3. Geological Setting

C.W. Jefferson, W.A. Spirito, S.M. Hamilton

The South Nahanni River crosses the structural grain of the eastern fringes of the Selwyn Mountains and the entire southern Mackenzie Mountains which terminate north of the Liard River Plain. These mountains expose mainly sedimentary rocks, including in very general terms: Neoproterozoic (about 800 Ma) to Late Cretaceous (about 100 Ma) platformal to shale basin sedimentary strata that were intruded by minor Devonian (350 Ma) granitoid rocks and deformed into folds and thrust faults during the Jurassic (~170 Ma) to Cretaceous collision of an island arc with western North America. During this collision the Selwyn and westernmost Mackenzie Mountains were intruded by major Cretaceous granitoid batholiths. Compressive and right lateral strike-slip adjustments continued through the Tertiary (~40 Ma), even to the present, as noted in the Nahanni Earthquake of 1985 (Wetmiller et al., 1988). The term Laramide Orogeny has been applied in broad terms to Cordilleran deformation and metamorphism since the Jurassic.

The National Park Reserve and proposed park expansion areas lie mainly within the large Meilleur River Embayment of the Selwyn Basin (Fig. 3.1), but also include a major zig-zag carbonate-shale facies change that outlines the boundary between basinal shales and the MacDonald Platform to the east and northeast. The Prairie Creek Embayment forms a northerly appendix to the Meilleur River Embayment. A northerly trending belt of Mesozoic granitoid intrusions forms the core of Logan Mountains (Ragged Ranges in the study area), and transects stratigraphic facies changes. These geological entities are the framework for both beautiful scenery and natural habitat (see illustrations in this Chapter, especially section , as well as for important mineral deposits in the region (Fig. 1.1; Chapter 6).

The regional geology used for mineral resource assessment in the South Nahanni River area is summarized in Figs. 3.1 to 3.3 inclusive and Table 3.1. The oil and gas assessment reported in Chapter 8 provides a more detailed geological introduction focused on the southeastern part of the Tlogotsho Plateau and the eastern fringe of the Nahanni Karst study area, which are on the northwestern margin of the Liard fold and thrust belt. The simplified maps presented in the following sections are based on decades of reconnaissance-scale (1:250,000) geological mapping and related research, mainly by officers of the Geological Survey of Canada, as cited in Table 3.1. Only a part of the assessment area has been previously mapped in moderate detail (e.g. the Tungsten area (CT) at 1:50,000 scale by Blusson (1968), the Nahanni (105I) map sheet at 1:50,000 by Gordey (1981b) and Gordey and Anderson (1993), and the Prairie Creek Embayment at 1:125,000 by Morrow and Cook (1987). Geological field work for the present study separated the Earn and Road River groups at a scale of 1:125,000 within the previously undivided Ordovician – Silurian - Devonian (OSDR) map-unit of Gabrielse et al. (1973). The terminology of formations and the understanding of their relationships are at greatly different stages from one area to the next, hence the multiple names in Table 3.1. Gordey and Anderson (1993) provide the most recent and comprehensive analysis of stratigraphy and the Selwyn Plutonic Suite in the western part of the region. Morrow and Cook (1987) provide detailed and highly relevant geological context for the eastern part of the region. Most of the following descriptions are based on their work, and the reader is referred to these extensive Bulletins for full details.

3.1. Rock Packages

The two resource assessment areas each straddle the junctions of four 1:250,000 map sheets which were mapped at different times and with different legends (Table 3). The large number of units that has been differentiated by various workers is impractical for the scale of this assessment. Therefore a simplified legend of nine major rock packages is here derived that reflects broad subdivisions of age, paleogeographic setting, composition and metallogeny. Some metallogenic indicators are shared by more than one rock packages. Some of these packages constitute natural rock-stratigraphic units of group and supergroup rank.

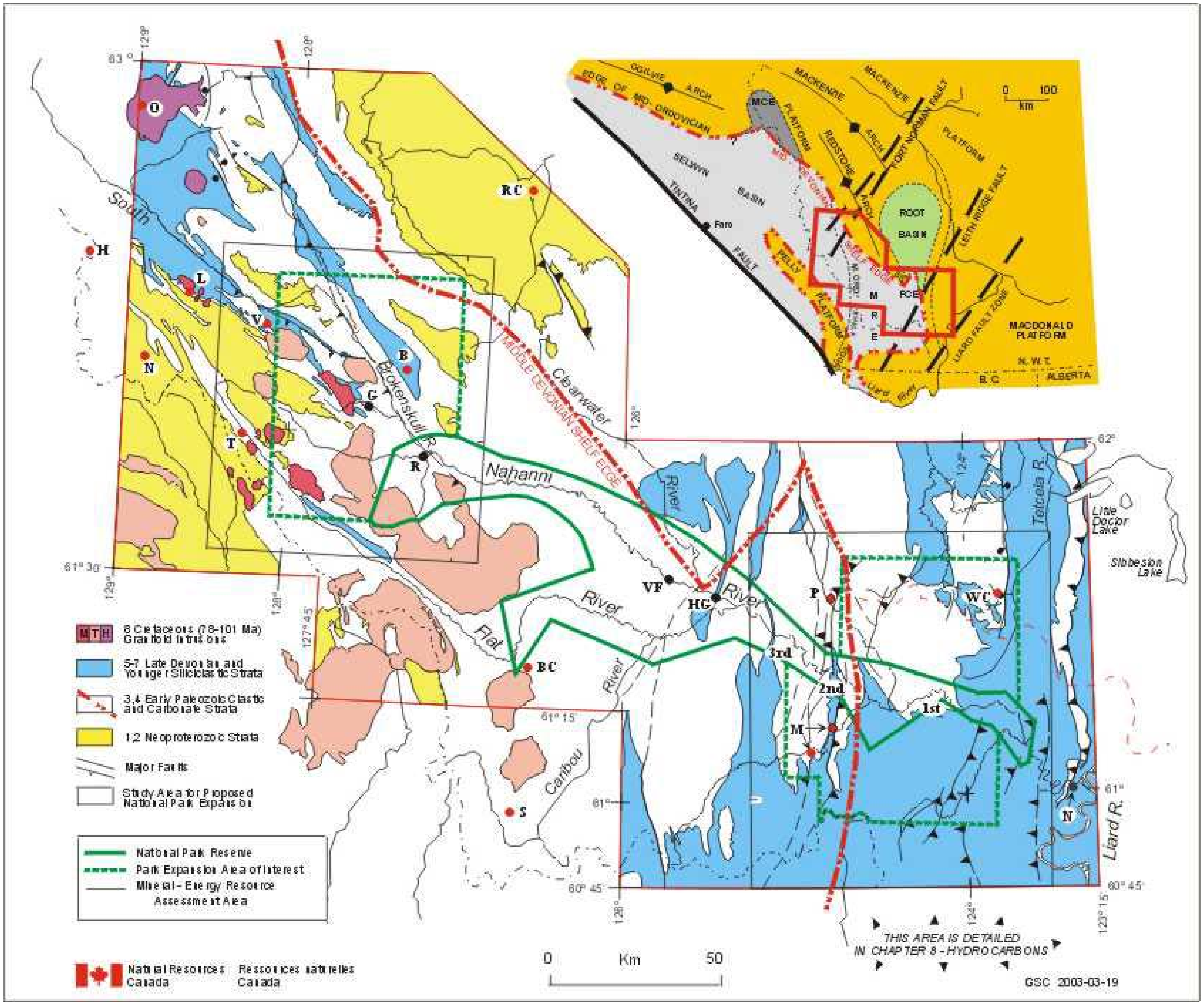


Figure 3.1. Summary geology of the South Nahanni River region. Rock units and references are detailed in Table 3.1, text and Figures 3.2, 3.3. Inset is paleogeographic setting after Cecile (1982), Gordey et al. (1993), Morrow (1984, 1987) and Morrow and Miles (2000). Abbrevs: MRE=Meilleur River Embayment, PCE = Prairie Creek Embayment, SS = Sombre Salient. Localities (black dots) and mineral sites (red dots) are: 1st, 2nd, 3rd = Canyons of Nahanni R.; B=Broken Skull; BC=Bennett Creek placer gold; G=Glacier L., H=Howards Pass zinc-lead; HG=Hells Gate; L=Lened tungsten; M=Meilleur River hot springs; N=Nahanni Butte community; O=O'Grady gemstones; P=Prairie Creek silver-lead-zinc; R=Rabbitkettle Hot Springs; RC=Redstone copper; S=Selena Creek placer gold; T=Tung-sten Mine and Hot Springs; V=Vulcan zinc-lead; VF=Virginia Falls; WC= "Wretched Creek" (inf.) placer gold. Mineral Occurrences are selected from 190 listed in Appendix 1.

Table 3.1. Rock types of South Nahanni River region. Major units 1 through 9 are used in this report for context of the mineral resource assessment. Sources are cited at bottom.

Unit	Map-units	Unit name and lithology
9	16, Qal, Q	**Unconsolidated glacial and alluvial deposits (not shown in Fig. 3.1.). (<1.6 Ma)**
8	15, Kqm, Kg, Ky	**Cretaceous granitoids** (includes pegmatites, aplite dykes; M=2 mica; T=Transitional; H=Hornblende). (**78-101 Ma**)

Late Devonian and younger strata (65-380 Ma)

5 Basinal shale-dominated				**6 Transitional**			**7 Platformal clastic- dominated**	
Map sheets / units			Unit name & lithology	Maps / units	Unit name & lithology		Maps / units	Unit name & lithology
105H,105I	95 B-L			95B,C,F,G			95B,C,F,G	
	Kps = lK_{FSJ} lK_G		"shale" = Fort St. John Gp. shale Garbutt shale				Ks	sandstone
							CPM	Mattson ss./sh./coal
				M_F	Flett limestone, silty			
				M_C	Clausen shale, black			
uD_S	uD_{FS}		Fort Simpson shale	M_Y	Yohin sandstone			
	mD_{HR}		Horn River shale					
uDMps	DM	Chert pebble conglomerate	Earn Group	DM_{BR}	Besa River shale, grey	approximate equivalents Earn Group		
MuDpt		Chert, siliceous shale, black		uDsh	shale, black			
				uDs	siltstone, mudstone			

Early Paleozoic strata (middle Devonian and older; 380-544 Ma)

3 Basinal shale-dominated & transitional			**4 Platformal carbonate and clastic**						Diagenetic/equiv. shelf facies
105H, I	95B-L	Unit name & lithology	105H,I	95E,L	95B,C,F,G	Unit name & lithology			
mDl	mD_{FH}	undiv. Headless + Funeral calc. shale	mmDl2	Dn	mD_N	Nahanni limestone		mDM, Dm, Dgb, Da_2	Manetoe + Bear-Rock + Grizzly Bear Diagenetic Facies
				Dh	mD_H	Headless limest.	MD_{LHN}		
				Dl	mD_L	Landry limest			
	mD_F/Df	Funeral calc. shale	$mmDl_1$	Dna		Natla lst.,crinoidal			
	lmD_{Ab}	Arnica basinal member	$lmDl_1$	Da	mD_A	limest., crinoidal	Arnica		
			lDl		lmD_A	limestone, black			
			mlDd			dolostone, dark			
			ulDl			Lst.,blue-grey,crin.			
12	lmD_{Sd}	Sombre (detrital member)	lDd	Ds	lmD_S/lD_S	Sombre dolostone			
	SD_C	Steel mudstone / Cadillac calc shale		Dc	lD_C	Camsell dolostone / limestone			
	SD_{Cm}	Steel mudst / Cadillac (megabreccia member)			lD_V	Vera limestone			
10,11, Ospt	SD_R	(locally includes DM_E) **Road River Group / Formation / Duo Lake Formation**	SDl			limestone, dark = OSw3/DS2/lower Da?			
	OSD_R		SDd		S_{RT}	Delorme = Root River dolostone			
	OSD]		uOSd	OSw	OS_{W3}	dolostone, cherty	Whittaker		OM_K = Mount Kindle
hf		pelitic hornfels (in OSD_R)			muO_{W2}	quartzarenite			
10,11		calc. Shale and orange- weathering silty dolomitic mudstone			muO_{W1}	limestone, grey			
			uCOSd	Os	mO_S	Sunblood dolostone			
			uCOd			Dolostone, white to orange weathering			
			uCOl \	CO		Argillaceous limestone, basalt			
		Rabbitkettle Formation - silty limestone	9,uCl,uCOdl	COr		Rabbitkettle limest.& dolost.			
			uClOl /	Cobs		Broken Skull dolostone			
		Gull Lake Formation – shale, siltstone	mCd?	Ca		Avalanche dolostone			
			mCl?	Cr		Rockslide limestone			
8	C	argillite, argillaceous limestone; Gull Lake.	4,5,6,7,lClds	Cs		Sekwi grey to tan carbonates			
	lmCp	calc.dolost./ shale / mudstone	Gull Lake	lmCp		Atan limestone			

Neoproterozoic strata (544-1200 Ma) (obs. Late Proterozoic)

1 Basinal shale-dominated and transitional					**2 Platformal carbonate and clastic**			
105H, 105I	95B-L	Unit name & lithology			105H,I	95E,L	Unit name & lithology	
3, HlCps	Cbr	siltstone / quartzite	Narchilla Form.	Windermere Supergroup	Vampire Form. HlCps	Cbr	Windermere Supergroup	Backbone Ranges quartzarenite + Ingta mudstones
	CH	Phyllite						
1C, HlCp		maroon / green slate						
1, 2, Hsp	H	Hyland Group (105 I) = Grit Unit, coarse grey subarkose with blue quartz			Backbone Ranges	10B,11		Gametrail, Blueflower & Risky carbonates
						Hs		Sheepbed dark shale & siltstone
						Hk		Keele dolostone, limestone, qtartzite, diamictite
						Hr		Rapitan maroon argillite & diamictite
						Hc	Coates Lake Group	Coppercap turbiditic limestone
						Hrr		Redstone River red mudst & gypsum
						Hth		Thundercloud dolost & red mudst.
						Hld	Mackenzie Mountains Super-group	Little Dal limestone and dolostone
						Hka,Ht		Katherine (Tigonankweine) quartzite, dolostone
						Hts		Tsetzotene grey shales
						H1		Map-unit H1 dolostone

References

95B	Fort Liard:	Douglas and Norris, 1959	95G	Sibbeston Lake:	Douglas and Norris, 1976a
95C	La Biche River:	Douglas and Norris, 1959	95J	Glacier Lake:	Gabrielse et al., 1973; Aitken, 1989; Fritz, 1982
95E	Flat River:	Gabrielse et al., 1973	105H	Frances lake:	Blusson, 1968; Roots et al., 1966
95F	Virginia Falls:	Douglas and Norris, 1976b, Morrow and Cook, 1987	105I	Nahanni:	Green et al., 1968; Gordey, 1981; Gordey and Anderson ,1993

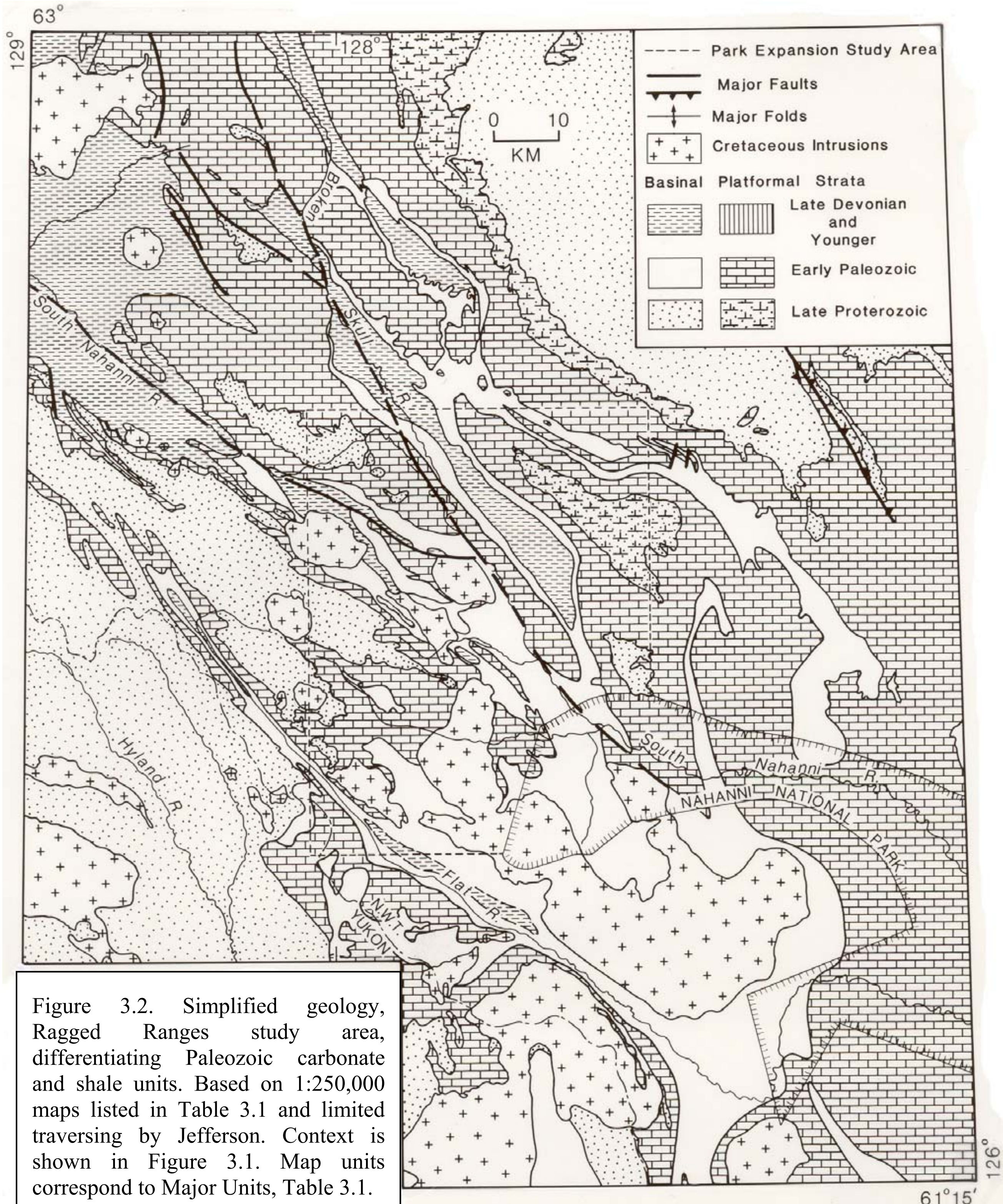


Figure 3.2. Simplified geology, Ragged Ranges study area, differentiating Paleozoic carbonate and shale units. Based on 1:250,000 maps listed in Table 3.1 and limited traversing by Jefferson. Context is shown in Figure 3.1. Map units correspond to Major Units, Table 3.1.

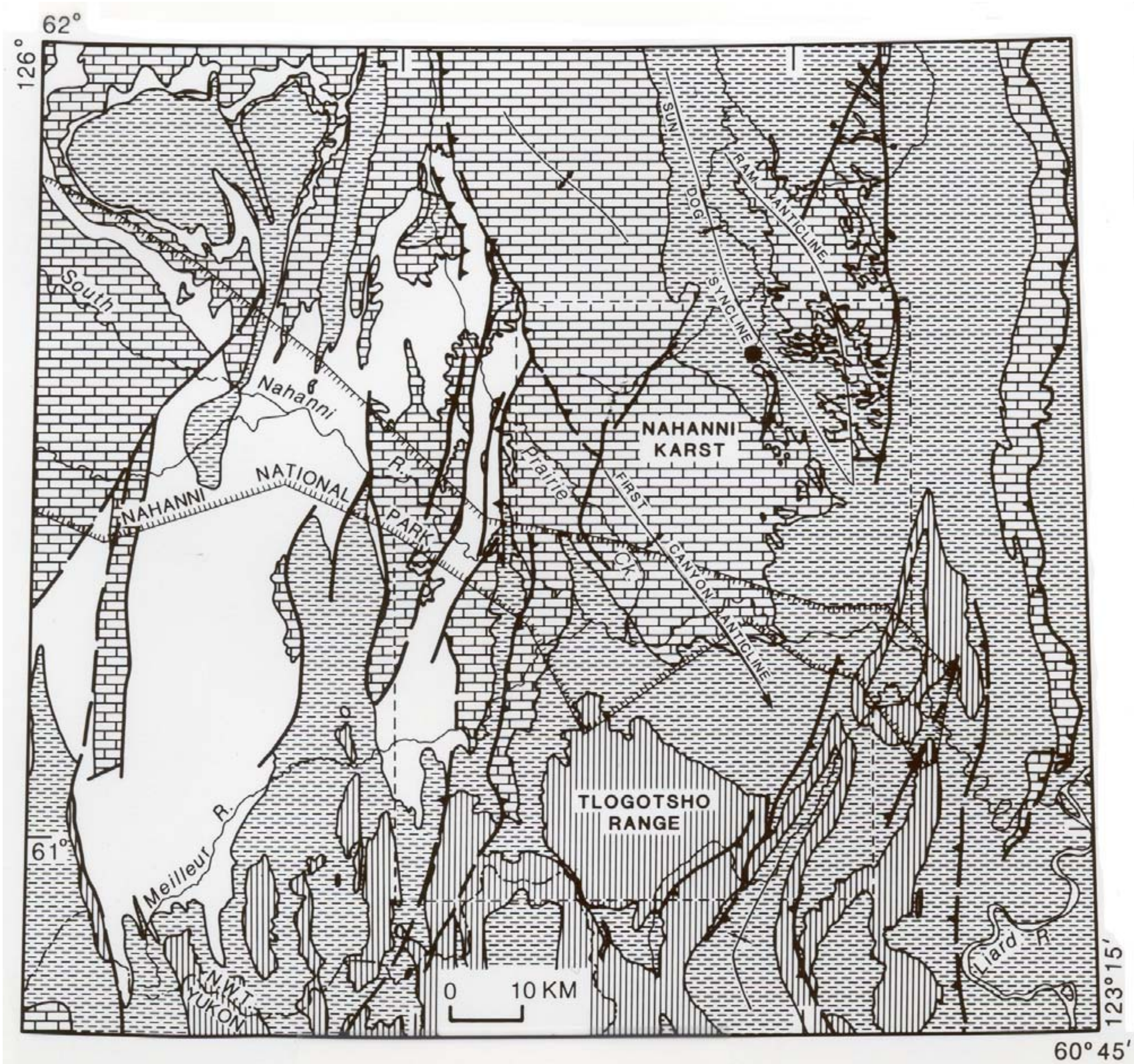


Figure 3.3. Simplified geology of the Nahanni Karst - Tlogotsho Plateau study area, differentiating Paleozoic carbonate and shale units, and separating Mattson Formation (vertical pattern) from overlying Cretaceous shales of Fort St. John Formation. Based on 1:250,000 and 1:125,000 maps and formations listed in Table 3.1. For generalized legend, see Fig. 3.2; context in Fig. 3.1.

3.1.1. Basinal shale-dominated and transitional Neoproterozoic strata

The oldest rocks exposed in the western Nahanni River region are Neoproterozoic (terminology on existing 1:250,000 maps is "Late Proterozoic") basinal coarse to fine clastic strata of the Windermere Supergroup (Gabrielse et al. 1973) that is very extensively exposed longitudinally along the Cordillera. The base of the lower, Grit Unit, is not exposed; it is intruded by Cretaceous granitoid rocks. In the Nahanni map sheet (105I) which contains the headwaters of the South Nahanni River, the Grit Unit has been named the Hyland Group and subdivided into the lower Yusezyu and overlying Narchilla formations (Gordey and Anderson, 1993). Lateral facies relationships are summarized in their

Figure 36. The Yusezyu Formation is typically thick-bedded, coarse-grained turbidites that contain blue quartz. Some of the pegmatites intruding this unit are anomalous in lithium (e.g. Little Nahanni Pegmatites prospect, Appendix 1).

The Narchilla Formation comprises maroon to dark grey shales. The eastward transition to platformal Neoproterozoic strata is generally not exposed, however the upper limestone unit of the Yusezyu Formation is thought to be equivalent to the middle carbonate unit of the Backbone Ranges Formation, and the Narchilla equates to the Vampire Formation: slate, phyllite and argillaceous quartzite that undergo a facies change eastward to the platformal upper Backbone Ranges quartzite, and constitute the top of the basinal Neoproterozoic section (Fritz, 1982). This Precambrian-Cambrian transition in the Ragged Ranges study area, at Vampire Peaks, is a geological reference section of heritage significance (Fritz et al. 1983).

The east-west facies change established in Neoproterozoic time persists throughout the overlying Phanerozoic section, migrating northeast or southwest from one formation to the next, across a boundary zone that is summarized in the inset to Fig. 3.1. This transitional boundary zone, labelled "EDGE OF MID-ORDOVICIAN PLATFORM" and "MID-DEVONIAN SHELF EDGE" roughly defines the shape of the SELWN BASIN and re-entrants of that basin that existed at various times and are labelled as follows. MCE = Misty Creek Embayment detailed by Cecile (1982), M R E = Meilleur River Embayment and PCE = Prairie Creek Embayment detailed by Morrow (1984, 1987). SS = Sombre Salient (ibid.) is a shelf promontory that flanks PCE to the west. ROOT BASIN is a transitional shale embayment that was developed over a wide area before and after the Meilleur River Embayment, and is much less distinctive.

Other structures shown on this inset that may be important to metallogeny are the FORT NORMAN LINE, LEITH RIDGE FAULT, BEAVER RIVER STRUCTURE and LIARD LINE whose long term histories were introduced by Aitken and Pugh (1984) and updated by Cecile et al. (1997) and Morrow and Miles (2000). The position and context of the Liard Line was moved by the latter, who also introduced the Beaver River Structure. The Leith Ridge Fault is slightly modified here, here in reference to the linear congruency of the Prairie Creek embayment, the mapped edge of the Sombre Formation, and the Caribou River (see discussion of Sombre Domain under Mineral Resource Assessment Domains). It also remains coincident with the southern limit of Proterozoic exposures in Mackenzie Mountains as noted by Aitken and Pugh (1984). The Beaver River Structure passes NE-SW through Nahanni Butte at the southern end of the Nahanni Thrust and may have formed part of the north side of Liard Basin (host of gas plays, see Chapter 8). Pb-Zn-Cu Mineralization shows at Nahanni Butte may be related to Beaver River Structure (Morrow and Miles, 2000).

At times, shales such as the Sheepbed formation lapped eastward onto the Mackenzie Arch, but the carbonate platform was re-established with the next formations such as the Gametrail, Blueflower and Risky. For this reason, and for geographic simplicity, those formations located basinward of the facies change shown on Figure 3.1, up to Middle Devonian time, constitute the Selwyn Basin, although most workers view Selwyn Basin as an early Paleozoic entity (see Gordey et al., 1993 for a historical perspective).

3.1.2. Platformal and transitional carbonate - clastic Neoproterozoic strata

The oldest rocks exposed in the northeastern Nahanni River region are the Mackenzie Mountains Supergroup (as defined by Jefferson and Parrish, 1989). Most of this supergroup is platformal carbonates and quartzarenites, however the Tsezotene Formation has a relatively deep-water shaley aspect, albeit with some stromatolitic carbonates as described by Gabrielse et al. (1973). The Basinal and Grainstone formations of the lower Little Dal Group are facies equivalents that straddle the platformal boundary (Aitken, 1981). Some 200 km north of the Nahanni region, the lower Little Dal Group hosts Mississippi Valley type lead zinc deposits at Gayna River (Hewton, 1982). All of these map-units are listed on the platformal side of Table 3.1 because they are geographically restricted to Mackenzie Arch, on the platformal side of the facies change in Fig. 3.1.

The Coates Lake Group, unconformably overlying the Mackenzie Mountains Supergroup, is a transitional sequence of sabkha carbonates, evaporites, red beds and conglomerates and turbiditic limestones that contain stratabound copper deposits in sabkha sequences (Jefferson and Ruelle, 1986). The lowest unit in the Group, Thundercloud Formation, is a relatively platformal sequence of sabkha dolostones and quartzarenites. The overlying Redstone River and Coppercap formations again have a basinal aspect because of the unstable depositional environment recorded by their conglomerates, mudstones and turbiditic carbonates, yet remain on the right-hand column of Table 3.1 because they are restricted to the Mackenzie Arch and record shallow water to terrestrial depositional environments.

The Windermere Supergroup in Mackenzie Mountains unconformably bevels (Jefferson and Parrish, 1989) most of the above-described rocks at an unconformity that has locally well developed paleo-weathering and karst features beneath it (Jefferson, 1983). The lower part of the Windermere Supergroup in southern Mackenzie Mountains (excluding Coates Lake Group, as defined by Jefferson and Parrish, 1989) is the Rapitan Group (glaciomarine conglomerates, iron-formation, argillites, shales and some carbonates). These are exposed only in Mackenzie and Redstone arches, and cannot be mapped into the Grit unit even though being about the same age and assigned to the same supergroup. The upper part of the Windermere Supergroup changes from generally platformal to generally basinal at about the location of the South Nahanni River (this is also the boundary between the Broken and Ragged domains). Northeast of South Nahanni River, platformal conditions are recorded by dolostones, limestones and quartzarenites of the Keele to Backbone Ranges formations.

3.1.3. Basinal shale-dominated and transitional Early Paleozoic strata

The early Selwyn Basin established by shaley facies in the Paleoproterozoic continued to be shale dominated but with a variable carbonate component (depending on proximity to the carbonate shelf) throughout the early Paleozoic. These units are summarized in Table 3.1 as generalized Unit 3.

The Paleoproterozoic Narchilla Formation shales are sharply overlain by buff brown-weathering, blue-grey slate and siltstone with minor limestone conglomerate of the early Cambrian Gull Lake Formation (Gordey and Anderson, 1993). This transition is recorded in the laterally equivalent to the Vampire shales-siltstones overlain by the upper Backbone Ranges limestone and quartzite. In the vicinity of Tungsten, Map Unit 8 that hosts the tungsten skarns (Blusson, 1968) appears to be a lateral equivalent of the Gull Lake Formation, consisting of calcareous shale, dolostone and mudstone overlain by argillite and argillaceous nodular limestone reminiscent of the overlying Rabbitkettle Formation.

The Cambro-Ordovician Rabbitkettle Formation is a regional blanket nodular limestone that is silty-shaley in basinal regions but more resistant nodular carbonate in platformal regions. It is laterally transitional to the Haywire dolostone and quartz sandstone around and east of Lened, sharply to transitionally overlies the early Cambrian shaley facies and unconformably overlies the Vampire in places.

The regional Road River Group consists of a number of calcareous graptolitic black shales and cherts interspersed with limestones and dolostones (Road River Formation of Gabrielse et al. 1973) that range in age from late Middle Ordovician to Early Devonian. Gordey and Anderson (1993) raised the Road River to Group status and recognized two new formations. Duo Lake formation "comprises recessive weathering, black siliceous graptolitic shale and chert and minor limestone" with lateral facies including "orange-buff weathering, black silty shale and minor limestone" (Gordey and Anderson, 1993, p. 53). Gordey recommended restricting the term Road River to the above two formations, but here we include transitional units such as the Sapper Formation ("tan weathering siltstone, calcareous siltstone and limestone, occupying an intermediate position between shallow shelf carbonates to the east and offshelf Road River rocks to the west", ibid). The reason for this inclusion is that such transitional units that are metallogenically better considered as basinal relative to the massive limestones and dolostones of the same age that wrap around the shales.

In Meilleur River embayment, the Selwyn Basin did not exist until the late Ordovician, as the platformal Sunblood Formation extended to approximately 128º as shown in the inset to Fig. 3.1. The Road River Formation then extended eastward to the approximate position of the MIDDLE DEVONIAN SHELF EDGE shown on Fig. 3.1. Morrow and Cook (1987) did not subdivide the shaley limestone and calcareous shales of the Road River Formation in the Meilleur River Embayment.

The overlying Steel Formation (Gordey and Anderson, 1993) is a very distinctive regional marker unit that was long known as the "Silurian Siltstone" throughout the length of Selwyn Basin and down into the Kechika Trough (as used by Jefferson et al., 1983) of northeastern British Columbia. This unit of orange-weathering intenesly bioturbated dolomitic siltstone ranges in age from mid-Silurian to Early Devonian.

In Meilleur River Embayment, the Silurian-Early Devonian strata preserve very complex facies relationships that are detailed by Morrow and Cook (1987). A tongue of Road River Formation shales onlaps the platformal Sunblood and deeper water Whittaker dolostones, and is overlain by various shaley carbonate rocks, calcareous siltstones and carbonate breccias of the Cadillac Formation, Sombre detrital member, and the basinal member of the Arnica Formation that record strong lateral differentiation and tectonically active facies changes between shallow and deep water environments. The boundary between shallow and deep water strata demarks the Sombre Salient (a south-pointing nose of platformal carbonates that closes at the South Nahanni between Hells Gate Virginia Falls) and the Prairie Creek Embayment (between Hells Gate and Second Canyon). This zig-zag facies change is shown on Fig. 3.1, extending south along the east side of Meilleur River Valley and continuing southward into Yukon Territory where it approximately parallels the western limit of the Liard Fold Belt as shown in Fig. 8.1 of Chapter 8 – Hydrocarbon Assessment.

The middle Devonian facies changes occupy roughly the same positions as the underlying strata, but are more gradual. The regional Selwyn Basin remained broadly defined as shown in Fig. 3.1 inset, but in the Meilleur River area the Prairie Creek Embayment was replaced by the broad Root Basin. In both areas, the basinal facies are as listed at the top of generalized Unit 3 of Table 3.1.

Selwyn Basin shales contain anomalous amounts of metals, as reflected in their many Sedex lead-zinc deposits (Carne and Cathro, 1982) and the Nick type of nickel-platinum deposits (Hulbert 1995). Basinal shales that are calcareous also formed skarns where intruded by the Cretaceous plutons, and these host tungsten or lead, zinc, and silver. Vanadium rich shales such as those hosting Nick type deposits are potential sources of trace elements to create gemstones such as found around the O'Grady and Lened plutons (see Appendix 1).

Portions of the basinal facies that record lateral changes in rock types are the most favourable sites for base metal deposits of the Sedex (sedimentary exhalative) type. The Howards Pass and Vulcan deposits are located at relatively gradational portions of the Ordovician-Silurian-Devonian facies changes, whereas the Prairie Creek vein and associated stratabound deposits are located at strong facies changes.

The Selwyn Basin shales were deposited in deep, generally anoxic conditions, preserving much organic matter as well as regionally abundant metals, mainly iron pyrite. Groundwaters and surface waters passing through or over these rocks pick up naturally high metal abundances as reflected in the naturally high background values of zinc, cadmium, copper, and iron in the South Nahanni River drainage basin (Halliwell and Catto, 1998) and as reported in Chapter 5. These same shales also make naturally fertile primitive soils, hence form most of the greenish mountain pastures on smooth slopes in Ragged Ranges (Fig. 3.4).

Figure 3.4. Typical Road River Group shales in foreground form relatively smooth grassy slopes. Silver-weathering ("Gunsteel") shales on right are typical of the late Devonian Earn Group. Rusty rocks are hornfelsed shales of both rock units adjacent to quartz monzonite of Mount Appler. View looking NW from Mt.Harrison Smith toward Vampire Peaks.

3.1.4. Platformal carbonate and clastic Early Paleozoic strata

The Cambrian to Devonian (CDM) section comprises platformal carbonate strata on the north, east and south of NNPR, on the continent side of the MIDDLE DEVONIAN SHELF EDGE. These units are listed in Table 3.1 under major unit 4. These are a sequence of cliff-forming carbonate rocks recording shallow marine platformal sedimentation by reef forming organisms, with very little sandstone or shale. During diagenesis the platformal rocks became dolomitized and developed secondary porosity due to solution collapse (Fig. 3.5.) and chemical changes during dolomitization. Such porosity is important for hosting both hydrocarbons and base metals. This is known as the Manetoe Facies as described by Morrow and Cook (1987).

3.1.5. Basinal shale-dominated and Transitional Late Devonian and younger strata (Major Units 5 and 6)

Devonian to Mississippian rocks of the Earn Group (DME) include basinal shales and westerly derived turbiditic sandstones to conglomerates (Gordey et al. 1982). The depositional basin of the Earn Group extended eastward past the Selwyn Basin, overlapping the Mackenzie Platform and interfingering with black Besa River and un-named shales of the Mackenzie Valley. These are overlapped by the Horn River and Fort Simpson shales whose equivalents extend northerly to the Arctic Platform.

Figure 3.5. Paleokarst solution collapse breccias in Middle Devonian Manetoe Facies Dolomite and Middle Devonian Arnica Formation, 1st Canyon of South Nahanni River. About 40m of section are shown. Photo GSC204367-S.

Barite-lead-zinc-silver Sedex deposits are located in places near the base of the Earn Group, associated with depositional sub-basins that are variously marked by local conglomerates, volcanic rocks, silicified thicker shaley strata and younger normal and thrust faults that appear to have been active during sedimentation. These favourable sites tend to be located toward the western part of the Ragged Ranges study area, and even there conglomeratic facies and evidence of exhalative activity such as gunsteel weathering black cherts with blebby barite are minor. Highly prospective Earn Group facies are not found east of 130º in the South Nahanni River area. In the eastern study areas, non-siliceous and non-metalliferous shales of the Besa River, Horn River and Fort St. John Group blanket the Devonian carbonates. Transitional units are those with some platformal elements such as carbonate content (Flett Limestone) and sandstone (Yohin Formation), but these facies changes are very gradual, and preserve no evidence of faulting or other local tectonic activity during sedimentation. The shales and shaley limestones form smooth slopes and tend to be wooded or grass-covered, in contrast to the cliff-forming carbonates and sandstones.

3.1.6. Platformal clastic-dominated Late Devonian and younger strata (Unit 7)

The Devonian to Jurassic map unit (DJF) includes Carboniferous shallow marine carbonates and continental sandstones with coal measures; overlain by basinal cherts and mudstones of Permian and Triassic ages. Late Jurassic to early Cretaceous (JKK) and late Cretaceous (KA) fine to coarse clastic rocks record a complex but gradational interrelationship of continental to marine deposition and include what used to be considered as important coal measures in the region (Stott 1982). The Mattson Formation, which hosts the coal, is the resistant unit topping the Tlogotsho Plateau and forms ridges along the sides of the synclines underlying Jackfish River and Yohin Lake areas. The shaley coal measures were formed in deltaic swamps (Potter et al., 1993), and are iron-rich, resulting in rusty iron springs of no metallogenic significance. These sandstones were again submerged under marine shales of the upper Fort Saint John Group which are the youngest strata in the study area.

These strata and their structural context are now being remapped in detail (e.g. Fallas and Lane, 2001; Hynes et al., 2002). A compilation and interpretation of these strata is presented in more detail in Chapter 8, to provide immediate context for the assessment of hydrocarbon resources. Their work substantiates the fundamental regional geology of previous mappers, but provides better details of both structure and stratigraphy for greater confidence and accuracy in assessing and exploring hydrocarbon potential.

3.1.7. Cretaceous intrusions

Granitoid rocks intrude a broad belt of the Omineca Belt of the northern Cordillera that includes the west-central third of the area shown in Fig. 1.1, shown geologically in Fig. 3.1. The intrusions range in age from Devonian to Tertiary (Sinclair 1986), most being Early and Mid-Cretaceous (78-101 Ma) plutons of the calc-alkaline Selwyn suite that are radiogenic, metaluminous to peraluminous granitoid rocks. The latter occupy an arc situated east of the Tintina Fault and are subdivided by Gordey and Anderson (1993) into three types: (1) hornblende-bearing (metaluminous) plutons, (2) two-mica (muscovite-biotite), non-hornblende (peraluminous) plutons, and (3) transitional plutons sharing characteristics of (1) and (2). They suggested an epizonal to mesozonal depth of emplacement for these plutons.

The two-mica Selwyn Plutons are spatially associated with significant tungsten deposits at Tungsten and showings at the Lened property (Fig. 1.1, 2.1), and the type locality for the two-mica variant is at MacTung, the other major tungsten deposit in the region (ibid.). The distribution of these plutons from Gordey and Anderson (1993, Fig. 63b) is shown in Fig. 3.1, with a cluster extending northeast from Tungsten as far as Glacier Lake.

Groat et al. (1995) reviewed the Selwyn plutons as the main focus of their study on granitic pegmatites in Yukon and the western Northwest Territories. They noted that pegmatites are of interest for their potential to contain rare elements such as Ta, Nb, Li, Rb, Cs, Be and Sn, rare mineral species, and gemstones such as emerald, topaz, aquamarine and tourmaline. They found that pegmatites are associated with many plutons of the Selwyn suite, with the peraluminous two-mica granites being the most evolved and therefore most prospective for the above-listed economic elements and minerals. Contact aureoles of andalusite and biotite around the Selwyn plutons have been mapped by most authors whose work was compiled here for Figures 3.1. Groat et al. (1995) noted that the first appearance of andalusite is typically within 0.5 km of intrusive contacts, and that pegmatites are associated with many of the plutons, of all types.

Groat and his colleagues have continued research on pegmatites in the South Nahanni River region, especially the Little Nahanni pegmatite field (Discovered in 1961 by D.C. Rotherham, previously known as Cali and now being explored by Nordac Resources Limited for its Li and Ta content) and the O'Grady aplite-pegmatite complex. The O'Grady batholith is located in the NW corner of Figures 3.1 and 3.2, approximately 100 km NNW of Tungsten, and is of type (1) - hornblende-bearing. Gordey and Anderson (1993) reported that the core of the batholith is a remarkably homogeneous megacrystic hornblende quartz syenite, with hornblende abundance being the only obvious variable; this is bounded by a marginal phase of massive equigranular hornblende-biotite granodiorite, separated by a foliated transitional phase. Groat et al. (1995) found that the pegmatite-rich area is about 5 km^2, localized at approximately 62º53'N, 128º59'W and comprises common leucocratic 1-3m en-echelon aplite dykelets, and somewhat larger zoned pegmatite and alaskite intrusions, all with abundant tourmaline. Further details of the Little Nahanni and O'Grady pegmatites are provided in Chapter 6 on Mineral Occurrences.

The "Ting" alkalic bodies were emplaced to the south in Yukon Territory (Fig. 1.1), near the intersection of the Leith Ridge Fault and the shale-carbonate facies change (Inset of Fig. 3.1), during the Laramide deformation (about 53 Ma; Harrison 1982) and are the youngest intrusions in the region. Although these bodies are elevated in rare earth elements, and a number of localities are shown in Fig. 8.1 in the same region of eastern Yukon, there is no indication that other intrusions like these are present in any of the eastern Nahanni study areas for this report.

3.1.8. Quaternary - unconsolidated glacial and alluvial deposits

Ford (1976) divided Nahanni National Park into three distinct glacial zones which are summarized below but not illustrated in this report. These zones do not correspond to his litho-structural zones which are broad divisions based on Douglas and Norris (1960) and Gabrielse et al. (1973). Duk-Rodkin and Lemmen (2000) provide the regional Mackenzie River Valley context, and the limited fieldwork done by this study corroborates their observations. The scale of Ford's divisions is appropriate to the scale of domains used here for mineral resource assessment.

The Cordilleran Glacial Zone of Ford extends from the western limit of NNPR to the west side of the Funeral Range (Third Canyon of South Nahanni River). This Zone was repeatedly scoured by valley glaciers (Fig. 3.6) from W to SW. In this case, "Cordilleran" refers to glaciers that originated in the Selwyn and Logan Mountains. Ford noted that they glaciologically resembled the Cordilleran Ice Sheet of B.C., but were not geographically linked to it.

Figure 3.6. Fog occupying the South Nahanni River valley near the Vulcan property, looking south-easterly toward Vampire Peaks. One could imagine this being the surface of a Quaternary valley glacier, occupying a U-shaped valley.

The Laurentide Glacial Zone was defined by Ford from the eastern park boundary (Yohin Lake area) to the eastern flanks of the Nahanni Karst and Tlogotsho Plateau where extensive knob and kettle terrain is found (Fig. 3.6). Ford found evidence of three successive Laurentide ice sheets. Work in this study has found abundant evidence of Laurentide ice transport, with both heavy mineral suites (See Chapter 4.5.4) and common rock types in stream gravels being characteristic of the Canadian Shield.

Figure 3.7. Knob and kettle terrain on the north side of South Nahanni River, opposite Rabbitkettle Lake (also a kettle lake).

The Unglaciated Zone of Ford lies between the Cordilleran and Laurentide zones, in the Funeral, Headless and Tlogotsho Ranges, the western half of Nahanni Karst Plateau and interior lowlands such as Deadmen Valley. Ford has found traces of ancient, small glaciations but no indication of recent invasion by large ice masses such as has been documented for the adjacent zones. Supporting evidence found in this study includes varved lacustrine deposits in places such as the Meilleur River Valley, which once lay beneath glacial lakes Nahanni and Tetcela that were confined to the present valleys of South Nahanni, Meilleur, Jackfish and Yohin rivers, between the Cordillean and Laurentide ice sheets.

Duk-Rodkin and Mellen (2000) showed that such lakes were common along the margin of the Laurentide ice sheet, and in particular at its interface with Cordilleran ice sheets. Post-glacial fluvial activity has eroded some of these lacustrine deposits, producing small cut sections of varved clay and armoured mud balls composed of glacial clay with pebbles adhering to the outside. Such lacustrine deposits are blanket like and tend to obscure the geochemical signature of bedrock beneath them. Fortunately they are restricted to river valleys, so that slopes and ridges on either side would still contribute geochemical information of local relevance.

Ragged Ranges study area lies in the Cordilleran Glacial Zone. Peaks in the Ragged Ranges reach elevations of 9000 ft. (2740 m.). Spectacular examples of alpine glaciation include cirques, arêtes, tarns, (Fig. 3.8); moraines (medial and terminal) and ice-cored rock glaciers that can be found in many mountainous valleys (e.g. Fig. 3.9).

Figure 3.8. Glacier Lake, here viewed looking east from Mount Harrison Smith (L) – Mount James MacBrien (R), is a large tarn – a glacial lake dammed by moraine at its downstream end.

Figure 3.9. Ice-cored rock glacier facing Lened, view looking east from Lened toward Ragged Ranges.

At higher elevations, the steep sides of U-shaped glacial mountain valleys are flanked by talus aprons and lateral moraines. These products of active alpine glaciation contribute locally derived clastic material to present drainage systems where it is reworked as alluvium. Larger valleys are flanked by thick accumulations of intermixed glacial tills and fluvially reworked glacial sands and gravels which are being undercut by the present rivers. This undercutting results in listric faulting and slope failures, such processes threatening any modern constructions that have been built on the outside banks of river meanders (Fig. 3.10).

Figure 3.10. Slumped alluvium, north side of Nahanni River bank, near Rabbitkettle River.

Figure 3.11. Bedded fluvial sands and gravels are also sculpted by rain and snow melt, locally forming hoodoos such as these on the east side of Black Wolf Creek (station SMH-N6).

Figure 3.12. Polje #1 looking north, full of water; registered as GSC Photo # GSC204872-Z.

The Nahanni Karst and Tlogotsho Plateau study areas straddle the Laurentide Glacial Zone and the Central Unglaciated Zone. In the Laurentide Glacial Zone, especially north of the South Nahanni River, Holocene and current karst activity is evidenced by numerous sinkholes, solution valleys, caves and disappearing streams (Figs. 3.12-).

Figure 12. Polje #1 looking north, empty of water. Note grassy floor and series of small depressions along the margins that reflect small vertical drainage channels. Photo by F. A. Michel; station no. FAM87N4-16.

Figure 3.13. Lateral drain hole on north side of polje #1. Adult person for scale.

Figure 3.14. Polje # 1 looking west over Pond at extreme eastern corner, Drainhole shown in Fig. 13 is on the right out of view. Station 87JP4, GSC Photo # 204872-S19.

Ancient karsting has also been preserved as part of the Manetoe Facies (Morrow and Aulstead, 1989), some examples of which are visible in the walls of the First and Second canyons of South Nahanni River (Fig. 3.5).

The eastern study areas were most recently affected by Laurentide glaciers although karst activity has destroyed the shapes of most of the deposits. Garnets from the Canadian Shield, present in the heavy mineral concentrates of many eastern streams (Chapter 4.5.4) and Canadian Shield granite pebbles and cobbles in the stream beds (Chapter 4) provide evidence of Laurentide glacial influence in the eastern part of NK/TP study area. This influenced our interpretation of fine placer gold in these sediments as also being derived from the Canadian Shield (Chapter 4.5.5).

Stream beds of the easternmost basins are composed entirely of sand and silt, and therefore no granite pebbles were noted. Rare granitic pebbles were noted in a few basins in the western part of the study area; these could have been derived locally, and were not included in the compilation. The documentation of granitic pebbles, like all other geological observations made during this and earlier studies in the region, is dependent on factors such as exposure, local abundance, the skill of the observer and the density of observations, therefore some other basins may also contain granite pebbles in their stream beds.

3.2 Metamorphism

The South Nahanni River region is of very low metamorphic grade, sub-greenschist facies, best measured by organic indices to pressure and temperature such as conodont alteration indices, and using stratigraphic means to estimate depth of burial (Gordey and Anderson, 1993 estimated no more than 10 km of burial). Local contact metamorphism and variably extensive alteration zones related to skarn deposits flank plutons in the Ragged Ranges. These obvious, rusty weathering zones include andalusite and biotite in shaley rocks, and alternating green diopside – reddish garnet – pale talc-tremolite-calcite zones in carbonate rocks, with sharp contacts and narrow aureoles reinforcing the shallow depth estimates noted above (ibid.).

In the eastern study areas, Mattson coals are of lower bituminous grade, and have reached sufficient temperatures and pressures to be oil and gas prone (Potter et al. 1993a, b). Underlying and overlying hydrocarbon-bearing strata detailed in Chapter 8 increase in maturity with depth, and have maturities ranging from the oil through dry gas windows. Details are in Chapter 8.

3.3. Tectonism and Paleogeography

The South Nahanni River region transects the southern end of the Mackenzie Mountains fold and thrust belt. Before deformation, this region was a continental margin with platformal carbonate and clastic strata on the east and basinal shaley strata on the west. Various tectonic features influenced the details of this transition as briefly discussed in the stratigraphy above. Some of these features, such as the Mackenzie, Ogilvie and Redstone arches, were positive topographic elements since the cratonic margin was created by rifting in Neoproterozoic time (about 750 Ma) and these continued to influenced Paleozoic sedimentation. For example the Redstone Arch flanks Root Basin on the west, is the core of the Sombre Salient, and is now a large anticlinal feature that was re-developed during the Laramide orogeny.

Regional to local extensional and strike-slip faults influenced the details of the Prairie Creek embayment, and facies changes elsewhere in Selwyn Basin. Pelly Platform west of the study area represents a large offshore island in Devonian time (350 Ma). Examples of such faults are discussed by Gordey and Anderson (1993, p. 94) as they affect middle to late Devonian Earn Group strata.

The Selwyn and Mackenzie fold belts were created as part of the western Cordillera, related to arc-continent collision during the Mesozoic, beginning about 170 Ma (Tempelman-Kluit, 1979). When the island arc collided with North America, folds and thrusts propagated eastward as far as the Liard River and Nahanni Butte (Fig. 3.15), where Devonian limestones are thrust over the Fort St. John Group shales of Cretaceous age. During the propagation of the folds and thrusts, the early Cordillera shed debris eastward, forming younger sandstones to the east. Deformation in the west was most intense, involving emplacement of crustal slices of Island Arc rocks on top of the Selwyn Basin and platformal strata. The widespread mid-Cretaceous granitic rocks described above, were generated by partial melting during the intense collision and intruded already deformed Paleozoic strata now exposed in the eastern Selwyn Fold Belt, including Ragged Ranges. As summarized by Gordey and Anderson (1993), right-lateral faulting along the Tintina Fault generated offsets estimated at 450 to 650 km.

Figure 3.15. West flank of Nahanni Butte looking East toward open anticline in cliff of Nahanni dolostone. Underlying Fort St. John Group shales are recessive, and not exposed in this area. Liard River is in far background, Nahanni River on right.

As summarized by Gordey and Anderson, structural style varies with lithology. Thick, massive units such as the Rabbitkettle Limestone, form large structures whereas thinly bedded shaley limestones form repeated small folds and fault panels. Structural style also varies with intensity of deformation, with tight folds and thrusts to the west, (e.g. Ragged Ranges area) and open folds but still thrusts to the east (e.g. Fig. 3.15). In the eastern area, the carbonate platform succession (Major unit 4) forms large structures, with the Nahanni Karst and Ram Plateau being the result of uplift over a large anticline. Tlogotsho Plateau is also underlain by such large structures, the underlying limestones controlling and being mantled by shales through sandstones of units 6 and 7. With increasing thickness of the thinner bedded units 6 and 7 toward the south and east, fold and fault structures become more complicated as outlined in Chapter 8. These structures form traps for hydrocarbons.

3.4. Definition of Resource Assessment Domains for Minerals and Coal

Two previous mineral and fuel resource assessments have been completed in the adjacent Yukon Territory (Geological Survey of Canada 1981a; Sinclair et al. 1981); some of the conclusions from this earlier work are applicable to the western part of the Nahanni area, but the original (Yukon) assessment domains were not extended into the Nahanni region of the District of Mackenzie. Assignment of the geology of the South Nahanni River area into relatively detailed assessment domains is most easily done in the east where folds are broad, there are no igneous intrusions, and large areas are covered by single major rock units (Table 3.1) that have undergone relatively specific geological histories.

Domains to the west are much less amenable to assignment because of more complicated structural repetitions and intrusions of the Selwyn Plutonic Suite. This results in overlapping of mineral deposit criteria of more and different deposit types. Western Domains are therefore very broad and difficult to subdivide unless one deals with the scale of individual stream catchment basins. However, uncertainties become very large in such small basins, so that using resource assessment domains to help define specific park boundaries is a challenge in Ragged Ranges. For this study therefore, the western domains have different subdivisions depending on the deposit type being considered., and require considerable subdivision in the application of resource potential ratings.

Eight metallogenic (combinations of geological and geochemical factors pertaining to mineral deposit types) domains that have generally consistent internal attributes in the South Nahanni River area are outlined below in alphabetical order, referring to geological relationships summarized in Figures 3.1 to 3.3. These domains, not relevant to hydrocarbons (see Chapter 8), are illustrated in Fig. 3.16.

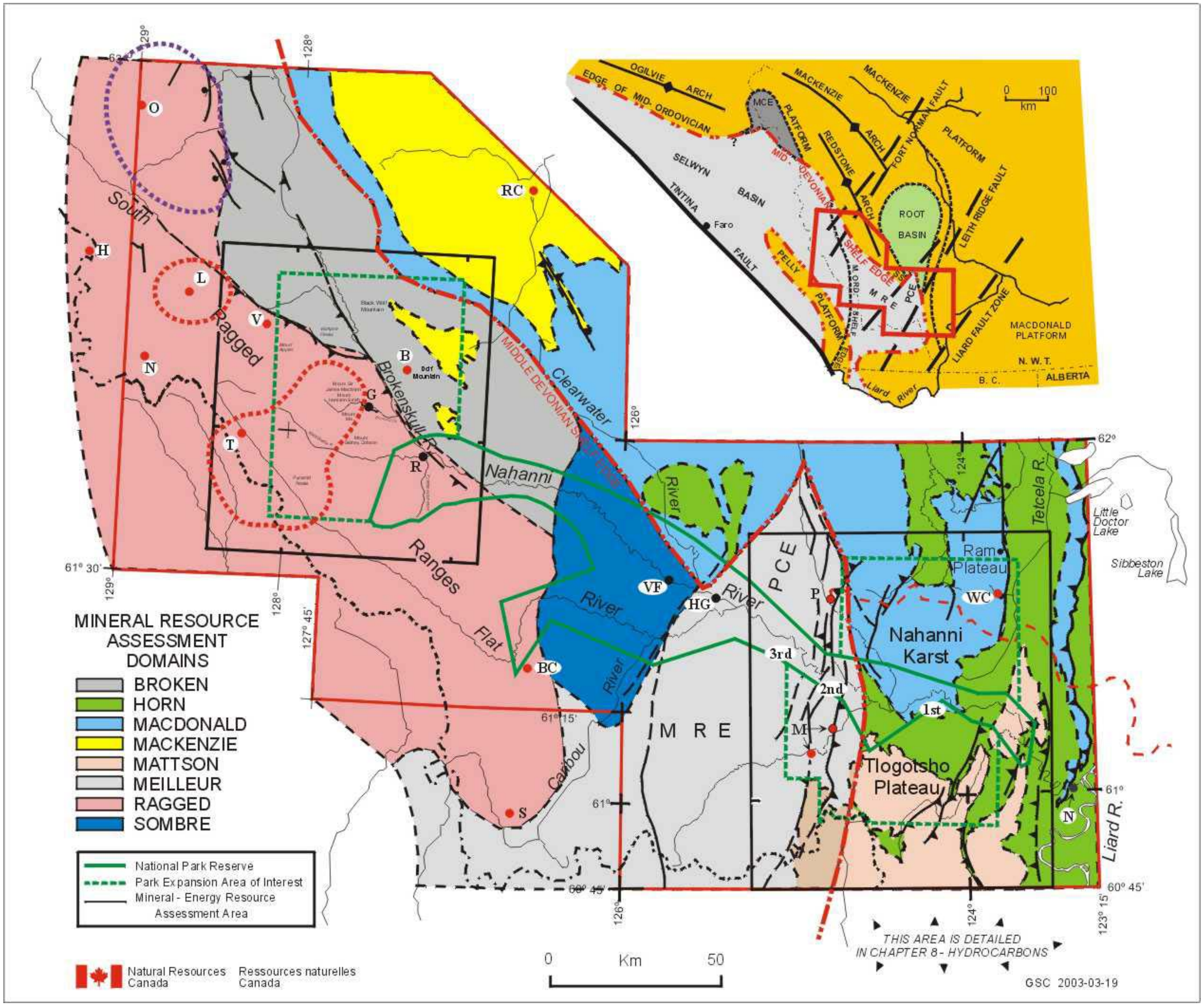


Figure 3.16. Assessment domains of the South Nahanni River region. Domains are explained in text; geography and inset as in Fig. 3.1.

The **Broken Domain** comprises a heterogeneous linear array of the five oldest rock packages (1 - 5), all on the shale (western) side of the MIDDLE DEVONIAN SHELF EDGE carbonate/shale facies boundary in the area of Broken Skull River. It is bounded on the southwest by the zone of intrusion by the Selwyn Plutonic Suite (Ragged Domain) and ends to the southeast against the uplifted salient of early Paleozoic limestones of Sombre Domain (Ordovician Sombre dolostone) that transects the Nahanni River. Each rock package in this heterogeneous domain has its own metallogenic signature, so that it will be impossible to generalize the resource potential here. Even the boundaries of this domain are indistinct. For example the Devonian carbonate-shale facies boundary is at different positions in strata of different ages and is actually a transition zone about 50 km wide between the shale-dominated Broken Domain and the carbonate-dominated MacDonald Domain.

The **Horn Domain** comprises thin Devono-Mississippian and Cretaceous shales and shaley carbonates of rock packages 5 and 6 that drape underlying carbonates of the MacDonald Platform and sandwich the Mattson Formation. These dark fine-grained rocks are very uniform in facies over wide areas. This domain is centred along the eastern South Nahanni River. Separate areas of this domain surround the Ram Plateau portion of the MacDonald Domain, cover the MacDonald Domain near Clearwater River, extend along the Liard River, and continue north along the Tetcela River and on the east side of Nahanni Butte (Fort St. John shales beneath the Nahanni Thrust) up to Little Doctor Lake area.

The **Macdonald Domain**, characterized by Paleozoic carbonate strata of the Nahanni Karst region, is the surface expression of the Mackenzie to MacDonald Platform as outlined in Figure 3.1. This surface domain is bounded on its southwestern side by the Devonian carbonate-shale facies boundary, and to the northwest wraps around the Mackenzie Domain (Neoproterozoic strata north of Clearwater River). It comprises rock unit 4 which includes the gas- and base-metal-bearing Manetoe Facies, with minor amounts of units 3 and 5. Large deviations from the Devonian facies boundary, and subdivisions in this domain result from structural exposure of different ages of strata. An outlier of this domain is the Nahanni Thrust East of the Nahanni Karst study area, where Devonian carbonates including the Manetoe Dolomite overlie Fort St. John Group shales. In the Nahanni Karst and Ram Plateau areas this carbonate platform is uplifted by gentle anticlines, transected by minor faults and lineaments, partly covered by Devonian shales, and extensively karsted.

The **Mackenzie Domain** forms the core of the Redstone Arch, bounded by the MacDonald Domain on the southwest and its southern end. It barely crosses the northeast corner of the Ragged Range study area, but outliers of this domain are located within Broken Domain, and it is included to complete the regional metallogenic discussion. This domain comprises rock-packages 1 and 2, Neoproterozoic strata, which are uplifted along the Redstone and Mackenzie arches (Fig. 3.1).

The **Mattson Domain** occupies the Tlogotsho Plateau area and extends southward into the Liard Fold Belt which is assessed for hydrocarbon potential in Chapter 8. The Mattson Domain is named for the Cretaceous sandstone formation that hosts minor coal seams, extends northeast into the Yohin Lake area, and overlaps the Meilleur Domain to the west. The limits of this domain are simply defined by the extent of the Mattson Formation (Figs. 3.1, 3.3, 3.4).

The **Meilleur Domain**, similar to the Broken Domain, comprises three main elements that are arranged in a north-trending linear array on the west (shale) side of the MIDDLE DEVONIAN SHELF EDGE. Paleogeographically, it occupies the Meilleur River and Prairie Creek embayments of Selwyn Basin. Stratigraphically it is restricted to rocks overlying the Sombre Formation and underlying the Besa River Shale. The latter, together with the overlying Flett Limestone and Mattson Formation, overlap Meilleur Domain south of the Meilleur River, but the most important metallotects of the Meilleur Domain continue underneath toward the south-southwest. Structural elements shown on Figs 3.1, 3.3 and 3.4 are concentrated along the eastern margin of Meilleur Domain, representing late tectonic reactivation of interpreted early faults that controlled the distinct east-west carbonate-shale facies change that is a prime favourable indicator for Sedex lead zinc mineral potential. The Meilleur Domain extends southwesterly where it wraps around the southern end of Sombre Domain and around the area of influence of Cretaceous intrusions that define the southern limit of Ragged Domain.

The **Ragged Domain** contains some of the oldest and the youngest rocks in the assessment area: some of the same heterogeneous elements as the Broken Domain are further complicated by lithologic diversity among Cretaceous quartz diorite-quartz monzonite intrusions, and the various thermal and hydrothermal alteration effects thereof. Associated mineral deposits were described by Sinclair (1986). A major stratigraphic difference from the Broken Domain is that most of the Late Proterozoic and much of the lower Paleozoic are shale-dominated rather than quartzite-carbonate-dominated. It may be more than coincidental that the northeastern boundary to this plutonic belt is approximately that of two major facies changes: (1) the Late Proterozoic facies change from Backbone Ranges to Vampire formations, approximately along the western South Nahanni River, and (2) the edge of the mid-Ordovician platform, some 20 km west of and sub-parallel to Broken Skull River. Within these shale-dominated packages, thin limestone units of latest Neoproterozoic, Cambrian and early Ordovician age host the world-class tungsten skarn deposits, adjacent to the two-mica type of intrusion. The area of these prospective intrusions is outlined by a red dashed line on Fig. 3.4 and extends from just southwest of Tungsten to Mount Harrison Smith and Glacier Lake. The Ragged Domain crosses the southwest half of the Ragged Ranges park-extension study area, and is even less amenable to generalizations than the Broken Domain.

The **Sombre Domain** is an oblong exposure of Ordovician carbonate rocks, the Sunblood Formation and Sombre Dolostone, that extends across the middle of Nahanni Park Reserve just above the confluence of the Flat and South Nahanni rivers. This area may in part have been covered by shales of the Road River Formation, but uplift has exposed the mid-Ordovician platform whose shale edge is located far west of the Mid-Devonian platform-edge and trends through the middle of Ragged Ranges (inset of Fig. 3.1). The western side of Sombre Domain is bounded by Road River shales, and the area of influence of Cretaceous granites that defines the Ragged Domain. Road River shales wrap around the southern end of the Sombre Domain and form its eastern margin along the Caribou River. This margin is roughly aligned with the northwest side of the Meilleur River and Prairie Creek embayments, and suggests the influence of a fundamental pre-existing basement structure akin to the Leith Ridge Fault.

3.5. Geological Features of Public Interest.

Many geological features of public interest have been described and illustrated above (Figs. 3.5 through 3.15 inclusive), as part of a systematic introduction to the geological history of the South Nahanni River region. A number of other specific features are described and illustrated in the following.

Virginia Falls marks the upstream limit of navigation by motorized vessels on the South Nahanni River and is situated on the resistant dolostones of the Sunblood Formation, which form ridges on the surrounding mountains. No specific structure explains the present falls, but like other limestone features and other falls, this cascade has likely evolved and migrated to its present site through millions of years.

Several times during its varied geological life, the South Nahanni River was a lake (Glacial Lake Nahanni, Ford, 1976), that covered the area of these falls. As in Nahanni Karst, the carbonate rocks that form the cliff over which Virginia Falls cascade, are prone to vertical dissolution which would be accelerated by the volume of water passing through. It would not be surprising if at one time the falls had existed at the mouth of the first canyon and though progressive down-cutting and upstream migration, ultimately reached their present location.

The ptygmatic shape of the 1st, 2nd and 3rd canyons is typical of entrenched meanders that one time were actively changing their shapes when the river flowed over the surface of the limestone. Later, the river started to cut down through bedrock and the shapes of these meanders became fixed.

At the specific site of Virginia Falls the Sunblood dolostones are gently dipping and include recessive shaley beds at the level of the base of the falls (Figure 3.17). These are the same ingredients that are found at Niagara Falls, with the recessive shaley beds at the base being continually undercut, causing repeated collapse and freshening of the cliff that forms the falls. Shaley horizons in the upper Sunblood beds are illustrated on Sunblood Mountain (see p. 12 Morrrow and Cook, 1987). Luvigsen (1975) provides more general information on the Sunblood, that was originally named by Kingston (1951, cited in Ludvigson) at Virginia Falls.

Figure 3.17. Virginia Falls (centre) are carved into the dolomitic Sunblood Formation that was named at this site by Kingston (1951). This resistant dolostone is gently folded and includes recessive shaley limestone (dark beds at water level, left at the base of the falls) which is undercut by the force of the falls to maintain the near-vertical cliff at the falls. A large block of Sunblood in the middle of the falls has broken off and is being gradually worn away as these falls migrate upstream, leaving an entrenched meander in the gorge below the falls. See text for more.

Many, varied, hot through cold springs are of interest to bathers and scientists alike in the South Nahanni River region. These are described fully in Chapter 5; a few illustrations are provided here. Scenic springs, like **Rabbikettle Hot Springs**, are characterized by picturesque build-ups of calcareous sinter that, through continued percolation of water and precipitation of calcite in many small pools (rabbit-sized "kettles"), ultimately form massive travertine limestone bodies. Rabbitkettle Hot Spring is located on the southeast side of Rabbitkettle Creek near its confluence with the South Nahanni River. The name Rabbitkettle has been given to nearby Rabbitkettle Lake that is actually a kettle lake in the glacial sense (A mass of residual glacial ice in till melted leaving a hollow to be filled with water). Geologists have used this name for a regionally extensive limestone of Cambro-Ordovician age (about 500-400 Ma) that is correlated from Williston Lake in northern British Columbia to western Yukon Territory.

Figure 3.18. Rabbitkettle tufa travertine springs are fault localized; their waters have high total dissolved solids but low trace metal contents (station 86-JPH-001; Type D of final classification, Chapter 5).

Figure 3.19. White Aster (86JPH-082; Meilleur R. area), a metal rich hot spring, was discovered by S.M. Hamilton during the course of his M.Sc.studies (see Chapter 5 and Figure 5.26, a painting by C. Blyth), but has been a tonic to wildlife for years.

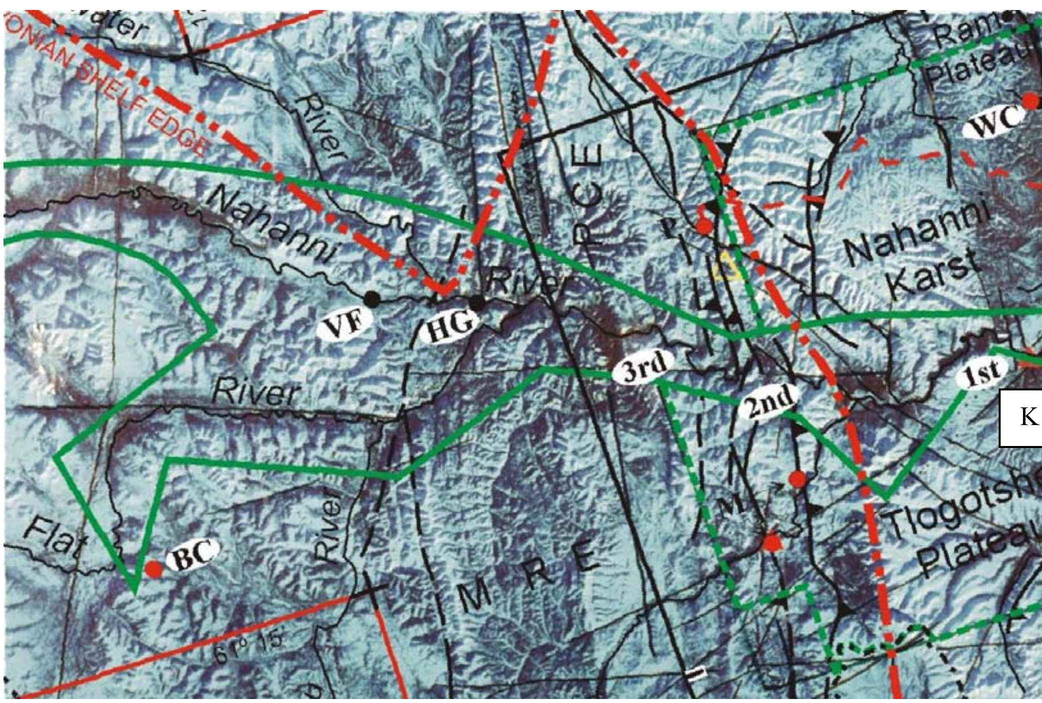
Whereas Rabbitkettle is characterized by mainly limey precipitates and a comfortable 21º C temperature, the **White Aster** hot spring of Meilleur River valley (Fig. 3.19) is a steamy 38.5º C at its source, and precipitates a mixture of both limey and lead-zinc rich precipitates. Other hot springs nearby are even more metal rich (see Table 5.12 and full discussion in Chapter 5). Nonetheless, the abundance of vegetation and the innocuous colour of the White Aster hot spring complex camouflage it from the passerby.

Figure 3.20. Iron-Spring Ragged Ranges area. FAM86-7-24 GSC204872-J_N37

Other metal-rich springs in the region are highly visible due to their bright red-ochre precipitates (Fig. 3.20). Many of these have iron as their only metal content, but in some there are high levels of zinc and cadmium related to the bedrock through which the waters flowed before venting. The iron oxides also act as metal scavengers, naturally concentrating elements such as zinc which are relatively soluble and can be leached from large volumes of low-zinc bedrock.

The location of many of the springs in the South Nahanni River region must be controlled by fracture systems that are active and deep enough to permit waters to circulate through hotter rocks at depth. A preliminary examination of satellite imagery shows that such structures have ideal late, brittle and vertical orientations, criss-cross the region, and their intersections form ideal sites to focus fluid flow. Fig. 3.21 illustrates use of LandSat imagery to assess the origin and suggest ways to model fluid flow that creates these hot springs.

.



Features E to W:
WC – Wretched Creek
K – Kraus Hot Springs
1st, 2nd, 3rd – Canyons on S. Nahanni River
M – Meilleur River Hot Springs
HG – Hells Gate
VF – Virginia Falls
BC – Bennett Creek (placer gold)
Red dashed line = middle Devonian shelf edge.
Solid green line = NNPR boundary
Dashed green line = proposed expansion to NNPR

Figure 3.21. Winter LandSat scene of the eastern NNPR area, from first canyon through to 50 km above Virginia Falls. Lineaments intersect at a number of springs, in particular Kraus and Meilleur River (White Aster) hot springs. No obvious lineament is associated with Virginia Falls. Image is about 143 km across.