Mapping and Review of Coal Geology in the Wolverine River Area, Peace River Coalfield (NTS 093P/03), Northeastern British Columbia

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KEYWORDS: Peace River coalfield, coal exploration, geological mapping, Gates Formation, Gething Formation, Bullmoose thrust fault, Mesa thrust fault, J seam, E seam, D seam

INTRODUCTION

This report discusses a compilation of coal geology in the Wolverine River area, west of the town of Tumbler Ridge, in northeastern British Columbia as illustrated in Figure 1. This is an area of old, new and potential coal-pit developments within the Peace River coalfield. New developments include Perry Creek of Western Canada Coal Corporation (WCCC). Potential pits include Hermann North and EB (also WCCC). Old pits, now reclaimed, include the Wolverine (originally known as Frame), Deputy, McConkey, Mesa, Mesa North and Mesa North Extension pits of Quintette Coal Ltd. (Quintette). This area of developed infrastructure, with power, rail and road, has the potential for surface coal and coal gas in the shallow subsurface and natural gas in Paleozoic reservoirs at depth.

The project objectives are to produce a map at 1:25 000 scale, improve understanding of the geological framework and suggest new areas for exploration. Geological linework, pit development locations and a line of section in the Gates Formation coal measures are included in Figure 2.

Existing maps, varying in scale from 1:50 000 to 1:5000, were reviewed prior to fieldwork. In addition, numerous coal assessment reports (COALFILE, 2006), available on the ministry's MapPlace website (BC Geological Survey, 2006), were accessed. The area was the focus of rapid development during the early 1980s with pits of Teck-Bullmoose Coal Inc. and Quintette coming online. Outlying areas underlain by coal measures received little additional scrutiny. Both these mines closed a few years ago and it is timely to step back and look again at the prospective ground. There is scope for new discoveries and this is facilitated by better definition of faults and folds affecting the coal measures.

Access is fairly good within the area and includes forestry, coal exploration, logging and petroleum-well access roads, together with numerous recent cutlines for seismic surveys. The level of exposure varies from excellent, in the alpine, to poor at lower elevations with gentler slope and in some drift-filled valley bottoms.

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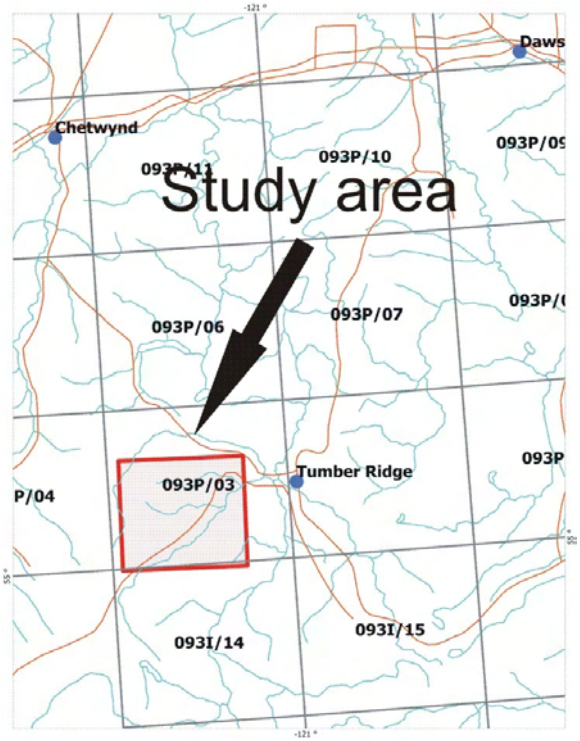

Figure 1. Location of study area, northeastern BC.

The current geological mapping complements previous work on the Gates Formation coal measures (Legun, 2006). That work focused on the relationships of marine tongues and nearshore deposits with coal measures in the area of Wolverine River.

A description of undrilled resource targets in the Gates Formation has been included in this paper. It is also suggested that Gething Formation coal measures, a target of early exploration in the area, deserve renewed scrutiny. The reported results are preliminary and subject to further ground examinations.

METHODOLOGY

Numerous maps from coal assessment reports were copied from digital assessment files and georegistered into Manifold project space. Bedding data was digitized from the maps and the compilation of a large database of structural data is in progress. Fieldwork was facilitated by stereopairs of colour airphotos flown in 2005, and orthophoto images provided control for linework. Digital elevation models (DEM) were brought into Manifold GIS

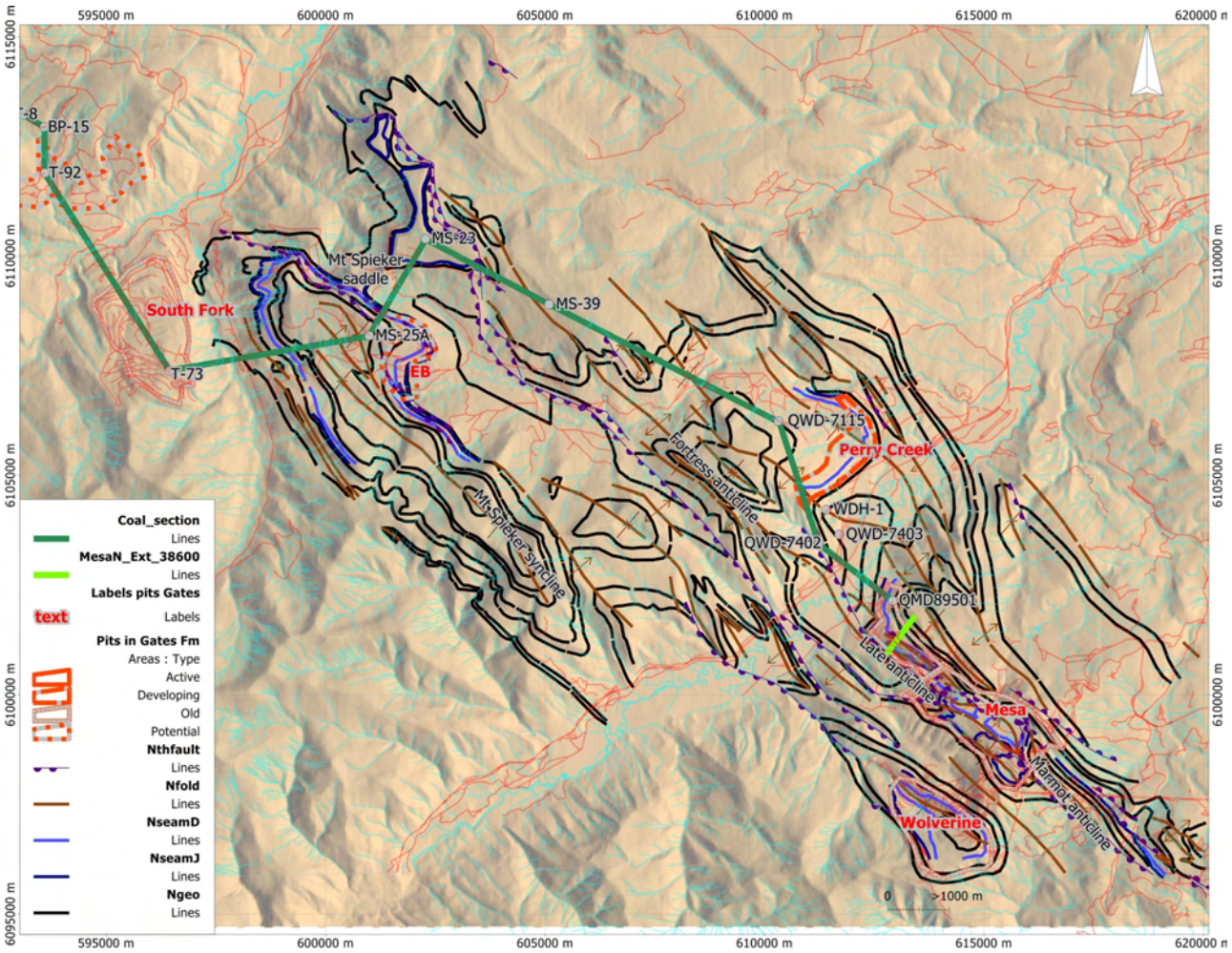

Figure 2. Some elements of the geological compilation in the Wolverine River area, Peace River coalfield, northeastern BC.

software as surfaces. The latter provide a sense of relief to orthophotos (when overlain as a transparency) and assist in the correct placement of contacts affected by topography.

The surface trace of two seam intervals, D and E at the top and J at the base of the middle Gates Formation, were digitized from various reports, which covered the Mesa, Hermann North, Mt. Spieker and Perry Creek areas. These two seams have considerable lateral extent and are the primary economic seams of interest in the Wolverine River area.

Approximately four weeks were spent in the field, with student assistance provided by A. Stephenson of the University of Victoria. Traverses were concentrated in peripheries of old and new pits, areas of limited data (Fortress Mt.) and in chasing major structures, such as the Bullmoose fault.

PREVIOUS WORK

Early exploration interest was in the Gething Formation coals, pursuing trends from the Sukunka property immediately to the north (MINFILE 093P 014; MINFILE, 2006). The focus then switched to Gates Formation coal, with intercepts of thick clean coal of metallurgical quality in the Gates interval within the Wolverine River area. Additional drilling indicated good continuity of the individual seams. Mapping in the northern part of the work area by Ranger Oil Ltd. resulted in a detailed map of the Mt. Spieker area being produced in the late 1970s (COALFILE 557). Quintette produced a series of 1:5000 scale maps in the south focusing on the Gates Formation (COALFILE 607, 615). Gilchrist and Flynn (1978) published a compilation prior to Quintette's development of a mine south of the Wolverine river and Kilby and Wrightson (1987) published during the main phase of mining. Industry continued mapping as the pit developed. However, some areas (*e.g.*, near the Frame pit) did not seem to receive much follow-up and this is one area where contacts below the Gates Formation remain unresolved.

REGIONAL STRATIGRAPHY

The mapped interval is Early Cretaceous with the Gething Formation coal measures ranging from Aptian to early Albian (Gibson, 1992), while the Gates Formation is limited entirely to the Albian. The following summary encompasses the stratigraphy from the Gething Formation to the Hulcross Formation shale. Related data can be found in summary tables of Quintette reports (*e.g.*, COALFILE 746, Table 3.1).

Hulcross Formation

The Hulcross Formation is a rusty marine sequence of shale and siltstone containing a thin ferruginous pebble zone, locally, at the base. The thin-bedded sequence occupies a recessive notch below Boulder Creek sandstone and conglomerate. The formation averages approximately 100 m in thickness in the area. The Hulcross Formation is similar to the Moosebar Formation but lacks the glauconitic zones towards the base as well as pure mudstone.

Gates Formation

The Gates Formation comprises basal, sheet sandstone (lower Gates member), a middle sequence rich in coals (middle Gates member) and an upper sequence (upper Gates member) usually comprising upward-coarsening deposits of marine origin capped by thin coals and silty beds. This division into members is informal and follows terminology in assessment reports covering the area from Wolverine River to the Alberta border. There is a broad transition zone at the base of the formation. Table 1 shows the stratigraphic correspondence of various unit names. A line of section relates the succession near the Bullmoose mine to that at the Quintette's Mesa pit (Fig 3).

The Gates Formation is 200 to 230 m thick within the field area. The value differs from that reported by Quintette due to a different pick for the base of the formation (*see* discussion following).

UPPER GATES MEMBER

The upper Gates member is defined by Quintette as the top of D seam to the base of the Hulcross Formation shale. In the area of interest, there is no economic coal in the upper Gates member. The member corresponds to the "major marine tongue" and overlying "silty member" of Duff and Gilchrist (1981). The marine tongue is known as the Notikewan in subsurface and the Babcock Member in surface coalfield terminology. Usually it is an upward-coarsening sequence with a characteristic gamma signature on geophysical logs. However, at Quintette Mesa pit a basal conglomerate, known as the caprock conglomerate, is in erosional contact with the top of D seam.

Carmichael (1988) ascribed much of the Babcock Member to an environment of estuarine shoals. The upper Gates member is approximately 120 m thick at the Mesa North pit. At Perry Creek, up to 100 m of upper Gates member is preserved within the core of Perry syncline. This must be almost a complete section, the Hulcross Formation contact is not noted in a WCCC correlation chart (Western Canada Coal Corporation, 2004, Fig 2.03-07). The Fortress Mt. unit shown on that chart is equivalent to Babcock/Notikewan and should be included in the upper Gates member.

MIDDLE GATES MEMBER

The middle Gates member was defined by the Quintette geologists as the base of J seam to the top of D seam. In the south, this includes some additional strata below J seam to K seam. The middle Gates member comprises the main coal-bearing interval within the Gates Formation. At Mesa pit, the member encompassed up to 18 m of coal in 60 m of section. Trends and details of the middle Gates member stratigraphy are discussed later.

LOWER GATES MEMBER

The lower Gates member has not been consistently defined. Quintette considered the base of the first thick sandstone (COALFILE 746, p 3–4) in the transition zone from Moosebar Formation shale as the base. Duff and Gilchrist (1981) also placed the contact low in the transition and defined a sandy 'Spieker' Member within the Gates Formation. Both definitions translate to a lower Gates member that is a non-coal bearing interval, which is more than 100 m thick. The base of the Gates Formation, however, has been formally defined (McLean, 1982) as the first sandstone not having significant shale above it. This definition often moves the contact to a stratigraphically higher sandstone unit, often within approximately 25 m of J seam.

The top of the lower Gates member is dominated by sheet sandstone, which forms a strandplain (Leckie, 1986).

TABLE 1. NOMENCLATURE OF COAL SEAMS AND LITHOLOGICAL UNITS, GATES FORMATION, WOLVERINE RIVER AREA, BC.

Gates Formation	Lithology	West Fork deposit	Teck-Bullmoose mine (reclaimed)	Perry Creek pit	Quintette Mesa pit (reclaimed)	Subsurface (oil and gas wells)	Carmichael (1983) regional study
Upper	interbeds sandstone/ conglomerate unit			Fortress Mt. unit	Babcock Member	Notikewan	Babcock Member
Middle	**coal**	**(E)**	**(E)**	**D seam**	**D seam**		
	interbeds **coal**	**(D)**	**(D)**	**E, F seams**	**E seam**		
	sandstone/ conglomerate unit			Wolverine unit	E conglomerate	Fahler C	
	coal	**(C)**	**(C)**	**G seam**	**G seam**		
	interbeds sandstone/ conglomerate unit	unnamed conglomerate		J conglomerate		Fahler D	
	coal	**A, B seams**	**A, B seams**	**J (plies 1 to 3)**	**J seam (plies 1 to 3)**		
Lower	sandstone unit			Quintette sandstone ("Torrens")	Quintette sandstone ("Torrens")	Fahler F	Sheriff Member
	sandstone unit					Fahler G	Torrens Member

Notes: brackets indicate comparable stratigraphic position; Torrens is an informal term for a unit of massive sandstones at base of J seam.

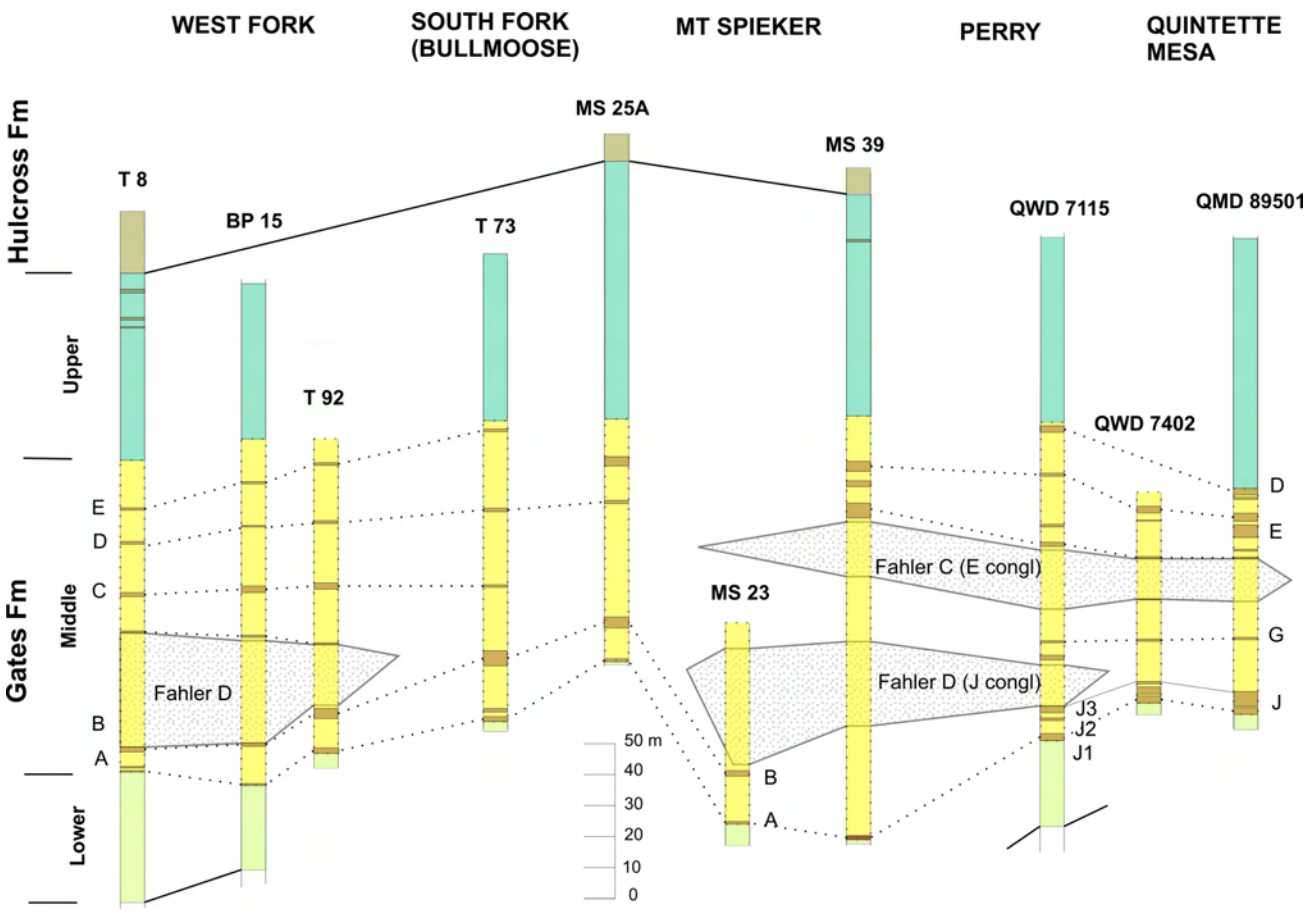

Figure 3. Line of section West Fork to Quintette's Mesa pit, illustrating the position of coal seams in the middle Gates member, northeastern British Columbia.

Moosebar Formation

The Moosebar Formation comprises approximately 80 m of dark marine shale followed by 70 to 95 m of interbedded, flaggy sandstone and shale. Quintette geologists restricted the formation to shale units. Using the formal definition of Gates Formation, the interbedded zone should be part of the Moosebar Formation and not the Gates Formation.

The thickness between the Gething Formation top and J seam is approximately 200 m in the area. This is composed of 175 m of Moosebar Formation followed by 25 m of the lower Gates member, according to the formal definition.

Gething Formation

The Gething Formation is divided into three members: a coal-bearing deltaic facies (Chamberlain Member), an underlying sequence of marine shale (Bullmoose Member) and a basal deltaic coal-bearing sequence of regional extent (Gaylard Member). The Chamberlain Member is 40 to 50 m thick in the Wolverine River area and shows some features of a wave-dominated delta. For example, it has a clean and widespread basal strandplain sandstone, which is the floor to a seam known as the Chamberlain seam. Lateral equivalents of the Skeeter and Bird seams found to the north (Sukunka area) are also present. The underlying sequence, of approximately the same thickness, comprises shale that coarsens upward to flaggy interbedded sandstone and shale. This 40 to 50 m thick interval is the Bullmoose Member and foreshadows, in its facies transitions, the younger and depositionally thicker Moosebar Formation to Gates Formation transition. The shale of the Bullmoose Member abruptly overlies sandy glauconitic beds of the lower Gething Formation or Gaylard Member. The Gaylard Member, approximately 120 m thick, has a coal interval approximately 45 m from the top, known as the middle coals.

The total thickness of Gething Formation strata is approximately 207 m in the Perry Creek area based on drillhole correlations (*see* COALFILE 597). Farther south, thickness is difficult to assess as the transition to the underlying Cadomin Formation conglomerate is gradual.

STRUCTURE

The area of study lies within the inner foothills characterized by broad, open synclines and box anticlines interspersed with tight folds of short wavelength. Tight folds include east-verging asymmetric anticlines related to thrusts. Both north and south-plunging fold structures are present. Open synclines, and straight fold limbs paralleling topographic slope, are the favoured ground for developing coal open pits.

Workers have noted that folding at the structural level of the Gething and Cadomin formations is tighter than in the overlying Gates Formation. Structures evident in the Gething Formation die at the level of the Moosebar Formation (COALFILE 556) and many long, tight synclines are confined to the Moosebar Formation. Moosebar Formation strata form the hangingwall over a considerable strike length within a number of thrust panels. These features suggest detachment occurs within the Moosebar Formation strata.

Fieldwork in 2006 indicated asymmetric anticlines with eastern, overturned limbs are more common than previously identified. Examples include the major anticline crossing Perry Creek valley, near the pit access road, and the Marmot anticline crossing the line of the Quintette conveyor belt.

Bullmoose Thrust Fault

The Bullmoose thrust fault is a major fault in the area. The fault cuts the eastern flank of the flat-top Mt. Spieker at a shallow dip of 10 to 15°. The fault steepens as it is traced to the valley side of Perry Creek. It includes mappable fault slices of Moosebar Formation shale. It is represented in the valley bottom of Perry Creek near Fortress Mt. by a complex zone of steeply dipping beds, faults and disharmonic folds involving Gates and Moosebar formation beds. A sequence of overturned beds (Moosebar Formation-Gates Formation transition), exposed to the west, forms the hanging wall. The fault parallels a low marshy and drift-filled linear valley west of Fortress Mt. Its exact trace is unknown but is constrained by Gething and Hulcross formation rocks facing each other across the valley. The fault crosses the Wolverine River Road east of tight folds involving Gething and Cadomin formation beds but west of roadside exposures of Moosebar Formation.

The hanging wall in this segment is believed to be Gething Formation strata. Between Mt. Spieker and Wolverine, the footwall ranges from the Gates Formation to the Hasler Formation.

The trace to the south is uncertain. Displacement may be spread on several splays, one of which is the Mesa thrust fault in the Quintette pit area. Farther south, a single major fault cuts the Transfer syncline with a stratigraphic displacement of approximately 350 m (COALFILE 753, cross-section 30000, Transfer area).

Mesa Thrust Fault and Fortress Mt. Anticline

An anticline, exposing Gething Formation rocks in the eroded core and Moosebar and Gates formation rocks at a higher structural and topographic level, extends across the Wolverine River. It is exposed as a prominent anticlinal arch on the higher slopes of Fortress Mt. (Fig 4). The east limb steepens and is locally overturned near the level of the Wolverine River.

On the south side of the river, the fold appears contiguous with the Late and Marmot anticlines in the Mesa-McConkey pit areas. The fold is overridden by the Mesa fault (a probable splay of the Bullmoose thrust fault) at the Quintette pits. It is underlain by a fault that brings Moosebar Formation strata over the middle Gates member, as exposed in a mine section at Perry Creek pit.

Incipient Triangle Zone Geometry (?)

Reverse faults with opposing dips and sense of vergence are noted in the Hermann North and Quintette Mesa areas. The general geological setting is illustrated in Figure 5, a view that is partly cross-sectional due to topographic relief. A drill section at the Mesa North Extension pit provides a more detailed view along strike (Fig 6).

This style continues along strike, well to the north. West-verging folds have been noted north of the map area by Hunter and Cunningham (1991). This pattern of paired reverse faults may mark an incipient triangle zone at the east margin of the coal belt.

DETAILS OF MIDDLE GATES MEMBER COAL STRATIGRAPHY

Middle Gates Member Trends

The middle Gates member thickens northward due to intrastratal bodies of marine sandstone and conglomerate. At the Mesa pit, there is 60 m of middle Gates member rock which expands to 75 m in the Mesa North pit (diamond-drill hole [ddh] QMD 89501 on Fig 3) due to an interval of E

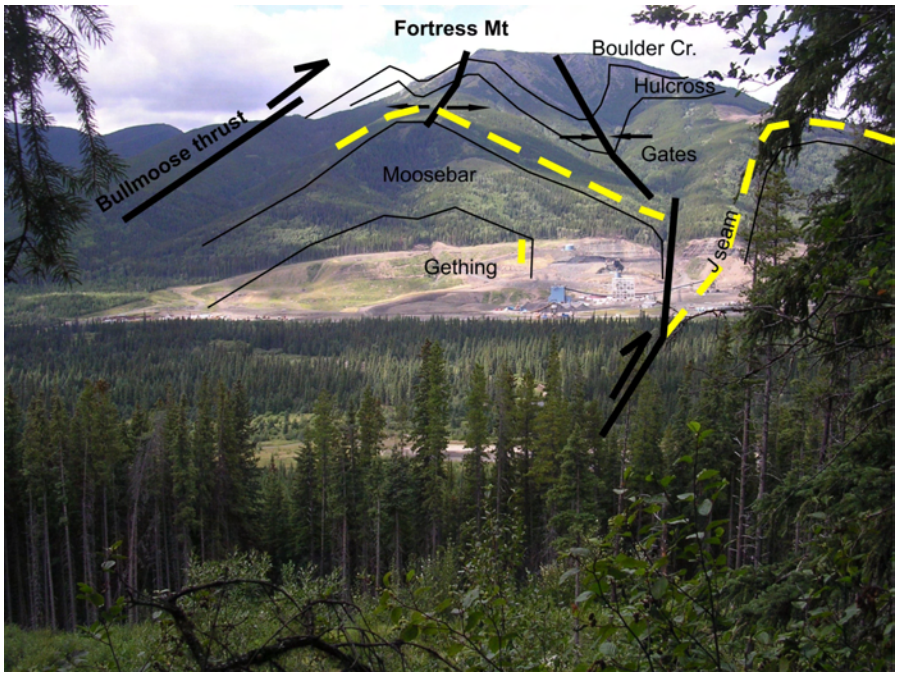

Figure 4. The Fortress Mt. anticline, outlined by a resistant arch of lower Gates member behind the Perry Creek plant site, northeastern BC. Note the faults bounding the anticline on east and west flanks.

conglomerate (Fahler C). This increases to over 100 m in the Perry Creek area (ddh QWD 7115 on Fig 3) and includes a second conglomerate wedge (J conglomerate or Fahler D). It reaches 125 m northeast of the Perry pit area (ddh QWD 7401) and even thicker to the northwest (approximately 136 m in ddh MS 39 on Fig 3). In these northern holes, the total coal in section is greatly reduced compared to the south.

The middle Gates member is approximately 85 to 90 m thick to the northwest, in the EB pit area, and 80 m thick at the former Bullmoose mine. Marine conglomerate reappears in the West Fork resource area north of Bullmoose and the middle Gates member correspondingly thickens.

Two significant coal intervals (J and E and D seam intervals) lie at the top and base of the middle Gates member and are extensive. The G seam at the Quintette pit (and roughly equivalent C seam at Bullmoose mine) is also a widespread coal interval which formed during the interval between Fahler D and C marine incursions.

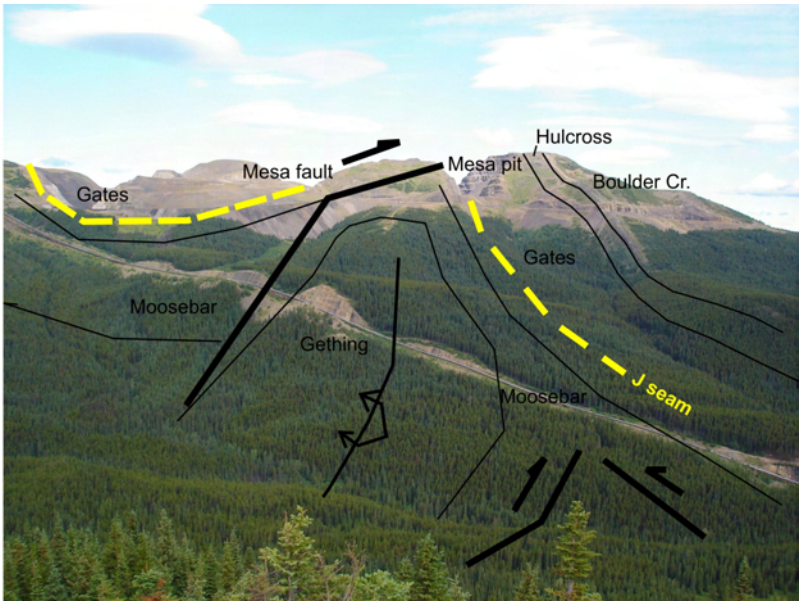

Figure 5. General cross-sectional view to the south side of Quintette Mesa pit from the Hermann North property, northeastern BC.

J SEAM

At Quintette's Mesa pit, J seam averages over 5.5 m in thickness. Remnants of J seam within the pit lie within approximately 10 cm of a hard competent floor of shallow marine sandstone, which is part of the lower Gates Formation. J seam developed on a strandplain behind barriers of a wave-dominated delta (Kalkreuth and Leckie, 1989). It is overlain by lacustrine deposits with nonmarine unionid bivalves (Carmichael, 1983, p 39).

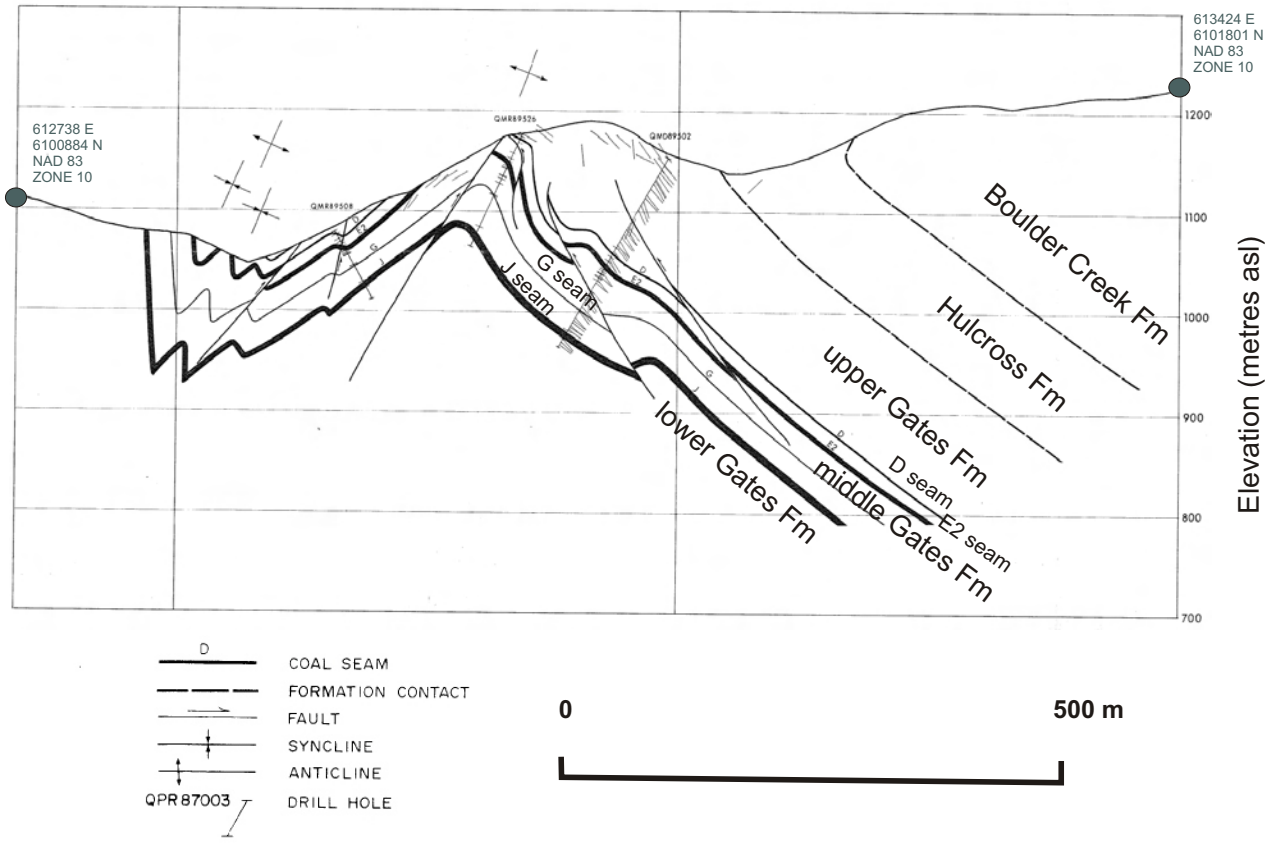

Figure 6. Drill section 38600 Mesa North Extension, northeastern BC.

North of Mesa pit, J seam splits into three plies (J1, 2, 3), the interseam interval thickens with indications of marine influence. In the Perry Creek pit area, the massive J conglomerate (Fahler D) overlies the northward thinning seam. In exposures along Perry Creek, the J seam is covered with a thin lag deposit of pebbles, followed by the massive marine sandstone of Fahler D.

The J seam thins westward with reduced thickness noted in Quintette's mined Wolverine (Frame) pit (average 3.5 m) and at the west end of Perry Creek pit. At the west margin of Mt. Spieker syncline (UTM Zone 10, 600909E, 6105026N, NAD 83), in exposures obscured by colluvium, the interval (approximately 3 m thick) is overlain by several metres of laminated papery shale.

The seam is present in the subsurface to the east and can be recognized in logs of wells (well authorization numbers 3403, 3319 and 15372, BC Oil and Gas Commission, 2006), as well as in deep drillhole Dupont Wolverine 79-2 (COALFILE 515).

The seam persists to the northwest. J seam may be correlated to the A, B seams at Bullmoose based on stratigraphic position relative to the Fahler D conglomerate above (Fig 3).

E AND D SEAM INTERVAL

The second major coal interval spans E and D seams at the Quintette pit and lies between Fahler C and the upper Gates Formation (Fig 3). It comprises numerous coal plies (E1 to E4, D3 and D4 at Quintette Mesa pit) separated by mudstone rich in plant impressions. The top of D seam shows marine influence in the Quintette pit area, documented in the coal petrography by Lamberson *et al.* (1991). The interval persists to the Perry Creek area and to the Mt. Spieker EB pit area, where a coal ply may be up to 4 m thick. At Bullmoose mine, a similar shale-rich interval with coal is present below the upper Gates Formation and includes D and E seams, using the local nomenclature. These seams are 2 m or less thick and were mined selectively at Bullmoose (Drozd, 1985).

Areas of Exploration Interest, Middle Gates Formation

Gates Formation coal measures are preserved in folded strata lying between Quintette's Mesa pit and WCCC's Perry Creek developments (Fig 7). The folds are on strike with folds across the river in the Perry Creek area. It appears that folds on the north side plunge to the south, while folds on the south side plunge to the north, resulting in a canoe-shaped configuration of geological units. Folds are tighter on the south side of the river. The area was identified as a resource in the early 1970s but was not examined subsequently. Several traverses were run in this area. Although the basal J seam is close to river level at the limit of mining in the Mesa North pit, it is above the river in the anticlinal structure facing the Perry Creek anticline.

An area of possible exploration interest lies on the access road to the Perry Creek pit. The subvertical limbs of a tight anticline intersect the access road and Gates Formation coal is sporadically exposed in the areas of roadside culverts.

The E and D coal interval may be present in areas east and northeast of the Mt. Spieker mesa. It was intersected in drillhole MS39 (Fig 3) east of the Bullmoose fault and included a 4 m coal interval at 265 m depth. This is the only drillhole in the area and it was spudded in the Boulder Creek Formation. There is potential for this seam to underlie the area at much shallower depths. The Gates Formation comes to surface in an anticlinal arch northeast of the mesa toward Bullmoose Creek. The area is not covered by coal licenses.

GETHING FORMATION TRENDS AND AREAS OF INTEREST

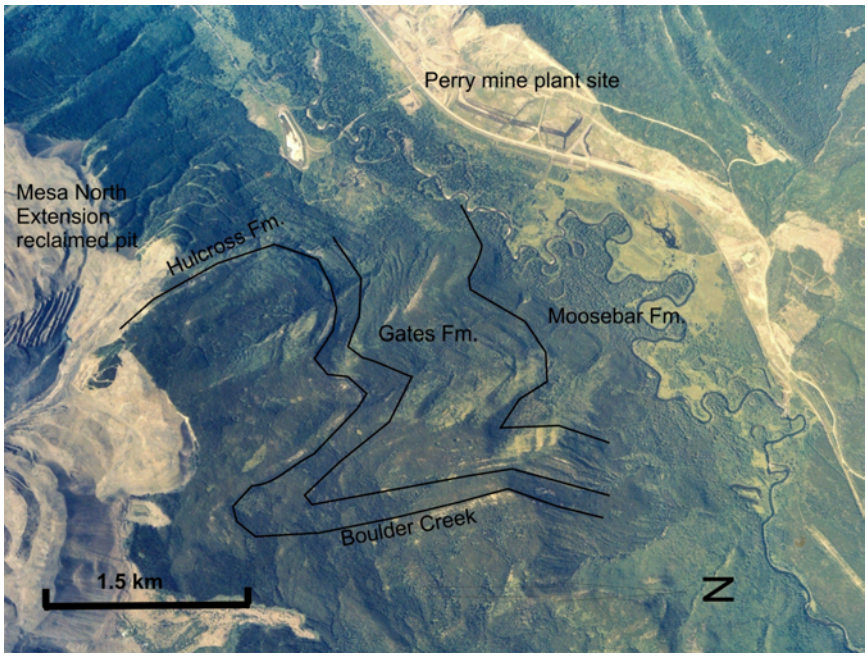

Figure 7. Fold structures between Quintette's reclaimed Mesa North pit and WCCC's Perry Creek pit, northeastern BC. North is to the right.

Trends in the Gething Formation are compiled in Legun (1990) and Gibson (1992). Gething coals show strong thickness variations within the area, reaching 6 m on WCCC's Hermann Gething property, just south of the study area. Gething coals are usually slighter higher in rank (medium to low volatile) than the Gates coals immediately above them in the section. Gething coals display a more variable free swelling index (FSI) and are generally of lower metallurgical quality than the Gates coals, but they tend to wash cleaner than the Gates coal (Ryan, 1997).

Coals of the Chamberlain Member

TREND MINE AREA

Northern Energy and Mining Inc. (NEMI) is exploiting Chamberlain Member coals on their Trend property south of the study area. An aggregate thickness of up to 8.1 m is

present in 3 to 4 closely spaced seams over a 15 m stratigraphic interval with a clean sandstone at the base and the Moosebar Formation shale above. These seams, where unoxidized, are mined as metallurgical coal and supply approximately 15% of the total tonnage of coal mined at the Trend mine, at a lower stripping ratio than for the Gates Formation seams (Norwest Corporation, 2005).

PERRY CREEK PIT AREA

A sloughed coal zone, extending for over 5 m of section, is exposed in a roadside bank (UTM Zone 10, 611063E, 6103077N, NAD 83). The zone is overlain by a rusty conglomerate and there are exposures of Moosebar Formation shale nearby. The coal seam is near the top of the Gething Formation, possibly correlating with the Skeeter and Chamberlain seams (also overlain by conglomerate) intersected in drillhole WDH1 approximately 1 km away (Fig 2). In that hole, the Skeeter seam is approximately 3 m in thickness and the Chamberlain seam is 2.6 m thick with a 1.4 m rock parting of mudstone and coaly shale. A correlation chart of the interval is available in COALFILE 606. The interval appears to thin northeast of WDH1 toward QWD 7115. Its development to the west could be tested by some trenching and drilling.

MESA AREA

Quintette drilled an upper coal zone within the Gething Formation at the edge of the Mesa North pit area. The company recognized three rather ashy coal seams with an average thickness of 2 m (COALFILE 842). These seams probably correspond to the Chamberlain Member.

Coals of the Gaylard Member

The middle coals in the area southwest of Perry Creek pit have been related to the Moosebar Formation contact via the deep drillhole QWD 7115 as well as QWD 7112 (*see* correlation chart in COALFILE 606). In ddh WDH1 (Fig 2), approximately 4.6 m of bright coal occur within an interval of 8.1 m. Diamond-drill hole QWD 7403 (Fig 2) has the thickest single seam at 2.4 m. The seams are approximately 135 m below the top of the Gething Formation and 45 m below the top of the Bullmoose Member *(i.e.,* below the marine tongue of the Gething Formation). These seams match seams GT1 and 2 at the Hermann Gething property (hole QHD 86010).

CONCLUSIONS AND FURTHER WORK

Ongoing compilation mapping at a 1:25 000 scale will help improve the understanding of the geological framework of this part of the northeastern coalbelt. Two major coal intervals in the Gates Formation are of wide extent in the Wolverine River area (J and E and D). Some secondary targets remain in the Gates Formation – an area of folded Gates Formation strata between the Perry Creek pit and Quintette's pits is a modest target for drilling. There is unknown potential for the E and D coal interval in the area east of the Mt. Spieker area and the Bullmoose thrust fault. Gates coal is present below the access road to Perry Creek pit, where the steep limb of a fold crosses the road.

The Gething Formation, an early exploration target for coal, merits a review on the ground. It is mined as supplementary metallurgical coal at the Trend mine south of the study area. Coals of the Chamberlain Member and Gaylard Member middle coals are stratigraphic drill targets.

ACKNOWLEDGMENTS

Andrew Stephenson provided reliable assistance in the field, followed good safety procedures, and was quick in data input. Al Kangas of Quintette Coal Ltd. facilitated access to the Quintette pits and the old map files in the office. A tour of the Perry Creek pit by Gary Gould of Western Canada Coal Corporation and the Trend mine by Kevin Sharman of Northern Energy and Mining Inc. was helpful. Support by the BC Ministry of Energy, Mines and Petroleum Resources, manager Brian Grant and chief geologist Dave Lefebure is gratefully acknowledged.

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