The Gates Formation in the Wolverine River Area, Northeastern British Columbia

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INTRODUCTION

The study area lies west of the town of Tumbler Ridge in the Peace River coalfield of northeastern BC (Fig. 1). It extends on either side of the Wolverine River, from Mt. Spieker in the northwest to Quintette Mountain in the southeast. The area encompasses new coal mine developments at Perry Creek (Western Canadian Coal Corp. [WCCC]) and Trend (Northern Energy & Mining Inc. [NEMI]) and significant exploration at Babcock (Quintette Coal Ltd.). The current development activity is near the existing transportation and power infrastructure, and load-out coal facilities of BC Rail at Tumbler Ridge. It is spurred by prices for metallurgical coal, which have doubled since early 2004 and at the time of writing are over $120/tonne freight on board (FOB). Old and potential coal pits, as well as those in development, in the Gates Formation in the study area are shown in Figure 1.

The two principal coal-bearing units in the area are the Gates and Gething formations of the Lower Cretaceous. The Gates Formation contains most of the economic coal resources at this latitude. Up to 18.5 m of coal may be found over 60 m of section in the Middle Member of the Gates Formation. The Gething Formation, characterized by more lenticular coals, gains economic prominence north of the Sukunka River.

Both formations represent material eroded from the Columbian Orogen in the west and deposited in the Rocky Mountains foreland basin during the Early Cretaceous. Deposits of the Gates Formation record shoreline migrations on a coastal plain that bordered the southern end of a boreal sea. In the Wolverine area, the sea shallowed at a transverse step in the basin, which marked an area of reduced subsidence to the south. Deltas, prograding from the south, were stalled at the margin by deeper waters and were affected by destructive wave, tidal and storm activity. As a result, nearshore stillstand and littoral drift deposits mark the limits of two marine tongues in the area. This report focuses on the relations of the marine tongues and nearshore deposits with coal measures to the south. Additional exploration data has become available since work done in the early 1980s.

Fieldwork also pursued other themes including 1) mapping in the Fortress Mt. area, 2) sampling the base of J seam to assess regional trends in Se, an element associated with coal interseam shales, and 3) sampling of conglomerates to assess carbonate content in relation to potential acid mine drainage (AMD) issues.

PREVIOUS WORK

Stott (1974) measured surface sections and noted that the basal sandstone of the Gates Formation varied in stratigraphic position. Stratigraphically lower sandstones underpinned the Gates Formation coal measures to the south. Duff and Gilchrist (1981) constructed regional lines of section using logs of petroleum wells, deep coal boreholes together with marine zones based on macrofossils and volcanic ash markers.

Smith *et al.* (1984), Cant (1984) and others noted upward coarsening cycles of regional extent in the subsurface of the plains. These ‘Fahler’ cycles were identified as deposits of marine incursion and retreat; a basal transgressive lag was followed by a thick regressive portion and capped by coals. Features further offshore were identified as barrier bar systems. Interpretations of cycles in eastern areas, for example the Elmworth area of Alberta, have become complex, with evidence of erosion and incision with sea level fall (Cant, 1995).

Leckie (1983, 1986) and Carmichael (1983, 1988) investigated the depositional environments of the coalfield. Leckie focussed on the northwest, placing coals in a “channel poor” strandplain environment, while Carmichael in the southeast saw evidence of deltaic distributary sedimentation, which influenced backswamps and floodbasins. Both authors identified the subsurface Fahler cycles in outcrop but did not quite meld their work north to south, particularly in relation to trends of Fahler C. Both investigated lithological components of the conglomerates, noting an erratic variation of carbonate content.

Kalkreuth and Leckie (1989) and Lamberson *et al.* (1991) investigated macerals of Gates Formation coals and interpreted types and conditions of the original peat swamps. Diessel *et al.* (2000) studied the wetting and drying cycles in Gates Formation coastal coals and their possible relationship to sea level changes.

On the industry side, personnel of Quintette Coal Ltd. made detailed seam correlations and collated summaries of total coal seam thicknesses, interseam thicknesses and coal quality data over the life of the pits at Shikano, Mesa, Wolverine and Transfer. Exploration drilling and related research on coalbed methane potential has provided additional data (Wyman, 1984; Lamberson and Bustin, 1993; Dawson and Kalkreuth, 1994; Ryan, 2000).

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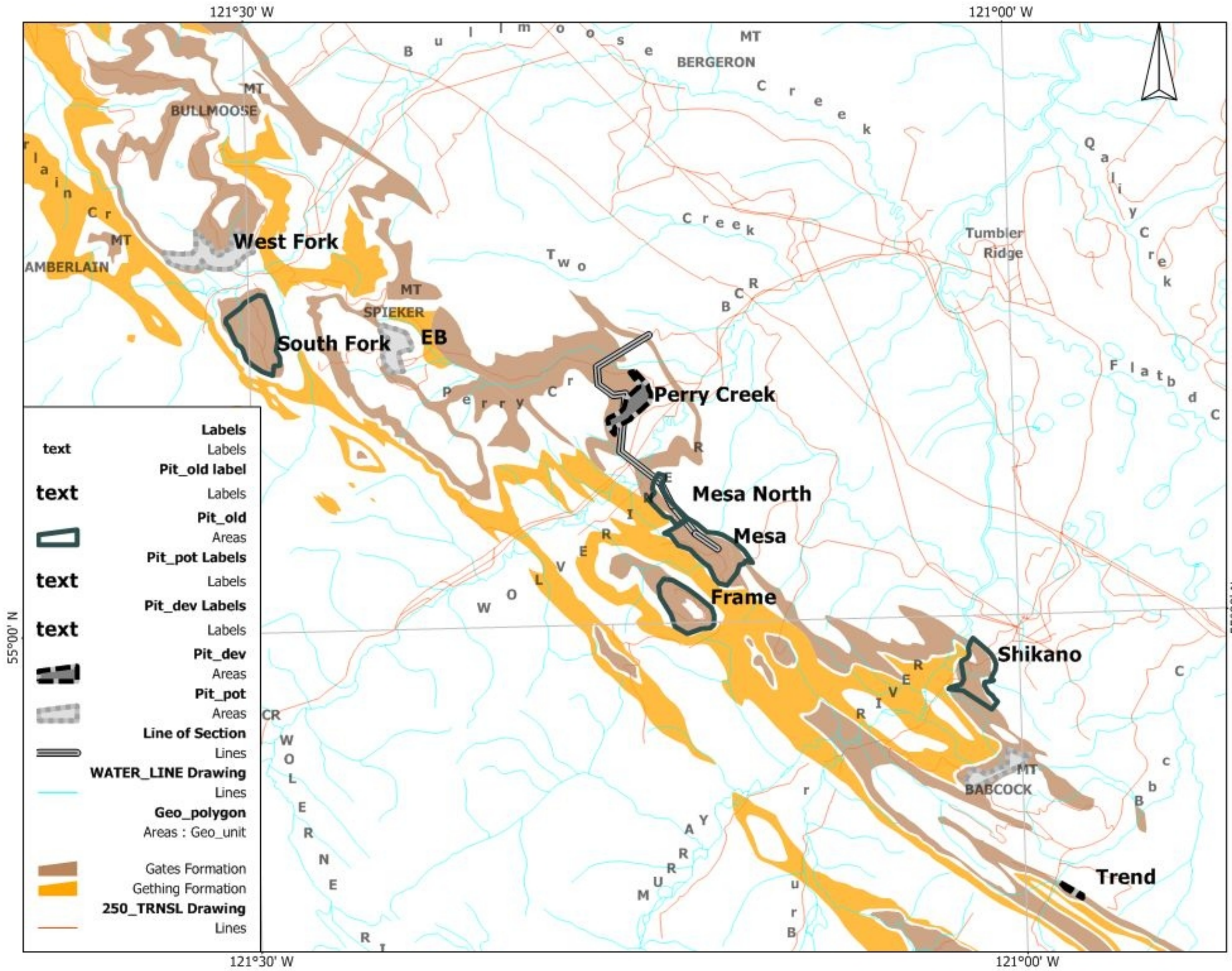

Figure 1. Study area with coal pit locations and the Gates and Gething formations.

REGIONAL STRATIGRAPHY

Table 1 shows the equivalence of various units between the coalfield, subsurface Fahler units, and local property terminology. The principal coal-bearing interval, between the base of J seam and the top of D seam, is described as the Middle Member of the Gates Formation. This Member ranges from 60 to 110 m in thickness and contains from 8 to 18.5 m of total mineable coal, as exposed in sections of various pits in the study area. The Middle Member corresponds to the interval between the top of the Quintette sandstone (Fahler F) and the base of the Notikewan conglomerate. The area south of Wolverine River (Quintette Mesa) lies landward of marine transgressions represented by Fahler D to A cycles.

J seam is the basal economic seam in the Wolverine area, resting on Fahler F marine cycle (Fig. 2, 3). It is often said to overly the ‘Torrens’. However the Torrens corresponds to a sandstone ‘leaf’ below Fahler F. It is known as Fahler G in Alberta and a separate coal interval lies between it and Fahler F.

J seam is thick (often >5 m) and continuous. The seam can be traced from the Wolverine River for more than 70 km along the southeast margin of the coalfield (Carmichael, 1983). East of the coalfield, in subsurface, it comprises most of the interval known as the 4th coal. The 4th coal isopach appears to be based on Fahler D +100 m and thus may include additional coal strata (Wyman, 1984, Fig. 21). North of the Perry Creek area, J seam thins and splits under Fahler D with partings thickening. To the northwest, it divides into two significant plies known as seams A and B in the mined out South Fork deposit (Bullmoose mine).

In the Wolverine area, J seam often rests almost directly on sandstones of marine shoals (Fig. 4). These shoals may have comprised the wave-dominated delta-top environment in the area.

A total thickness of coal in each pit area was estimated from the sum of average thicknesses of each seam in the pit area (Table 2).

G seam is also a regionally persistent seam, often used as a datum in correlations through the coalfield. It lies above Fahler D.

E seam lies above Fahler C. It amalgamates with D seam in Quintette’s Mesa area. It is thick and ashy, but

TABLE 1. STRATIGRAPHIC UNITS OF THE MIDDLE GATES FORMATION, WOLVERINE RIVER AREA.

Subsurface	Carmichael (1983)	Perry Creek Area	Quintette Mesa Area	Bullmoose Mine Area (adapted from Drozd [1985])
Notikewan	Babcock Member	Fortress Mt. unit?	Caprock conglomerate	
		D seam	D seam	E seam
Fahler A		Not present	not present	Not present
Fahler B		Not present	not present	Not present
		E,F seam	E seam interval	D seam
Fahler C		Wolverine unit	E congl	Not present
		G seam	G seam	C seam
Fahler D		J congl	not present	Unnamed congl in West Fork deposit
		J seam (J1,J2,J3 plies)	J seam	A,B seams
Fahler F	Sheriff Member	Quintette sandstone	Quintette sandstone	

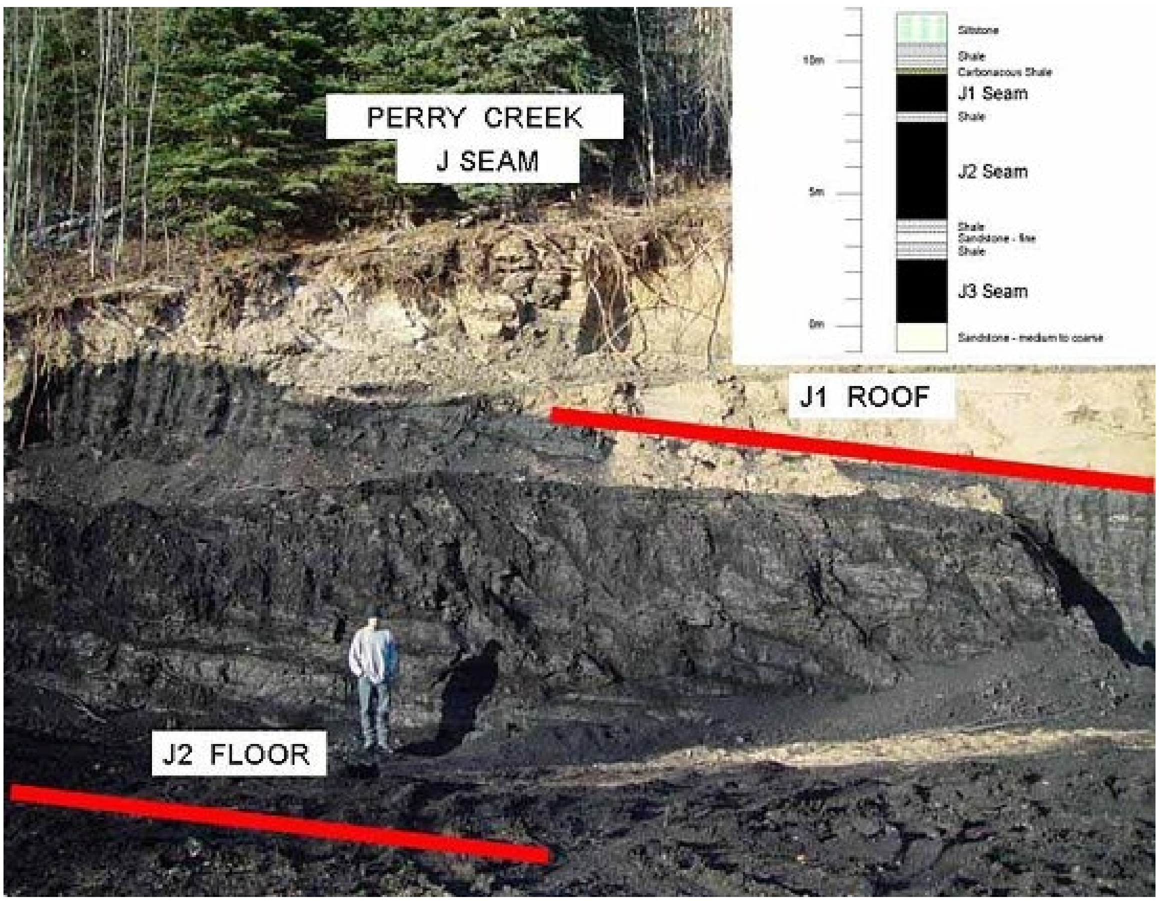

Figure 2. The J seam at Perry Creek thins, and partings thicken, below the Fahler D marine tongue to the north. Image from WCCC project description at http://www.westerncoal.com/properties.

Figure 3. Floor of J seam is exposed at Quintette's reclaimed Mesa pit.

Figure 4. Shoal megaripples are preserved at the top of Sheriff Member (Fahler F) and very close to base of J seam. These ripples are exposed in Quintette Coal Ltd.'s Wolverine pit wall. The view is looking up a steep (70°) face of the pit. Hammer is for scale.

Depositional Setting

The Gates Formation is not a typical coal measure sequence because conglomerates, often associated with sandstones, occur in the coal measure sequence. The association of conglomerates, typical of deposits of higher gradients, and coals originating in peat deposits of shallow basins requires explanation, especially given the continuity of individual seams of the Gates Formation coal measures.

There is a change in the relation of conglomerate bodies to coals along the coalfield (Carmichael, 1988, Fig. 4). The trend described here is from the Alberta border northwest to the Wolverine River. Near the Alberta border (lat 54°15′), fluvial channels (of the upper delta plain) may incise coals. At about lat 54°45′ (Kinuseo Creek area), coals wrap up and below major distributary channel bodies. Carmichael (1983, Fig. 31, 32) documents the trends and overbank deposits of similar distributaries in the Babcock area (lat 54°55′). Channels with aprons of sediment on either side may have perched above the floodbasins. At Babcock, conglomerate channels also sit on sheet sands. This suggests basin fills by distributary lobes of sediment.

North of Babcock (lat 55°00′), channel bodies are infrequent in the Middle Gates Formation. The Wolverine-Babcock area shows a maximum development of coal over the stratigraphic interval, due to a lack of section-thickening channels. Somewhat enigmatically, the nearshore conglomerates of Fahler C and D lie adjacent to this area on the north. Leckie (1986) invokes a major channel at Mt. Spieker as a source for the nearshore conglomerate of Fahler D.

The continuity of the coals suggests floodbasins of considerable extent. J seam apparently formed under widespread limno-telmatic conditions (Diessel *et al*., 2000). J seam can be traced southeast for over 70 km into facies of the upper delta plain, according to Carmichael (1983).

locally eroded at the contact with the conglomerate of the Notikewan (Upper Gates Formation).

There is no formal seam correlation between the stratigraphy at South Fork (Bullmoose mine) and the various pits of the Quintette mine area south of the Wolverine River. However, J, G and E seams appear to persist. Their equivalents are shown in Table 1. J seam is equivalent to A and B seams at Bullmoose.

LOCAL STRATIGRAPHY

The local stratigraphic setting is illustrated in a north-south line of section extending from Quintette's Mesa pit area to the Perry Creek area (Fig. 5). A key coal borehole in the area is QWD 7115, within the area of the Perry Creek development. This borehole is utilized in lines of sections by Leckie (1983, 1986), Duff and Gilchrist (1981) and Quintette Coal Ltd. (1990). The section shows J seam overlain by Fahler D conglomerate. Fahler C is overlain by thick shaly coals of the D/E interval at Quintette. Fahler C can be traced as far south as the Mesa North pit in the Wolverine , while the southern limit

TABLE 2. SUMMARY OF COAL THICKNESS DATA, FROM OLD, DEVELOPING AND POTENTIAL PITS IN THE STUDY AREA

Area	J Seam Average (m)	Total Coal Average (m)
Shikano	5.26	18.43
Mesa North	5.73	18.48
Frame	3.46	16.66
Perry Creek	5.69	11.89
EB	5.6	11.6
South Fork	7.01	12.59
West Fork	5.2	<8
Trend (South)	4.68	17.53
Babcock	4.42	17.19

of Fahler D falls between drillholes QWD 7715 and 7719 in the Perry Creek area. New holes further constrain the trend of the southern bounds of Fahler C and D.

Fahler D and Fahler C

The coarse clastic units of Fahler D and Fahler C thicken rapidly northward, widen the stratigraphic separation between major coals, and reduce the mineable section. The cumulative effect is a fairly sharp northern boundary to economic coal resources in the Gates Formation.

The Fahler D and Fahler C marine tongues are exposed in cliff and ridge-forming sandstone and conglomerate units north of the Wolverine River. They are continuous bodies but not formally correlated across coal properties. Local terminology is used. Fahler C is the Wolverine sandstone at Perry Creek and E conglomerate in Quintette's Mesa North area. Fahler D is the J conglomerate at Perry Creek. No name is given to the equivalent conglomerate overlying B seam at West Fork.

Fahler C and D are massive conglomerates at their southern boundaries. The conglomerates extend seaward, fine seaward, and cap upward coarsening sequences. Further to the north (seaward), the upward coarsening interval includes shale at the base. Regional isopachs published by Leckie (1986) involve clean sand and conglomerate, and do not include shale of the marine interval.

The boundary of Fahler D is exposed on Mt. Spieker and this area of excellent exposures was chosen for reviewing the ground observations made by Leckie (1983). A number of closely spaced drillholes at the new Perry Creek development also illustrates Fahler D is at its limit here. The southern boundary of Fahler C is found in Mesa North pit of Quintette Coal Ltd. It is more accessible in cliff-wall exposures paralleling the Perry Creek road.

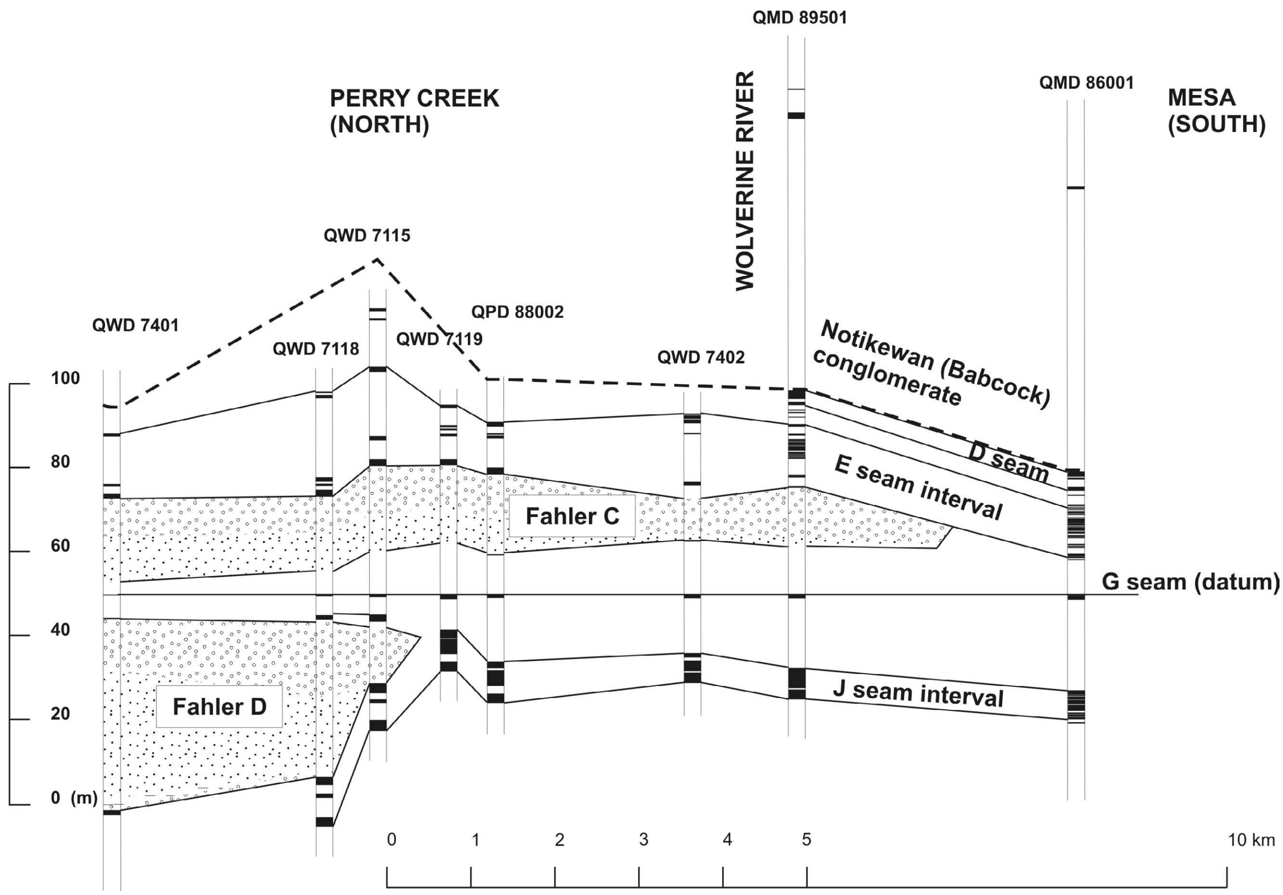

Figure 5. Line of section (Quintette Mesa pit to Perry Creek area). Location of line of section is shown in Figure 1.

Data Compilation and Contouring

Leckie's (1983) original data was reviewed and supplemented by data from Western Canadian Coal Corp., Quintette Coal Ltd. and the ministry's oil and gas database. Coal borehole data is being corrected for bedding angle so that a true thickness can be given (not all holes had been corrected at the time of writing so apparent thickness is included). Location data was checked and compiled in UTM NAD 83. Sixty-three records were available for Fahler D and thirty-seven for Fahler C. Thickness values ranged up to 43 m for Fahler D and 23 m for Fahler C. A bullseye thickness of 35 m for Fahler C, recorded by Leckie (1986) for well QUASAR MOBIL D- 057-D/093-P-02 (WA# 3194), appears to be a mistake.

Manifold software was utilized to manipulate database information, to create point data and to create a contoured surface. A triangulation algorithm was used for contouring. The base geology map was imported from AutoCad.

FAHLER D TRENDS

A contour plot (Fig. 6) emphasizes the rapid thinning to the south and the more gradual thinning to the north of the Fahler D unit, as well as the linear trend of the southern boundary.

The Fahler D boundary extends generally east-southeast across the coalfield. In the west, it lies within the area of the West Fork deposit (just north of the former Bullmoose mine). At Mt. Spieker, the trace cuts the saddle area just north of the EB pit area (see Mt. Spieker discussion). At Perry Creek, a straight east-trending segment is evident, constrained by numerous holes near QWD 7115 and 7119. This east-trending segment may continue to well # 15372 (SHELL B- 003-G/093-P-03), where the lithological log suggests a 10 m thickness of Fahler D. In the outer foothills, the boundary is constrained by well # 3319 (CNRL D- 080-A/093-P-03) and well # 3403 (KM ET AL B- 060-A/093-P-03) and then by the pair of well # 3814 (QUASAR MOBIL C- 076-D/093-P-02) and well # 3194 (QUASAR MOBIL D- 057-D/093-P-02 [0 m]).

FAHLER C TRENDS

Fahler C maintains a thickness of 15 to 20 m over a wide area (Fig. 7). The Fahler C boundary trends southeasterly, across the coalbelt. Its southern limit in the Wolverine area is marked by drillhole QMD 88003 in the Mesa North pit area. It is intersected just to the east in deep coal borehole Dupont Wolverine DDH-79-2. This suggests a more eastwardly trending segment. Its trace apparently continues southeast (outside the area of Fig. 7) and parallels the

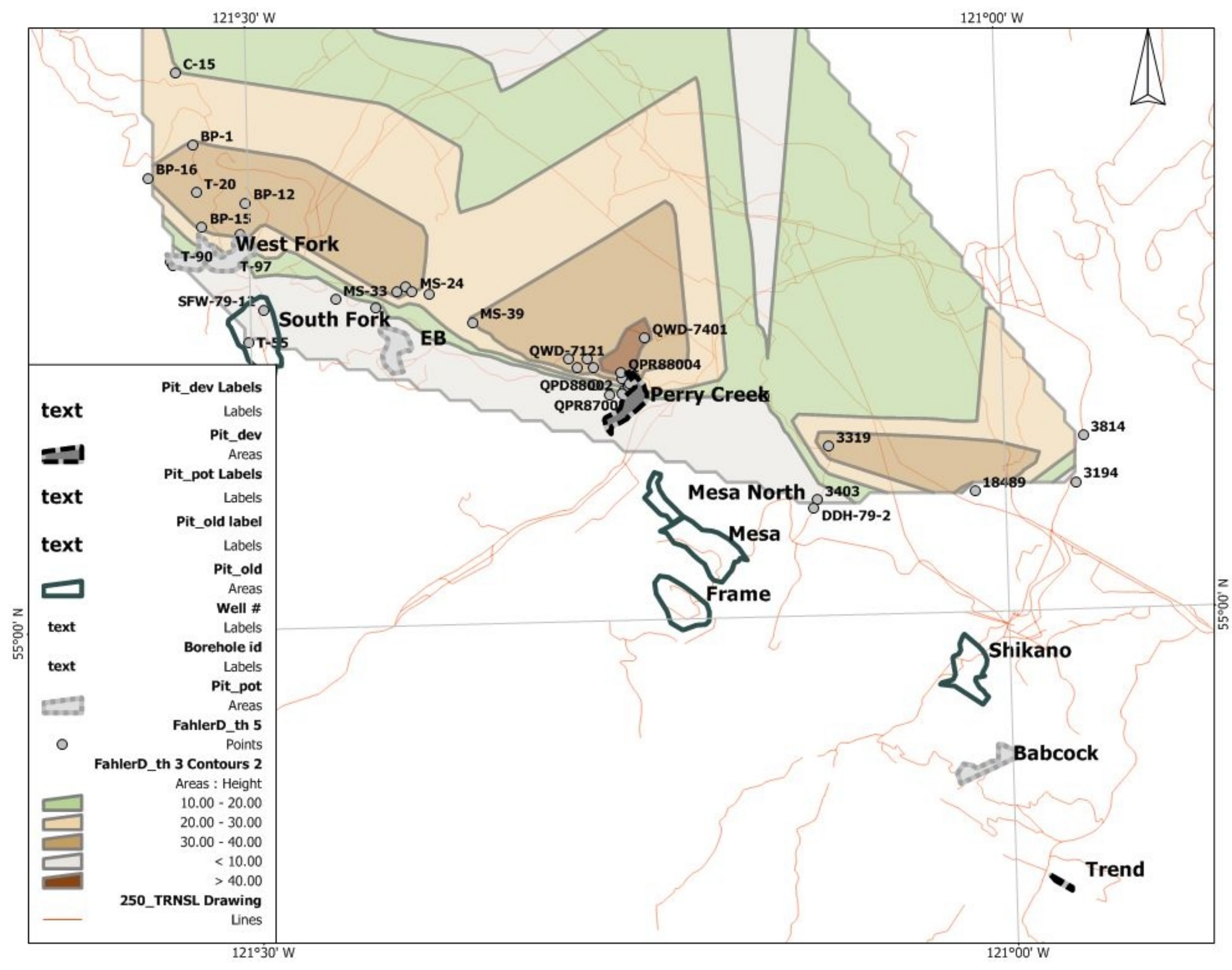

Figure 6. Contour plot of Fahler D using Manifold software triangulation algorithm.

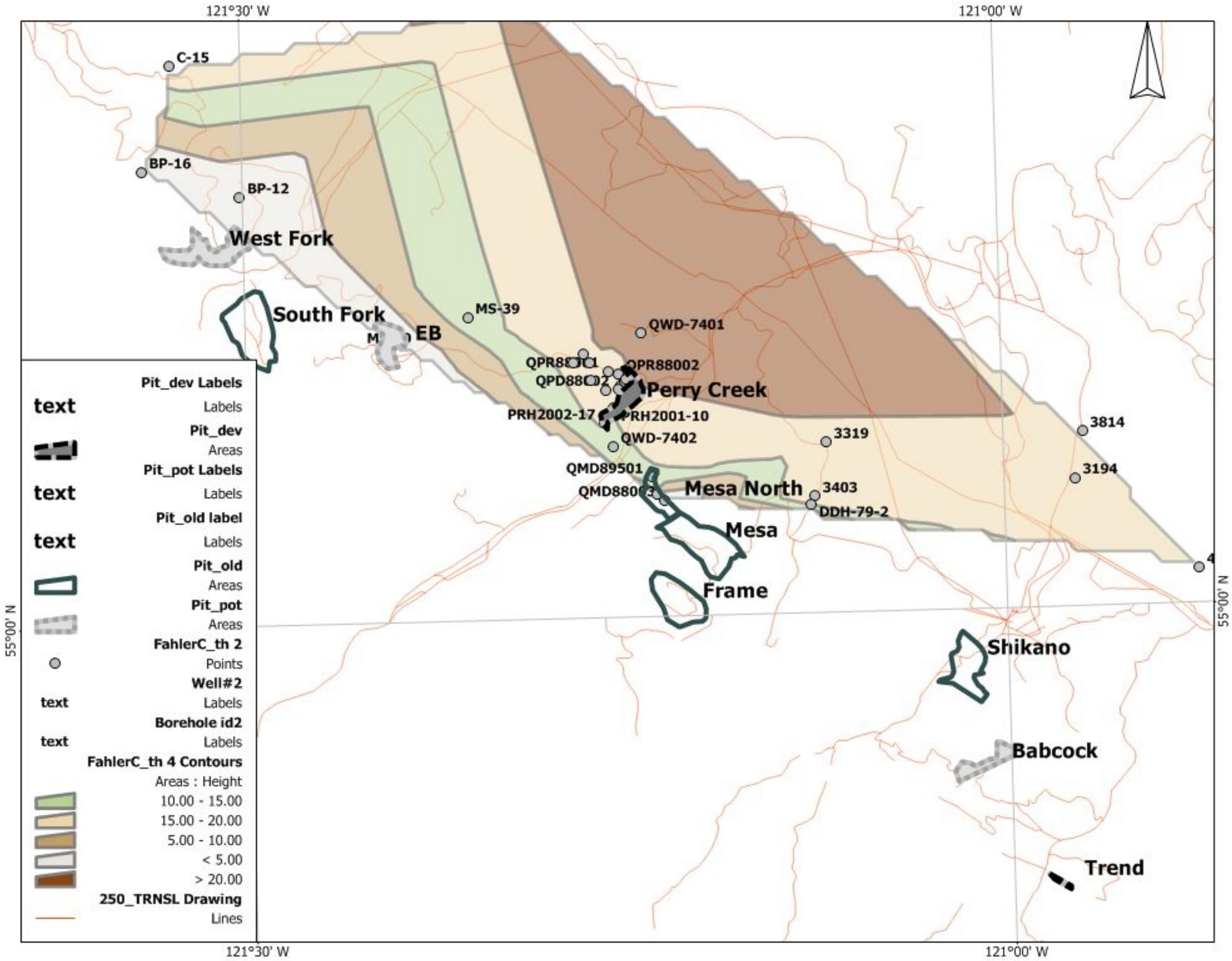

Figure 7. Contour plot of Fahler C using Manifold software triangulation algorithm.

coalfield in the subsurface. Carmichael (1983) shows it to be pinned by petroleum well KM ET AL B- 060-A/093-P-03l (WA #9439) in the Kinuseo Creek area.

Fahler D Exposures at Mt. Spieker

Fahler D at Mt Spieker is up to 38 m thick. The north to south facies changes of Fahler D are presented in a well known section diagram (Leckie and Walker, 1982, Fig. 3). In the north, in exposures along the west side and top of the mesa, shallow marine facies include subaqueous symmetrical and assymetrical gravel dunes, small-scale beach bars and ridges, herring bone (tidal) cross-stratification, pebble lag horizons, and finer beds containing the marine trace fossil *Rhizocorallium.*

At the south end, the most prominent features are long shallow dipping surfaces, which comprise over 15 to 18 m of section, dip to the south, and are exposed along a valley wall. They extend for several hundred metres to bluffs overlooking a topographic saddle (Fig. 8). Vertical tree casts are evident near the base of the bluff facing west (into the valley). Conglomerate, poorly to well sorted, is capped by well sorted (washed) sandstone and granule beds with current directions to the east. A few quartzitic clasts over 10 cm are randomly distributed. The writer found one sizable clast measuring 35 by 23 by 10 cm. This clast, which must weigh about 13 kg, is still cemented to granular matrix at one corner of the clast (Fig. 9).

Leckie and Walker (1982) noted small channel features trending 170° at the base of Fahler D.

The Fahler D conglomerate is missing on the south side of the saddle and apparently pinches out in the intervening few hundred metres where the section is not preserved. Coal seams provide stratigraphic control for the south side of the saddle (*e.g.*, drillhole MTSP MS 19, Robertson Research Limited [1978]). The shale above the Fahler D conglomerate has thickened and apparently takes up most of the interval, the conglomerate having thinned out.

INTERPRETATION

The low south-dipping surfaces are a major feature of Fahler D at its southern boundary. The boundary has a linear trend as shown in the contour plot (Fig. 6). Fahler D may represent a barrier bar and the dipping surfaces are the south-facing landward slope of the bar. As the dipping surfaces extend over 15 to 18 m of the stratigraphic section, a similar depth of water is implied. This would indicate a lagoon of some depth on the landward side.

The interpretation of these slopes as lateral accretion surfaces of a fluvial channel (Leckie 1983, 1986) implies

Figure 8. Low angle, south-dipping surfaces in Fahler D conglomerate, near southern limit of the conglomerate on Mt. Spieker.

Figure 9. A large, flat, ellipsoid clast sits in granule conglomerate of Fahler D at Mt. Spieker. The location of the clast is towards the base of the exposure shown in Figure 8.

an east-trending channel parallel to shore. However, the thickness of lateral accretion sets is greater than that described for most fluvial systems in the literature. It is possible that these sets might have been deposited in an estuarine channel.

Low-angle accretion bodies, of similar appearance, have been described by Carmichael (1988) as migrating shoals in estuaries normal to the shoreline. In this study area, accretion parallels the shoreline. The context suggests an alternative interpretation of a washover delta.

There are indications of marine influence south of the barrier bar. The barrier may have been broken by tidal channels, such as those suggested by small channel features oriented normal to the shoreline. Lagoonal sediments are preserved south of the barrier on Mt. Spieker. They include upward-coarsening shale, carbonaceous mudstones, some root zones but also forams and delicate echinoderms, which Leckie and Walker (1982, page 153) suggest have been washed in.

There are indications of a marine influence in other areas south of the Fahler D limit. Near Perry Creek, in the Perry Creek development, drilling by Quintette Coal Ltd. (Quintette Coal Ltd., 1989) showed sulphur to be elevated in J1 and J2 seam plies, when compared with values immediately south of the Wolverine River. The marine fossil *Psilomya peterpondi* (Duff and Gilchrist, 1981) overlies J seam in QWD 7402, located more than 2 km south of the boundary near the southern limit of the Perry Creek pit.

Further south, in the Mesa pit area, Carmichael (1983) notes lacustrine shales and freshwater fossils immediately above J seam, suggesting this area was outside the influence of coastal marine waters.

General Discussion of Fahler D and Fahler C

The overall trend of Fahler C is to the southeast while that of Fahler D is east-southeast. The coastal configuration had apparently changed by the time of the Fahler C transgression. However, both transgressions reached approximately the same position in the Mt. Spieker area.

The shoreline trends provide some explanation as to why an appreciable thickness of coal was mined in the South Fork deposit (Bullmoose mine), some 20 km northwest of the Quintette mine area at Wolverine River. The Bullmoose mine was landward of both Fahler C and D marine margins.

There are several indications of nearshore subsidence coinciding with stillstand deposits of Fahler D. The first is the burial of standing trees below 15 to 18 m of nearshore sediments. The second is the splits of J seam under the Fahler D edge. The third is the thickening of shale above the conglomerate, landward of a barrier bar. The presence of a bar, even submerged, would certainly have been able to compress peat deposits immediately below and to an uncertain lateral extent. Falini (1965) discusses the general aspects of the loading and compression of peats by sediments. At Mt. Spieker, the load on peat deposits at the barrier and landward of the bar might be appreciably different. The thickening of shale, landward of the conglomerate, suggests (subaqueous) relief that was eventually levelled with further sedimentation and prior to renewed peat formation. The concept of coastal loading is worth further investigation and modelling.

The presence of large quartzitic clasts in Fahler D raises questions as to the source of the sediment. It is difficult to envisage clasts approximately 35 cm long being carried through the channels of a low-gradient coastal plain. These channels did not incise the plain. The large clasts may have a common source, a point along the coast that was subjected to erosion, perhaps where the barrier bar approaches the western margin of the seaway. There is abundant evidence of storm activity and vigorous wave action in the seaway, in the form of swaley and hummocky cross-stratification (Leckie and Walker, 1982).

The source of Fahler D conglomerate is not clear. Channels are not evident in the EB pit area or in areas immediately south of the Perry Creek mine development. The area south of the Fahler D boundary has appreciable coal in a relatively thin and channel-free Middle Gates Formation. Further work needs to be done to answer the question – is the clast composition of Fahler D significantly different from other conglomerates?

FURTHER WORK

Mapping

There is scope for further mapping west of Fortress Mt. and the Bullmoose-Mesa thrust. This area (southern portion of Mt. Spieker syncline) has undergone minimal drilling. It is a prospective but underexplored area on the north side of the Wolverine River. It lies landward of Fahler D and C nearshore marine deposits. Mapping at a 1:20 000 scale has the potential to delineate additional resource areas that might be missed in 1:50 000-scale work.

Conglomerate Sampling

Gates Formation conglomerates are occasionally silicic and carbonate free. This effectively eliminates their neutralization potential and they have potential to generate acid mine drainage (AMD) depending on their pyrite content. Carbonate-free conglomerates have been noted at Babcock (Kim Bellfontaine, MEMPR Environmental Review Office, pers comm., 2005) and Perry Creek. For example, J2 conglomerate (Fahler D) at Perry Creek is recorded as containing 0.7% pyrite, 93.3% quartz and no carbonate (Lorax Environmental Services, 2004). Carbonate contents up to 11.4% are present in other sandstones and conglomerates, usually as dolomite. About 30 conglomerate samples, representative of marine, nonmarine and possibly estuarine depositional environments, were collected. Figure 10 illustrates estuarine conglomerate that buried the long-lived peat swamps of the D/E interval at Quintette. Sample processing at the time of writing is incomplete. The erratic distribution of carbonate lithic clasts in the Gates Formation, documented by both Leckie (1983) and Carmichael (1983), remains unexplained.

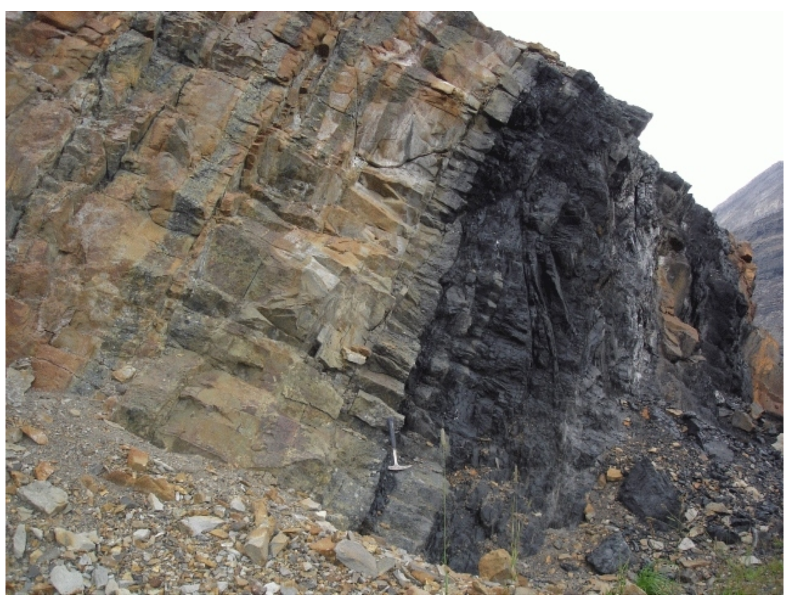

Figure 10. Silicic and pyritic conglomerate of Upper Gates Formation (Notikewan) overlying D/E seam in the Quintette Mesa pit.

Sampling for Selenium

Selenium is a group 6a element that shares many similarities with sulphur. Coal mining releases the inorganic form of selenium. It is most likely to be present as selenate (SeO_4; +6 oxidation state) in oxygenated waste rock drainage waters. In low concentrations, selenium is required for good health. However, in high concentrations, in the organic form, it is a health hazard to wildlife and humans when absorbed. Generally speaking, fine-grained rocks, mudstones and shales, have higher selenium concentrations. At Wolverine, zinc and lead were found to have a strong positive correlation with selenium (EVS Consultants, 2004). Selenium is closely related to sulphur and sulphur-rich coals are often ascribed to marine influence. The thin shale overlying the marine Quintette sandstone and underlying J seam (base of coal measures) was chosen as a sampling horizon for Se. The sampling horizon is relatively easy to locate in the field as the Quintette sandstone (*i.e.*, top of Fahler F) forms a prominent ridge. The base of the coal measures is often recessive and covered but some carbonaceous shale is often preserved (or remains after mining) at the J seam's basal contact. Results of environmental sampling are not fully available at the time of writing and this will be the subject of a subsequent report.

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