Using Paralic Coal as an Indicator of Accommodation Space and Correlation Tool in Terrestrial Sediments: Examples from the Mannville Group and Falher Member

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Summary

Terrestrial sediments are difficult to correlate because they have high laterally variability and lack easily identifiable chronostratigraphic surfaces. However, systematic variations in the petrographic properties of paralic coal can be used as a proxy to recognize changes in accommodation. Paralic peat cycles characterized by wetting-upward and drying-upward behaviour, linked to variations in the groundwater table, are interpreted as transgressive and regressive coals, respectively. They are associated with a range of terrestrial stratigraphic surfaces that record responses to changing accommodation. A combination of these coal parameters, together with the facies characteristics of the surrounding terrestrial and marginal marine sediments, enables recognition of distinctive high-resolution sequence stratigraphic signatures. This in turn provides a previously unavailable ability to correlate stratigraphic units from their down-slope marine position, through the shoreline zone, and into the terrestrial realm.

Coal-bearing rocks from the Lower Cretaceous upper Mannville Group and Falher Member of the Western Canadian Sedimentary Basin provide an opportunity to investigate high resolution stratigraphic correlation in terrestrial to marginal marine rocks. Maceral properties of these coals reveal that they are more complex than simple ‘transgressive’ or ‘regressive’ style coals. They comprise a number of wetting- and drying-upwards cycles representing repeated episodes of peat deposition under rising or falling accommodation conditions, with or without internal hiatuses between the cycles. These accommodation cycles are driven by changes in groundwater levels that are in turn hydraulically linked to relative sea level, and thus form the basis for identifying a characteristic terrestrial sequence stratigraphic style, which has potential as a correlation tool.

Introduction

Coals formed in coastal and delta plain environments have three unique properties that make them suitable as a tool for identifying and characterizing changes in accommodation that are driven by base level change.

1. Coals often accumulated over a long duration, and offer a continuous record of sedimentation. At the time of deposition, the peat mires may have been volumetrically more important than the surrounding clastic sediments, but the significance of this relationship is obscured due to different compaction ratios. Unless there is evidence of hiatal surfaces, a metre of bituminous coal is likely to represent a reasonably continuous interval of 5 to 10 ka, whereas many fluvial and floodplain deposits are geologically instantaneous, with time gaps between individual beds. Therefore even thin coals may actually preserve a much more continuous record of terrestrial deposition than the underlying and overlying clastic sediments.

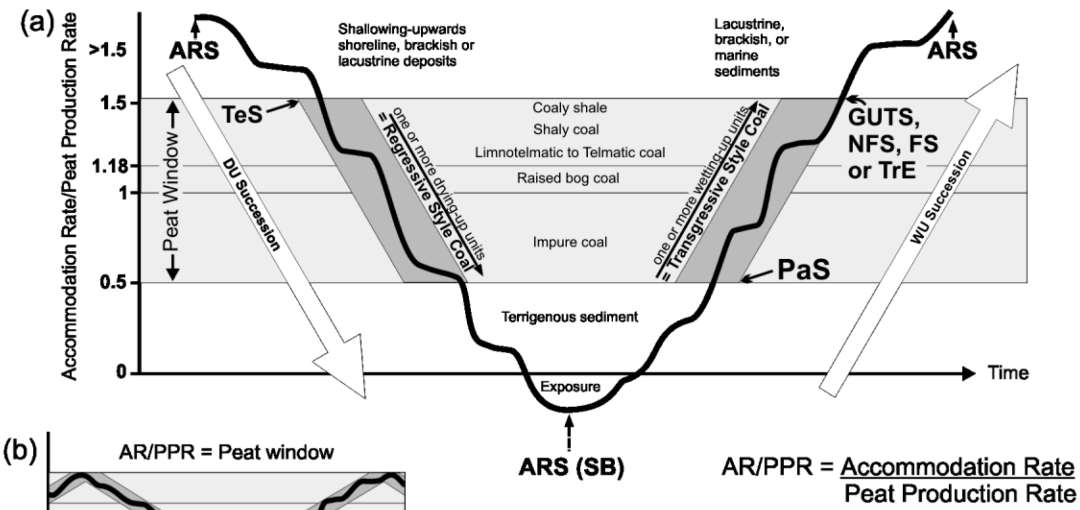
2. The organic matter in a peat-forming environment is highly sensitive to groundwater oscillations, so that even minor changes in the hydrologic regime of the mires can result in compositional differences in the maceral components of the subsequent coal seams (Frenzel, 1983, Snedden and Kersey, 1981; Diessel, 1992). The base level in paralic peat mires is defined by the position of the groundwater table, which in turn is controlled by sea level and the precipitation/evaporation ratio. As relative sea level rises, so does the connected groundwater base level and this effect can extend at least 150 km inland.

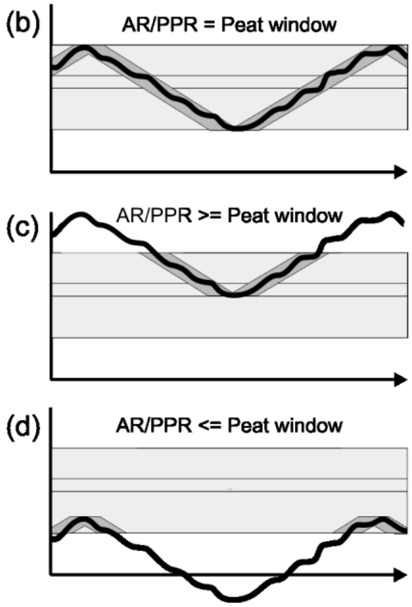
3. Vertical changes in the composition of a coal seam are the result of variations in the balance between the rates of accommodation and rates of peat production, and can be used as a proxy for base level changes (Fig. 1). Peat can only accumulate if the ratio between accommodation rate and peat production rate remains within a certain "peat-forming window" (Bohacs and Suter, 1997; Diessel et al., 2000). Although peat production may differ greatly between various climatic zones, variations within a climate zone are relatively small. This implies that any imbalances in the ratio of accommodation rate to peat production rate are due to changes in accommodation (Shanley and McCabe, 1994; Boyd and Diessel, 1995). Therefore, petrographic indicators can be used to distinguish between paralic coals formed in a transgressive setting and coals formed in a regressive setting.

Coal as a Correlation Tool in the Upper Mannville Group

The Upper Mannville was interpreted as a highstand systems tract by Cant and Stockmal (1993) and consists of a regressive clastic wedge that prograded northwards into the Boreal Sea. In south-central Alberta(Fig. 2), this wedge consists mainly of undifferentiated coal- bearing fluvial and estuarine deposits, representing an extensive coastal plain. Correlations to the northwest and east link Upper Mannville Group strata to the Falher, Waseca and Lloydminster (Fig. 3), and suggest that a higher order of stratigraphic subdivision, controlled by transgressive-regressive cycles, must also be present in the Upper Mannville.

Stratigraphic analysis in the study area, based on over 1200 km of cross-sections and 50 cores, show that the Upper Mannville Group in this region overlies shoreface parasequences of the Ostracod Member. The bituminous Glauconite Coal marks the transition from marine sediments below to dominantly terrestrial sediments above (Fig. 4). It overlies a lagoonal shale (Rosenthal, 1988) and shows a remarkably uniform and widespread geometry of 1-2 m thickness over at least 250 km, based on wireline logs (Wadsworth et al., 2002). The seam wedges out towards the southeast, and no seam splits are evident except for a minor cleaving and thinning-out above the Hoadley shoreface complex, which suggests that it formed during a period of uniform basement subsidence, except in this localized region (Wadsworth et al., 2002).





(e)

	Surface	Description	Hiatal/ Non-Hiatal
TeS	Terrestrialization Surface	Initiation of peat formation due to upward-shallowing	Non-Hiatal
PaS	Paludication Surface	Initiation of peat formation due to upward-deepening	Hiatal or Non-Hiatal
GUTS	Give-up Transgressive Surface	Gradual termination of peat due to upward-deepening	Non-Hiatal
ARS	Accommodation Reversal Surface	Transition between shallowing and deepening-upward cycles, or vice-versa	Hiatal or Non-Hiatal
NFS	Non-marine Flooding Surface	Abrupt deepening of non-marine facies	Hiatal
FS	Marine Flooding Surface	Abrupt deepening of marine facies	Hiatal
TrE	Transgressive Surface of Erosion	Abrupt deepening of facies associated with sediment reworking	Hiatal

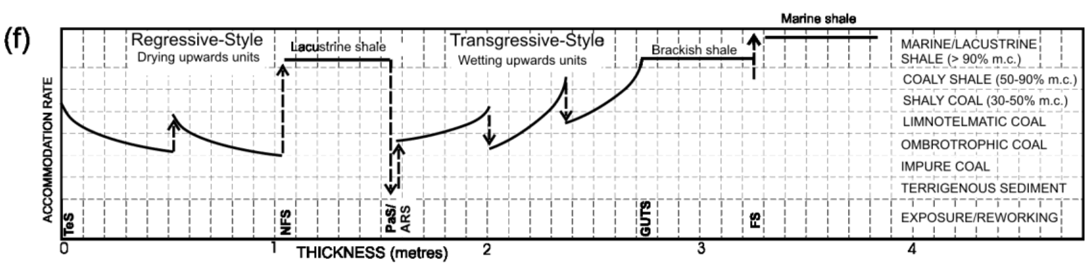


Figure 1. Idealized curves showing relationship between peat accommodation rate (AR) and peat production rate (PPR), modified from Wadsworth et al. (2002). The latter is assumed to remain relatively constant for an individual coal seam, and therefore accommodation is the key variable. The “peat window” occurs where the ratio of accommodation rate to peat production (AR/PPR) falls between 0.5 and 1.5 (Bohacs and Suter, 1997. **A)** If the amplitude of the AR/PPR curve is greater than the amplitude of the peat window, then both regressive and transgressive coals separated by hiatal surfaces may form. **B)** If the AR/PPR curve lies entirely within the peat window, then a compound coal seam, with no internal hiatal surfaces, may develop. **C)** If the AR/PPR curve lies mainly above the peat window, then the coals are dominated by shaly, limnotelmatic, telmatic, or ombrotrophic coals. **D)** If the AR/PPR curve lies mainly below the peat window, then the coals will be impure and characterized by exposure surfaces. **E)** Summary of terrestrial sequence-stratigraphic surfaces associated with coal (from Diessel et al., 2000). **F)** Hypothetical example of a coal signature diagram, constructed by plotting the thickness of coal units against their interpreted changes in accommodation rate, based on coal facies as derived from maceral analysis.

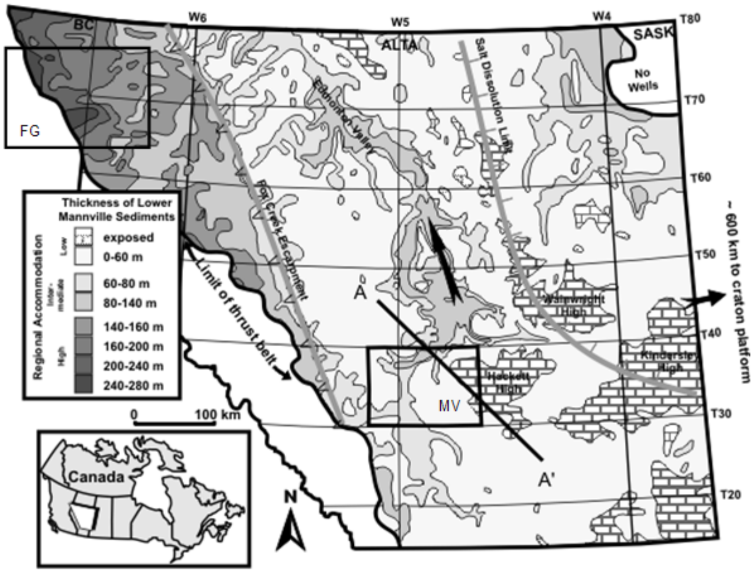


Figure 2. Map of Alberta Foreland Basin showing Upper Mannville study area (MV) and Falher-Gates study area (FG). Isopach contours represent thickness of the lower Mannville Group (modified from Cant and Abrahamson, 1994 and after Diessel et al., 2000) which can be used as a proxy for regional subsidence and accommodation patterns. Areas of low, intermediate and high subsidence-driven accommodation are defined on the basis of sediment thickness. This map suggests that the Falher lies in a high accommodation setting, whereas the Upper Mannville study areas occurs in a broadly intermediate accommodation setting. Arrows indicate paleodrainages (from Leckie and Smith, 1992). Inset map shows position of study area within Canada. From Wadsworth et al. 2002.

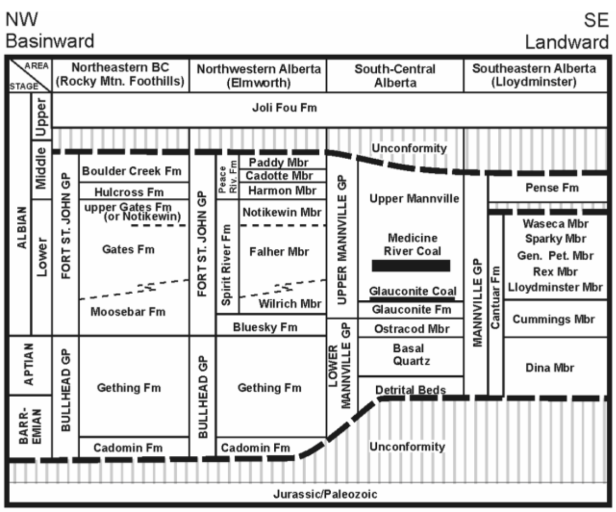


Figure 3. Stratigraphic nomenclature of the Lower Cretaceous strata,Western Canadian Sedimentary Basin. From Wadsworth *et al*. 2002.

The Glauconite Coal – Lateral Correlation of a Coal Seam

The Glauconite Coal has been analyzed at two locations. Both seams contain mostly consist of high-ash coal, shaly coal, and coaly shale, with very little pure coal, which suggests that peat-forming conditions were unfavourable due to high accommodation rates which caused frequent submergence of the mire (Wadsworth et al., 2002). The number of depositional cycles identified in the coal increases from landward (6-7-40-24W4) to basinward (10-25-40-25W4). In both localities the coal consists of a basal terrestrialization surface overlain by drying-upwards cycles (i.e. a regressive-style coal), followed by an accommodation reversal surface which is in turn overlain by wetting-up cycles (i.e. a transgressive-style coal). In both cases, a non-marine flooding surface occurs at the base of the second cycle, beneath a regionally correlatable silt-laminated, burrowed, dark shale. Two give-up transgressive surfaces are present in the top part of the basinward coal, whereas only one is evident in the landward coal. These results suggest that despite its appearance as a simple, widespread coal, the Glauconite Coal comprises two amalgamated seams, formed during decreasing and then increasing accommodation conditions. The more basinward seam contains a more complex signature with more subunits, perhaps due to its greater proximity to the shoreface. The implication is that, under uniform subsidence conditions, coal seams closer to the marine source will be more sensitive to perturbations in ground-water cycles linked to marine cycles, and will contain more internal subunits.

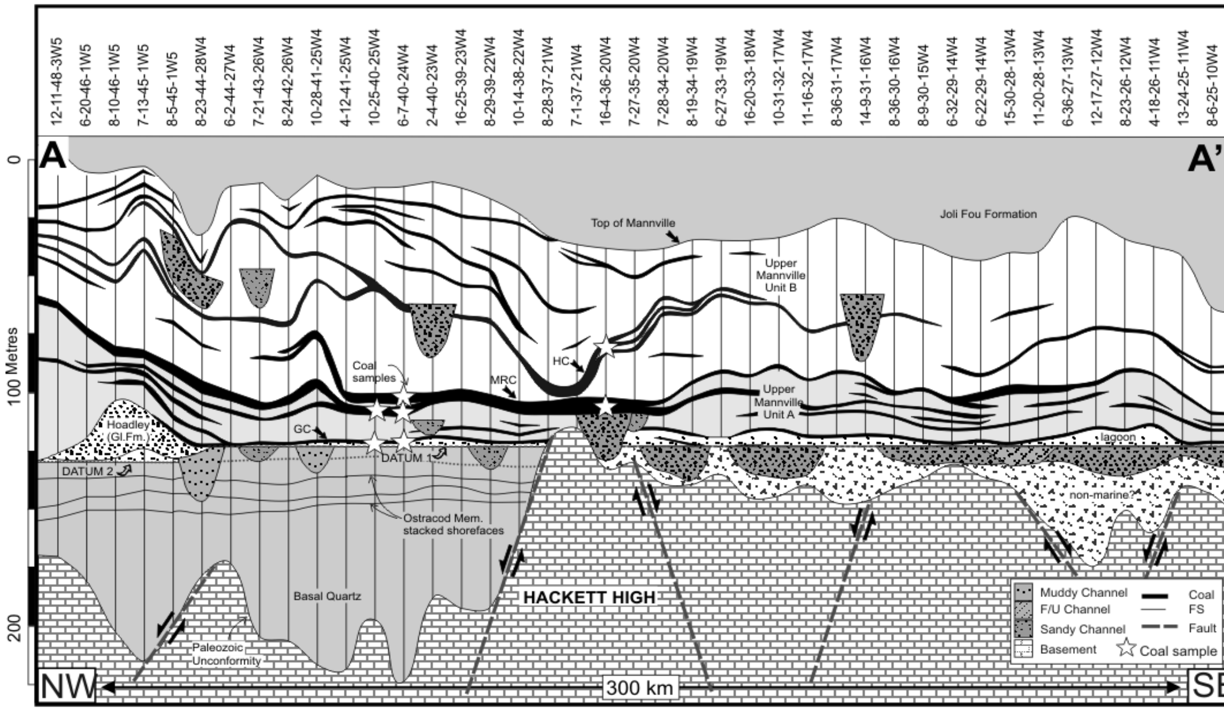


Figure 4. Mannville Group detailed core cross-section. Gamma log is shown. Datum 1 is the flooding surface on the uppermost Ostracod parasequence; Datum 2 is the flooding surface on an underlying Ostracod parasequence.. Gl Fm is Glauconite Formation. Location is shown on Fig. 1. Stars indicate location of coal samples from core. From Wadsworth et al., 2002.

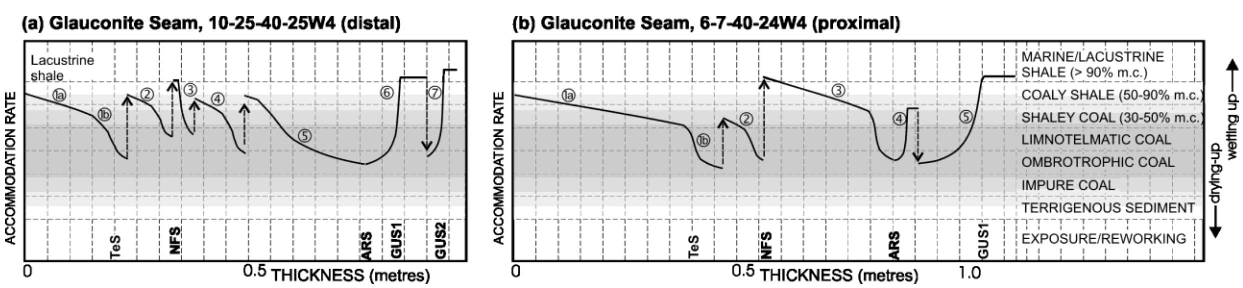


Figure 5. Coal-signature diagrams A) 10-25-40-25W4 and B) 6-7-40-24W4. The petrographic data have been used to divide the coal seams into subunits (shown by number in circle) that have either wetting-upwards or drying-upwards characteristics, caused by small changes in accommodation which affected the AR/PPR ratio. The thickness of the coal unit is plotted against the interpreted coal facies change. Drying-upwards cycles typically grade from coaly shale or shaly coal, to a limnotelmatic, telmatic, or ombrotrophic (raised mire) coal. Wetting-upwards cycles are typically initiated by ombrotrophic coal, which grades into telmatic, limnotelmatic, or shaly coal, or even coaly shale and pure shale. m.c. = mineral content. (After Wadsworth et al., 2002.) TeS, NFS, ARS, and GUS are defined in Figure 1.

Falher Member Coal – Lateral Correlation of Coal Seams

Coal maceral data has been analysed for the Falher A seam in wells 6-7-70-11W6, 11-4-70-11W6, and 6-7-69-10W6 (Fig. 6). Coal signature diagrams (Fig. 7) summarize the accommodation cycles (Wadsworth et al., 2003). In 6-7-70-11W6 the seam is 1.75 m thick and represents the full core. It begins with a terrestrialization surface above a shallowing-upwards marine cycle, and is capped by brackish bay fill sediments. Four drying-upwards, intra-seam units have been distinguished on the basis of alternating coal and stone bands, and show an overall pattern of upward thickening. Approximately 2 km landward, the Falher A Seam from 11-4-70-11W6 shows a similar signature. Three intra-seam units have been distinguished on the basis of alternating coal and sediment bands, and represent a set of upward drying cycles. A further 15 km landward, the Falher A Seam (6-7-69-10W6) was initiated by terrestrialization as indicated by a seam floor comprising wet floodplain deposits. The lower part of the seam comprises 5 units, each beginning with very low detrital mineral contents. This indicates ombrotrophic, raised-mire conditions at the beginning of each cycle. An upward increase in accommodation is indicated by increases in the proportion of dispersal indicators for each cycle individually and for the lower seam portion as a whole. This pattern culminates at the top of Unit 5, above which a 5-cm-thick shale indicates that peat formation was temporarily replaced by predominantly clastic sedimentation. The upper part of the seam consists of very clean coal. It has been divided into two drying-upwards units. The seam is abruptly overlain by a coaly shale (bay fill deposits), the base of which has been interpreted as an non-marine flooding surface.

The two most seaward samples from Falher A (6-7-70-11W6 and 11-4-70-11W6) are similar in that both comprise a set of drying-upwards sub-units, which in turn directly overlie shoreface and lagoon deposits. The two samples differ in that the more distal one (6-7-70-11W6) is thicker, and contains an additional subunit. However, these differences may partially stem from the fact that the uppermost part of the 11-4-70-11W6 core appears to be missing. In any case, both samples indicate a regressive-style coal seam with a strong signature of terrestrialization. Fifteen kilometres landward, the same Falher A seam (6-7-69-10W6) overlies wet floodplain deposits. The accommodation trend signature in this sample is significantly different than the previous two, in that it comprises a regressive component, a transgressive component and another regressive component. This suggests that it is a compound seam, comprising coals belonging to separate accommodation cycles, separated by accommodation reversal surfaces. The coal splits basinward along the upper accommodation reversal surface (ARS/TeS) into two seams (Fig. 6), with an intervening unit of bay fill sediments. Only the upper (regressive) part of the Falher A seam in 6-7-69-10W6 correlates with the Falher A seams in 6-7-70-11W6 and 11-4-70-11W6.

These results indicated that the non-marine component of the Falher A cycle does not represent the simple culmination of shoreface progradation. Instead, the peat formation began under conditions of enhanced accommodation, possibly related to transgression in the back-barrier zone. This peat only formed in the most landward of the three samples (i.e., bottom part of seam in 6-7-69-10W6); basinward it probably correlates to marine sediments. This initial phase of peat formation was eventually terminated as accommodation outpaced peat-accumulation rates. Peat accumulation once again resumed when accommodation slowed down, forming a widespread coal sheet that disconformably capped the shoreface deposits in 6-7-70-11W6 and 11-4-70-11W6.

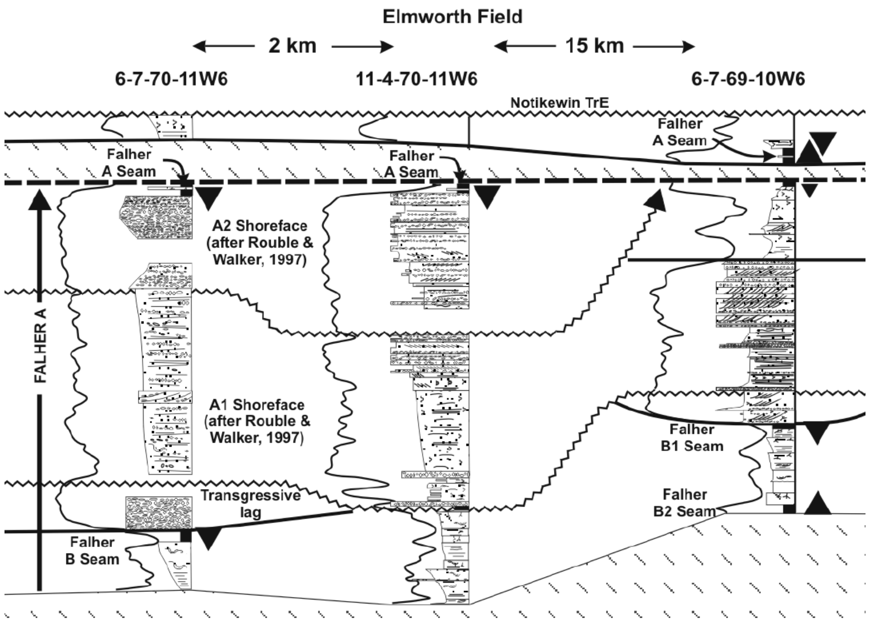


Figure 6. Both transgressive- and regressive-style coals are present in the Falher A Seam. Transgressive-style coals are thought to occur mainly at the base of a Falher cycle as part of the transgressive package. They are often associated with the turn-around point marking the change from decreasing to increasing accommodation conditions. Regressive-style coals occur mainly at the top of a cycle as part of the regressive package and are similarly associated with the accommodation reversal surface marking a change from increasing to decreasing accommodation (from Wadsworth et al., 2003).

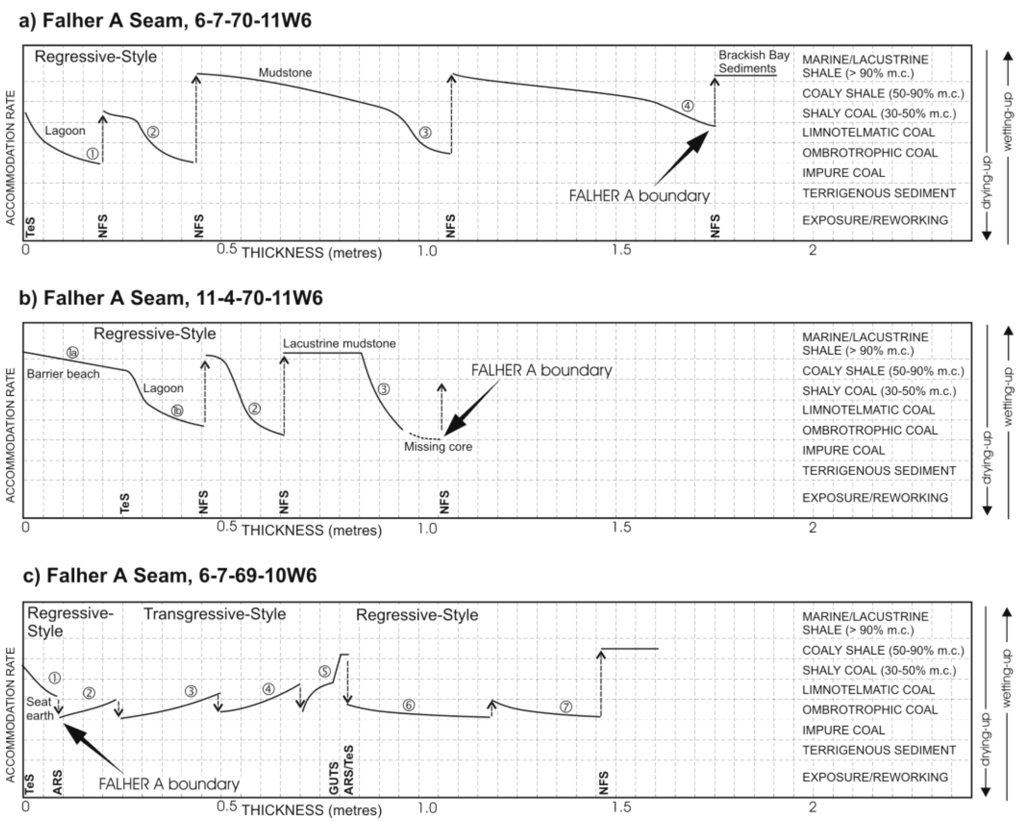


Figure 7. Coal signature diagrams for seams in Falher A. a) 6-7-70-11W6 is the most basinward coal, b) 11-4-70-11W6 is in an intermediate position, and c) 6-7-69-10W6 is the most landward coal. See Figure 1 caption for definitions of abbreviations used. The upper regressive-style part of 6-7-69-10W6 correlates seaward to the regressive-style seams in 11-4-70-11W6 and 6-7-70-11W6.

Conclusions

1) Coals may occur in both regressive and transgressive styles and may initiate or terminate parasequences. Coals may also occur as compound coals that span more than one parasequence and contain internal discontinuity surfaces. Coal compositional characteristics provide key information in determining their stratigraphic position and the stratigraphic behaviour of surrounding strata.
2) The wider implications of these studies are that previous concepts of parasequences in marine sediments need to be significantly modified in the terrestrial realm. Sharp hiatal parasequence boundaries in the marine realm may correlate up-slope to packages of sediments that pass gradationally from transgressive to regressive units and preserve the transitions between the two. Accumulation of terrestrial sediments, including coal, may be associated with both shoreline regression, and shoreline transgression. The exact style and preservation of the terrestrial stratigraphic package depends on the local balance between accommodation and sediment flux at the time of deposition.

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