Organic Facies Analysis of the Cretaceous Lower and Basal Upper Colorado Group (Cretaceous), Western Canada Sedimentary Basin – A Preliminary Report

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Abstract

The Cretaceous Colorado Group (Albian-Santonian) is a sequence of dominantly homogeneous organic-rich shales derived from sediments deposited within the Western Interior Seaway of North America. Bulk geochemical analysis (Rock-Eval, TOC, Total Carbon, and Total Sulphur), and palynofacies observations have been conducted on 452 core samples in order to reconstruct the organic facies variations through the lower part of the Group and along transects across the Canadian portion of the Western Interior Seaway.

The Viking and Westgate formations are typified by low percentages of poorly preserved (weakly fluorescent) marine amorphous organic matter (AOM) and abundant terrestrial phytoclasts, associated with low TOC and average measured hydrogen indices of only 106 mgHC/gTOC (Type III kerogen). The Fish Scales and Belle Fourche formations have a transitional organic facies reflecting mixing with better preserved marine AOM, and thus exhibit higher mean TOC and measured HI values (158 and 170 respectively). The Second White Specks Formation and the basal Upper Colorado Group are both dominated by moderate to strongly fluorescent AOM, resulting in a mean measured HI of 320 (Type II kerogen). The mean average HI values of the Type III and Type II kerogen components, computed from the slope of S2 versus TOC trends, are approximately 170 and 500 respectively. The transgressive Albian-Turonian interval is associated with a progressive upward decrease in terrestrial phytoclast supply, and progressive improvement in the preservation of the AOM, related to changing basin redox conditions.

Stable carbon isotope analysis has identified a significant (~4 ‰) positive shift in $\delta^{13}C_{org}$ *values in the vicinity of the Belle Fourche–Second White Specks Formation boundary in three Western Canada Sedimentary Basin cores. This is interpreted as the regional expression of the isochronous Cenomanian-Turonian (C-T) global isotopic event. The formation boundary apparently becomes older towards the east, where the lower siliciclastic input allows the development of a calcareous facies to occur earlier than in the west.*

Keywords: *Cretaceous, Colorado Group, Western Canada Sedimentary Basin, palynofacies, organic facies, Rock-Eval, stable carbon isotopes, Cenomanian-Turonian.*

1. Introduction

The Western Canada Sedimentary Basin (WCSB) provides a near-continuous west to east 1000 km long profile of cored sections through the Cretaceous Colorado Group, including fair to good coverage of several of the fine-grained marine units. The basin is well documented, with a well understood tectonic and depositional history (Mossop and Shetson, 1994); the western Cordillera is the major sediment source, resulting in a clear transition from proximal to distal environments with associated changes in thickness and lithofacies. The biostratigraphy of both the western and eastern margins of the basin has been studied in great detail (McNeil and Caldwell, 1981; Bloch *et al.*, 1999; Schröder-Adams *et al.*, 2001), and together with basin-wide wireline log signatures, allows good lateral correlation. The great areal extent of the WCSB, the availability of samples throughout the basin, and the low thermal maturity of the majority of the samples, particularly in the east (Stasiuk *et al.*, 1993), provide an excellent framework for studying proximal-distal variations in palynofacies and organic facies within a large shelf seaway. The Colorado Group is also commercially important; the Second White Specks Formation is a known source rock of light crude oil within Alberta, and forms a reservoir for biogenic methane within southwestern Saskatchewan.

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The Westgate, Fish Scales, and Belle Fourche formations of the WCSB are also potential source rocks of a lesser (more gas-prone) quality (Bloch, 1995).

2. Previous Work

The stratigraphic nomenclature of the Lower Colorado Group was revised by Bloch *et al.* in 1993 who formally subdivided the shales into the Westgate, Fish Scales, Belle Fourche, and Second White Specks formations (Figure 1) based upon wireline log signatures and bulk geochemical analysis. This terminology is followed herein. The interbedded reservoir units, including the Viking and Cardium formations, contain 14% of the total current hydrocarbon reserves in Western Canada (Leckie *et al.,* 1994), but prior to the mid-1990s relatively little work was performed on the shales. Previous studies include aspects of the biostratigraphy, micropaleontology, sedimentology, and organic geochemistry (Norris, 1967; Stasiuk and Goodarzi, 1988; Kyser *et al*., 1993; Stasiuk *et al*., 1993; Mösle, 1995; Gilboy, 1996, 1997; Schröder-Adams *et al*., 1996, 1998; Bloch *et al.,* 1999; White *et al*., 1999).

3. Lithostratigraphic Framework

The uppermost Viking is typically composed of coarse-grained, cross-laminated sandstones; however, some interbedded lenticular shale and siltstone bands were sampled for comparative purposes. A coarse conglomeratic horizon, tens of centimetres in thickness, caps the Viking sandstones in most cores. The overlying Westgate Formation predominantly consists of homogeneous, medium-grey, *Chondrites*-bioturbated mudstones, but some lithological variation was observed between wells, ranging from well laminated mudstones, sometimes with occasional lenticular sandstone units, to well bioturbated siltstones. Sporadic laminated bentonites up to 30 cm in thickness were also recorded. The overlying Fish Scales Formation has an erosive base that is often clearly observed in many cores, represented by a thin bed, several centimetres thick, of disarticulated phosphatic debris. This is overlain by a homogeneous mudstone, exhibiting coarse *Chondrites* bioturbation. Westward, the mudstones are coarser grained, becoming silty mudstones with lenticular siltstone interbeds; bioturbation is common and fish scale debris occurs intermittently. Lithologically, the Belle Fourche Formation is near identical to the Fish Scales Formation, and the boundary between the two was tentatively placed where phosphatic fish scale debris decreases in relative abundance (although in several cores fish scales were found to continue into the basal part of the Upper Colorado Group). Because the occurrence of fish scales is a non-distinctive criterion, the Canadian oil industry has never distinguished between the Fish Scale and Belle Fourche shales (O'Connell, 2002). The Second White Specks Formation is also composed of laminated mudstones and bioturbated siltstones, but is distinctive due to its high $CaCO_3$ content, including abundant coccolithic white specks (<2 mm diameter) and inoceramid bivalves. A gradual boundary is generally observed between the Second White Specks and the underlying Belle Fourche Formation, and so the boundary

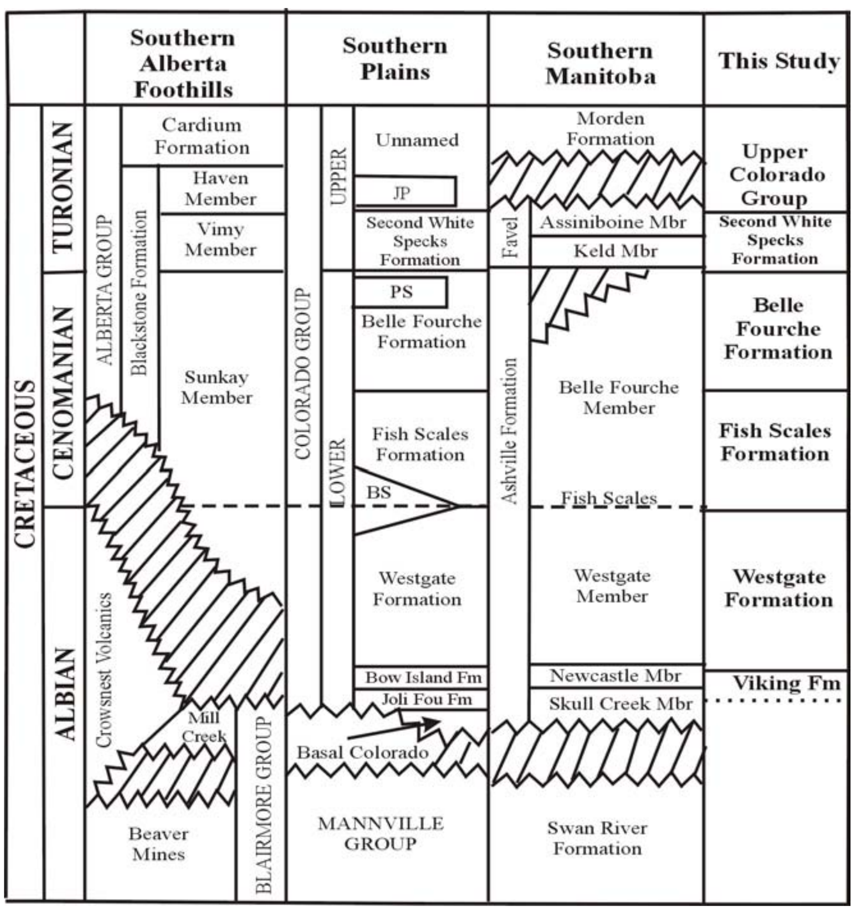

Figure 1 - Stratigraphic nomenclature of the Colorado Group in the study area (after Bloch** et al.**, 1993; Leckie** et al.**, 1994; and Bloch** et al.**, 1999). Abbreviations used: JP = Jumping Pound Sandstone; PS = Phillips Sandstone; and BS = Barons Sandstone.

was operationally defined as the point where the shales reacted vigorously to dilute hydrochloric acid (following Bloch *et al*., 1993). The boundary with the Upper Colorado Group shales is typically gradational, and is expressed by a rapid decrease in grain size and the disappearance of the white calcareous specks. The overlying dark, fine-grained shales exhibit strong lamination, and contain a well preserved ammonite fauna in some cores.

4. Palynofacies Analysis

Palynofacies analysis uses transmitted light to evaluate the total microscopic particulate organic-matter assemblage within a sedimentary rock following the chemical breakdown and removal of any carbonate and siliciclastic mineral constituents. The remaining HF- and HCl-insoluble organic matter provides valuable information on the sedimentary facies, paleoenvironment, and source rock potential, including the relative importance and distance from terrestrial source areas, depositional energy, and basin redox conditions. Previous palynofacies studies have shown that palynofacies variations exhibit a marked correlation with proximal-distal gradients in facies, and thus also with sequence stratigraphy (Frank and Tyson, 1995; Tyson, 1996 and references therein; Tyson and Follows, 2000).

The primary aim of the current research is to calibrate the distribution of palynofacies parameters within the WCSB with the actual distance from the western Cordillera. This will be performed by reconstructing the depositional history of the section based upon variations in amorphous organic matter (AOM), phytoclast (terrestrial higher plant debris) and palynomorph (pollen, spores, dinocysts, prasinophyte) assemblages. Detailed palynofacies analysis, categorizing the phytoclast and palynomorph assemblages, is a particularly useful tool for distinguishing proximal-distal relationships, and can distinguish sequence stratigraphic boundaries even within macroscopically homogeneous shales (Tyson and Follows, 2000).

5. Samples and Methods

This investigation is based upon the analysis of 452 samples from 40 cores in Alberta and Saskatchewan. Table 1 and Figure 2 provide the location of each core examined, and the number of samples taken. Initially, 91 samples were selected from the previous Bloch *et al.* (1993) study. Further sample sets were later collected from the McNeil and Gilboy (1999) sample set, and from the current research of Dale Issler (Geological Survey of Canada, Calgary). A final set of core samples was based on an approximate east-west transect of wells between 51º and 53º North.

Total Organic Carbon, Total Sulphur, and Total Carbon values were determined using a LECO CS-244 Carbon Sulphur Determinator. Rock-Eval-type pyrolysis (S0, S1, S2, and Tmax values) was conducted on a LECO THA-200 apparatus. In addition, $\delta^{13}C_{org}$ isotope analysis has been conducted on 58 decarbonated samples from four cores across the Cenomanian-Turonian (C/T) boundary using ANCA-SL (Automated Nitrogen Carbon Analysis unit for Solids and Liquids) apparatus.

All 452 samples were subjected to non-oxidative palynological processing using hydrofluoric and hydrochloric acids (Barss and Williams, 1973). *Lycopodium* spore tablets were added for determination of particle concentrations, and the isolated kerogen assemblage was sieved using a 10 µm nylon mesh and studied using both transmitted light and blue light fluorescence. Preliminary analysis involved a 300 count, distinguishing between amorphous organic matter (AOM), phytoclasts (higher plant debris) and palynomorphs (organic-walled microfossils); more detailed separate counts of the palynomorph and phytoclast fractions are in progress. Based on past experience, particles classified as AOM represent variably preserved marine organic matter rather than highly degraded terrestrial material.

6. Preliminary Results

The mean and range of the organic facies characteristics of the sample set are summarised in Table 2. Note that from a bulk perspective, the Viking and Westgate samples are geochemically similar. The Fish Scales and Belle Fourche are distinctly richer in total organic carbon. Although the lithological formation boundary between these two units was somewhat tentative, a significant shift in the organic facies is apparent between the Belle Fourche and the Second White Specks samples, including more than a doubling in the carbonate-free TOC and the Hydrogen Index (but no major change in the optical character, as AOM is already very dominant). The Upper Colorado Group samples reveal a slight decline in the quality of the organic facies.

Table 1 - List of cores sampled, refer to Figure 2 for location.

Well Name	Well Location	No. of Samples	Well Location
International Yarbo*	01-24-20-33W1	19	38
SWP Bredenbury*†	11-36-22-01W2	29	39
Margo 8 11*	08-11-33-09W2	5	37
Kennecott Crooked River‡	01-04-45-10W2	48	40
Dome Talmage*	11-36-10-13W2	7	35
Kennecott Leather River‡	04-23-46-16W2	27	36
Imperial Findlater*	16-04-21-25W2	9	33
Grey Owl Syndicate*	16-10-44-27W2	6	34
CMS Vanscoy†	11-16-35-08W3	17	32
Netherhill No 1 Strat Test*	07-28-29-20W3	7	31
Hardy Prairiedale*	15-07-32-25W3	5	28
Anderson et al Ribstone*	06-18-45-01W4	25	29
Anderson Husky Roros*§	10-35-45-02W4	68	30
Pacific Amoco Sapphire†	07-14-01-05W4	6	18
Amoco B1 Youngstown†	06-34-30-08W4	11	27
CPOG Rainbow§	06-23-14-10W4	3	20
Dome Richdale*	08-33-30-12W4	7	24
Amoco A1 Conrad†	11-12-06-16W4	17	15
Mobil Penzl 1B Donalda§	11-15-41-18W4	4	26
Merland Donalda§	11-30-41-18W4	2	25
Paz Fennbv§	09-03-36-19W4	1	23
Banner et al Ironsup§	07-09-12-21W4	2	8
PCP et al Hussar*	10-09-28-21W4	7	16
CNRL et al Bashaw*	10-34-42-22W4	8	22
Barons Superior No 1§	16-10-12-23W4	3	6
Melaar Barons†	11-21-12-23W4	14	4
Marathon Threehck*	14-18-36-24W4	8	17
Husky et al Lancombe§	08-06-40-25W4	1	19
Sinclair C & E Dahl 2A§	03-07-13-27W4	3	2
Canadian Superior Oxley§	06-07-12-28W4	6	1
Murphy et al Sylvan Lake*	16-28-37-05W5	16	12
CPOG Leaf§	16-15-39-05W5	1	14
Resman et al Willgr§	16-18-39-05W5	2	11
BVI Willgr*	04-27-39-06W5	8	13
Pembina Unit 1 Ferrier§	14-22-39-08W5	2	7
Esso Ferrier§	06-10-39-09W5	1	5
Gulf et al Brazr§	16-30-45-12W5	2	10
Trilogy et al Brazr§	12-35-45-13W5	1	9
Imperial Kathleen†	05-01-77-20W5	21	21
Imperial Wembley†	05-09-72-08W6	23	3

Notes:

* sampled from AEUB and Saskatchewan Energy and Mines Subsurface Geological Laboratory

† sampled from Bloch *et al.* (1993)

‡ sampled from McNeil and Gilboy (1999)

§ sampled from Dale Issler study (ongoing)

The nature of the kerogen assemblages is summarized in Figure 3 as ternary Amorphous Organic Matter-Phytoclast-Palynomorph (APP) diagrams (Tyson, 1995). The Viking Formation samples are the most enriched in phytoclasts, but depleted in palynomorphs. This is generally typical of sandstones and sand-rich facies, and reflects a combination of poor preservation (AOM weakly fluorescent) and the hydrodynamic equivalence of phytoclasts and sand- and silt-sized siliciclastic particles. The Westgate Formation shows a relative decline in phytoclasts, with more AOM now being deposited and preserved, and an increase in the abundance of palynomorphs as the clay size fraction increases. The palynomorphs are also notably more varied, and include trilete spores, bisaccate pollen, and a diverse array of dinocysts. Preliminary results from the Westgate Formation also indicate a significant lateral change within the phytoclast component, with the brown (more vitrinitic) component decreasing eastwards from around 80% to 55 %; this is a common proximal-distal trend and can reflect selective degradation of the brown, vitrinitic component, and the selective transportation of smaller and more porous, inertinitic, black particles (Tyson, 1995). The contrast between the Viking and Westgate samples is much clearer from the optical data than it is from the bulk geochemistry. All of the subsequent formations are rich in AOM, apart from some samples of the Belle Fourche from the western part of the basin. This probably reflects declining oxygenation in the basin and increasing preservation potential for organic matter, and the overall transgressive nature of the succession.

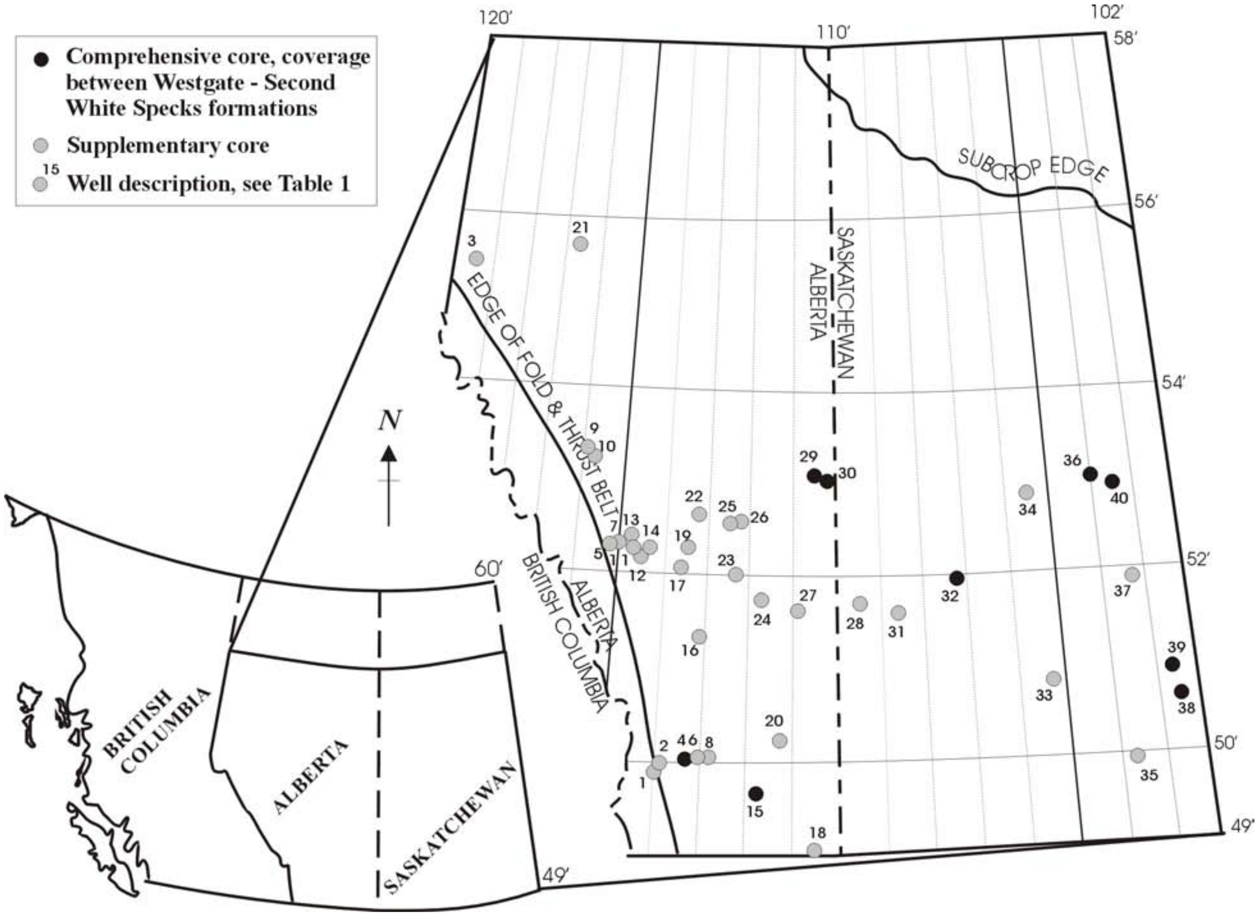

Figure 2 - Location of cores analysed during the course of this study.

Table 2 - Mean and range of bulk geochemical parameters through the Lower and basal Upper Colorado Group. Bold denotes average values. TOC = Total Organic Carbon (wt %); cf-TOC = carbonate-free Total Organic Carbon (wt %); HI = Hydrogen Index (mg HC/g TOC); % AOM = amorphous organic matter (% relative numeric frequency); and FS = fluorescence scale (a six-point ordinal scale reflecting increasing organic matter preservation based on autofluorescent intensity upon short-term exposure to incident blue light, Tyson, 1995).

Formation	TOC	cf-TOC	Total Sulphur	S2	HI	% AOM	FS
Upper Colorado Group	**5.56** 0.2-11.8	**6.78** 0.8-17.5	**3.69** 0.2-5.7	**17.4** 0.6-47.0	**286** 142-430	**88** 55-99	**4**
Second White Specks	**4.80** 0.1-11.7	**9.89** 0.1-31.8	**2.82** 0.1-10.4	**18.2** 0.2-53.4	**353** 100-620	**92.5** 55-100	**4**
Belle Fourche	**2.97** 0.4-11.4	**4.33** 0.8-18.4	**2.11** 0.1-6.0	**7.7** 0.1-51.7	**170** 5-489	**77.5** 21-99	**4**
Fish Scales	**3.08** 1.2-8.0	**3.08** 1.7-6.7	**2.41** 0.2-5.9	**5.8** 0.4-33.0	**158** 28-438	**82.3** 51-96	**4**
Westgate	**1.63** 0.4-4.6	**1.59** 0.4-4-6	**1.58** 0.0-5.0	**1.5** 0.2-8.7	**85** 19-256	**74.0** 23-96	**3**
Viking	**1.60** 0.1-10.2	**1.73** 0.1-12.1	**1.21** 0.1-8.7	**2.1** 01-20.5	**127** 30-770	**53.5** 22-90	**3**

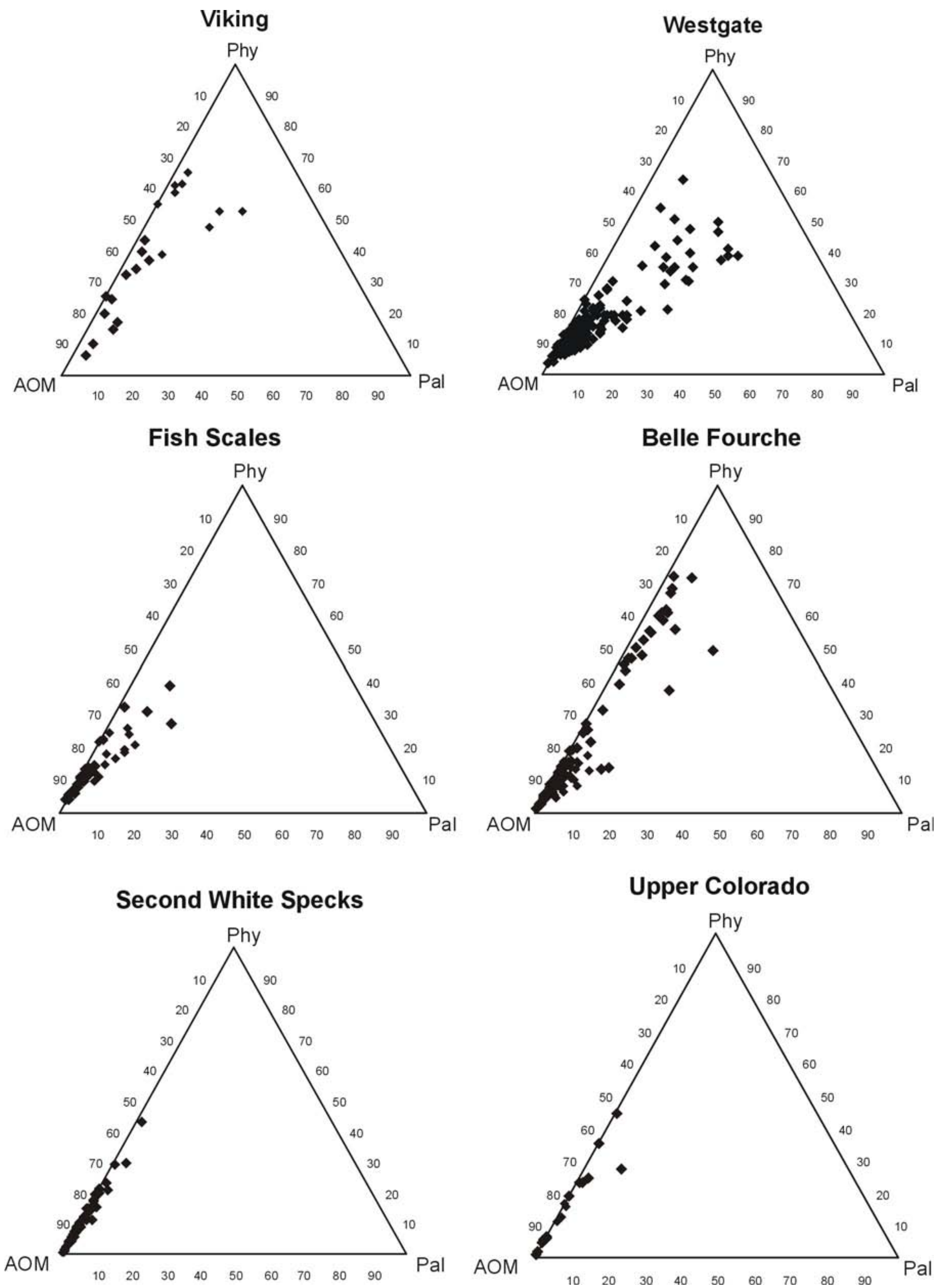

Figure 3 - Ternary APP plots illustrating the varied palynofacies composition through the Lower and basal Upper Colorado Group. AOM = amorphous organic matter; Phy = phytoclasts; and Pal = palynomorphs.

The S2 versus TOC diagrams (Figure 4) reveal a clear mixing between gas-prone and oil-prone samples. The gas-prone component is defined by a S2 versus TOC trend with a mean hydrogen index of around 170 (fairly typical for Type III kerogens in marine mudstone sequences); this component dominates in the lower Viking and Westgate formations. Note that these units, although enriched in phytoclasts, still have a significant AOM content; the Type III composition is thus associated with both the phytoclasts and the partly degraded AOM (even when the latter is >70%). The Fish Scales Formation records the first appearance of a well preserved Type II kerogen with a mean HI of around 500, which then dominates in the younger AOM-rich Second White Specks Formation and basal Upper Colorado Group. The S2 versus TOC diagrams show that the Type II trend has an apparent positive TOC intercept of around 2.0 in the Bell Fourche and around 1.0 in the Second White Specks samples; the intercept values indicate the approximate TOC at which the kerogen assemblages change in composition from Type III to Type II.

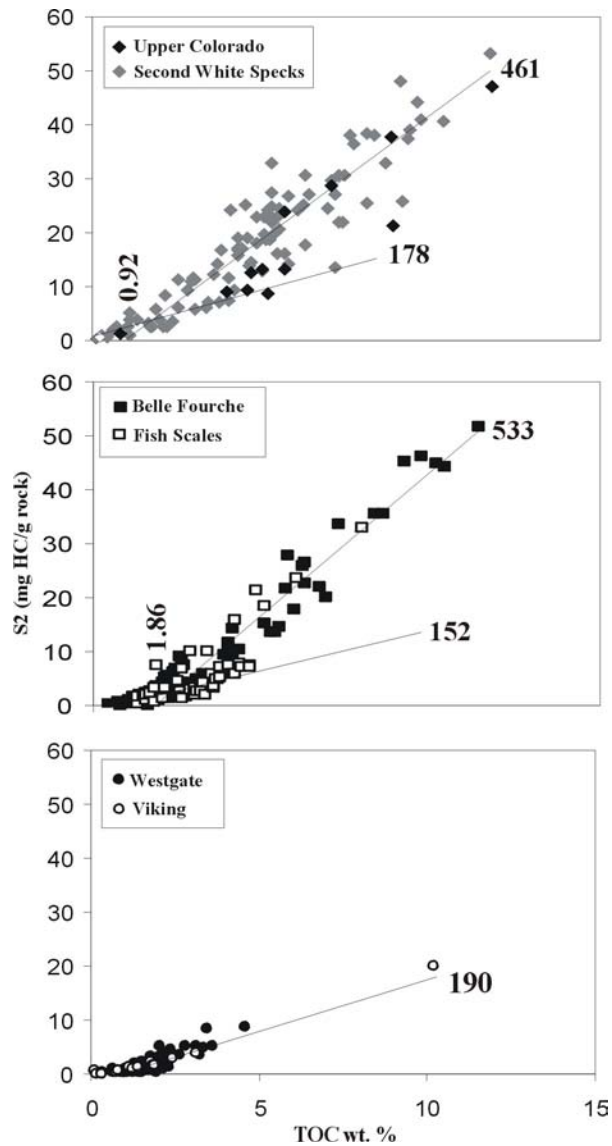

Figure 4 - Cross plot of S2 versus Total Organic Carbon (wt %) for formations within the Lower and basal Upper Colorado Group. Note mixing of Type II and Type III kerogen. Vertical figures on the plots are the TOC intercept values for the Type II trends; horizontal figures are the HI values of the reactive component calculated from the slope of the regression line (following Langford and Blanc-Valleron, 1990).

7. Relationships Between Palynofacies and Bulk Organic Geochemistry

The two hydrogen index trends evident in Figure 4 can also be distinguished when cross plotted against AOM percentage (Figure 5). The relative content of AOM

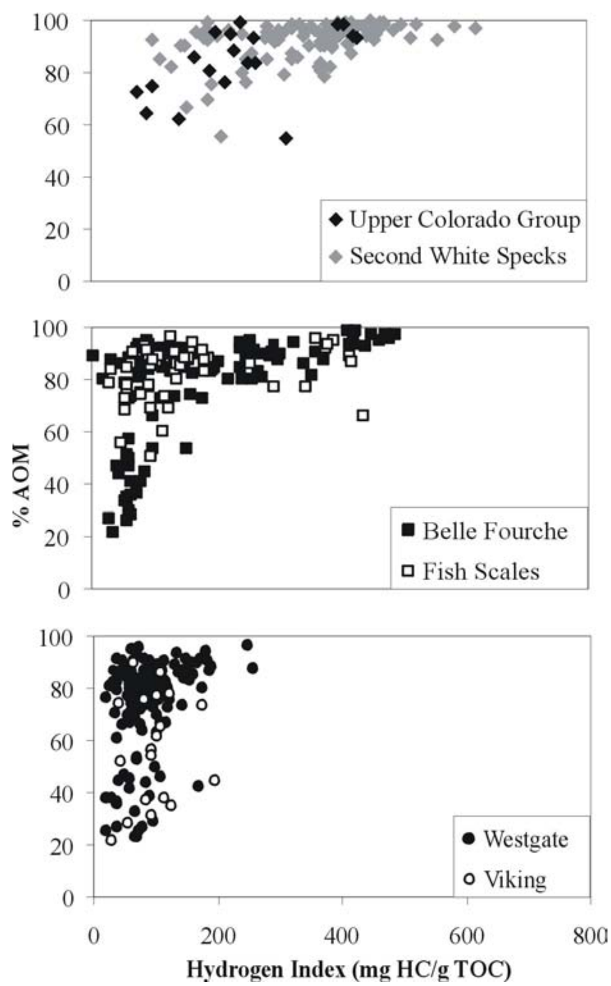

Figure 5 - Cross plot of Hydrogen Index values versus % Amorphous Organic Matter (AOM), and its variation throughout the Lower and basal Upper Colorado Group. Hydrogen Indices do not increase significantly until AOM content exceeds 80%, partly due to kerogen mixing and partly due to AOM preservation. The level of preservation increases as the supply of terrestrial organic matter decreases.

appears to have little influence on the hydrogen index until it comprises greater than 80% of the palynofacies assemblage, when HI values increase to up to 600. This suggests AOM preservation is more critical than AOM abundance. Wells in the western WCSB exhibit low hydrogen index values which is partly due to their higher maturity and partly to the higher phytoclast content (at least in some formations). The log of the AOM:Phytoclast ratio versus distance from basin margin (not shown) indicates significant lateral changes in the Westgate and Fish Scales formations. Higher phytoclast percentages in the west almost certainly reflect a greater terrestrial input; also, preservation of AOM was possibly somewhat poorer there (but the higher maturity may be influencing assessments of fluorescence). The AOM:Phytoclast ratio may potentially be influenced by the maturity, due to preferential thermal conversion and volume loss of the AOM during maturation (Stasiuk, pers. comm., 2003), however, the palynofacies data are based on relative numeric frequencies rather than relative volumes, and the thermal reactivity of the AOM may partly be a function of its original preservation state. The Belle Fourche Formation shows a marked lateral variation; the mean AOM: Phytoclast ratio increases from around 1:1 in the Alberta Foothills in the west, to around 100:1 in the east.

The maximum carbonate-free total organic carbon is also observed to vary across the WCSB, the latter from <2% in the west to >5% in the east. This can be explained by several mechanisms, including increased preservation, greater productivity, or lower dilution. We consider the last explanation as probably the most applicable as it is agrees with the eastward-thinning isopachs shown by Colorado Group strata in the basin. The Belle Fourche Formation alone thins from 150 m in the Alberta Foothills to just 20 m in the east near the Saskatchewan-Manitoba border (Bloch *et al.,* 1993), which must imply greatly decreased siliciclastic dilution.

The fluorescence of the kerogen assemblage, in particular that of the AOM, reflects the redox status of the depositional environment, and indicates whether an AOM-dominated assemblage is actually oil or gas prone. The relationship between fluorescence scale (Tyson, 1995), kerogen assemblage, and bulk geochemistry can be observed in Figure 6. Fluorescence intensity increases with AOM content, suggesting AOM abundance is generally

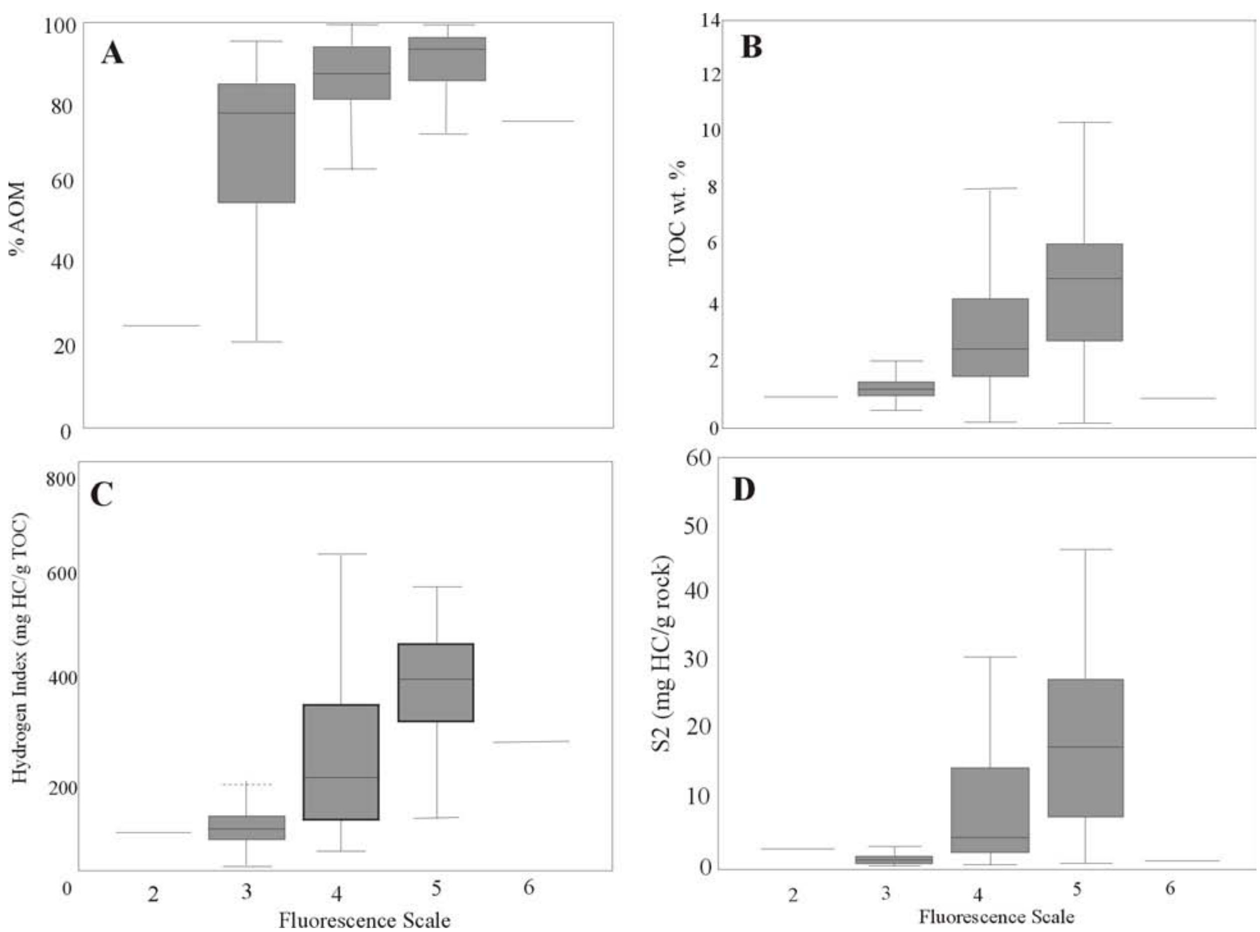

***Figure 6** - Box plots (quartile distributions) demonstrating the relationship between Fluorescence Scale (Tyson, 1995) and A) % amorphous organic matter, B) Total Organic Carbon, C) Hydrogen Index, and D) the Rock-Eval S2 parameter. Note that only one sample each had a fluorescence-scale value of 2 (only palynomorphs fluorescent) and 6 (uniform bright fluorescence of AOM).*

influenced by AOM preservation. This trend is also associated with higher total organic carbon, increased S2 values, and hydrogen indices. Low fluorescence-scale values correspond with the low TOC content and low HI values which typify the Viking and Westgate formations. These are characteristic of relatively proximal depositional environments, where not only is the supply of phytoclasts greater, but the more oxygenated conditions permit greater bioturbation and partial degradation (chemical but not necessarily physical) of the AOM.

Maturity may influence the fluorescence-scale estimates in the western wells. The Tmax values gradually decrease by ~20°C for each increase in fluorescence-scale value up to 5, where the samples fall below the oil window at 435°C. The lower Tmax of the best preserved assemblages may partly reflect the influence of greater organic sulphur contents, associated with lower siliciclastic and Fe supply (e.g. Vetö *et al.,* 2000).

An east to west maturity gradient is evident in the Tmax values of samples from the Westgate and Second White Specks formations (Figure 7). In the western portion of the WCSB, Second White Specks Tmax values are consistently lower than those from the Westgate, and no overlap of values has been observed. In general, Tmax values begin to gradually decrease with increasing distance from the western Cordillera, and the division between the Westgate Formation and the lower Second White Specks Formation persists. In the eastern portion of the basin, towards the Manitoba Escarpment, Tmax values lie between 395º to 435°C, and the division between the two formations is no longer distinct as Tmax values for the Westgate and Second White Specks formations overlap throughout and are consistently ~20°C lower than in the western part of the basin. The wedge-shaped geometry of WCSB deposits, with strata thinning toward the east, means significantly shallower burial along the Manitoba Escarpment.

8. $\delta^{13}C_{org}$ Analysis

Samples from four cores have been analyzed across the Belle Fourche–Second White Specks boundary (Figure 8) to establish if the well known positive excursion of $\delta^{13}C_{org}$ values characteristic of the Cenomanian-Turonian (C-T) boundary is present. Previous studies have reported this isotopic expression of a global atmospheric/ paleoceanographic event from a variety of marine lithologies in the U.S. Western Interior, Italy, Germany, United Kingdom, Alaska, Venezuela, and Libya, synchronous with a global positive $\delta^{13}C_{carb}$ excursion (Schlanger *et al.,* 1987). The amplitude of the $\delta^{13}C_{carb}$ excursion is ~2 ‰, compared with the $\delta^{13}C_{org}$ excursion of 3 to 6 ‰ described by Arthur *et al*. (1988), and a 2 to 4 ‰ positive shift in $\delta^{13}C_{org}$ described by Pratt and Threlkeld (1984) from the Western Interior Basin to the south. A positive excursion of $\delta^{13}C_{org}$ values also was identified in eastern Saskatchewan and western Manitoba by Kyser *et al*. (1993).

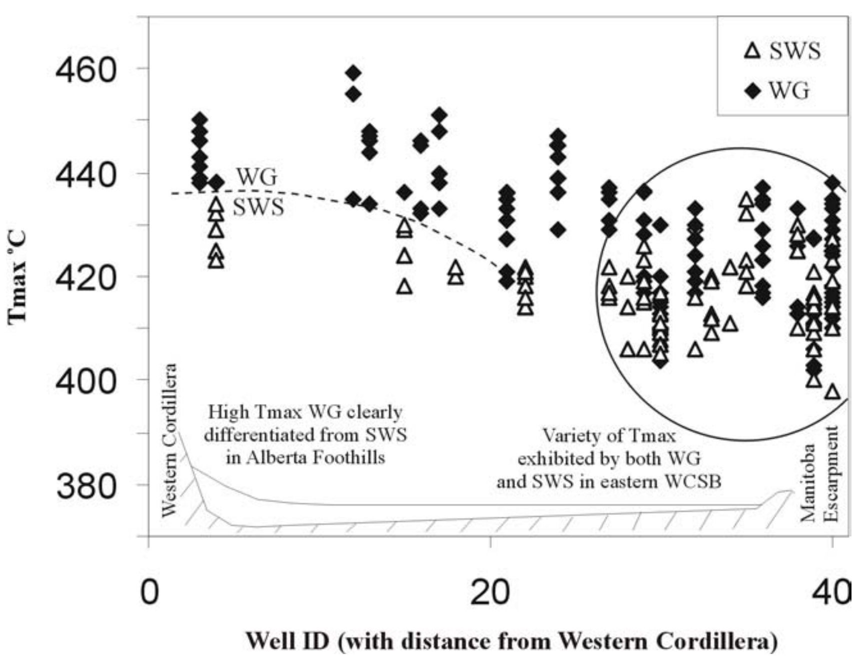

Figure 7 - Tmax values for Westgate (WG) and Second White Specks (SWS) formations across the WCSB, with increasing distance from the western basin margin (for well IDs refer to Figure 2). Note progressive increase in Westgate maturity toward the west. The pattern is less clear in the SWS, suggesting other (organic facies) factors are also influence the Tmax variation.

In lithologically homogeneous sections typified by the Cretaceous Colorado Group shales of the WCSB, the positive $\delta^{13}C_{org}$ excursion provides a potentially useful isochronous chemostratigraphic marker. All the samples from within the location most proximal to the Cordillera (Amoco A1 Conrad 11-12-06-16W4; a >30 m thick interval) appear to be from within the excursion as nearly all the values are heavier than -24 ‰. In the Western Interior, the interval over which the excursion occurs is only 5 to 10 m thick (Pratt and Threlkeld, 1984) which may imply a significantly higher sedimentation rate in the Amoco A1 Conrad well. Samples heavier than -25 ‰ appear to bracket the excursion within Anderson Husky Roros 10-35-45-02W4, indicating the excursion here occurs within a 10 m interval, compatible with the overall eastward decline in sedimentation

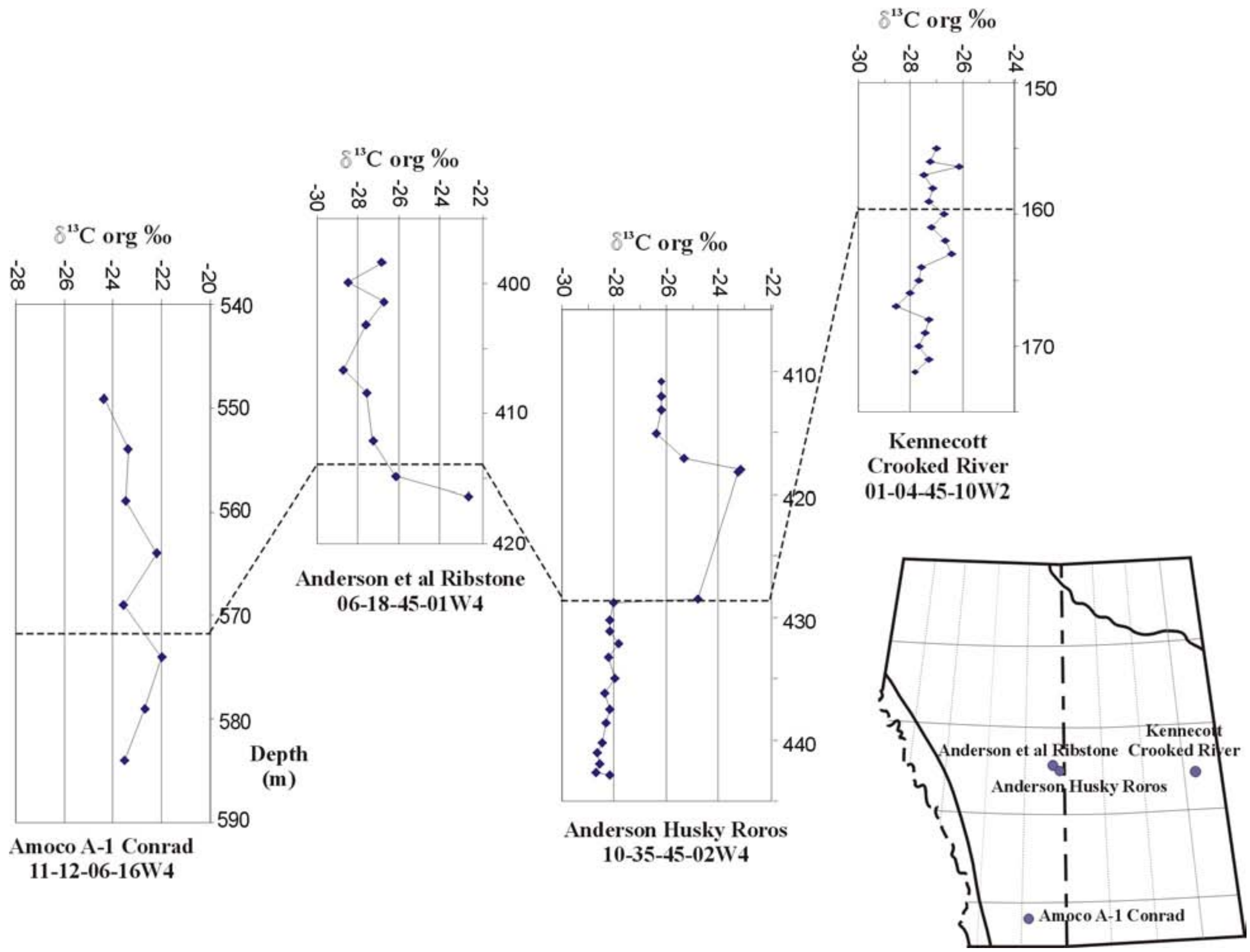

***Figure 8** - $\delta^{13}C_{org}$ profiles for four cores in the Western Canada Sedimentary Basin across the Belle Fourche–Second White Specks formation boundary (dashed line), proposed to be simultaneous with the Cenomanian-Turonian boundary. The lithological boundary may be diachronous, becoming older to the west, where lower siliciclastic dilution allows a more calcareous facies to develop earlier.*

rates in the WCSB. Only the top of the excursion was observed in Anderson et al Ribstone 06-18-45-01W4. Samples from Kennecott Crooked River 01-04-45-10W2 appear to be all from below the excursion (assuming no missing section), and show a similar progressive upward gentle positive shift in ‰ values similar to that observed in the lower Anderson Husky Roros section, but about 1 ‰ lighter. As the Belle Fourche to Second White Specks boundary is defined lithologically by relative carbonate content, it would not be surprising if this facies boundary were somewhat diachronous. It appears that the formation boundary may become older to the east (relative to the Cenomanian-Turonian isotopic excursion), reflecting the generally lower siliciclastic dilution in this direction, and thus an earlier development of the calcareous White Specks facies.

9. Summary

The Lower Colorado Group shales analyzed in this study exhibit a mixture of Type II and Type III kerogen. The Albian Viking and Westgate formations are dominated by Type III kerogen, enriched in phytoclasts but often dominated by partially degraded marine AOM. The assemblages became enriched with Type II kerogen throughout the deposition of the Fish Scales and Belle Fourche formations, as the Cretaceous Western Interior Seaway transgressed. The Second White Specks Formation marks the maximum transgression, characterised by Type II kerogen assemblages which continue into the Upper Colorado Group.

Higher proportions of phytoclasts and palynomorphs in Fish Scales, Belle Fourche, and Second White Specks formations are restricted to western proximal locations, in particular from Imperial Wembley 05-09-72-08W6, Imperial Kathleen 05-01-77-20W5, Murphy et al Sylvan Lake 16-28-37-05W5, Melaar Barons 11-21-12-23W4, and Amoco A1 Conrad 11-12-06-16W4 cores. These proximal types of palynofacies assemblages are not observed within the Lower Colorado Group shales along the eastern margin of the basin. This confirms that the Manitoba Escarpment margin provided an insignificant amount of terrigenous matter, and kerogen assemblages here were controlled by the deposition and preservation of marine organic matter. Carbonate-free TOC, Total Organic Carbon, and Hydrogen Index analyses are consistent with this view, indicating significantly lower dilution of sedimentary organic matter along the eastern margin of the basin.

Isotopic analysis has shown that the positive $\delta^{13}C_{org}$ excursion observed at the C-T boundary is present in three of the four cores studied, and has a profile consistent with that described by Pratt and Threlkeld (1984). Where the excursion is evident, it is not consistently above or below the Belle Fourche–Second White Specks formation boundary, which is therefore probably diachronous.

10. Current and Ongoing Work

Continued research is focused on completing the detailed palynofacies analysis of the phytoclast and palynomorph components. The phytoclast analyses will provide information on distance from source area, variations in the depositional energy, and relative sediment accumulation rates. It is hoped that these changes can be correlated to isopach trends.

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