The higher mountains in Ivvavik attain elevations up to 1600 m, with ridge heights and valley depths ranging from 450 to 900 m. Higher elevations experience less extreme temperatures, but greater precipitation, than adjacent lower terrains. Nevertheless, foothills and mountains are affected by frequent freezing and thawing, as well as being underlain by a continuous layer of permafrost (see *Permafrost—cold, cold ground* section).

A mostly unglaciated landscape

The Quaternary Period spans the last 2.6 million years of Earth's history, with global climate regularly alternating between long-term cooler and warmer intervals that each lasted many thousands of years. During cooler periods, glaciations were caused by the build-up and advance of ice sheets across vast tracts of land, principally in the mid- and upper-mid-latitude regions of the Northern Hemisphere. These ice sheets subsequently melted and retreated during the warmer, interglacial intervals. The most recent glaciation occurred between approximately 80,000 and 10,000 years ago during the Wisconsin Glacial Stage. Currently, the Earth is within a warmer, interglacial stage.

Almost all of Canada was covered by glacial ice at least once during the Quaternary Period, with most areas being covered multiple times. The country's various landscapes are therefore characterized by erosional or depositional landforms created by glacial movement and glacial meltwater-related processes. However, this is not the case in much of northwestern Yukon and the majority of the interior of Alaska, which have never known glaciers. The cold, dry climates of these regions inhibited the local formation and build-up of glacial ice, and they remained far from other major ice accumulation zones located towards the south or southeast, which were also on the other side of mountain ranges that acted as barriers.

The geomorphic features found in Ivvavik testify to this absence of glaciers in most of the area. The Firth Valley lacks the distinct landforms shaped by powerful rivers of ice, such as U-shaped valleys, cirques, hanging valleys, arêtes, and truncated ridges. Nor does the area contain those depositional landforms left by retreating glaciers, such as moraines or a widespread, thin veneer of sediment known as till.

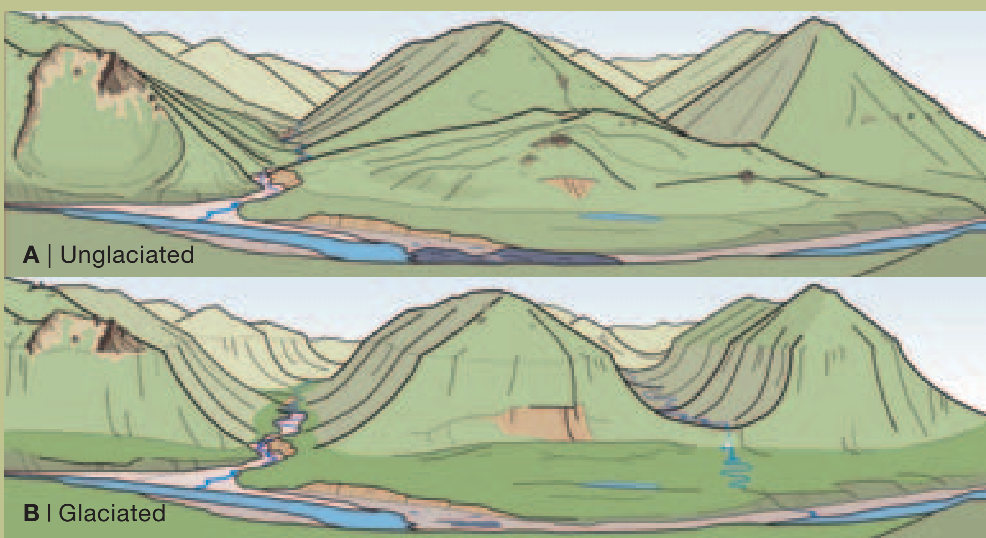
Instead, the local mountain landscape is dominated by strongly-developed fluvial and physical weathering features that would have been heavily modified or destroyed by glaciers. Such features include

◀ Three major physiographic regions are present within Ivvavik Park: the British Mountains, Buckland Hills, and Yukon Coastal Plain. Also shown are the four river reaches that are traversed by travelers of the Firth River. (Map: Parks Canada)

Ivvavik National Park boundary

Physiographic boundary

▼ Schematic view of the Firth River valley looking north across the area of Sluice Box Campsite showing **A)** the contemporary modern, unglaciated mountain landscape, and **B)** how the view might look if the area had experienced a glaciation where valley glaciers filled much of the valleys. Obvious features that are specific to the glaciated landscape include U-shaped valleys, a “hanging” valley and waterfalls, the truncation of the mountain ridges where they meet the main valley, and the lack of tors along the mid and lower valley-side slopes. (Diagrams: Jan Aylsworth, NRCan)



tors, bedrock terraces, and pediment surfaces along the valley sides (see *Tors—rock pinnacles in the mountains* and *Steps along the valley* sections). These mountains also include V-shaped valleys and deep weathering profiles, the result of uninterrupted stream incision and mass-wasting of the valley side slopes, which act together to maintain the straight-sided, tapering form. Such topography is common within the Firth River watershed, occurring at scales ranging from alpine creeks to major

Continued on page 11

▲ The British Mountains, along the Canyon Reach of the Firth River. (Photograph: Greg Brooks, NRCan)

The Buckland Hills represent the foothills of the British Mountains, lying between the northwestern edge of those mountains and the Yukon Coastal Plain. Their orientation is similar to that of the British Mountains, while their slopes are less steep and their tops are generally rounded, seldom reaching higher than 750 m. These hills also include a major landmark along the Firth River, called Engigstciak, the 'new or young mountain', a traditional vantage point where indigenous hunters scan for caribou or other large animals (see *Engigstciak—the 'New Mountain'* section).

▶ Tundra vegetation on the Yukon Coastal Plain, near Engigstciak, Delta Reach. (Photograph: Greg Brooks, NRCan)

The Yukon Coastal Plain lies adjacent to the Beaufort Sea and forms a buffer between the coast and the mountains-foothills. Devoid of trees but populated with numerous wetlands, this flat to rolling landscape generally slopes from the mountains and foothills towards the sea, with dips and rises that are generally less than 30 m. The area is underlain by permafrost and the ground is characterized by 'patterned ground', reflecting the occurrence of ice-wedge polygons in the immediate subsurface (see *Permafrost—cold, cold ground* and *Freezing and thawing in a cold landscape* sections).

Many of the watercourses draining the mountains or foothills are incised into the plain, and larger rivers like the Firth have formed broad fans that splay northwards (see *Delta Reach—the river meets the sea* section). At the mouth of the Firth River and eastward, the coastal plain was overridden by glacial ice during the Wisconsin glaciation between 10,000 to 30,000 years ago (see *A mostly unglaciated landscape* section). Coastal landforms are present along the edge of the Beaufort Sea, including the long, narrow Nunaluk Spit and a chain of barrier islands off the mouth of the Firth River.

Ecosystems

Three major vegetation types occur along the Firth River valley: taiga, Arctic tundra, and alpine tundra. The plant communities within these ecosystems all have one thing in common: they are able to flourish in the short summer growing seasons and tolerate the long, harsh winters that characterize the area's Arctic climate.

Taiga consists of open stands of stunted spruce and balsam poplar marking the transition between boreal forest and tundra ecosystem—the northern limits of the treeline. In Ivvavik, white spruce and balsam poplar trees grow to within 30 km of the Beaufort Sea coast, representing some of the northernmost woodlands found in Canada. Sparse stands of white spruce often grow on the slopes of the mountains along the Firth River valley, especially on sites that are well-sheltered or face south to receive more warmth from the sun.

Arctic tundra vegetation is made up largely of dwarf woody shrubs (including willow, birch, and alder), heath plants (including

▼ Three scales of V-shaped valley development within the Firth River valley:

Several small alpine valleys studded with tors, near Loyd Creek along the Aufeis Reach. (Photographs: Greg Brooks, NRCan)

Along the river within the Mountain Reach, just upstream of Upper Sluice Campsite. (Photographs: Greg Brooks, NRCan)

A creek valley within Ivvavik Park. (Photograph: Paul Dixon, Parks Canada)

▲ Thin stands of stunted spruce trees amongst tundra vegetation, in the area of Canyon Creek, Canyon Reach. (Photograph: Greg Brooks, NRCan)

Labrador tea), and a class of flowering plants known as forbs (including the purple-flowered alpine sweetvetch). Lower and flatter vegetation occurs in the alpine tundra of higher elevations, which harbours rock lichens, mountain avens, and heather. Towards the moister coastal plain portion of the Firth River valley, sedge-moss vegetation like tussock dominates.

A large portion of eastern Siberia, northern Alaska, and the Yukon Territory—including most of Ivvavik—was never covered by ice during the glacial episodes of the last two million years. When climate change caused sea levels to drop significantly, this landscape, known as Beringia, extended continuously across the area now submerged beneath the Bering Strait. At a time when most of the continent was covered by glaciers that could be more than a kilometre in thickness, Beringia became a refuge for many plants and animals. Consequently, the diversity of plant species in Ivvavik (and the Yukon Territory as a whole) is high relative to glaciated areas of the western Arctic, despite the harsh growing conditions of the region. Examples of Beringian plant species in the Firth River valley include bear flower, boreal wormwood, Scamman's springbeauty, northern larkspur, pink dandelion, and Siberian trisetum.

The Beringia refuge also supported unique communities of large mammals that are

Continued on page 13

◀ Well-developed, rounded and smoothed mountains and hills within Aspen Creek valley, a tributary of Joe Creek. This morphology reflects the presence of deeply weathered and disintegrated bedrock that has crept downslope over time. (Photograph: Greg Brooks, NRCan)

Continued from page 7

tributary valleys and a section of the Mountain Reach immediately upstream of the Upper Sluice Campsite.

Many of the hills, mountain-tops, and side-slopes in the Firth River watershed are made up of deeply weathered and disintegrated rock. There is a general roundness and smoothness to the landscape, as freezing and thawing processes have slowly transported this loose material down various slopes (see *Freezing and thawing in a cold landscape* section). The look of these landforms will vary from one place to the next; the degree of rounding depends on the type of rock that is present, since different types weather in different ways. A greater degree of rounding indicates a long, uninterrupted span of physical weathering. Had glaciation occurred, it would have eroded the slopes, causing widespread exposure of unweathered bedrock. If this happened, the weathering process would have started over, and erosional landforms formed by glaciers that are found in almost every other part of the country would also be present here.

Nevertheless, a small portion of the Firth River valley was glaciated. Located at the river mouth, this area was overridden by a portion of the Laurentide ice sheet that originated from the Mackenzie Valley and advanced along the Yukon Coastal Plain following the outer edge of the Buckland Hills. The glacial ice truncated the course of the Firth River and stopped just to the west of the river, before reaching the lower Malcolm River. Locally, this ice advance is termed the Buckland Glaciation and it occurred between 30,000 and 10,000 years ago during the late Wisconsin Glacial Stage.

This area includes a rolling hill terrain known as moraine, composed of sediment deposited directly by the glacier. Cutting through the hilly terrain are large spillway valleys that once carried large volumes of glacial meltwater. The bedrock hill known as Engigstciak is surrounded by moraine, with spillway valleys visible towards the southeast along the front of the Buckland Hills.

Another glacial feature can be seen from the river mouth is Herschel Island, which forms the low hills located about 10 km to the east of the airstrip at Nunaluk Spit. This island is composed of deposits that were pushed by glacial ice overriding and displacing sediments originally located to the southeast of the island. In addition, amongst the gravel on the surface of Nunaluk Spit are pebble- and cobble-sized granitic and gneissic rocks that do not occur locally, having originated in the Canadian Shield far to the east of the McKenzie Valley. Such displaced stones were transported directly to this site by flowing glacial ice.

▲ Herschel Island, visible along the skyline in the background, is a glacial depositional landform formed during the Buckland Glaciation by glacial ice pushing sediment into an elevated feature. (Photograph: Greg Brooks, NRCan)

◀ Meltwater channel eroded into bedrock on the Yukon Coastal Plain. This channel once carried large quantities of meltwater along the margin of a tongue of the Laurentide ice sheet. The ice sheet occupied the area on the far-side of the channel. (Photograph: Larry Lane, NRCan)

▼ The Firth River within the Mountain Reach, looking downstream across the area of the Upper Sluice Campsite. Several sets of bedrock terraces are visible in the foreground, reflecting a short portion of the very long, continuous history of fluvial activity in the valley. (Photograph: Greg Brooks, NRCan)

Canada's oldest river?

Since the Firth Valley was never glaciated, the Firth River has been called the oldest river in Canada. Its mountain stream network has never been obstructed, displaced or eroded by ice, unlike the vast majority of other waterways in the country. The ancestral Firth River therefore has flowed continuously in the landscape since the Tertiary Period when the local mountains and valleys began to develop, etching a long history of fluvial development that can be seen in its broad floodplain, alluvial terraces, bedrock canyons, V-shaped valleys, and bedrock terraces. Whether the Firth River is exclusively the oldest river in Canada is perhaps moot, but certainly the river system and the fluvial landscape are very old indeed.

☙

Continued from page 10

now extinct, including woolly mammoths, saber-toothed cats, wild horses, camels, long-horned bison, and giant beavers. The ecosystems in Ivvavik still support a number of large mammal species. The Porcupine caribou herd, numbering between 90,000 and 150,000 animals, migrates each spring from north-central Yukon to their calving grounds within Ivvavik and along the coastal plain in Alaska. Towards mid-July, large caribou herds start moving southeast back through the Park before finally leaving the area by September for the fall migration to their wintering areas. Networks of

trails are present on the mountain slopes that are used by migrating caribou, following the same routes year after year.

Other large mammals in Ivvavik are Dall's sheep in the mountains, muskoxen on the coastal plain and foothills, and grizzly bears, moose, wolves, and foxes throughout the park. Arctic ground squirrels are common small mammals in the area, especially at camping areas. The Yukon Coastal Plain also boasts polar bears and a dense summer population of bird species, some of which only nest in this region.

The Firth River supports two species of game fish: Arctic grayling and Dolly Varden char. Grayling, the smaller of the two species, is easily recognized by its large, purplish-blue, sail-like dorsal fin. Dolly Varden char have olive green or muddy grey shading on their back, a white belly, and pale yellow or pinkish-yellow spots scattered on their body. The char population normally migrates each summer to the Beaufort Sea to feed, then returns to spawn in the Firth, spending the winter in deep pools and spring-fed areas along the Aufeis Reach.

◀ Arctic ground squirrel (Photograph: Jean-François Bisaillon, Parks Canada)

▲ Caribou trails crossing the slope of a mountain ridge in the Firth River valley. (Photograph: Greg Brooks, NRCan)

GEOLOGICAL EVOLUTION OF IVVAVIK

The landscape of Ivvavik Park is the product of hundreds of millions of years of continuous and occasionally catastrophic geological processes. Although weathering, erosion, and deposition played a significant part in this process, more fundamental changes were caused by the movement of continent-sized tectonic plates that make up the Earth's crust. As these plates moved across the globe, they created massive, slow-motion collisions and break-ups. The resulting uplift, deformation, and subsidence affected topography, morphology, sea level, and ecology. This plate movement resulted in crust that now forms the northern Yukon region to move gradually but steadily from equatorial areas to its present northerly latitude.

An early history of marine sedimentation

The earliest geological history of Ivvavik begins about 700 million years ago during the Proterozoic Eon of geologic time (see Geological Time Scale diagram on page 15), when a continental landmass (possibly what is now Siberia) split away from what would eventually become the North American continent. This movement formed a new ocean and created a continental margin extending from what is now northwestern Yukon to northern Greenland.

The oldest rocks in Ivvavik date back to this time. They are found in layers of limestone, siltstone, slate and hard silica-rich rock called chert, deposited gradually or by catastrophic underwater mudflows from the continental shelf into deeper water. Along the Firth River, these old sedimentary rocks are exposed along the Mountain and Canyon reaches between Wolf Creek and the Red Hills Campsite, near Big Bend (see unit PtPz-l on the geologic map (p.16)).

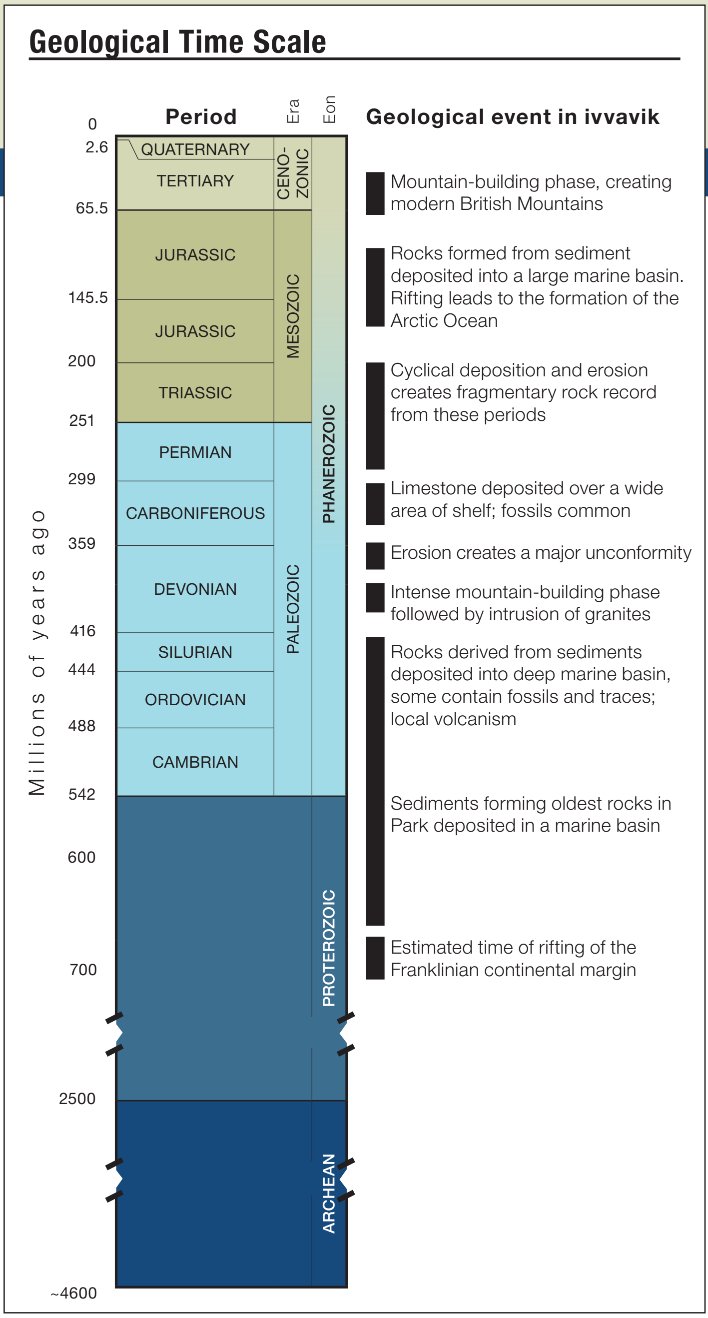
These rocks were later covered by successive deposits of sand and silt, which later formed sandstone and siltstone. The latter rocks are known as the Neruokpuk Formation, which is widely distributed in Ivvavik. This process took place over millions of years, from the end of the Proterozoic Eon to the beginning of the Cambrian Period. The weathered surfaces of these rocks are

Freezing and thawing in a cold landscape

Freezing and thawing cycles of the ground are fundamental aspects of Arctic, sub-Arctic and alpine regions, where the mean annual air temperature is less than 3°C. In Ivvavik, where permafrost is nearly continuous across the landscape, these processes

typically a rusty brown colour. They are hard and resistant to erosion, yielding a rugged landscape wherever they are exposed. Along the Firth River, the Neruokpuk Formation defines the mountain range through which much of the Mountain Reach flows between Joe and Wolf creeks, as well as the Big Bend area of the Canyon Reach (see geologic map unit PtCm-n and *Mountain Reach—the valley sides converge* section).

During the Cambrian, Ordovician and Silurian periods, a succession of predominantly shales and mudrocks formed from fine-grained sediments that accumulated on top of the Neruokpuk Formation sandstones. The Cambrian strata include distinct red and green beds, whereas the Ordovician and Silurian deposits are typically black and contain beds of chert. Some beds from these periods contain fossil tracks, trails or burrows that record the presence of soft-bodied organisms which once lived in the sediments as they were accumulating. Along the Firth River, rocks from these periods are now exposed below the Big Bend from the area of Camping Creek to Engigstciak (see geologic map unit CmDv-r and the *Canyon Reach—confined and colourful* and *Engigstciak—the 'New Mountain'* sections). This particular



◄ Summary of the geological time scale and the major events forming the geological landscape of Ivvavik Park.

characterize what is called the active layer of the ground, which thaws on an annual basis (see *Permafrost—cold, cold ground* section).

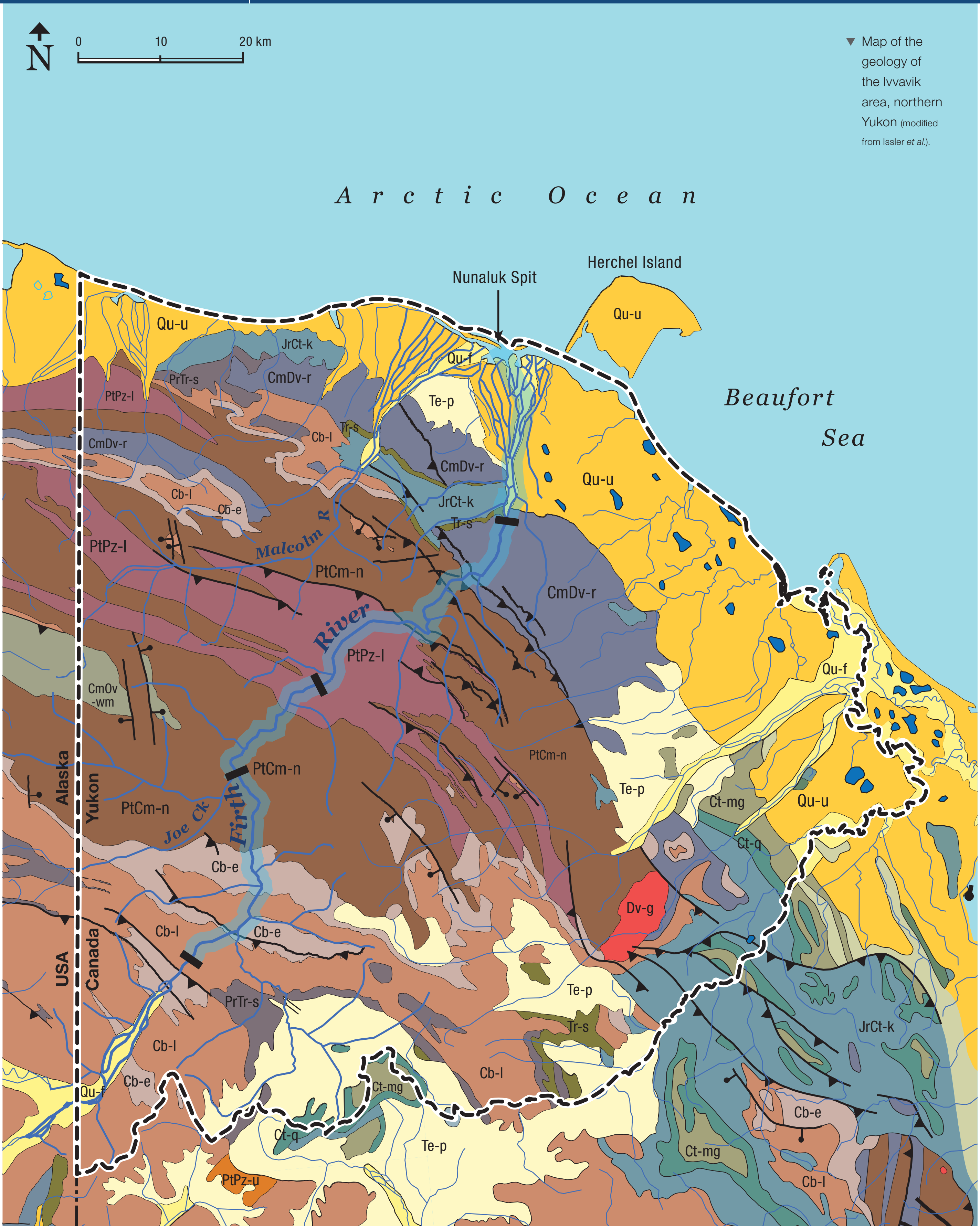
The result can been seen throughout the British Mountains, where fields of angular, jagged rocks are ubiquitous. These 'block fields' are created when water enters the pores and cracks of rocks, only to freeze and expand. Over time, this expansion will cause the rock to split or shatter, depending on rock porosity, the amount of moisture, and the frequency of freezing and thawing.

In the Firth River valley, block fields occur at the base of large rock faces, along mountain ridges, and on valley sides surrounding tors (see *Tors—rock pinnacles in the mountains* section). Block fields at the base of cliffs commonly form relatively steep slopes with angles of 40° to 45°, made up of debris known as scree or talus, which has fallen from the overlying cliff face. Block fields situated on more gentle slopes have formed more or less in place from the frost shattering of underlying rock. These latter block fields are also called felsenmeer, meaning "sea of rock" in German.

Cycles of freezing and thawing within the active layer can produce distinctive types of

Continued on page 18

◄ A steeply-sloped block field of frost-shattered rock, Joe Creek Valley. (Photograph: Greg Brooks, NRCan)



▼ Map of the geology of the Ivvavik area, northern Yukon (modified from Issler *et al.*).

succession of rocks is typical of deposits that have accumulated in deep ocean basins.

Between the headwaters of Joe Creek and Sheep Creek, a localized unit of dark reddish volcanic rock and related sedimentary rock is exposed that contains Cambrian fossils (see geologic map unit CmOv-wm). This is the eastern end of a more extensive exposure preserved in Alaska. Small boulders and pebbles eroded from these volcanic rocks can be found along the Firth River, especially downstream from Sheep Creek.

▲ The hill known as Engigstciak is an erosional remnant of Ordovician bedrock (part of geologic map unit CmDv-r) which was thrust-faulted and tilted when ancient mountains formed during the Devonian Period. Now a protected archaeological site, it served as a quarry for tool materials and a lookout for Inuvialuit hunters searching for game along the coastal plain. (Photograph: Greg Brooks, NRCan)

LEGEND—Geologic map units

Quaternary Period

Qu-u	Glacial, lacustrine, marine or estuarine deposits
Qu-f	Fluvial silt, sand and gravel

Tertiary Period

Te-p	Colluvium and/or organic deposits overlying pediment surface(s)

Cretaceous Period

Ct-mg	Marine shale, siltstone and sandstone
Ct-q	Sandstone and shale

Jurassic and Cretaceous periods

JrCt-k	Marine shale, siltstone and sandstone

Triassic Period

Tr-s	Marine limestone and sandstone

Permian and Triassic periods

PrTr-s	Marine sandstone, shale and limestone

Carboniferous Period

Cb-l	Marine limestone
Cb-e	Marine and non-marine conglomerate, sandstone, shale, coal and limestone

Devonian Period

Dv-g	Granite

Cambrian and Devonian periods

CmDv-r	Marine shale, chert and limestone

Cambrian and Ordovician periods

CmOv-wm	Volcanic rocks, limestone and argillite

Proterozoic Eon and Paleozoic Era

PtPz-l	Limestone, argillite and siltstone
PtPz-u	Quartzite, argillite, sandstone and siltstone

Proterozoic Eon and Cambrian Period

PtCm-n	Argillite, quartzite, chert, limestone and siltstone

Other Symbols

- Stream network, lake
- Route of travellers along the Firth River with divisions between river reaches
- Park boundary
- Major faults (normal, thrust)

▼ Patterned ground on upland ridge composed of irregular, sorted polygons.
(Photograph: Stephen Wolfe, NRCan)

Continued from page 15

patterned ground, including polygons, circles and stripes. Such patterns are described as "sorted" or unsorted", depending on the material they contain. For example, a sorted circle consists of fine sediment surrounded by larger stones, while an unsorted one is bounded by a circular margin of vegetation. The polygon and circle shapes usually occur on flat or nearly flat surfaces, while on slopes they deform to the point of becoming stripes running up and down the slope. Unsorted polygons are not to be confused with ice-wedge polygons generated by permafrost (see *Permafrost—cold, cold ground* section).

Repeated cycles of freezing and thawing slowly mix and organize the soil to produce these polygons, stripes and circles. Under these conditions, a buried patch of ice known as an "ice lens" can form. When these structures freeze, they cause the ground to heave; conversely, when they melt, the ground above them settles.

Circles from half to three metres in diameter are common in moderately drained sites, such as on uplands and gently inclined surfaces. Circles with a raised centre area are called hummocks, referred to as earth hummocks when they are completely covered in vegetation, and mud hummocks or frost boils when their centre remains unvegetated.

Ivvavik is also affected by another aspect of freezing and

Continued on page 22

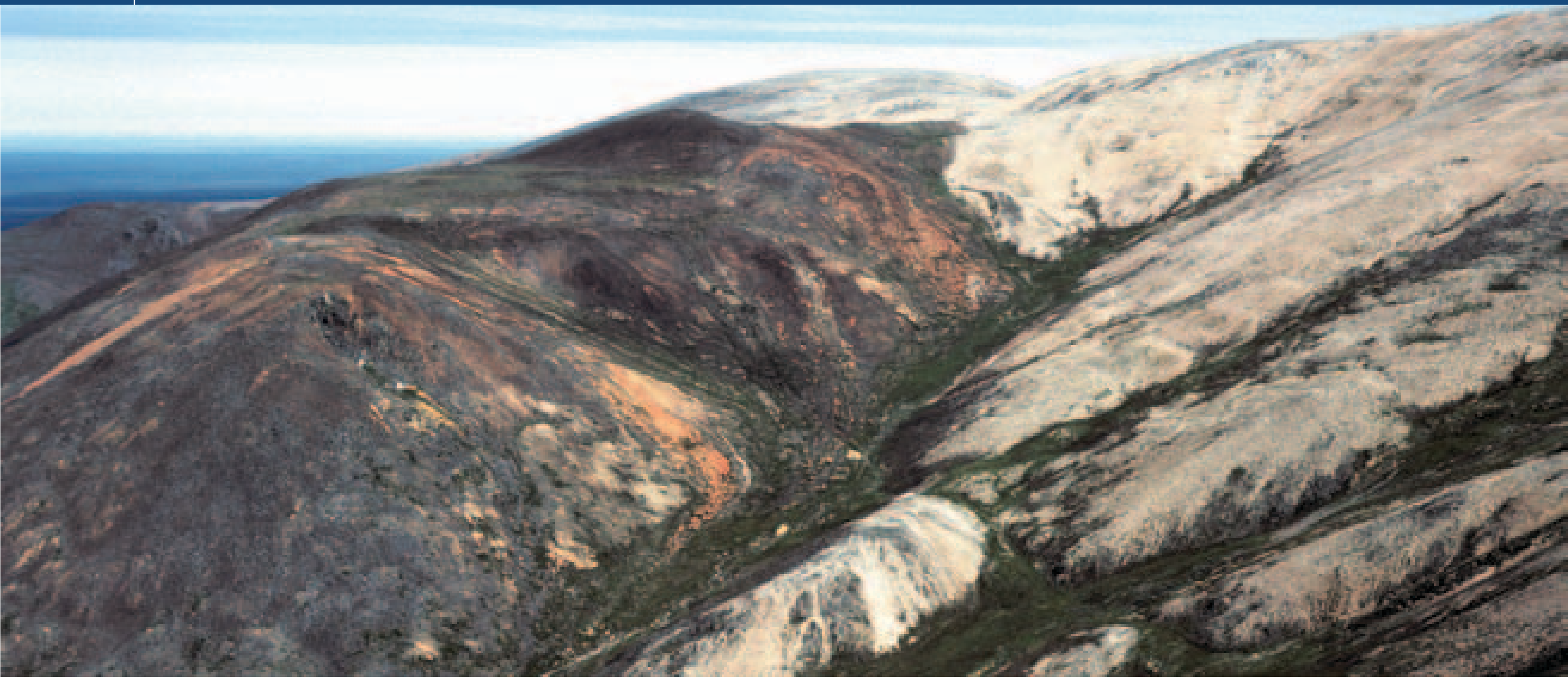
Mountain-building, erosion and a warm ocean

The Devonian Period, some 400 million years ago, was a calamitous part of Earth's geological history. Collisions of tectonic plates around the world led to mountain-building episodes known as orogenies. Over tens of millions of years, the land that became North America would undergo the Acadian Orogeny in the east, the Antler Orogeny in the west, and the Innuitian Orogeny in the north.

Evidence of the Innuitian Orogeny is easy to spot in Ivvavik. Sedimentary rocks that were originally deposited nearly horizontally have been bent and tilted into vertical attitudes and tight folds, and also displaced by faults. These same rocks were further deformed by mountain-building forces over the last 70 million years, from the last part of the Cretaceous through the Tertiary periods. The resulting structures are exposed along many kilometres of the Firth River, from the Mountain and Canyon reaches all the way to Engigstciak (see *Mountain Reach—the valley sides converge* and *Canyon Reach—confined and colourful* sections).

After the Innuitian Orogeny, some parts of the northern Yukon were affected by molten rock moving from deep underground into the upper levels of the Earth's crust. These intrusions are now preserved as several bodies of granite, including the Sedgwick Granite in southeastern Ivvavik (geologic map unit Dv-g).

By the Early Carboniferous Period, about 355 million years ago, these mountains had been worn down to a gently undulating erosional plain cutting across the deformed sedimentary and intrusive rocks. Far to the southwest, tectonic movement established a new ocean margin, lowering this erosional plain below sea level and trapping sediments collected from highlands located to the north. The first deposits consisted of coarse angular gravels from the erosion of local rocks. Later, as the



region continued to subside, deposits of finer-grained sediments eventually formed sandstone and shale (see geologic map unit Cb-e).

These layers of rock alternate between sandstone, shale and coal, indicating that the original local environment shifted between plant-rich, swampy coastal ecosystems with a sandy shoreline (from which the coal and sandstone eventually formed), and an offshore environment where clay and silt were deposited (which eventually formed the shale). As the land subsided, it was permanently inundated by seawater and became a marine environment.

The Carboniferous Period also featured tropical climatic conditions, creating a warm, shallow marine environment suitable for the widespread deposition of limestone. These limestones are readily distinguishable from the other rock types in the area because they form high, rugged, light-grey and yellowish ridges, with many large bluffs and long talus slopes. Carboniferous conditions also supported a diverse population of marine life, including corals, which are widely preserved as fossils in Ivvavik limestone exposures such as those along the Aufeis Reach of the Firth River (geologic map unit Cb-l).

▲ Rocks of the 370 million year-old Sedgwick Granite (light-coloured rocks on the right; part of geologic map unit Dv-g) originated from the intrusion of magma into the upper levels of the crust and were later exposed due to regional uplift and erosion. The hot magma has baked and altered the dark-coloured surrounding rocks, seen on the left of the photograph. Photograph: Larry Lane, NRCan)

◀ Dark-coloured rocks of the Early Carboniferous Period (area left of centre) were deposited onto previously upturned beds of the Neruokpuk Formation (to the right and foreground). The contact between the two formations represents a major gap in time (in this case about 200 million years) that is known as an unconformity. The rocks of the Neruokpuk succession were deformed, uplifted, and eroded during the mountain-building of the Devonian Period. (Photograph: Larry Lane, NRCan)

▲ A high, rugged, mountain face composed of Carboniferous limestone (part of geologic map unit Cb-l), viewed from the Firth River, near the Muskeg Mouth Campsite, Aufeis Reach. (Photograph: Greg Brooks, NRCan)

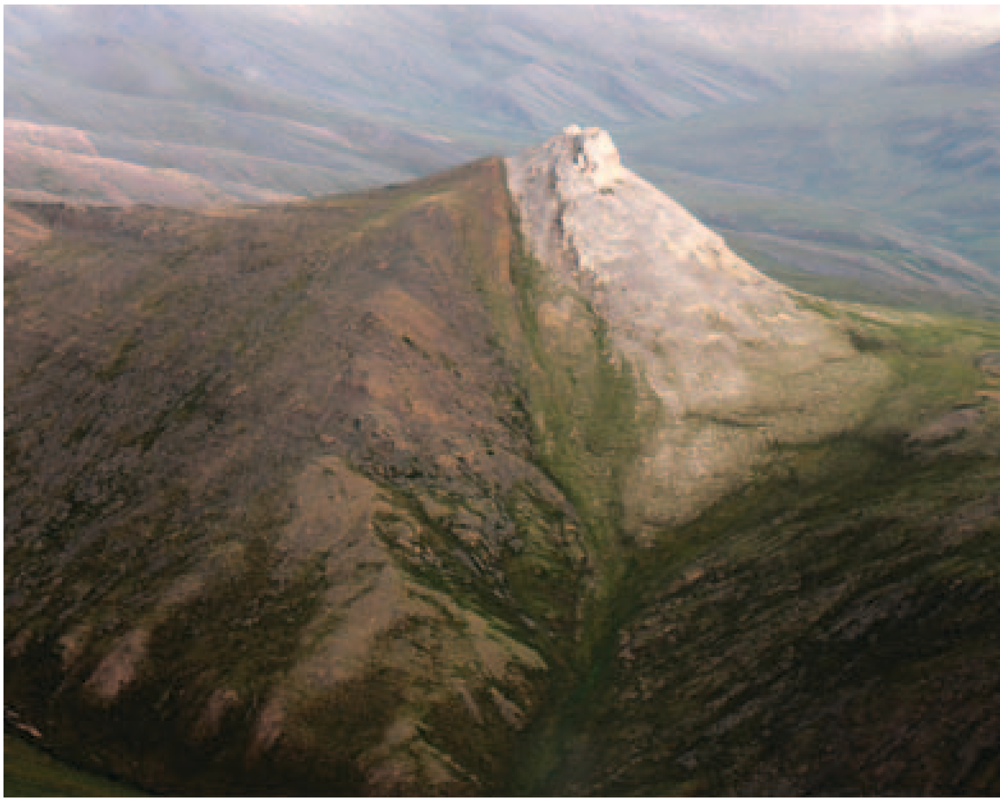
Formation of the Arctic continental margin

For about 100 million years, the landscape was repeatedly submerged under the sea, then exposed again and eroded. This process led to the thin deposits of shale, limestone, and sandstone that formed in the Permian, Triassic, and Early Jurassic periods between 300 and 200 million years ago (geologic map units PrTr-s and Tr-s). From the Early Jurassic to the Early Cretaceous periods, about 200 to 115 million years ago, the landscape experienced major faulting that eventually led to the formation of the western Arctic Ocean. Evidence of these faults is often hidden by later folding and faulting, but good examples can be found at several places along the eastern bank of Malcolm River, where light-coloured Carboniferous limestone is sharply juxtaposed against much older rocks. These formations match others found in sedimentary rocks beneath the Beaufort Sea off the coast of Alaska and beneath the Mackenzie Delta.

The Jurassic and Early Cretaceous periods are also represented by successions of sandstone, siltstone, and shale (geologic map unit JrCt-k). Within the Ivvavik area, shale is the dominant rock type from these periods, while sandstone is more common to the south and east. The transition from a given sandstone formation to a similarly aged shale formation is an indication of increasing distance from shore, since sand accumulates near a coast, and silt, mud and clay typically build up farther offshore. Thus, the sandstone to shale transitions within the local rocks of Jurassic and Early Cretaceous periods indicate that the region was covered by a broad seaway and that the shoreline lay some 200 kilometres to the south and east at that time.

The details of how and when seafloor spreading formed the western Arctic Ocean (and the Beaufort Sea) are poorly understood. However, evidence from across northern Yukon points to major faulting at the end of the Early Cretaceous Period, followed by a long period of slow subsidence across the region. That sequence of events likely began when Earth's crust welled up from the ocean bottom to create mid-oceanic ridges, establishing an ocean basin that persists to this day as the Beaufort Sea.

In the last half of the Cretaceous Period, less than 100 million years ago, the landscape of Ivvavik was submerged beneath a shallow sea. Far off to the south and southwest, silt eroded from the (now) Brooks and Mackenzie mountain ranges was deposited across the floor of this sea. However, the rocks now exposed in the Ivvavik area (including those of geologic map units Ct-mg and Ct-q), were located some 120 km to the southwest of their present location. During this time, the Mackenzie and Rocky mountain ranges to the south were separated from the rest of North America by the Western Interior Seaway that connected Arctic waters to the tropics. The shores of this sea were a favourite habitat for many species of large dinosaurs whose fossil bones and foot prints have been found from Montana to the Alaska North Slope. The presence of dinosaur fossils in northernmost Alaska and the Yukon indicates that the region had a much more temperate climate than exists today.



▲ The near-vertical surface between the dark-coloured Proterozoic rocks and light-coloured Carboniferous limestone in this hill is an extensional fault that cuts through the peak, above the east bank of Malcolm River. (Photograph: Larry Lane, NRCan)

▶ Clusters of fossil corals preserved in limestone from the Carboniferous Period, Muskeg Creek campsite, Aufeis Reach. (Photograph: Larry Lane, NRCan)

▼ TOP: Patterned ground on upland ridges formed by sorted stripes. (Photograph: Stephen Wolfe, NRCan)

▼ BOTTOM: Unsorted patterned ground composed of mud hummocks or frost boils. (Photographs: Stephen Wolfe, NRCan)

Continued from page 18

thawing, known as solifluction, which causes the gradual movement of materials downhill. This movement is another by-product of the ground heaving as it freezes and settles as it thaws. In this case, thawed soil is also saturated with moisture, and flows downhill. Solifluction can cause soil to flow at rates of half to five centimetre per year and in some places pile up in lobes of material that are half a metre in height. The solifluction process is particularly important in areas where deeply-weathered slope materials are present. The downslope movement of deeply weathered materials by solifluction contributes to forming the smooth, rounded profiles of many ridge tops and valley sides along the Firth River valley (see *A mostly glaciated landscape* section).

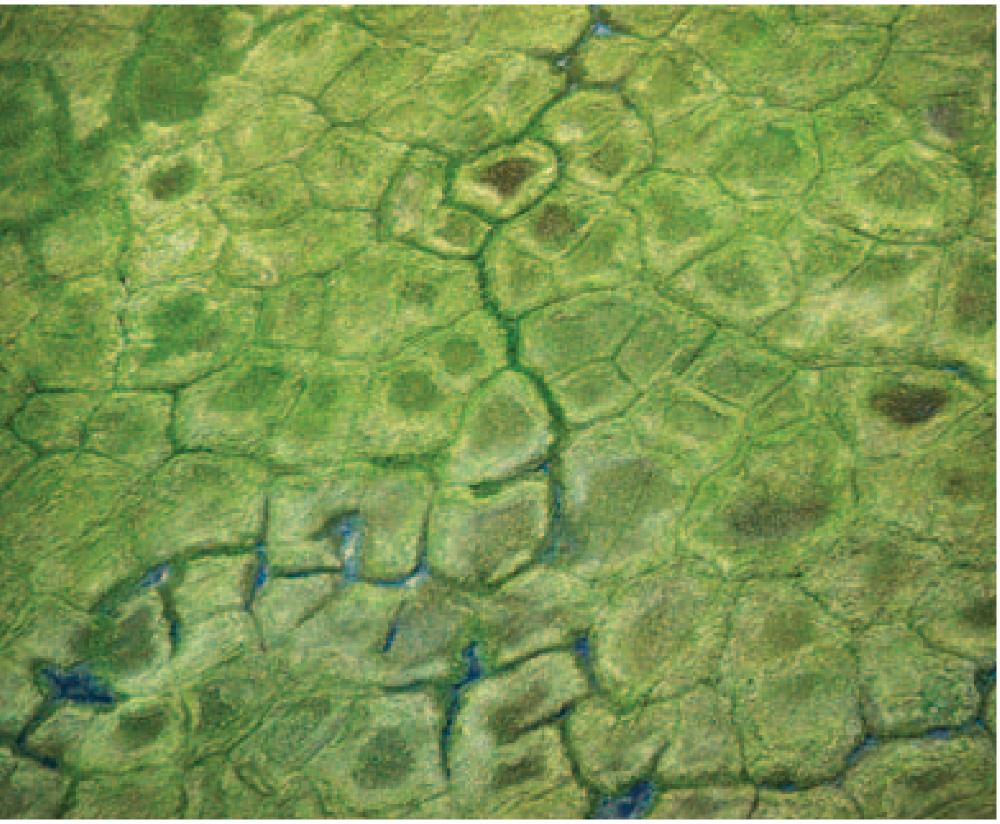
Building the British Mountains

In the Late Cretaceous and early Tertiary periods (about 70 to 45 million years ago), colliding tectonic plates caused a final major period of mountain building that affected all of what would become western North America. North America, pushing westward against Alaska, eventually crumpled the Earth's crust in the Ivvavik region. This caused folding, faulting and uplift across northern Yukon. The rock formations now within Ivvavik were displaced

▲ Example of Tertiary-age folds that developed in the Ivvavik region. The sedimentary rocks shown here were deposited during the Carboniferous and Permian periods. This locality is a short distance west of the Park in the northeastern Brooks Range, Alaska. (Photograph: Larry Lane, NRCan)

northeastwards by some 120 km, uplifting what is now the British Mountains by 5 to 7 km. At the same time, rivers eroded drainage courses to create the valleys seen today. This combination of uplift and erosion allowed major streams like the Firth River to incise valleys that are roughly perpendicular to the orientation of the mountain ridges.

This Late Cretaceous-early Tertiary mountain building was the last major event in the area's geological history, producing a mountain landscape that closely approximates that of the present day northern Yukon. The folding and faulting created by this mountain building is seen in Ivvavik where Carboniferous and younger rocks are exposed (see photograph immediately above). Along the Firth River, these rocks are present along the Aufeis Reach. Evidence of this event is also present in older rocks elsewhere along the river through the Mountain and Canyon reaches, but it can be difficult to distinguish from the deformation in these rocks that was caused from the much older mountain-building phase of the Devonian Period.



▲ Polygon shapes of patterned ground on the Yukon Coastal Plain adjacent to Delta Reach of the Firth River. (Photograph: Greg Brooks, NRCan)

Creating the modern landscape

Since the middle Tertiary Period (about 45 million years ago), minor deformation slowly continued to uplift and displace the northern Yukon region northward at rates of a few millimetres per year. This has produced folds and faults in the young sediments and sedimentary rocks located offshore beneath the Beaufort Sea. At the same time, the Firth and other rivers draining the British Mountains have cut through gently sloping plains that extend outwards toward the coast from the foot of the mountain slopes (see geologic map unit Te-p). These plains developed after the early Tertiary mountain-building event; the existence of these plains is evidence of a long period when there was no significant rise in the land.

Extensive lake and river sediments deposited during the late Tertiary and Quaternary periods (23 million to 100,000 years ago) are preserved in the Old Crow and Bluefish basins just south of Ivvavik National Park. River deposits of Pliocene age (less than 10 million years old) in the Bluefish Basin preserve plant debris, such as pine cones, including species now limited to southern Canada, which would indicate that the region had a climate much warmer than it does today. By a million years ago, however, the climate had become much colder, allowing permafrost to develop and persist to the present day. Evidence of this change can be seen in distinctive ice-wedge polygons that can be several tens of metres across. These are found adjacent to the Firth River on the plain surrounding Engigstciak along the Delta Reach, and elsewhere along the Yukon Coastal Plain (see ***Freezing and thawing in a cold landscape*** section).

The glaciations of the Quaternary Period affected the majority of Canada, but most of Ivvavik escaped being overridden by glacial ice, although glacial ice was present within the headwaters area of Malcolm River valley on several different occasions. Also, during the late Wisconsin Glacial Stage (30,000 to 10,000 years ago), glacial ice advanced westward along the Yukon Coastal Plain across and just to the west of the area of the large fan-delta located at the mouth of the Firth River (see ***A mostly unglaciated landscape*** section). Along the area formerly covered by this ice (within geologic map unit Qu-u), a veneer of glacial sediment (till) covers much of the landscape.

In the wake of this dynamic geological history, the modern landscape of Ivvavik would seem to be static. However, geomorphic processes still impose change, and the evolution of the area continues as it has done over the past 700 million years. Evidence of this can be seen, for example, in the presence of talus at the bases of cliffs or sand and gravel bars along the river.

▶ Valley side tor outcropping from a steeply-sloped field of frost-shatter boulders, near the Red Mountain Campsite. (Photograph: Greg Brooks, NRCan)

Tors—rock pinnacles in the mountains

Tors are outcrops of bedrock that form pinnacles on mountain tops and valley side slopes. They are remnants of a larger rock mass and develop where bedrock has experienced variable rates of weathering in combination with slope retreat over an extended period of time. The variable weathering rates may reflect the presence of a more resistant rock types within a mountain, or differences in rock characteristics, such as jointing or fracturing. In cold-climate regions, tors commonly occur within fields of angular, frost-shattered boulders (see *Freezing and thawing in a cold landscape* section), but they can also be found protruding from a barren bedrock surface. In the Firth Valley, tors are seen on many mountain side slopes along the Aufeis, Mountain and Canyon reaches. At some locations along the Mountain Reach, they are situated low on the valley side near the river. They usually occur within areas of hard

Continued on page 26

▼ Valley side tors along a mountain side near the Crooked Creek Campsite. (Photographs: Greg Brooks, NRCan)

Continued from page 25

bedrock such as limestone, dolomite and sandstone, as opposed to areas with softer rocks like shale. The specific location of tors on valley side slopes is closely linked to the outcrop pattern of the resistant rock layers on a given mountain. This pattern can mean tors occur on some slope aspects but not others, while groups of tors may be aligned up and down or across a given slope.

Valley side tors are important evidence that the mountain landscape of the Firth River valley has never been glaciated (see *A mostly unglaciated landscape* section). Although composed of resistant bedrock, tors are

▼ Tors on a mountain ridge above Loyd Creek Campsite. (Photographs: Greg Brooks, NRCan)

relatively small-scale features that would be eroded easily by a glacial ice flowing down the mountain valleys. Their presence, especially along the lower side slopes, implies that the glaciers have not advanced down the Firth River valleys in the past.

▲ Alluvial channel at Crooked Creek Campsite showing the channel, a gravel bar (with sand), the floodplain, and an alluvial terrace on the opposite side of the river.
(Photograph: Greg Brooks, NRCan)

AUFEIS REACH—an alluvial channel with ice

The Aufeis Reach extends about 35 km from Margaret Lake to the confluence with Joe Creek. This is the initial section of the river traversed by rafters disembarking from the Margaret Lake landing strip. The name aufeis is somewhat of a misnomer, however, because this portion of the river is better described as an alluvial reach along which aufeis forms (see *Aufeis—ice formed from leaky ground* section). An alluvial reach is one where the channel flows on sediments previously deposited by the stream. Such sediments, called alluvium or alluvial deposits, consist of sand, silt, and pebble- to boulder-sized gravel. The proportion of these sediment sizes vary widely between rivers, depending on the local geomorphic setting. In mountainous areas like the Firth River valley, alluvial deposits contain abundant gravel, and hence such streams are referred to as gravel-bed rivers. When gravel is transported by water, it will develop a relatively smoother surface and rounder shape caused by grinding actions or impacts between particles as they are moved by the flow.

Alluvial deposits are relatively well organized along a gravel-bed river. In general, the larger-sized gravel forms the surface of the channel bed and smaller-sized gravel with sand forms the river bars. The floodplain consists of a relatively flat, vegetated surface adjacent to and up to several metres above the river channel. Underneath is a layer of primarily fine-grained sediments, including sand, silt, and organic materials. These floodplain deposits in turn lie on top of more gravel that originated as channel and bar deposits, which were subsequently incorporated into the floodplain.

Along the Aufeis Reach, the Firth River occupies a wide channel that flows within a broad, relatively flat valley bottom. This surface

Continued on page 31

▼ Aufeis exhibiting its characteristic layering and bluish colouring which is seen on sunny days. (Photograph: Greg Brooks, NRCan)

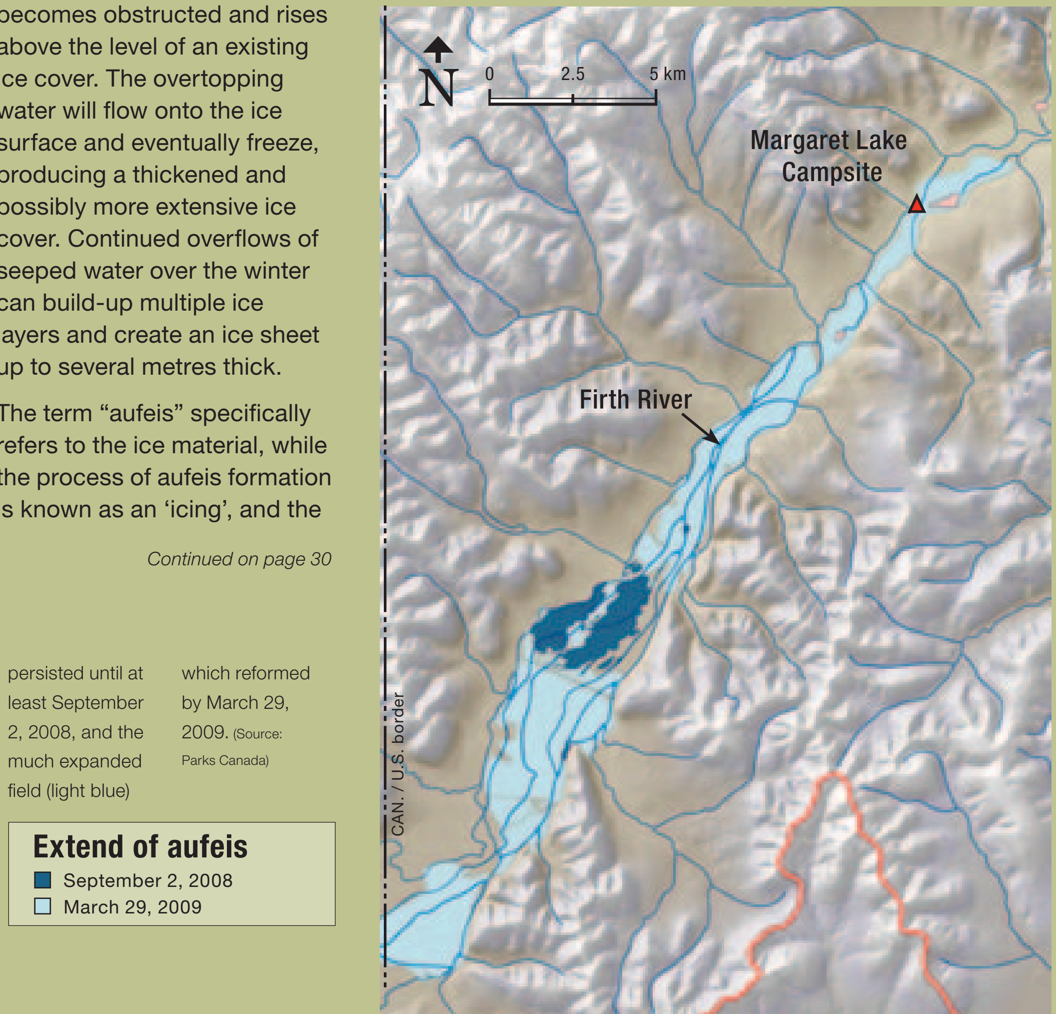
Aufeis—ice formed from leaky ground

Aufeis is ice formed from ground water that freezes as it seeps from springs during the winter months. It can be found along reaches of many Arctic and sub-Arctic river and stream valleys where winter springs are present beneath the stream bed or adjacent to the channel margins. Aufeis generally forms where seeped water becomes obstructed and rises above the level of an existing ice cover. The overtopping water will flow onto the ice surface and eventually freeze, producing a thickened and possibly more extensive ice cover. Continued overflows of seeped water over the winter can build-up multiple ice layers and create an ice sheet up to several metres thick.

The term “aufeis” specifically refers to the ice material, while the process of aufeis formation is known as an ‘icing’, and the

Continued on page 30

▶ Aufeis fields change in size seasonally, forming in the winter and melting through the spring and summer months. This map of the portion of the Firth River between Margaret Lake and the Yukon-Alaska border shows a remnant of aufeis (dark blue) that persisted until at least September 2, 2008, and the much expanded field (light blue) which reformed by March 29, 2009. (Source: Parks Canada)



◀ Residual aufeis along the Firth River channel adjacent to the Margaret Lake West Campsite and airstrip. (Photographs: Greg Brooks, NRCan)

Continued from page 29

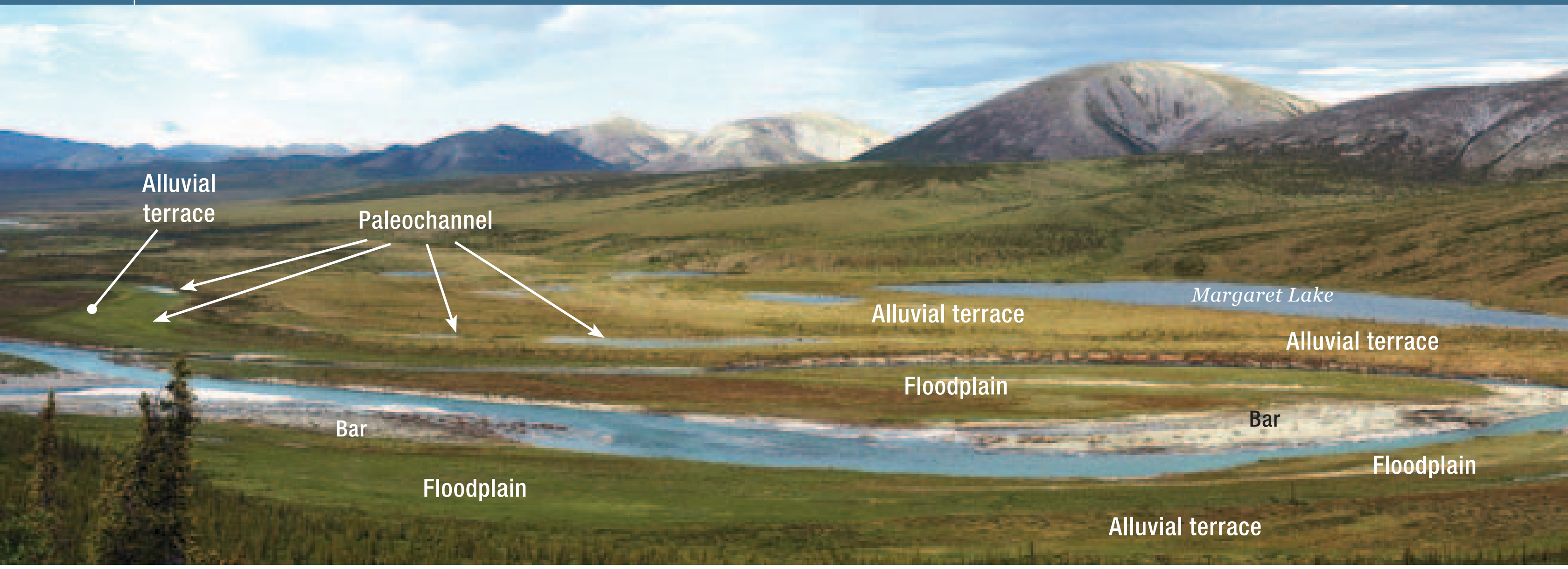
resulting ice sheet landform is known as a naled or aufeis field. Depending on local conditions, aufeis fields can completely cover a valley bottom and, in large fields, extend continuously for many kilometres. Aufeis generally melts in summer, but remnants may persist from year to year. Meltwater derived from aufeis fields contributes to runoff helping to maintain summer stream flow. However, aufeis is not to be confused with the glacial ice that is common to many alpine areas. This ice, formed and maintained by annual snowfalls that eventually compact into ice, is much thicker than aufeis. Glacial ice also forms within distinct accumulation and melt zones, and it flows because of internal deformation of the ice mass.

Aufeis forms along the Malcolm, Babbage and many other rivers and streams in Ivvavik. It develops in many locations along the Firth River, including the Aufeis Reach and along Joe, Wolf, and Loyd creeks, as well as near the river mouth along the Delta Reach (see *Delta Reach—the river meets the sea* section). Springs responsible for aufeis are associated with aquifers in limestone bedrock areas, including those along the Aufeis Reach, but others have different ground water sources. At some aufeis fields, unfrozen pools of spring water form important aquatic habitat where Dolly Varden char can overwinter within a river system that otherwise freezes to the river bed. These pools are locations of traditional winter sources of fish for Inuvialuit within the Ivvavik area.

In the summer months, residual sheets of aufeis can be found near the Margaret Lake landing strip and

Continued on page 34

▲ Aufeis field extending along the stream course of Loyd Creek and splaying into the Firth River channel, view from ridge above Loyd Creek Campsite. (Photographs: Greg Brooks, NRCan)



▲ Alluvial features along the Aufeis Reach in the Margaret Lake area. The Margaret Lake airstrip is located in the right foreground on the near-side of the river channel. (Photograph: Greg Brooks, NRCan)

Continued from page 28

typically is interrupted by alluvial terraces, one or more steps above the general floodplain. Each terrace is a remnant of an older, higher floodplain surface. In this way, the floodplain and the terrace surfaces represent a combination of two basic fluvial processes: lateral migration of the river channel, which has gradually built and widened the floodplain; and incision, which has gradually lowered the river into the valley bottom.

The Margaret Lake campsite and landing strip are both situated on the river floodplain. Alluvial terraces are present on both sides of the valley bottom and form distinct steps up to 10 m above the floodplain. A moderate hike up one of the ridges behind the airstrip provides a panoramic view of the valley bottom showing the river channel, bars, floodplain and alluvial terraces, as seen in the photograph above and the photograph of the view overlooking Loyd

◀ Exposure of an alluvial terrace near Crooked Creek Campsite, revealing a layer of floodplain sand, silt and organic materials overlying a core of gravel. The gravel, in turn, rests upon a buried bedrock surface that has been truncated by the lateral migration of the river channel. (Photograph: Greg Brooks, NRCan)

Creek (above). On both the floodplain and terrace surfaces across from Margaret Lake landing strip, elongated ponds mark the locations of linear depressions known as paleochannels, watercourses which were abandoned by the river long ago.

The alluvial channel extends more or less continuously from the Margaret Lake campsite to the Joe Creek confluence and is an area with numerous examples of unvegetated and partially vegetated gravel bars. The alluvial deposits beneath the floodplain or terrace surfaces are exposed at locations where the river is eroding into the bank, usually revealing a layer of sand, silt and organic matter overlying gravel. In the area of Crooked Creek and downstream, there are bank exposures where the alluvial deposits can be seen overlying bedrock that has been planed down by the river. In places, this bedrock surface has been eroded further and can be seen under the water extending across the channel bottom.

▲ Panoramic view of the wide alluvial channel along the Aufeis Reach, viewed from ridge above the Loyd Creek campsite. (Photograph: Greg Brooks, NRCan)

▼ The large aufeis field located upstream of Margaret Lake, viewed from ridge behind airstrip. (Photograph: Greg Brooks, NRCan)

Continued from page 30

along the Aufeis Reach to at least the Crooked Creek Campsite. Aufeis at the mouth of Loyd Creek, across from Loyd Creek Campsite, is the downstream end of a 2–3 km long aufeis field that splays into the Firth River channel. A very large aufeis field is present in the Firth Valley 6–7 km upstream of Margaret Lake, where the ice develops completely across the valley bottom and can be as much as 14–15 km long and 3 km wide. This field can be seen from the window of the airplane while flying into Margaret Lake or from the ridge behind the landing strip. Along the Delta Reach, some of the braided channels of the river flow through a similarly large aufeis field. Here, river travellers may find themselves amongst large aufeis sheets that extend for hundreds of metres from the river channel and may represent the only available "dry" ground, depending on the channel route followed and the timing of the trip.

On a sunny day, the internal layers of aufeis can be seen at the edge of an ice sheet, where variations in ice density exhibit striking bluish colours. These layers reflect the accumulation of aufeis by successive icings. Gritty sand-like grains of whitish calcium carbonate, precipitated out of solution when the spring water initially froze, can also be present within aufeis. These grains can be concentrated by meltwater into elongated mounds that can be 2 metres long, 1.5 metres wide, and 60 centimetres high. Aufeis can even display a yellowish staining on its surface, caused by the concentration of tree pollen.

▼ Navigating a channel within the large aufeis field along the Delta Reach. (Photograph: Greg Brooks, NRCan)

▶ Upper section of the Mountain Reach where slopes along the lower valley sides are inclined steeply towards the river forming a narrow, well-defined 'V' shaped valley profile. Note, the narrow channel and the lack of a floodplain surface within the valley bottom. (Photograph: Greg Brooks, NRCan)

MOUNTAIN REACH—the valley sides converge

The Mountain Reach is 22 km long and extends from the confluence of Joe Creek to Lamb Rapids at the head of the Canyon Reach. It forms the second reach of the river traversed by rafters, flowing through a rugged and high portion of the British Mountains. Here the river is narrower than the Aufeis Reach, being predominantly single-channeled and closely confined by the valley sides. This confinement is especially pronounced between Eagle Nest and Sluice Box campsites, where the lower portion of the steeply sloped valley sides form a well-defined V-shaped profile. Below Sluice Box Campsite, the valley opens substantially, particularly along the east side of the valley, but the channel remains narrow and confined by a margin composed of coarse boulders or bedrock. In these tight quarters, an alluvial floodplain is absent and larger river bars occur only sporadically.

Relative to the Aufeis Reach, the river through the Mountain Reach is noticeably

▼ An example of a discontinuous pediment surface along the Firth River, located just downstream of Trapper's Campsite along the Canyon Reach. A bedrock terrace is situated much lower in the valley, several tens of metres above the level of the river. The Firth River flows from left to right. (Photograph: Greg Brooks, NRCan)

Steps along the valley

The formation of a mountain range is the product of two fundamental geologic processes: uplift, which physically raises the landmass and is driven by the forces of plate tectonics; and incision, which carves the valleys and mountain sides. Incision occurs primarily through water action, aided by cold-climate weathering, landsliding, wind erosion, and chemical processes. In this way, bedrock breaks down into sediment and becomes redistributed locally or transported to low-lying areas. Incision is intrinsically linked to uplift, driving erosion that in turn triggers more uplift as the crust is unloaded and becomes lighter. And while both processes occur slowly—at rates in the order of centimetres per century—together they raise and carve whole mountain ranges over the course of millions or tens of millions of years.

Major cycles of uplift and incision as well as intervening periods of stability, are revealed in mountain valleys by the presence of pediment surfaces and bedrock terraces. These are flat to gently-sloped surfaces cut into bedrock. They can take the form of a raised level along the valley bottom, or they may create steps along the valley sides. Bedrock terraces are situated relatively close to the valley bottom (within 30–50 m; see

▼ A 'paired' bedrock terrace along the Firth River canyon immediately above Layover Campsite (on lower left, opposite side of the river). The terrace is about 20 m above the river and is covered with a veneer of alluvial gravel up to several metres thick. (Photograph: Greg Brooks, NRCan)

Canyon Reach—confined and colourful section). Pediment surfaces are similar, but these are found at higher positions above the valley bottom; they are also substantially older than terraces.

Each level of terrace or pediment is the remnant of a former valley bottom; it represents a period of stability, when the valley was widened by a combination of lateral stream erosion and retreating slopes. Later there was an uplifting, which caused streams to cut further into the land, and so deepen the valley. In this way, repeated cycles of stability and incision add terraces and pediment surfaces to the profile of a valley. A given level of step often can be followed continuously or discontinuously along a valley

Continued on page 40

steeper in gradient and flows more swiftly. Rafters can expect to be splashed by rapids of varying sizes, which occur where the channel crosses beds of rock that are relatively resistant to fluvial erosion and hence form minor steps in the river profile.

Bedrock geology determines the morphology of this part of the Firth Valley. The narrow, steeply-sloped section of the reach from Joe Creek confluence to Sluice Box campsite coincides with the occurrence of sandstone and siltstone of the Neruokpuk Formation that formed during the late Proterozoic Eon and Cambrian Period (see *Geological evolution of Ivvavik* section). These sedimentary rocks are rich in grains of quartz, a hard mineral that resists weathering and erosion processes. Consequently the mountains composed of these rocks are the highest and most rugged seen along the Firth River.

◀ Raft having just descended through a minor rapids along the Mountain Reach below Sluice Box Rapids. This set of rapids is located where a formation of resistant bedrock crosses the river channel and forms a minor step in the river profile. (Photograph: Paul Dixon, Parks Canada)

Downstream from the Sluice Box Rapids the valley broadens with the transition from the Neruokpuk Formation to older limestone and slate rocks that are more prone to weathering, creating lower and less rugged mountains.

▲ View of the lower section of the Mountain Reach looking upstream toward Wolf Tors Campsite. The valley bottom is much more open than the upper section of the reach (see photograph on page 36), reflecting a change in the susceptibility of the bedrock forming the landscape to weathering and erosion. (Photograph: Greg Brooks, NRCan)

Continued from page 38

and even into the foothills area beyond the mountain range.

A suite of bedrock steps along a valley side may represent uplift and incision cycles occurring over hundreds of thousands or even millions of years. As such, these features are themselves subject to weathering and erosion that may heavily modify their original morphology. For example, valley widening and retreat of the lower slope may narrow step surfaces, while material from higher elevations may be deposited on step surfaces to modify their topography. Older surfaces thereby become more subdued, and their origins more obscure.

Travellers in the Firth River valley can see at least one level of bedrock terrace or pediment surface most of the way from Margaret Lake to the end of Canyon Reach. Multiple levels are preserved more locally, best seen from elevated lookout points in the wider portions of the Firth Valley. One excellent vantage point is along the Eagle Nest

Hike, looking across the Firth River into Joe Creek Valley. As shown on the accompanying mosaic above, five possible levels can be seen here, with the highest forming a succession of mountain ridges along one side of Joe Creek Valley. Other examples of pediment surfaces and bedrock terraces along the Firth River include the pair of bedrock terraces forming the top of the canyon through the Canyon Reach (see *Canyon Reach—confined and colourful* section), the surface on which the Caribou Stick Fence is situated, and the surface of Sheep Creek Ridge above the Parks Canada station. While the ages of these various terrace levels are not known, they could span several million years and extend into the Tertiary Period.

ᘓ

▲ Panoramic view of the multiple pediment surfaces and bedrock terraces visible in the area of the Joe Creek-Firth River confluence. Up to five levels (as numbered) are present with the higher surfaces being progressively older. (Photograph: Greg Brooks, NRCan)

▲ Downstream view of the Canyon Reach of the Firth River, below Trapper's Campsite. The sedimentary rocks exposed along this portion of the Canyon Reach formed in the Proterozoic Eon. (Photograph: Greg Brooks, NRCan)

CANYON REACH— confined and colourful

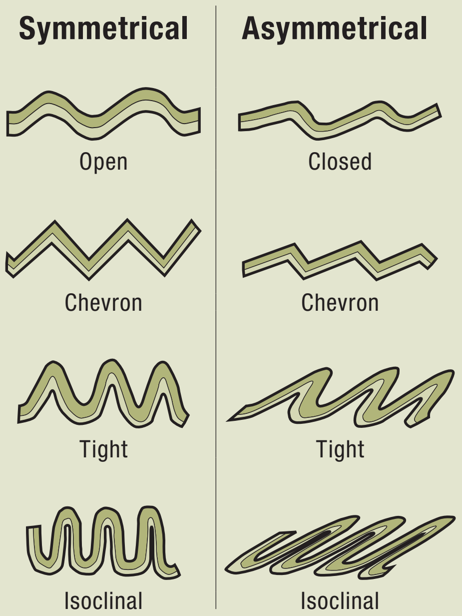
Beginning at the downstream end of the Mountain Reach, the Firth River flows within a narrow canyon from Lamb Rapids to just upstream of Engigstciak, a distance of about 46 km. Here the channel margins and bed consistently reveal the bedrock, which has resisted erosion. Such canyons are typically the narrowest and steepest portion of a river course, where the flow is fastest and alternates between a series of rapids and pools.

Along the Canyon Reach, the steep-sided, rugged canyon walls are up to 50 m high. Their length reveals a continuous exposure of Proterozoic, Cambrian, Ordovician, Silurian, and Devonian sedimentary rock layers (see *Geological evolution of Ivvavik* section).

The sedimentary beds are tilted nearly vertically in this reach and consistently cut obliquely across the river. This creates a succession of strata that change from one rock type to another over distances of metres to tens of metres. The types of rocks along the canyon include rusty to dark brown sandstones, light to dark grey limestones, dolomites, cherts and slates, as well as striking light green and red shales.

The rock strata exposed along the canyon are small segments of large-scale folds that developed during an ancient episode of mountain building in the Devonian Period. This folding also caused smaller scale deformation within individual strata, producing a range of localized structures that can be seen along the canyon walls. Such features can be symmetrical or asymmetrical, with folds falling into various

▼ Examples of relatively simple fold structures all of which can be seen along the sides of the Canyon Reach.



▲ Steeply dipping strata of sedimentary rocks from the Cambrian Period exhibiting a variety of colours, exposed along the left side of the Firth Canyon near the Water Survey Campsites. (Photograph: Greg Brooks, NRCan)

categories outlined on the accompanying diagram above. The effect is plain to see: down the Canyon Reach, for kilometre after kilometre, the type of rock and deformation varies significantly, yielding a spectacular mosaic of shapes in the strata and colours.

In addition to folding, the rock strata along the canyon exhibit other characteristics, depending on their orientation relative to the side of the canyon. At the mouth of Glacier Creek or the mouth of Sheep Creek, for example, evidence of ancient current ripples is preserved on surfaces that dip steeply along the side of the canyon. These structures formed from fine-grained silt or sand, which was transported by currents along what was once the surface of an ancient sea floor. The sediment forming the ripples became buried shortly afterwards, then compacted into rock that was later folded, uplifted, and ultimately eroded to become exposed along the canyon today.

The rock strata along the bottom of the canyon significantly influence the profile of the river. This influence can be determined by the orientation of these strata relative to the river channel, but even more crucial are variations in the erosive resistance of adjacent rock types. The rate of erosion can be affected by a rock's chemical makeup, hardness, thickness, internal structure and the degree of faulting, fracturing and jointing within a stratum. The particular blend of these characteristics will produce the irregularities seen on the river bed.

Rapids form at locations of more resistant rock, for instance, which yield steeper or narrower sections of channel. At some locations within the Firth Canyon, rapids are generated across a ledge or series of

▶ Asymmetrical, open folding within Proterozoic rock, along the left (west) side of the canyon just downstream of Red Hills Campsite. (Photograph: Paul Dixon, Parks Canada)

▶ Ancient current ripples preserved on the surface of Proterozoic sedimentary rock beds exposed along the right (east) side of the canyon at the mouth of Glacier Creek. (Photograph: Paul Dixon, Parks Canada)

▶ Asymmetrical, tight folding (and faulting) within Proterozoic rocks, along the right (east) side of the canyon immediately downstream of Sheep Horn Rapids. (Photograph: Greg Brooks, NRCan)

▶ Aysmmetrical, tight, chevron folding within Proterozoic rock, along the left (west) side of the canyon between Trapper's and Anticline campsites. (Photograph: Larry Lane, NRCan)

▲ Aerial view of, in downstream succession, Lamb, Sheep Slot and Sheep Horn rapids at the upstream end of the Canyon Reach. Each rapids occurs where beds of resistant limestone cut across the channel and cause a local drop in the river profile. Flow accelerates markedly down each drop in response to the increase in gradient. The rapids are separated by pools of slower moving water. (Photograph: Greg Brooks, NRCan)

ledges composed of resistant rocks within the underlying sedimentary strata. In contrast, areas of less resistant rock erode more easily, forming channels with wider sections of lower slope or even depressions known as scour holes. Flow will be relatively slow through such sections, sometimes establishing comparatively tranquil pools.

This fundamental relationship between rapids and resistant bedrock also applies to portions of the Mountain Reach, such as Sluice Box Rapids. Rapids can also form for other reasons, including the presence of large boulders that obstruct flow or alluvial fans that constrict flow at the mouth of tributaries.

River level likewise affects the character of flow. For example, Sheep Slot Rapids, which is situated between the nearby Lamb and Sheep Horn rapids, becomes more passive and can even disappears at high water levels. Other rapids may become markedly faster and more turbulent under similar conditions. At lower levels, on the other hand, some rapids become more challenging to navigate. In this way, the location of a preferred route through a major rapids can change with water levels, hence the need to scout rapids and use good judgement before running them, as recommended by the *Firth River Map & Guide* booklet.

The narrow canyon of the Firth River is the product of incision by flowing water. This process can also result in an upstream extension of the canyon over time. The development of a canyon along a river valley can occur for a number of reasons, including regional uplift of the landscape (see ***Steps along the valley*** section), a substantial decrease in the amount of sediment carried by the river, or the development and retreat of a water falls. Flowing water erodes bedrock in different ways, including the impact of sediment grains carried by current, the collapse of small bubbles generated within fast, turbulent water, and chemical action dissolving the bedrock.

When viewed from the air or from high along a valley-side ridge, it is readily apparent that the Firth River canyon is incised into a relatively broad and flat plain that is up to several kilometres wide. This higher level of the valley bottom is a paired bedrock terrace which represents an older surface that the river flowed upon prior to eroding the canyon (see ***Steps along the valley***

Continued on page 48

▼ The rugged south-facing slope of Engigstciak. (Photograph: Greg Brooks, NRCan)

Engigstciak—the 'new mountain'

Engigstciak, meaning 'new or young mountain' in Inuvialuktun, is a small hill rising from the Yukon Coastal Plain near the head of the Delta Reach. It is part of the Buckland Hills, which form the foothills of the British Mountains. The hill is an erosional remnant of Early Ordovician chert. These beds were folded, thrust-faulted, and tilted during the Devonian mountain-building episode. This was the event that tilted and folded the rock strata along the Canyon Reach (see *Geological evolution of Ivvavik* and *Canyon reach—confined and colourful* sections).

The hill is situated within the portion of the Yukon Coastal Plain that was overridden by ice during the Buckland Glaciation of the late Quaternary Period. Consequently, the plain immediately adjacent to Engigstciak represents a moraine, a landform made from debris left behind by a glacier (see *A mostly unglaciated landscape* section). Patterned ground consisting of ice-wedge polygons can be seen on this plain (see *Permafrost—cold, cold ground* section).

Projecting about 35 m above the surrounding plain, Engigstciak offers a stunning and unobstructed view of the treeless tundra, including views upstream and downstream along the Firth River, across the coastal plain towards Herschel Island to the north-northeast, and towards adjacent foothill and mountain areas to the northwest, southwest and southeast. This hill is an obvious vantage point to scan for caribou or other large animals, particularly since the

Continued on page 50

▶ Angular boulders in the foreground delineate the outline of a shelter used by Thule and Inuvialuit people, perhaps for many centuries and as recently as the 19th century. This specific site is designated by archeologists as Engigstciak Rock Shelter, Site 56Y. (Photograph: Greg Brooks, NRCan)

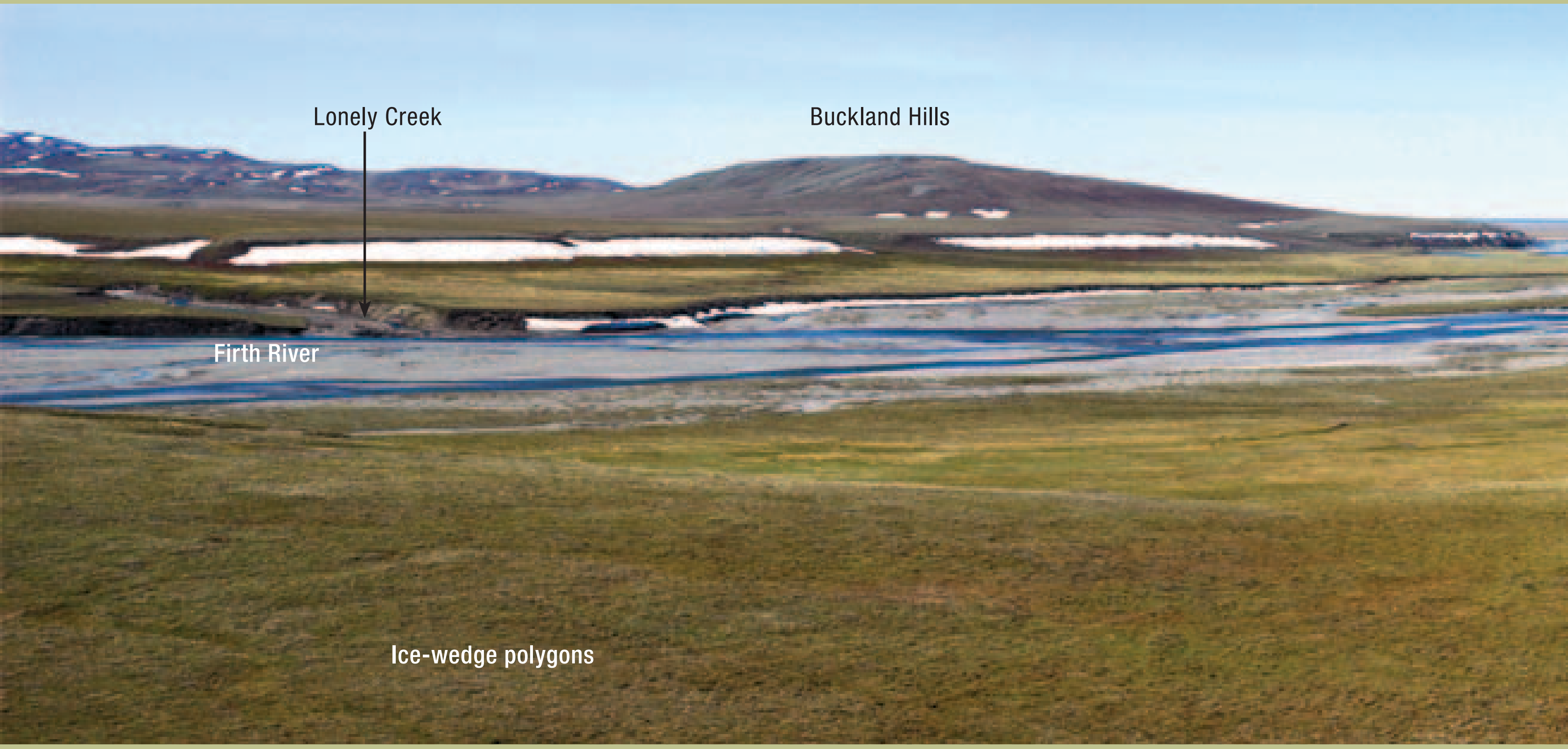
▲ The Firth River Canyon within the broad, relatively flat valley bottom, view from the ridge above the Red Hills Campsite. Paleochannels (as indicated by arrows) and relic bars are present adjacent to the river on the surface of the bedrock terrace. Along the river in the foreground, light-coloured deposits of gravel associated with the paleochannels overlie the darker coloured bedrock exposed along the steeply-sided portions of the canyon walls. (Photograph: Greg Brooks, NRCan)

Continued from page 46

section). Geomorphic evidence of the river flowing on this surface can be seen from the ancient channels that are preserved adjacent to the canyon, which commonly occur as a series of branching channels separated by slightly elevated areas that were mid-channel bars. The occurrence of the sub-divided channels and bars suggests that the ancestral Firth River once exhibited a braided channel pattern prior to incising the canyon. This ancient braided channel morphology is similar to that of the modern river along the Aufeis Reach.

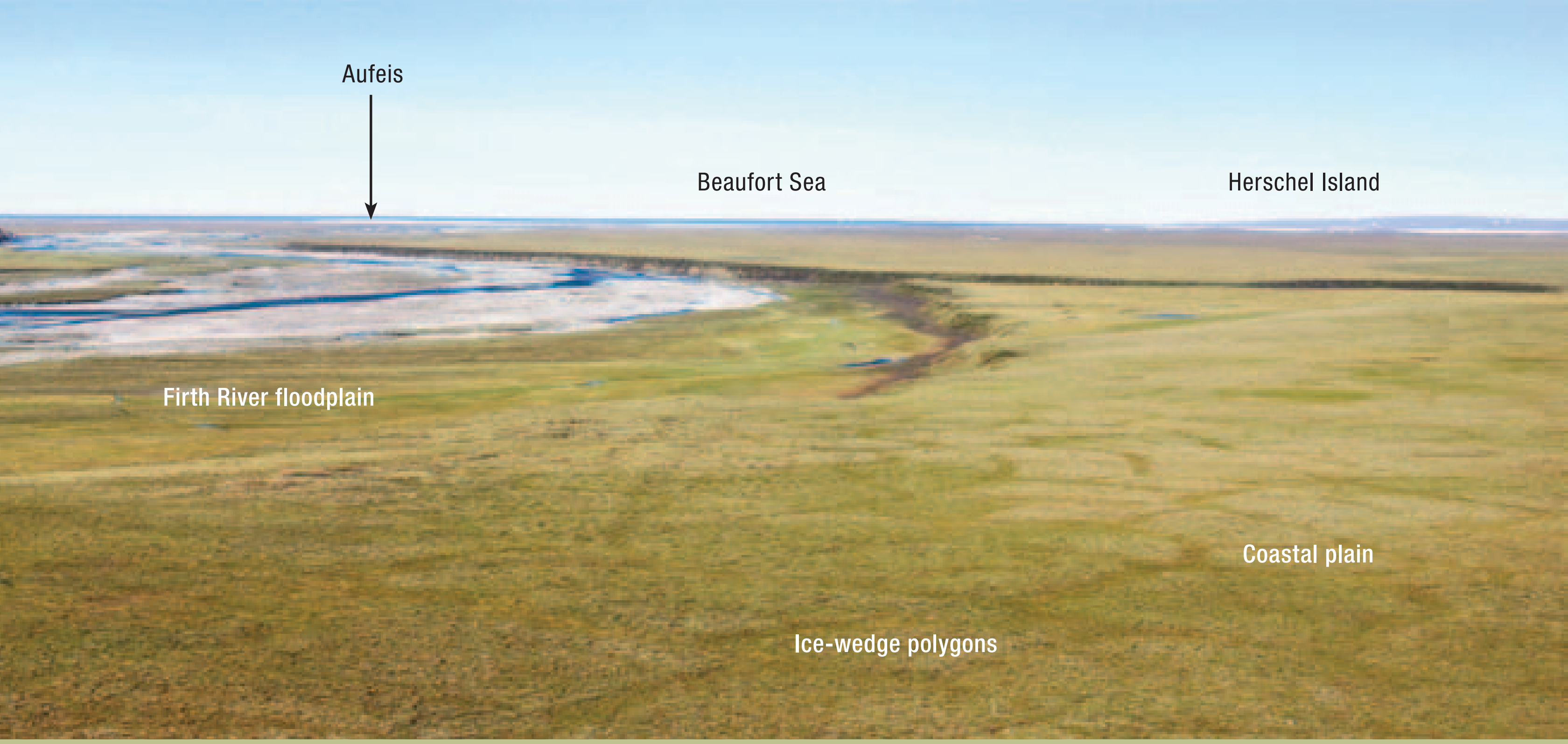
Further evidence of the river's past can be seen at the top of the canyon walls, where alluvial gravels typically lie directly on bedrock. These high gravels are also associated with ancient channels and bars that once resembled some portions of the modern channel along the Aufeis Reach. While the age of these gravel deposits is not known, they may be at least many tens of thousands of years old.

▶ Aerial view of the canyon looking looking downstream toward the areas of Anticline and Red Hills campsites. Interbranching paleochannels and relic bars are preserved on this surface and were formed by the ancestral Firth River prior to it incising the canyon. (Photograph: Greg Brooks, NRCan)



Continued from page 47

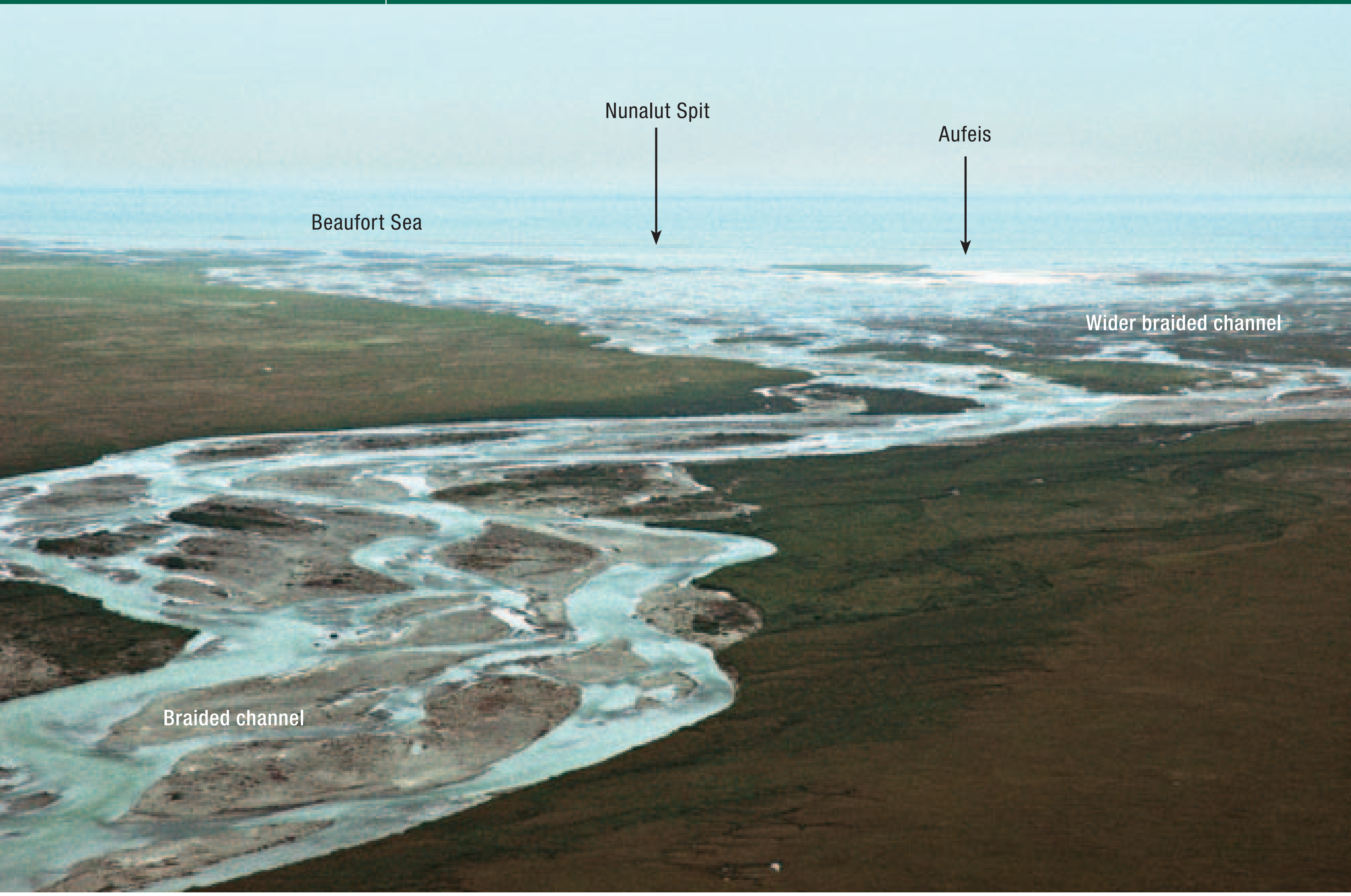
Firth River canyon—located just upstream (to the south)—is a natural obstruction to the east-west migration routes, and thus tends to direct migrating animals northward towards the Engigstciak area and beyond. Other advantages of the location include a nearby source of fish in the Firth River, well-drained areas for camping, and shelter from cold winds. These virtues have long been recognized by indigenous hunters and gatherers. Archeological investigations on the plain west of Engigstciak have revealed that use of the site began at least 11,000 years ago, and continued into the Thule Inuit period, between 1200 and 1600 AD. The bones of muskox, bison, caribou, moose, elk, Rocky Mountain sheep, birds, and fish



uncovered during excavations are thought to be the remains of animals hunted over the intervening ages. Unearthed artifacts—including stone scrapers, burins, projectile points, antler flakers, bone needles, and pottery—further testify to ongoing occupation. Collectively, this evidence makes Engigstciak one of the most important archaeological sites in the Canadian Arctic.

▲ TOP: View from Engigstciak looking upstream into the Firth River valley.

▲ BOTTOM: View from Engigstciak looking downstream along the Delta Reach towards the Beaufort Sea. (Photographs: Greg Brooks, NRCan)



▲ The lower part of the Delta Reach showing the pronounced widening of the river (in the middle distance) that occurs due to the presence of a large aufeis field. Remnants of the aufeis field are visible in this photograph, taken in late July 2008. (Photograph: Greg Brooks, NRCan)

DELTA REACH— the river meets the sea

The Delta Reach, the final section of the Firth River traverse, is about 24 km long and extends from the mouth of the Canyon Reach to Nunaluk Spit on the Beaufort Sea. Over most of this reach, the Firth River flows down the surface of a low-angled, alluvial fan that splays northward from the Buckland Hills, across the Yukon Coastal Plain to the Beaufort Sea. The surface occupied by the river and its floodplain are incised into an older, broader fan surface that forms a terrace adjacent to the modern alluvial plain. Aerial photography and satellite imagery reveals a network of ancient braided channels in the vegetation and drainage patterns on this surface, which would seem to be the downstream extension of the channels found on the bedrock terrace along the Canyon Reach (see *Canyon reach—confined and colourful* section). If so, then this network extends along the lower 70 km of the Firth Valley, preserving a relatively recent aspect of the history of the Firth River.

Most of the Delta Reach—the upper 21 km of its entire 24 km length—consists of an interbranching network of relatively shallow channels separated by raised bars, a pattern described as "braided". Only the lowest few kilometres of the reach near the Beaufort

Sea are typical of a river delta. Here, there is an abundance of fine-grained sediments on the river bars and within the channels. As well, distributary channels develop that split off one another and generally widen downstream, and water level fluctuations are caused by tides. This area also includes a shallow lagoon immediately off the river mouth that is bounded by the elongated Nunaluk Spit and a line of barrier islands situated about a kilometre offshore. In combination, these deltaic features form a narrow band that extends over a lateral distance of about 7 km across the river mouth. Nunaluk Spit, the final destination of rafting trips and the pick-up point for river travelers, is located on the western portion of the river mouth.

The morphology of the 21 km-long braided portion of the Delta Reach has two distinct aspects. Over the upper 14.5 km, the braided plain is 0.5 to 1 km wide, while along the lower 6.5 km of the river, it is up to 4.5 km wide. The bars within this lower segment become much more subtle, as channels become wider, shallower, and more sub-divided than those upstream.

These changes directly relate to the large aufeis field along the lower Delta Reach (see *Aufeis—ice formed from leaky ground* section). Covering an area of up to about eight square km, this field affects the re-establishment of the river channels during the earliest stages of the annual melt period, promoting channel relocation from one year to the next.

Early in the spring melt period, the topography of the aufeis field can also direct stream flow towards the margins of the braid plain causing it to widen because of lateral channel erosion. In addition, aufeis inhibits the deposition of overbank deposits on the gravel channel bars and hampers the growth of vegetation because of the delayed exposure of a bar surface. Together, these factors contribute to the subtle topography, shallow channels, and pronounced widening of the braided plain along the lower segment of the Delta Reach.

Although aufeis is present elsewhere along the Firth River, the extent of the aufeis fields along the lower Delta Reach elicits a unique experience of river and ice. Rafting these

Continued on page 56

▲ Pulling a raft through a shallow, braided channel amongst aufeis of the lower Delta Reach. (Photograph: Greg Brooks, NRCan)

Permafrost—cold, cold ground

Permafrost is perennially frozen ground that is defined as remaining at or below 0° C from one year to the next. It forms in cold climates when the ground cools sufficiently in winter to produce a frozen layer that persists through the following summer.

The existence of permafrost is mainly a function of climate, but its spatial distribution, thickness, and temperature are influenced by a number of local factors that affect the temperature of the ground. These include the following: relief; the direction a slope faces; rock or soil type (which affects the absorption of solar energy); vegetation cover (which insulates the ground from heat during summer); snow cover (which insulates the ground from cold during winter); drainage (which affects soil moisture levels); the frequency of forest fires (which can alter the vegetation cover); and the presence of larger water bodies (which are a local source of heat).

In areas of permafrost from the sub-Arctic to Arctic locations, the upper portion of the ground surface is subject to thaw during the summer and refreezing the following winter. Known as the active layer, this thawed ground forms on top of the permafrost and can range in thickness from 10–20 centimetres to 1–2 metres. The depth of thaw varies from year to year with annual fluctuations in winter and summer weather. Thaw within the active layer is sensitive to local ground conditions and its thickness can be increased by disturbances such as the loss of vegetation cover to a forest fire.

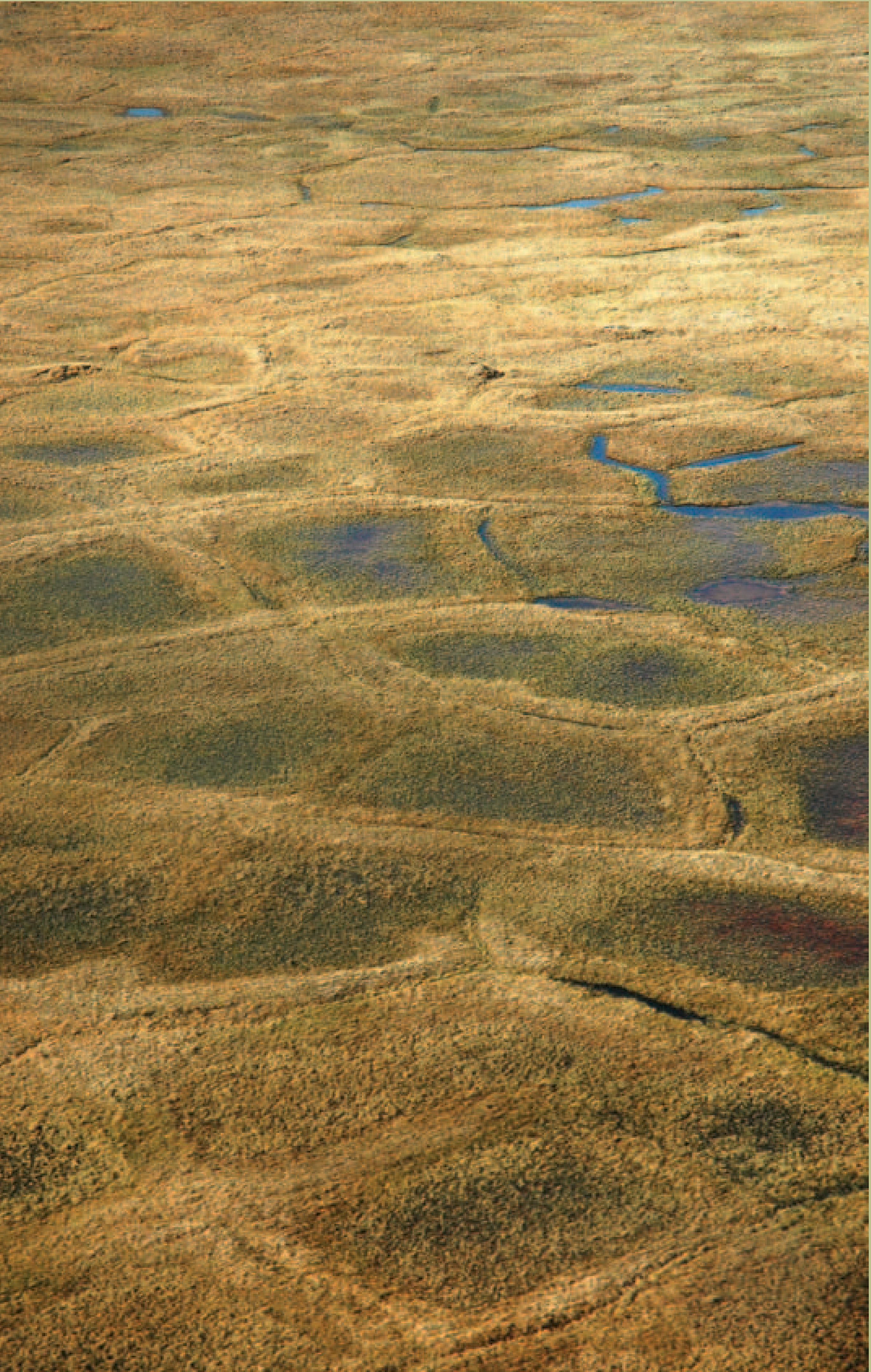
Permafrost can contain large bodies of pure ice as well as ice bonded to the enclosing sediment. The latter includes pore ice, icy coatings on soil particles, ice veins, ice lenses, and intrusive ice. Large ice bodies can take the form of structures, such as ice wedges, massive ground ice, and ice-cored mounds. The distribution of ice is strongly influenced by soil texture. In general, organic soils and fine-grained soils rich in clay or silt contain more ice than coarse-grained soils composed of sand and gravel. Ice can account for up to 50–70% of the volume of the upper 2–3 m of the ground in fine-grained soil, and in some cases more than 90%.

The long-term persistence of a cold, harsh climate in the northern Yukon region has created permafrost under virtually all of the Ivvavik landscape. Permafrost is reported to be at least 300 m thick under the Yukon Coastal Plain. It is interrupted, however, by unfrozen zones beneath larger lakes or rivers which are deep enough not to freeze to their beds in winter. Permafrost is also absent locally at locations where the seepage of ground water during winter supplies the formation of aufeis (see *Aufeis—ice formed from leaky ground* section). "Relic" permafrost extends under coastal areas of the Beaufort Sea, which is warming and thawing very gradually. This permafrost formed during the time of the last glaciation when global sea level was lower and the (now) sea bed was exposed to a cold climate.

Permafrost is ubiquitous along the Firth River valley, but is not generally seen along the river because the surface of exposed alluvial deposits are part of the active layer. The ice within permafrost, however, is not to be confused with aufeis which might be seen buried beneath gravel on bars within the river channel.

Instead, the presence of permafrost can be recognized by the occurrence of characteristic geomorphic features on the ground surface. The most widespread and obvious of these is patterned ground formed by ice-wedge polygons that can be several tens of metres across. Each polygon is defined by vegetation patterns related to immediate moisture conditions and topography, which directly reflect the presence of a wedge-shaped body of ice in the underlying permafrost. These wedges develop over winter, when falling temperatures open up cracks in the frozen ground; these spaces are then filled with frost, sediment, or meltwater that subsequently freezes. As the cracking and in-filling continues over the course of many years, the wedge of ice thickens and grows. Visible networks of polygons are common on the Yukon Coastal Plain, including the area adjacent to the Delta Reach on both unglaciated and glaciated terrain (see *A mostly unglaciated landscape* section). They are very obvious from the air when, for example, departing from Nunaluk Spit airstrip, but they also can be seen from Engigstciak on the immediately surrounding plain (see *Engigstciak—the 'New Mountain'* section).

ଔ



◀ Patterned ground formed by ice-wedge polygons on the Yukon Coastal Plain just east of the mouth of the Delta Reach. This surface feature is indicative of terrain underlain by permafrost. (Photograph: Greg Brooks, NRCan)

▲ Broad, shallow channel within an aufeis field along the lower braided segment of the Delta Reach. Water depths in this area can hinder rafting. (Photograph: Paul Dixon, Parks Canada)

Continued from page 53

innumerable shallow channels becomes a challenge, and route selection must be made with care. The constant merging, widening, and subdivision of channels makes some of them progressively shallower, to the point where the passage of a raft is no longer possible. The trick is to keep a careful eye downstream to identify and navigate to areas where channels are converging while there is still a sufficient depth of water under the raft to do so. This often means diverting into a shallow channel, anticipating it to deepen as flow converges downstream. It may be inevitable that raft occupants will have to get out and pull their raft through a shallow section of channel, but having to laboriously portage a raft and its contents to a nearby deeper channel is best avoided.

At the river mouth, the lagoon is an elongated expanse of shallow, brackish water that is protected from the direct effects of Beaufort Sea waves by Nunaluk Spit and a line of barrier islands just offshore. These waters can be up to two metres deep, but substantially shallower in many places, with a bottom consisting of bars composed of sand and silt sediment. These deposits represent fine-grained sediment eroded from the upstream watershed, carried by the Firth River to its mouth. Although the tidal range is less than 50 cm, the higher

▶ View of the Delta Reach looking upstream across the sand bars of the lagoon and the aufeis fields at the river mouth towards the Buckland Hills and British Mountains. (Photograph: Greg Brooks, NRCan)

▲ An example of coastal erosion along Nunaluk Spit, looking westwards with the Beaufort Sea on the right. This erosion will eventually result in this cabin falling into the sea. (Photograph: Greg Brooks, NRCan)

surfaces of the bars can become exposed during low tide. It may ultimately be necessary to pull rafts across the surface of some bars, depending on the tidal stage and the strength and direction of the winds.

Nunaluk Spit is some 12 km long and has a relief of up to 2 m. Most of the spit is composed of sand and gravel derived from coastal bluffs located to the west of the Malcolm River mouth, where the edge of the Yukon Coastal Plain is directly exposed to erosion from Beaufort Sea waves. A nearby example of coastal erosion can be seen adjacent to a cabin located on an isolated area of higher ground about 1.5 km down the spit. Erosion at this site is reported to have averaged about one metre per year between 1996 and 2007. The cabin will eventually be undermined by the coastal erosion.

The spit is covered with an abundant amount of driftwood, including large logs that are far thicker and longer than any trees growing within the Firth River valley. These appear to originate from within the Mackenzie River watershed. In the area of the airstrip, this driftwood has been used to construct make-shift tent shelters to provide protection from strong winds blowing off the Beaufort Sea.

SELECTED BIBLIOGRAPHY

ADAMS, G. 2005. Cultural history along the Firth River, 1995.
Parks Canada Report.

DUK-RODKIN, A. 1999. Glacial limits map of Yukon Territory.
Geological Survey of Canada, Open File 3694, (Yukon Territorial Government, Yukon Geology Program, Geoscience Map 1999-2), 1:1,000,000 scale map.

FRENCH, H. 2007. The Periglacial Environment, third edition.
John Wiley and Sons. 458 p.

ISSLER, D.R., Hu, K., Lane, L.S., and Dietrich, J.R. 2011. GIS compilations of overpressure, permafrost distribution, geothermal gradient, and geology, Beaufort, Mackenzie Region, Northern Canada.
Geological Survey of Canada, Open File 5689, 1:1,000,000 scale map, 1 CD-ROM.

LANE, L.S. 1991. The Pre- Mississippian "Neruokpuk Formation," northeastern Alaska and northwestern Yukon: review and new regional correlation.
Canadian Journal of Earth Sciences. v. 28, p. 1521–1533.

LANE, L. S. 1998. Late Cretaceous-Tertiary tectonic evolution of northern Yukon and adjacent Arctic Alaska.
American Association of Petroleum Geologists Bulletin, v. 82. p. 1353–1371.

LANE, L. S. 2002. Tectonic evolution of the Canadian Beaufort Sea—Mackenzie Delta region: A brief review.
Recorder, Canadian Society of Exploration Geophysicists, v. 27, p. 49–56.

LEITH, R.M. 1993. Hydrology of Northern Yukon National Park.
In: Northern Yukon National Park resource description and analysis. (Parks Service), Natural Resource Conservation Section, Canadian Parks Service, Prairie and North Region, Winnipeg (RM Report 93-01/INF), p. 6–1—6–60.

MACKAY, J.R., Mathews, W.H. and MacNeish, R.S. 1961. Geology of the Engigstciak archaeological site, Yukon Territory.
Arctic, v. 14, p. 25–32.

MACNEISH, R.S., 1956. The Engigstciak site on the Yukon Arctic Coast.
Anthropological Papers of the University of Alaska, v. 4, p. 91–111.

PARKS CANADA, 2003. Firth River Map & Guide. Ivvavik National Park, Parks Canada, 26 p.

RAMPTON, V.N., 1982. Quaternary geology of the Yukon Coastal Plain.
Geological Survey of Canada Bulletin 317, 49 p.

SMITH, C.A.S., Meikle, J.C. and Roots, C.F. (editors), 2004. Ecoregions of the Yukon Territory—Biophysical Properties of Yukon Landscapes.
Agriculture and Agri-Food Canada, PARC Technical Bulletin 04-01, Summerland, British Columbia, (specifically Yukon Coastal Plain (Ecoregion 32) and British Richardson Mountains (Ecoregion 165)).

WELCH, D.M. 1993. Geomorphology of the Northern Yukon National Park.
In: Northern Yukon National Park resource description and analysis. (Parks Service), Natural Resource Conservation Section, Canadian Parks Service, Prairie and North Region, Winnipeg (RM Report 93-01/INF), p. 4–1—4–118.

WELCH, D.M. 1993. Soils of the Northern Yukon National Park.
In: Northern Yukon National Park resource description and analysis. (Parks Service), Natural Resource Conservation Section, Canadian Parks Service, Prairie and North Region, Winnipeg (RM Report 93-01/INF), p. 5–1—5–58.

Acknowledgements

A Guide to the Landscape of the Firth River Valley, Ivvavik National Park would not have been completed without the contribution of many people, including colleagues from Parks Canada and Natural Resources Canada. Their number precludes us from listing all of them here. We are thankful for their role in producing this guide, and share with them any recognition that it receives.