VITRINITE REFLECTANCE STUDY OF NANAIMO GROUP COALS OF VANCOUVER ISLAND (92F)

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INTRODUCTION

Preliminary results of a vitrinite reflectance study on Nanaimo Group coals are presented in this report. This study is part of an ongoing project begun in 1987 to provide an update of critical geologic relationships of the Vancouver Island coal deposits. The objective of the project is to provide sufficient data and analysis to assist industry and government in assessing the potential of the Island coals with respect to utilizing this resource for the production of coal-seam gas, coal-water fuel and the traditional thermal and metallurgical applications.

Vitrinite reflectance data will provide a quick and effective method for determining coal rank distribution over the study area. Because vitrinite is abundant in coal, easy to isolate, and undergoes changes consistently, it is an excellent medium for rank studies (Teichmuller and Teichmuller, 1966). Reflectance data can aid in stratigraphic correlation and can also provide information relevant to structural interpretations. Rank variations assist in determining the relative timing of coalification and provide information which is critical in the evaluation of coal deposits.

Previous work involved compiling and analysing existing data as well as reconnaissance mapping and sampling during the 1987 field season. Details of this work have been published previously (Bickford and Kenyon, 1988). During the 1988 field season additional outcrops were sampled in the Comox sub-basin and detailed geological mapping was completed in the Quinsam area. Details of this mapping are presented in Bickford *et al.* (this volume).

The study area is located on the east side of Vancouver Island (Figure 4-2-1). The Comox sub-basin is approximately 1230 square kilometres in area and the Nanaimo sub-basin covers nearly 780 square kilometres. Elevations range from sea level to 500 metres but the topography is fairly gentle. Exposures in both sub-basins are limited to creeks and roadcuts throughout most of the area, due to dense forests and thick underbrush. Logging roads provide the main access.

GEOLOGICAL SETTING

The coal measures of eastern Vancouver Island are found in Nanaimo Group rocks of Santonian to Maastrichtian age (Muller and Jeletsky, 1970). They lie unconformably on a basement of Paleozoic to middle Mesozoic volcanic, intrusive and sedimentary rocks. The Nanaimo Group consists of a sequence of conglomerates, sandstones, shales and coals. They occupy the western erosional margin of the Late Cretaceous Georgia basin within the Insular Belt of the Canadian Cordillera.

Two distinct sub-basins, Comox and Nanaimo, contain Nanaimo Group rocks. These basins are separated by a northeast-trending basement uplift, the Nanoose arch (Figure 4-2-1). Sediments in both sub-basins generally dip 5 to 14 degrees in a northeasterly direction and numerous faults contribute to the structural complexity. Economic coal measures in the Nanaimo sub-basin are found in the Pender and Extension formations and in the Comox sub-basin they occur in the Comox Formation, specifically in the Dunsmuir and Cumberland members (Table 4-2-1). Detailed coal-measure stratigraphy and the relationship of the Nanaimo Group rocks across the sub-basins can be found in Bickford and Kenyon (1988).

TABLE 4-2-1
STRATIGRAPHIC UNITS OF THE NANAIMO GROUP

Maastrichtian	Spray Fm.	Dark shale: COAL
Late Campanian	(Boundary within Spray Fm.)	Classic turbidites, mostly shales
	Geoffrey Fm.	Conglomerate and sandstone
	Northumberland Fm.	Classic turbidites, mostly shales
	De Courcy Fm.	Sandstone and conglomerate
	Cedar District Fm.	Classic turbidites, mostly shales
Early Campanian	Protection Fm.	(Subdivided in Nanaimo coalfield)
	McMillan Mbr.	Sandstone and siltstone
	Reserve Mbr.	Siltstone and sandstone: COAL
	Cassidy Mbr.	Sandstone and conglomerate
	Pender Fm.	(Subdivided in Nanaimo coalfield)
	Newcastle Mbr.	Shale and conglomerate: COAL
	Cranberry Mbr.	Sandstone and siltstone
	Extension Fm.	(Subdivided in Nanaimo coalfield)
	Millstream Mbr.	Conglomerate: COAL
	Northfield Mbr.	Siltstone and sandstone: COAL
	East Wellington Fm.	Sandstone (Nanaimo sub-basin only)
	Haslam Fm.	Classic turbidites, mostly shales
	Comox Fm.	(Subdivided in Comox sub-basin)
	Dunsmuir Mbr.	Sandstone: COAL
	Cumberland Mbr.	Siltstone and sandstone: COAL
	Benson Mbr.	Conglomerate and red beds

UNCONFORMITY
Older basement rocks, chiefly volcanics

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989-1.

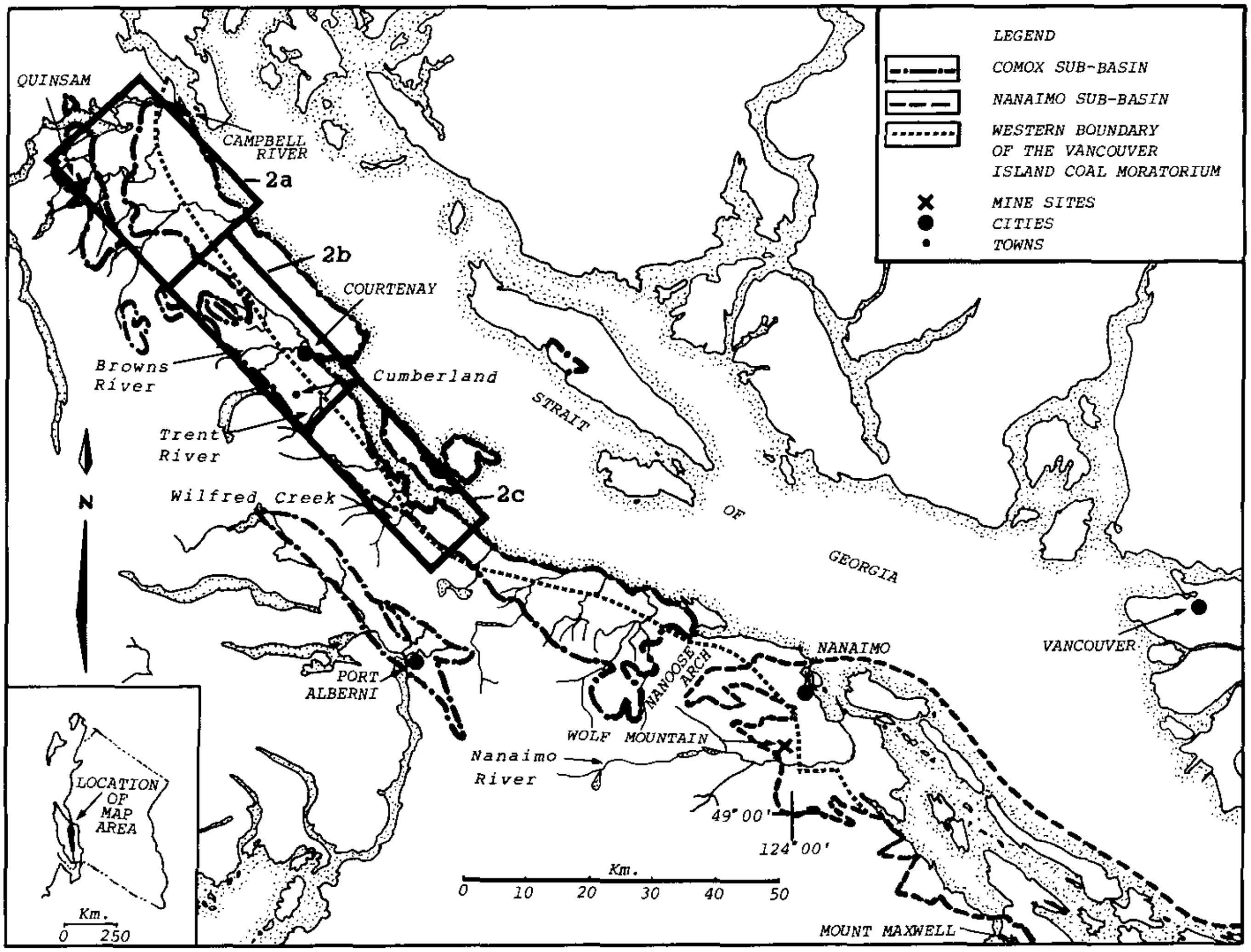

Figure 4-2-1. Location map, Vancouver Island coal basins.

FIELDWORK AND METHODS OF STUDY

Preparation for sampling coal on Vancouver Island involved a search of archived information to obtain outcrop, adit and mine locations. An exploration map from 1914 (no author) indicated possible outcrop locations throughout the Comox sub-basin and was used as a guide in this area. Exposures of coal in the Nanaimo sub-basin are limited and generally confined to the Newcastle seam (Table 4-2-1). Exposures of the Comox Formation coal measures are more readily accessible. Logging activities have contributed to the disappearance of many old coal showings either by stream diversion or sediment build-up behind dams.

Limited exposure results in difficulties placing outcrops accurately in the stratigraphic section. Borehole information in these areas is being used for data interpretation. Sections along Browns River, Trent River and Wilfred Creek were measured and sampled in detail (Figure 4-2-1). Sampling is continuing.

Sample locations were plotted on 1:20 000 air photographs and transferred to 1:20 000 base maps. UTM coordinates and elevations for each location were picked from the base maps and recorded (Tables 4-2-2 and 4-2-3). Geological maps of the Comox sub-basin (Bickford and Kenyon, 1988) were modified by data collected during the 1988 field season. Sample locations were plotted on these maps and also on a map depicting coal seam traces in the Nanaimo sub-basin (Figures 4-2-2a, 2b, 2c and 3).

All coal intervals were sampled and multiple samples were taken at most locations. Weathered material was cleaned off and, whenever possible, a channel sample was taken across the total seam thickness. Partings more than 1 centimetre thick were not included. One sample from each location was chosen for a vitrinite reflectance test. In addition, channel samples for proximate analysis were taken from fresh coal at the Quinsam mine. A tonstein contained in a coal seam outcropping along the Iron River was sampled (No. 46, Figure 4-2-2a) and has been sent to The University of British Columbia for zircon uranium-lead dating.

Coal samples selected for vitrinite reflectance tests were crushed using a mortar and pestle. The −20 mesh fraction was combined with epoxy and pelletized. A Leitz MPV-3 reflecting-light microscope was used to determine the reflectance of the polished coal surfaces. On each sample, 50

TABLE 4-2-2
SAMPLE LOCATION AND REFLECTANCE DATA
COMOX SUB-BASIN

Sample No.	UTM EASTING	UTM NORTHING	ELEVATION (m)	% R_oMax
30	323490	5534650	239	0.59
32	323350	5534100	242	0.63
18	322525	5533200	351	0.80
44	322280	5531420	314	0.72
45	322185	5530880	338	0.77
46	325065	5532420	274	0.85
67	325400	5528230	501	0.72
16	326750	5527350	526	0.71
15	326770	5526320	564	0.81
17	331250	5530000	210	0.73
83	334360	5526900	145	0.74
61	340380	5518560	135	2.52
33	346100	5509100	195	1.19
12	343600	5506270	478	1.76
13	343620	5506180	450	1.81
74	346640	5506230	178	1.63
75	346660	5506260	176	1.63
76	346720	5506350	170	1.55
77	346780	5506390	168	1.31
78	346820	5506400	165	1.38
79	346850	5506400	164	1.31
81	347060	5506250	155	3.21
82	347320	5506100	150	1.51
39	347770	5506220	138	1.09
38	347822	5506200	135	1.05
72	348920	5506240	110	0.88
70	349600	5506440	90	0.79
10	349500	5495880	555	0.88
11	351960	5497100	180	0.98
49	352100	5496860	190	0.99
9	351900	5493290	475	0.84
48	354200	5493410	270	0.89
47	354345	5493490	255	0.81
51	354100	5493760	250	0.82
50	354260	5493650	240	0.83
36	354590	5493770	235	0.79
42	354820	5493940	228	0.76
41	355090	5494290	198	0.65
40	355480	5494410	190	0.73
34	355700	5494580	175	0.75
69	362430	5486170	170	0.96
60	363610	5484740	142	0.87
86	366420	5481220	115	0.97
85	366830	5481410	80	0.85
84	366990	5481480	70	0.98

TABLE 4-2-3
SAMPLE LOCATION AND REFLECTANCE DATA
NANAIMO SUB-BASIN

Sample No.	UTM EASTING	UTM NORTHING	ELEVATION (m)	% R_oMax
22	432160	5449985	0	0.68
25	431410	5449525	20	0.69
24	431340	5449480	40	0.67
23	432860	5448525	0	0.65
26	431630	5446490	10	0.64
27	433060	5439280	102	0.66
5	433625	5439800	60	0.68
4	433670	5439675	60	0.72
6	425575	5440625	570	0.71

randomly oriented vitrinite particles were measured for maximum and minimum apparent reflectance. Histograms and reflectance crossplots were prepared for data interpretation using computer programs developed by Kilby (1986). The graphic data, produced by the reflectance crossplot technique, provide a method for determining the three principal reflectance axes which describe the shape of the vitrinite reflectance-indicating surface, using a new technique developed by Kilby (1988). Samples were assigned an ASTM rank following the classification of McCartney and Teichmuller (1972).

RESULTS

Preliminary vitrinite reflectance data in the Nanaimo sub-basin are limited to the Newcastle seam, except for one value from the Wellington seam, due to limited exposures (Figure 4-2-3). A composite section indicates the position of the coal seams in the Pender and Extension formations (Figure 4-2-4). Detailed geology of the Nanaimo sub-basin can be found in Buckham (1947). Mean maximum reflectance values from the Newcastle seam range from 0.64 per cent to 0.72 per cent while the single value from the Wellington seam is 0.71 per cent A summary of this information is presented in Table 4-2-3. Results indicate little variation in rank within the sub-basin. Interpretation of crossplots for eight samples produced reflectance-style values (R_{ST}) of -3.0 to $+3.81$ indicating the coals have biaxial-even reflectance-indicating surfaces.

Sample locations in the Comox sub-basin are more numerous due to better exposure. Reflectance values for this area are summarized in Table 4-2-2. Mean maximum reflectance data throughout the sub-basin exhibit values ranging from 0.59 to 3.21 per cent. The lowest value is from an outcrop close to the top of the Comox Formation (No. 30, Figure 4-2-2a) while anomalous values are found north of the Puntledge River, specifically at sample locations 61, 12, 13, 33, and along the Browns River (Figure 4-2-2b, Section A-A'). Excluding anomalous values, there is a trend of increasing coal rank from north to south in the Comox sub-basin, contrasting with a lack of variation in the Nanaimo sub-basin. Crossplots examined to the time of writing have produced R_{ST} values ranging from -7.0 to $+7.2$. Data again suggest that the reflectance-indicating-surface patterns are biaxial-even.

Detailed sampling of a 200-metre section along Browns River (Section A-A', Figure 4-2-2b) produced mean maximum reflectance values ranging from 0.79 to 3.21 per cent. The lowest value is from the top of the section and the highest value is located adjacent to a porphyritic dacite sill (Figure 4-2-5). The high rank sample has been coked and shows strong mosaic anisotropy and devolatilizing bubbles. The trend down-section illustrates that the temperature gradient increases approaching the sill, decreases beyond it and increases again near the basement volcanics. Crossplot data interpretation has not been completed for this section.

Reflectance values range from 0.65 to 0.89 per cent over a 280-metre section along the Trent River (Section B-B', Figure 4-2-2b). Some data scatter is present, but the reflectance

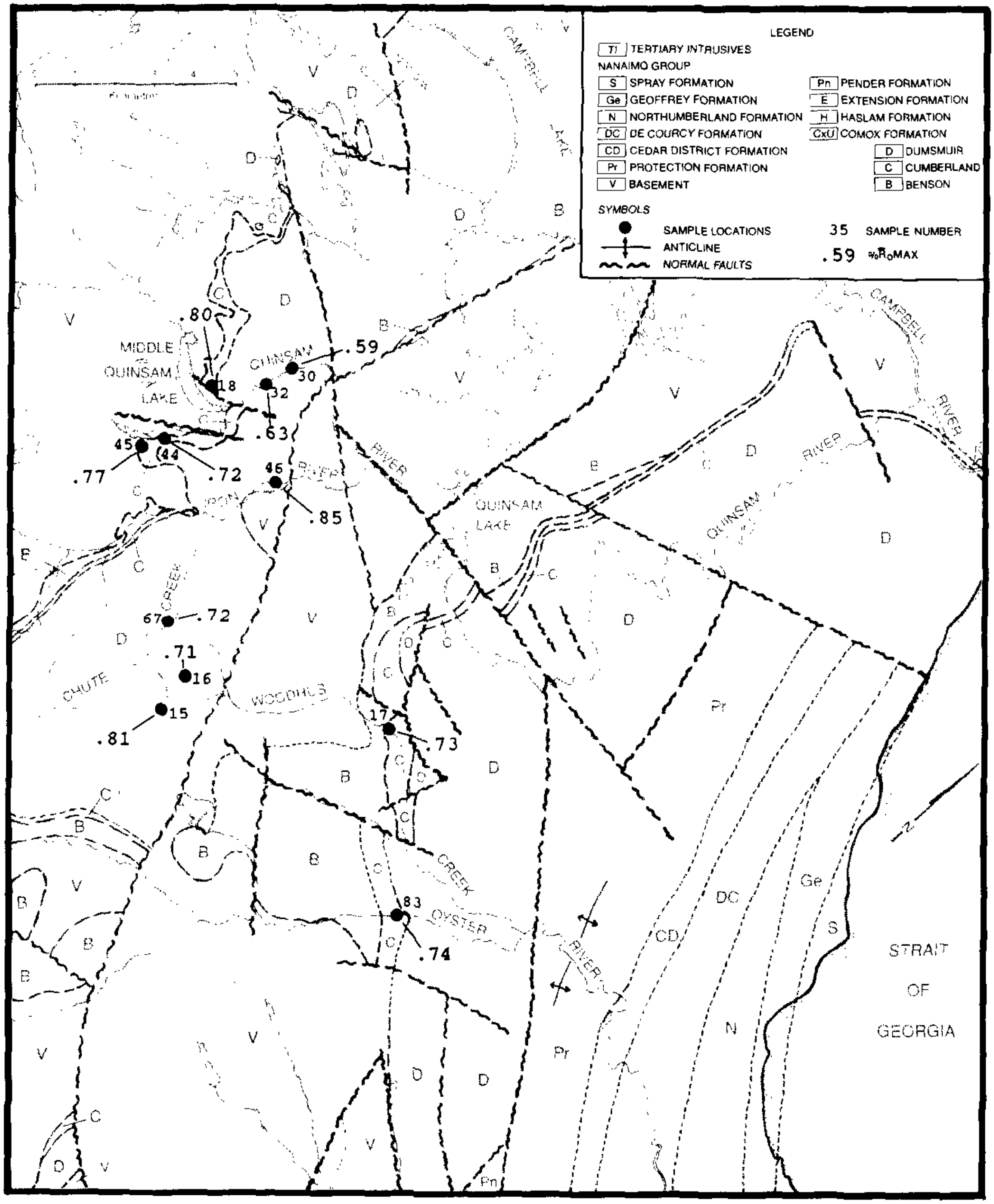

Figure 4-2-2a. Geology of the Comox sub-basin (revised, 1988) with coal sample locations and R_o max values. Refer to Figure 4-2-1.

gradient generally increases down-section (Figure 4-2-6). A depth-reflectance profile of this section is presented in Figure 4-2-7. As in the Browns River section, this illustrates an obvious increase in temperature gradient close to the basement. Crossplot interpretations from these sample locations yielded R_{ST} values from −6.0 to +7.2. The majority of values were negative but fairly low, illustrating biaxial-even reflectance patterns.

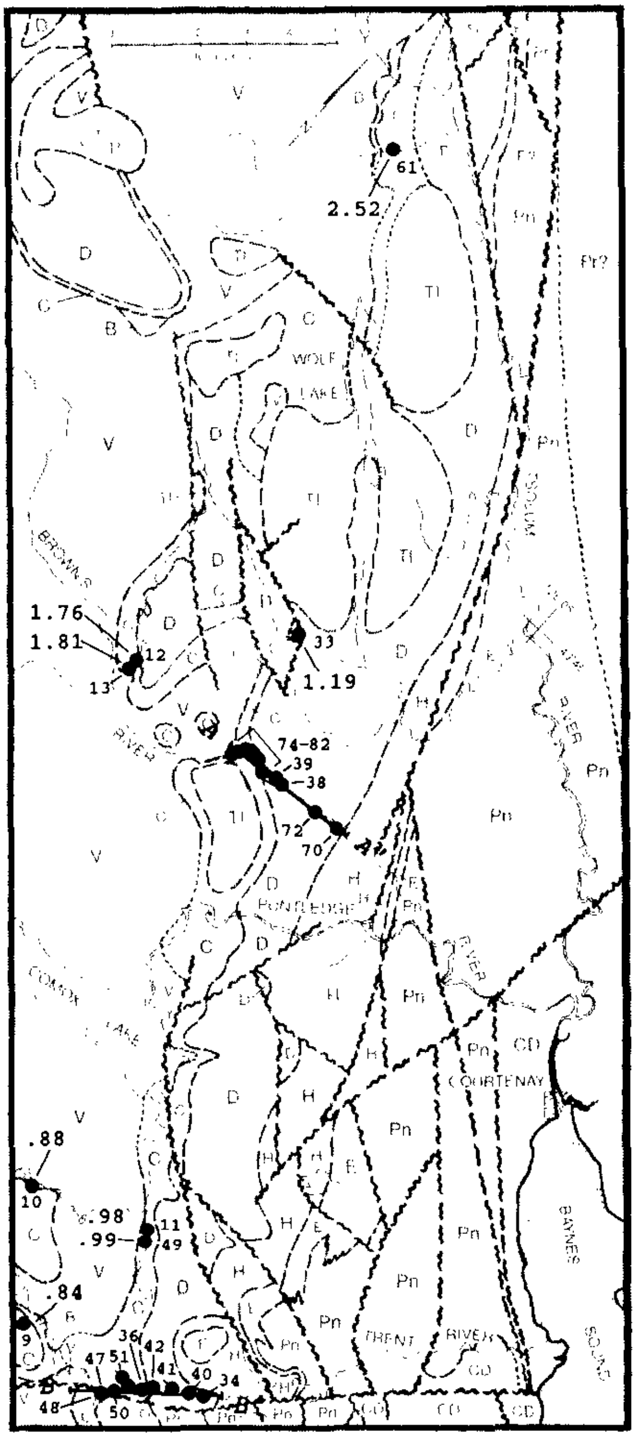

Figure 4-2-2b. Geology of the Comox sub-basin (revised, 1988). Refer to Figure 4-2-2a for legend and also to Figure 4-2-1.

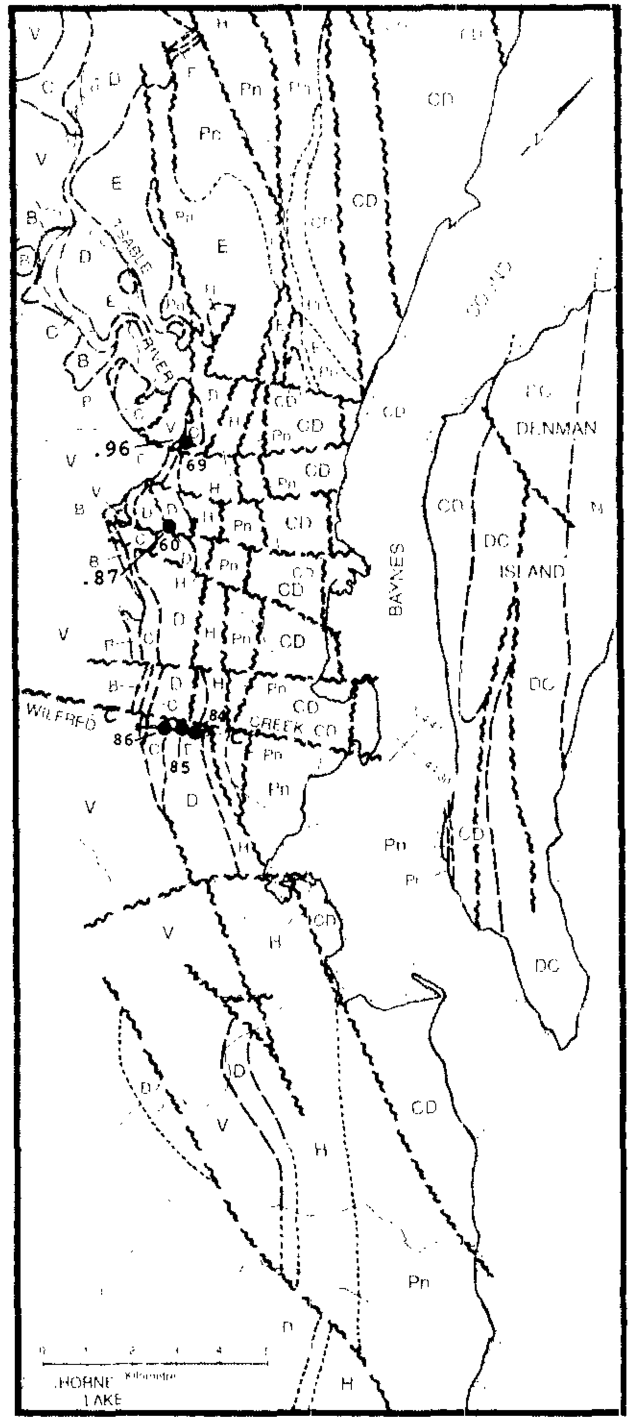

Figure 4-2-2c. Geology of the Comox sub-basin (revised, 1988). Refer to Figure 4-2-2a for legend and also to Figure 4-2-1.

The Comox Formation on Wilfred Creek is approximately 210 metres thick (Section C-C', Figure 4-2-2c). There are fewer coal seams in this section than along the Trent and Browns rivers to the north (Figure 4-2-8). Mean maximum reflectance values ranged from 0.85 to 0.98 per cent with no obvious trend in the reflectance gradient. Reflectance values obtained from coals in the Dunsmuir member are higher in Wilfred Creek than in Trent River. Crossplots have not been interpreted for Wilfred Creek.

The one location available for obtaining a fresh coal sample for detailed quality analysis was at the Quinsam mine (No. 18, Figure 4-2-2a). Two channel samples were taken on a 2.27-metre section. Sample 1, over 1.28 metres, was obtained above a 3-centimetre mudstone parting and Sample

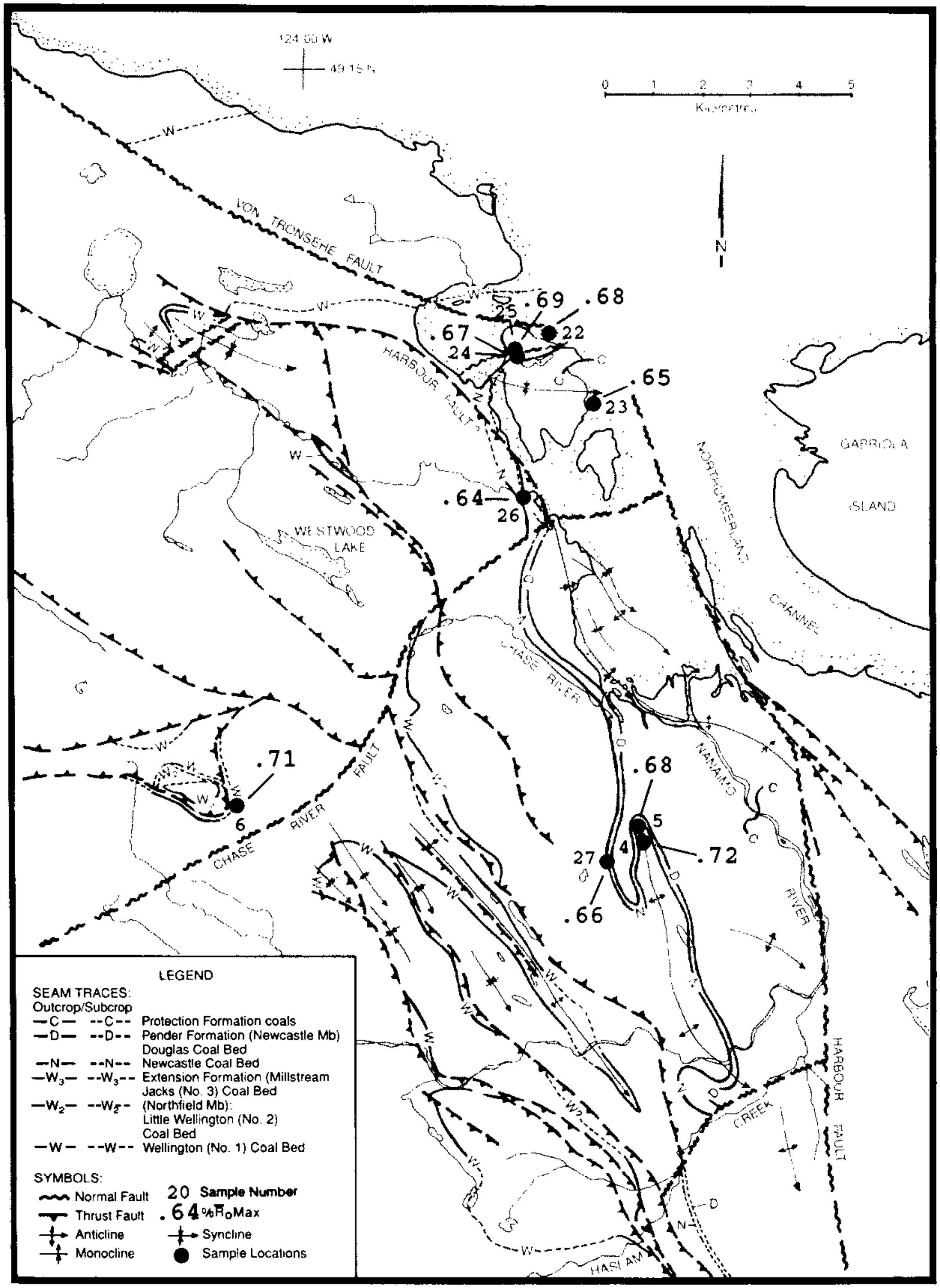

Figure 4-2-3. Coal seam traces, coal sample locations and R_0 max values, Nanaimo sub-basin.

2, over 0.95 metre, was taken below the parting. The samples were analysed by Commercial Testing and Engineering Company in Vancouver. Test results are included in Table 4-2-4 because vitrinite reflectance from bituminous coal is correlatable with other parameters such as volatile matter, carbon content, and the hydrogen:carbon ratio used in determining rank distribution (McCartney and Teichmuller, 1972). These data indicate a high-volatile bituminous coal and are supported by the R_0 max measurements (Table 4-2-2 and Figure 4-2-2a).

TABLE 4-2-4
ANALYSIS DATA FROM QUINSAM MINE

Proximate Analysis (dry basis)	Sample 1	Sample 2
% Ash	9.97	8.50
% Volatile matter	40.35	39.62
% Fixed carbon	49.68	51.88
	100.00	100.00
% Sulphur	1.24	0.46
Calorific value (Btu/lb)	11 862	12 318
Sulphur forms (dry basis)		
% Pyritic sulphur	0.51	0.05
% Sulphate sulphur	0.04	0.01
% Organic sulphur (difference)	0.69	0.40
% Total sulphur	1.24	0.46
Ultimate Analysis (dry basis)	Composite of 1 + 2	
% Carbon	72.42	
% Hydrogen	5.13	
% Nitrogen	0.97	
% Chlorine	0.02	
% Sulphur	0.92	
% Ash	9.33	
% Oxygen (difference)	11.21	
	100.00	

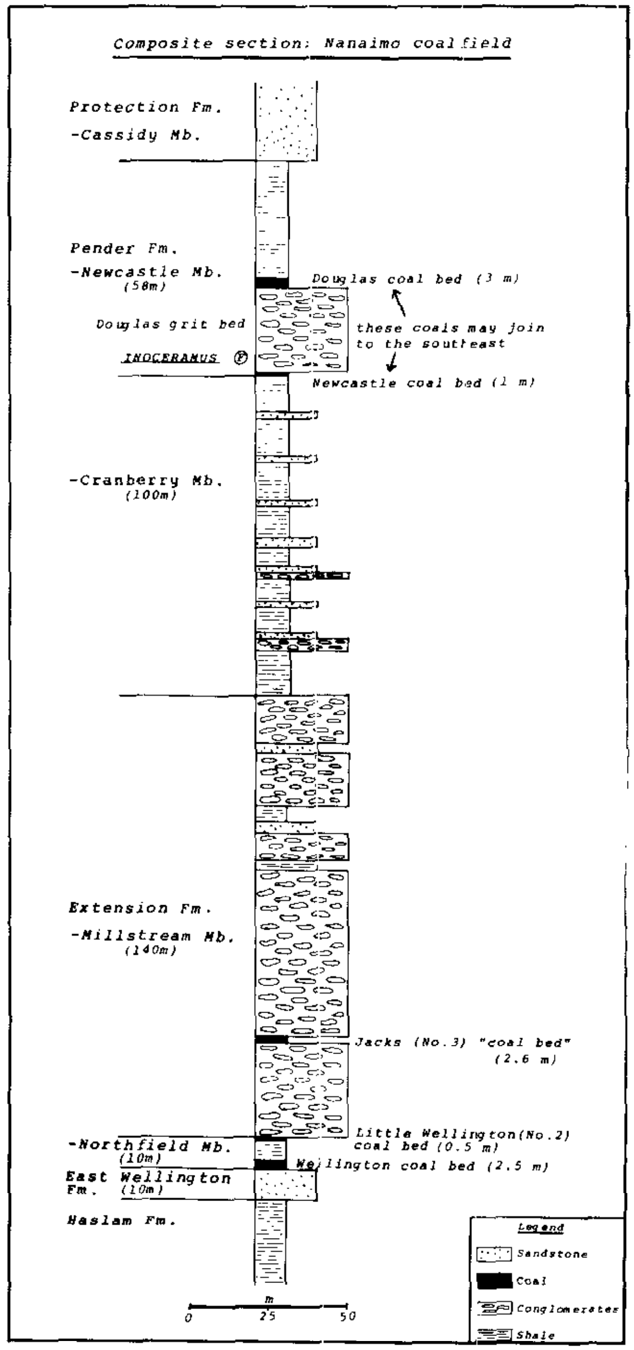

Figure 4-2-4. Composite section of the coal measures in the Nanaimo sub-basin.

DISCUSSION

Preliminary studies indicate that regional coalification patterns differ between the two sub-basins. In the Nanaimo sub-basin, evidence suggests structural changes occurred before final coalification. Data obtained from the Comox sub-basin indicate coalification was pre-deformational with localized post-tectonic thermal overprinting. Evidence supporting these ideas follows in this discussion.

Lateral variation of coal-rank distribution is not apparent in the Nanaimo sub-basin whereas there is a rank gradient increase from north to south in the Comox sub-basin. Reflectance studies indicate the presence of high-volatile bituminous A and B coals in the Nanaimo sub-basin. The same coal ranks exist in the Comox sub-basin, however, anomalous data obtained from samples north of Puntledge River (Figure 4-2-2b) provide rank values ranging from high-volatile bituminous to anthracite (Table 4-2-2).

The absence of lateral rank variation in the Nanaimo sub-basin is evidenced by the R_0 max values from the Newcastle and Wellington seams. Coal rank distribution is essentially uniform at surface. Taking into account that the Wellington seam is more than 225 metres below the Newcastle seam (Figure 4-2-4), it is inferred that an isorank line would be horizontal in cross-section (Bustin *et al.*, 1983). This could indicate a fold-thrust deformation of the coal-measures into the pattern we see today, followed by deep burial by Tertiary sediments which have subsequently been eroded. Further work is expected to indicate an increase in reflectance with depth along the seams. Biaxial negative reflectance-indicating-surface data obtained on samples from the Newcastle seam can be interpreted as a product of random scatter, or evidence of tectonic stress in addition to overburden loading.

Complex coalification patterns are apparent in the Comox sub-basin due to overprinting by thermal events. The re-

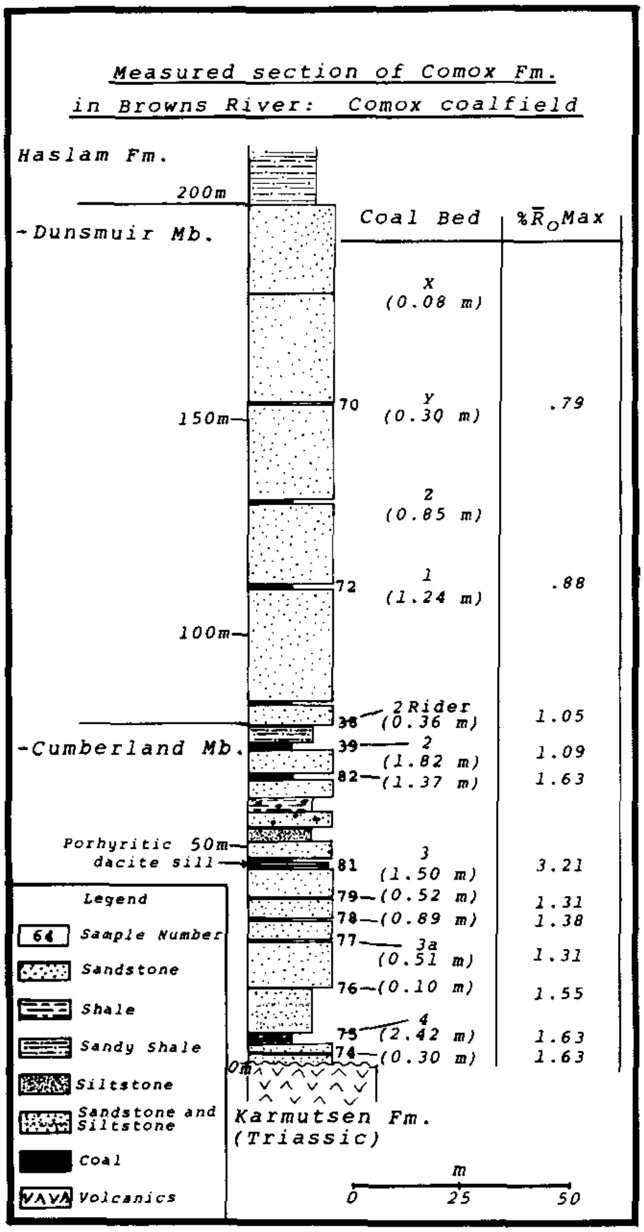

Figure 4-2-5. R_0 max values from coal samples along the Browns River. Refer to Section A-A′ in Figure 4-2-2b.

gional increase in rank from north to south has two possible explanations: progressively deeper burial towards the south of the basin (now eroded) may have caused the rank gradient (Nurkowski, 1984), or a higher geothermal gradient existed in the southern part of the basin.

Seam rank gradient in the Comox sub-basin follows Hilt's Law, in that rank increases regularly with depth. This is evidenced in the Trent River section (Figure 4-2-5). Proximate analysis data from old mines in this area, on file with the Ministry of Energy, Mines and Petroleum Resources in Victoria, indicate constant rank values in the same seam. Pretectonic coalification causes a seam to maintain constant rank, given that other factors have not affected the coal (Bustin *et al.*, 1983). Some scatter is present which could be

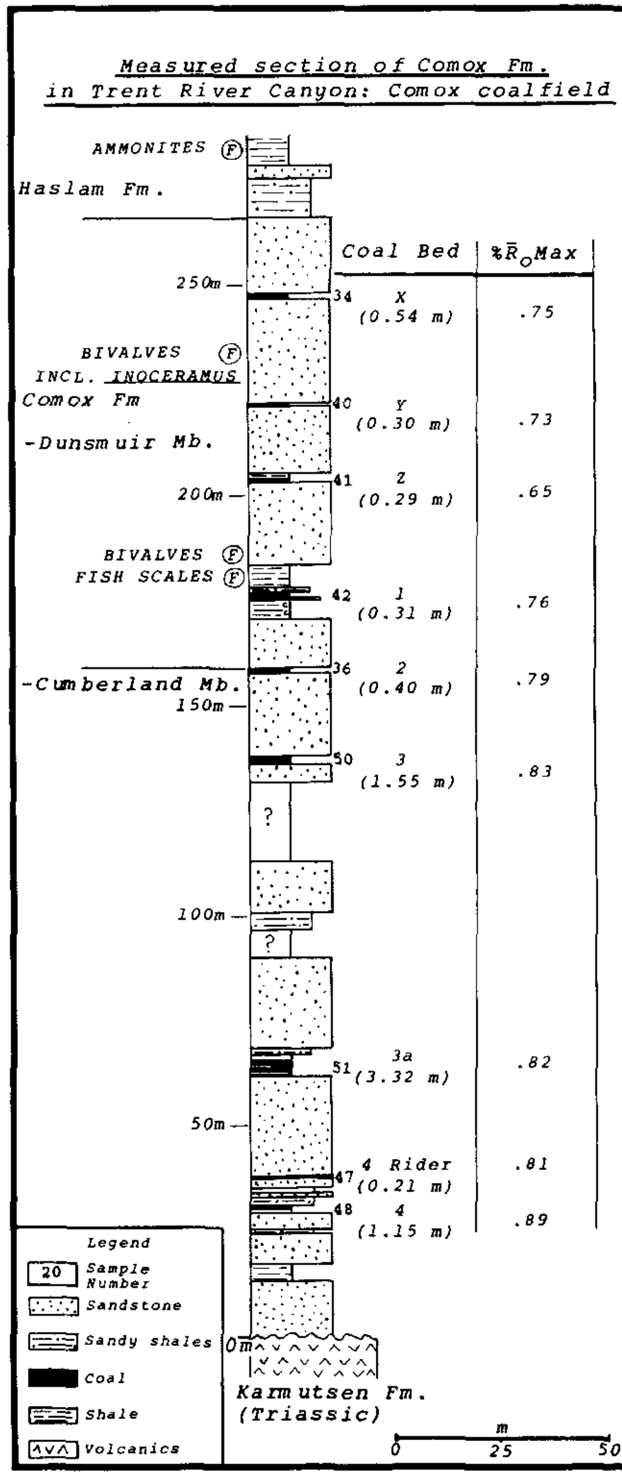

Figure 4-2-6. R_0 max values from coal samples along the Trent River. Refer to Section B-B′ in Figure 4-2-2b.

attributed to analytical or sample variability or to the difference of heat flow characteristics of rock types (Grieve, 1987). The latter may explain the abrupt increase in rank at the base of the section.

The regional pattern of coalification in the Comox sub-basin is overprinted by thermal aureoles associated with regional plutonism. Intrusions may affect coal by hydrothermal activity or contact metamorphism. A good example of the latter is provided by the Browns River section (Figure 4-2-5) where coal rank increases within the thermal aureole surrounding a porphyritic dacite sill.

There is a fairly broad area of hydrothermal activity associated with plutons (Stach and Mackowsky, 1975). Samples taken close to Tertiary intrusions have anomalous reflectance values due to the affects of circulating hot water (Figure 4-2-2b).

The shapes of reflectance-indicating surfaces are influenced by time, temperature and tectonism (Kilby, 1986). If the surface is not uniaxial (–), the assumption can be made that post-tectonic coalification occurred. Data obtained from the Comox sub-basin support this assumption.

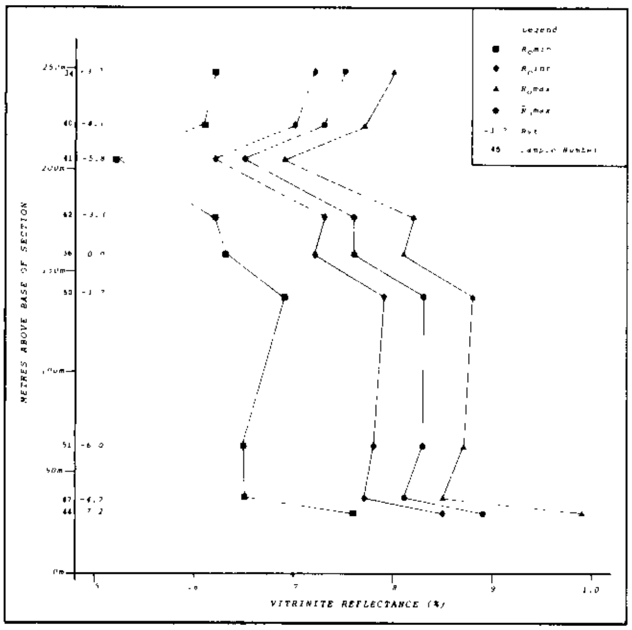

Figure 4-2-7. Reflectance-depth profile of measured section of the Trent River Comox Formation. Refer to Figure 4-2-6.

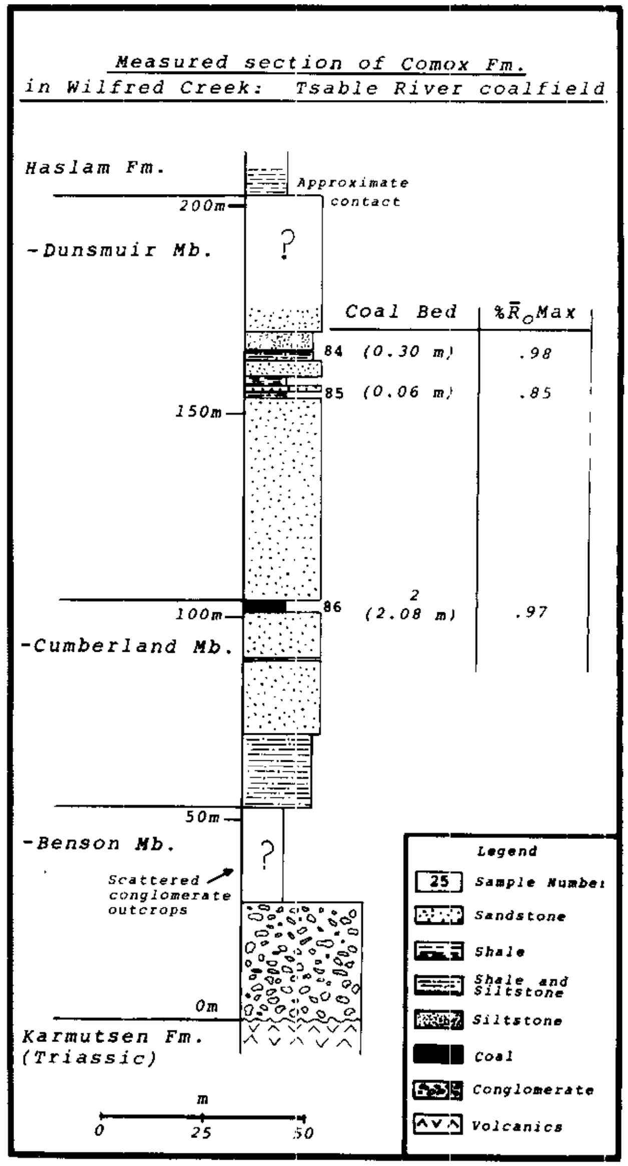

Figure 4-2-8. R_o max values from coal samples along Wilfred Creek. Refer to Section C-C′ in Figure 4-2-2c (modified from Atchinson, 1968).

FURTHER WORK

Investigations of vitrinite reflectance for rank determination are continuing in both sub-basins. Detailed section measurement of the Comox Formation will be completed in the northern part of the Comox sub-basin, for seam correlation purposes. An attempt will be made to sample along major faults in the Nanaimo sub-basin to further demonstrate the relationship between anomalous rank and hydrothermal circulation. Further reflectance-indicating-surface studies will lead to a better understanding of the stresses in effect during coalification. The information determined from the biaxial reflecting coals will help in the interpretation of the structural and thermal history of the coal deposits of Vancouver Island.

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REFERENCES

Atchinson, M. (1968): Stratigraphy and Depositional Environments of the Comox Formation (Upper Cretaceous), Vancouver Island, British Columbia, Unpublished Ph.D. Thesis, *Northwestern University*, Evanston, Illinois, 139 pages.

Bickford C.G.C., Hoffman G. and Kenyon, C. (1989): Coal Measures Geology of the Quinsam Area (92F), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1988, This Volume.

Bickford, C.G.C. and Kenyon, C. (1988): Coalfield Geology of Eastern Vancouver Island (92F), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1987, Paper 1988-1, pages 441-450.

Buckham, A.F. (1947): Preliminary Map, Nanaimo Coal Field, *Geological Survey of Canada*, Paper 47-22.

Bustin, R.M., Cameron, A.R., Grieve, D.A. and Kalkreuth, W.D. (1983): Coal Petrology, its Principles, Methods, and Applications, *Geological Association of Canada*, Short Course Notes, Volume 3, Victoria, 1983.

Grieve, D.A. (1987): Subsurface Coal Rank Profiles, Ewin Pass to Bare Mountain, Elk Valley Coalfield, Southeastern British Columbia (82G/15, 82J/2), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1986, Paper 1987-1, pages 351-360.

Kilby, W.E. (1986): Biaxial Reflecting Coals in the Peace River Coalfield (93O, P, I), *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1985, Paper 1986-1, pages 127-137.

——— (1988): Recognition of Vitrinite with Non-uniaxial Negative Reflectance Characteristics, *International Journal of Coal Geology*, 9, 1988, pages 267-285.

McCartney, J.T. and Teichmuller, M. (1972): Classification of Coals According to Degree of Coalification by Reflectance of the Vitrinite Component, *Fuel*, Volume 51, pages 64-68.

Muller, J.E. and Jeletsky, J.A. (1970): Geology of the Upper Cretaceous Nanaimo Group, Vancouver Island and Gulf Islands, British Columbia, *Geological Survey of Canada*, Paper 69-25.

Nurkowski, J. (1984): Coal Quality, Coal Rank Variation and its Relation to Reconstructed Overburden, Upper Cretaceous and Tertiary Plains Coals, Alberta, Canada, *American Association of Petroleum Geologists*, Volume 68, Number 3, pages 285-295.

Stach, E. and Mackowsky, M. (1975): Stach's Textbook of Coal Petrology, *Gebruder Borntraieger*, Berlin, Stuttgart.

Teichmuller, M. and Teichmuller, R. (1966): Geological Causes of Coalification, *Coal Science*, Advanced Chemistry Series 55, pages 133-155.