Tectonic Controls on Sand Distribution in the Late Cretaceous-Tertiary Coal Basins of Southern Saskatchewan

by Paul Broughton

There are seven major coal basins in the Ravenscrag Formation (Palaeocene) in the northern Williston Basin of southern Saskatchewan (Fig. 1). Contemporaneous crustal subsidence is not adequate to explain the origin and geometry of thick coal beds within them. Many of the coal basins are interpreted as an effect of salt solution tectonics. Leaching of up to 137 metres thickness of salt from the Prairie Evaporite (Middle Devonian) during Late Cretaceous to Tertiary time resulted in sufficient local subsidence to be structurally reflected in the 1800 to 2400 metres of overlying Palaeozoic to Cenozoic strata. Several Palaeocene coalfields accumulated above vertically stacked deltaic deposits of the Frenchman Formation (Late Cretaceous) linked to subsidence in the salt solution troughs. The initiation of thick seam deposition on the northern limb of the Williston Basin occurred in successively younger coal basins southeastward toward the cratonic depocentre in northwestern North Dakota. This was contemporaneous with the transition up-section of subsidence dominated by salt solution to one dominated by the craton. Salt solution subsidence only affected the flanking coal basin whereas that basin next to the depocentre was controlled primarily by cratonic movements. The distribution of sands and silty sands are similarly related to the structural controls that affected the accumulation of coal.

The western coal basins (basins 1-3, 5, 6, Fig. 1), i.e., those modified by salt solution subsidence structures, correspond to areas with high percentages of sand in the underlying section whereas the cratonic coal basin (basin 7, Fig. 1) corresponds to a low sand percentage, but is adjacent to an arcuate trend with a high percentage of sand. Most of the coal basins lie parallel to southeastward flowing tributaries of an ancestral Missouri River. However, the thick coal beds of basin 7 represent flood plain deposits marginal to a main channel fill. These palaeogeographic trends, in turn, are aligned with basement tectonic lineaments.

Structural Setting

The study area is fronted by the subcrop of the Frenchman (Late Cretaceous) and Ravenscrag (Palaeocene) Formations across southern Saskatchewan and includes seven major coal basins (Fig. 1). These are the Cypress (basin 1), Wood Mountain

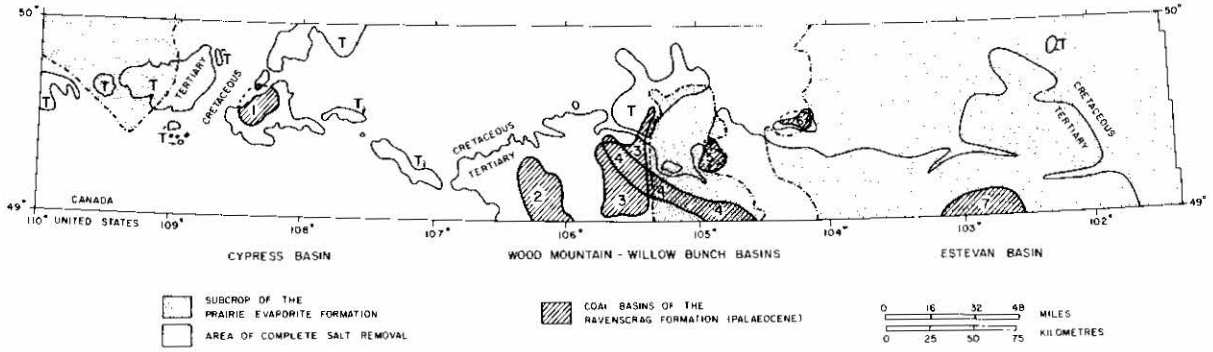

Fig. 1 - Distribution of coal basins in the Ravenscrag Formation (Palaeocene): Cypress (1), Wood Mountain (2), Willow Bunch (3-6), and Estevan (7). The coalfields of the Willow Bunch Basin are: Coronach (3), Willow Bunch (4), Bengough (5), and Radville (6).

(basin 2), Coronach (basin 3), Willow Bunch (basin 4), Bengough (basin 5), Radville (basin 6) and Estevan (basin 7).

The Roncott Platform (Fig. 2) is the structural drape of the Middle Devonian Prairie halite outlier in the 2000 sq. km region of salt removal in southern Saskatchewan. The western margin is bounded by the Coronach Trough and the Wood Mountain Basin coalfields and the eastern margin by the Hummingbird Trough. There is no evidence of salt solution tectonics having affected the accumulation of sediments in the coal basins east of the Hummingbird Trough. The general geology of the Late Cretaceous and Tertiary continental succession is summarized in Irvine, Whitaker and Broughton (1978).

Sand Distribution

Sand distribution in the Frenchman Formation is approximately coincidental with the overlying Palaeocene coal basins west of Longitude 104° (Fig. 3). The largest area of sand accumulation is situated between Longitude 107° and the western margin of the Roncott Platform at approximately Longitude 105° 30'. It is arcuate 96 kms long, and as outlined by the 70 percent sand isopleth, is oriented north-south in the Coronach Trough parallel to the western margin of the Roncott Platform, and northwest approximate to the Rockglen-Killdeer Trough axes across the southern Wood Mountain Basin (Broughton, 1977, 1978). In the Cypress Basin, the sand percentage increases basinward from less than 60 percent to over 90 percent.

East of the Hummingbird Trough the sand percentages are divisible into four

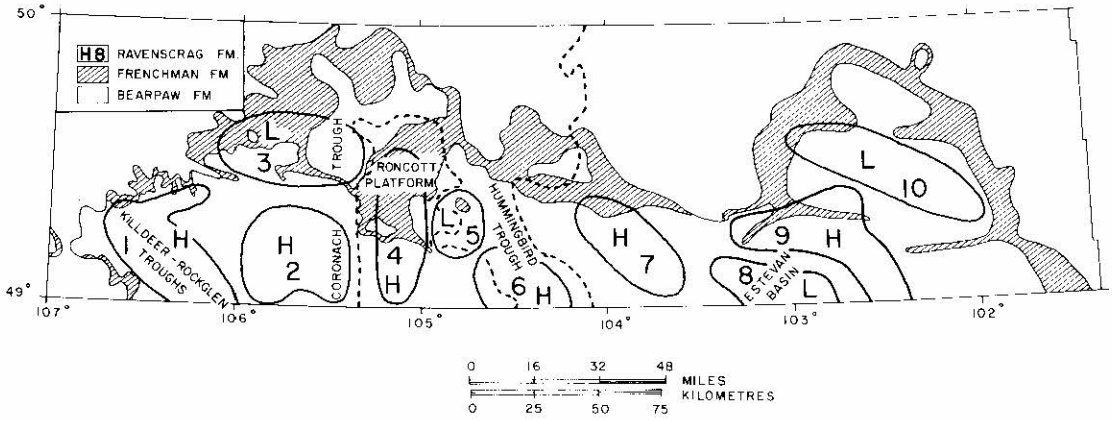

Fig. 2 - Generalized high (H) and low (L) sand percentage areas for the Ravenscrag Formation.

arcuate trends between Longitude 101° and somewhat west of Longitude 104°. There are two high sand trends alternating with two high mud (low sand) belts. These trends correspond to structural features on the base of the formation. Thus the mud belt just west of Longitude 103° with 40 to 60 percent sand is in the structurally lowest portion of the Estevan coal basin.

The sand percentage maps for the Ravenscrag Formation between Longitudes 101° and 107° are illustrated in figure 4. Comparison of the sand distribution maps for the basal 100 (30 m) 200 (61 m) and 300 (91 m) feet, and the isopach map of the formation, delineates 6 common areas of high and 4 areas of low sand percentages (Fig. 2). The high sand percentage areas include sand and silty sand bodies for 30 to 50 percent of the stratigraphic interval, but locally as much as 80 percent. The low sand regions feature only 10 to 30 percent sand and silty sand, with consequently higher mud, silt and clay. The bulk sand percentages of the Palaeocene section in the region west of Longitude 107° ranges between 10 and 35 percent over the lower 100 to 150 feet (30-45 m) of the formation.

Origin of Sand Distribution Patterns

The sedimentation of the Frenchman sands is controlled by two major structural processes. Respectively,(1) solution subsidence of the buried Elk Point (Devonian) evaporites, dominant in the western half of the area, and (2) cratonic subsidence in the eastern half. The accumulation of vertically stacked deltaic sands in the western part of the region is attributed to (1).

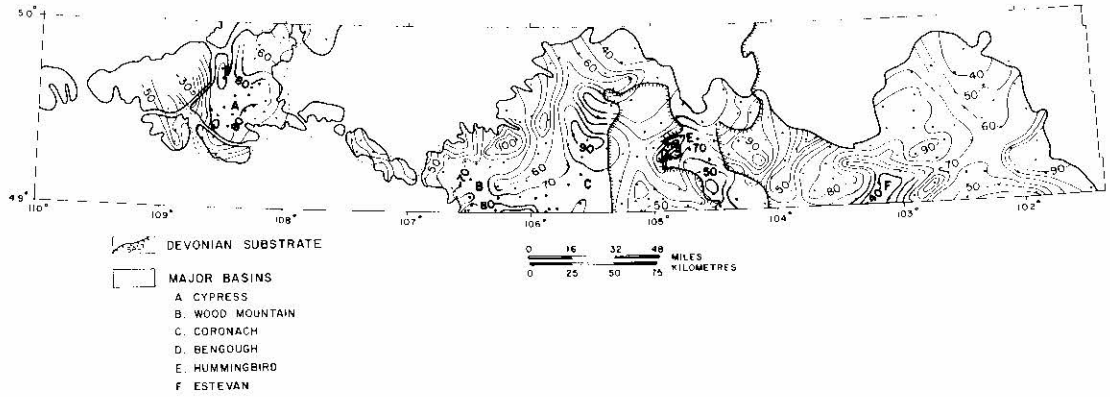

Fig. 3 - Sand distribution in the Frenchman Formation (Late Cretaceous), expressed as percentage of stratigraphic interval. The Palaeocene coal basins are superimposed.

The distribution of sand bodies in the Tertiary coal basins (Fig. 2) is broadly similar to the Late Cretaceous pattern. The high sand percentage area 1 is associated with the Killdeer-Rockglen troughs, and the high sand area 2 is in the southern Coronach Trough. These spatially overlie the Frenchman Formation deltaic sands. The Roncott Platform is a site of high sand percentage (area 4) but is separate from the adjacent high sand area in the southern half of the Coronach Trough. Low sand percentage area 5 is situated at the east-central edge of the Roncott Platform where it is deeply embayed by the Hummingbird Trough. High sand percentage area 6 lies at the southeastern margin of the Roncott Platform and in the southern part Hummingbird Trough.

The mapping of coal seams as stratigraphic markers across the Willow Bunch Basin reveals characteristics of Ravenscrag clastic sedimentation not readily ascertained from examination of the sand distribution maps. The large sand-filled channels lie outside the coal basins. Sand bodies within the coal basins are narrow and not traceable for long distances, even where borehole control is dense (quarter-mile centres). They tend to be linear and locally bifurcated over short distances. These sand bodies are interpreted as having been deposited in small distributaries lateral to main channels.

This is illustrated at the western margin of the Coronach coal basin where a 9 to 16 km wide alluvial body of coarse clastics accumulated on the western margin. This channel fill trends southeast across the international boundary just east of 106°. It is situated between the Killdeer-Rockglen subsidence basin (high sand area 1) to the west, and the Coronach Trough subsidence basin (high sand area 2) to

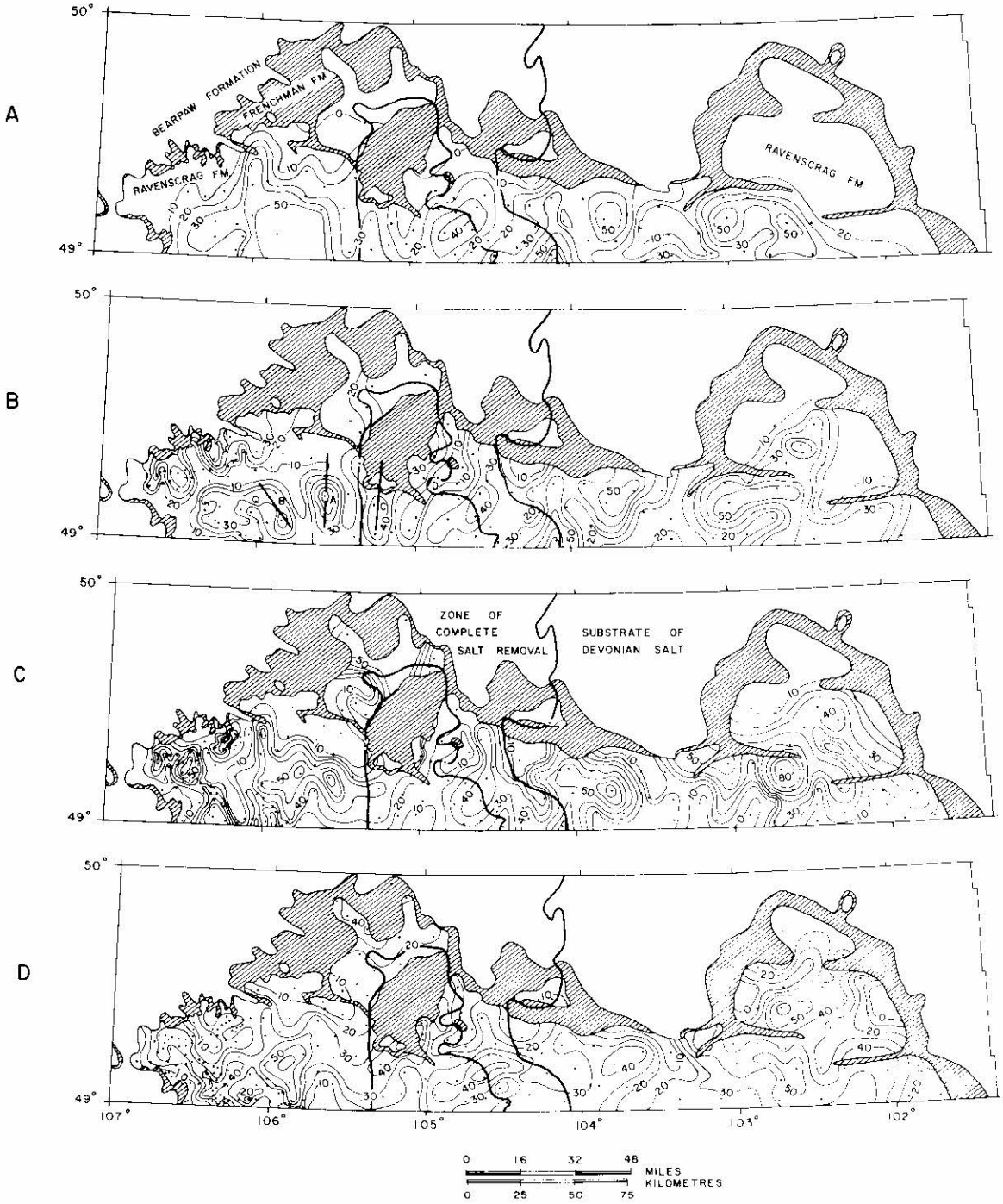

Fig. 4 - Sand distribution in the Ravenscrag Formation (Palaeocene), expressed as percentage of basal 300 feet (A), 200 feet (B), 100 feet (C) and preserved thickness of the formation (D).

the east (Fig. 2) and is interpreted as a Palaeocene rejuvenation of a main feeder channel that supplied the two subjacent deltas during the uppermost Cretaceous. These large extra-basinal channels emptied across the coal basin region during episodes of greater subsidence, resulting in the high sand percentage association with the coal basin sections. This is in distinct contrast to the clastic sedimentology of the coal basins, the subsidence of which is controlled directly by the craton.

The area east of Longitude 104° is dominated by cratonic subsidence of the Williston Basin and deposition of the Estevan coalfield (Fig. 2). The flanking arcuate sand and mud trends in this area reflect the gross geometry of the Basin.

West of Longitude 104°, the assertion of cratonic subsidence over salt solution subsidence late in the coal series culminates in the encroachment of the Willow Bunch zone coal beds and clastics across the Roncott Platform. The sedimentation associated with cratonic (and moderate salt solution subsidence-modified) basins during peat accumulation is that characteristic of aggradation in a major channel complex and its floodplain. The cratonic subsidence basins have coalfields that accumulated as elongate interdistributary deposits parallel to the river course. The two main cratonic basins, the Willow Bunch seam basin (basin 4, Fig. 1) and Estevan Basin (basin 7, Fig. 1) include 8 to 16 km -wide complexes of coarse clastic fluvial sand bodies. These alluvial deposits persisted during subsidence even when conditions were not conducive to peat accumulation. However coal basin growth occurred in the regions adjacent to the margins of the alluvial trends. The coal deposits are thus situated above low sand areas in the section e.g., the Estevan coalfield. The Estevan coalfield, is also an erosional remnant preserved in the arc formed by the curve of the fluvial sand complex trend following the trend of the Williston Basin.

The Willow Bunch seam basin (basin 4, Fig. 1) is also an example of peat deposits flanking the entrenched meanders of a river and accumulated as intermittent response to cratonic subsidence. The major difference is its centripetal orientation to the cratonic basin. The Willow Bunch seams are thickened along the axis of the Coronach Trough which is salt-solution controlled, however this activity had sufficiently diminished to favour accumulation across the Roncott Platform, unlike the more restricted accumulation of the lower seams.

DISCUSSION

Bulk Sand Distribution and Subsidence

The Frenchman sediments are interpreted to reflect relatively rapid rates of

sedimentation as a response to both salt solution tectonics and Williston Basin cratonic subsidences. This combination of sedimentation and subsidence was too great for thick accumulations of peat. During the Tertiary, these conditions improved, so that the salt solution axes and the regional Williston Basin structure was able to accommodate the growth of extensive coal basins above the earlier deltas and basin shelf.

The coal basins west of the Roncott Platform are dominated by salt solution subsidence, whereas eastward cratonic subsidence of the Williston Basin becomes more important. This eastward change in the structural control also affects the relationship of coal basins to the accumulation of coarse clastics in the section. The coal basins west of the Roncott structure are also troughs accumulating high percentages of sand in the section. On the other hand, the cratonic subsidence structures proximal to the Williston Basin depocentre are associated with low sand percentages in the vertical section. The smaller coal basins along the margins of the Hummingbird Trough are transitional and correspondingly have only moderate sand concentrations in the section.

The geometry of the sand bodies between the coal beds is comparable to the form of the coal beds. Thus, isopach trends of the coal beds in salt solution troughs are generally similar to the more rounded, lacustrine-like sand bodies. The coal beds result from deposition in limited subsiding ponds topset to lacustrine fills. On the other hand, cratonic coal beds are elongate parallel to a major sand filled river valley within the coal basin. For example, the major fluvial valley between the Wood Mountain Basin to the west and the Coronach Basin to the east separates two basins rather than lying within a single super-basin. This interpretation is suggested by the fact that coal bed isopach trends within each coal seam are independent of the position of the river channel. This is in distinct contrast to the cratonic dominated Willow Bunch seam basin and the Estevan Basin wherein the coal bed isopachs are elongated parallel to the river course. When cratonic subsidence was not sufficiently slow to accumulate peat, the major river probably flowed behind a levee barrier. The inter-seam section is dominated by muds (low sand percentage) from overbank deposits. During accelerated subsidence of the salt solution trough coal basins, the major river channel outside the basin became the source of clastics of coalescing sheet sands that characterize the basin as a high sand percentage area.

The sand bodies mapped in the Ravenscrag coal beds across the Willow Bunch Basin suggest a gradual up-section change from a southerly to a southeasterly drainage. This reflects the initial dominance of the north-south oriented salt

solution axes but an up-section assertion and spread of cratonic subsidence. This shift is observable with the eastward shift of the major sand bodies between the Killdeer-Rockglen subsidence basin (Wood Mountain coalfield) and the Coronach Trough coalfield. The isopach trends within the Coronach Trough coal beds also become more easterly up the section. A final and major shift to the southeast in the upper section is also indicated for the Willow Bunch seam basin by its down-dip orientation across the Roncott Platform, towards the Williston Basin depocentre.

References

Broughton, Paul L., 1977, Origin of coal basins by salt solution. Nature, vol. 270, P. 420-423.

_____1978, Emplacement of coal basins within salt solution troughs on a subsiding craton (Abs). Tenth Int. Congr. Sedimentology, Jerusalem, p. 92.

Irvine, J.A., Whitaker, S.H. and P.L. Broughton, 1978, Coal Resources of Southern Saskatchewan: A Model for Evaluation Methodology, Geol. Surv. Canada Econ. Geol. Rept. 30, Sask. Resear. Coun. Rept. 20, Sask. Dept. Miner. Res. Rept. 209, 2 volumes (vol. 1, 156 p.; vol. 2, 56 p. altas).