BC

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Ministry of Energy, Mines
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Hon. Anne Edwards, Minister

MINERAL RESOURCES DIVISION
Geological Survey Branch

SELECTED THERMAL COAL BASINS OF BRITISH COLUMBIA

By A. Matheson, P. Geo., D.A. Grieve, P. Geo.,
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VICTORIA
BRITISH COLUMBIA
CANADA

OCTOBER 1994

TABLE OF CONTENTS

PHOTOS

GENERAL HISTORICAL BACKGROUND

Coal was first mined in British Columbia in 1836 at what was to become known as the Suquash coalfield near Port McNeill, northern Vancouver Island. The primary purpose was to supply fuel to the Hudson Bay Company's steamer "Beaver". When larger deposits of good quality coal were discovered in Nanaimo in 1852, Suquash was closed and operations moved southwards. New mines were opened near Cumberland in the Comox coalfield in 1888 and production increased rapidly, reaching a peak in 1922, after which there was a gradual but steady decline due to the increasing competition from petroleum. Mining on Vancouver Island ceased in 1968 after having produced a total of 65 million tonnes of coal. Most of the coal was used for thermal purposes. Significant production did start again two decades later at Quinsam, in the Comox coalfield, near Campbell River. The mine is currently in production and produced 1 400 000 tonnes between 1988 and 1992.

On the Mainland, thermal coal occurs in numerous intermontane basins varying from mid-Jurassic to Early Tertiary in age. The first of these to be developed was at Merritt in the Nicola Valley of south-central British Columbia, which produced about 3 million tonnes of thermal coal from 1896 to 1963. The completion of the Canadian Pacific Railway in 1906 boosted the production considerably.

Records of the occurrence of coal in the Bulkley Valley date back to the latter part of the 19th century but mining did not start until 1918, finally petering out in the 1970s after producing only about 500 000 tonnes, due to limited local

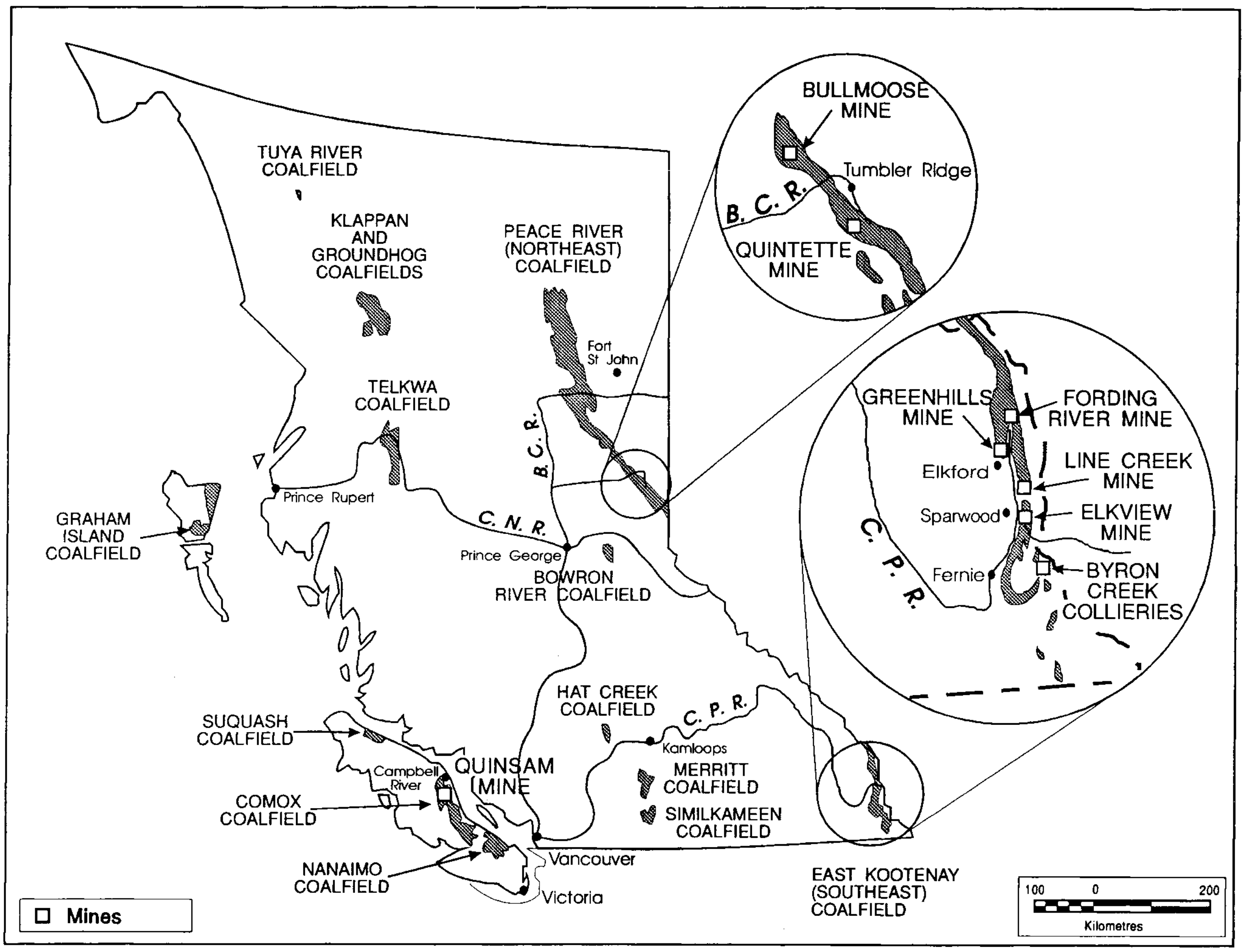


Figure 1. Coalfields of British Columbia.

demand. However, the reserves and resources in the Telkwa deposit are considerable.

Mining started around Princeton, in the Similkameen coalfield, in 1910 and continued through to 1961, producing a little over 1.6 million tonnes from numerous small mines. Production from the nearby Tulameen deposit occurred intermittently between 1915 and 1957, producing over 2.6 million tonnes in 27 years.

Some development took place at the Bowron River coal deposits but there has not been any production and the workings have since been razed for safety reasons.

The first mine opened in the Crowsnest coalfield in southeast British Columbia in 1897. By 1960, 55 million tonnes of thermal and metallurgical coal had been produced. At about that time, Japanese steel mills started purchasing metallurgical coal and by 1970, large long-term contracts with these mills relegated thermal coal to a 10 to 15% share of these larger volumes. Most of the coal sold for thermal use today is oxidised.

In the Peace River area of northeastern British Columbia, coal mining started in earnest in 1983, and had produced a little over 100 million tonnes of coal up until 1992. However, only a very small percentage of this is used as thermal coal, generally coal which is oxidized.

The northern fields have access to the Pacific Ocean at Ridley Terminals, Prince Rupert via the Canadian National Railway. In the south the Canadian Pacific Railway serves Westshore Terminals (Roberts Bank) at Delta, just south of Vancouver (Figure 1), and Neptune Terminals in North Vancouver.

INTRODUCTION

In 1988 the British Columbia Geological Survey Branch implemented a drilling program to obtain precise and detailed information on the quality of the thermal coal deposits of the province. The initial program lasted a period of four years from 1988 to 1991 and the drilling took place at the Comox, Telkwa, Bowron River and Merritt coalfields. The only current production from these coalfields is at Quinsam in the Comox coalfield, which has only recently come into operation, while two others were mined at various periods in the past. The least expensive method of data gathering would have been the sampling of coal outcrops. However, there are two drawbacks to this method: first, all coal outcrops are oxidized or leached to variable depths, which affects many of the properties to be tested; second, several areas have few surface exposures, for example, Bowron River and Merritt. Any fieldwork should therefore not only incorporate outcrop sampling but selective diamond drilling as well.

The viability of such a drilling program was assessed during the first field season and reported by Matheson (1989). In the first year studies centred in the Quinsam mine area. The drills used were the Packsack 4M drill and the X-ray drill. The Packsack drill (Photo 1) is a portable machine driven by a 10-horsepower, two-cycle, air-cooled gasoline engine and utilizing an IEX 25.4-millimetre (1 inch) diameter, single, rigid core barrel. It can penetrate to a maximum depth of 15 metres. This hand-held unit with variable throttle control is probably the lightest drill on the market. With accessories, but excluding rods, it weighs about 50 kilograms. It can be operated by one person, but two make the work considerably easier. Two holes were drilled with this machine. One was abandoned at 10 metres when the bit mudded in. The second, hole 88-1B, reached a depth of 8.3 metres and obtained 89% core recovery. The main drawback of the hand-held drill is that with a constantly changing fulcrum, the direction of pressure applied varies, resulting in deviation of the hole.

The X-ray drill was a very old unit which the suppliers, JKS Boyles Ltd., replaced with the Winkie. It was powered by a 9-horsepower, two-cycle, air-cooled gasoline engine, and could penetrate to a depth of over 100 metres. The unit, which was mounted, had two gears and weighed about 75

Photo 1. The Packsack 4M drill.

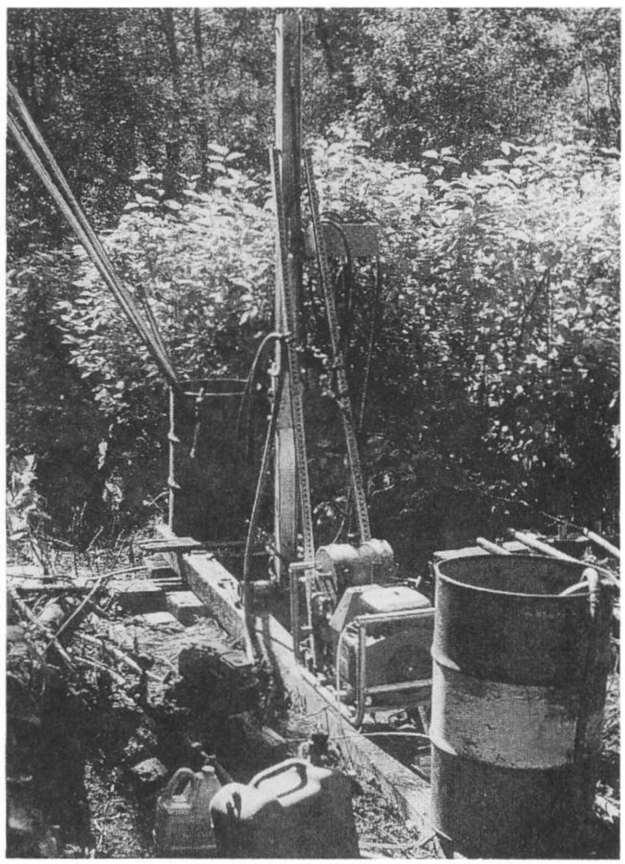


Photo 2. Quinsam study area.

kilograms without the rods. Holes GSB-88-1 and 88-3 used the double swivel type of core barrel with an internal diameter of 35.0 millimetres (IAX); average core recovery was 96.6% to depths of 34.25 and 54.25 metres, respectively. Hole GSB-88-2 was drilled with a double swivel type of core barrel, with an internal diameter of 22.3 millimetres (EX). The core recovery was 89% over a depth of 45.5 metres.

After the first field season the field budget was augmented by funds from the Institute of Sedimentary and Petroleum Geology, enabling the drilling metreage to be doubled. Throughout the program the drilling was carried out under contract by Neill's Mining Company, thus maintaining consistency in the high drilling standards. The drill used during this period from 1989 to 1991 was a Prospector 89, manufactured by Hydrocore Drills Ltd (Photo 2) (Matheson and Ven Den Bussche, 1990; Matheson 1992). This drill is light and portable with a total weight of about 200 kilograms (excluding the rods). The weight of the heaviest component, the engine, is 45 kilograms. The unit, which is mounted, is powered by a 16-horsepower air-cooled Briggs and Stratton engine and can drill to a vertical depth of 150 metres. A double swivel core barrel with an internal diameter of 35.0 millimetres (IAX) was used. Core recovery was good, at an average of 94% at Telkwa and 96% at Bowron River. At Merritt, however, it varied from 63% to 97%, due to poorly consolidated sandstone and mine workings.

ACKNOWLEDGMENTS

We would like to thank M. Fournier for his invaluable help and time in creating tables and figures. Cheerful and capable field assistance was provided by B. Van den Bussche and M. Sadre. The Neill family provided competent and professional diamond drilling service.

COMOX COALFIELD

LOCATION OF STUDY AREA

The Comox coalfield occupies a part of the eastern coastal plain of southern Vancouver Island. It extends approximately 130 kilometres northwest-southeast from southwest of Nanoose Bay to Campbell River, and up to 20 kilometres across, from the Vancouver Island Ranges to the coast (Figure 2) The extent of the coal measures under the Strait of Georgia is unknown. The area is covered by NTS maps 92F/1, 7, 8, 10, 11 and 14.

The coalfield contains several deposits, amongst which are the Tsable River deposit, the Cumberland deposit, and the northernmost, the Quinsam deposit. The latter, located 20 kilometres southwest of Campbell River, was selected for this study. The area was drilled and sampled in the summer of 1988.

The Island Highway (19) from Victoria, 150 kilometres to the southeast, passes through the coalfield, along the coast to Port Hardy, 238 kilometres northwest of Campbell River.

Access to the sea is not as easily attainable as it appears, due to the continuous residential and industrial development along the coast. Coal from the Quinsam area is trucked to Middle Point, a docking facility, 8 kilometres south of Campbell River. It is then barged across Georgia Strait to the Ideal Cement loading facility on Texada island, 65 kilometres south of Middle Point, which can accommodate Panamax size ships.

The present transportation system is under review. A deep water Panamax size ship (77 000 dwt) loading facility proposed near the existing barge terminal at Middle Point, would reduce transportation costs by $5 to $8 per tonne.

EXPLORATION AND DEVELOPMENT HISTORY

Production started in the Cumberland area of the Comox coalfield in 1876 and continued through to 1953, producing 18 million tonnes of coal. Between 1946 and 1957, 2 million tonnes were produced from the Tsable River area. Exploration had taken place throughout that 80-year period, but many records and locations of drill holes have been destroyed or lost.

After some minor exploratory drilling in 1973 and 1974, intensive exploration of the Quinsam deposit started in 1977 on Weldwood freehold lands, with Luscar Ltd. as the operator. Later, other coal lands were examined by various companies, and by 1975 a total of 613 holes had been drilled, 15 trenches excavated, and 7 bulk samples taken; all

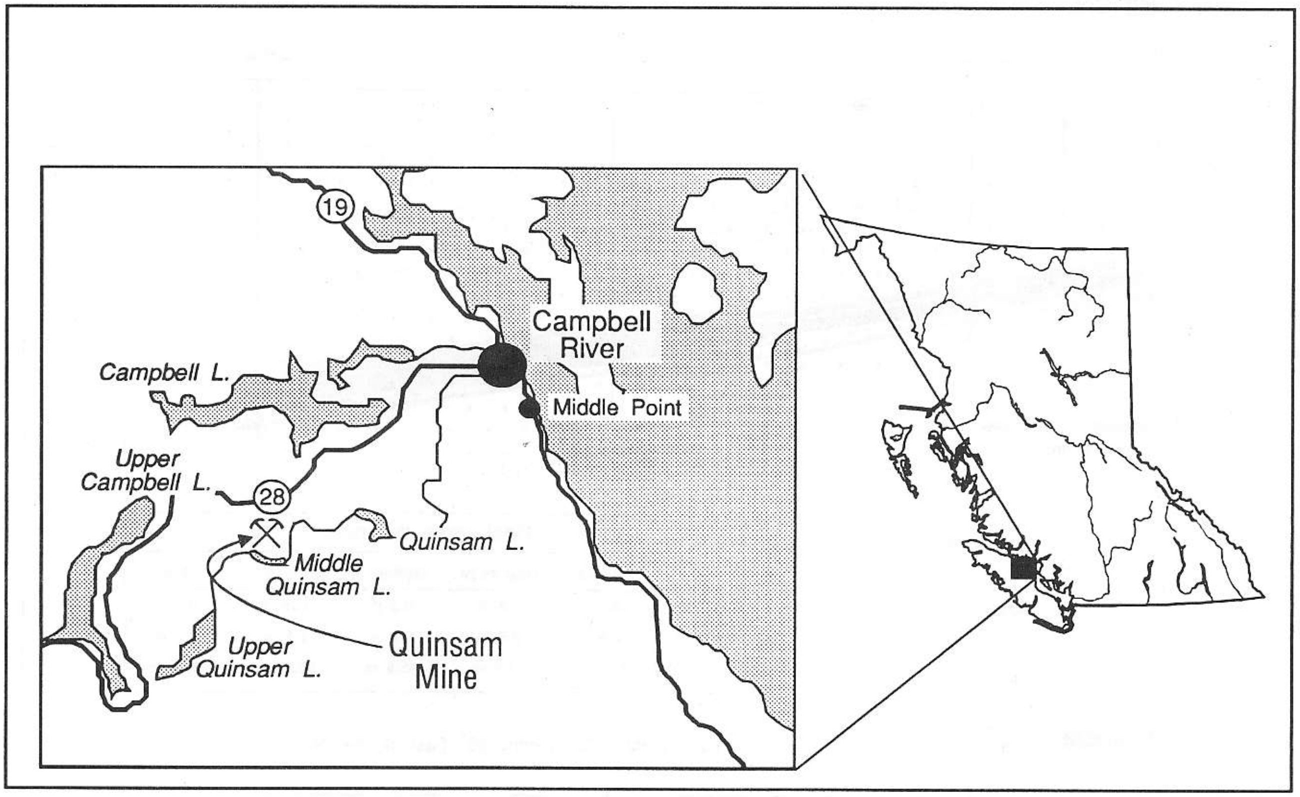


Figure 2. Quinsam study area.

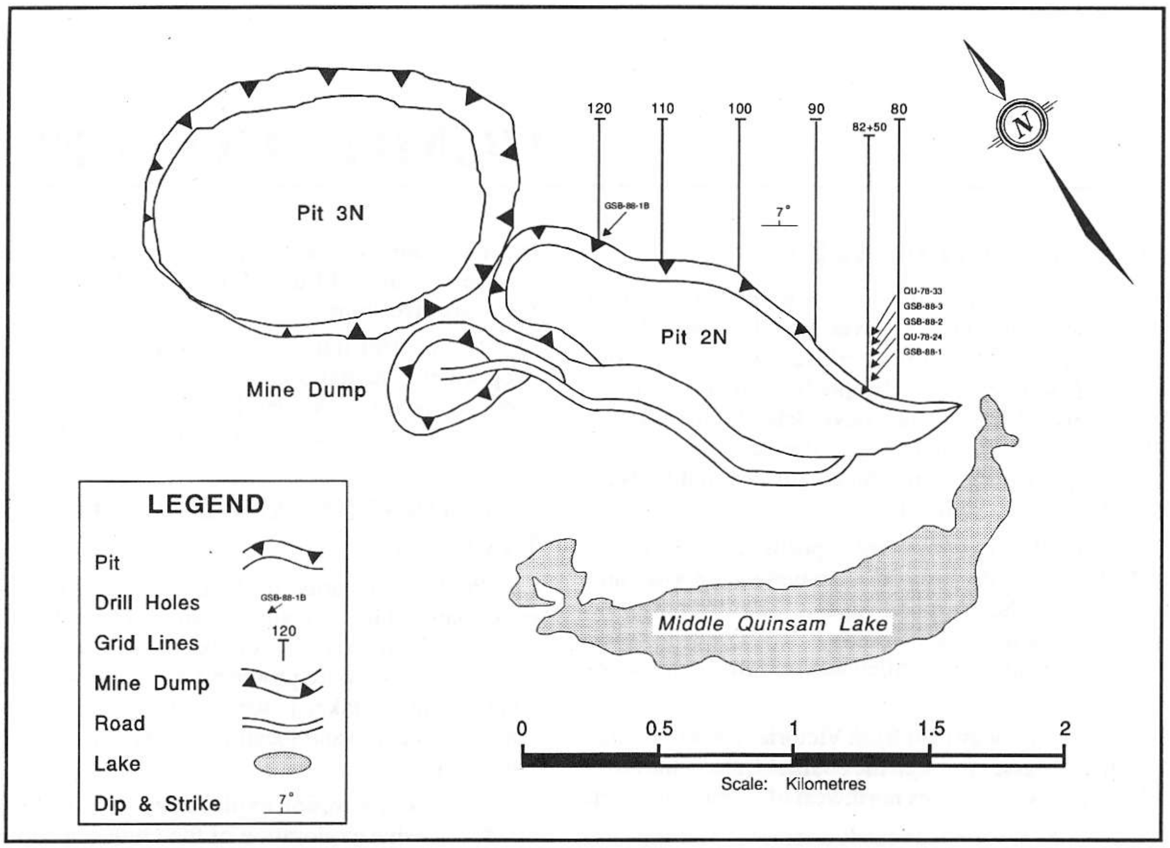
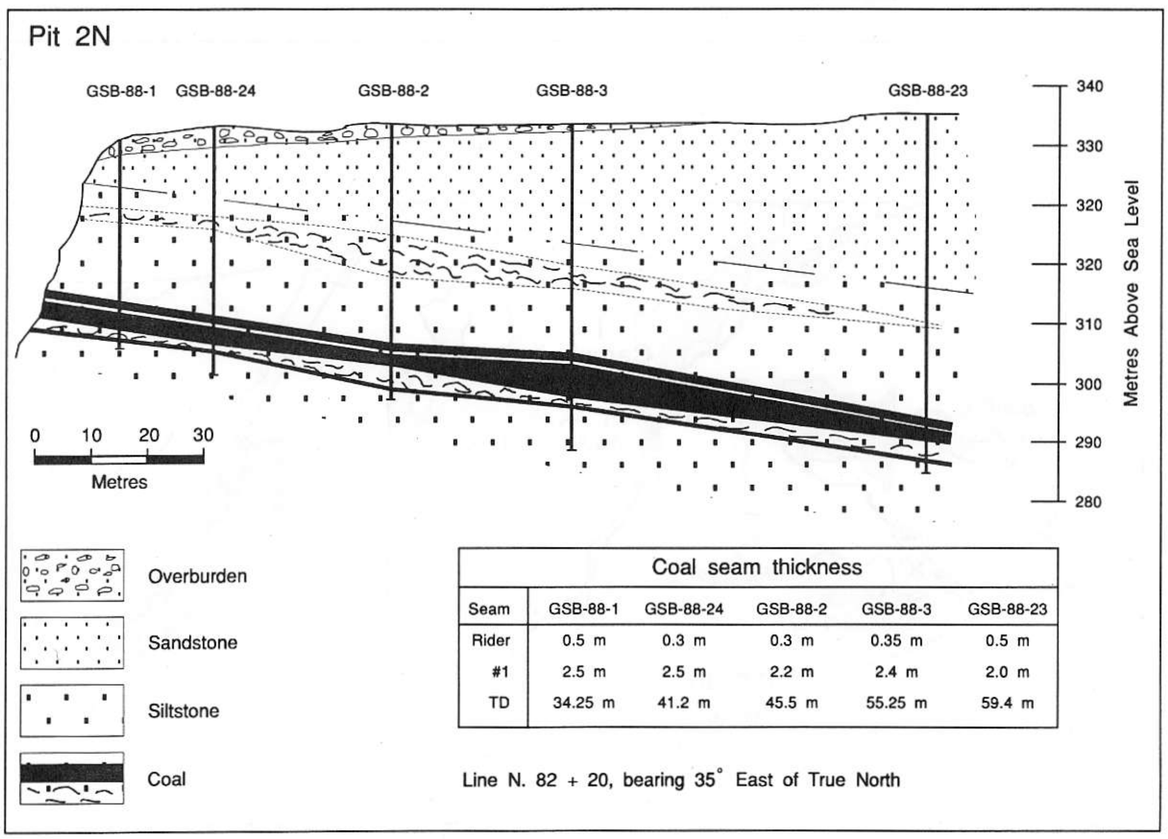


Figure 3. Quinsam mine site. The area is underlain by the Upper Cretaceous Comox Formation of the Nanaimo Group.



Coal seam thickness					
Seam	GSB-88-1	GSB-88-24	GSB-88-2	GSB-88-3	GSB-88-23
Rider	0.5 m	0.3 m	0.3 m	0.35 m	0.5 m
#1	2.5 m	2.5 m	2.2 m	2.4 m	2.0 m
TD	34.25 m	41.2 m	45.5 m	55.25 m	59.4 m

Figure 4. Quinsam coal mine, Comox Formation cross-section.

samples were analyzed and geophysical logs of holes recorded.

Quinsam Coal Ltd., owned and operated by Consolidated Brinco Limited, started open-pit mining at Quinsam, in the northern part of the Comox coal basin, in 1985. In 1988, 130 000 tonnes were produced and the name was changed to Brinco Coal Corporation. In December 1991, Brinco Coal, formed a joint exploration company with Hillsborough Resources Limited which at the end of 1993, became Quinsam Coal Corporation. To date, the mine has produced 1.4 million tonnes of raw coal. A fine-coal recovery circuit, using heavy media cyclones, has been put on hold until the 1994 construction season. Previously, two water cyclones were used to produce clean coal. Production for 1993 was 550 000 tonnes. Planned annual production for 1994 is the same or slightly better. Underground mining began in 1990 using the room and pillar method and the open pit will eventually be phased out.

GEOLOGICAL SETTING

Strongly folded and faulted Triassic and Jurassic basement rocks, which were subsequently eroded after uplift, are unconformably overlain by the Benson basal conglomerate of the Upper Cretaceous Comox Formation of the Nanaimo Group. The Comox Formation, consisting of sandstone, siltstone and mudstone, contains coal beds in the lower part of the formation. The sequence is moderately deformed by block faulting and tilting to the northeast. The dominant Tertiary fault system trends northwest. The general strike of the sediments is 305°, with an average dip of 15° to the northeast. The Nanaimo Group is intruded throughout by Late Eocene granitic stocks and associated porphyritic dacite dikes and sills (Kenyon *et al.*, 1992). The Karmutsen Formation, which forms the Beaufort Range, separates the coastal Comox coal deposits from the Quinsam deposit, lying in a faulted asymmetric graben in the Alberni Valley.

The Comox formation was developed in a coastal nonmarine depositional environment (Martonhegyi, 1985), however, several marine incursions did occur, such as those above No. 1 coal seam and its rider.

DESCRIPTION OF COAL MEASURES

The thickness of the Comox Formation in the basin is reported to range from 175 metres to 250 metres (Bickford *et al*, 1989). There are four coal seams numbered from the base upwards, No. 1 and its rider, No. 2, No. 3 and No. 4. They occur above the Benson basal conglomerate in a series of mudstone, siltstone and sandstone strata. No. 1 seam varies from 1.5 to 2.5 metres thick with some structural thickening up to 5.0 metres. The seam consists predominantly of bright, hard blocky coal with shaly partings and generally overlies a well-rooted podzol. The rider is similar in character but tends to be a little more friable with closer cleat spacing.

No. 2 coal seam could more accurately be described as a coal zone, consisting of bands of dull and bright, moderately friable coal, interbedded with bands of dirty coal and coaly mudstone. It pinches and swells up to 5 metres in thickness, (diamond-drill hole GSB-88-2), and is separated from No. 1 seam by 12.0 to 15.0 metres of strata, predominantly siltstone.

No. 3 seam is more aptly described as a zone, though it has been denoted as "No. 3 leader" and "seam No. 3" in the Quinsam area. It overlies No. 2 seam and is separated from it by 20 to 30 metres of sandstone with intercalated pebble bands. The zone varies from 2.5 to 3.5 metres thick. The coal is described as dull and bright to bright banded, hard and blocky, with abundant blebs and cleat fillings of pyrite (Kenyon *et al.*, 1992).

No. 4 coal bed, the uppermost, is about 1 metre thick, and occurs only locally. It consists of a bright blocky coal with abundant pyrite blebs and occasional thin bands of brown and black coaly mudstone (Kenyon *et al.*, 1992). A cross-section illustrating the coal beds intersected in the drilling program is shown in Figure 3.

DRILLING

Seventy percent of the previous drilling done on the property was rotary. Drill hole GSB-88-1B was spudded on a bench 3.2 metres above the No. 1 rider, which at that point is 25 centimetres thick. The No. 1 seam, 0.05 centimetre below the rider is 3.0 metres thick. The hole was drilled 1.5 metres from the face of old workings. As a result, the coal was both weathered and oxidized. This shallow hole (4 m) was drilled with the hand-held Packsack drill, whereas GSB-88-1, 88-2 and 88-3 were drilled with the X-ray drill. The latter three holes were collared on line 82+50 of the Quinsam mine grid. The bearing of the line is 035°, which is the average dip direction (Figure 4).

Hole GSB-88-1 was spudded 4 metres from the highwall and 15 metres southwest of Quinsam drill hole QU-78-24. Coal bands in No. 2 zone were intersected from 10.4 to 10.92 metres, giving a true thickness of 0.5 metre. No. 1 rider was intersected at 27.38 to 27.78 metres, and No. 1 seam at 28.0 to 30.5 metres, resulting in an overall true thickness of 3.0 metres 12 metres from the face.

Hole GSB-88-2 was drilled 30 metres northeast of QU-78-24 and 45 metres northeast of GSB-88-1. In No. 2 zone, coal bands sampled were between 19.5 to 20.1 metres, resulting in a true thickness of 0.58 metre. No. 1 Rider occurred between 37.25 to 37.85 metres, with a split between 37.55 and 37.75 metres. No. 1 seam was intersected at 38.2 to 41.0 metres, giving an overall true thickness of 3.55 metres.

Hole GSB-88-3 was collared 30 metres northeast of GSB-88-2 and 60 metres southwest of QU-78-24. The coal band sampled from No. 2 coal zone was from 22.0 to 22.15 metres. No. 1 rider was intersected between 39.2 metres and

39.55 metres and No. 1 coal seam from 39.87 to 42.4 metres, giving an overall true thickness of 3.1 metres. Drilling has shown the attitude and thickness of the coal seams to be fairly consistent, but with some local pinching and swelling (Figure 4). The type section is illustrated in Figure 5.

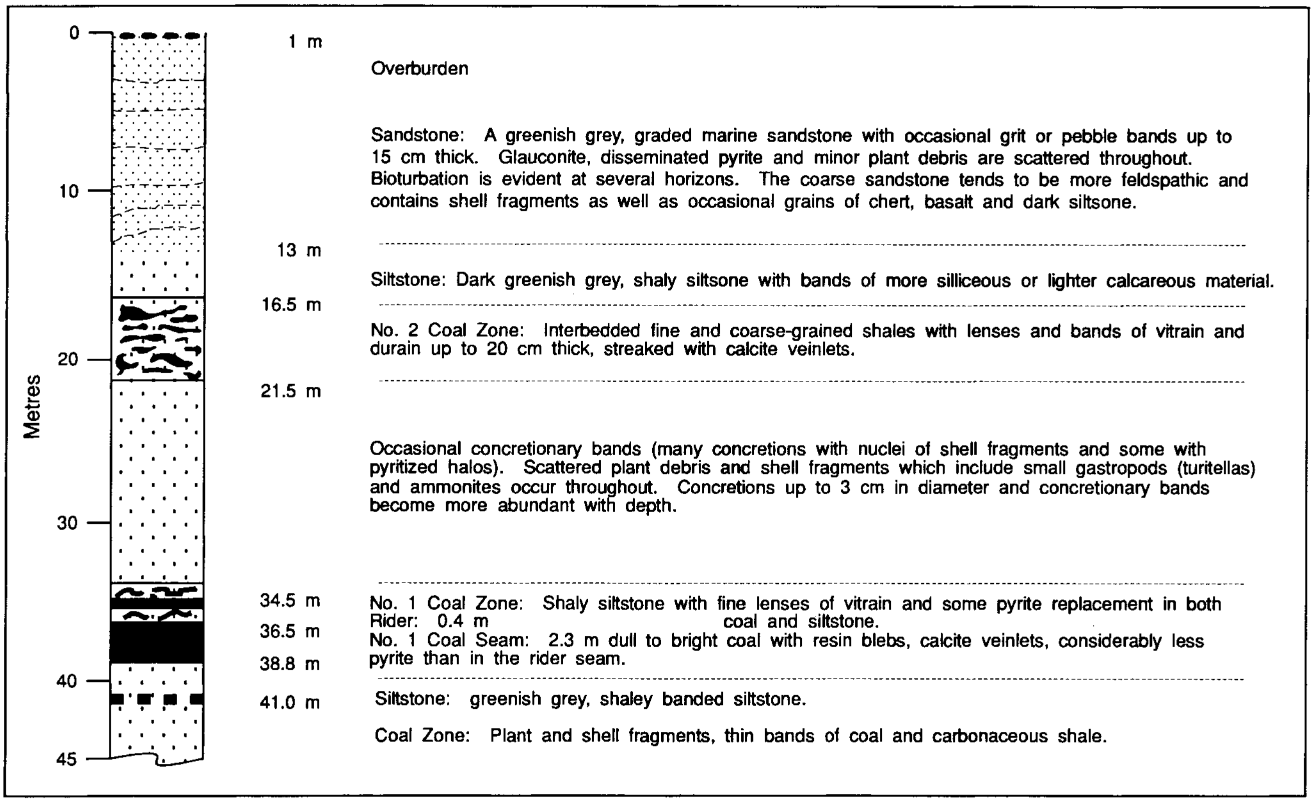


Figure 5. Type section, Quinsam mine.

TELKWA COALFIELD

LOCATION OF STUDY AREA

The drilling took place in the Telkwa coalfield located southwest of the village of Telkwa on the Yellowhead Highway (16), 18 kilometres southeast of Smithers in west-central British Columbia (Figure 6). The Canadian National Railway, which carries the coal from the Peace River coalfields to tidewater, passes through the village and connects it to the port of Prince Rupert, 370 kilometres to the west.

The first six diamond-drill holes were located along the banks of Goathorn Creek, near the old Bulkley Valley collieries. The last two holes were collared on the north bank of the Telkwa River south of the old Avelling mine (Figure 6).

EXPLORATION HISTORY

Interest in the coal occurrences of the Telkwa area was first shown at the turn of the century. Since that time there have been several intermittent periods of exploration and minor underground development. Total production from 1918 to 1985 amounted to a little over 500 000 tonnes, and was used mainly for local domestic purposes. In the final decade, production petered out to a few hundred tonnes per year, due to lack of local demand.

Between 1972 and 1979, ten holes were drilled, for a total of 963 metres, in addition to trenching and geological mapping. The next and more intensive phase of exploration was conducted mainly on the Telkwa property by Crows Nest Resources Limited, a subsidiary of Shell Canada Ltd. From 1982 to 1989, 25 rotary holes were drilled for a total of 3964 metres, in addition to 224 diamond-drill holes, with a total of 30 600 metres, together with geophysical logging, geological mapping and trenching.

GEOLOGICAL SETTING

The Lower Cretaceous Telkwa coal measures of the Skeena Group occur in the Bulkley Valley area on the southern margin of the Bowser Basin. The strata are moderately folded but in places faulting is severe. Widespread block faulting, forming horsts and grabens, has been postulated from Crows Nest Resources Ltd. drill-hole data. The coal measures consist of interbedded marine and nonmarine sediments divided into three units (Koo, 1983). This sequence unconformably overlies volcanic rocks of the Jurassic Hazelton Group and was subsequently intruded by Tertiary dikes and sills.

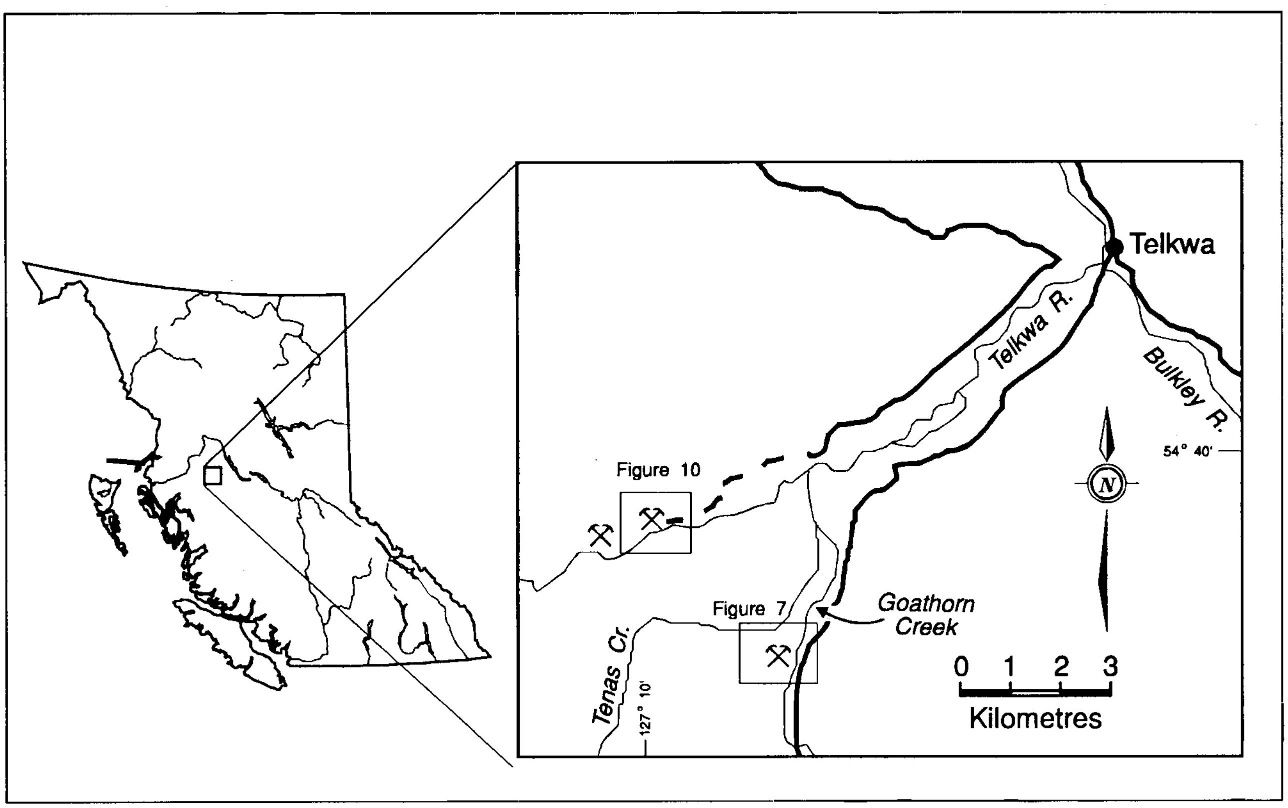


Figure 6. Telkwa study area.

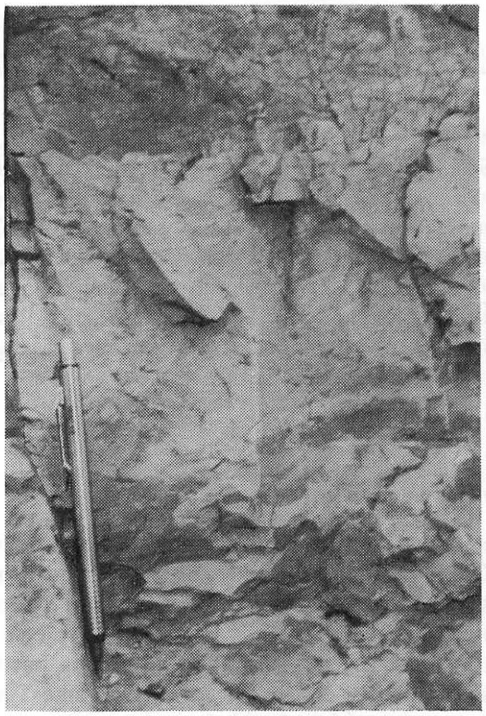


Photo 3. Paleosol exhibiting distinct root structures, Telkwa coal measures, lower unit.

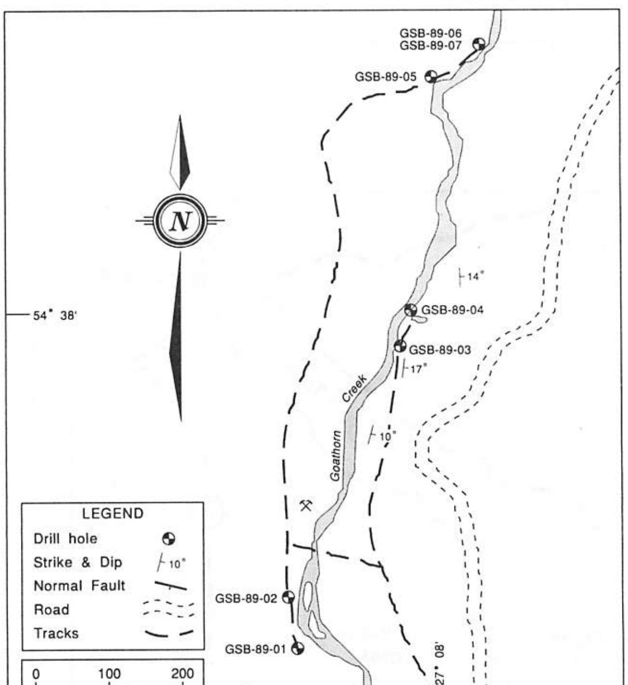


Figure 7. Location of drill holes along Goathorn Creek near Bulkley Valley mine. The area is underlain by the Lower Cretaceous Telkwa coal measures of the Skeena Group.

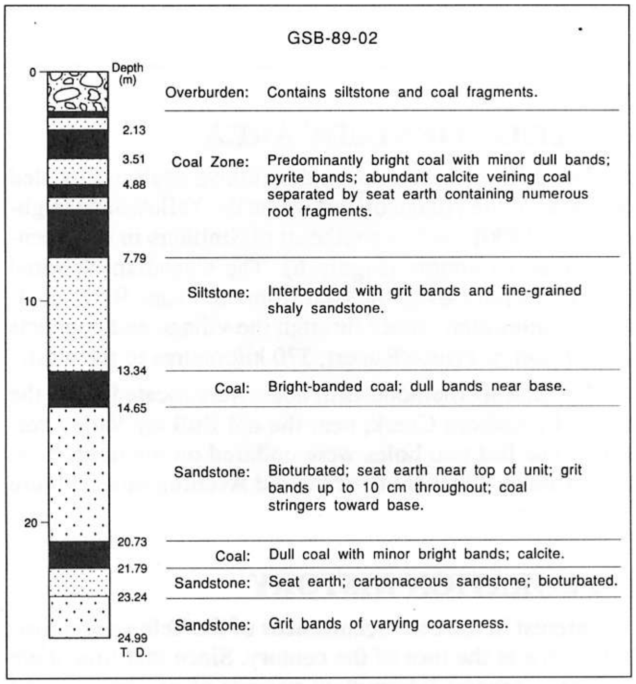


Figure 8. Simplified stratigraphic log of hole GSB-89-02.

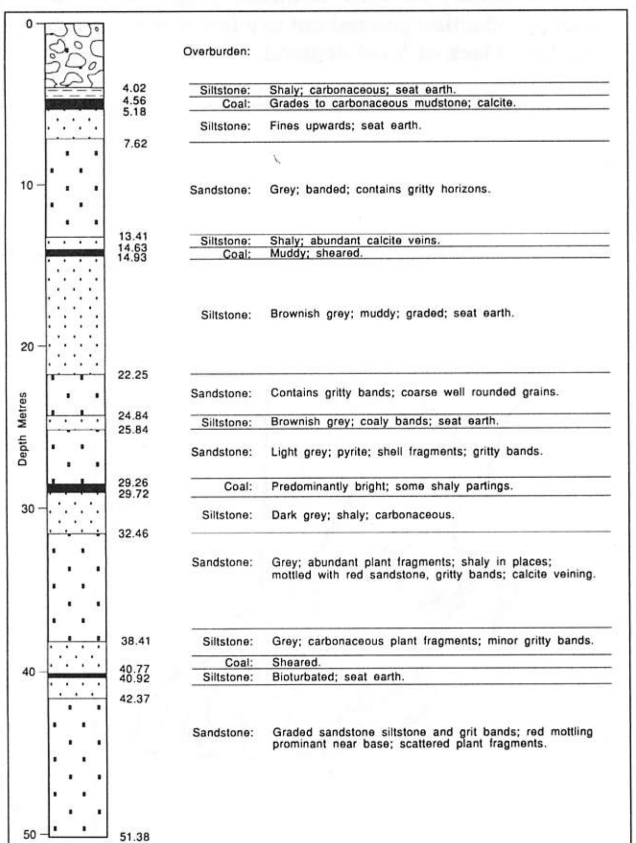


Figure 9. Simplified stratigraphic log of hole GSB-89-03.

Outcrop is sparse in the study area and it is only in some valleys that the coal measures have been exposed by river erosion. The sediments in the area strike 340° to 350° and dip 10° to 30° east.

DESCRIPTION OF THE COAL MEASURES

The Telkwa coal measures are about 400 metres thick with ten major correlatable coal seams recorded, amounting to an aggregate thickness of up to 24 metres of coal.

The lower nonmarine unit comprises siltstones, sandstones, coal and grits overlying a discontinuous basal conglomerate. Distribution of the conglomerate is controlled by paleotopography. Some thin coal seams and the No. 1 coal zone occur in this unit, which attains a thickness of up to 120 metres in places. The No. 1 coal zone, near the top of the unit, ranges up to an aggregate thickness of 3.5 metres. Paleosols, containing root structures and coalified plant remains, are common throughout (Photo 3). Near the base, the sandstones become a reddish purple colour, indicating the proximity of the underlying volcanic basement.

The middle marine unit of medium to fine-grained sandstones, siltstones and mudstones, ranges up to 140 metres thick and is devoid of any carbonaceous material.

The upper nonmarine unit comprises up to 300 metres of mudstones, siltstones, sandstones and coal, and is characterized by an absence of coarse-grained material. The coal occurs in the lower 180 metres. There are nine correlatable coal seams varying from 0.5 to 6.0 metres thick, with an aggregate thickness varying from 13 to 21 metres. These seams contain the indicated reserves. Paleosols occur throughout the lower half of the unit.

DRILLING

Drill holes GSB-89-01 and 02 (Figure 7), 28.5 and 25.0 metres deep respectively, were each drilled 7 metres from the west bank of Goathorn Creek and 70 metres apart. The northern hole is about 100 metres south of the Bulkley Valley mine site. Both holes were spudded in the lower unit, along strike from each other. The coal seams intersected are in the No. 1 coal zone (Figure 8). There is evidence of seams

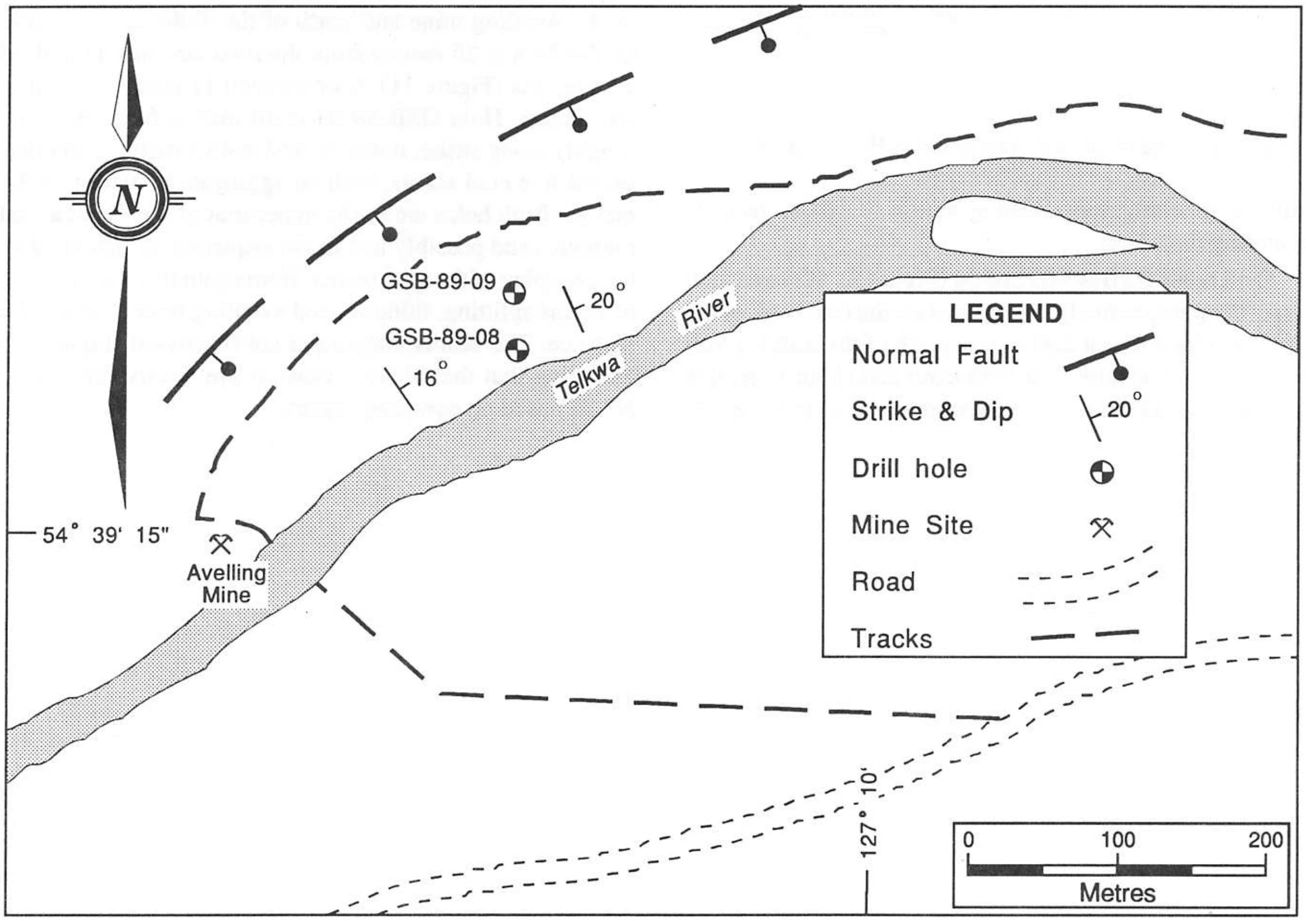


Figure 10. Location of drill holes along the Telkwa River near Avelling mine. The area is underlain by the Lower Cretaceous Telkwa coal measures of the Skeena Group.

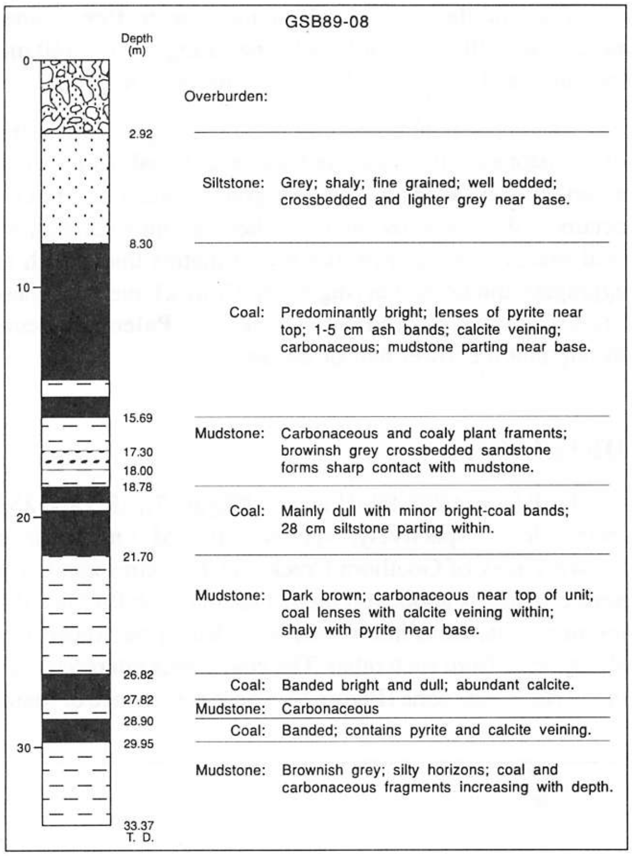


Figure 11. Simplified stratigraphic log of Hole GSB-89-08.

splitting, pinching and swelling within the short distance separating the holes.

Drill holes GSB-89-03 and 04 (Figure 7), 52.0 and 25.0 metres deep respectively, are located on the east bank of the Goathorn Creek about 250 metres north of the Bulkley Valley mine site. They are 55 metres apart and about 15 metres from outcrops in the river. They were spudded in the lower unit of the Telkwa coal measures and each intersected three coal zones, in all probability below the No. 1 zone (Figure 9). The holes were stopped before reaching the basement, after having intersected the reddish purple mottled sandstone indicative of proximity to underlying volcanics.

Hole GSB-89-05 is located 350 metres north of GSB89-04 on the west side of Goathorn Creek, 22 metres from a cliff face (Figure 7) and was drilled to a depth of 45.6 metres. It cut rocks of the lower unit which are generally coarser grained than those in the upper unit. Four minor coal zones were intersected, assumed to be below 1-seam.

Holes GSB-89-06 and 07 were drilled 100 metres to the northeast (Figure 7). Hole GSB-89-06 was abandoned at 19.2 metres because the coal seam exposed in the river was not intersected and appears to have been eroded. This proved to be correct as hole GSB-89-07, which was drilled halfway to the outcrop, 12 metres from the west bank of the Goathorn Creek, intersected 0.7 metre of coal as expected and was stopped at a depth of 10.3 metres. This intersection is believed to represent the lower coal unit from below 1-seam.

Holes GSB-89-08 and 09 (Figure 10) are located south of the Avelling mine and north of the Telkwa River. Hole GSB-89-08 is 20 metres from the river and has a depth of 33.4 metres (Figure 11). It intersected 11 metres of coal in five seams. Hole GSB-89-09 is 40 metres from the river, roughly along strike. It was drilled to 43.3 metres and intersected five coal seams, with an aggregate thickness of 9.6 metres. Both holes are in the upper unit of the Telkwa coal measures and possibly low in the sequence, as indicated by the grouping of the coal seams. Here again there is evidence of seams splitting, thinning and swelling over a very short distance. The seams intersected are illustrated (Figure 11) assuming that the thickest seam as previously reported is No. 5, based on company reports.

BOWRON RIVER COALFIELD

LOCATION AND ACCESS

The Bowron River coal deposit is situated in the Interior Plateau, in east-central British Columbia (Figure 12), 50 kilometres east-southeast of Prince George. The city of Prince George is on the Canadian National Railway, 750 kilometres east of the port of Prince Rupert where the coal loading facility at Ridley Island is located.

Access to the workings on the deposit is by a dirt road 55 kilometres east of Prince George on Highway 16 (Yellowhead Highway). The old adit site is reached by travelling 7 kilometres along this road to the south and a further 7 kilometres eastwards from the T-junction, on a good forestry road. The adit is on the west bank of the Bowron River. The area is covered by NTS map sheets 93G/NE and 93H/NW. The four diamond-drill holes were drilled on the west bank of the Bowron River over a distance of about 300 metres.

EXPLORATION HISTORY

The existence of coal on the Bowron River was first reported by G.M. Dawson in 1871, however, it was not until 1910-11 that development work started, with the driving of an adit and a survey of the area. After a 35-year period of inactivity, diamond drilling and trenching were undertaken in 1946 and continued for a three-year period. In 1967 work restarted with two exploration adits and several diamond-drill holes completed, and continued in a desultory manner until 1981. A total of about 140 holes, some as deep as 1220 metres, were drilled over the entire exploration period from 1946 to 1981. Despite the exploration and development work, the property was never brought into production. The licences were forfeited in 1982 and in 1994 none are held in the area.

GEOLOGICAL SETTING

The Tertiary coal measures of the Bowron River graben overlie and are bounded by Mississippian volcanics and sediments of the Slide Mountain Group (Figure 13). Outcrop is sparse in the immediate vicinity of the graben due to the Quaternary overburden of alluvium and glacial deposits, which varies in thickness from a few metres to 300 metres.

The graben trends in a northwesterly direction. It is 2.5 kilometres wide and may be 25 kilometres long. The coal measures comprise the lowest 100 to 150 metres of the Tertiary sequence and consist of siltstone, sandstone, grit, conglomerate and coal. In previous reports three coal zones are inferred, upper, middle and lower (Borovic, 1980, 1981).

The regional strike varies from 325° to 330° and the dip along the western flank varies form 30° to 35° northeast. The dip appears to lessen with depth. The structure, previously reported as a syncline, is in all probability a monocline, as indicated by drilling results. The strike of the western boundary fault, as indicated by outcrop and drill-hole data, is roughly parallel to that of the Tertiary sediments. The position of the eastern boundary fault, which probably has a greater displacement, is inferred beneath the extensive overburden. Two minor subparallel faults down-drop the strata towards the centre of the basin.

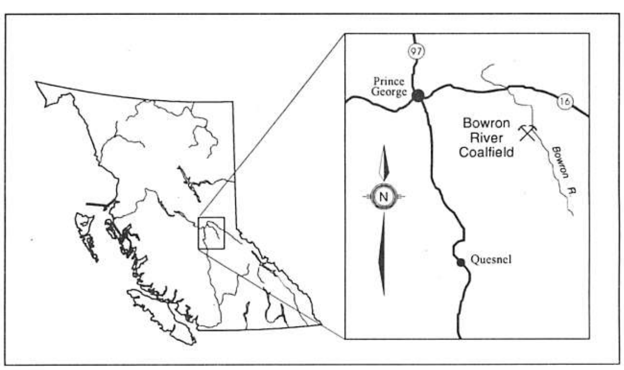


Figure 12. Bowron River study area.

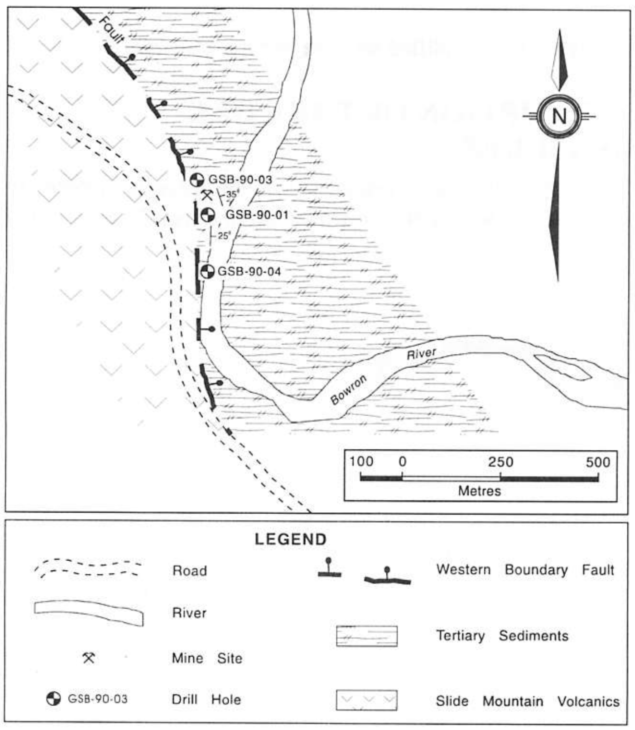


Figure 13. Location of GSB drill holes in the Bowron River coalfield.

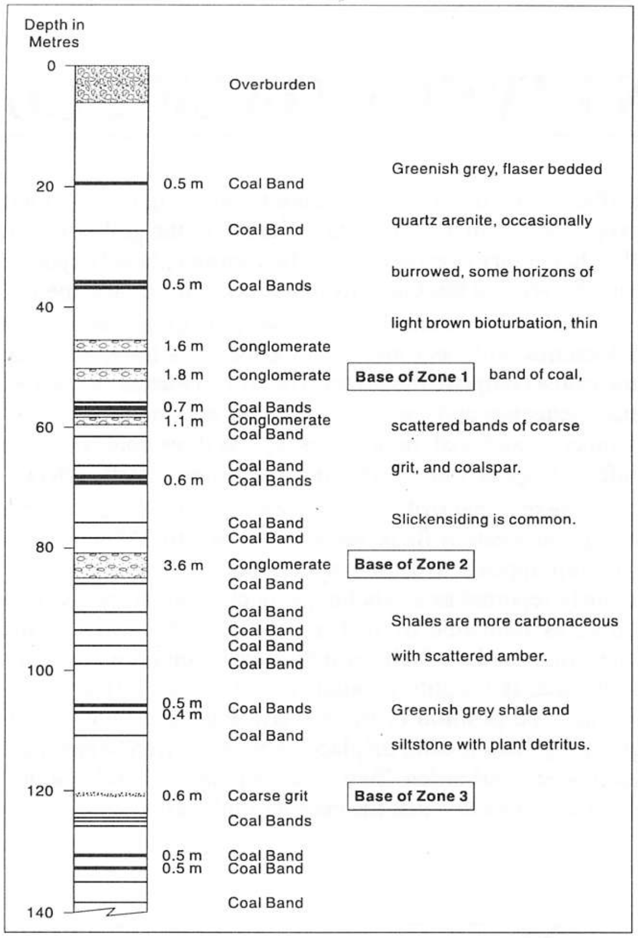


Figure 14. Simplified stratigraphic log hole GSB-90-03.

DESCRIPTION OF THE COAL MEASURES

Despite the close proximity of the three drill holes to one another along strike, correlation between holes is difficult. A moderately active period of deposition is indicated by rapid facies changes. Flaser-bedded quartz arenites with rippled shale streaks predominate. Occasional horizons exhibiting discrete burrows and other bioturbation occur in the sequence. Podzols containing coalified plant material and root structures occur intermittently.

Four coal zones were tentatively identified (Figure 14), the bases of which are defined by conglomerates of corresponding stratigraphic horizons. Lateral facies changes as well as splay faulting associated with the western graben fault, make definite identification of the conglomerates difficult. The only positively identifiable coal zone is the lowermost, with an aggregate thickness of about 5 metres of coal over 24 metres. Due to cost considerations, none of the holes reached the basement rocks of the Slide Mountain Group.

DRILLING

The two major restrictions on the siting of the drill holes were the variable thicknesses of the overburden and the depth of the coal zones, given the limited capabilities of the small drill. The deepest hole was 140 metres. The coal zones are at their shallowest near the western boundary fault. As a result the holes were sited close to the fault (Figure 13) and the southwest bank of the Bowron River. The spacing was about 100 metres to 120 metres. Depths of the holes are: GSB-90-01, 130.3 metres; GSB-90-02 was abandoned in overburden after two attempts; GSB-90-03, 139 metres; GSB-90-04, 24.5 metres. The dip of the western boundary fault is to the northeast, and as a result, the greater the depth of the samples, the closer they were to the fault zone.

Despite the largely broken core, the recovery was good at 95%.

The 1990 field season was the first year the Geological Survey Branch conducted field tests on methane desorption in the province. The results are reported by Matheson and Sadre (1992).

MERRITT COAL DEPOSITS

LOCATION OF THE STUDY AREA

The Merritt coal deposits are located 90 kilometres south of Kamloops, in the Nicola Valley, south-central British Columbia (Figure 15). The occurrences surround the town of Merritt on the Coquihalla Highway, and extend 8 kilometres east-west and 5 kilometres north-south. The locations of the mined areas are indicated on Figure 16. The Quilchena deposit was not sampled in this study.

EXPLORATION AND PRODUCTION HISTORY

The earliest reference to coal in the Nicola Valley area, near the present town of Merritt, appeared in the "British Colonist", Victoria, British Columbia, on August 20, 1896, reporting on its use in a forge in Victoria. The coal was generally mined by the local inhabitants for domestic purposes. Regular production from the Middlesboro Collieries on Coal Gully Hill began in 1906. A total of 2.93 million tonnes

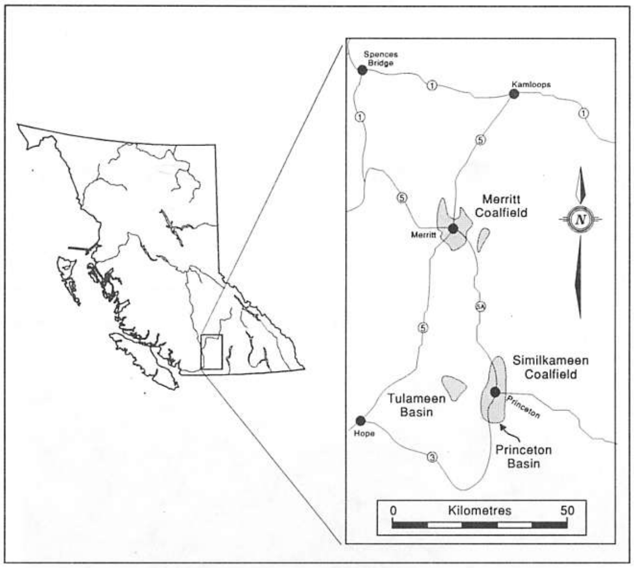


Figure 15. Merritt and Princeton study area.

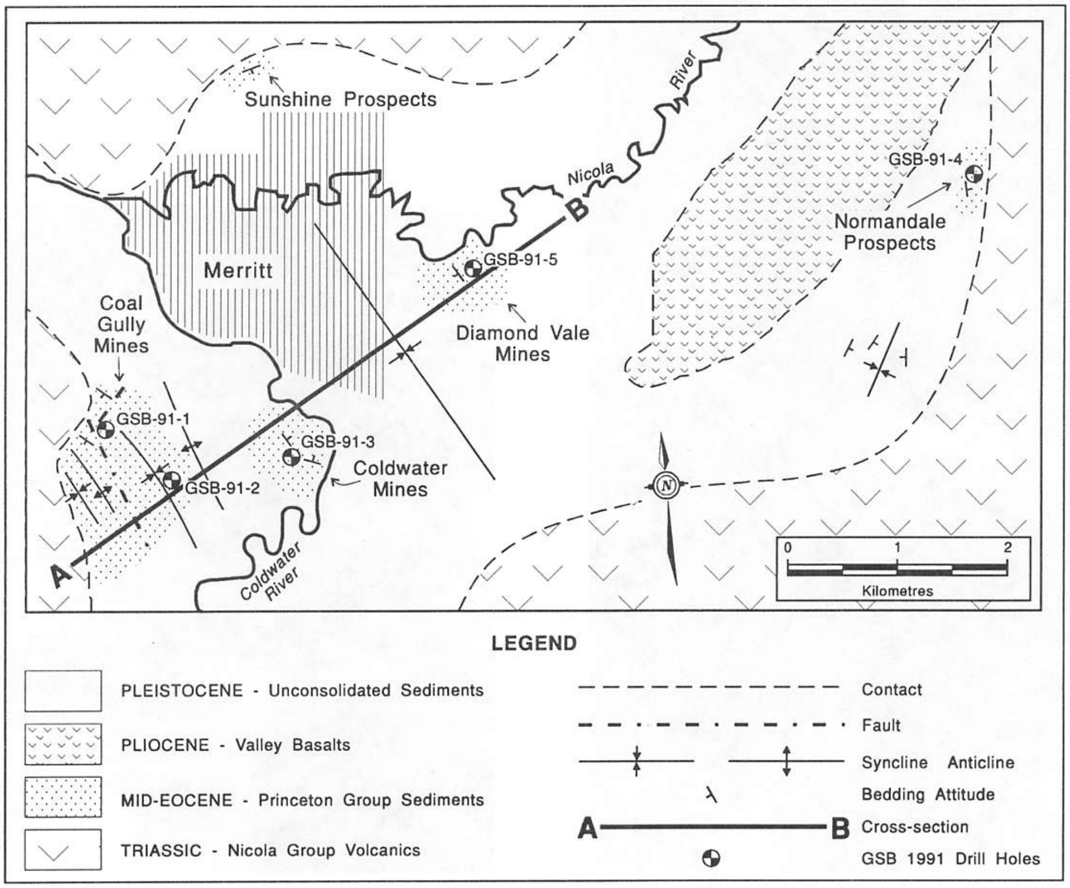


Figure 16. Geology of the Merritt area showing GSB drill hole locations.

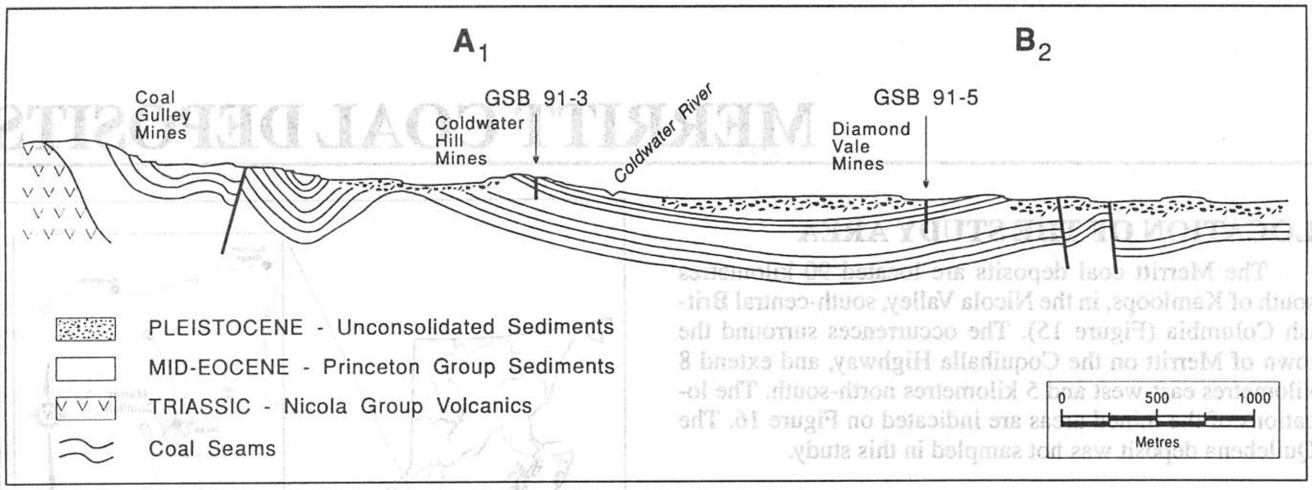


Figure 17. Schematic cross-section of the Merritt coal basin.

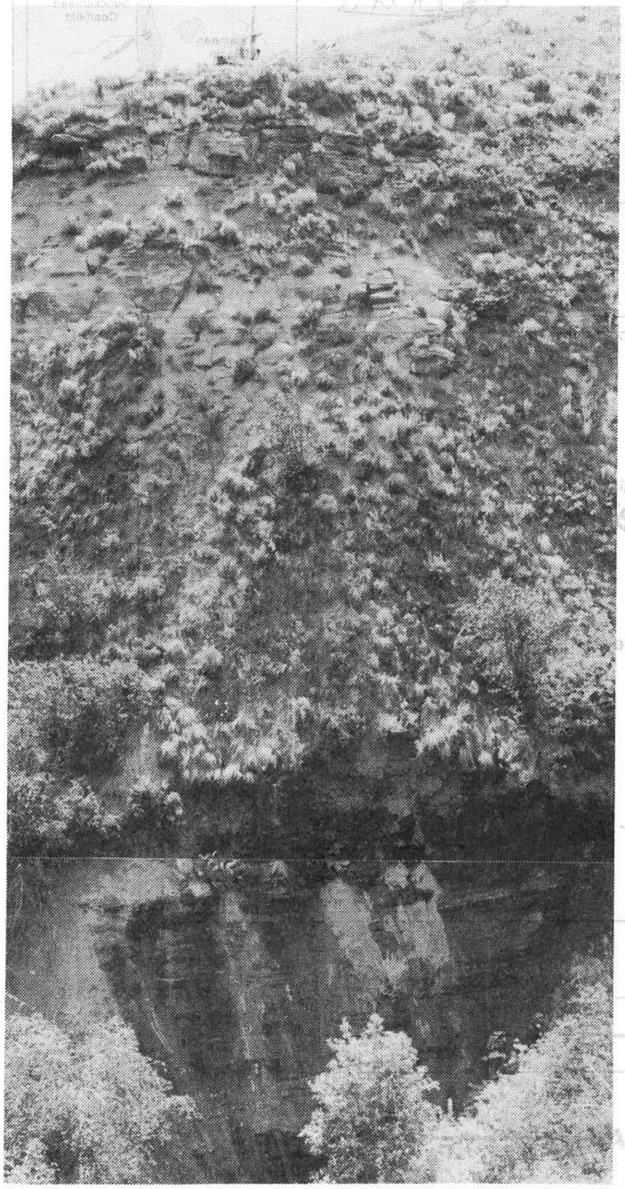


Photo 4. Number 4 seam exposed at Coal Gully Hill and intersected by GSB-91-1. Note the Prospector 89 drill at the top of the hill.

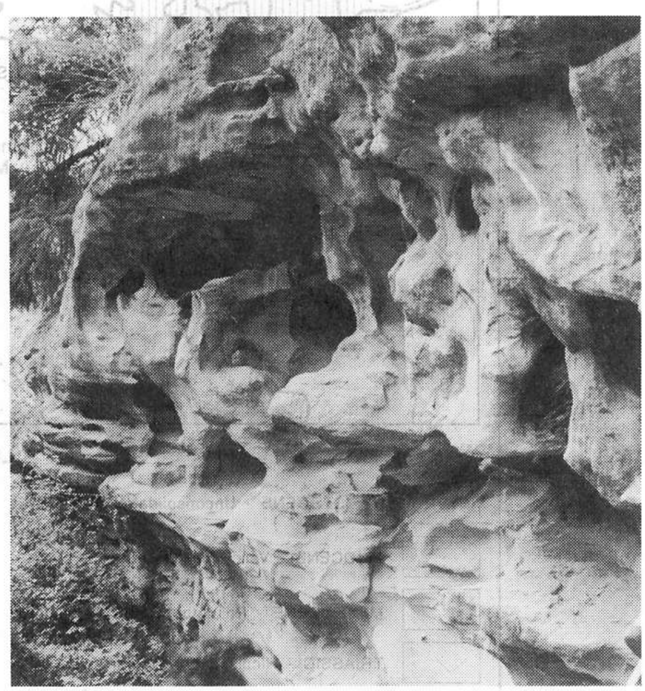


Photo 5. Poorly consolidated sandstone in the Merritt coalfield, with cavities resulting from solution.

was produced underground from the Merritt coal deposits until mining ceased in 1963. Middlesboro Collieries mined 92% of the total, from the Coal Gully area and a large area of Coldwater Hill. Other productive collieries mined were the Diamond Vale (mining ceased in 1912, after an explosion which resulted in the deaths of seven men), Normandale and Sunshine areas. A very small amount was taken out of Quilchena by a local rancher for domestic purposes.

In 1994, Imperial Metals Corporation holds the freehold coal rights to the Coal Gully Hill and Coldwater areas. Renewed interest in thermal coal in 1980 and 1981 resulted in Crows Nest Resources Limited taking up coal licences and options on freehold lands in the area. Mapping was carried out from the Coal Gully Hill deposit to Quilchena, 27 holes were drilled and a trench was excavated at Quilchena. Due to rapid weathering and the character of the rocks in the area, nearly all the adits have caved and trenches have filled with rubble. No further exploration has been carried out since that time.

GEOLOGICAL SETTING

The Tertiary (Eocene) coal measures of the Coldwater Formation overlie and are bounded by volcanic rocks of the Upper Triassic Nicola Group (Figures 16 and 17). A tongue of the younger Pliocene valley basalt outcrops in the northeast corner of the study area, covering the Nicola volcanics, and extends southwestwards, covering a part of the Coldwater Formation. Pleistocene and Recent unconsolidated sediments, both glacial and fluvial, cover much of the valley floor (White, 1947).

The Coldwater Formation is a sequence of nonmarine conglomerate, sandstone, shale and coal (Photos 4 and 5). It occupies one of several early Tertiary basins in the Cordilleran Intermontane Belt. The lake with which deposition was related corresponds with the present topography. The coal formed in the early stages of lake development (Graham, 1977).

The conglomerate, grit and sandstone are largely composed of quartz and feldspar, derived mainly from local granitic sources. The shales are thinly bedded and are associated with the coal horizons of the sequence. The basal conglomerate is composed mainly of Nicola rock fragments. Calcareous horizons occur throughout the sedimentary sequence.

Due to the thick Pleistocene cover in the valley, the structural pattern of the underlying sediments is unclear. In the west, where the geology is better known as a result of the mining and exploration activity, there are moderately tight northwest-trending folds, offset by numerous strike-slip faults (Figure 17). To the east, the dips become more gentle and the coal deeper. In the centre of the basin the sediments appear to have been less disturbed by tectonic activity. In the southeast sector, near the eastern boundary, the beds strike northeast and the folds are more open. The eastern boundary of the Coldwater sediments is a fault contact with the Nicola volcanics (Read, 1988).

DESCRIPTION OF THE COAL MEASURES

The thickness of the coal measures varies up to 300 metres at the western rim of the basin where the coal zones tend to be thicker and more numerous than in the eastern part. In the Coal Gully area, where the strata are quite steeply folded, seven coal zones have been reported. Starting from the lowest in the succession, the average thicknesses of the zones are: No. 1 is 7.9 metres, No. 5 is 1.5 metres, No. 4 (Photo 4) is 7.6 metres, No. 8 is 2.44 metres, and No. 6 is 1.8 metres (Swaren, 1977). Of the seven zones, four were intersected by drill holes. Hole GSB-91-1 intersected zone 4 (Figure 18), and GSB-91-2 intersected zones 2, 3 and 6 (Figure 19).

To the east and south, the coal zones generally diminish in thickness. However, No. 5 zone increases to 3 metres and 2.2 metres, respectively, and the No. 3 zone increases to 1.3 metres. The zones pinch and swell, and the intervals between them may vary up to 30 metres.

Drilling in the Coldwater Hill area in 1991 confirmed that the No. 6 zone, previously reported absent in this area, does occur, but thins to about 1.1 metres (Figure 20). The beds strike northwestwards and dip to the northeast at an average of 35° at outcrop, and form the southwest limb of a broad symmetrical syncline.

In the Diamond Vale mine, zones 2, 3 and 6 were mined. The lower zones, 8, 4, 5 and 1 were not exploited due to

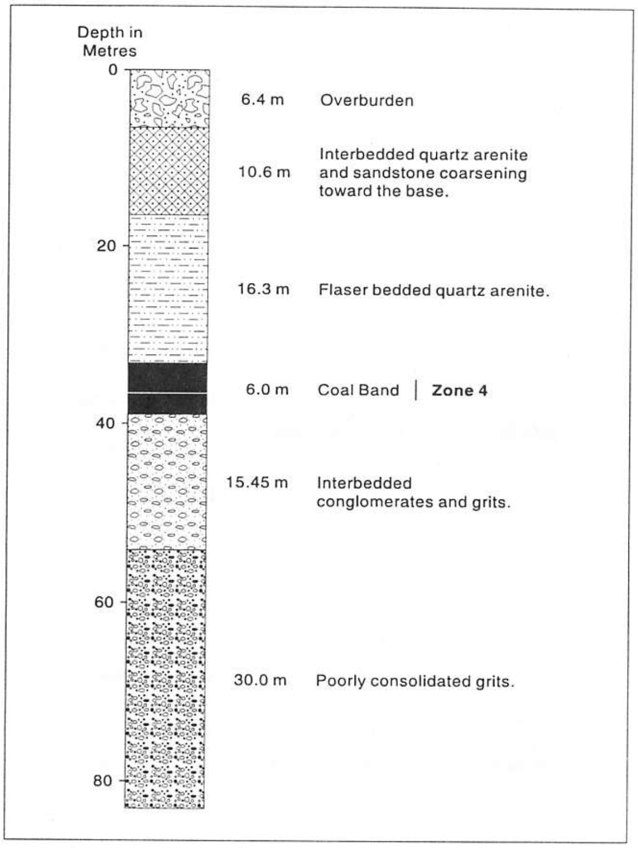


Figure 18. Simplified stratigraphic log of hole GSB-91-1.

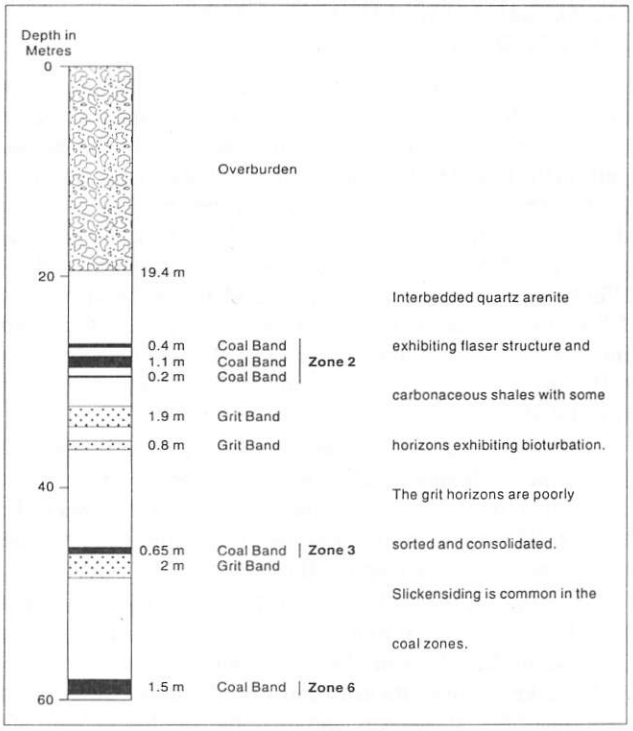


Figure 19. Simplified stratigraphic log of hole GSB-91-2.

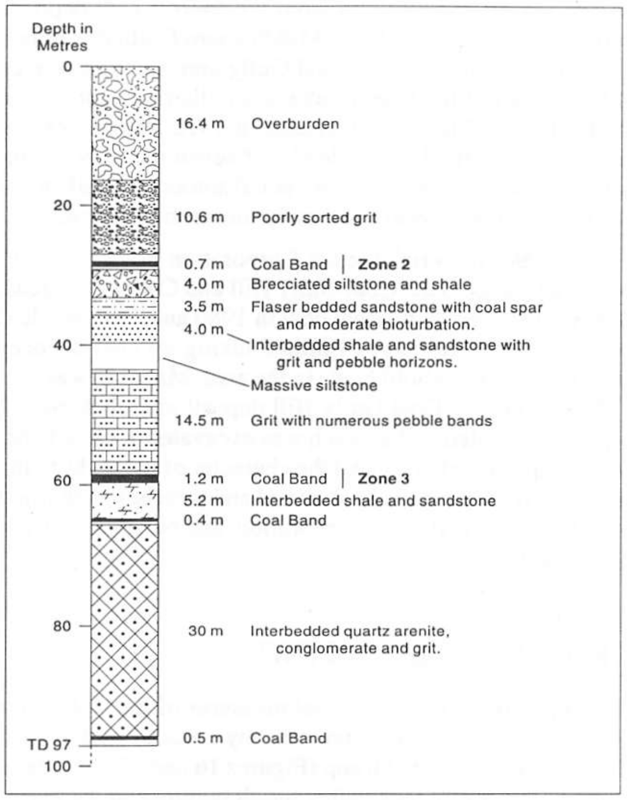


Figure 21. Simplified stratigraphic log of hole GSB-91-5.

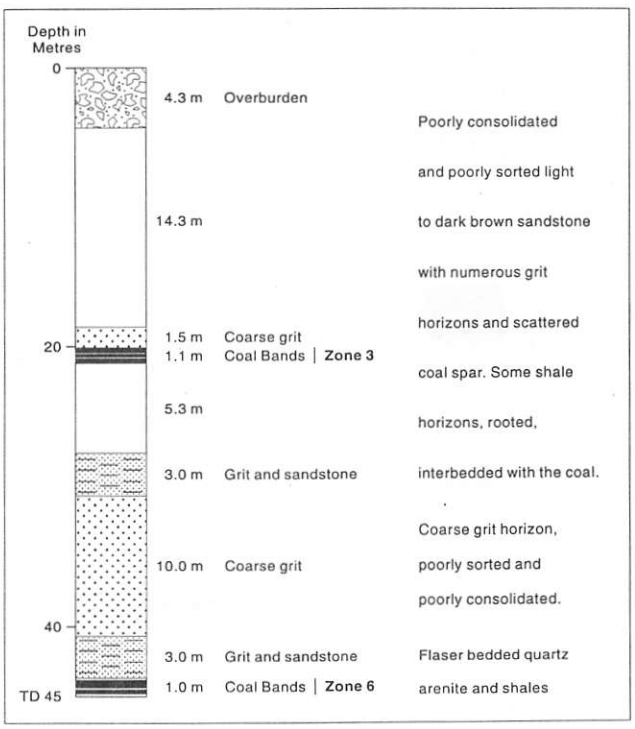


Figure 20. Simplified stratigraphic log of hole GSB-91-3.

depth. Zones 2 and 3 were intersected by GSB-91-5 (Figure 21). The mine is on the northeast limb of the syncline and coal seams dip to the southwest at an average of 40° at outcrop. East of the Diamond Vale mine, two strike-slip faults had been identified by previous drilling (Figure 17), but little more is known about this area.

The coal is interbedded with shale and rooted quartz arenite, in parts calcareous, with coalspar and horizons exhibiting burrowing and bioturbation. The typical depositional environment ranged from back-barrier lagoons to mixed sand and mud flats, corresponding to areas of low to moderate energy, and subject to variable current velocities.

DRILLING

There were several major restrictions in selecting drilling sites. Water was not readily available and in several cases had to be pumped from a source over 800 metres away. The water required for drilling at Normandale had to be brought in by truck from Nicola Lake, 6 kilometres distant. There are no accurate mine plans available, and, as a result, drill sites had to be carefully selected to avoid any breakthrough into old workings. Finally, burning coal of unknown extent at Coldwater Hill had to be avoided.

The sandstone is poorly consolidated and cavities occur as a result of dissolution (Photo 5). Consequently there was frequent caving and loss of water circulation while drilling. Hole GSB-91-4 at Normandale had to be abandoned at 60 metres due to constant caving, jamming the drill rods.

Two holes were collared on Coal Gully Hill. A vertical hole (GSB-91-1; total depth 83.2 m) intersected the No. 4 zone (Figure 18). Due to the very broken character of the coal in the core, only 4.25 metres (true thickness) of core was recovered from the zone measuring 8 metres (true thickness at outcrop). Hole GSB-91-2, was angled at 60° from the horizontal at an azimuth of 220°. Number 2, 3 and 6 zones were intersected before the hole was stopped at 60.2 metres (Figure 19). A vertical hole on Coldwater Hill, GSB-91-3 (depth 45 m), intersected the No. 3 and No. 6 zones (Figure 20). The final hole, GSB-91-5, drilled at Diamond Vale (depth 91.3 m), intersected coal zones Nos. 2, 3 and 6 (Figure 21). Most previous reports on this area indicate the existence of only six coal zones. However, No. 6 zone was intersected in three holes, and though it may not be continuous, it does bring the total to seven zones.

SAMPLING AND ANALYSIS

As a result of the length of the study and funding constraints, different suites of analyses were carried out on samples from each basin. To keep costs down, samples were composited.

In the first year, at Quinsam, coal from the drill core was generally sampled in 10-centimetre increments, although a few varied from 5 to 15 centimetres. The samples were taken from No. 1 seam and its rider and No. 2 seams. In all, 31 samples were taken from GSB-88-1, 32 from GSB-88-1B, 23 from GSB-88-2 and 29 from GSB-88-3. All 104 samples were submitted for vitrinite reflectance examination. Thirty samples, essentially all the samples from GSB-88-1, were analyzed microscopically for their maceral compositions.

TABLE 1
BOREHOLE AND SAMPLE DATA - QUINSAM

Horizon	GSB Borehole GSB88-1		GSB88-1B	GSB88-3
Zone #2				
Upper	C1	CA		
Lower	C2	CA		
Coal Seam #1 Rider	C3	CB	C15, CF	C18, CI
Coal Seam #1				
(Uppermost)	C4	CC	C16, CG	C19, CJ
	C5	CC	C16, CG	C19, CJ
	C6	CC	C16, CG	C19, CJ
	C7	CC	C16, CG	C19, CJ
	C8	CC	C16, CG	C19, CJ
	C9	CD	C17, CH	C19, CJ
	C10	CD	C17, CH	C19, CJ
	C11	CD	C17, CH	C19, CJ
	C12	CE	C17, CH	C19, CJ
	C13	CE	C17, CH	C19, CJ
Lowermost	C14	CE	C17, CH	C19, CJ

Samples from GSB-88-1 were composited to reflect the upper and lower parts of No. 2 seam, No. 1 rider and 20-centimetre increments of No. 1 seam; Table 1. These were analyzed for proximate and ash analysis and the calorific values were determined. Samples were further composited to reflect No. 2 seam, No. 1 rider and the upper, middle and lower parts of No. 1 seam. The analyses done on these were for ultimate, sulphur forms, fluorine, chlorine and mercury, and ash fusion temperatures. Maceral analyses and vitrinite reflectance determinations were also carried out on these samples.

Samples from drill hole GSB-88-1B were composited for No. 1 rider, the upper half of No. 1 seam and the lower half of No. 1 seam. Samples from drill hole GSB-88-3 were composited for No. 1 rider and No. 1 seam. Analyses included the combination of those listed for both sets of composites from DH-88-1 samples, with the exception of maceral analysis.

In the Telkwa coalfield, 197 coal samples were taken from drill core in 20-centimetre increments or shorter intervals as dictated by partings. All but one were submitted for vitrinite reflectance examination. Thirty-nine samples, essentially all those from GSB-89-1 and 89-4, were analyzed for their maceral composition. Roughly 190 were analyzed for their ultimate composition. *See* Table 2 for a summary of composites.

In GSB-89-1, four composites from 32 samples were analyzed. In GSB GSB-89-2 there were five composite samples from 27 samples. All samples were from coal zone No. 1 in the lower unit.

One composite sample from two samples and two composite samples from eight samples were analyzed from GSB-89-3 and GSB-89-4, respectively. The coal horizons are low in the lower unit.

TABLE 2
BOREHOLE AND SAMPLE DATA - TELKWA

Horizon	GSB Borehole GSB 89-1	GSB 89-2	GSB 89-3	GSB 89-4	GSB 89-5	GSB 89-7	GSB 89-8	GSB 89-9
Zone #5 (upper unit)	-	-	-	-	-	-	C16-18	C22-25
Zone #4 (upper unit)	-	-	-	-	-	-	C19	C26
Zone #3 (upper unit)	-	-	-	-	-	-	C20&21	C27&28
Zone #1 (lower unit)	C1-4	C5-9	-	-	-	-	-	-
Undetermined (lower unit)	-	-	-	-	C13&14	C15	-	-
Near Base (lower unit)	-	-	C10	C11&12	-	-	-	-

Two composites from GSB-89-5 and one from GSB-89-7 are assumed to be coal horizons from the middle of the lower unit below coal zone No. 1.

Six composites from 52 samples from GSB-89-8 and seven composites from 59 samples from GSB-89-9 were analyzed. It is assumed, from the well developed coal seams, that the sequence is in the lower part of the upper unit.

TABLE 3
BOREHOLE AND SAMPLE DATA - BOWRON RIVER

Horizon	GSB Borehole GSB 90-1	GSB 90-3	GSB 90-4
Zone #1 (uppermost)	C1	C7	
Zone #2	C2	C8	
Zone #3	C3	C9	-
Zone #4 (lowermost)	C4-6	C10	C11&12

TABLE 4
BOREHOLE AND SAMPLE DATA - MERRITT

Horizon	GSB Borehole GSB 91-1	GSB 91-2	GSB 91-3	GSB 91-5
Zone #2	-	C3	-	C8
Zone #3	-	C4	C6	C9
Zone #6	-	C5	C7	C10
Zone #8	-	-	-	-
Zone #4 (upper unit)	C1	-	-	-
Zone #4 (lower unit)	C2	-	-	-

All 28 Telkwa composite samples were submitted for the following analyses: proximate, ash analysis, calorific value, sulphur forms, fluorine, mercury and ash fusion. A summary of the samples from various horizons is shown in Table 2.

In the Bowron River coalfield, 138 coal samples were taken from the drill core. Coal bands more than 5 centimetres in thickness were sampled and thicker seams were sampled in about 20-centimetre increments. Thirty-nine were submitted for rank determination using the vitrinite reflectance method, and fifteen were analyzed for their maceral composition. Seventy-one samples and composite samples were subjected to ultimate analysis.

Four zones were postulated in the lower part of the Tertiary sequence. Samples were composited to reflect these zones (large or zone composites, compared with those created for ultimate analysis; Table 3). The analyses carried qut on the twelve zone composites were the same suite as for the Telkwa composites, plus ultimate analysis.

In the Merritt coal deposits, 67 samples were taken from drill core from coal bands more than 10 centimetres thick. The sediments are highly friable and, as a result, some samples were contaminated and yielded a high ash content which does not realistically reflect the intrinsic ash content of these coals.

The numbering of the seams appears to have been random. In ascending order, they are 1 (the lowermost), 5, 4, 8, 6, 3, 2. The samples were composited to represent separate seams or zones as set out in Table 4. The ten composite samples were analyzed for the same suite as the Telkwa composite samples plus vitrinite reflectance, maceral analysis and ultimate composition.

ANALYTICAL METHODS

With the exception of petrographic analyses, ASTM techniques and methodologies were used throughout. Results are reported on an air-dried basis. Mathematical conversions to other bases are made in certain cases, such as

TABLE 5
PROXIMATE ANALYSIS AND CALORIFIC VALUE DATA

	Moisture, % (ad)	Ash, % (ad)	Volatile Matter, % (dry)*	Volatile Matter, % (daf)*	Calorific Value (MJ/kg) @ 15% Ash	Calorific Value (MJ/kg) (maf)*
Quinsam	2.53 m (2.10-2.89) r	13.69 (5.36-38.45)	37.25 (29.53-40.75)	43.48 (41.26-48.68)	26.72	31.46 (28.82-32.25)
Telkwa	0.64 (0.49-0.83)	23.78 (6.29-61.75)	27.01 (21.22-31.53)	35.37 (29.38-45.13)	28.67	32.97 (28.99-34.43)
Bowron River	3.47 (1.51-5.26)	23.02 (6.01-65.76)	35.24 (27.57-44.83)	43.92 (36.56-47.81)	25.5	29.84 (29.07-30.96)
Merritt	3.14 (1.97-4.64)	35.14 (11.92-66.04)	30.17 (24.67-36.82)	43.45 (40.98-47.69)	27.02	31.15 (28.45-32.67)

* based only on samples with <50% ash.
m = mean
r = range

calculation of dry, ash-free (daf) volatile matter, and moist, ash-free (maf) calorific value, to give approximate rank indicators and to allow comparisons between basins.

Vitrinite reflectance was determined using the methods of Kilby (1988), as summarized in Grieve (1993). Mean random and mean maximum reflectance results are reported in Appendices 1 to 4, and mean random results are cited in the text and tables. The random vitrinite reflectance of a given coal particle is defined as the square root of the product of the apparent maximum and apparent minimum reflectance under polarized light (Kilby, 1988). Mean random reflectance is converted to ASTM ranks using boundaries established for western Canadian coals by Cameron (1989, Table 5). In particular, the sub-bituminous-to-bituminous rank threshold is 0.50%, the high-volatile bituminous B to A threshold is 0.75%, and the high to medium volatile bituminous threshold is 0.95%.

Maceral analyses were done using a Swift point-counting stage using one pellet per sample. Results are reported on a mineral-matter-free basis (coal only), and as many as possible, up to 500, points were counted per sample. In the cases of Quinsam, Telkwa and Merritt samples the following macerals were identified: vitrinite A, vitrinite B, other vitrinite (chiefly vitrodetrinite), sporinite, cutinite, other liptinite (chiefly resinite), semifusinite, fusinite, macrinite, micrinite, inertodetrinite and sclerotinite. With the Bowron River samples, which are lower in rank, the macerals identified were basically the same with the addition of the liptinite macerals fluorinite, alginite, exsudatinite and suberinite.

Trace element determinations (except for B, F and Hg) were made by instrumental neutron activation analysis (INNA). Boron content was determined using sodium hydroxide fusion followed by inductively coupled plasma emission spectrometry (Pollock, 1975). Concentrations of mercury were determined by atomic absorption. Fluorine concentrations were determined by the oxygen bomb digestion method (ASTM, 1979), known to give low results for many coals (Godbeer and Swaine, 1987).

COAL QUALITY

Complete analytical results are contained in Appendices 1 to 4, and summary data are found in Tables 5 to 8 and 10 to 12. Results are summarized here under the headings of the various analytical tests. Coal rank is discussed under vitrinite reflectance, although other types of data, especially calorific value, also bear on the interpretation. Sulphur data are considered as a separate subject, rather than as a subheading of ultimate analyses. The emphasis throughout is on the suitability of the coals for power generation. Table 1 in Skorupska (1993, page 16) is used as a guide to desired and typical limits of the various quality parameters.

Data are not broken out stratigraphically within each basin unless significant differences occur.

PROXIMATE ANALYSIS

Values of moisture, ash, volatile matter and fixed carbon were determined on an air-dried basis for samples from all basins (Table 5). Volatile matter was converted to a dry, ash-free basis, to allow for comparison between the four basins and to aid in rank determination, and also to a dry basis.

AIR-DRIED MOISTURE

Moisture in thermal coal is detrimental as it represents noncombustible material which absorbs heat during its vaporization. It also affects ignition and combustion characteristics, as well as ease of handling and susceptibility to spontaneous combustion (Carpenter, 1988). Air-dried moisture (sometimes referred to as residual moisture) data are described here (Table 5), although as-received moisture values are more relevant to actual utilization. Air-dried moisture is highest in the Bowron River snmples and lowest in the Telkwa samples. The means are: Quinsam, 2.53%; Telkwa, 0.64%; Bowron, 3.47%; and Merritt, 3.14%. The relative order of the four deposits would probably be followed for as-received moisture data.

AIR-DRIED ASH

Ash is the residue of the mineral matter in coal after combustion (Carpenter, 1988). In thermal coal, mineral matter functions mainly as an inert dilutant, and the ash contents, as determined by proximate analysis, are negatively correlated with the calorific value (*see* next section). In some ways, the chemistry of the ash is the more critical factor affecting thermal behaviour of coal (*see* section on ash characteristics).

Not much interpretation is applied to the ash content data in this study. This is because the ash contents of these samples are believed to be partly an artifact of initial sampling methods, and the manner of sample selection for compositing. It would appear, however, that Quinsam samples have the lowest ash in this study (range 5.36 to 38.45%, mean 13.69%). Telkwa and Bowron River with means of 23.78 and 23.02%, respectively, are very similar to each other. The high end of the range, in both cases, is above 60%. The mean ash content in the Merritt composite samples is highest at 35.14%. These ash values for Merritt are considerably higher than some previously published ash data. Dickson (1941), for example, cites a range in ash contents in six samples from Middlesboro Collieries of 6.5 to 14.3%. Dilution by drill-hole caving is a possible source of the high ash contents seen in these Merritt samples.

The generally desired range for ash in thermal coal is 15 to 20%, occasionally up to 30% (Skorupska, 1993). All of the Quinsam coal seams and parts of the stratigraphic sections of the other three coal basins can potentially provide coal in this range. Coal preparation would enhance the coal quality even further, and allow for use of higher ash portions of seams.

DRY, ASH-FREE AND DRY VOLATILE MATTER

The volatile matter content of a coal is a rough measure of its reactivity (Skorupska, 1993), which determines its ignition and flame characteristics. A coal with a higher volatile matter content will usually have an easier ignition and a more intensive flame than a lower volatile coal (Skorupska, 1993), attributes considered desireable in a thermal coal. However, if too high, volatile matter can be a safety concern because of the potential for spontaneous combustion. There are no general correlations between volatiles and combustion behaviour (Carpenter, 1988). Nonetheless, it is safe to assume that none of the coals represented here will present any difficulties with ignition, due to the volatile contents (air-dried) being consistently above 25% .

Based on samples containing less than 50% ash, volatile matter (daf) is roughly equivalent in samples from Quinsam, Bowron and Merritt, and is markedly lower in Telkwa samples. The ranges are as follows: Quinsam composites, 41.26 to 48.68%; Telkwa composites, 29.38 to 45.13; Bowron composites, 36.56 to 47.81; Merritt composites, 40.98 to 47.69. The means are: Quinsam, 43.48%; Telkwa, 35.37%; Bowron, 43.92%; and Merritt: 43.45%. Assuming there is not a great deal of difference between dry, ash-free and dry, mineral-matter-free volatile matter, all of the samples, with only a few exceptions, are lower than medium-volatile bituminous in rank (ASTM). The exceptions are some of the samples at the low end of the range of volatile matter contents from the Telkwa coalfield, which appear to be medium volatile. Coal ranks, based mainly on vitrinite reflectance and calorific value, are discussed further in the section on vitrinkte reflectance.

Volatile matter contents on a dry basis are highest for the Quinsam samples (mean 37.25%) and lowest for the Telkwa samples (mean 27.01%) (Table 5), based on samples with less than 50% ash. The Quinsam values are enhanced relative to the samples from the other basins because of their lower ash contents, while the Merritt values are probably depressed by their higher ash. The samples from Merritt and Telkwa basically fall within the desired range for side-fired furnaces (20 to 35%, Skorupska, 1993); while the Quinsam and Bowron samples are higher but do overlap into the desired range.

CALORIFIC VALUE (AIR-DRIED AND MOIST, ASH-FREE)

Calorific values on related samples (collected from individual properties and/or seams) on an as-received, air-dried or dry basis usually show a very strong negative correlation with ash content (same basis). Ash, in other words, has mainly a dilutant effect on the energy content of a coal, other factors being equal. Therefore, calorific value is a good indicator of coal grade on a local basis (Cameron, 1989). Correlation coefficients between air-dried calorific value and air-dried ash at these locations (Figure 22) range

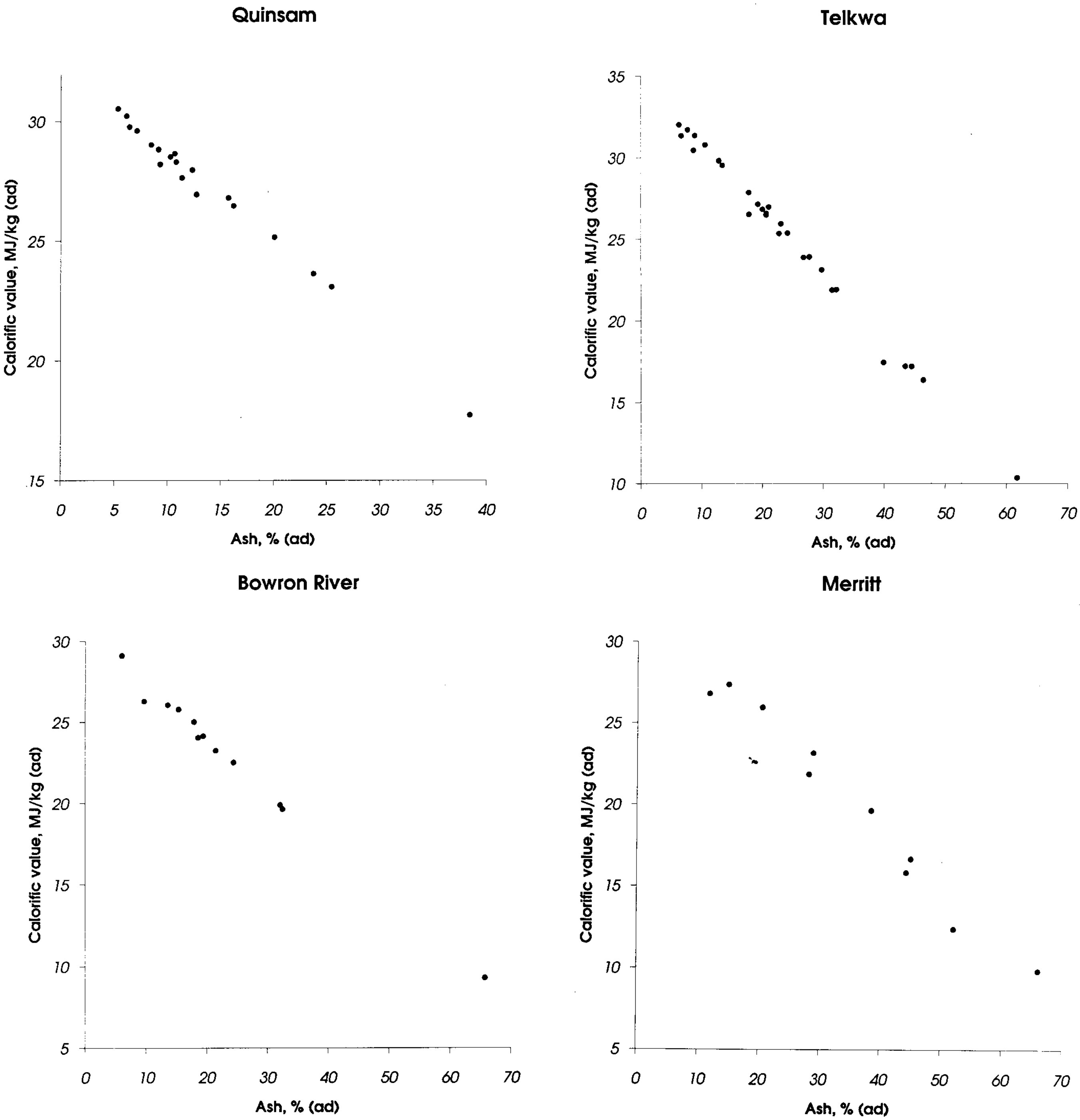


Figure 22. Relationships between calorific value (air-dried basis) and ash.

from -0.987 (Merritt) to -0.997 (Telkwa and Bowron). These strong relationships allow a reliable prediction of the energy content of a particular coal at a given ash content. In this case, we have used an arbitrary value of 15% ash (air dried), to allow us to compare the relative energy content of the four coal deposits (Table 5). The predicted values (air-dried) at 15% ash are: Quinsam, 26.72 megajoules/kilogram; Telkwa, 28.67; Bowron, 25.50; and Merritt, 27.02. In other words, at this ash level Telkwa coal has the highest energy content, Bowron coal has the lowest, and the other two are intermediate and similar. Thus, with the possible exoeption of the Bowron River samples, coals from these basins containing 15% ash should meet the minimum (24 to 25 MJ/kg, as-received) calorific value requirements of typical power plants (Skorupska, 1993). This of course depends on what the as-received moisture levels are. By reducing ash content, coal preparation wonld improve the performance of these coals.

Calorific values were also converted to a moist, ash-free basis (Table 5), to allow rough comparison with the ASTM classification of coals by rank (*see* next section). Only samples with less than 50% ash were used. The ASTM classification uses moist, mineral-matter-free calorific value, so a strict comparison is not possible. Telkwa coal samples have the highest values (mean 32.97 MJ/kg), Bowron samples have the lowest (29.84 MJ/kg), and Quinsam and Merritt are intermediate and similar (31.46 MJ/kg and 31.15 MJ/kg, respectively).

VITRINITE REFLECTANCE AND RANK

Mean random vitrinite reflectance (R_m) is known to be both a sensitive rank indicator and a useful coal quality characteristic. Reflectance generally increases with rank, although it can be affected by other factors, such as coal composition, coal unit thickness and the nature of enclosing sediments.

In this study, vitrinite reflectance values are generally highest for Telkwa coals and lowest for Bowron coals, and the other two deposits are intermediate and quite similar (Table 6). In the case of the Quinsam samples, random reflectance (R_m) ranges from 0.48 to 0.87%, with a mean of 0.67%. The 1-rider-seam has a lower mean reflectance (0.57%) than either 2-seam (0.65%) or 1-seam (0.69%). The reflectance values of Telkwa samples range from 0.79 to 1.06% and have a mean of 0.91%. There do not appear to be stratigraphic or geographic variations, although the means for holes 8 and 9 are slightly higher than the means for the other six holes. Drill holes 8 and 9 are the only ones representing the upper unit and the north part of the deposit. Reflectance values in the Bowron samples range from 0.52 to 0.69%, with a mean of 0.61%. There are no consistent stratigraphic or geographic variations. Lastly, the Merritt samples have reflectance values ranging from 0.62 to 0.82%, with a mean of 0.71%. There are no consistent stratigraphic variations, but there may be a positive reflectance (rank) gradient from southwest to northeast.

The combination of reflectance and calorific value (maf) data allows a fairly rigorous determination of the rank of the coals in this study. In the case of calorific value, the ASTM classification of coals by rank is used assuming there is not much difference between moist, ash-free and moist, mineral-matter-free values. Reflectance data, on the other hand, are converted to ASTM rank classes using the empirical relationships for western Canadian coals established by Cameron (1989, Table 5). In general, the two approaches complement each other in this study, and together provide greater resolution than either by itself. The rank order of the deposits is:

Telkwa>Quinsam ~= Merritt > Bowron River

The average rank of the Quinsam coal samples is believed to be high-volatile B, and overall the samples span a range from high-volatile C to A. The Telkwa samples span a range from high-volatile B to medium-volatile, but the

TABLE 6
COAL PETROGRAPHIC DATA

Coalfield	Rm %	Vitrinite A %	Vitrinite B %	VA/VB	Total Vitrinite %	Total Liptinite %	Semifusinite %	Inerto-detrinite %	Total Inertinite %
Quinsam	0.67 m	34.5	44.7	0.84	79.6	2.2	10.4	4.6	18.2
	(0.48-0.87) r	(20.2-68.0)	(25.7-59.0)	(0.38-2.62)	(65.1-94.0)	(0.3-4.8)	(3.3-19.4)	(0.4-12.5)	(5.6-31.8)
Telkwa	0.91	48.9	24.6	2.26	74.2	0.8	14.6	5.2	24.9
	(0.79-1.06)	(14.6-77.8)	(14.0-42.3)	(0.58-5.56)	(36.8-94.6)	(0-2.4)	(2.8-44.4)	(0.5-13.6)	(4.2-62.4)
Bowron River	0.61	68.9	14.1	33.0	88.9	9.0	0.7	*	1.7
	(0.52-0.69)	(40.0-92.6)	(0.5-38.8)	(1.03-175)	(84.0-95.9)	(3.2-13.6)	(0-2.4)		(0.4-4.8)
Merritt	0.71	45.8	50.0	1.28	97.8	1.3	0.8	0	0.8
	(0.62-0.82)	(29.7-81.7)	(14.4-64.5)	(0.46-5.67)	(95.4-99.9)	(0-3.4)	(0-3.0)	(0-0.3)	(0-3.0)

m = mean
r = range
* not identified

mean and majority of samples are high-volatile A. The presence of some medium-volatile Telkwa samples was also determined by volatile matter (daf) calculations (*see* section on proximate analyses). Bowron River samples range from high-volatile C to B, and the mean rank is probably near the C/B boundary. Merritt samples span the range from high-volatile C to A, and the average rank is believed to be high-volatile B. If the reflectance gradient noted in the Merritt samples (above) is real, then the average rank may be increasing from high-volatile B to A in a northeast direction within the Merritt Basin.

The general rank order of the four deposits is also confirmed by other coal properties, such as moisture (ad basis; decreases with increasing rank), elemental carbon (daf basis; increases) and hydrogen/carbon ratio (decreases). These last two properties are described later in this report, as part of the section on ultimate analyses (*see* Table 7).

MACERAL COMPOSITIONS

Macerals, the microscopically identifiable organic constituents of coal, are the most fundamental indicators of coal type. They are important coal quality parameters, as well as useful indicators of sedimentary environment. They are used here mainly as coal quality indicators. Most of the vitrinite, all of the liptinite and a part of the semifusinite are generally considered to be reactive.

Because of the lower rank of the Bowron River samples, a larger suite of liptinite macerals was counted. Results for all four basins are summarized in Table 6; all values are reported on a mineral-matter-free basis. In general, the Mesozoic coals (Quinsam and Telkwa) contain less vitrinite and more inertinite than the Tertiary coals (Bowron River and Merritt).

Total vitrinite in the Quinsam samples averages 80%. The 1-rider-seam contains less than this average while 2-seam contains more. The amount of vitrinite B is fairly high in these coals; the mean of the ratio vitrinite A to B is less than 1 overall and in 1-seam and 1-rider-seam. The liptinite macerals are in low concentration throughout, with sporinite being the most abundant. The overall mean total inertinite content is 18.2%, and inertinite content is highest in 1-rider-seam and lowest in 2-seam. Semifusinite is, on average, the most common inertinite maceral, with an overall mean of 10.4%. Inertodetrinite is also common, with an overall average of 4.6%.

Total vitrinite in the Telkwa samples averages 74%. The mean ratio of vitrinite A to B is greater than 2. Liptinite is rare throughoat, and sporinite is the most common liptinite maceral. The overall mean total inertinite content is 24.9%. Semifusinite is the most common inertinite maceral (mean 14.6%) and inertodetrinite is also common (5.2%).

Bowron River samplas are very vitrinite rich and inertinite poor. Average total vitrinite of all the samples analyzed is just under 90%, and the average for the individual zones ranges from about 87% to over 92%; the latter value represents zone 1. The mean ratio of vitrinite A to vitrinite B is 33 overall, and in the individual zones ranges from 2.5 (3-zone) to 63 (1-zone). It is significant that zone 1, with the highest mean vitrinite contents, also has the highest ratios. Avarage total liptinite is 9%, and does not vary widely be-

TABLE 7
ULTIMATE ANALYSIS AND SULPHUR FORMS

Coalfield	C, % (daf)*	H, % (daf)*	H/C (atomic)*	N, % (daf)	S, % (daf)	Pyritic S % of Total S	Organic S % of Total S
Quinsam	78.95 m	5.20	0.79	1.02	2.21 **	49.1 ***	47.7
	(74.60-81.12)c r	(5.07-5.44)c	(0.75-0.83)c	(0.98- 1.07)c	(0.32-7.65)c	(3.6-84.5)c	(11.1-92.9)c
Telkwa	83.86	5.08	0.72	1.36	1.58	33.7	63.2
	(72.83-87.41)	(4.39-5.98)	(0.61-0.94)	(0.95-2.05)	(0.42-5.60)c	(5.6-65.7)c	(32.5-94.4)c
Bowron River	75.76	5.30	0.83	1.52	1.88	44.6	51.9
	(68.30-78.48)	(4.28-6.07)	(0.73-0.99)	(1.02-2.14)	(0.63-7.42)c	(16.7-79.3)c	(13.6-82.1)c
Merritt	79.79	5.41	0.81	2.48	1.09	29.4	64.8
	(76.55-83.57)c	(4.83-5.74)c	(0.73-0.87)c	(1.90-2.78)c	(0.47-2.64)c	(5.6-55.8)c	(37.8-91.7)c

m = mean.
r = range.
c = composite samples data.
* based only on samples <50% ash.
** mean of 1-Seam samples is 0.65%.
*** mean of 1-Seam samples is 32.2%.

tween zones. Sporinite, cutinite and resinite are the most common liptinite macerals, with mean values greater than 1.5%. There are also lesser amounts of liptodetrinite, fluorinite, alginite, exsudatinite and suberinite. Inertinite is extremely rare in Bowron River coals; the mean of all the samples is less than 2%. Semifusinite is the most common inertinite maceral.

Merritt samples are also very vitrinite rich. Total vitrinite counts are over 95%, with vitrinite A and B in roughly equal proportions. Liptinite is rare and inertinite is practically nonexistent.

In the case of the Quinsam and Telkwa (Mesozoic) samples, total vitrinite and inertinite contents fall well within normal coal quality requirements (55 to 80%, and 10 to 25%, respectively; Skorupska, 1993). In the two Tertiary deposits (Bowron River and Merritt), vitrinite (and hence the reactive component of the coals) is apparently overabundant. However, this overabundance does not necessarily adversely affect combustion characteristics, which are generally considered to be enhanced with increasing reactive maceral content (Tait *et al.*, 1989).

ULTIMATE ANALYSIS (CARBON, HYDROGEN AND NITROGEN, DRY, ASH-FREE)

Ultimate analysis is the determination of the main organic elemental composition (C, H, O, N and S) in coal. Moisture and ash are also determined. Sulphur is discussed in the next section. Oxygen is not discussed, because the nature of its determination (by difference) is fraught with potential errors, and the results here are not considered reliable. Of the other three elements, Skorupska (1993) lists a range of desired concentration levels only for nitrogen, and defining those concentrations is problematic, as will be seen below.

Carbon and hydrogen contents are known to be rank and composition dependent. As noted in the section on rank, carbon (daf) contents in these samples follow the rank order, that is, Telkwa values are highest, Bowron are lowest, and Quinsam and Merritt are intermediate and roughly equivalent (Table74). Mean values are: Quinsam, 78.95%; Telkwa, 83.00%; Bowron, 75.37%; and Merritt, 79.11%. Mean hydrogen (daf) values for the four deposits are in the 5.2 to 5.5% range, but do not vary systematically. However, mean hydrogen/carbon atomic ratios, with a range from 0.75% (Telkwa) to 0.84% (Bowron River), decrease in the order that rank increases, as expected.

Nitrogen oxides (abbreviated as NO_x) contribute to acid precipitation. However, nitrogen is a difficult element to discuss in the context of acceptable limits, because some of the NO_x emitted from a power plant originate from air, and emission levels are greatly influenced by combustion conditions (Carpenter, 1988). The Quinsam samples have the lowest mean nitrogen (daf) contents (1.02%, Table 4) and are the only ones which fall entirely within the "typical limits" of coals used in power plants (0.8 to 1.1%, Skorupska, 1993).

SULPHUR AND SULPHUR FORMS

Total sulphur content is determined as part of the ultimate analysis, but sulphur is considered as a separate topic in this paper because of its potential to be an environmental contaminant. British Columbia is renowned for its low-sulphur export coals, which originate in the Rocky Mountain belt in the northeast and southeast of the province and on Vancouver Island (Quinsam mine). Coals from the four basins examined in this study generally have higher average sulphur contents than those from the northeast and southeast. Mean sulphur contents (daf) for these samples (Table 7) are: Quinsam, 2.21%; Telkwa, 1.58%; Bowron River, 1.88%; and Merritt, 1.09%. However, sulphur is not evenly distributed in these deposits. The best example is 1-seam, the main economic seam at the Quinsam deposit, which has a mean sulphur content of only 0.65% less than a third of the mean for all Quinsam samples. For this reason, the Quinsam thermal coal product is classed as a low-sulphur coal. Variations in sulphur contents in all basins are described below.

The form of occurrence of sulphur in coal is a critical factor in determining the potential for its removal. The two main sulphur forms are organic and pyritic. Organic sulphur is extremely difficult to remove, while pyritic sulphur can be easy or difficult to remove, depending on how readily it can be liberated.

In British Columbia coals the contribution of pyritic sulphur to total sulphur in general increases with increasing total sulphur composition (Holuszko *et al.*, 1992). In this study, for example, pyritic sulphur is, on average, lowest in the Merritt samples (mean 29.4% of total sulphur), and highest in the Quinsam samples (49.1%). Again, data are not uniform within the deposits. In the case of Quinsam, for example, the 1-seam data appear quite different to the total sample data: pyritic sulphur in 1-seam is only 32.2% of the total sulphur on average. The form and size of the pyrite are also quite variable. These variations will be explained below.

The sulphur distributions of the three basins with the highest sulphur contents and most data (Quinsam, Telkwa and Bowron River) are described in detail by Holuszko *et al.* (in preparation). A brief summary of these data and the Merritt data is provided here.

QUINSAM

As noted above, 1-seam at Quinsam has the lowest mean sulphur content (0.65%, daf basis), and the lowest mean contribution of pyritic sulphur to total sulphur (32.2%). The sulphur content of the upper part of 1-seam is much higher than that of the remainder of the seam and correlates with an increase in pyrite content. The trend of increasing sulphur towards the top of the seam is in agreement with studies from other areas (Casagrande, 1987; Querol *et al.*, 1991), and with 1-zone at Telkwa (*see* below). The highest average seam sulphur content at Quinsam, 4.80%, occurs in 1-rider-seam. Here, pyritic sulphur comprises an average 74% of the total sulphur. The average total sulphur content for Quinsam 2-seam is 3.78%. These higher sulphur values reflect the marine influence on 1-rider and 2-seams.

Pyrite in the Quinsam samples is mainly in two forms, framboidal and euhedral (Holuszko *et al.*, 1992, 1993, in preparation). The proportion of framboidal to total pyrite, as well as the average size of the framboids, increases with increasing total sulphur. It is not surprising, therefore, that the larger framboids, some in excess of 250 microns in diameter, are mainly associated with the upper part of 1-seam, as well as with 1-rider and 2-seams. The framboids appear to be mainly associated with vitrihite-rich microlithotypes, while the smaller euhedral pyrite grains are associated with open spaces in inertinite macerals and with fractures. The framboids are probably mainly syngenetic, while the euhedral pyrite crystals are probably secondary in origin.

TELKWA

The mean sulphur content (daf) in the Telkwa composite samples is 1.58%, and the average contribution of pyritic to total sulphur is 33.7%. Mean sulphur in the samples from drill holes 8 and 9, from the upper unit, is 2.02%, which is higher than the mean in samples from the lower unit (drill holes 1 to 5, mean 1.25%) or the 1-zone in the lower unit (drill holes 1 and 2, mean 1.49%). This reflects a marine influence in the upper unit (Koo, 1983; Palsgrove and Bustin, 1991). The relative contributions of pyritic to total sulphur occur in the same order. The proportion of pyritic sulphur to total sulphur in the upper unit samples is highest at 42.1%. Sulphur contents in both drill holes 1 and 2, from the 1-zone, are highest near the top. This probably reflects the marine transgression above the lower unit.

Pyrite forms were described in the top nine samples from drill hole 1 (Holuszko *et al.*, 1992, 1993, in preparation). Pyrite occurs in three basic forms in these samples, framboidal, euhedral and irregular. The last type are massive and large (ranging from 50 to 100 μm), although not as large as some of the framboids, which reach 250 microns in diameter in the most sulphur-rich samples at the very top of drill hole 1. Euhedral pyrite grains are small (usually less than 5 μm), and their abundance is inversely related to the abundance of the framboids. Framboidal pyrite is associated with vitrinite-rich microlithotypes, while the irregular form of pyrite is mainly associated with semifusinite, which, in part, it appears to have replaced. Euhedral pyrite grains are associated with cavities in inertinite macerals, and with fractures.

BOWRON RIVER

The mean sulphur (daf) in the incremental samples from the Bowron River drill holes is 1.88%. The mean sulphur contents of the four zones decreases upsection. Zone 4, the deepest zone, with a mean of 2.44%, has the highest average sulphur content, followed by zones 3 and 2 (both at 1.51%) and then zone 1 (0.90%). In the composite sample data, it is evident that increases in total sulphur are a result of increases in pyritic sulphur. For example, the contribution of pyritic sulphur in zone 4 is 44.4%, while in zone 1 it is 27.3%.

Samples representing all four coal zones were described petrographically to determine the form of pyrite association in the coals (Holuszko *et al.*, in preparation). Framboidal forms of pyrite are the most common. The lowermost zone (4) is characterized by framboids up to 300 microns in diameter, sometimes in contact with carbonate minerals. In zone 3, smaller framboids are intermixed with clay minerals. Zones 1 and 2 contain framboids ranging from 10 to 15 microns across; veinlet pyrite is also very common. Given the high vitrinite content of the Bowron River coals, it is not surprising that framboids are associated with vitrinite and euhedral pyrite grains are associated with fractures in vitrinite (cleats). Proximity of pyrite to resinite and cutinite is also noted.

MERRITT

The Merritt composite samples have both the lowest mean sulphur content, 1.09%, and the lowest proportion of pyritic to total sulphur, 29.4%. The 4-seam has the highest mean sulphur at Merritt (1.49%), but this is based on very few samples. The other three seams sampled have 0.5% or less mean sulphur. Samples from 4-seam also have the highest amount of pyritic sulphur, 42.3% of total sulphur.

ASH CHARACTERISTICS

The properties of the ash are crucial characteristics of a given coal during combustion. Ash chemistry, in particular, is the main determinant of problems such as slagging, fouling and corrosion. The potential for these problems can to some extent be predicted by use of ash analysis data (ash analysis refers to major oxide concentrations in the ash produced during proximate analysis). Ash behaviour under experimental heating conditions is observed in determination of ash fusion temperatures.

ASH CHEMISTRY

The chemistry of coal ash, as determined by ash analysis, can be viewed in simplest terms as consisting of acidic and basic components. The acidic components are SiO_2, Al_2O_3 and TiO_2, while the basic components are Fe_2O_3, CaO, MgO, K_2O and Na_2O. Ash chemistry can be influenced to some extent by coal preparation.

Ash oxide compositions for the four deposits, together with typical limits for power generation are summarized in Table 8. The mean concentrations of most elements are within typical limits for all the deposits. Some exceptions include: silica values are relatively low in Quinsam samples; iron values are relatively high in Bowron River samples; calcium values are relatively high in Quinsam, Telkwa and Bowron samples; magnesium values are high in Bowron River samples; sodium values are high in Merritt samples; and potassium values are low in Quinsam and Telkwa samples. Some elements exhibit a large variation between the deposits. For example, silica values are highest in the ash of the Merritt samples (mean 59.67%) and lowest in the Quinsam samples (mcan 29.95%). Conversely, calcium is highest in Quinsam coals (23.63%) and lowest in Merritt coals (1.53)%. Sodium values are highest in Merritt samples (1.49%) and lowest in the Telkwa samples (0.15%). Potassium valnes are also highest in the Merritt samples (1.82%), and lowest in Quinsam samples (0.19%).

TABLE 8
ASH ANALYSES

Coalfield	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5	SO_3
Quinsam	29.95m (11.09-57.88)r	22.28 (14.32-32.46)	1.57 (0.40-2.61)	10.20 (3.56-31.73)	23.63 (4.11-39.86)	0.74 (0.39-1.28)	0.31 (0.16-0.64)	0.19 (0.01-0.42)	0.30 (0.01-2.59)	8.60 (3.60-19.55)
Telkwa	57.32 (46.16-69.11)	21.92 (5.67-30.22)	1.43 (0.43-2.04)	7.27 (1.29-26.15)	6.52 (0.79-17.16)	1.07 (0.20-3.21)	0.15 (0.05-0.24)	0.41 (0.13-0.95)	0.63 (0.05-2.37)	2.54 (0.27-7.92)
Bowron River	53.66 (22.29-79.70)	14.75 (2.40-22.71)	0.61 (0.09-0.90)	17.62 (4.12-37.13)	4.04 (1.22-9.49)	2.04 (1.15-4.52)	0.69 (0.30-1.55)	1.73 (0.14-2.92)	0.58 (0.15-1.32)	5.09 (1.18-15.86)
Merritt	59.67 (48.34-64.40)	25.71 (23.53-31.21)	1.01 (0.68-1.46)	6.61 (3.95-12.06)	1.53 (0.51-4.21)	1.06 (0.50-1.39)	1.49 (0.61-2.53)	1.82 (0.70-2.87)	0.43 (0.11-1.04)	0.73 (0.21-3.80)
Typical Limits*	45-75	15-35	0.4-2.2	1-12	0.1-2.3	0.2-1.4	0.1-0.9	0.8-2.6	0.1-1.5	0.1-1.6

m = mean.
r = range.
* from Skorupska !993).

Coal ashes have been classified into "lignitic" and "bituminous" types (rank categories not intended), based on the relative amounts of CaO, MgO and Fe_2O_3 (Skorupska, 1993). Where the sum of CaO and MgO exceeds the amount of Fe_2O_3, the ash is termed "lignitic", and where the reverse is true the ash is classified as "bituminous". These categories have bearing on the application of calculated ash indices (next section). In the Quinsam samples, the mean CaO, MgO and Fe_2O_3 values imply a lignitic ash, consistent with the individual samples (16 lignitic, 3 bituminous). The same is true for Telkwa (20 lignitic, 8 bituminous). Bowron River and Merritt samples, in contrast, have mean CaO, MgO and Fe_2O_3 values in the bituminous ash category, and only one sample, from the Bowron River deposit, has a lignitic ash.

Sodium content (Na_2O in ash) can be used as a predictor of fouling propensity (Schmidt, 1976; Skorupska, 1993). Different limits are applied for lignitic and bituminous ashes (*see* Skorupska, Table 8). Quinsam and Telkwa ash sodium compositions suggest that both have a low fouling propensity, while Bowron River samples have a medium propensity and Merritt samples a high propensity. Further predictions of fouling and slagging potential are dealt with in the next section.

CALCULATED ASH INDICES

Ash analysis results can be used in mathematical relationships to calculate various chemical and performance indices (*see* Schmidt, 1976; Skorupska, 1993). We have calculated the base-acid ratio, total alkalis in coal, fouling factor and slagging factor (*see* Table 9 for formulae and Table 10 for results). Categories of coal fouling and slagging tendencies based on these indices are given in Schmidt (1976, Table 2) and Skorupska (1993, Table 11).Because the boundaries of the categories are empirical and were established using coals from other parts of the world, the results here can be used to categorize coals in only a very general way.

TABLE 9
ASH INDEX FORMULAS

Base/acid ratio (slagging propensity in lignitic ash)	$\frac{\%\,(Fe_2O_3 + CaO + MgO + Na_2O + K_2O)}{\%\,(SiO_2 + Al_2O_3 + TiO_2)} = B/A$
Total alkali on coal (fouling prospensity in bituminous ash)	$[\%Na_2O + 0.6589\,(\%K_2O)]\,\frac{\%\ ash}{100}$
Fouling factor (bituminous ash)	$(B/A)(\%Na_2O)$
Slagging factor (lignitic ash)	$(B/A)\,(\%S_{dry})$

Source: Skorupska (1993); Schmidt (1976)

TABLE 10
CALCULATED ASH INDEXES

Coalfield	Base/acid ratio	Total alkali on coal	Fouling factor	Slagging factor
Quinsam	0.78m (0.20-1.82)r	0.071 (0.016-0.33)	0.22 (0.054-0.51)	1.80* 0.69**
Telkwa	0.20 (0.056-0.50)	0.11 (0.017-0.36)	0.029 (0.004-0.064)	0.35 (0.014-1.80)
Bowron River	0.50 (0.10-1.47)	0.43 (0.073-1.17)	0.46 (0.039-2.28)	0.84 (0.096-3.88)
Merritt	0.15 (0.12-0.18)	1.01 (0.16-2.41)	0.21 (0.11-0.40)	0.11 (0.050-0.38)
Range for "high" values***	>1.0	0.45-0.6	0.5-1.0	2.0-2.6

* Product of mean sulphur and mean base/acid ratio, all Quinsam samples.
** Product of mean sulphur and mean base/acid ratio, 1-seam only.
*** Sources: Skorupska (1993); Schmidt (1976).
m mean.
r range.

TABLE 11
ASH FUSION TEMPERATURES

Coalfield	Initial deformation	Softening	Hemi-spherical	Fluid
Quinsam	1303[m] (1175-1420)[r]	1327 (1205-1430)	1341 (1220-1440)	- (1255-1450+)
Telkwa	1253 (1126-1400)	- (1147-1458+)	- (1157-1458+)	- (1247-1458+)
Bowron River	- (1064-1538+)	- (1073-1538+)	- (1119-1538+)	- (1148-1538+)
Merritt	- (1409-1538+)	- (1431-1538+)	- (1490-1538+)	- (1535-1538+)

m mean.
r range.

Mean base-acid ratio in the four deposits ranges from a high of 0.779 (Quinsam) to a low of 0.146 (Merritt). These results correspond with the relatively high calcium content, mainly present as calcite on cleat surfaces (Kenyon *et al.*, 1992), of Quinsam coal, and the relatively high sihca content of Merritt coals. In the case of Quinsam and Telkwa (lignitic ashes), the base-acid ratio can be used as an indicator of slagging propensity: Quinsam samples are predicted to have medium propensity and Telkwa samples low.

Slagging propensity for coals with bituminous ash is sometimes predicted using the slagging factor. Bowron River and Merritt mean slagging factor values, 0.11 and 0.84, can be classed as low and medium slagging tendencies, respectively.

Mean total coal alkali values in the four deposits range from a low of 0.071% in the case of Quinsam, to 1.011% in the case of Merritt. In the case of coals with bituminous ash, total alkali is an indicator of fouling propensity (Schmidt, 1976). These values represent severe fouling tendencies for the Merritt samples, and medium tendencies in the case of Bowron River samples.

Mean fouling factor is also an indicator of fouling propensity in coals with bituminous ash. Predicted fouling tendencies are medium in both Bowron River and Merritt samples, although the Merritt coals are borderline low to medium.

Based on calculated ash indices, and the sodium concentrations (above), Quinsam and Telkwa coals have favourable ash compositions with respect to tendency for slagging and fouling. This appears to be especially true of the Telkwa samples, while the Quinsam samples do have a somewhat higher ("medium") predicted slagging propensity. Bowron River coals also have quite favourable ash properties, although fouling propensity is classed as medium. Merritt coals would appear to have potential problems with fouling, based on their high alkali contents. Again it must be emphasized that the reliability of these predictions is not considered high, and they are intended to give a general indication only.

ASH FUSION TEMPERATURES

The physical properties of the ash can be determined by observing temperatures of ash fusibility. High values of the four temperatures (below) are generally desirable. The test is somewhat subjective and does not realistically represent actual conditions, so it is necessary to be cautious in using the results (Skorupska, 1993). Results are given in Table 11; in all cases, ashes were heated under reducing conditions. Because there are so many temperature ranges which have a maximum expressed as a greater-than value, no statistical analysis was done on these data, and the description of results is general and qualitative. It should also be borne in mind that there is a great deal of variation among the samples from one deposit.

The first observed temperature (initial deformation) is highest on average in the Merritt samples, followed in order by Quinsam, Telkwa and Bowron. For the next temperature (softening) Merritt is again the highest, on average, followed by Quinsam and Telkwa (roughly equivalent?) and then by Bowron, the lowest. For hemispherical and fluid temperatures the order appears to be Merritt, Telkwa, Quinsam and Bowron (highest to lowest). With the exception of some of the Bowron River samples, samples here have values above the minimum typical limits for power generation (Skorupska, 1993, Table 1), which are as follows: initial, 1075°C; softening, 1150°C; hemispherical, 1180°C; and fluid, 1225°C.

The most desirable ash fusion characteristics therefore belong to the Merritt samples. The uniformly higher temperatures for Merritt coals are probably a reflection of their higher contents of the refractory oxides, silica and alumina. The relatively low temperatures for the Bowron River samples may be partially a function of their lower rank, and perhaps their relatively low alumina contents.

TRACE ELEMENTS

For purposes of discussion, trace elements are divided into highly volatile elements (F, Hg and Cl) and other elements (Sb, As, B, Br, Cr, Co, Cu, Mn, Mo, Ni, Se, Th, W, U, V and Zn). Mean concentrations of the first group are given in Table 12, and those for the second group are in Table 13. The typical ranges in concentrations of most elements in world coals, based on Swaine (1990), are also given in these tables.

VOLATILE TRACE ELEMENTS

FLUORINE

Fluorine values are by far the lowest in the Quinsam samples; all concentrations there are less than the detection limit of 5 ppm (Table 12). With a mean of 81 ppm, the Telkwa samples have the next lowest fluorine concentrations. Samples from the upper unit have a higher average fluorine content (118 ppm) than those from the lower unit (48ppm). Bowron River and Merritt samples both have mean fluorine concentrations of about 150 ppm. At Bowron River, the lowermost coal zone, number 4, has the highest mean fluorine content (202 ppm). In the case of Merritt, 6-seam has the highest mean fluorine content (203 ppm).

TABLE 12
MEAN FLUORINE MERCURY AND CHLORINE CONCENTRATIONS

Coalfield	F (ppm)	Hg (ppb)	Cl (ppm)
Quinsam	<5	208	130
Telkwa	81	95	221
Bowron River	153	320	11.3
Merritt	151	84	89
World Coals*	20-500	20-1000	50-2000

* after Swaine, 1990.

TABLE 13
MEAN TRACE ELEMENT CONCENTRATIONS (ppm)

	World coals*	Telkwa	Bowron River	Merritt
Sb	0.5-10	0.3	3.7	0.9
As	0.5-80	1.4	37	8.0
B	5-400	27.6	84.4	30.0
Br		3.0	0.6	2.4
Cr	0.5-60	15.1	27.0	22.0
Co	0.5-30	5.4	13.5	7.0
Cu	0.5-50	16.7	16.7	62.0
Mn	5-300	12.0	95.4	296
Mo	0.1-10	2.5	15.3	5.5
Ni	.5-50	6.20	34.4	76.0
Se	0.2-1.4	1.0	1.6	2.7
Th	0.5-10	1.9	2.5	4.9
W		0.3	0.4	1.9
U	0.5-10	1.3	5.6	2.5
V	2-100	39	49	70
Zn	5-300	13.3	48.0	40.9

* after Swaine, 1990

Swaine (1990, page 113) estimated that 150 ppm is an approximate average in world coals, so these British Columbia thermal coals are not unusually rich in fluorine. Raw coals from the southeastern and northeastern British Columbia coalfields have generally higher fluorine contents than these coals (Grieve and Goodarzi, 1993).

In the cases of the Merritt and Bowron River samples, there is a positive correlation between fluorine and ash, suggesting a probable mineral matter (inorganic) association (Figure 23). Telkwa samples show an ambiguous relationship of fluorine with ash content, but it is quite likely that fluorine in Telkwa coals is also inorganically associated. Fluorinel data from coals from northeastern and southeastern British Columbia behave similarly to these Telkwa data, despite the fact that much of their fluorine is tied up in the mineral fluorapatite (Grieve and Goodarzi, 1993). Quinsam fluorine data can not be used for statistics.

MERCURY

Mercury values (Table 12) are lowest in the Merritt and Telkwa samples (means of 84 and 95 ppb, respectively). These values are well below the estimated average of 180 ppb in U.S. coals (Finkelman, 1980). Mean mercury concentration in the Quinsam coals is 208 ppb, and, at 320 ppb, the Bowron River samples have the highest contents.

Mercury in coal is thought to be mainly associated with pyrite (Finkelman, 1980; Swaine, 1990). The stratigraphic variations in mercury contents in general follow the variations in sulphur in this study (Figure 24), which tends to confirm this. In the Quinsam samples, for example, the 1-rider and 2-seams have higher mean mercury contents than 1-seam (263 and 225 ppb, respectively, compared with 177 ppb). Similarly at Telkwa the upper zone samples have higher mean mercury contents than the lower zone samples (137 ppb compared with 58 ppb). This relationship breaks down in the case of the Bowron River samples, as zones 2 and 3, which have intermediate sulphur concentrations, have the highest mean mercury concentrations (greater than 600 ppb). The zone with the highest sulphur content, number 4, has a mean mercury concentration of 166 ppb; the value in zone 1 is 123 ppb. The overall relatively high mercury concentrations in Bowron River coals suggests that another factor instead of, or in addition to, pyrite is functioning to control mercury in some samples. At Merritt, on the other hand, the highest mean mercury concentration, 210 ppb, is in 4-seam, the seam with the highest sulphur content of those sampled. The other seams, which all have low sulphur contents, have low mean mercury concentrations of 40 ppb (2-seam), 33 ppb (3-seam) and 80 ppb (6-seam).

Positive correlations between mercury and sulphur also seem to bear out the pyrite association (Figure 24).

CHLORINE

The mean chlorine concentration (Table 12) is extremely low in the Bowron River samples (11 ppm). Samples from the other three basins are somewhat higher, but are well within the range of most world coals. The highest concentration, by a factor of almost two, occurs in the Telkwa samples; the mean there is 221 ppm (0.022%). In comparison, raw coals from the two Peace River coal mines, Bullmoose and Quintette, have mean chlorine contents of about 250 ppm (Grieve *et al.*, in preparation). Chlorine is generally believed to occur in organic form in coals (Swaine, 1990), and so ash content and mineralogy of individual samples do not directly affect its concentrations.

OTHER TRACE ELEMENTS

Mean values of other trace element concentrations in samples from Telkwa, Bowron River and Merritt are given in Table 13. Values for Quinsam coals were not obtained. Trace element geochemistry of Comox Basin coals, including some Quinsam samples, are given by Van der Flier-Keller and Goodarzi (1992). Table 13 also contains estimated

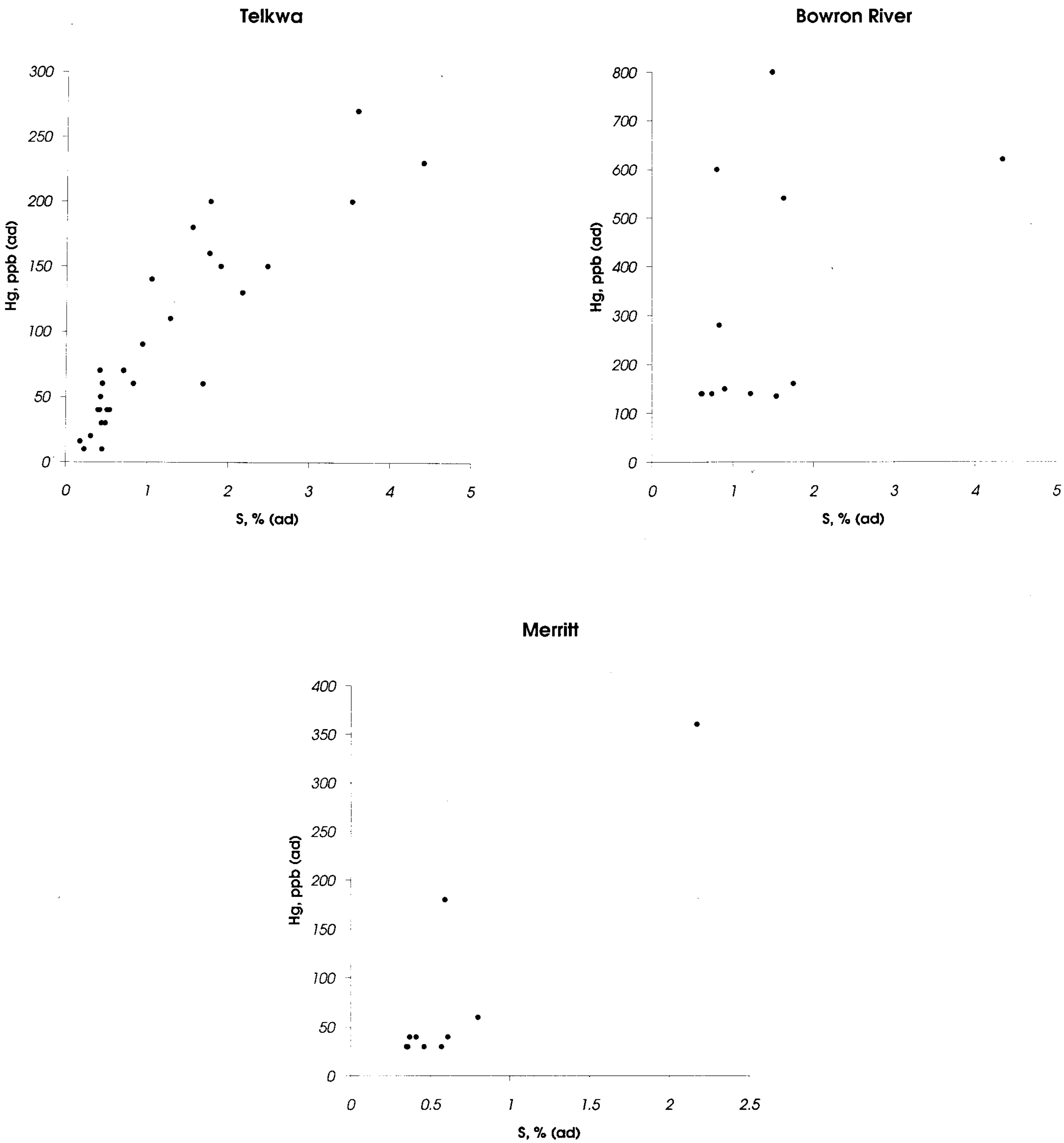


Figure 23. Relationships between fluorine concentrations and ash.

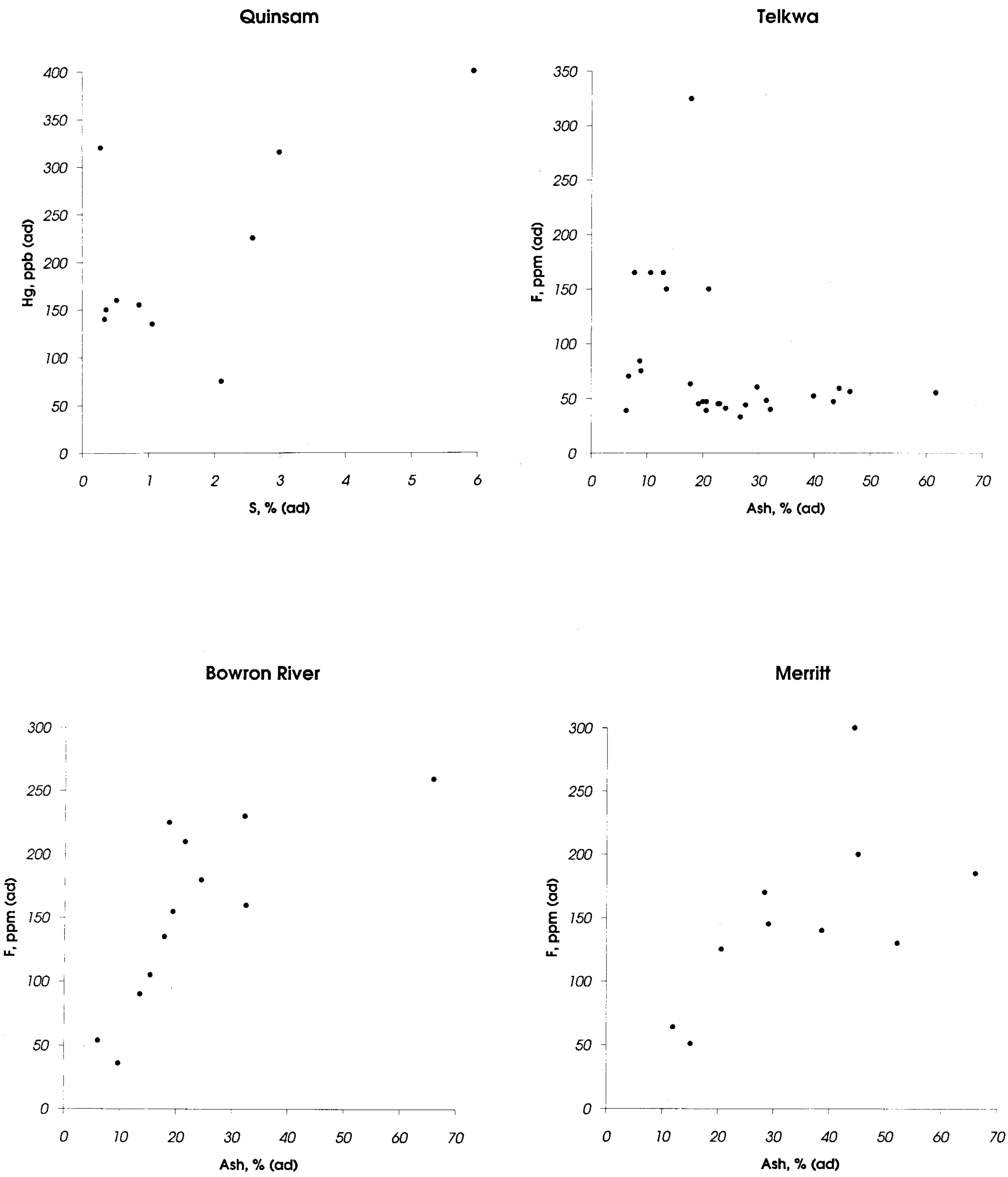


Figure 24. Relationships between mercury and sulphur concentrations.

typical world ranges for most elements, based on Swaine (1990).

In comparing Telkwa, Bowron River and Merritt samples, the latter two basins tend to contain higher mean trace element concentrations than the first (Table 13). For example, Bowron River contains the highest values of one suite of elements (Sb, As, B, Cr, Co, Mo, U and Zn), while Merritt contains the highest values of an entirely different suite (Cu, Mn, Ni Se, Th, W and V). Telkwa samples are highest in only one element, bromine, and contain the lowest mean concentrations of essentially all the other elements.

For the most part, the mean concentrations of the elements studied here are within their estimated typical world ranges, as given by Swaine (1990). The most notable exceptions are in the Merritt samples, where mean concentrations of copper, nickel and selenium are above the upper end of the world range, and where the mean manganese concentration is equivalent to the high end of the range. Two other exceptions to note are the mean concentrations of molybdenum and selenium in Bowron River samples, both of which are higher than the upper end of the range for most world coals.

Geological controls on trace element concentrations in British Columbia coals are complex. Some factors include tectonic setting, depositional environment, source rock composition, mineral matter in coal, rank, groundwater regimes during and after coalification, and weathering (Van der Flier-Keller and Goodarzi, 1992). For example, it is believed that relatively high concentrations of some trace elements in Bowron River coals (for example, boron and arsenic) are related to their removal and mobilization from Mississippian volcanics by groundwater circulation through faults (Goodarzi *et al.*,1992). Further study will be needed to identify specific factors influencing geochemistry of these coals.

CONCLUSIONS

- The use of small-diameter diamond-drilling is an effective method of sampling unoxidized, shallow subsurface coal in the four basins studied. Core recovery rates were good, and meaningful coal quality data were obtained in all cases.
- With the possible exception of some of the Merritt coal seams, all coals studied meet typical requirements for ash content in thermal coals. Moreover, there is some suggestion that the Merritt samples may have become contaminated with inorganic material.
- Due to the high-volatile nature of the coals, all are expected to have favourable ignition and combustion characteristics.
- With the possible exception of some of the Bowron River samples, energy contents (calorific value) of the coals studied meet typical requirements for thermal coals.
- Telkwa coals are predominantly high-volatile A bituminous in rank. Merritt and Quinsam coals are mainly high-volatile B in rank, while Bowron River coals are high-volatile C to B.
- All the coals are vitrinite rich, especially the Tertiary coals, Bowron River and Merritt. Liptinite is in low abundance throughout, with the exception of the Bowron River coals, which contain more than 1.5% on average of each of sporinite, cutinite and resinite. Semifusinite is the most abundant inertinite maceral, but exceeds 10% mean concentration only in the Quinsam and Telkwa samples.
- Mean sulphur concentrations are highest in the Quinsam samples, and lowest in the Merritt samples. Sulphur at Quinsam is not evenly distributed, however; the highest values occur near the top of 1-seam and in 1-rider and 2-seams. In general, the proportion of pyritic sulphur increases with increasing total sulphur content in all basins. The occurrences of higher sulphur coal in the Quinsam and Telkwa seams are related to marine depositional influence.
- Base-acid ratio in coal ash is highest in the case of Quinsam and lowest in the case of Merritt coals. High calcium in the Quinsam coals is the main contributor to their high ratio.
- Quinsam and Telkwa coals have generally favourable ash chemistry in relation to slagging and fouling propensity.
- Merritt coals have the most favourable ash fusion characteristics, while Bowron River coals have the least.
- In this study, Merritt coals have the highest mean concentrations of Cu, Mn, Ni, Se, Th, W and V; Bowron River coals have the highest mean concentrations of Sb, As, B, Cr, Co, F, Hg, Mo, U and Zn, while Telkwa samples have the highest mean Cl and Br concentrations (concentrations for trace elements other than Cl, F and Hg in Quinsam samples were not determined). Telkwa coals have the lowest mean concentrations of most of the trace elements studied. Means of most trace elements are within typical ranges for world coals, with the exceptions of Cu, Ni and Se in Merritt coals, and Mo and Se in Bowron River coals, which are above world ranges.

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APPENDICES

APPENDIX 1: QUINSAM

Comp. sample no.	Resid. mois. (ad) %	Ash (ad) %	Vol. matter (ad) %	Fixed carbon (ad) %	Cal. value (ad) MJ/kg	SiO_2 %	Al_2O_3 %	TiO_2 %	Fe_2O_3 %	CaO %	MgO %	Na_2O %	K_2O %	P_2O_5 %	SO_3 %
1	2.37	23.76	33.28	40.59	23.61	43.95	28.01	2.230	16.98	4.11	1.06	0.61	0.38	0.010	3.600
2	2.24	38.45	28.87	30.44	17.74	44.48	32.46	2.610	7.68	7.60	1.28	0.64	0.34	0.010	4.540
3	2.10	20.08	36.38	41.44	25.16	27.91	16.84	1.210	31.73	9.74	0.94	0.39	0.42	0.140	10.010
4	2.32	10.69	37.94	49.05	28.64	25.69	26.59	1.450	12.73	16.20	0.65	0.27	0.17	2.590	11.610
5	2.53	6.16	39.72	51.59	30.22	12.89	17.47	0.730	16.11	25.40	0.98	0.27	0.14	0.320	19.550
6	2.34	8.48	39.15	50.03	29.01	14.76	14.32	0.680	7.54	37.36	0.74	0.26	0.13	0.110	15.110
7	2.50	7.14	38.91	51.45	29.60	11.09	15.69	0.400	10.00	38.20	0.83	0.28	0.11	0.010	13.130
8	2.44	12.74	35.80	49.02	26.94	26.95	24.46	1.900	4.83	32.78	0.65	0.28	0.13	0.080	6.790
9	2.44	9.31	37.65	50.60	28.19	20.29	20.15	1.450	5.58	37.57	0.88	0.28	0.05	0.010	10.640
10	2.19	16.22	33.92	47.67	26.47	57.88	20.83	2.480	3.56	11.91	0.53	0.35	0.12	0.100	4.000
11	2.62	12.34	36.22	48.82	27.95	43.73	22.60	1.890	4.81	21.39	0.63	0.23	0.11	0.010	4.370
12	2.86	6.44	38.45	52.25	29.76	17.72	19.68	1.220	7.36	39.86	0.83	0.24	0.01	0.010	6.720
13	2.78	5.36	38.32	53.54	30.52	24.03	24.04	1.370	8.62	30.27	0.88	0.27	0.07	0.010	8.170
14	2.83	11.37	35.40	50.40	27.62	26.08	21.29	0.830	6.02	34.83	0.50	0.22	0.16	0.350	3.970
15	2.43	25.47	33.10	39.00	23.07	43.10	23.37	2.200	14.01	8.04	0.66	0.16	0.36	0.010	7.520
16	2.89	9.16	36.41	51.54	28.81	29.49	24.08	1.660	8.42	26.45	0.43	0.25	0.21	0.940	7.840
17	2.84	10.29	36.79	50.08	28.50	34.15	27.09	1.940	5.85	25.80	0.39	0.24	0.18	0.040	5.640
18	2.53	15.74	36.31	45.42	26.80	37.42	23.81	2.060	12.31	13.68	0.68	0.37	0.35	0.820	9.990
19	2.80	10.83	37.13	49.24	28.29	27.49	20.56	1.510	9.57	27.79	0.53	0.23	0.12	0.210	10.210

Comp. sample no.	Resid. mois. (ad) %	Ash (ad) %	C (ad) %	H (ad) %	O (ad) %	N (ad) %	S (ad) %	S [pyr] (ad) %	S [org] (ad) %	S [sulfate] (ad) %	T initial deg. C	T soften deg. C	T hemisph deg. C	T fluid deg. C	F (ad) ppm	Hg (ad) ppb
A	2.65	28.85	51.61	3.88	12.34	0.73	2.59	1.99	0.52	0.08	1380	1410	1430	1450	5	225
B	2.10	20.08	61.50	4.47	7.21	0.79	5.95	5.03	0.66	0.26	1175	1205	1220	1255	5	400
C	2.60	8.02	71.41	4.98	13.63	0.90	1.06	0.59	0.45	0.02	1385	1410	1420	1430	5	135
D	2.60	12.58	67.42	4.64	14.16	0.84	0.36	0.03	0.32	0.01	1280	1305	1315	1345	5	150
E	2.81	8.59	70.56	4.82	14.88	0.87	0.28	0.01	0.26	0.01	1420	1430	1440	1450	5	320
F	2.43	25.47	53.79	4.00	13.02	0.72	3.00	2.34	0.53	0.13	1235	1280	1315	1370	5	315
G	2.89	9.16	70.42	4.78	14.19	0.93	0.52	0.07	0.44	0.01	1255	1280	1290	1305	5	160
H	2.84	10.29	69.92	4.77	13.81	0.87	0.34	0.20	0.13	0.01	1305	1315	1320	1330	5	140
I	2.53	15.74	65.24	4.56	11.49	0.86	2.11	1.23	0.78	0.10	1335	1350	1365	1385	5	75
J	2.80	10.83	70.06	4.87	12.50	0.88	0.86	0.46	0.38	0.02	1265	1290	1300	1315	5	155

APPENDIX 2: TELKWA

Comp. sample no.	Resid. mois. (ad) %	Ash (ad) %	Vol. matter (ad) %	Fixed carbon (ad) %	Cal. value (ad) MJ/kg	SiO_2 %	Al_2O_3 %	TiO_2 %	Fe_2O_3 %	CaO %	MgO %	Na_2O %	K_2O %	P_2O_5 %	SO_3 %	Resid. mois.* (ad) %	Ash* (ad) %	C* (ad) %	H* (ad) %	O* (ad) %	N* (ad) %	S* (ad) %	S [total] (ad) %	S [pyr] (ad) %	S [org] (ad) %	S [sulfate] (ad) %	T initial deg. C	T soften deg. C	T hemisph deg. C	T fluid deg. C	F (ad) ppm	Hg (ad) ppb
1	0.49	23.01	28.21	48.29	25.93	55.45	21.08	1.18	14.98	2.82	0.76	0.23	0.87	0.11	1.61	0.93	23.15	62.53	4.17	5.90	0.81	3.44	3.52	1.99	1.38	0.15	1284	1310	1326	1379	45	200
2	0.51	20.62	28.44	50.43	26.57	57.27	23.77	1.54	3.43	7.01	2.56	0.16	0.29	0.09	3.40	0.90	23.36	63.30	4.11	7.81	0.99	0.42	0.43	0.08	0.34	0.01	1268	1321	1342	1452	47	50
3	0.57	31.42	26.04	41.97	21.86	55.25	25.87	1.48	2.77	8.34	3.21	0.18	0.31	0.06	2.02	0.81	36.09	50.71	3.42	8.58	0.86	0.35	0.40	0.06	0.33	0.01	1247	1347	1363	1458	48	40
4	0.49	46.40	21.12	31.99	16.35	61.22	29.50	2.03	1.38	2.53	0.80	0.23	0.26	0.09	1.04	0.85	46.24	41.40	3.12	8.22	0.77	0.25	0.31	0.03	0.27	0.01	1350	1458	1458	1458	56	20
5	0.66	20.00	30.35	48.99	26.83	55.17	21.90	1.45	11.23	4.46	1.69	0.24	0.95	0.21	1.82	0.92	22.17	63.50	4.24	5.79	1.04	3.27	2.48	1.12	1.20	0.16	1184	1310	1331	1452	47	150
6	0.58	27.69	26.83	44.90	23.90	60.35	22.34	1.75	7.48	2.55	1.01	0.15	0.59	0.09	3.22	0.85	31.98	53.86	3.58	4.40	0.98	5.21	1.69	1.11	0.55	0.03	1363	1458	1458	1458	44	60
7	0.66	29.73	25.23	44.38	23.10	64.71	24.70	1.41	2.08	2.53	1.28	0.05	0.83	0.09	1.66	0.87	27.41	59.37	3.85	7.88	1.05	0.44	0.44	0.08	0.35	0.01	1321	1458	1458	1458	60	30
8	0.58	22.73	27.64	49.05	25.34	52.08	25.11	1.67	2.85	10.83	3.16	0.24	0.31	0.08	0.69	0.81	21.50	63.95	3.98	9.09	1.01	0.46	0.45	0.06	0.38	0.01	1279	1323	1331	1437	45	10
9	0.54	44.50	21.64	33.32	17.19	62.77	27.49	1.59	1.94	2.91	1.05	0.17	0.78	0.08	0.69	0.86	46.19	41.52	3.06	8.18	0.79	0.26	0.23	0.02	0.21	0.01	1331	1458	1458	1458	59	10
10	0.68	61.75	19.01	18.56	10.34	65.22	24.80	1.87	2.09	2.97	1.04	0.08	0.76	0.07	0.52	0.92	61.63	26.38	2.47	8.77	0.60	0.16	0.18	0.02	0.16	0.01	1363	1458	1458	1458	55	16
11	0.49	32.13	27.54	39.84	21.89	57.13	26.80	1.96	2.12	6.80	2.10	0.12	0.31	0.07	2.19	0.77	34.65	52.08	3.65	8.38	0.87	0.38	0.42	0.08	0.33	0.01	1331	1458	1458	1458	40	40
12	0.51	43.45	25.29	30.75	17.20	60.26	24.38	1.90	2.15	7.60	1.14	0.15	0.39	0.05	1.60	0.83	46.71	40.16	3.10	8.89	0.76	0.38	0.42	0.14	0.27	0.01	1289	1458	1458	1458	47	70
13	0.67	24.10	28.58	46.65	25.37	59.09	30.22	2.04	1.29	4.05	0.39	0.07	0.26	0.09	1.87	0.88	27.26	59.76	4.15	7.39	0.94	0.52	0.49	0.08	0.39	0.02	1321	1458	1458	1458	41	30
14	0.77	39.90	24.60	34.73	17.43	46.16	27.42	1.21	3.31	17.16	0.49	0.22	0.57	0.11	2.77	1.19	37.95	46.82	3.18	10.36	0.74	0.97	0.94	0.48	0.38	0.08	1400	1458	1458	1458	52	90
15	0.70	26.75	26.30	46.25	23.87	59.32	26.66	2.00	1.29	6.10	0.41	0.14	0.34	0.05	2.59	0.94	25.90	60.65	4.02	8.08	0.94	0.41	0.45	0.06	0.38	0.01	1142	1458	1458	1458	33	60
16	0.79	6.29	30.16	62.76	32.03	52.14	23.14	1.74	18.50	1.73	0.20	0.15	0.19	0.73	0.42	0.77	8.93	76.41	4.65	6.29	1.37	2.35	1.76	0.94	0.75	0.07	1258	1363	1379	1426	39	160
17	0.68	8.89	27.57	62.86	31.37	57.61	20.41	1.24	6.28	7.48	0.57	0.21	0.74	1.11	3.82	0.80	9.29	77.39	4.51	6.79	1.26	0.76	0.83	0.25	0.53	0.05	1263	1286	1292	1431	75	60
18	0.53	19.25	26.94	53.28	27.14	57.31	25.88	1.37	6.85	4.20	0.42	0.09	0.40	0.16	2.46	0.82	18.90	67.87	4.25	6.61	1.09	1.29	1.55	0.82	0.68	0.05	1226	1458	1458	1458	45	180
19	0.60	10.58	28.03	60.79	30.78	61.18	14.82	0.84	1.57	12.87	0.70	0.11	0.14	2.12	5.34	0.76	10.80	76.10	4.44	6.82	1.26	0.57	0.54	0.03	0.51	0.01	1268	1284	1289	1402	165	40
20	0.65	21.02	25.33	53.00	26.96	69.11	5.67	0.43	5.85	10.46	1.24	0.05	0.19	1.15	5.45	0.66	20.79	65.56	3.94	7.50	0.92	1.72	1.28	0.60	0.64	0.04	1279	1458	1458	1458	150	110
21	0.63	17.79	25.56	56.02	26.52	51.21	14.06	0.91	11.19	12.43	0.97	0.09	0.21	2.14	6.18	0.79	17.16	70.07	4.02	5.60	0.91	2.25	2.17	1.13	0.94	0.10	1152	1200	1210	1268	325	130
22	0.77	6.68	31.29	61.26	31.35	50.90	20.11	1.90	18.65	4.35	0.39	0.13	0.21	1.41	1.84	0.79	6.27	79.05	4.83	6.60	1.33	1.92	1.77	0.69	0.99	0.09	1136	1268	1289	1379	70	200
23	0.78	8.70	27.36	63.16	30.45	58.05	28.39	1.29	2.85	4.99	0.53	0.15	0.30	0.90	2.02	0.88	9.67	76.95	4.37	7.25	1.19	0.58	0.51	0.10	0.40	0.01	1286	1458	1458	1458	84	40
24	0.76	7.70	26.89	64.65	31.71	63.81	20.87	1.22	4.35	4.04	0.42	0.16	0.39	2.37	0.84	0.92	7.48	79.27	4.41	6.69	1.20	0.95	0.71	0.23	0.46	0.02	1200	1458	1458	1458	165	70
25	0.75	20.61	25.89	52.75	26.48	51.63	21.08	1.32	23.40	0.79	0.29	0.15	0.31	0.22	0.27	0.88	14.35	72.44	4.32	7.10	1.02	0.77	4.40	2.74	1.57	0.09	1152	1300	1310	1394	39	230
26	0.83	12.84	27.95	58.38	29.81	59.09	15.47	1.03	6.38	9.35	0.96	0.14	0.26	1.84	4.78	0.85	10.83	76.35	4.44	6.35	1.31	0.73	1.05	0.45	0.57	0.03	1126	1279	1286	1416	165	140
27	0.61	13.42	26.95	59.02	29.54	51.30	11.60	0.92	26.15	4.99	0.36	0.12	0.13	1.64	2.14	0.80	14.29	72.87	4.20	5.00	1.10	2.54	3.59	2.05	1.44	0.10	1126	1189	1236	1300	150	270
28	0.61	17.76	26.97	54.66	27.87	50.29	10.17	0.85	11.20	16.26	1.91	0.10	0.25	0.46	7.92	0.75	19.98	67.84	3.82	4.81	1.02	2.52	1.90	1.02	0.80	0.08	1129	1147	1157	1247	63	150

*Average values of determinations on individual samples

APPENDIX 3: BOWRON RIVER

Comp. sample	Resid. mois. %	Ash %	Vol. matter %	Fixed carbon %	Cal. value MJ/kg	SiO_2 %	Al_2O_3 %	TiO_2 %	Fe_2O_3 %	CaO %	MgO %	Na_2O %	K_2O %	P_2O_5 %	SO_3 %	C %	H %	O %	N %	S %	S [pyr] %	S [org] %	S [sulfate] %	T initial deg. C	T soften deg. C	T hemisph deg. C	T fluid deg. C	F ppm	Hg ppb
1	4.15	21.43	33.28	41.14	23.25	56.22	22.71	0.90	8.41	2.73	2.43	0.85	2.83	0.81	2.62	56.62	4.67	15.52	1.15	0.61	0.17	0.43	0.01	1206	1274	1363	1399	210	140
2	3.41	17.85	36.85	41.89	25.01	54.20	20.08	0.88	12.99	2.66	2.05	0.58	2.92	0.24	3.62	58.08	4.44	16.00	2.00	1.63	0.98	0.59	0.06	1167	1201	1279	1348	135	540
3	3.55	15.32	37.38	43.75	25.79	35.57	14.36	0.55	34.00	4.91	2.19	0.87	1.55	0.80	6.67	61.88	4.60	12.08	1.78	4.34	3.44	0.75	0.15	1084	1087	1119	1168	105	620
4	3.19	32.05	26.69	38.07	19.88	66.28	18.45	0.89	6.42	1.97	1.52	0.43	2.53	0.22	2.09	48.77	3.45	13.70	1.41	0.62	0.17	0.44	0.01	1290	1342	1352	1362	230	140
5	3.39	24.37	32.43	39.81	22.52	58.61	16.40	0.71	11.21	5.06	2.00	0.51	2.36	0.24	4.69	56.42	4.06	12.82	1.59	0.74	0.23	0.50	0.01	1177	1207	1279	1293	180	140
6	3.66	18.54	35.39	42.41	24.04	36.34	11.49	0.38	33.81	8.10	1.87	0.39	0.60	1.32	8.29	59.66	4.13	14.51	1.94	1.22	0.71	0.48	0.03	1064	1073	1119	1148	225	140
7	5.26	9.65	31.11	53.98	26.28	79.70	2.40	0.09	10.85	2.24	1.15	0.66	0.14	0.15	3.65	61.43	3.99	22.28	1.75	0.90	0.24	0.64	0.02	1538	1538	1538	1538	36	150
8	3.53	6.01	43.25	47.21	29.10	22.29	11.36	0.38	34.00	9.49	4.52	1.55	0.57	0.64	15.86	69.51	5.32	15.50	2.17	1.49	0.65	0.79	0.05					54	800
9	3.55	13.52	39.50	43.43	26.05	29.49	12.04	0.32	37.13	5.60	2.38	1.15	0.83	1.09	8.32	63.50	4.73	15.60	1.85	0.80	0.25	0.54	0.01	1083	1086	1119	1153	90	600
10	3.71	19.34	28.93	48.02	24.14	69.61	16.16	0.70	4.28	2.70	1.78	0.56	2.40	0.74	2.02	61.53	4.04	12.65	1.61	0.83	0.14	0.69	0.01	1283	1343	1441	1453	155	280
11	2.75	32.44	28.70	36.11	19.64	63.06	15.15	0.75	14.22	1.81	1.40	0.30	1.90	0.27	2.09	52.54	3.51	8.09	1.67	1.75	1.08	0.59	0.08	1166	1218	1296	1311	160	160
12	1.51	65.76	15.94	16.79	9.28	72.50	16.45	0.78	4.12	1.22	1.29	0.38	2.12	0.43	1.18	23.03	1.86	6.77	1.04	1.54	1.10	0.21	0.23	1362	1440	1516	1534	260	135

APPENDIX 4: MERRITT

Comp. sample no.	Resid. mois. (ad) %	Ash (ad) %	Vol. matter (ad) %	Fixed carbon (ad) %	Cal. value (ad) MJ/kg	SiO_2 %	Al_2O_3 %	TiO_2 %	Fe_2O_3 %	CaO %	MgO %	Na_2O %	K_2O %	P_2O_5 %	SO_3 %
1	4.04	11.92	35.33	48.71	26.79	48.34	31.21	1.18	7.61	4.21	0.84	0.99	0.70	0.20	3.80
2	2.63	15.07	35.16	47.14	27.35	58.65	24.27	0.79	12.06	0.54	0.50	0.61	0.72	0.11	0.24
3	4.64	52.17	22.79	20.40	12.38	58.58	25.46	0.68	9.23	1.45	0.88	1.27	1.40	0.15	1.00
4	4.17	28.36	29.39	38.08	21.85	62.14	25.72	0.96	6.13	1.30	1.02	1.44	1.34	0.62	0.22
5	4.30	44.41	24.46	26.83	15.81	58.36	25.47	0.96	7.58	1.75	1.02	1.36	1.48	1.04	0.46
6	2.67	45.16	24.01	28.16	16.65	61.79	26.53	1.04	4.15	1.17	1.17	1.47	2.40	0.23	0.35
7	2.53	20.60	31.50	45.37	25.94	61.71	23.53	1.07	5.96	1.52	1.22	2.53	2.44	0.36	0.43
8	2.16	29.07	28.51	40.26	23.15	62.30	24.89	1.00	5.24	1.12	1.22	1.53	2.30	0.49	0.30
9	2.32	38.65	25.45	33.58	19.63	60.45	25.78	1.46	4.14	1.75	1.39	1.96	2.56	0.89	0.32
10	1.97	66.04	15.60	16.39	9.81	64.40	24.23	0.99	3.95	0.51	1.38	1.76	2.87	0.18	0.21

Comp. sample no.	C (ad) %	H (ad) %	O (ad) %	N (ad) %	S (ad) %	S [pyr] (ad) %	S [org] (ad) %	S [sulfate] (ad) %	T initial deg. C	T soften deg. C	T hemisph deg. C	T fluid deg. C	F (ad) ppm	Hg (ad) ppb
1	65.93	4.51	15.23	1.61	0.80	0.23	0.52	0.05	1497	1538	1538	1538	64	60
2	65.70	4.76	10.74	1.56	2.17	1.21	0.87	0.09	1441	1482	1518	1535	51	360
3	32.11	2.78	11.47	1.10	0.37	0.20	0.14	0.03	1485	1504	1517	1536	130	40
4	53.59	3.96	11.75	1.73	0.61	0.11	0.47	0.03	1490	1522	1538	1538	170	40
5	39.26	3.29	11.25	1.22	0.57	0.26	0.27	0.04	1436	1468	1514	1537	300	30
6	41.00	3.29	8.70	1.39	0.46	0.08	0.36	0.02	1538	1538	1538	1538	200	30
7	64.24	4.57	8.18	2.06	0.35	0.02	0.33	0.01	1409	1431	1490	1538	125	30
8	54.15	3.90	10.72	1.75	0.41	0.03	0.37	0.01	1502	1537	1538	1538	145	40
9	49.10	3.63	6.62	1.64	0.36	0.07	0.27	0.02	1483	1507	1538	1538	140	30
10	25.10	2.26	5.12	0.89	0.59	0.25	0.27	0.07	1513	1538	1538	1538	185	180