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LITHOSTRATIGRAPHICAL AND SEDIMENTOLOGICAL FRAMEWORK OF COAL-BEARING UPPER CRETACEOUS AND LOWER TERTIARY STRATA, COAL VALLEY AREA, CENTRAL ALBERTA FOOTHILLS

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CONTENTS

Appendices

Plates

Figures

Tables

LITHOSTRATIGRAPHICAL AND SEDIMENTOLOGICAL FRAMEWORK OF COAL-BEARING UPPER CRETACEOUS AND LOWER TERTIARY STRATA, COAL VALLEY AREA, CENTRAL ALBERTA FOOTHILLS

Abstract

Important coal deposits are present in the Upper Cretaceous-lower Tertiary strata of the Coal Valley area. Knowledge of the lithostratigraphical and sedimentological framework within which they occur can assist in exploration for, and exploitation of, these resources.

The Saunders Group includes all of the Upper Cretaceous and Paleocene nonmarine strata (up to 3600 m thick) above the youngest Cretaceous marine beds, the Wapiabi Formation (late Santonian), in the central Alberta Foothills. It can be divided into three mappable units which are, in ascending order, Brazeau, Coalspur, and Paskapoo. The former position of the base of the Paskapoo Formation at the top of the Brazeau Formation in the Foothills is not valid since palynological studies have shown that the major coal seams above the Brazeau Formation correlate with seams below the Paskapoo Formation in its type area. The base of the Paskapoo Formation is placed at the base of the first prominent sandstone unit above the highest major coal seam. The name Coalspur beds is applied informally, at present, to the stratigraphic sequence between the Brazeau and Paskapoo Formations.

An alluvial environment dominated sedimentation and lateral variability of facies over short distances is characteristic. Channel and overbank deposits display a distinct cyclicity on two scales and a larger scale cyclicity can be observed in the Saunders Group as a whole. Paleoslope was consistently to the northeast during deposition of the Saunders Group in the Coal Valley area. Coal was formed in extensive swamps on the floodplain and in abandoned channels.

Résumé

Il existe d'importants gisements de charbon dans les strates du Crétacé supérieur et du Tertiaire inférieur, dans la région de Coal Valley. La connaissance de la lithostratigraphie et de la sédimentologie qui s'y rapportent peut contribuer à la recherche et à la mise en valeur de ces ressources.

Le groupe de Saunders comprend toutes les strates non marines de la fin du Crétacé et du Paléocène (jusqu'à 3 600 m d'épaisseur) au-dessus des couches marines les plus récentes du Crétacé qui constituent la formation de Wapiapi (fin du Santonien), dans le centre des Foothills de l'Alberta. Il peut se diviser entre trois unités de cartographie qui sont en ordre ascendant les unités Brazeau, Coalspur et Paskapoo. L'ancienne position attribuée à la base de la formation de Paskapoo au sommet de la formation de Brazeau, dans les Foothills, n'est pas correcte étant donné que des études palynologiques ont montré que les couches majeures de charbon au-dessus de la formation de Brazeau correspondent à celles qui se trouvent sous la formation de Paskapoo, dans sa zone type. La base de la formation de Paskapoo repose à la base de la première unité importante de grès au-dessus de la plus haute couche majeure de charbon. Le nom de couches Coalspur s'applique de façon officieuse, actuellement, à la succession stratigraphique qui se trouve entre les formations de Brazeau et Paskapoo.

Un environnement alluvial a dominé la sédimentation et on peut remarquer une variabilité latérale de faciès sur de courtes distances. Les gisements du chenal et des berges laissent voir une périodicité distincte répartie sur deux échelles, et une autre périodicité à échelle plus grande peut être observée dans l'ensemble du groupe de Saunders. La paléopente a constamment été en direction nord-est au cours du dépôt du groupe de Saunders dans la zone de Coal Valley. Le charbon s'est formé dans de vastes marécages sur la plaine inondable et dans les chenaux abondonnés.

LITHOSTRATIGRAPHICAL AND SEDIMENTOLOGICAL FRAMEWORK OF COAL-BEARING UPPER CRETACEOUS AND LOWER TERTIARY STRATA, COAL VALLEY AREA, CENTRAL ALBERTA FOOTHILLS

INTRODUCTION

The Upper Cretaceous-lower Tertiary succession in the Coal Valley area (Fig. 1) contains commercially important coal beds. This study was undertaken to determine the lithostratigraphic and sedimentological framework within which the coal occurs.

T. Jerzykiewicz, with the Geological Survey for 14 months in 1976-77 on a National Research Council post-doctoral fellowship from Poland, conducted most of the field investigation and contributed the sections on lithofacies, facies change and paleocurrent analysis. J.R. McLean contributed the sections on lithostratigraphy, lithofacies sequence analysis, cyclicity, and geology of coal.

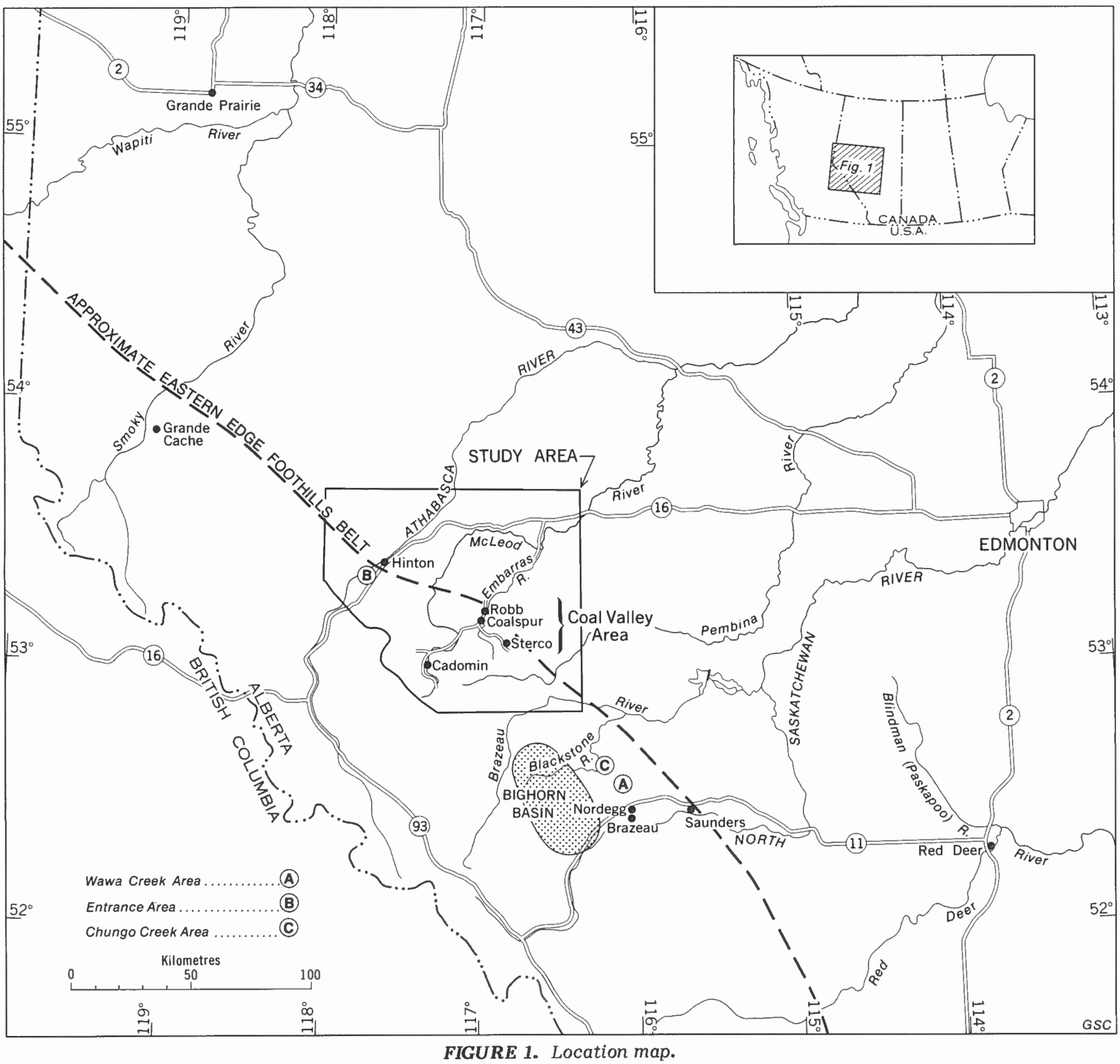


***FIGURE 1.** Location map.*

Outcrop is generally poor throughout the area, and structure is not easily deciphered due to a lack of markers. The best and most accessible sections are along the Embarras River and the road between Robb and Cadomin (Figs. 1, 2) and many of the principal sections are located there (Fig. 2). Figure 3 shows a structural cross-section along this line with section locations.

Acknowledgments

Palynological examinations by A.R. Sweet, of the Geological Survey, were invaluable in determining ages and correlations of the coal seams and other beds. The manuscript was critically read by J.D. Hughes and D.G.F. Long and we appreciate their comments and suggestions. Comments and suggestions by R.J.W. Douglas were very helpful to us in achieving a workable lithostratigraphic nomenclature. Pat Ward assisted ably in the field during the summer of 1977.

LITHOSTRATIGRAPHY

Introduction

The entire Upper Cretaceous-lower Tertiary sequence of strata above the Upper Cretaceous Alberta Group is nonmarine in the central Alberta Foothills. The top of the sequence is always erosional so that the thickness varies greatly from one area to another. The maximum estimated thickness is over 3600 m. Lithologies include sandstone with subordinate conglomerate, siltstone, mudstone, coal, bentonite and tuff. Interbedded sandstones, siltstones and mudstones in various combinations and thicknesses compose the bulk of the sequence. Coal seams are common in certain intervals. Bentonite and tuff beds, making up only a small proportion of the total section, are important marker beds in some areas.

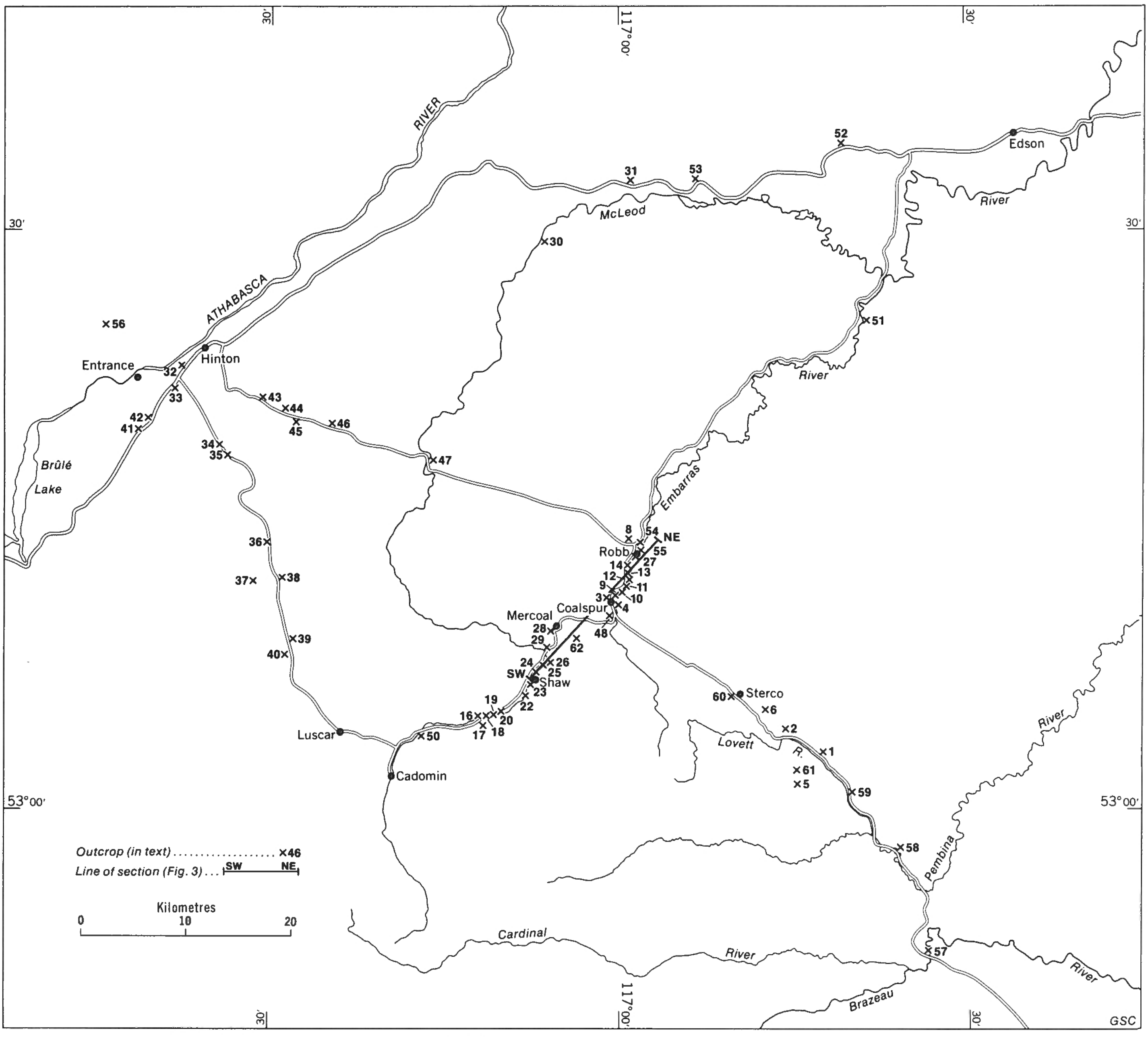


FIGURE 2. Outcrop locations.

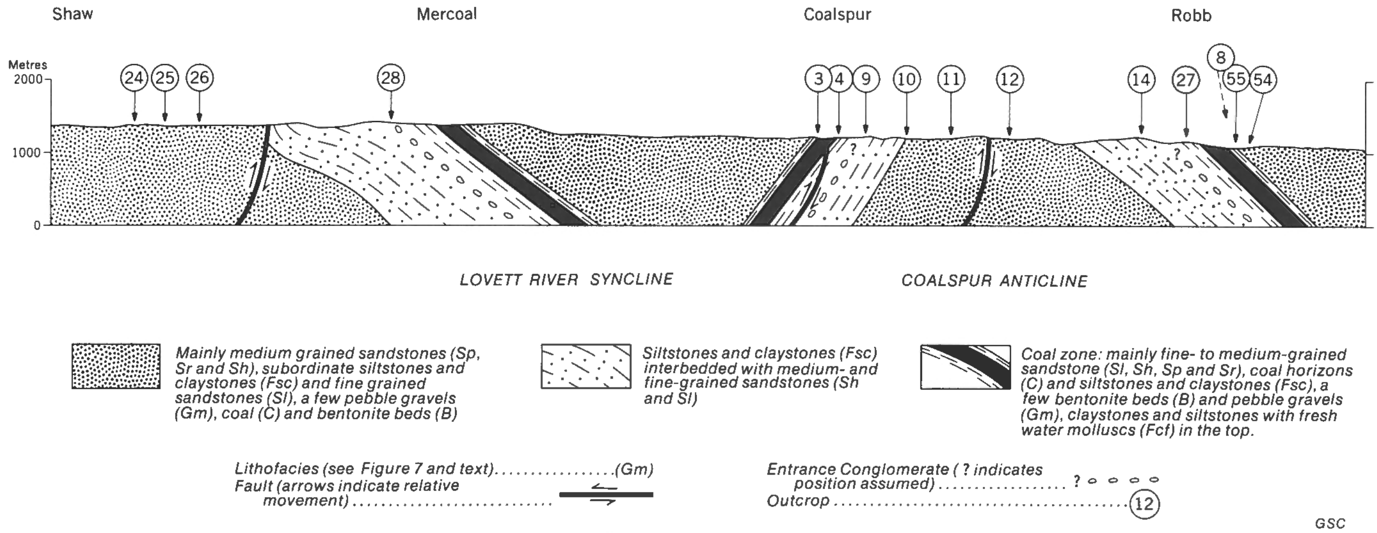


FIGURE 3. *Structural cross-section from Shaw to Robb.*

Group nomenclature

Subdivision of the post-Wapiabi section into units which can be recognized everywhere with confidence has been inhibited by: (1) a scarcity of good marker beds; (2) generally poor outcrop; (3) the similarity of lithology throughout; and (4) the rarity of complete sections. However, the entire sequence is easily recognizable since there is distinct, dark grey shale below and only the erosional surface above. For this reason, a group name encompassing the undivided sequence is warranted and useful.

Three names have been applied to the entire undivided sequence. Brazeau was introduced informally by MacKay (1929, 1930), but was later dropped and the name was relegated to only the lower part of the succession. Saunders Formation, or group, was introduced by Allan and Rutherford (1923), while working in the Saunders Creek and Nordegg coal basins (Fig. 1). They applied the name to the entire estimated 3030 to 3634 m of section which lie above the Wapiabi Formation. Age relations were uncertain but they suggested that the group was predominantly Cretaceous, although possibly Tertiary in part.

Allan and Rutherford (1923) were able to subdivide the Saunders Formation into three mappable units: lower and upper Saunders separated by the Saunders coal series. In subsequent mapping to the north, Allan and Rutherford (1924) and Rutherford (1925, 1926) were unable to maintain the subdivision and applied the name Saunders to the entire undivided succession.

Unfortunately, the name Saunders was not utilized by other workers (MacKay, 1929, 1930; Evans, 1930) or was confined to beds below the Paskapoo (Russell, 1932), and, by 1934, Allan and Rutherford felt that there was confusion in use of the names Brazeau, Paskapoo, and Saunders and in the applicability of the three subdivisions of the Saunders. Therefore, they (1934, p. 34) proposed the name Foothills series, ". . . to include all strata above the Upper Cretaceous marine beds in the foothills". They go on to state (Allan and Rutherford, 1934, p. 35): "In the general absence of stratigraphical breaks or marked changes, it has not been possible to determine the position of the base of the Paskapoo or earlier Tertiary. Because of these difficulties, the general term Foothills series is used for these beds. The use of such a general term is similar to the application of the term Alberta shale, except that in the case of the Foothills series the upper limit has not been determined." The present authors concur with Allan and Rutherford (1934) that an all-encompassing name is desirable and useful. Both Foothills and Saunders are possibilities and arguments can be put forward in favour of either.

Discontinuation of use of the name Saunders by Allan and Rutherford (1923, 1934) is the only really persuasive reason for using the name Foothills. Also, publications by Russell (1932, 1950) and by Teifke (1972), both of whom limited the name Saunders to the beds below their Paskapoo Formation, indicate that the all-encompassing nature of the name Saunders was not universally accepted.

However, the name Saunders should be favoured for several reasons:

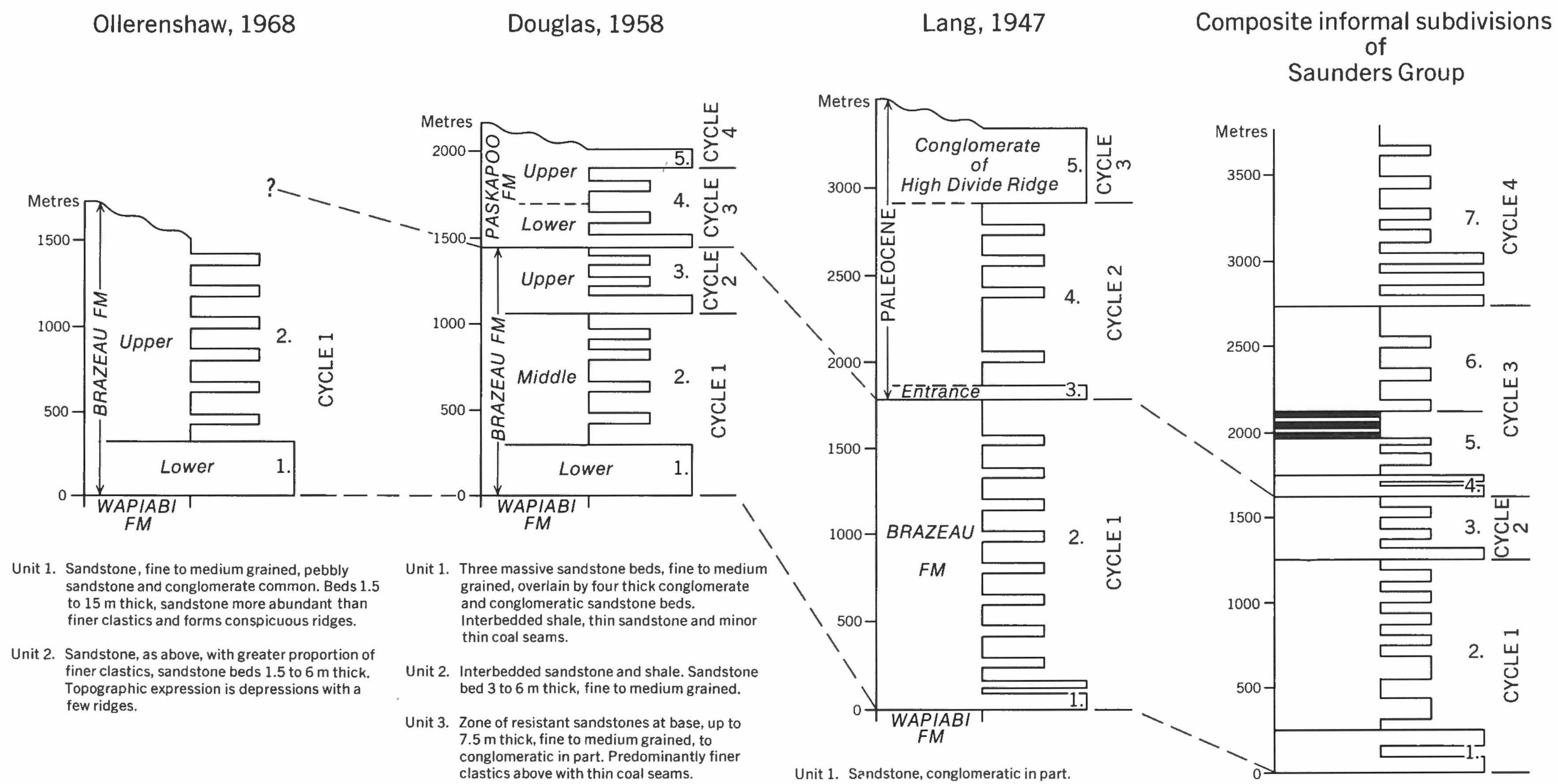
(1) It has priority.

(2) Except for the paper wherein Allan and Rutherford (1934) introduced the name Foothills, that name has not been used. Indeed, in a subsequent paper, Rutherford (1947) used the name Saunders exclusively. Bell (1949) did not mention the name Foothills, and Stelck et al. (1972, 1976) used only the name Saunders Group.

(3) The Alberta Society of Petroleum Geologists lexicon (1960, p 306) includes the Saunders Group, but not the Foothills Group. However, the brief report on the Saunders Group in the lexicon suggests that the author was not familiar with much of the pertinent literature.

Thus, on the basis of usage and popularity, the name Saunders must be considered more acceptable than Foothills.

It could be argued that a group name is not required at all. Certainly, in some areas, subdivision is possible and the group name may not be needed. However, we have found that it is often useful to have a name to refer to the whole undivided sequence. As well, there are many smaller outcrops that cannot be readily assigned to one subdivision or another, and they can only be assigned to the entire post-Wapiabi succession.



Ollerenshaw, 1968

Unit 1. Sandstone, fine to medium grained, pebbly sandstone and conglomerate common. Beds 1.5 to 15 m thick, sandstone more abundant than finer clastics and forms conspicuous ridges.

Unit 2. Sandstone, as above, with greater proportion of finer clastics, sandstone beds 1.5 to 6 m thick. Topographic expression is depressions with a few ridges.

Douglas, 1958

Unit 1. Three massive sandstone beds, fine to medium grained, overlain by four thick conglomerate and conglomeratic sandstone beds. Interbedded shale, thin sandstone and minor thin coal seams.

Unit 2. Interbedded sandstone and shale. Sandstone bed 3 to 6 m thick, fine to medium grained.

Unit 3. Zone of resistant sandstones at base, up to 7.5 m thick, fine to medium grained, to conglomeratic in part. Predominantly finer clastics above with thin coal seams.

Unit 4. Zone of resistant sandstones at base, 6 to 7.5 m thick, up to 25 m, coarse grained to conglomeratic in part. Prominent coal seams start 250 m above base.

Unit 5. Massive sandstones, up to 15.2 m thick, coarse grained to conglomeratic in part.

Lang, 1947

Unit 1. Sandstone, conglomeratic in part.

Unit 2. Interbedded sandstone, shale, pebble conglomerate, with minor bentonite and coal. Conglomerate more abundant in lower half.

Unit 3. Conglomerates, 6 m average thickness, up to 15 m. Clasts 2 to 5 cm average, up to 15 cm.

Unit 4. Relatively recessive interbedded sandstone, shale, with minor conglomerate and bentonite.

Unit 5. Conglomerate, cobble-sized clasts.

Composite informal subdivisions of Saunders Group

Unit 1. Sandstone, fine to medium grained, and conglomerate, with interbedded mudstone, siltstone, and thin coal seams.

Unit 2. Interbedded sandstone and mudstone with minor coal and bentonite.

Unit 3. Interbedded sandstone and shale. Sandstone beds more prominent near base.

Unit 4. Coarse grained sandstone with conglomeratic beds. Thick conglomerate beds in part.

Unit 5. Interbedded mudstone and sandstone in lower part. Coal seams, interbedded with mudstone, siltstone and sandstone in upper part.

Unit 6. Interbedded sandstone and mudstone, moderately recessive.

Unit 7. Sandstone and mudstone interbedded. Sandstone and conglomerate more prevalent in lower part.

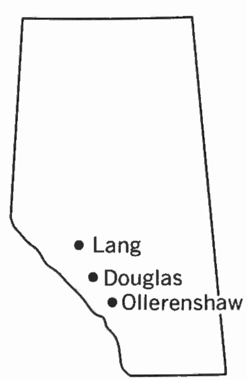


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FIGURE 4. *Informal subdivisions of the Saunders Group.*

Subdivision of the Saunders Group

Subdivision of the Saunders Group has always been based on the concentrated occurrence of topographically positive conglomerate or coarse grained sandstone beds within a prevalently finer grained sequence. Coal seams and zones have been mapped but they have not normally been used to define subdivisions as they lack distinctive topographic expression.

Several authors have noted gross subdivisions of the Saunders Group, which are useful for mapping purposes. Three of these subdivisions, shown in Figure 4 (Arabic numerals of columns 1 to 3), are schematic representations illustrating the relative resistance of subdivisions and their subsequent topographic expression. A review of these reports, plus others by the Geological Survey of Canada, suggests that several informal subdivisions (Fig. 4) can be recognized in the area from the North Saskatchewan River to the Athabasca River (Fig. 1) and possibly beyond:

(1) A lower unit, about 300 m thick, characterized by thick sandstones with some conglomerates and an overall more resistant weathering character than units above or below.

(2) A second unit, 600 m to possibly 1500 m thick, of less resistant interbedded sandstone and shale and some coal.

(3) A third unit which may not always be recognizable and distinguishable from the underlying unit but, where present, characterized by more resistant, ridge-forming sandstone units, at least near the base.

(4) A zone, usually less than 30 m thick, of coarse sandstones with conglomeratic beds and thick conglomerate beds in part, particularly well developed in the Entrance area but distinquished by most geologists at least as far south as the North Saskatchewan River.

(5) A zone 300 to 450 m thick, the lower part characterized by moderately recessive, interbedded sandstone and shales. The upper part is characterized by a series of coal seams, starting from 180 to 270 m above zone 4 and continuing through 60 to 180 m of section. This includes the coal zone at Coal Valley and probably the seams in the Saunders-Alexo area along the North Saskatchewan River.

(6) A zone of indeterminant thickness, but up to 600 m thick, and possibly very thin to absent in places, of similar character to the interbedded sandstones and shales of the lower part of zone 5.

(7) A more resistant, sandstone and conglomerate rich unit, which is most resistant in its lower part, overlain by soft interbedded sandstones and shales up to 1210 m thick. The upper surface of this unit is always erosional and the entire unit, as well as underlying units, may be absent due to erosion.

Nomenclature for subdivisions of Saunders Group

Introduction

Three earlier summaries of the history of lithostratigraphic nomenclatural development were presented by Lang (1947), Bell (1949), and Eliuk (1969) and only the highlights will be repeated here. Table 1 shows the nomenclatural usage of several authors for the Foothills and Plains areas and that of the present authors.

Only two names - Brazeau and Paskapoo - have gained wide acceptance in the Foothills region between the North Saskatchewan and the Athabasca Rivers. The name Brazeau is used only in the Foothills but the name Paskapoo was introduced from the Plains nomenclature and correlation of the lower boundary between the Foothills and the type area has never been entirely clear. The name Entrance was used in the type area (Lang, 1947) and is useful in the Coal Valley study area, but has not been applied to more southerly areas.

Brazeau Formation

The name Brazeau was first introduced by Malloch (1911) for 520 m of ". . . alternating beds of black and brown shales, with greenish-grey sandstones containing pebbles of chert . . ." which he observed above the marine Wapiabi Formation in the Bighorn Basin of the Central Foothills. He indicated that the observed thickness was not the true thickness, as the top had been removed by erosion.

MacKay (1929; 1930, p. 486) introduced the name Brazeau to the Coal Valley area where he applied it to the entire estimated thickness of 3330 m of post-Wapiabi strata including the coal beds. Later, MacKay (1943, p. 3) modified his ideas on the Brazeau Formation and limited it to about 1425 m of strata above the Wapiabi Formation and up to the base of a cobblestone quartzite-conglomerate at the base of his Edmonton Formation which, he observed, lies about 275 m below the lowest coal seam.

Lang (1947, p. 32) used the name Brazeau for the interval from the Wapiabi Formation up to the base of a prominent conglomerate bed which he named the Entrance Conglomerate. This conglomerate lies about 242 m below the lowest coal seam and is considered correlative with that observed by MacKay farther south.

The Brazeau Formation has subsequently been utilized in mapping by Douglas (1958), Irish (1947, 1949, 1950, 1952), and Ollerenshaw (1966, 1968, 1971a, b, c, 1972, 1978) and appears to be a useful, as well as entrenched, name in the lithostratigraphy of the Foothills.

The name Brazeau encompasses the lower three informal subdivisions of the Saunders Group (Fig. 4, Column 4). None of these subdivisions has been named, but Ollerenshaw (1971b, c, 1978) has mapped an upper and a lower subdivision of the Brazeau Formation, and Douglas (1958) has mapped three subdivisions. Their mappability would imply that each subdivision might have formational status and, if so, the name Brazeau could be elevated to group status. Use of the name Saunders, then, might be discontinued.

Entrance Conglomerate

The name Entrance was applied to what we have called the fourth subdivision of the Saunders Group (Fig. 4, Column 4) by Lang (1945, 1947) in the Entrance map area which straddles the Athabasca River west of Hinton (Fig. 1). Lang (1947, p. 34) describes the unit as follows:

" . . . The uppermost massive sandstone bed of the Brazeau formation is overlain conformably by a conspicuous bed of conglomerate termed the 'Entrance conglomerate'. This member has an average thickness of about 20 feet, but is about 50 feet thick at Entrance. It consists of closely packed pebbles of quartzite and chert averaging 1 to 2 inches in diameter, although some are as much as 6 inches. The matrix is sandy, and the rock fractures around the pebbles. In places the bed is all conglomerate; elsewhere there are sandstone interbeds, but generally there is little difficulty in

TABLE 1

Lithostratigraphic correlation chart

CENTRAL FOOTHILLS	CENTRAL FOOTHILLS	WAWA CREEK	ENTRANCE AND BRÛLÉ	CHUNGO CREEK	COAL VALLEY	RED DEER RIVER	GRANDE PRAIRIE	SOUTHERN FOOTHILLS
Allan and Rutherford, 1923, 1934	Russell, 1932, 1950	MacKay 1943	Lang 1947	Douglas 1958	This Report	Gibson, 1977 McLean, 1971	Kramers and Mellon, 1972	Carrigy, 1971 McLean, 1971
SAUNDERS GROUP (1923): Upper Saunders Coal-bearing Saunders Lower Saunders FOOTHILLS GROUP (1934)	PASKAPOO FORMATION SAUNDERS GROUP	PASKAPOO FORMATION EDMONTON FORMATION: Coal Beds BRAZEAU FORMATION	PALEOCENE Entrance BRAZEAU FORMATION Solomon Member	PASKAPOO FORMATION: Upper, Lower, Sandstone and conglomerate BRAZEAU FORMATION: Upper, Middle, Lower	SAUNDERS GROUP: PASKAPOO FORMATION Coalspur Beds: Val d'Or Seam, Mynheer Seam Entrance BRAZEAU FORMATION	PASKAPOO FORMATION EDMONTON GROUP: SCOLLARD FORMATION: Ardley Coal Zone BATTLE FM WHITEMUD FM HORSESHOE CANYON FORMATION BEARPAW FORMATION JUDITH RIVER FORMATION	PASKAPOO FORMATION WAPITI GROUP: Ardley Coal Zone Upper Kneehills Middle Lower	PORCUPINE HILLS FORMATION WILLOW CREEK FORMATION Kneehills ST. MARY RIVER FORMATION BEARPAW FORMATION JUDITH RIVER FORMATION
WAPIABI FORMATION						LEA PARK FORMATION	SMOKY GROUP	PAKOWKI FM

recognizing the member, as the pebbles are larger and more closely packed than in the pebble beds of the Brazeau formation . . . ".

The name Entrance has not been applied beyond the Entrance map-area because laterally-equivalent beds are not so distinctly conglomeratic. However, Douglas (1958) has equated a zone of coarse-grained sandstones, conglomeratic sandstones, and conglomerates in the vicinity of the North Saskatchewan River to the Entrance Conglomerate on the basis of similarity of their position relative to the coal zone and their lithological resemblance.

Paskapoo Formation

The name Paskapoo was introduced by Tyrrell (1887, p. 135-138) for beds lying above his Edmonton Series (now Edmonton Group: Gibson, 1977) along the Blindman River (formerly Paskapoo River, Cree word for blindman) in the Central Alberta Plains. It consists of " . . . hard, light grey or yellowish, brown-weathering sandstone, usually thick-bedded, but often showing false bedding (crossbedding); also of light bluish-grey and olive sandy shales, often interstratified with bands of hard, lamellar ferruginous sandstone . . .". Tyrrell (1887, p. 138) went on to say " . . . it seems reasonable to place the close of the Cretaceous Epoch at the time of deposition of the topmost beds of the Edmonton series; and that the Tertiary Epoch began with the commencement of the Paskapoo period . . . ".

This unfortunate correlation of a lithostratigraphic unit with a postulated time boundary has always hindered the use of the name Paskapoo as a strictly lithostratigraphic name. Subsequent attempts (Russell, 1932; MacKay, 1943; Douglas, 1958; Irish, 1965) to introduce the name into the stratigraphy of the Foothills belt have not been entirely successful for two reasons:

(1) It has not been possible to physically correlate the Paskapoo Formation from its type area into the outcrop areas of the Foothills.

(2) There has been little success, until recent palynological work, in placing the Cretaceous-Tertiary boundary with any precision within the entirely nonmarine Foothills section.

Examination of Table 1 shows that the name Paskapoo has not been used consistently. Russell (1932, Pl. 2) placed the base of his Paskapoo Formation approximately 1670 m above the Coalspur coal zone, or approximately 2120 m higher than Douglas (1958) subsequently placed the base of his Paskapoo Formation. MacKay's (1943) placing of the boundary was similar to that of Russell. MacKay (1943, p. 4) placed the base at a series of brown-weathering sandstones, conglomerates, and earthy shales which are similar in general appearance to the basal strata of the Paskapoo Formation farther southeast. Bell (1949, p. 14) suggested that the coal zones at Coal Valley and at Saunders belonged to an older stage of the Paleocene than the basal Paskapoo of the type area on Blindman River, but that the lithology of the associated sediments was not sufficiently different to justify their removal from the Paskapoo Formation. However, his criteria for similarity and difference are not stated and he was basing his arguments mainly on his interpretation of the age of plant remains. Douglas (1958, p. 17) included all of the beds referred to the Edmonton and Paskapoo Formations by MacKay (1943) or to the Coalspur beds and Paskapoo Formation by MacKay (1947) in his Paskapoo Formation following the usage of Lang (1947) and Bell (1949).

Correlation with other areas

Introduction

Correlation of the Saunders Group and its subdivisions with lithostratigraphic units in the southern Alberta Foothills and in the Alberta Plains is not certain at this time. This is due to the lack of continuous exposure or even closely spaced sections, and to the scarcity of marker beds of regional significance. Faunal and floral evidence has been both helpful and misleading in correlations. Recent work on palynology has proved rewarding.

Palynology

The work of Tyrrell (1887) first suggested the location of the Cretaceous-Tertiary boundary at the base of the Paskapoo in the Red Deer area of the central Alberta Plains. Since that time, many geologists have attempted to locate the boundary more precisely in both the Plains and Foothills by means of vertebrate paleontology (Sternberg, 1947), invertebrate paleontology (Russell, 1932, 1950), paleobotany (Bell, 1949) and, most recently, palynology (Snead, 1969; Eliuk, 1969; Srivastava, 1970). Opinions have varied widely on the location of the boundary, both on the Plains, and in the Foothills. Recent work in palynology has been most successful because of the small size and abundance of the working material and the greater chance of preservation in an identifiable form. The results of Snead (1969) and Srivastava (1970) in the Plains and of Eliuk (1969) and Gunther and Hills (1972) in the Foothills are shown in Table 2, together with lithostratigraphic nomenclature columns for the two areas.

Snead (1969) indicated that the Cretaceous-Tertiary boundary lies within the interval between his two major floral breaks (Table 2), and Srivastava (1970) placed it at a floral break at the top of the Nevis Seam in the Red Deer River Valley area. The Ardley Coal Zone is, thus, well within the Paleocene Epoch as is the overlying Paskapoo Formation.

The work of Eliuk (1969) suggested an approximate correlation of the Entrance Conglomerate with the Kneehills Tuff, part of the distinctive mauve-weathering Battle Formation of the Red Deer River Valley area. Both are of late Maastrichtian age. Unfortunately, he was unable to position the Cretaceous-Tertiary boundary precisely, indicating only that it is in the 1060 m of strata above the Entrance Conglomerate.

Gunther and Hills (1972) studied a section along the Blackstone River (Fig. 1) and located a single prominent floral break which they correlated with a similar break discovered by Snead (1969) at the boundary between the Scollard Formation (Gibson, 1977) and the overlying Paskapoo. However, their palynological basis for this conclusion is not definitive (Sweet, pers. com., 1978) and their floral break could correlate with a stratigraphic level well down in the Scollard Formation of the Red Deer River Valley area. This floral break appears to be at least 100 m below the main coal-bearing zone on the Blackstone River, which is interpreted to be the stratigraphic equivalent of the coal zone at Coal Valley.

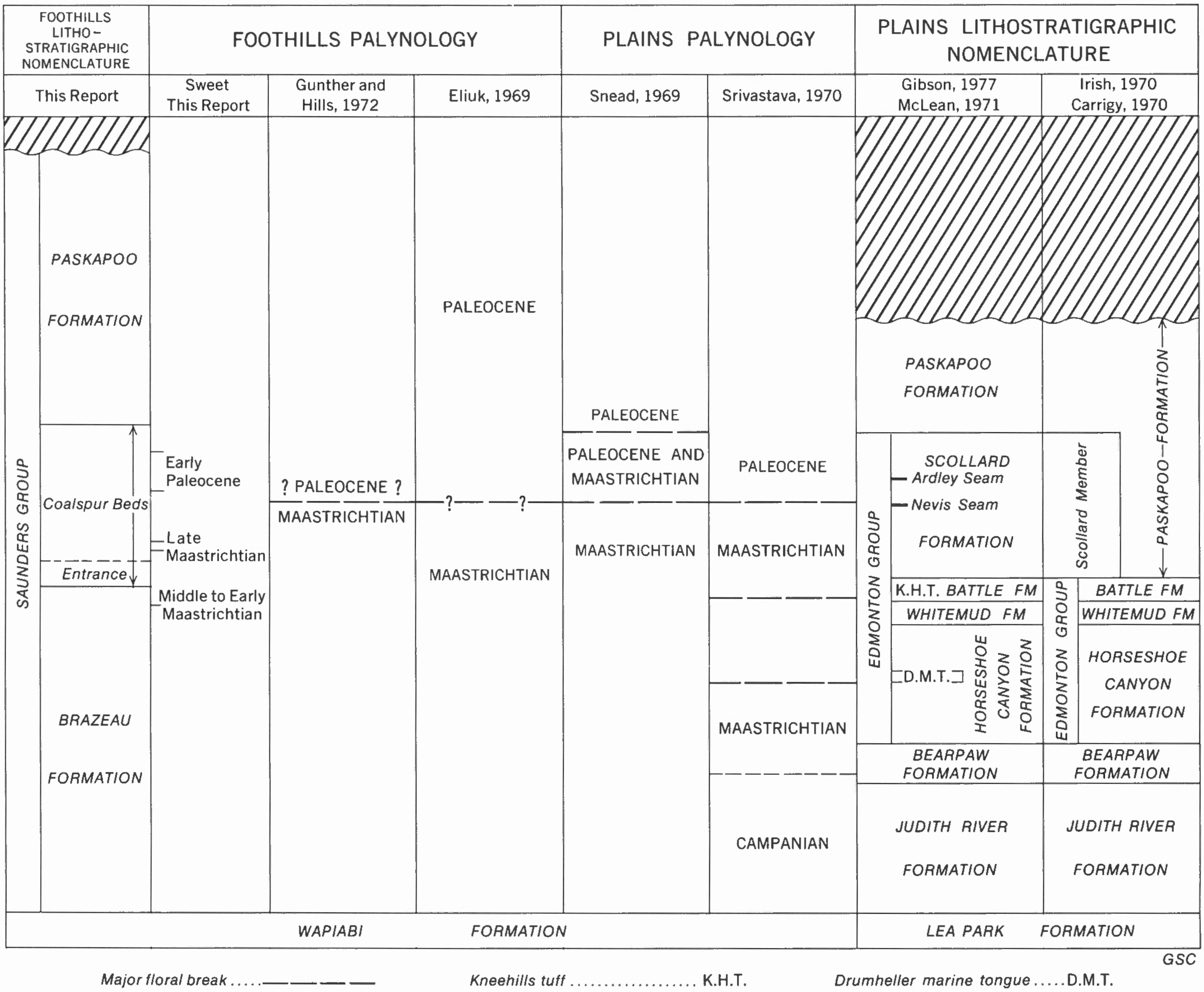
Sweet (Appendix 1) indicated that samples from above the Entrance Conglomerate and below the coal zone at Coal Valley are of latest Cretaceous age, whereas samples from the coal zone are Paleocene. This demonstrates that the Cretaceous-Tertiary boundary lies somewhere in the 275 m above the Entrance Conglomerate, but lack of a complete section precludes exact positioning at present. It is of note that this equates well with the conclusions of Bell (1949) who considered the coal seams as Paleocene. Geologists with the Geological Survey of Canada have followed his designation since that time, and have been correct in considering the Coal Valley coal beds younger than the Ardley zone because, until recent palynological work, the latter was considered latest Cretaceous in age.

We showed previously that Lang (1947) and Douglas (1958) both placed the base of their Paskapoo (or Paleocene) Formation at the base of the Entrance Conglomerate or beds which are considered equivalent. If Eliuk's (1969) approximate correlation of bentonite beds below the Entrance Conglomerate with the Kneehills Tuff is correct, then the base of this Paskapoo Formation would be close, in a time sense, to the proposed revised position of the base of the Paskapoo Formation in the Red Deer River Valley (Irish, 1970; Carrigy, 1970; see Table 2), but well below the originally designated boundary (Tyrrell, 1887; Allan and Rutherford, 1945; Gibson, 1977). Certainly, precedence and lithostratigraphic significance would dictate in favour of the original stratigraphic definition, but this would then place the lower boundary of the Paskapoo Formation well above the Entrance Conglomerate in the Foothills, and leave a thick, unnamed stratigraphic unit between the Entrance Conglomerate and the base of the Paskapoo. If the original definition is maintained in the Plains and the base is placed at the base of the Entrance in the Foothills (Douglas, 1958), then we have the untenable situation of having equivalent coal zones in different formations — the Nevis-Ardley coal zone in the Scollard Formation of the Edmonton Group in the Plains and the Mynheer-Val d'Or coal zone in the Paskapoo Formation in the Foothills. Correlation of the Coal Valley area with the Red Deer River Valley area of the central Plains is shown in Figure 5.

The same situation prevails in correlation between the Coal Valley area and the northwest-central Plains area (Kramers and Mellon, 1972). The main coal-bearing zone in the Wapiti Group in this area has been correlated with the Ardley zone of the Red Deer River valley and the base of the Paskapoo Formation is placed over 100 m above the coal zone (Fig. 6). Thus, the coal zone is in the Wapiti Group here, but correlates with the coal zone in the Paskapoo at Coal Valley. The base of the Paskapoo Formation is approximately 450 m lower stratigraphically at Coal Valley than it is in the Wapiti River area. This discrepancy is also apparent on the Athabasca River map (Price et al., 1977) where the base of the Paskapoo Formation is shown well above both the Kneehills Tuff and the coal zone in the northwest-central Plains, but well below the coal zone at Coal Valley.

TABLE 2

Cretaceous-Tertiary boundary as defined from palynological evidence



Volcanic ash and radiometric dating

Radiometric age determinations were not included in this study but the common occurrence of volcanogenic ash and tuff beds in the Saunders Group make this a potentially very valuable correlation tool as our knowledge of this group improves.

The Kneehills Tuff is a prominent and widespread marker horizon (Sanderson, 1931; Irish and Havard, 1968) which, because of its airborne volcanogenic origin, is essentially isochronous over its area of occurrence in the southern and central Plains of Alberta. It is part of the Battle Formation (Irish and Havard, 1968, p. 10) which is only about 9 m thick but weathers a distinctive mauve-grey colour. A potassium-argon date of 65.1 Ma ± 1.0 was determined by Shafiquallah et al. (1964, p. 3). The Cretaceous-Tertiary boundary is slightly younger at about 63 Ma.

Sanderson (1931, p 64) identified a tuff and bentonite zone in the Coal Valley area which he named the Saunders tuff. He indicated that it occurs 245 m below the Mynheer coal seam and was useful in this area for locating coal seams. However, the authors did not find that it was a readily identifiable marker nor that it was commonly found as outcrop.

Erdman (1945, p. 12) reported, in the Saunders area just north of the North Saskatchewan River (Fig. 1), a 0.3 to 0.6 m thick bed of hard, purple, massive tuff in a section just above a cobble conglomerate zone which appears to be equivalent in stratigraphic position to the Entrance Conglomerate. Coal-bearing beds were located 150 to 180 m above this conglomerate. Thus, the relative stratigraphic positions of this tuff and the Saunders tuff appear to be the same.

If Eliuk's (1969) suggestion that bentonite beds observed 20 m below the Entrance Conglomerate may be equivalent to

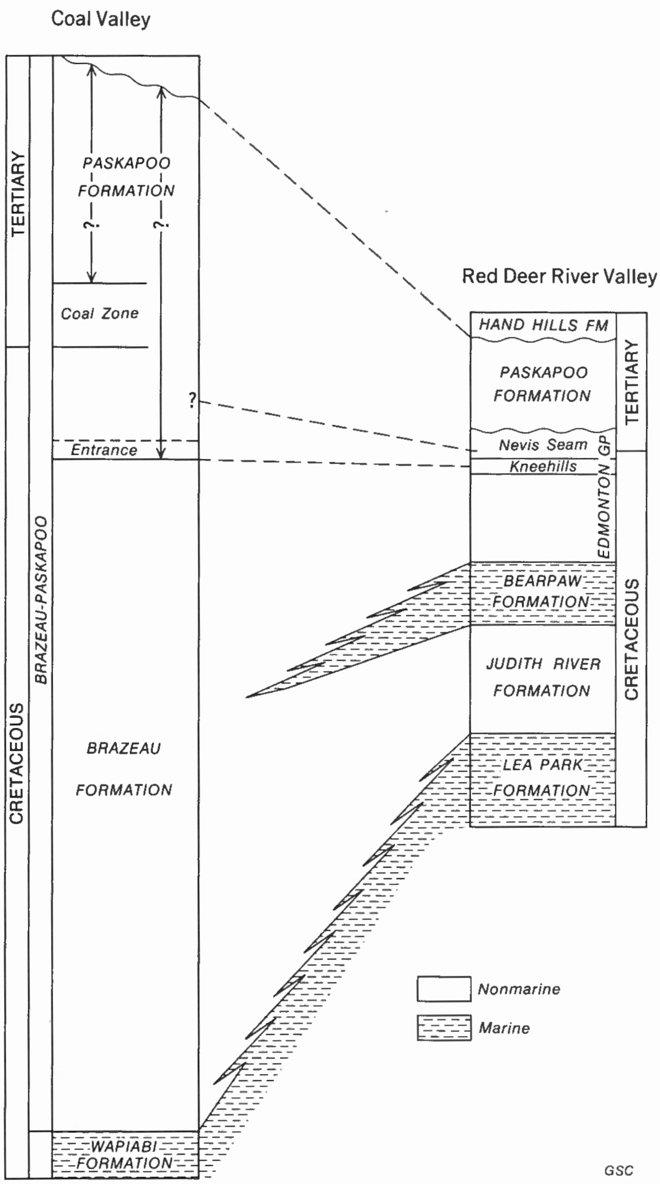


FIGURE 5. *Schematic stratigraphic cross-section from Coal Valley to the Red Deer River Valley.*

the Kneehills Tuff is correct, then the Saunders tuff is younger than 65.1 Ma, but no independent analyses have been done to confirm this. However, the Saunders tuff and the tuff bed of Erdman are located only a short distance (less than 30 m) above the Entrance Conglomerate and may be genetically related to the bentonite beds of Eliuk. Several tuff and bentonite beds make up the Battle Formation in the Red Deer River Valley area, and the higher rate of sedimentation in the Foothills might cause the equivalent beds to be much farther apart stratigraphically than they are in the Plains.

A prominent zone of volcanogenic cherts and bentonites, investigated by Jerzykiewicz and McLean (1977), contains palynomorphs which correlate with the palynomorph zone (Srivastava, 1970) which includes the Kneehills Tuff of the Red Deer River section (Sweet, pers. com., 1978). This does not indicate definitely that the two are physically correlative, but only that they occurred within the same time period and may be physically continuous with one another. The Saunders tuff also occurs within the same palynological zone so that the beds investigated by Jerzykiewicz and McLean (1977) may be equivalent. If this is so, then the vertical displacement on the northeast-dipping thrust fault discussed in that paper, and also by Alexander (1977), would be at least 245 m and probably more than 300 m.

Implications of palynological correlation to lithostratigraphic nomenclature

Equation of the seams at Coal Valley with the Ardley zone seams in the Red Deer River Valley suggests that the base of the Paskapoo Formation in the Foothills should be above the coal seams, if we accept the original stratigraphic definition of the Paskapoo Formation (Tyrrell, 1887; Gibson, 1977). A gap in nomenclature is thus created between the top of the Brazeau Formation and the base of the Paskapoo Formation.

Douglas (1958 and unpub. maps) has been able to map the top of the coal-bearing zone northwestward from the Chungo Creek area to the Coal Valley area. The interval between the base of the Entrance Conglomerate (or top of Brazeau Formation) and the top of this coal-bearing zone comprises a distinct and mappable unit (informal subdivisions 4 and 5 of Saunders Group). This unit appears to be the same as that to which MacKay (1947, 1949) applied the name "Coalspur beds". Although MacKay did not define the boundaries of this lithostratigraphic unit, it is clear from comparison of MacKay's (1949) map no. 18 of the Prairie Creek area with Lang's (1947) Entrance map-sheet that the base is at the top of the Brazeau Formation and at the base of the Entrance Conglomerate. The upper limit was not defined and is unclear from MacKay's (1949) maps. However, it was evidently a name designed to encompass the economically important coal seams and differentiate them from units below and above. Thus, we can readily accept the top as the base of the first prominent sandstone unit above the last major (greater than 0.6 m thick) coal seam. This is comparable to Gibson's (1977) definition of the top of the Scollard Formation, although this does not imply a time equivalence.

The increasing interest in its coal resources make it desirable to have a name for this unit and, following the advice of Douglas (pers. com., 1978), we shall informally use the name Coalspur beds in this report. The Paskapoo Formation lies above the Coalspur beds as shown by MacKay (1949).

The Coalspur sequence differs from the "Saunders coal series" of Allan and Rutherford (1923), which encompassed only the coal zone, in that it includes all of the beds from the base of the lowest major coal seam down to the base of the Entrance Conglomerate or equivalent strata.

The name Brazeau is often considered equivalent to the undivided Belly River Formation and Edmonton Group west and north of the pinchout of the Bearpaw Formation (Figs. 5,6). Correlation between the Red Deer River Valley and the Coal Valley area would place the top of the Brazeau Formation at the base of the Paskapoo Formation thus encompassing the Coalspur beds. However, as stated above, the present usage of the name Brazeau, including only beds up to the base of the Entrance Conglomerate, is consistent and would appear to be firmly entrenched. For this reason, we prefer to use "Coalspur beds" as a separate unit.

We do not feel that we have sufficient data at present to resolve the various complicating factors in the

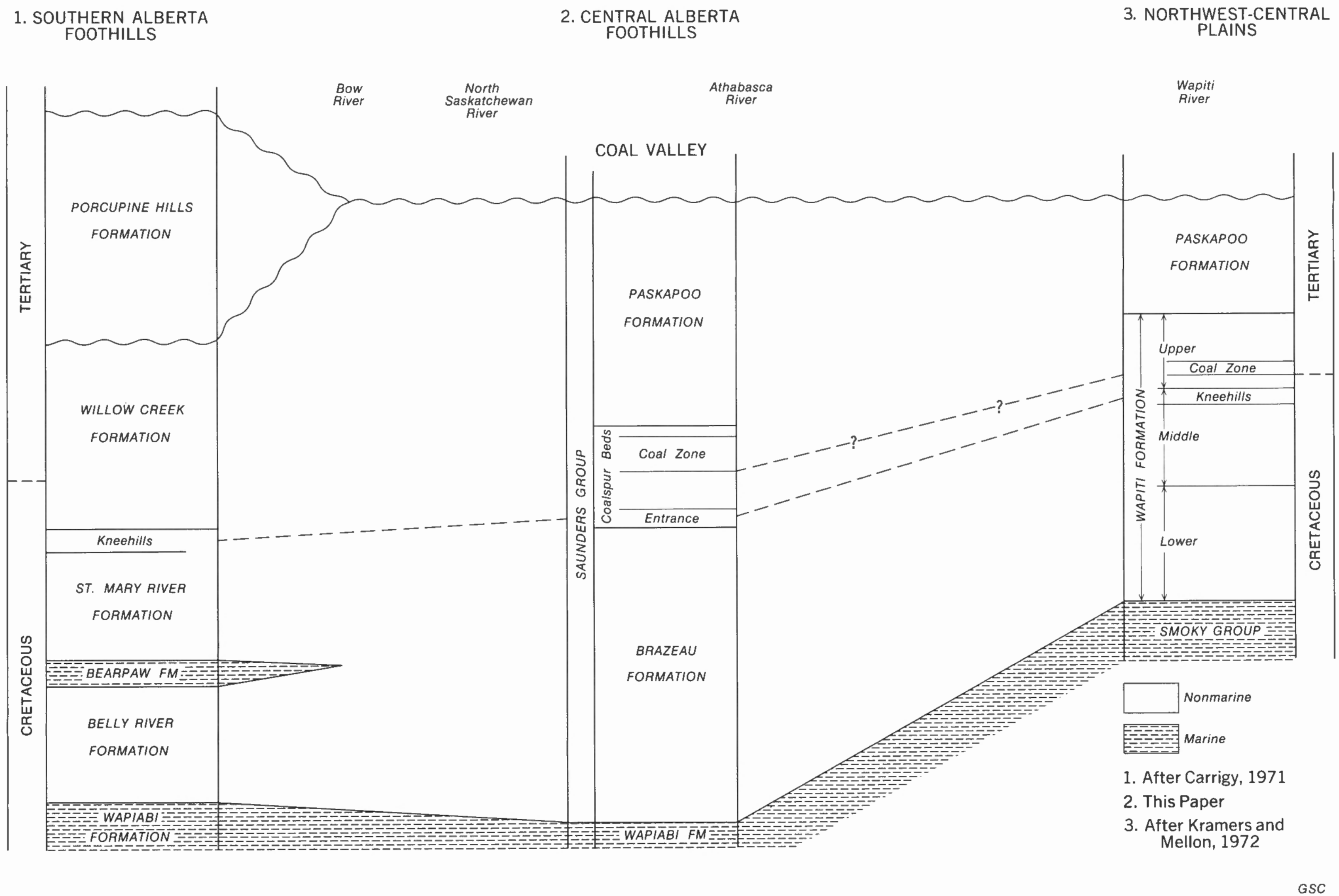


FIGURE 6. *Schematic stratigraphic cross-section from the southern Alberta Foothills to Coal Valley to the northwest-central Plains.*

lithostratigraphic nomenclature of these Upper Cretaceous-lower Tertiary beds. We will use Saunders Group as an all-encompassing name, Brazeau Formation as used by Lang (1947) and Douglas (1958), Coalspur beds informally as defined above, and Paskapoo Formation for higher strata with the lower boundary as defined above and the upper boundary as the erosional surface.

TECTONIC SETTING AND PROVENANCE

The Coal Valley area is situated in the outer Foothills of the Rocky Mountain thrust belt. It is approximately 40 km northeast of the present position of the leading edge of the Front Ranges. Price and Mountjoy (1970) provided evidence that the Front Ranges were probably involved in thrusting in Late Cretaceous time and their restored cross-section (ibid., Fig. 2-3) suggests that the leading edge of the nearest thrust sheet, and therefore the nearest potential source area, may have been less than 120 km from the Coal Valley area.

The Saunders Group constitutes the upper of two major northeast-thinning clastic wedges (Eisbacher et al., 1974) which represent the synorogenic deposits (molasse) of the rising Rocky Mountains. Sediment deposited in the lower, Kootenay-Blairmore clastic wedge may have been involved in thrust fault movements and been eroded to contribute some detritus to this younger clastic wedge (Bally et al., 1966). However, the composition of the Saunders Group sediments (Teifke, 1972) indicates that much of the detritus was coming from a source west of the present Rocky Mountain Trench which included low- to high-grade metasedimentary and metavolcanic rocks. Carbonate grains were probably derived from Paleozoic carbonate rocks in the Front and Main Ranges of the Rocky Mountains.

McLean and Jerzykiewicz (1978) discussed the relationship of gross cyclicity in the Saunders Group to thrust faulting and to subsidence in the foredeep. The Coal Valley area was not in the nearest part of the foredeep but, as suggested above, was only a relatively short distance removed, and the estimated 3600 m of section included in the Saunders Group indicate that the area was subjected to great downwarping during Late Cretaceous-early Tertiary time.

Structure in the area has been mapped most recently by Douglas (in prep.) and in the immediate vicinity of Sterco by Alexander (1977).

LITHOLOGY

Methods

Lithological analysis was effected by detailed measurement and description of columnar sedimentological sections in the field. Ten sections were described in the middle of the study area along the Shaw-Robb line from well-exposed road cuts, railroad cuts, river banks, and abandoned open pit mines (see Figs. 2, 3 and columnar sections 3u, 3, 4, 10, 14, 25, 26, 27, 54, and 55; also Pl. 5A, B). Seven additional detailed sections were measured, close to the Shaw-Robb line (columnar sections 8W, 8E, 18 and 23), and in the Coal Valley area (columnar sections 1, 5 and 6).

These sections range from 3 to 81 m in stratigraphic thickness, with a total of 333 m of section being examined. Characteristics noted on the columnar sections (Fig. 7) are: (1) cumulative thickness (in metres); (2) type of lithology; (3) nature of contact between beds; (4) type of bedding; (5) other sedimentary structures; (6) paleocurrent directions; (7) occurence of fossils; and (8) colour according to the G.S.A. Rock Colour Chart (see Fig. 7 for detailed key to columnar sections). Numbers in column 9 refer to units distinguished in field description and column 10 refers to cyclicity within these units. Column 11 shows the various lithofacies which were recognized and are discussed below. A comparison of section position with the informal subdivisions of the Saunders Group (Fig. 4) is shown in the legend of Figure 7.

Six depositional lithofacies among the coarser clastics were distinguished using symbols modified from those of Miall (1977): (1) Gm - pebble-conglomerate; (2) St - trough crossbedded sandstone; (3) Sp - planar crossbedded sandstone; (4) Sh - horizontally and/or inclined bedded generally medium- to coarse-grained sandstone; (5) Sl - horizontally and/or inclined laminated, generally very fine to fine-grained sandstone; (6) Sr - cross-laminated sandstone.

Finer grained deposits were grouped into the following five lithofacies (1) Fsc - massive and/or laminated siltstones, silty claystone or claystone; (2) Fcf - claystone with freshwater molluscs; (3) Fch - cherts and very fine grained siliceous sandstones; (4) C - coal and carbonaceous shales and sandstones; (5) B - bentonite and tonstein.

Lithofacies Gm: pebble conglomerate

Description

There are two types of lithofacies Gm: (1) those composed predominantly of extraformational clasts; and (2) those composed predominantly of intraformational clasts. The latter are more common and consist of thin layers of rip-up clasts in a sandstone matrix, occurring at the base of sandstone units with abrupt bases. Fragments of claystone, mudstone, siltstone and concretions were observed. Redeposited, angular, clay flakes produced by desiccation were observed in a few places and, in one place, a large claystone clast exhibited a desiccation crack pattern (Pl. 8C).

The only example of a prominent extraformational conglomerate bed in the study area is the Entrance Conglomerate. It is up to 16 m thick with clasts usually 5 cm or less in maximum dimension, but up to 15 cm. Pebbles are usually well rounded and sorted with spheroidal or discoidal shape, and often exhibit good imbrication. The conglomerate is massive to crudely horizontally bedded, but does contain irregular lenses of sandstone, up to 0.5 m thick, which exhibit planar crossbedding in some cases. Extraformational pebble types include quartz, chert, siliceous phyllite, metaquartzite, quartz-muscovite schist, and some volcanic rock fragments.

Examples

Examples of intraformational conglomerates are shown on columnar sections 8E, 8W, 10, 14, 18 and 54. Those shown in Plate 10A and B are examples of the Entrance Conglomerate. The extraformational conglomerate in Plate 13B may also be the Entrance Conglomerate.

Lithofacies St: trough crossbedded sandstone

Description

Lithofacies St is characterized by co-sets of trough crossbeds in medium grained sandstone. Thickness of individual sets varies from 15 to 50 cm. Occasionally, solitary units, with thicknesses up to 1 m, are associated with massive sandstone units (Pl. 11B).

Examples

This facies is a minor component of the sections examined but examples are shown in columnar sections 3, 4 and 23, and illustrated in Plates 11B and 12B.

Lithofacies Sp: planar crossbedded sandstone

Description

These sandstones are characterized by co-sets of both tabular planar and wedge-shaped planar crossbeds. Thickness of individual sets ranges from 0.2 to 1.5 m. Solitary tabular planar crossbedded units have thicknesses up to 3 m. Sandstones are usually medium to coarse grained, sometimes with subordinate granule- or pebble-sized grains scattered throughout or concentrated in irregular pockets or nests.

Examples

This lithofacies is represented in sections 1, 3, 8E, 10, 25, 54, and 55. Illustrations are shown in Plates 4A, 11A, 12A and 13A.

Lithofacies Sh and Sl: flat and/or inclined bedded (laminated) to massive sandstones

Description

These two lithofacies types differ in the size grade of sand grains. Lithofacies Sh is composed of medium- to coarse-grained sandstones and thickness of individual beds is usually greater than 0.5 cm. Lithofacies Sl is composed of very fine to fine-grained sandstones with laminations less than 0.5 cm thick.

Both lithofacies characteristically appear massive in outcrop. This is due to the lack of differences in grain size or composition which would reveal bedding or laminae when differentially weathered. The lack of apparent bedding or lamination does not indicate that the unit is internally massive but only that planes of sedimentation are not visible (see Hamblin, 1965).

Both lithofacies may exhibit horizontal or only slightly inclined (about 5°) bedding or lamination. Laterally, these are transitional to massive beds and, occasionally also, to planar crossbedding in the same unit (see Pl. 13A). Wavy lamination was observed in a few places associated with lithofacies Sl. Plant debris and intraformational pebbles are common in the lower portion of thick Sh sandstone units.

Examples

These lithofacies were observed in sections 3, 4, 8W, 8E, 14, 18, 27 and 54 and are illustrated on Plates 11A and 13A.

Lithofacies Sr: cross-laminated sandstone

Description

Cross-lamination occurs as both trough and planar types in very fine to fine-grained sandstone. Planar cross-lamination was observed most often (Pl. 2B) and is formed by migration of straight-crested ripples (Allen, 1963). Trough cross-lamination, formed by migration of various non-linear crested ripples, was observed less frequently (Pl. 7B).

These structures are commonly observed on intra-bedding surfaces where they exhibit the characteristic rib-and-furrow structure (Pl. 7C), or on upper bedding surfaces where the ripple morphology is visible (Pl. 2C). Occasionally, convolute bedding and other plastic deformation of lamination were observed. Plant detritus is commonly associated with this lithofacies (Pl. 3C). Where lithofacies Sr is associated with coal beds, roots and stems in growth position are common in the upper part of the bed.

Examples

Lithofacies Sr was recorded from sections 3, 3u, 4, 8W, 8E, 10 and 14 and is illustrated in Plates 2A and B, 4B, and 7B and C.

Lithofacies Fsc and Fcf: siltstone, silty claystone and claystone

Description

Lithofacies Fsc and Fcf often consist of thin bedded and laminated alternating units of claystone, mudstone, and siltstone (Pl. 6), although thicker, apparently structureless, beds are plentiful. Plant remains are common and rootlets were observed in some places.

Three distinct associations of Fsc and Fcf lithofacies were recognized:

(1) As thin layers (usually several centimetres thick; occasionally up to 1 m) associated with coal and carbonaceous shale. Examples are illustrated in columnar sections 3, 3u and 8W.

(2) Alternating with sandstone beds of lithofacies Sl or Sr as units usually less than 2 m thick. For example, see columnar sections 8W, 8E, 14, 18 and 27.

(3) As thick sequences composed mainly of claystone or silty claystone with subordinate thin beds of coal or carbonaceous shale and, occasionally, bentonite and ironstone. Where freshwater molluscs were recognized, this sequence represents lithofacies Fcf.

Molluscs were found in several blocky beds of lithofacies Fcf (section 3/bed 35, 8E/38 and 40). Fossils are extremely numerous in some parts of these beds, forming coquina beds. Gastropods and pelecypods are the most frequent components of the coquinas, the former being represented mainly by the genus Viviparus and the latter by the genus Sphaerium (see Tozer, 1956).

Species identified by T. Jerzykiewicz are:

(1) Viviparus sp. cf. leai (Meek and Hayden); see Tozer, 1956, p. 51, Pl. IV, figs. 4-6.

(2) Sphaerium sp. cf. gietzi (Tozer); see Tozer, 1956, p. 43, Pl. II, figs. 10-12.

(3) Unio sp. cf. Stantoni (White); see Tozer, 1956, p. 37, Pl. I, figs. 1-2.

Examples

Numerous examples of these lithofacies are observed in columnar sections 3, 3u, 8W, 8E, 14 and 18. Lithofacies Fcf is particularly prominent in section 8E. Plate 6 illustrates these facies.

Lithofacies Fch: cherts and siliceous sandstones

Description

This lithofacies has been discussed in detail in Jerzykiewicz and McLean (1977). It consists of volcanogenic cherts and very fine grained siliceous sandstones which exhibit cross-lamination and de-watering structures.

Examples

Lithofacies Fch was encounterd only in columnar section 6.

Lithofacies C: coal and carbonaceous shale and sandstone

Description

Lithofacies C includes both coal seams and carbonaceous mudstones and sandstones. Coal in the Coal Valley area is usually of high volatile bituminous rank. In outcrop, seams are commonly highly weathered and friable, but in open pits good bedding and cleat are often well preserved. In certain areas, tectonic thickening of seams has led to destruction of original internal structure (see Alexander, 1977).

Carbonaceous shales are dark grey to brownish-yellow weathering units with a high proportion of carbonaceous or coaly debris. They generally exhibit a distinct platiness or fissility. Carbonaceous sandstones may be dark grey or laminated light and dark grey, with abundant reworked coaly or carbonaceous material or a high proportion of clay and carbonaceous material.

Examples

This lithofacies is common in several sections: 1, 3, 3u, 5, 6, 8W and 8E. Illustrations are presented in Plates 1, 2A, 3A, 5 and 9.

Lithofacies B: bentonite and tonstein

Description

Bentonite beds are usually a very light grey to pale yellow colour. Beds range from a few millimetres to 50 cm or rarely more. They are commonly best preserved where interbedded with coal due to the greater preservation potential in this environment. They are also common in the anomalous columnar section 6, associated with cherts and siliceous sandstones.

The results of several x-ray diffraction analyses of clay-rich sediments is shown in Table 3. Samples 3/8, 3/23 and 8E/52h are unusually rich in kaolinite and are interpreted as tonsteins. All occurrences of tonsteins are intimately associated with coal and carbonaceous beds.

Examples

Lithofacies B is represented in columnar sections 3, 3u, 5, 6, 8E, 8W and 55. It is also common in the anomalous section 6, associated with cherts and siliceous sandstones (Jerzykiewicz and McLean, 1977).

TABLE 3

X-ray diffraction analyses of very fine grained sediments

		CLAY MINERALS						SILICATES			CARBONATES				
SECTION	Bed Sampled	MONTMORILLONITE	ILLITE	KAOLINITE	KAOLINITE AND/OR CHLORITE	CHLORITE	PYROPHYLLITE	QUARTZ	FELDSPAR	CRISTOBALITE	CALCITE	DOLOMITE	SIDERITE	GYPSUM	LITHOLOGY
3	8	7		71				11	11						TONSTEIN
	10	9	3	16				68	4						CLAYSTONE
	16		17		15			56	5			7			
	23	38		53				9							TONSTEIN
	35		8			5		47	3		23	14			CLAYSTONE
	38a		12		14			59	8		3	4			SILTY-CLAYSTONE
3u	33	59							16	25					BENTONITE
	38	86						9			5				
5	2	75		15				6	4						
	11	86						7	3	4					
	16	85	5					5	5						
	18	67						5	16	12					
6D	1	57		19				15	6	4					
	2	27		6				54	13						CLAYSTONE
	4	17						76	7						SILTY-CLAYSTONE
	5	16			3			68	3					10	CLAYSTONE
8 W	3	85			5			3	7						BENTONITE
	6	81	7		5			7							
	9	68	5	14					8	5					
	12	42		27				20	11						
	20	95						5							
	22	15	7	13				65							CLAYSTONE
8E	4	85			3			3	7	2					BENTONITE
	8	89	3		2			4		2					
	11	83	4						13						
	14	71		13				7	9						
	22	90						3		7					
	28a	83	3	14											
	42i		5		4			43	2		17	9	20		CLAYSTONE
	42m		8		11			67	4		5	5			
	47	13	8	26				50	3						
	52h	40	4	45				7	4						TONSTEIN
14	13b	5	3		3		1	77	11						SILTY-CLAYSTONE
55	c	83	4					2	5			6			BENTONITE

GSC

Facies changes

Lateral variability in facies type and thickness is the rule in the Upper Cretaceous-Tertiary sequence of the Coal Valley area. Subsurface correlation between boreholes (Smith et al., 1977) has shown that the main coal seams are the most persistent beds and, therefore, most useful for correlation.

An exceptionally fine example of lateral variability was afforded by an open pit cut (Fig. 2, Loc. 8) northwest of Robb. The Val d'Or coal horizon was mined here exposing the seam and overlying beds at the two ends of the pit approximately 1 km apart (columnar sections 8E and 8W, and Pls. 1A and 6A). Figure 8 shows the two sections with interpreted correlation of facies. The Val d'Or seam at the base is readily correlated and can be physically traced along the walls of the pit. At the top of each section is a thick sandstone unit (lithofacies Sh) with prominent pebble unit at the base (lithofacies Gm). This unit can be traced along the northern pit wall between the two sections.

Between the coal and the sandstone unit, there is little similarity in the sections, and no bed which can be definitely correlated over this 1 km distance. The principal difference is that the eastern wall (section 8E) contains a high proportion of lithofacies Fcf and Fsc, interpreted as lacustrine deposits, whereas the western wall (section 8W) contains an abundance of lithofacies Sh, interpreted as levee and crevasse splay deposits and thus indicating greater proximity to an active channel. Similar lateral variability over relatively short distances can be expected elsewhere as well.

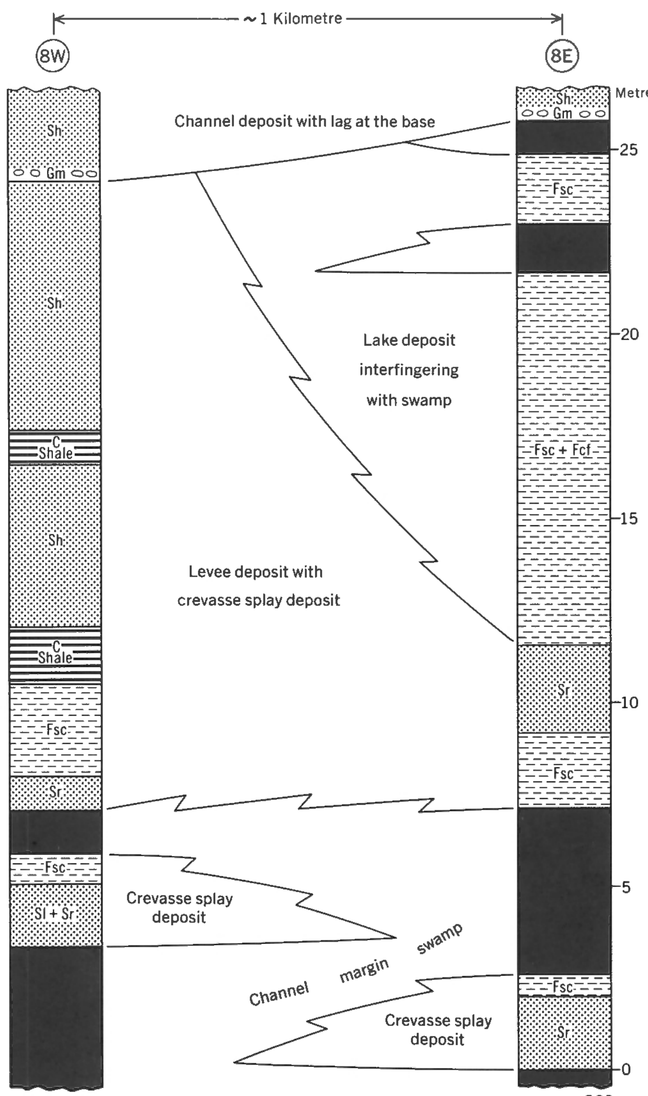


FIGURE 8. *Correlation of stratigraphic sections 8W and 8E.*

LITHOFACIES SEQUENCE ANALYSIS

Methods

"If modern sedimentology has shown anything, it was surely that sedimentary sequences were the resultants of processes which have logical and determinable relationships in both time and space." (A.C. Benfield in Selley, 1970, p. 579.)

Examination of vertical sequences in sediments is probably the fundamental tool in sedimentology. The order in which lithofacies follow one another and the nature of the contacts between lithofacies indicate the changes which took place with time at a particular locality as well as the lateral variability which was present at any one time.

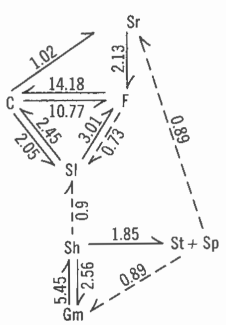
Examination of columnar stratigraphic sections such as those in Figure 7 clearly reveals repetitive vertical sequences and cycles. However, to gain a more objective appreciation of vertical lithofacies sequences and variations in sequence between sections, a more rigorous method of examination is desirable, and a Markov analysis was used. Where a given lithofacies is found to follow another lithofacies with greater than random frequency, the sequence is said to exhibit statistical memory, the Markov property. The simplified technique of Selley (1970) was used which, although he does not refer to it as such, is essentially the same as a first order embedded Markov chain analysis. Multistory transitions (a lithofacies following upon itself) are permitted in this type of analysis.

A total of 410 m are represented by the 17 columnar sections (Fig. 7). Ten of these were not sufficently long to be of value in this analysis. Two were composed predominantly of lithofacies C and were not included. The other five with a total of 296 m were employed. The data available are not completely satisfactory for two reasons: (1) a complete section of the Saunders Group was not obtainable and the five sections probably represent less than 10 per cent of the total post-Wapiabi section; (2) there is some difficulty in positively identifying the location of each section in the stratigraphic column due to paucity of usable marker beds. The result is that it is impossible, at present, to say anything definite about either vertical trends through the whole Saunders Group or lateral trends because of the incompleteness of the 'reference' section and the lack of sufficiently lengthy sections laterally, with which to compare. However, the data presented here are the most complete sedimentological data available on this important sedimentary sequence, and provide some interesting insights into the sedimentology of the group as a whole.

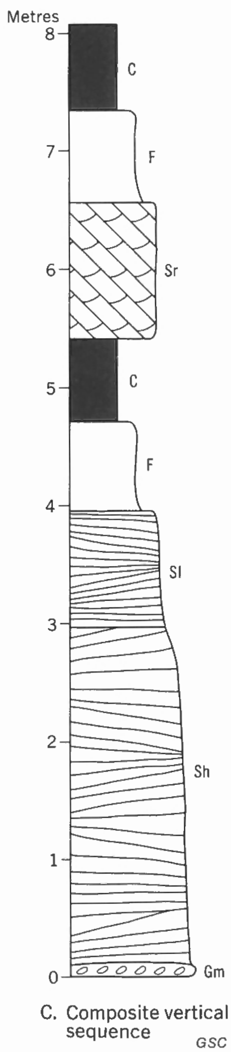
All facies in the columnar sections were used in the analysis except the bentonite beds (lithofacies B) which are believed to have been derived from airborne ash and, thus, are independent of the other, genetically related, waterborne sediments. Sections 3, 8W and 8E were evaluated (Fig. 9) together as they come from approximately the same interval within, or just above, the Val d'Or coal-bearing section. Section 18 (Fig. 11) from the lower Brazeau Formation and section 14 (Fig. 10) from the interval immediately below the Entrance Conglomerate were each evaluated separately. Neither of these latter two sections contains lithofacies C. Figures 9A, 10A and 11A show the tally and difference matrices for each of the sections or section groups. The greatest positive values in the difference matrices were then used to construct facies sequence diagrams (Figs. 9B, 10B, 11B). These are oriented vertically, rather than in the usual horizontal style, since they are easier to interpret and are a more logical format for presenting vertical sequence data. Composite vertical sequences

	Gm	St + Sp	Sh	Sl	Sr	F	C	
Gm	—	0 −0.17	6 +5.45	0 −0.83	0 −0.33	0 −1.87	0 −1.71	6
St + Sp	1 +0.89	—	0 −0.18	0 −0.28	1 +0.89	0 −0.62	0 −0.57	2
Sh	3 +2.56	2 +1.85	—	2 +0.90	0 −0.44	0 −2.50	1 −1.28	8
Sl	0 −0.88	0 −0.44	0 −1.47	—	1 +0.12	8 +3.01	7 +2.45	16
Sr	0 −0.33	0 −0.17	1 +0.45	1 +0.17	—	4 +2.13	0 −1.71	6
F	1 −0.71	0 −0.85	1 −1.84	5 +0.73	1 −0.71	—	23 +14.18	31
C	1 −0.98	1 +0.01	2 −1.30	7 +2.05	3 +1.02	22 +10.77	—	36
	6	3	10	15	6	34	31	105

A. Tally and difference matrices
2 - tally
+1.78 - difference between observed number of transitions and the number of transitions in a random sequence



B. Facies sequence diagram



C. Composite vertical sequence

GSC

FIGURE 9. Lithofacies sequence analysis for sections 3, 8E and 8W.

(Figs. 9C, 10C, 11C) show average thicknesses for each lithofacies, arranged in their most frequent pattern. Data are insufficient for these to be considered as norms, but they do give a useful indication of the relative thicknesses of the various facies encountered.

Observations

Lithofacies Gm is a natural starting point in analysis of sequences for two reasons: (1) it overlies a scoured base, representing an erosional event preceding a series of accretionary events; and (2) it contains the coarsest clast sizes and thus probably represents the highest energy conditions in the sequence. Where lithofacies Gm is absent, lithofacies Sh, Sl, Sp or St may occur at the base of the accretionary unit. Examination of the logs of longer sections (Fig. 7, sections 3, 8E, 8W, 14, 18) or the composite vertical sequences (Fig. 9-11) indicate clearly that the sections can be divided into coarser grained and finer grained facies. The coarser grained facies are composed of one or more of lithofacies Gm, Sh, Sl, Sp, St and Sr. The finer facies are composed of the other lithofacies described previously plus some of those in the coarser grained facies such as lithofacies Sl and Sr (see Fig. 7, sections 3, 14 and 18).

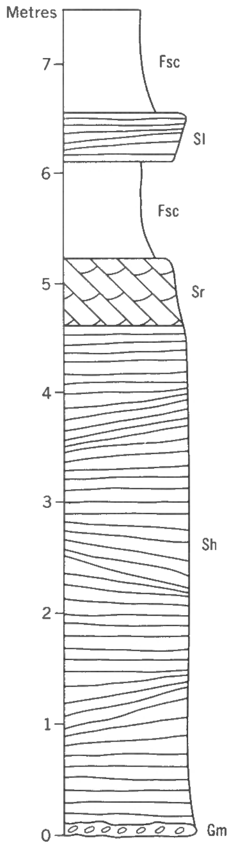
Lithofacies Sh is predominant at the base of the coarser grained facies overlying lithofacies Gm (sections 3, 8E, 8W, 14 and 18). The frequent lack of distinctive bedding planes of any type in this lithofacies renders interpretation difficult as there may be unseen crossbedding. Where grain size is less than medium grained, the lithofacies becomes Sl (sections 14, 27) rather than Sh, but they are otherwise similar. Lithofacies Sp and St are not commonly associated with lithofacies Sh and Sl. Where observed (as in section 8E/53 and 55), Sp overlies Sh abruptly, and St overlies Sp gradationally (section 3, 7 to 9 m). These associations were not observed frequently enough to establish them as typical.

The coarser grained facies is often, but not always capped by a unit of Sr (sections 3, 3u, 8W, 14). Lithofacies Sl is frequently overlain by lithofacies Fsc, and occasionally by lithofacies C. In a few sections (3, 8E, 8W) the coarser lithofacies truncate and overlie older units of the coarser lithofacies.

The finer grained lithofacies are characterized by very thin to very thick interbedding of lithofacies Fsc, Fcf, C, Sl, and Sr. The distinction between the Sl here and that associated with the coarser grained facies is not always clear but, in the former, the Sl units tend to be markedly thinner and do not have a Gm unit at the base (see section 14/15). Lithofacies Sr occurs isolated from other coarser grained facies (sections 8E and 8W) or with facies Sl (section 3u).

Two couplets occur frequently in the finer grained facies. Lithofacies Fsc and Sl alternate with one another (section 14) with Sl abruptly overlying Fsc but Fsc gradational upward from Sl (/Sl → Fsc/Sl → Fsc/). In coal-bearing sequences, Fsc commonly alternates with C (sections 3u, 8E, 8W). Both contacts may be gradational or abrupt. Lithofacies Sl may also occur in this sequence and may form a triplet, /Sl → Fsc → C/ (section 8W/14 to 18 m) or may be associated only with lithofacies C (section 3u/17 and 18 m).

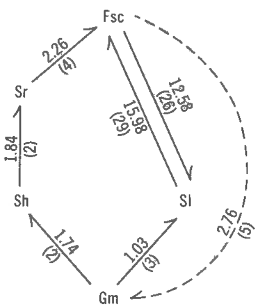
Lithofacies Fcf was distinguished from lithofacies Fsc only by the presence of recognizable freshwater fauna. It was recognized only in sections 8E/38 to 40 and 3/34 to 35. In both cases it is associated with lithofacies C.



C. Composite vertical sequence

	Gm	Sh	Sl	Sr	Fsc	
Gm	0 −0.33	2 +1.74	3 +1.03	0 −0.26	0 −2.17	5
Sh	0 −0.20	0 −0.16	1 −0.18	2 +1.84	0 −1.30	3
Sl	0 −1.97	0 −1.58	0 −11.84	1 −0.58	29 +15.98	30
Sr	0 −0.26	0 −0.21	0 −1.58	0 −0.21	4 +2.26	4
Fsc	5 +2.76	2 +0.21	26 +12.58	1 −0.79	0 −14.76	34
	5	4	30	4	33	76

A. Tally and difference matrices

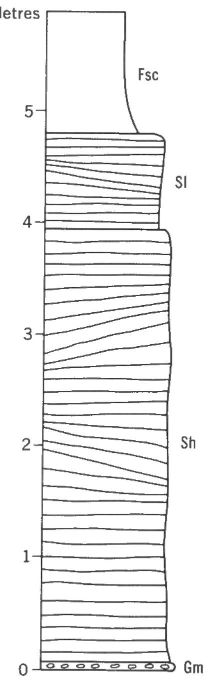


B. Facies sequence diagram

2.76 - Difference value from matrix
(5) - Number of observed transitions

GSC

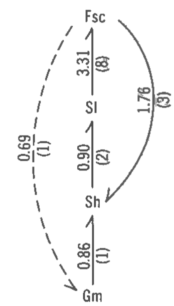
FIGURE 10. Lithofacies sequence analysis for section 14.



C. Composite vertical sequence

	Gm	Sh	Sl	Fsc	
Gm	0 −0.03	1 +0.86	0 −0.55	0 −0.28	1
Sh	0 −0.07	0 −0.28	2 +0.90	0 −0.55	2
Sl	0 −0.59	0 −2.34	9 −0.38	8 +3.31	17
Fsc	1 +0.69	3 +1.76	5 +0.03	0 −2.48	9
	1	4	16	8	29

A. Tally and difference matrices



B. Facies sequence diagram

0.86 - Difference value from matrix
(1) - Number of observed transitions

GSC

FIGURE 11. Lithofacies sequence analysis for section 18.

Lithofacies Sr occurs either randomly in the section within a coal-bearing unit (section 3u/25) or as a couplet with lithofacies Fsc (section 8E/35 and 36 and 8W/31).

Interpretation of depositional environments

General

Comparison of the observed lithofacies and their sequence with the abundant examples of modern and ancient terrigenous clastic depositional environments to be found in the literature indicates a nonmarine, fluvially dominated environment of deposition for the Saunders Group sediments. The coarser grained lithofacies were deposited within or proximal to fluvial channels and the finer grained lithofacies in the floodplain or in abandoned channels (Fig. 12).

Channel lithofacies

The products of deposition in fluvial channels can be very complex and are influenced by many factors such as hydrology, topography, tectonic setting and the amount of vegetation (cf. papers in Miall, 1978). However, internal morphology of individual bedforms is related to specific hydrological conditions which relate all bedforms of the same type. Studies of modern and ancient fluvial environments plus controlled flume studies make certain conclusions possible.

Lithofacies Gm, when present as thin units at the base of sandstone units, is interpreted as a channel lag deposit – the coarse debris which accumulates in the thalweg of a channel and is moved only by the most powerful flood currents. Extraformational pebbles may have been transported long distances, but intraformational clasts of penecontemporaneously deposited sediments are believed to be of very local derivation. Thicker conglomerate beds, such as the Entrance Conglomerate, are interpreted as the product of superimposed longitudinal bars (cf. Rust, 1972).

Lithofacies St, trough crossbedded sandstone, is formed by downstream migration of sinuous-crested dunes. They may occur as single sets or several superimposed sets (Allen, 1963) or associated with other sedimentary structures such as in point bar deposits (Allen, 1970).

Lithofacies Sp, planar crossbedded sandstone, is formed by downstream migration of large scale asymmetrical dunes with essentially straight crests. They can occur in the same associations as trough crossbeds. Both St and Sp are formed under lower flow regime conditions (Simons et al., 1965).

Lithofacies Sh and Sl, when composed of low angle crossbeds, may be lateral accretion deposits of point bars (similar to epsilon crossbeds of Allen, 1963). However, when the sandstone is massive there is the possibility of cryptic sedimentary structures and interpretation is uncertain. Horizontal bedding or lamination may be due to upper flow regime, high energy, conditions (Simons et al., 1965) when bedforms are obliterated and only horizontally bedded

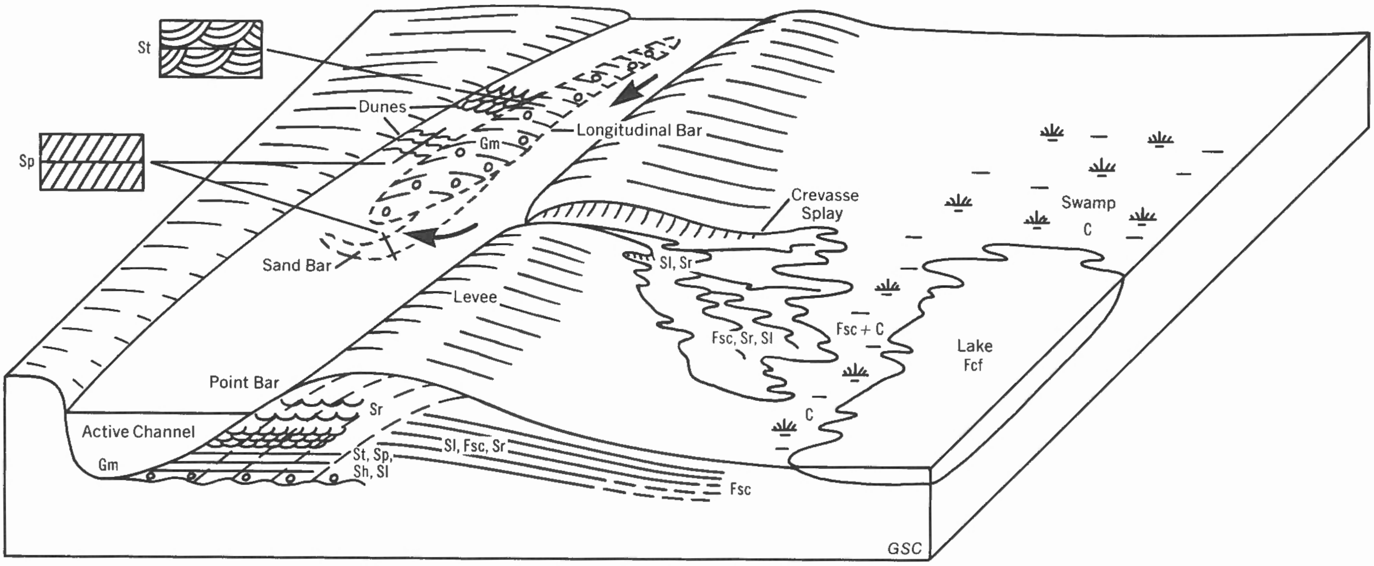


FIGURE 12. *Schematic environmental disposition of lithofacies.*

deposits are formed. The interpretation of these deposits is discussed in McLean and Jerzykiewicz (1978) and will not be pursued here except to say that they may represent preferential preservation of highest energy, unusual flood event deposits.

Lithofacies Sr may consist of planar or trough type ripples formed by migration of ripple trains of the same morphology as their larger counterparts, Sp and St. They may form almost anywhere in a channel if conditions are right, but are most often preserved as bar top deposits above higher energy forms such as other coarser grained lithofacies (Fig. 12).

Floodplain lithofacies

The finer grained lithofacies form outside of active channels and may be very complex in their internal geometry. They can be effectively subdivided into two classes: lower and higher relative energy. The higher energy deposits are those which are deposited during the active phase of flooding when flood waters inundate part of the floodplain and then gradually recede. Lithofacies Sl and Sr are the two most commonly identified and, as already seen, are also common in the coarser grained lithofacies. They are deposited as levees, crevasse splays, or by the flow of flood waters across the floodplain during flooding or during recession of the flood. The lower energy deposits can be divided into two types: (1) those formed by settling of flood-derived detritus in depressions infilled by the flood waters (lithofacies Fsc and Fcf are of this type); and (2) those formed by locally derived sediment, such as lithofacies C where represented by coal deposits. Lithofacies C may be associated with the first type of lower energy deposit in the form of carbonaceous mudstones, and with higher energy deposits in the form of carbonaceous sandstones. Coal beds clearly represent swamp deposits situated distally from active channels. The presence of lithofacies Fsc interbedded with coal indicates that occasional inundation by floodwaters did occur, and the occasional bed of Sl or Sr suggests either greater proximity to an active channel (possibly only a flood channel tributary to the main channel) or a flood of unusual intensity. Lithofacies Sl, Fsc and Sr in association (sections 8E, 8W, 14, 18) represent natural levee, crevasse splay, and well-drained (noncarbonaceous) swamp deposits (Fig. 12). Lithofacies Fcf is interpreted as lake deposits and the common association with lithofacies C suggests that lakes may have formed over former swamps when the latter were drowned by rising water tables, and that swamps formed in former lakes as the latter gradually infilled and vegetation was able to thrive.

Both lithofacies Fch and B are derived from diagenetic alteration of airborne volcanic ash and, while not indigenous to floodplain environments, are preferentially preserved there because of lower energy conditions.

CYCLICITY

Examination of lithostratigraphic sections in association with sequence analysis indicates two levels of cyclicity in the Upper Cretaceous-Tertiary sequence. The larger of the two consists of successive couplets of in-channel and overbank sequences, each cycle representing: (1) introduction of a channel to the area by lateral migration or avulsion with scouring of underlying beds; (2) aggradation with infilling of part or all of the channel before the channel shifted position; and (3) deposition of overbank sediments on the floodplain which continued until a channel again occupied the particular site. The best example of this is in section 14.

The second level of cyclicity is encompassed in the overbank sediments themselves and has been described in the previous section. The cycles are composed principally of couplets of /Sl → Fsc and /Fsc → C representing alternation of energy levels on the floodplain - higher energy and coarser sediment during flood peaks, and lower energy and finer sediments during waning floods and between floods. Excellent examples are shown in sections 3u and 14.

A higher order cyclicity, not observable in individual outcrops, can be seen in the entire Upper Cretaceous-Tertiary sequence. Parts of the section contain a higher proportion of sand beds and coarser clasts (Fig. 4). The data are taken from regional mapping by Lang (1947), Douglas (1958) and Ollerenshaw (1968). Sedimentologically, the data are incomplete but they do indicate a large scale cyclicity, each cycle encompassing hundreds of metres. Detailed sedimentological examination would probably reveal a greater number of cycles and greater complexity of cyclicity than are apparent in Figure 4.

A comprehensive discussion of the nature and interpreted origin of the three orders of cyclicity has been presented elsewhere (McLean and Jerzykiewicz, 1978) and will not be repeated.

PALEOCURRENT ANALYSIS

The following sedimentary structures were examined as paleocurrent indicators: (1) large scale planar crossbedding; (2) inclined bedding; (3) trough crossbedding; (4) cross-lamination and (5) pebble imbrication. Where available, bedding plane features such as sole markings and ripple marks also were employed.

Field data were corrected for tectonic tilt using the method described by Potter and Pettijohn (1963, p. 259). Computation of mean azimuth followed the method of Curray (1956). Data for planar and trough crossbedding and inclined bedding were weighted using the method of Miall (1974) which gives greater directional importance to larger crossbeds using a standard calculation to estimate volume of each crossbed set. Tectonic tilt-corrected data, as well as results of mean computation, are presented in Appendix 2.

Paleocurrent readings are shown on the columnar sections (Fig. 7) adjacent to the bed in which the reading was taken (column 6 of all sections).

The paleocurrent map (Fig. 13) presents the data grouped according to each structure type and for each outcrop. Arrows correspond to mean paleocurrent directions calculated for each outcrop or to individual readings if only one measurement was obtained. Rose diagrams summarize data from the whole area grouped together according to each sedimentary structure type. The rose diagram for imbricate pebbles in the Entrance Conglomerate is from a single outcrop (outcrop 33, Fig. 2).

The relatively small number of readings obtained from the entire 3000 m thick sequence does not permit a detailed interpretation of vertical or lateral variation in the alluvial paleocurrent system. However, some useful observations can be made.

The principal paleoslope was to the northeast. This is illustrated particularly well by the trough crossbedding which resulted from downstream migration of dunes on the channel floor. The rose diagram for planar crossbedding is also unimodal and indicates a dominant northeasterly transport direction. The greater directional variability can be explained as accretion on the slipface of bars oriented obliquely to the mean channel direction (High and Picard, 1974; Miall, 1977).

The rose diagram for inclined bedding is polymodal although the mean direction is still to the northeast. However, modes nearly perpendicular to this direction are also present. We believe that most of the inclined bedding is of two origins: (1) lateral accretion deposits on point bars in the fluvial channel which would be oriented approximately perpendicular to the mean channel direction; and (2) levee and crevasse splay deposits accumulated immediately adjacent to the channel and also oriented approximately perpendicular to the mean channel direction. These beds should be distributed nearly equally on both sides of the channel and, when combined, would tend to give an average downstream reading. The mean current direction is clearly to the northeast, rather than the southwest because both types of inclined bedding have a tendency to be oriented slightly downstream rather than exactly perpendicular to the mean flow direction.

The mean current direction indicated by the cross-lamination is also strongly northeast, although there is a secondary mode perpendicular to this to the southeast and some values to the northwest as well. This is to be expected since many ripples in overbank deposits (lithofacies Sr) would be oriented approximately perpendicular to the channel orientation. However, many ripples in the overbank setting may be oriented nearly parallel to the channel due to sheet flow during late stages of flooding when floodwaters are moving in collection channels back toward the main channel.

The rose diagram for imbrication in the Entrance Conglomerate shows the orientation of poles perpendicular to the inclined surfaces of imbricate pebbles. There is a broad spread of values in the northeast and northwest quadrants but, again, the mean indicated current direction is distinctly to the northeast.

No attempt has been made to differentiate the data according to relative vertical position in the section but the similarity of mean paleocurrent directions from all sources suggests a consistency of mean paleoslope during deposition of the entire succession. The indicated source area is to the southwest.

Studies by Carrigy (1971) and Rahmani and Lerbekmo (1975) included interpretation of paleoslope for sediments of the same age. Carrigy (1971, Fig. 5) indicated an east-southeasterly (108°) paleocurrent direction from crossbedding readings from the entire Paskapoo Formation in Alberta. Data presented by Carrigy in the area of the present study are sparse, and indicate a north-northwesterly paleocurrent direction. Neither of these coincides with our findings but our level of detail is much greater than that of Carrigy, who was examining the succession regionally.

The work of Rahmani and Lerbekmo (1975, Fig. 9C), based on analysis of heavy mineral suites with no paleocurrent determinations, suggested a predominantly southeasterly paleoslope. This is not consistent with our findings and, indeed, their results must be viewed critically as their methods do not yield unequivocal evidence of paleoslope. However, our area of study is toward the western margin of the depositional basin and the paleoslope here may reflect only the slope of proximal deposits. The fluvial system may have turned to the east and southeast once it had reached beyond the Coal Valley area. Carrigy (1971, Fig. 4) indicates such a paleoslope in the Red Deer River area, well east of the Foothills and approximately 300 km southeast of the Coal Valley area.

GEOLOGY OF COAL

Stratigraphy of coal seams at Coal Valley

The main coal zone, consisting of several seams or seam groups over a stratigraphic interval of 250 m, lies some 275 m above the Entrance Conglomerate (Table 1, Fig. 15) which is approximately 1820 m (Lang, 1947) above the base of the Brazeau Formation. Figure 14 shows the named seams and the approximate stratigraphic thickness between them. Mining, confined to the Val d'Or, Silkstone, and Mynheer seam groups, began in the early part of this century and continued into the 1950's. Loss of the steam locomotive market forced mines to close, and only now is activity being renewed with the beginning of production by Luscar Sterco Ltd. at Sterco (Fig. 1) in 1978.

Allan and Rutherford (1923, 1924), and Rutherford (1925, 1926) studied the coal-bearing sequence between the North Saskatchewan and Athabasca Rivers. They observed

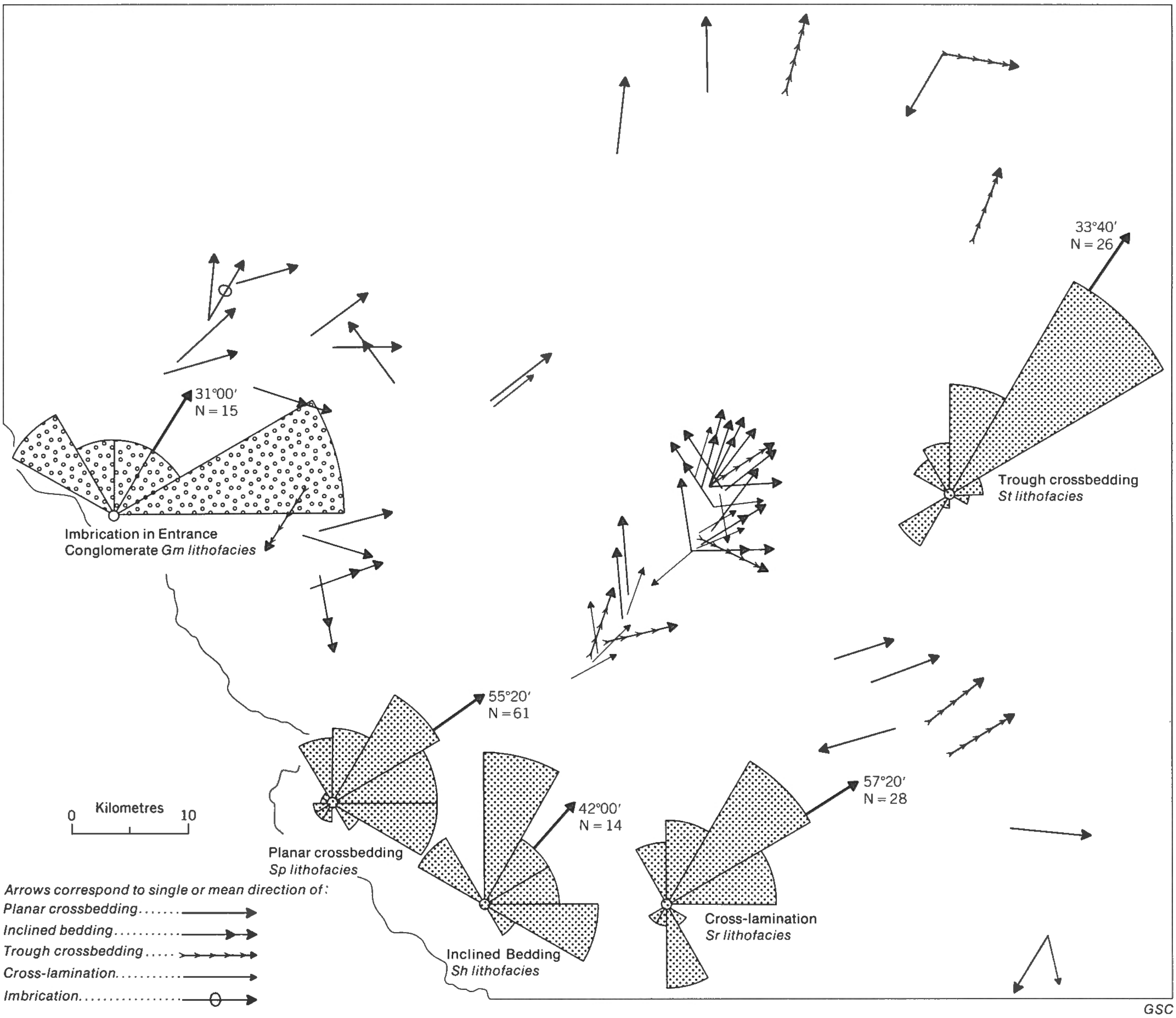


***FIGURE 13.** Paleocurrent map. Area as shown in Figure 1.*

that the thickest seams and the greatest number of seams occur in the area of Coal Valley and the Brazeau River. The stratigraphic section in Figure 15 summarizes their observations for the Brazeau River area. The number and stratigraphic position of their seam groups may not be reliable as they were correlating isolated outcrop sections over long distances. The No. 3 seam group is the only one mined in the Coal Valley area but other seam groups have been mined in adjacent areas to the south and north. The lateral continuity of these seam groups is unknown but, only 19 km south of the Brazeau River, along the Blackstone River, only one seam group was recognized (Allan and Rutherford, 1924) suggesting that lateral continuity may not be great. Later work by MacKay (1943), Lang (1947), and Douglas (1958, and in prep. a, b) suggests that the seam group at Saunders is the same as that at Coal Valley, and palynological work suggests that these are equivalent to the Ardley seam group of the Plains. Great lateral continuity is thus indicated.

Continuity of individual seams is less than that of groups but insufficient data were available to give exact figures. Some indication of seams pinching out laterally is shown in Figure 14.

Rutherford (1925, p. 55) observed that there appears to be a rapid decrease in the thickness and number of coal seams from northeast to the southwest across the strike of the formations, and that this appears to be a general characteristic of the sequence in the Foothills belt. This observation could not be substantiated in the relatively small area studied.

Characteristics of coal

The seams being mined at the Luscar-Sterco mine are high-volatile C bituminous coal. Ash content averages about 15 per cent, calorific value 11,200 BTU/lb, and sulphur

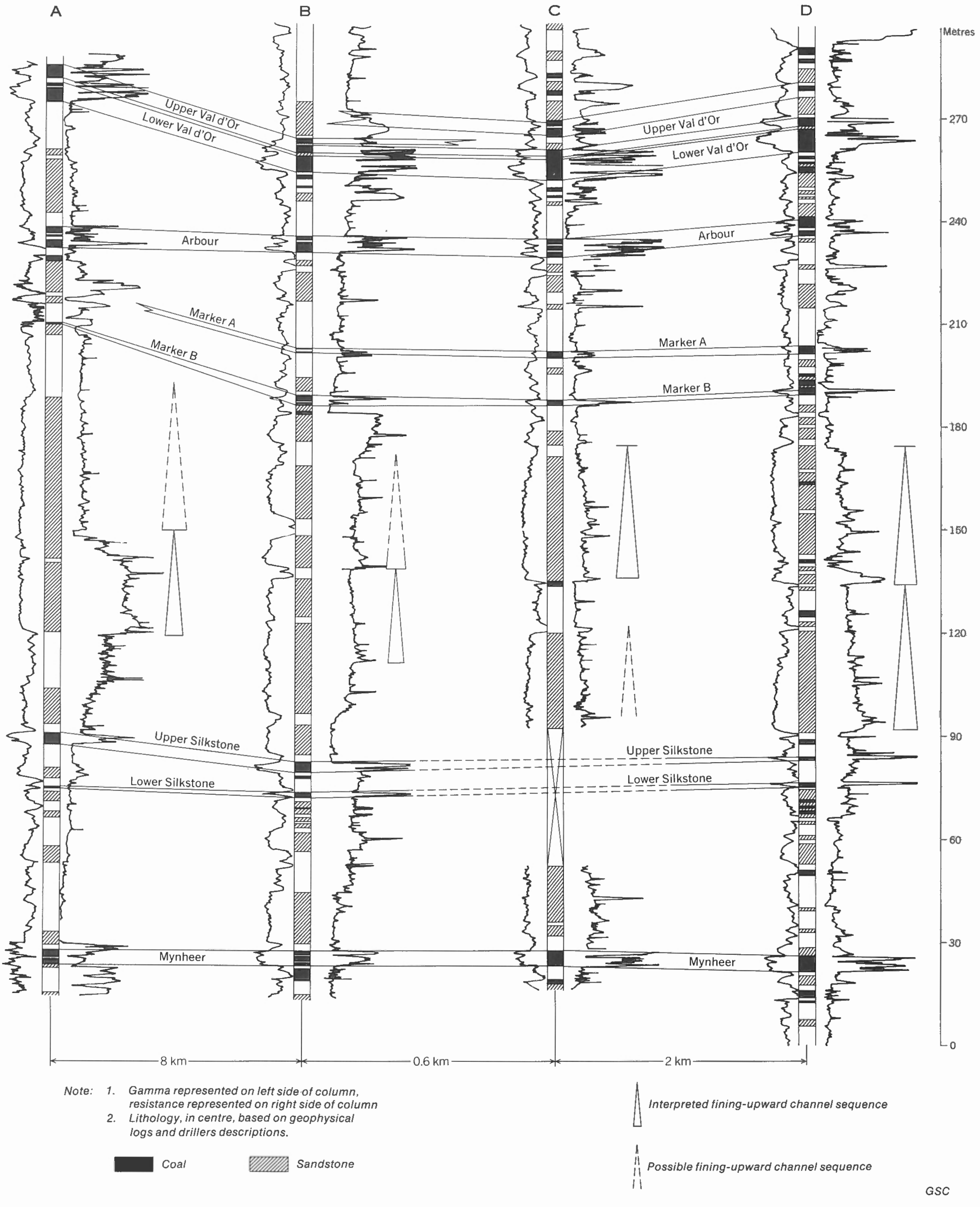


FIGURE 14. *Coalspur coal zone correlated on geophysical logs (modified after Smith et al., 1977).*

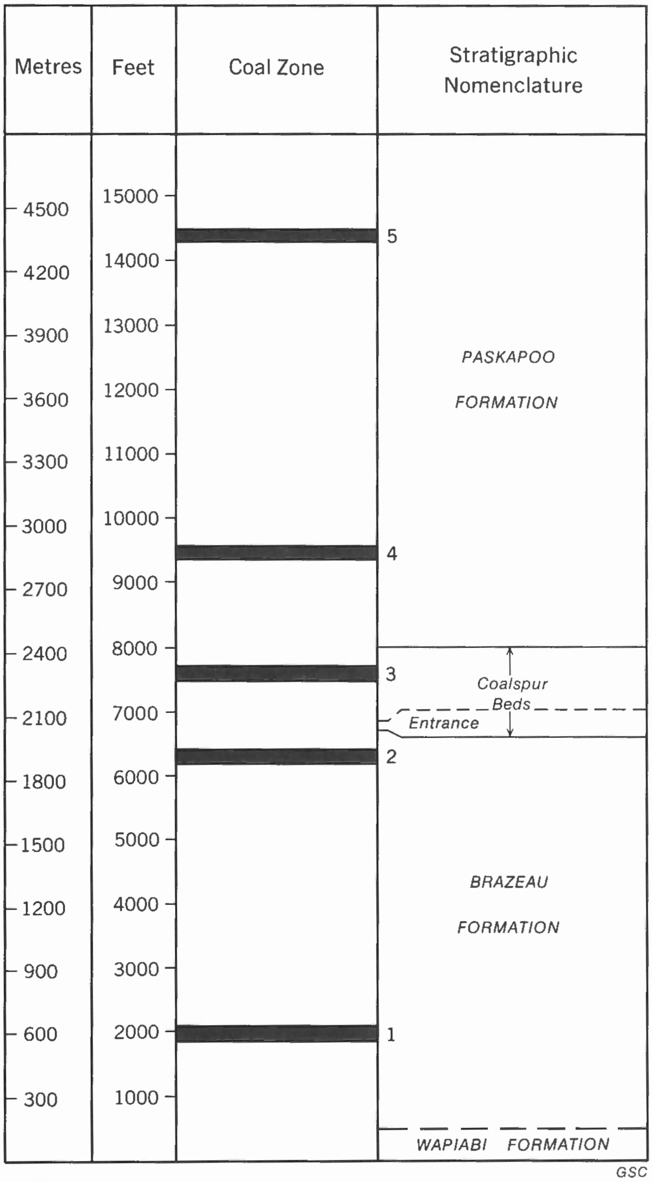


FIGURE 15. *Coal zones in Saunders Group, Brazeau River (data from Allan and Rutherford, 1924).*

less than 0.5 per cent. Number and thickness of partings vary widely and, in some areas, thick seams are not mined due to inferior quality (Rutherford, 1925, p. 18) caused by clay partings and bands of dirty coal. Some indication of lateral variation in seam characteristics can be seen in Figure 14 (from Smith et al., 1977). Some of the partings are bentonite and are interpreted as altered airborne volcanic ash. Others are of waterborne origin (see Fig. 14; Smith et al., 1977; and columnar sections 8E and 8W).

Sedimentology of coal seams

Analysis of sediments associated with the coal seams at Coal Valley indicates that the coal formed in an alluvial environment. Channel sandstones and overbank deposits have been described and illustrated from outcrop, and can also be seen on geophysical logs. In Figure 14, the interval between the Upper Silkstone seam and marker B shows two distinct channel sandstones identified by the upward convergence of the gamma and resistivity curves (bell shaped). The two channels can be identified in logs C and B as well. In log A, only one good bell shape is observed, but the thick sand immediately above may be the second channel sand, the resistivity signature of which is not clear, possibly due to greater conductivity in this sand than in the underlying sand. The lateral extent of seams is not known definitely but the Mynheer seam (Fig. 14) has been mined over a distance of at least 30 km in a northwest-southeast strike direction although there may be gaps in the coal seam over this distance. Its extent perpendicular to strike is unknown.

The presence of many root zones suggests that at least some of the coal beds are autochthonous. Their absence elsewhere may indicate an allochthonous origin for some coals. The relatively small amount of mineral matter observed in these coals, as well as their relatively great lateral extent, suggests that they may be 'hypautochthonous' coals (Stach et al., 1975, p. 19) rather than coals derived from vegetation transported significant distances. Hypautochthonous coals are not strictly *in situ* but the original vegetation was moved about only within the depositional area. Floating peat batteries (Gleason and Stone, 1976) such as those observed in the Everglades area today may have produced extensive peat accumulations with no visible root zones beneath.

Coal in the alluvial environment

The scarcity of good outcrop exposures in the Coal Valley area precludes any attempt to reconstruct the alluvial setting in detail. However, there are characteristics of modern peat accumulations in alluvial settings which may be useful as predictive and interpretive tools.

There are five prerequisites for accumulation of sufficiently thick peat deposits to form commercial coal seams: 1) a favourable climate, particularly one which provides sufficient moisture (temperature is a secondary consideration); 2) an adequate supply of plant material; 3) freedom from influx of detrital clastic material; 4) a balance between the groundwater table and the depositional interface; and 5) persistence of conditions in space and time (Stach et al., 1975; Weimer and Land, 1976; Schopf, 1973). All of these conditions have been met when a thick coal seam is preserved.

Peat accumulations are normally found only in those river systems with well-developed floodplains and those in which overbank deposits constitute a substantial proportion of the alluvial record. Peat is usually not associated with sandy braided rivers but is common along meandering rivers, although in certain settings both peat deposits and thick overbank sediments could be associated with braided rivers (see McLean and Jerzykiewicz, 1978).

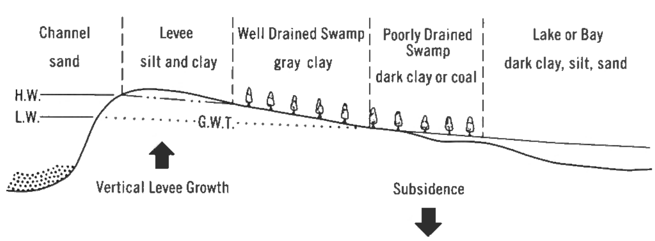
There are three common settings in which peat may accumulate: 1) in abandoned channels; 2) in the overbank area of active channels; and 3) on the floodplain, isolated from the active channel.

Abandoned channel segments or meander loops are good natural depressions in which floating vegetation or rafted vegetation can accumulate and, depending on depth, rooted plants and trees may be common. The latter will increase in abundance as the abandoned channel is infilled by vegetation and flood-borne sediment. Coal seams from such peat accumulations tend to be narrow and elongate with a curved or sinuous pattern. They are often thin and contain a high proportion of fine terrigenous clastics but may be thick and clean in some cases. Examples of this type of deposit are units 14 and 15 of columnar section 3.

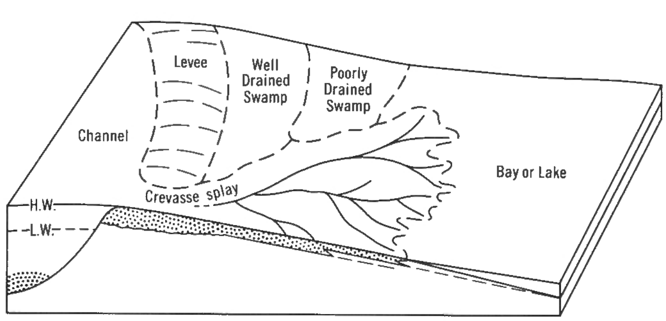
Peat may accumulate in the backswamp area behind levees of active channels. Weimer (1973) has discussed the effect of groundwater fluctuations in producing well-drained (non-peat forming) swamps and poorly drained (peat-forming) swamps adjacent to the channel (Fig. 16). These swamps generally tend to be restricted, elongated parallel to the channel system and, due to frequent flooding, may be high in terrigenous clastic sediment. Alternatively, however, they may be very extensive, covering hundreds of square kilometres (particularly in tropical settings such as the Amazon River of Brazil or the Mekong River of southeast Asia). Abundant vegetation stabilizes river banks by binding the sediment together making it much more resistant to erosion (Smith, 1976) so that rivers are retarded from destroying swamps. As well, vegetation traps sediment introduced during floods, and areas proximal to the channels protect areas more distally which may not receive any sediment. The acidic waters associated with swamps also assist by flocculating clays and thus removing them from suspension near the channels.

The third type, peat deposits isolated from an active channel, is similar to the second type but these deposits are physically isolated from floodwaters by older alluvial ridges formed by the topographically higher position of levees along abandoned channels. As long as all factors conducive to peat accumulation are present, this area has the greatest potential for producing clean coals as it is less subject to the periodic introduction of terrigenous clastic material than is the second type.

The example of coal in the Mynheer zone at Robb being too "dirty" to mine (Rutherford, 1925) suggests a case where the swamp was proximal to an active channel. The mined coal of the Mynheer zone farther to the southeast was



A. Environments of deposition and processes occurring in channel-channel margin areas (after Weimer, 1973)



B. Relationship of crevasse splay to other channel margin environments (after Weimer, 1973)

GSC

FIGURE 16. *Swamps adjacent to active channels.*

apparently sufficiently removed from the channel so that relatively little sediment was introduced into the swamp. It may have been protected by alluvial ridges but insufficient information was available to us to ascertain this.

Work in Appalachian coal fields by Caruccio and Ferm (1977) has shown that coals formed in alluvial settings are relatively low in reactive pyrite so that sulphur content is below 1 per cent. In contrast, coals associated with coastal plains or lower delta plains often contain 2 to 5 per cent sulphur. These high values result in highly acidic mine drainage and lower utility of the coal. Sulphur values are consistently low in coal from Coal Valley (Hacquebard and Birmingham, 1973) which is consistent with our interpretation of an alluvial plain origin.

Use of sedimentology in coal exploration

Coal seams in Western Canada are always associated with clastic sediments. The interpretation of clastic sediments, in terms of original depositional setting, is a rapidly developing field of study due mainly to ever increasing knowledge of modern depositional environments. This knowledge can be used in coal exploration and development, and will become more useful as our interpretative skills improve.

Sedimentological results in this report can be used as a predictive tool and as a guide to coal exploration geologists working on a more detailed level in the Coal Valley area. The two key observations are: 1) the coals occur in an alluvial plain setting; and 2) the paleoslope was to the northeast. Channel sandstones can, in general, be expected to have a southwest-northeast orientation, nearly perpendicular to the strike of the Foothills structures, although much local variation can be expected. However, in general, where "dirty" coal is encountered, a shift in activity to the northwest or southeast, perpendicular to the paleoslope, should yield a cleaner product. This may be the case, as mentioned previously, for the Mynheer seam in the Robb to Sterco area.

Directional sedimentary structures in levee or crevasse splay deposits may also be useful in predicting lateral trends. The presence of levee and splay deposits immediately indicates proximity to an active channel; examination of directional structures will give an indication of the direction in which a channel lies.

A hypothetical depositional model, presented in Figure 17, has been constructed from the lithofacies observed in sections 8W and 8E. It is based on the sedimentological principle that facies which are laterally correlative at a particular time will, in a dynamic depositional setting, tend to follow one another vertically with time in a logical and predictable manner. Thus, the various lithofacies seen in vertical section at 8W and 8E are believed to have been represented at the time of deposition of the Val d'Or seams, somewhere laterally from the location of outcrops 8W and 8E.

Four lines of evidence are particularly pertinent to the spatial geometry of the proposed model:

(1) Section 8W is northwest (to 325°) of section 8E.

(2) Levee deposits are prominent in section 8W (Fig. 8) but are replaced by lake and swamp deposits to the southeast at section 8E. This indicates that section 8W was closer to the channel than was section 8E.

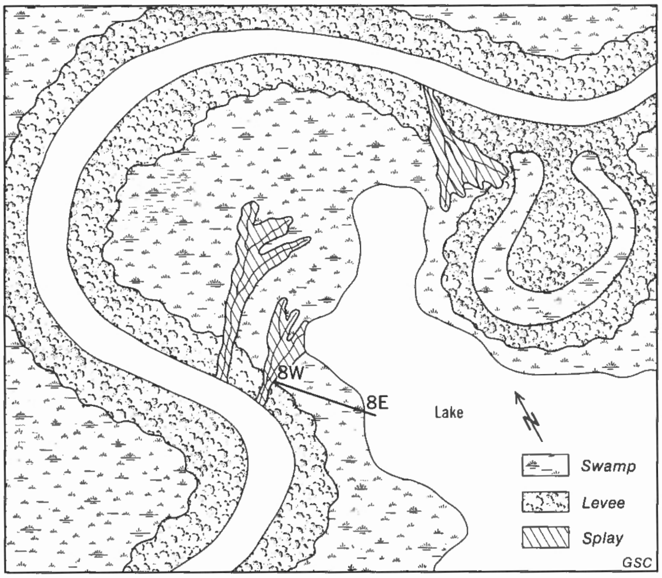


FIGURE 17. Schematic interpretation of data from section 8W and 8E.

(3) Paleocurrent readings from the overbank sediments in both sections show a persistent 020° (north-northeast) orientation. Overbank flow tends to follow the levee gradient and is nearly perpendicular to the channel orientation, but may be oblique to the channel, particularly in more distal portions of the levee or splay. A channel oriented to 110° (east-southeast) or 290° (west-northwest) is indicated.

(4) Paleocurrent readings from the overlying channel sandstones in sections 8W and 8E indicate flow to the north, northeast, and east.

Some disparity is evident, particularly between (2) and (3) above. A river flowing to 110° producing crevasse splays oriented to 020° would have to be south of locations 8W and 8E, and a greater proportion of levee deposits would then be expected at 8E, rather than 8W. If the channel were north of the locations, the splays would be more likely to have 200° orientation, rather than 020°. A channel oriented to 290° is contrary to the regional paleoslope but locally this is certainly not impossible to achieve in a meandering river system. However, this orientation is only 35° off parallel with the line of section between 8E and 8W and would place the channel closer to 8E than 8W, which seems contrary to the second line of evidence above.

The hypothetical model shown in Figure 17 can satisfy all of the conditions imposed, but it should not be considered as a unique solution, and certainly not taken as correct, as there are too few control points. It must be considered as only a preliminary working hypothetical model, which will be modified as more information becomes available. Its main value at this stage is: (1) to orient the observer toward the right type of model (fluvial rather than coastal plain, for example); and (2) to try to orient the major depositional environments within the model.

Exploration for coal in the Foothills is most concerned with four factors: the structural configuration, depth, thickness, and quality of the coal seams. Of these, only thickness and quality are related to the original depositional setting. In the example given, the sedimentology of the beds overlying the Val d'Or seam, as well as the many clastic interbeds within the seam, indicates proximity of the peat swamp to a river and possibly to a lake. Quality of peat, due to greater influx of terrigenous clastic detritus, will decrease toward the river, and the swamp may terminate altogether at the lake margin due to insufficient vegetation. If structural aspects were favourable and a drilling program was initiated in the vicinity of sections 8W and 8E, results of first stage drilling on a grid pattern, which in the Foothills would probably be concentrated along tectonic strike (northwest-southeast), could be compared with the model based on study of outcrops (Fig. 17). If the coal quality was observed to deteriorate markedly to the northwest due to a greater number of partings, the existence of the hypothetical contemporaneous river would be strongly indicated and further exploration in this direction might be terminated. However, if the property extends for several kilometres to the northwest, the coal could be sought on the opposite side of the fluvial system. The value in knowing that the depositional model is alluvial plain rather than coastal plain is apparent here. If the coal were deteriorating in quality toward a barrier sand body, there would be little chance of finding coal on the opposite side since that is where the sea was situated. Knowing that a channel sand body is more likely, there is a good probability that coal will be found on the opposite side.

If there was no indication of the coal pinching out to the southeast, it would suggest that the postulated lake (Fig. 17) developed over the swamp and was not present during swamp development. In this case, exploration activity would be continued to the southeast, if the other factors were still favourable.

Development of a depositional model is certainly of secondary importance in exploration of coal seams in the Foothills. However, as we have attempted to show, it can be a useful tool in explaining variations in coal seam thickness and quality, and in predicting changes that can be expected laterally. Detailed sedimentological observation of outcrop sections can be a very valuable supplement to borehole information since paleocurrents normally cannot be measured in the latter, and larger sedimentary structures, as well as the interrelationship between structures, cannot be adequately studied in core. The working model is also important to the exploration geologists as an intellectual guide, allowing him to utilize the results of each drillhole more fully, right from the first hole, because there is a frame of reference already established with which these results can be compared, and within which results from different drillholes can be compared.

SUMMARY AND CONCLUSIONS

Lithostratigraphic nomenclature for the Upper Cretaceous-lower Tertiary succession in the outer Foothills belt of central Alberta is still in a state of flux. A name which encompasses the whole undivided succession from the top of the Wapiabi Formation to the present erosional surface is desirable, and the name Saunders is considered most suitable. The name Brazeau is widely and consistently used and is retained for the lower part of the Saunders Group. The name Coalspur beds, adapted from MacKay (1949), is used informally for the beds between the top of the Brazeau Formation and the base of the lowest prominent sandstone bed above the highest thick coal seam in the coal zone recognized from the vicinity of the North Saskatchewan River, north to the McLeod River. This includes the mineable seams at Coal Valley. The Entrance Conglomerate is recognized as a distinct and useful unit in the area as mapped by Lang (1947) and is retained as a member of the Coalspur beds. The Paskapoo Formation includes all beds above the Coalspur beds.

The sediments of the Saunders Group are predominantly of fluvial origin and are composed of channel and overbank sediments which show distinct cyclicity. A much larger scale cyclicity is exhibited by alternating sand-rich and sand-poor sections of the Saunders Group.

Paleocurrent readings indicate a strongly unimodal current direction to the northeast which persisted throughout deposition of the Saunders Group. Coal was deposited in abandoned meander loops and on the floodplain both proximally and distally from active channels.

Structure is the principal factor in determining the location of mineable coal deposits in the Coal Valley and adjacent areas of the outer Foothills belt. However, within a structurally favourable area, knowledge of the sedimentological framework within which the coal was deposited can aid in a logical approach to exploratory drilling and provide the key to explaining the lateral variations observed in the coal deposits.

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APPENDIX 1

PALYNOLOGY

by A.R. Sweet

Field Sample and Laboratory Preparation No.	Selected pollen and spore taxa, comments and age	GSC Loc. No.
77-TS-3-38 P2056-1	Comments: Pollen and miospores very sparse; fungal hyphae, fungal spores and coaly fragments abundant, herbaceous debris common.	C-69130
77-TS-3-38a P2056-2	Comments: Bisaccate pollen; smooth trilete spores and fungal spores common, preservation poor; coaly fragments and woody material abundant. No diagnostic forms other than one specimen of Pesavis observed.	C-69132
77-TS-3-28 P2056-3	Comments: Pollen and miospores sparse to common; woody material abundant; fungal spores sparse.	C-69126
77-TS-3-25 P2056-4	Comments: Pollen and miospores rare; woody and herbaceous material abundant.	C-69122
77-TS-3-23 P2056-5	Brevicolporites copella Anderson 1960 (abundant) Comments: Pollen and miospores abundant; other types of organic debris sparse.	C-69121
77-TS-3-19 P2056-6	Paraalnipollenites alterniporus (Simpson) Srivastava; 1975 (sparse) Comments: Pollen and miospores common; preservation poor (degraded); in addition to Paraalnipollenites, common large inaperaturate pollen grains, Cyathidites and Laevigatosporites; herbaceous material abundant; woody material sparse.	C-69119
77-TS-3-18 P2056-7	Comments: Pollen and miospores very sparse; coaly fragments abundant; coarse fraction with abundant megaspores [Azolla cf. A. velus (Diskstra) Jain and Hall 1969] and seeds. The combination of sparse pollen and miospore recovery with abundant Azolla megaspores and seeds might well indicate that the unit which this sample represents was deposited either within or adjacent to an open body of water.	C-69118
77-TS-3-14 P2056-8	Comments: Pollen and miospore recovery very sparse; woody and coaly material common.	C-69116
77-TS-3-10 P2056-9	Comments: As above except for abundant woody and coaly material.	C-69112
77-TS-3-9 P2056-10	Comments: As in C-69116.	C-69111
77-TS-3-7 P2056-11	Comments: As in C-69116.	C-69109
77-TS-3-4 P2056-12	Comments: As in C-69116.	C-69107
77-TS-3-1 P2056-13	Comments: As in C-69116.	C-69103

Age of Section 77-TS-3: The combined occurrence of Brevicolporites copella, Paraalnipollenites alterniporus and Azolla cf. A. velus together with the low pollen and miospore diversity in all the above samples from the Section 77-TS-3 indicates an early Paleocene age for this section.

77-TS-5-20 P2056-14	Comments: Pollen and miospores very sparse; herbaceous and woody fragments abundant; sparse fungal material.	C-71197
77-TS-5-14 P2056-15	Cingulatisporites dakotaensis Stanley 1965 Insulapollenites rugulatus Leffingwell 1970 Ulmoideipites krempi Anderson 1960 Comments: Pollen and miospores sparse; preservation poor; degraded herbaceous material abundant.	C-71194

Field Sample and Laboratory Preparation No.	Selected pollen and spore taxa, comments and age	GSC Loc. No.
77-TS-5-12 P2056-16	Comments: Sample effectively barren; coaly, woody and herbaceous debris sparse.	C-71192
77-TS-5-9 P2056-17	Cingulatisporites dakotaensis Stanley 1965 Comments: Pollen and miospores abundant; woody debris common. In addition to the above species the sample contains abundant bisaccate pollen and Laevigatosporites and some Osmundacidites.	C-71190
77-TS-5-5 P2056-18	Comments: Sparse coaly material; sample effectively barren.	C-71187

Age of Section 77-TS-5: The combined occurrence of Cingulatisporites dakotaensis, Insulapollenites rugulatus and Ulmoideipites krempi together with the low pollen and miospore diversity indicates, as for Section 77-TS-3, an early Paleocene age for Section 77-TS-5.

Section 77-TS-5 spans part of the lowest coal horizon at Coal Valley. The lack of relic Maastrichtian forms such as Wodehouseia spp. and Aquilapollenites reticulatus might be taken to indicate that this coal horizon is younger than the Nevis seam which occurs at the base of the Ardley coal zone at Huxley, Alberta and the Ferris coal zone of Saskatchewan. It is possible, however, that Section 77-TS-5 is correlative to the upper seams of the Ardley coal zone. To verify these observations the examination of more samples would be required.

77-TJ-6-605 P2056-19	Aquilapollenites amicus Srivastava 1968 (rare) A. attenuatus Funkhouser 1961 (rare) A. calvus Tschudy and Leopold 1970 (scarce) A. delicatus var. delicatus Tschudy and Leopold 1970 (rare) A. hirsutus Srivastava 1969 (rare) Carmarozonosporites concinnus Srivastava 1972 (scarce) Cranwellia sp. (rare) Erdtmanipollis sp. (rare) Liliacidites complexus (Stanley) Leffingwell 1970 Liburnisporis adnacus Srivastava 1972 (rare) Proteacidites auratus Srivastava 1969 (scarce) Wodehouseia cf. W. avita Wiggins 1976 (rare) Comments: Pollen and miospore abundant; preservation excellent; coaly debris common.	C-72405
77-TJ-6-604 P2056-20	Comments: Sample effectively barren of palynomorphs; coaly material sparse.	C-72404
77-TJ-6-602 P2056-21	Aquilapollenites amicus Srivastava 1968 (rare) A. cf. A. attenuatus Funkhouser 1961 (rare) A. calvus Tschudy and Leopold 1970 (rare) A. delicatus var. delicatus Tschudy and Leopold 1970 (rare) A. hirsutus Srivastava 1969 (rare) A. reticulatus (Mtchedlishvili) Tschudy and Leopold 1970 (rare) Liliacidites complexus (Stanley) Leffingwell 1970 (rare) Wodehouseia cf. W. avita Wiggins 1976 W. spinata Stanley 1961 Comments: Pollen and miospore common; preservation good; coaly debris and amorphous kerogen common.	C-72402
77-TS-6-601 P2056-22	Aquilapollenites calvus Tschudy and Leopold 1970 (scarce) Carmarozonosporites concinnus Srivastava 1972 (common) Liliacidites complexus (Stanley) Leffingwell 1970 (abundant) Comments: Pollen and miospores abundant; preservation excellent; coaly debris common.	C-72401

Age of Section 77TJ6: Based on the combined presence of a diverse assemblage of Aquilapollenites spp., Wodehouseia spp., Liliacidites complexus and Proteacidites auratus, this section is of Maastrichtian age. The presence of Wodehouseia spinata identifies the section most closely with the Late Maastrichtian, Wodehouseia spinata Zone of Srivastava (1970) which spans the Battle Formation and overlying strata up to the Nevis coal horizon (base of the Ardley coal zone). The absence of Polycolpites pocockii and Aquilapollenites conatus combined with the presence of Proteacidites auratus might be taken to suggest a correlation only with the lower part of the Wodehouseia spinata Zone.

Field Sample and Laboratory Preparation No.	Selected pollen and spore taxa, comments and age	GSC Loc. No.
77-TJ-14-19 P2056-23	Aquilapollenites argutus Srivastava 1969 (rare) A. cf. A. attenuatus Funkhouser 1961 (rare) A. hirsutus Srivastava 1969 (rare) A. cf. A. laticorpus Tschudy 1969 (scarce) A. cf. A. reductus Norton 1965 (common) A. sentus Srivastava 1969 (rare) A. validus Srivastava 1968 (scarce) Cranwellia sp. (scarce) Kurtzipites sp. (scarce) Liburnisporis adnacus Srivastava 1972 (rare) Loranthacites pilatus Mtchedlishvili 1961 (rare) Mancicorpus cf. M. rostratus Srivastava 1968 Orbiculapollis lucidus Chlonova 1961 Comments: Pollen and miospores abundant; preservation excellent; diversity high; coaly material also abundant.	C-71131
77-TJ-14-13a P2056-25	Aquilapollenites argutus Srivastava 1969 (scarce) A. cf. A. attenuatus Funkhouser 1961 (rare) A. cf. A. laticorpus Tschudy 1969 (rare) A. cf. A. reductus Norton 1965 (scarce) A. sentus Srivastava 1969 (scarce) Beaupreaidites sp. (concave sides, rare) B. cf. B. angulatus (Samoilovitch) Srivastava 1969 (rare) Fibulapollis scabratus Tschudy 1969 (scarce) Gabonisporis bacaricumulus Srivastava 1972 (scarce) Liburnisporis adnacus Srivastava 1972 (rare) Liliacidites complexus (Stanley) Leffingwell 1970 (rare) Mancicorpus cf. M. rostratus Srivastava 1968 (rare) Pulcheripollenites krempii Srivastava 1969 (rare) P. narcissus Srivastava 1969 (scarce) Senipites drumhellerensis Srivastava 1969 (rare) Comments: As for C-71131.	C-71117
77-TJ-14-12 P2056-26	Aquilapollenites amygdaloides Srivastava 1968 (rare) A. argutus Srivastava 1969 (rare to scarce) A. cf. A. attenuatus Funkhouser 1961 (scarce) A. augustus Srivastava 1969 (scarce to common) A. cf. A. laticorpus Tschudy 1969 A. pulcher Funkhouser 1961 (rare) A. cf. A. reductus Norton 1965 (scarce to common) A. reticulatus (Mtchedlishvili) Tschudy and Leopold 1970 (rare) A. sentus Srivastava 1969 (scarce to common) A. validus Srivastava 1968 (rare) Cranwellia spp. (scarce) Expressipollis sp. (rare) Fibulapollis scabratus Tschudy 1969 (scarce) Gabonisporis bacaricumulus Srivastava 1972 (scarce) Liburnisporis adnacus Srivastava 1972 (rare) Liliacidites complexus (Stanley) Leffingwell 1970 (rare) Mancicorpus cf. M. rostratus Srivastava 1968 (rare) Proteacidites sp. (rare) Pulcheripollenites narcissus Srivastava 1969 (rare) Comments: As for C-71131.	C-71115
77-TJ-14-10a P2056-28	Aquilapollenites cf. A. attenuatus Funkhouser 1961 (scarce) A. hirsutus Srivastava 1969 (rare) A. cf. A. reductus Norton 1965 (rare) A. sentus Srivastava 1969 (rare) Fibulapollis scabratus Tschudy 1969 (rare) Gabonisporis bacaricumulus Srivastava 1972 (rare) Proteacidites spp. (rare) Comments: As for C-71131 except for lower diversity and more abundant bisaccate pollen.	C-71112

Field Sample and Laboratory Preparation No.	Selected pollen and spore taxa, comments and age	GSC Loc. No.
77-TJ-14-18 P2056-29	Aquilapollenites argutus Srivastava 1969 (abundant) A. cf. A. attenuatus Funkhouser 1961 (common) A. hirsutus Srivastava 1969 (scarce) A. cf. A. laticorpus Tschudy 1969 (scarce) Beaupreaidites angulatus (Samoilovitch) Srivastava 1969 (scarce) Cranwellia sp. (rare) Fibulapollis scabratus Tschudy 1969 (abundant) Gabonisporis bacaricumulus Srivastava 1972 (common) Kurtzipites spp. (abundant) Liburnisporis adnacus Srivastava 1972 (rare) Mancicorpus rostratus Srivastava 1968 Pulcheripollenites narcissus Srivastava 1969 (rare) Comments: As for C-71131 except for abundant Spermatites spp., Molaspora and Styx and less coaly debris.	C-71110
77-TJ-14-6 P2056-30	Aquilapollenites augustus Srivastava 1969 (scarce) A. hirsutus Srivastava 1969 (rare) A. cf. A. laticorpus Tschudy 1969 (rare) A. cf. A. reductus Norton 1965 (scarce) A. sentus Srivastava 1969 (rare) A. validus Srivastava 1968 (rare) Cranwellia spp. (scarce) Gabonisporis bacaricumulus Srivastava 1972 (scarce) Liburnisporis adnacus Srivastava 1972 (rare) Mancicorpus rostratus Srivastava 1969 (rare) Comments: As for C-71112	C-71108
77-TJ-14-5 P2056-31	Comments: Pollen and miospore recovery very sparse; coaly debris abundant; some megaspores recovered.	C-71107
77-TJ-14-3 P2056-32	Comments: Pollen, miospores and coaly debris sparse. No diagnostic forms observed.	C-71105
77-TJ-14-1 P2056-33	Aquilapollenites cf. A. attenuatus Funkhouser 1961 (scarce) A. hirsutus Srivastava 1969 (abundant) A. cf. A. laticorpus Tschudy 1969 (common to abundant) Cranwellia spp. (scarce) Gabonisporis bacaricumulus Srivastava 1972 (scarce) Kurtzipites spp. (abundant) Liliacidites complexus (Stanley) Leffingwell 1970 (common) Mancicorpus rostratus Srivastava 1969 (common) Pulcheripollenites krempii Srivastava 1969 Comments: As for C-71112.	C-71103

Age of Section 77TJ14: Utilizing the range chart given for angiospermous pollen from the Edmonton Group by Srivastava (1970), it appears that the assemblages recovered from this section are best assigned to either the Pulcheripollenites krempii Zone IV or the Mancicorpus vancampoi Zone V – M. vancampoi being morphologically very similar to M. rostratus. Hence, this section is most probably of Early to late Early Maastrichtian age.

77-TJ-27-3c P2056-34	Aquilapollenites cf. A. attenuatus Funkhouser 1961 (rare) A. calvus Tschudy 1970 (scarce) A. pulcher Funkhouser 1961 (scarce) A. reductus Norton 1965 (common) A. cf. A. sentus Srivastava 1969 (scarce) Beaupreaidites occulatus (Samoilovitch) Srivastava 1969 (rare) Circumflexipollis sp. (scarce) Cranwellia sp. (rare) Liburnisporis adnacus Srivastava 1972 (scarce) Wodehouseia spinata Stanley 1961 (scarce to common) Comments: Pollen and miospores abundant; preservation slightly degraded; coaly debris common.	C-71169
77-TJ-27-3b P2056-35	Comments: Pollen and mispores sparse; herbaceous and coaly material abundant. No diagnostic forms observed.	C-71168

Field Sample and Laboratory Preparation No.	Selected pollen and spore taxa, comments and age	GSC Loc. No.
77-TJ-27-3a P2056-36	Aquilapollenites attenuatus Funkhouser 1961 (rare) A. reductus Norton 1965 (common) Circumflexipollis sp. (scarce) Cranwellia sp. (rare) Expressipollis sp. (rare) Gunnera microreticulata (Belsky, Boltenhagen and Potonié) Leffingwell 1970 (rare) Comments: Pollen and miospores and coaly debris abundant.	C-71167
77-TJ-27-1 P2056-37	Aquilapollenites attenuatus Funkhouser 1961 (rare) A. pulcher Funkhouser 1961 (rare) A. reductus Norton 1965 (scarce) Circumflexipollis sp. (common) Gunnera microreticulata (Belsky, Boltenhagen and Potonié) Leffingwell 1970 (scarce) Paraalnipollenites alterniporus (Simpson) Srivastava 1975 (rare) Wodehouseia spinata Stanley 1961 (scarce) Comments: Pollen and miospore scarce; preservation good; herbaceous and coaly debris abundant.	C-71163

Age of Section 77TJ27: Like Section 77TJ6, Section 77TJ27 can be referred to the Wodehouseia spinata Zone VIII of Late Maastrichtian age. Unfortunately it is not possible to resolve with certainty the relative stratigraphic position of these two sections.

General comments: Utilizing palynology, Eliuk (1969) and Gunther and Hills (1972) proposed a correlation between the Brazeau and overlying strata in the Foothills with the Upper Cretaceous and Tertiary strata of the Plains. Eliuk (1969) considered strata contiguous to the Entrance Conglomerate to be correlative with the basal part of the Wodehouseia spinata Zone based on his recovery of assemblages similar to those from Sections 77TJ6 and 27 of this report.

Gunther and Hills (1972) considered the uppermost coal-bearing interval (15 m to about 60 m) of the Blackstone River as correlative with the Paskapoo Formation (Paskapoo Formation plus Scollard Member) based on the presence of Azolla schopfii Dijkstra 1961. Both Snead (1969) and Sweet (1972) report A. schopfii as occurring as low as the base of the Ardley coal zone at Huxley (Nevis seam) which occurs within the upper part of the Scollard Formation of Gibson (1976). Azolla schopfii is also found within and above the Ferris coal zone of Saskatchewan. Hence, Gunther and Hills' report of Azolla schopfii does not exclude the possibility of their 15 to 60 metre interval being correlative with the upper part of the Scollard Formation (Member). Rather it tends to support this correlation as A. schopfii is the dominant species of Azolla within the Ardley coal zone interval. In the Paskapoo Formation, A. schopfii occurs in reduced numbers and usually in association with two other species, Azolla stanleyi Jain and Hall 1969 and A. bulbosa Snead 1969.

Gunther and Hills (1972) assign the upper middle part of their section (about the 150 to 300 m interval) to the Scollard Member (Formation) based in part on the presence of Azolla filosa Snead 1969 and A. lauta Snead 1969. These species are two of the dominant taxa of Azolla in the lower part of the Scollard Formation (Snead, 1969; Sweet, 1972) below the Nevis seam. It is therefore likely that their 150- to 300-metre interval does, as they state, belong to the Scollard Member (Formation). More exactly, it is probable that this interval is correlative with the Frenchman, Hell Creek and Lance Formations.

APPENDIX 2

DATA ON PALEOCURRENT READINGS

A. Summary of field data for tabular planar crossbedding (Sp) and inclined bedding (Sh)

Location	Bedding	Crossbedding	Tilt corrected	Mean azimuth	Mean crossbed set thickness (metres)	Lithofacies
1	000°/00°	065°/25°			0.60	
		045°/20°		51°30'	1.00	Sp
		055°/15°			1.00	
3-13	225°/58°	240°/47°	352°/19°		1.30	Sp
	232°/57°	207°/46°	103°/24°	89°30'	2.20	Sh
	232°/57°	205°/30°	076°/31°		2.20	Sh
6	050°/10°	055°/35°	057°/25°		0.50	Sp
		065°/35°	072°/25°	69°	0.50	Sp
		070°/35°	078°/25°		0.50	Sp
8W-40	041°/35°	034°/45°	013°/11°	16°	0.50	Sh
		034°/50°	019°/15°		0.50	Sh
8W-42	040°/35°	040°/53°	040°/17°	22°	0.50	Sh
		025°/57°	004°/23°		0.50	Sh
8W-44	040°/35°	045°/56°	095°/15°		0.50	Sh
8N-5	040°/35°	045°/46°	060°/11°		1.00	Sp
		053°/36°	075°/12°	87°	1.00	Sp
		050°/46°	130°/08°		1.00	Sp
8N-6	040°/35°	048°/56°	062°/20°	17°	1.20	Sp
		017°/46°	332°/20°		1.20	Sp
8E-53	015°/50°	037°/40°	145°/19°		1.00	Sp
8E-55	015°/18°	039°/57°	051°/38°		0.50	Sp
10	230°/60°	220°/30°	058°/28°		0.50	Sh
12	060°/24°	050°/40°	035°/17°		1.00	Sp
14	035°/50°	020°/58°	327°/16°		0.25	Sh
25	050°/17°	015°/40°	356°/28°		1.50	Sp
28	045°/44°	025°/70°	356°/29°		0.30	Sp
30	005°/05°	005°/25°	005°/19°		1.50	Sp
		005°/35°	005°/29°	6°40'	1.50	Sp
		010°/30°	010°/24°		1.50	Sp
31	015°/10°	010°/30°	007°/19°		2.00	Sp
		000°/25°	350°/15°	359°/30'	2.00	Sp
		005°/30°	360°/20°		2.00	Sp
32	005°/15°	035°/33°	055°/22°		0.80	Sp
		055°/30°	084°/23°		0.50	Sp
		065°/25°	102°/22°	74°	0.50	Sp
		045°/25°	080°/16°		0.50	Sp
		075°/26°	110°/25°		0.50	Sp
33	195°/45°	215°/18°	003°/28°		0.25	Sp
		210°/30°	350°/17°	6°	0.30	Sp
		200°/23°	010°/22°		0.50	Sp
34	030°/55°	050°/60°	117°/20°		0.50	Sh
37	055°/21°	085°/30°	125°/16°		0.25	Sp
		080°/35°	110°/19°	109°	0.40	Sp
		075°/33°	104°/16°		0.40	Sp
38	275°/25°	055°/10°	076°/34°		0.25	Sp
39	195°/14°	185°/25°	172°/10°		0.50	Sh
40	215°/18°	165°/10°	070°/14°		0.20	Sh
41	025°/60°	030°/71°	055°/10°		0.50	Sp
	030°/76°	025°/63°	235°/12°	74°	0.20	Sp
	030°/37°	051°/65°	075°/32°		1.20	Sp

Location	Bedding	Crossbedding	Tilt corrected	Mean azimuth	Mean crossbed set thickness (metres)	Lithofacies
42	025°/50°	055°/75°	098°/36°		0.40	Sp
	015°/35°	025°/63°	040°/27°	47°	1.50	Sp
	025°/41°	028°/55°	040°/13°		1.00	Sp
43	055°/10°	050°/40°	049°/30°		0.50	Sp
		080°/27°	093°/18°	53°30'	0.50	Sp
		035°/20°	020°/11°		0.50	Sp
44	030°/15°	065°/34°	090°/23°		0.20	Sp
46	015°/40°	000°/50°	315°/15°	325°30'	0.30	Sh
		010°/65°	002°/23°		0.20	Sh
47	040°/15°	020°/37°	007°/22°			Sp
		045°/40°	050°/25°	52°		Sp
		080°/40°	099°/30°			Sp
52	170°/05°	205°/32°	210°/27°		0.80	Sp
54	040°/25°	005°/38°	327°/23°		1.50	Sp
55	040°/20°	045°/35°	053°/15°		0.50	Sp
57	225°/05°	225°/25°	225°/19°		0.50	Sp
		210°/30°	210°/25°	211°	0.80	Sp
		115°/18°	100°/20°		0.30	Sp
58	255°/26°	195°/10°	097°/22°		1.00	Sp
		185°/10°	097°/24°	97°	1.00	Sp
		200°/10°	097°/21°			Sp
60	230°/05°	080°/20°	073°/25°		0.50	Sp
61	000°/00°	245°/20°				Sp
		255°/20°		265°		Sp
		295°/18°				Sp

B. Summary of field data for trough crossbedding A-axis

Location	Bedding	A-axis of trough	Mean azimuth	Mean crossbed thickness (metres)
8N-8	040°/35°	055°		1.20
11	235°/15°	115°		0.80
23	030°/14°	035°		0.50
		045°		0.50
		055°		0.50
		355°	21°25'	0.50
		005°		0.50
		025°		0.50
		350°		0.50
24	025°/15°	070°	77°30'	0.50
		085°		0.50
36	205°/35°	215°	212°/30'	0.90
		210°		0.50
51		345°		0.50
		005°		0.40
		030°	21°50'	0.60
		035°		0.50
		040°		0.70
52		100°		0.60
53		350°		0.50
		025°	16°50'	0.50
		035°		0.50
59		040°		0.50
		075°	58°25'	0.50
		060°		0.50

Mean = 33°40'

C. Summary of field data for cross-lamination (rib-and-furrow structure)

Location	Bedding	Rib and Furrow*	Mean azimuth
3-13	225°/58°	230°	
8W-31	030°/41°	020°	19°
8W-37	038°/39°	018°	
8E-17	040°/45°	025°	25°
8E-36	045°/45°	025°	
9	205°/65°	065°	
10	230°/60°	060°	
		065°	58°20'
		050°	
14	035°/47°	083°	
20	055°/25°	050°	
		060°	62°30'
		065°	
		075°	
21	025°/05°	053°	
23	030°/14°	340°	
		350°	350°
		000°	
27	037°/45°	165°	
		175°	173°20'
		180°	
29	000°/00°	040°	20°
		000°	
47	015°/15°	055°	52°30'
		050°	
57	200°/05°	125°	
		170°	168°/20'
		210°	

*Implied paleoflow direction.
Mean = 57°20'

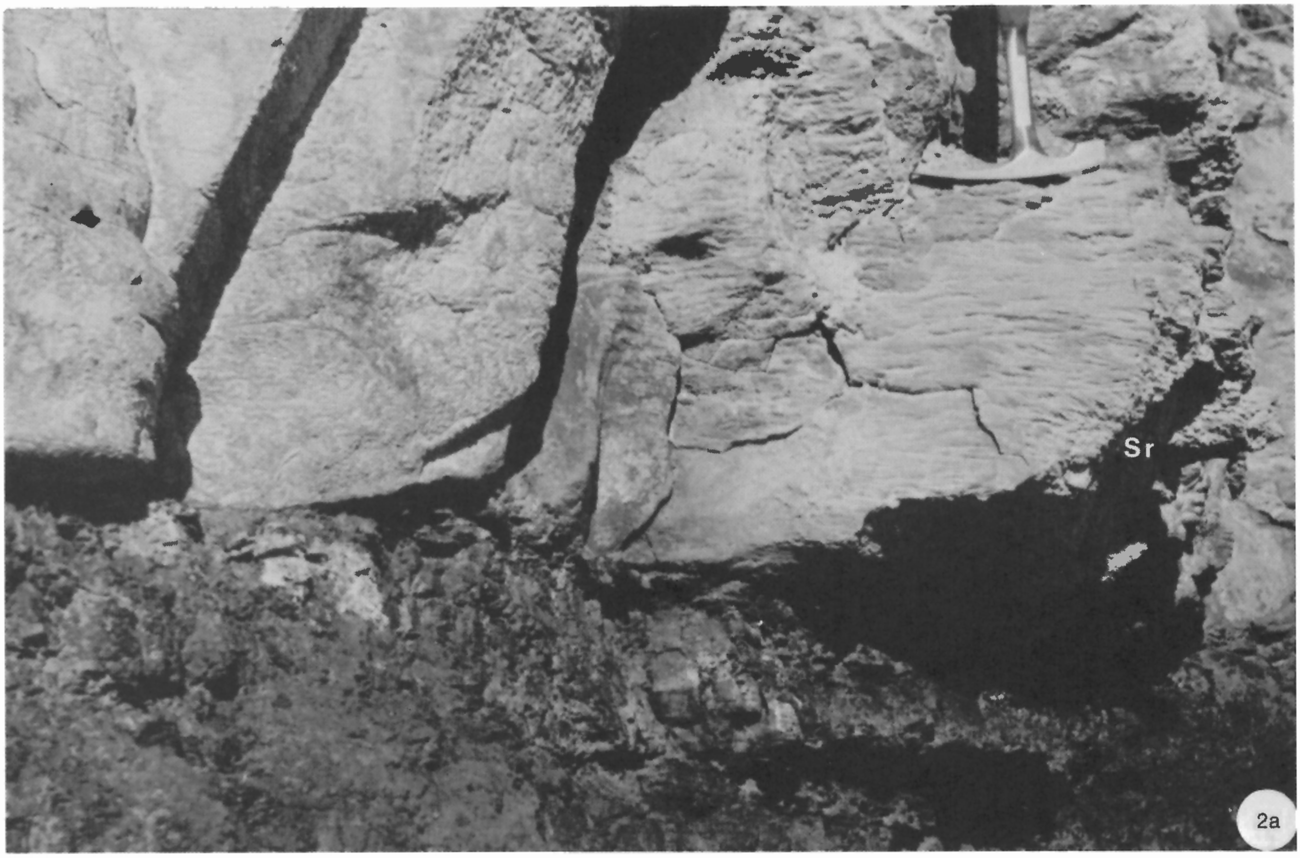
D. Orientation of pebble imbrication in Entrance Conglomerate

Location	Bedding	Dip direction of AB plane	Tilt corrected	Mean azimuth
33	195°/45°	180°/65°	260°/10°	
33		175°/60°	260°/40°	
33		205°/50°	263°/36°	
33		190°/55°	255°/33°	
33		170°/70°	245°/30°	
33		165°/68°	242°/33°	
33		195°/70°	235°/27°	
33		200°/75°	234°/16°	211°
33		225°/75°	209°/27°	
33		220°/70°	195°/22°	
33		215°/75°	170°/10°	
33		210°/70°	151°/33°	
33		205°/60°	133°/23°	
33		225°/70°	135°/33°	
33		215°/70°	125°/35°	

Plate 1

a. Outcrop 8W. Val d'Or coal seam interbedded with sandstone beds of crevasse splay origin (c.s.) and overlain by a sandstone bed of levee origin (1).

b. Close-up view of same wall. Three sandstone beds of splay origin (c.s.) are present within the coal and associated very fine grained sediments. Compare with columnar section 8W up to bed 39.



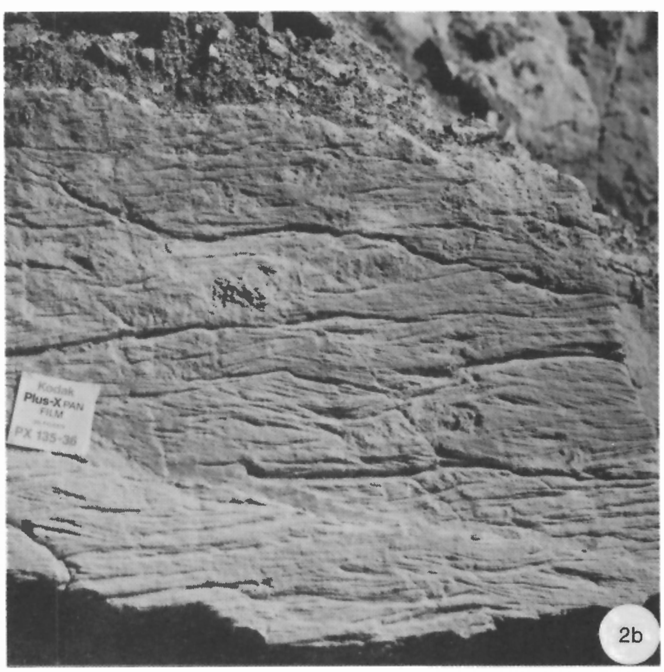


Plate 2

a. Outcrop 8W. Sharp contact between Val d'Or coal seam and overlying sandstone bed of splay origin. Note cross-lamination in sandstone bed (lithofacies Sr).

b. Detail of lithofacies Sr in the same bed. Current direction from left to right. Scale is 3.8 cm square.

c. Outcrop 27. Ripple marks on upper surface of sandstone.

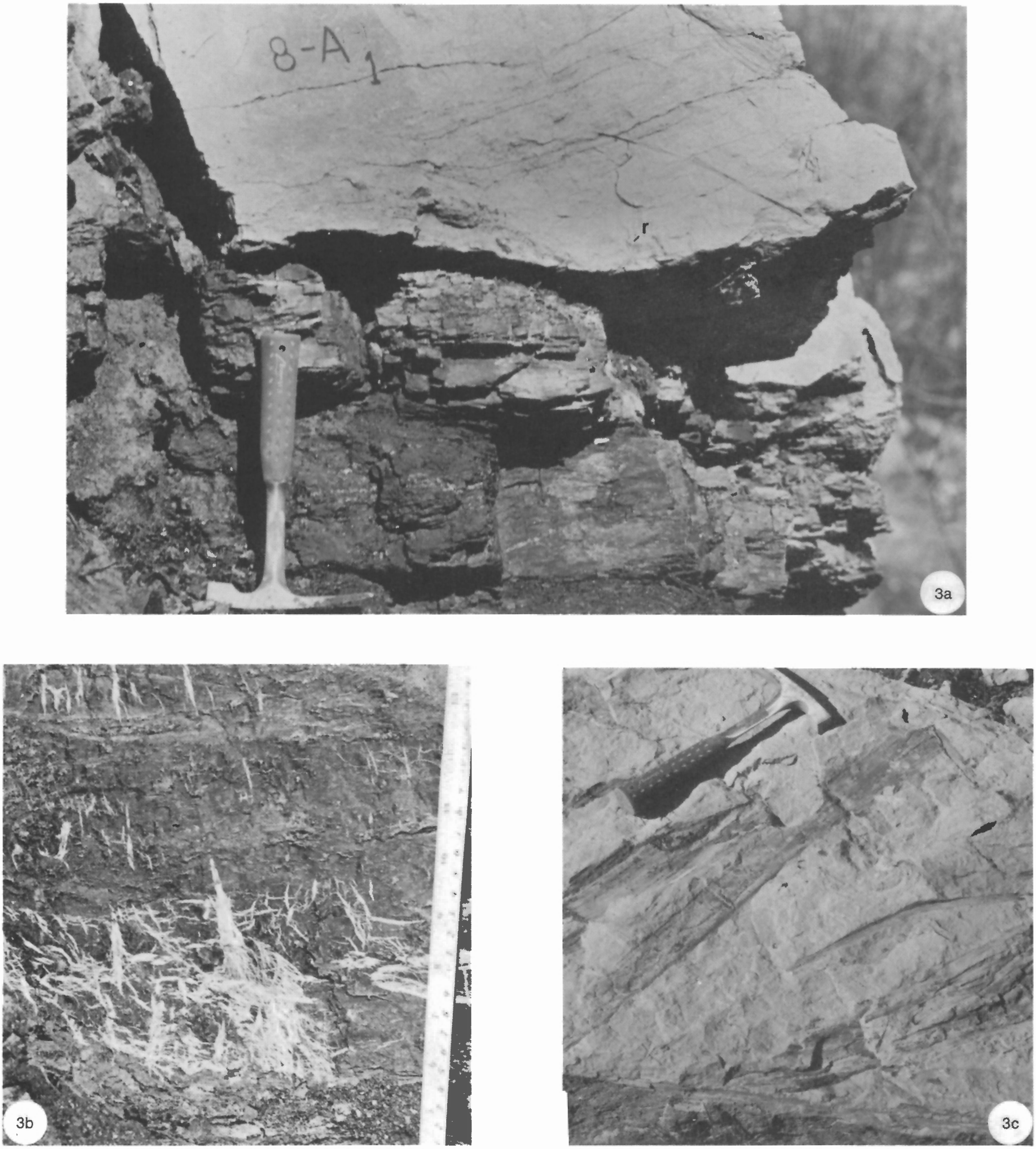
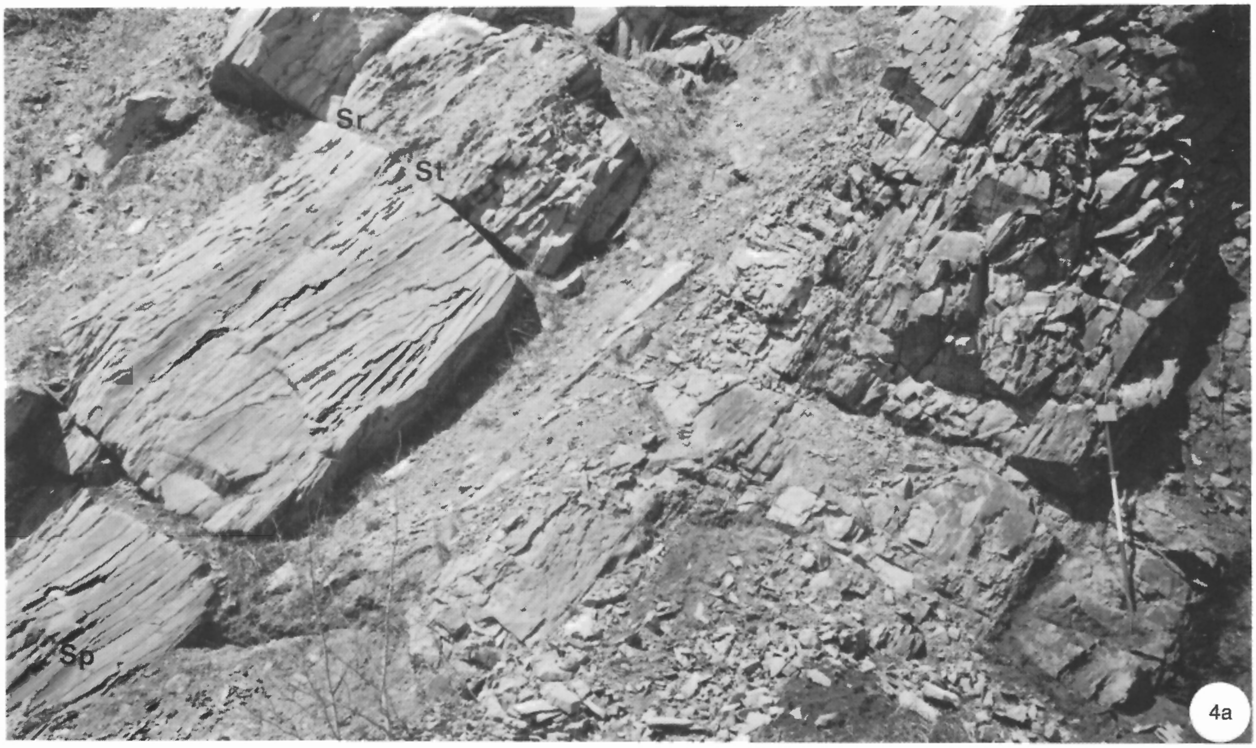


Plate 3

a. Outcrop 8W. Sharp contact between sandstone bed of splay origin (lithofacies S1) and Val d'Or seam. Slight loading deformation of coal. Note plant stems and roots (r) visible in lowermost part of sandstone bed.

b. Outcrop 8, bed 7. Relicts of plant roots in Val d'Or coal seam.

c. Outcrop 8W, bed 14. Plant stems on intrabedding surface of sandstone unit of splay origin.



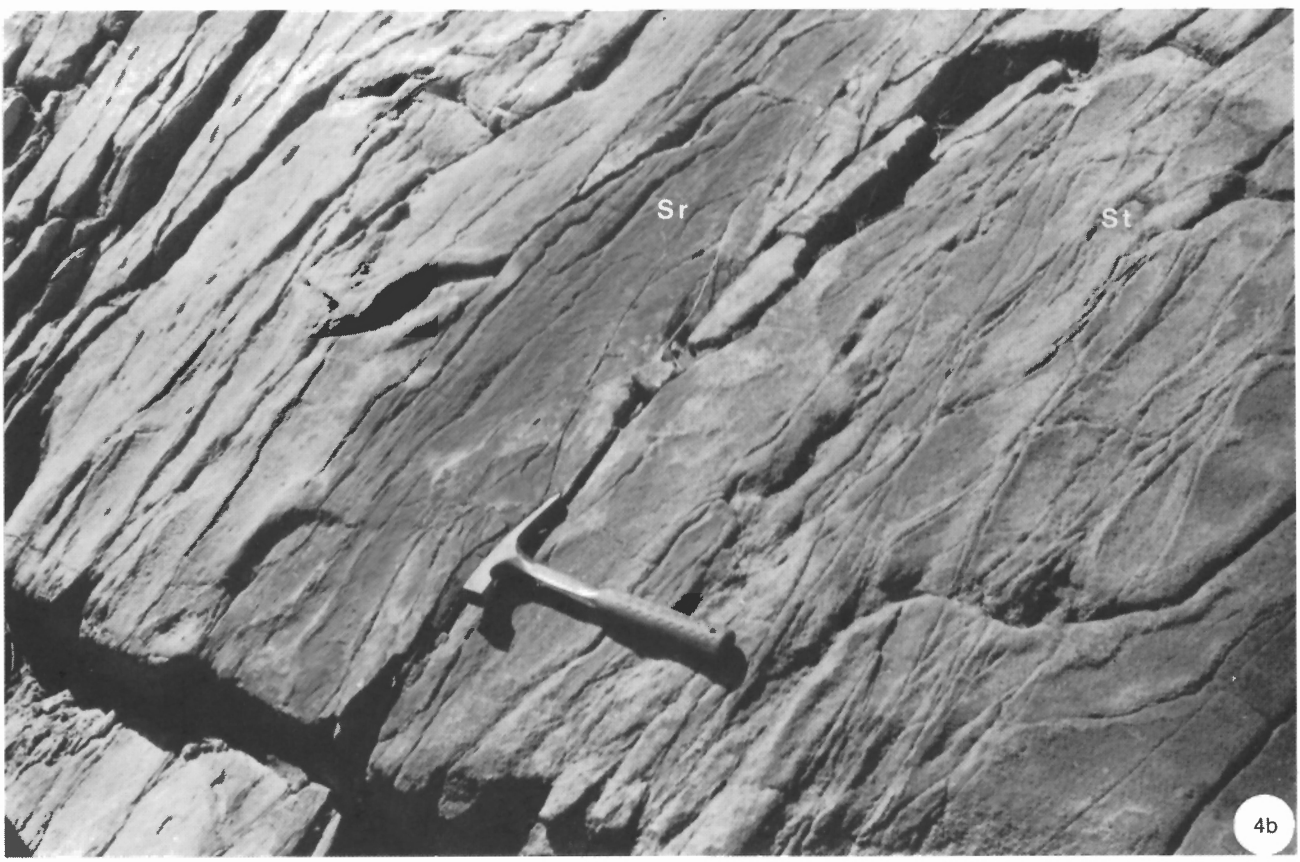


Plate 4

a. Outcrop 3. Point bar sequence with fining-upward grain size. Note the upward vertical succession of structures: planar crossbedding (Sp), trough crossbedding (St) and cross-lamination (Sr).

b. Details of lithofacies St and Sr in 4a.

Plate 5

a. Outcrop 4. Sandstone bed of crevasse splay origin within the Silkstone coal seam.

b. Detail of contact between the same beds as 5a.

Plate 6

a. Outcrop 8E. Val d'Or coal seam with interbedded sandstone beds of crevasse splay origin (c.s.), overlain by sediment of levee (l) and lacustrine (la) origin.

b. Detail of lithofacies Fcf, the lacustrine deposits of 6a.

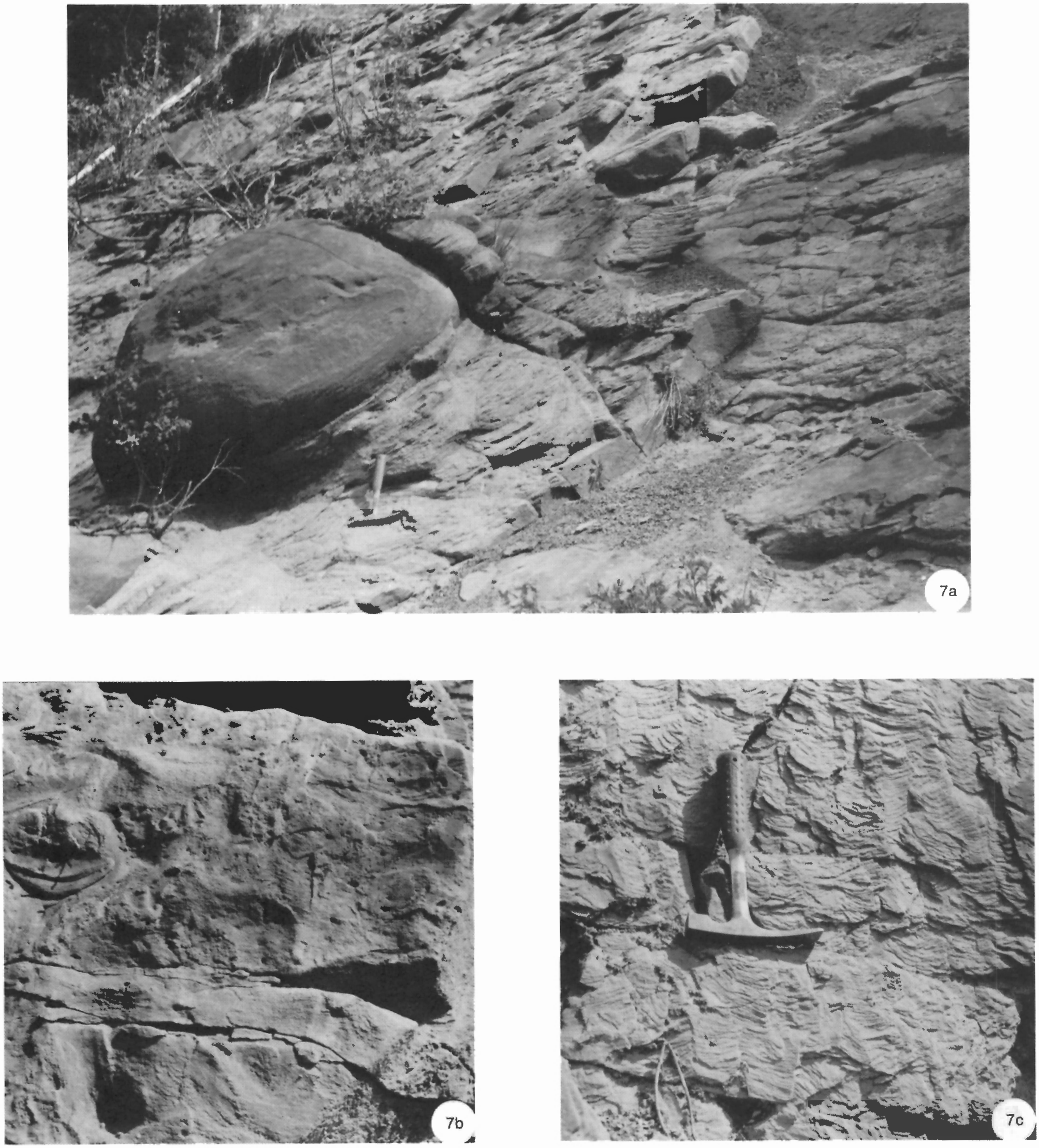
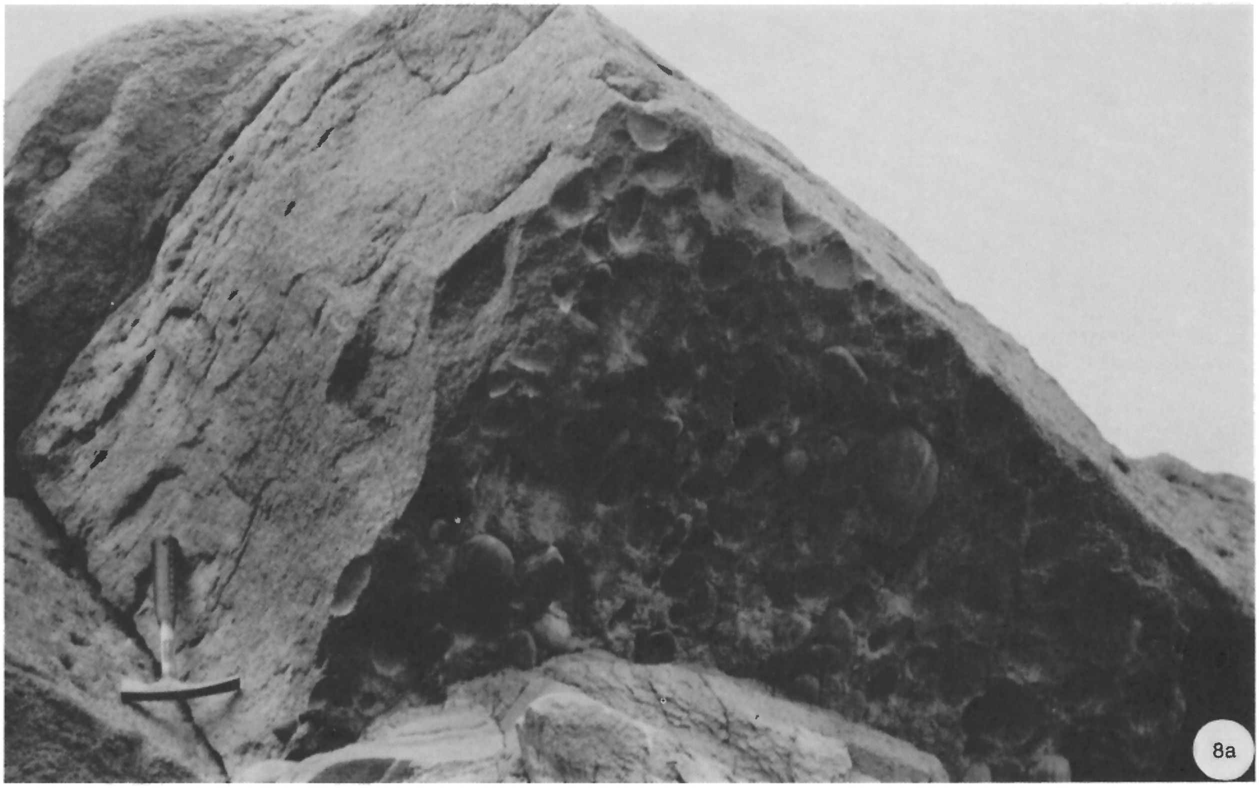


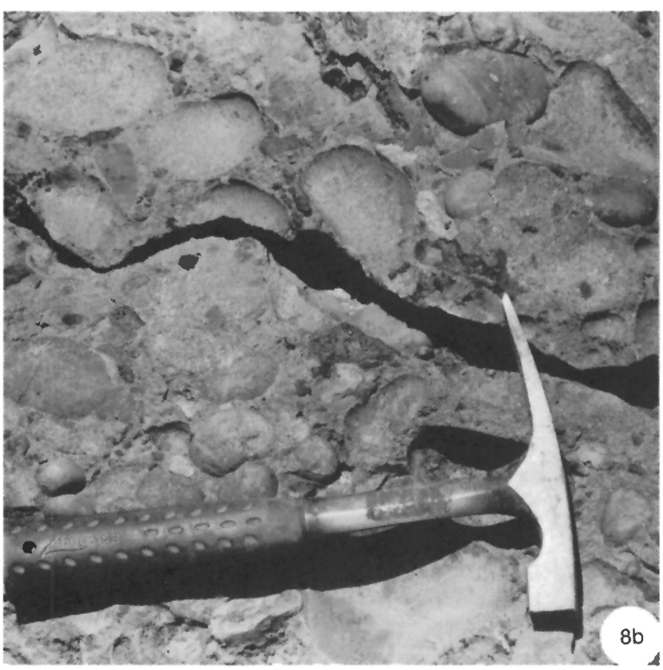
Plate 7

a. Outcrop 10, beds 3 and 4. Upper bedding plane of planar crossbedded and cross-laminated units of sandstone.

b. Outcrop 10, bed 4. Upper bedding plane with trough cross-lamination. Note small dune with current direction indicated by arrow.

c. Upper intrabedding surface of the same unit showing rib-and-furrow structure. Current from bottom to top.





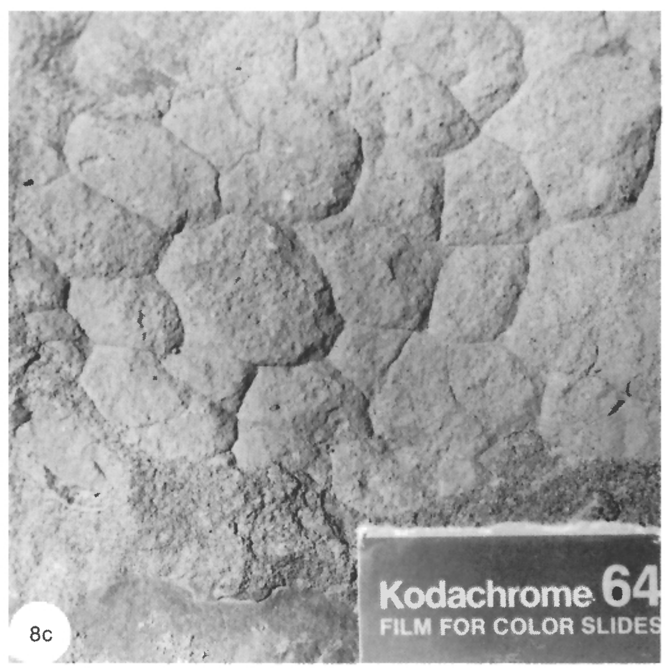


Plate 8

a. Outcrop 8, bed 43. Typical thin channel lag deposit.

b. Detail of same bed as 8a.

c. Outcrop 14, bed 14. Fragment of claystone bed with desiccation crack pattern found among redeposited claystone clasts in intraformational conglomerate. Scale is 3.9 cm/wide.

Plate 9

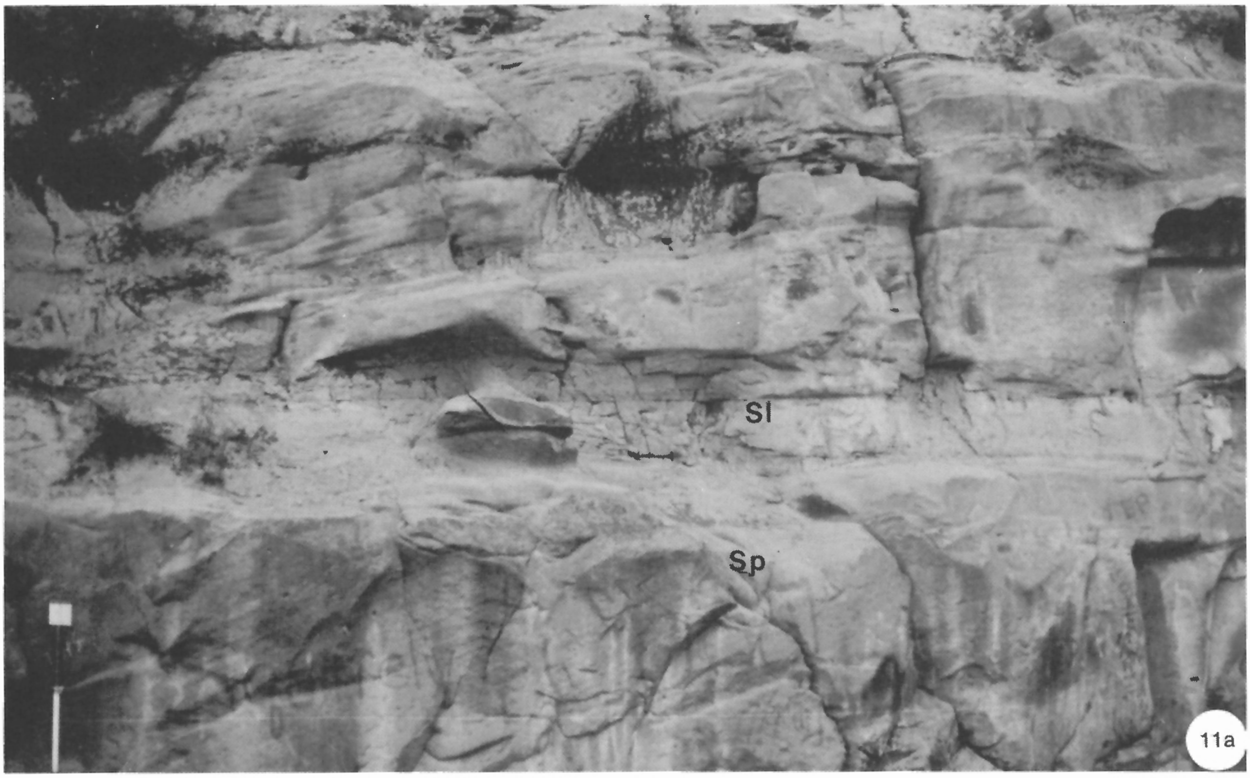
a. Outcrop 8W, beds 39 and 40. Incline bedded unit of sandstone (lithofacies Sh) overlying carbonaceous shale.

b. Outcrop 3, bed 17. Flat and wavy laminated sandstone (lithofacies Sl) of crevasse splay origin between coal and claystone beds.

Plate 10

a. Outcrop 33. Entrance Conglomerate with sandstone lenses.

b. Detail of 10a showing imbrication of pebbles.



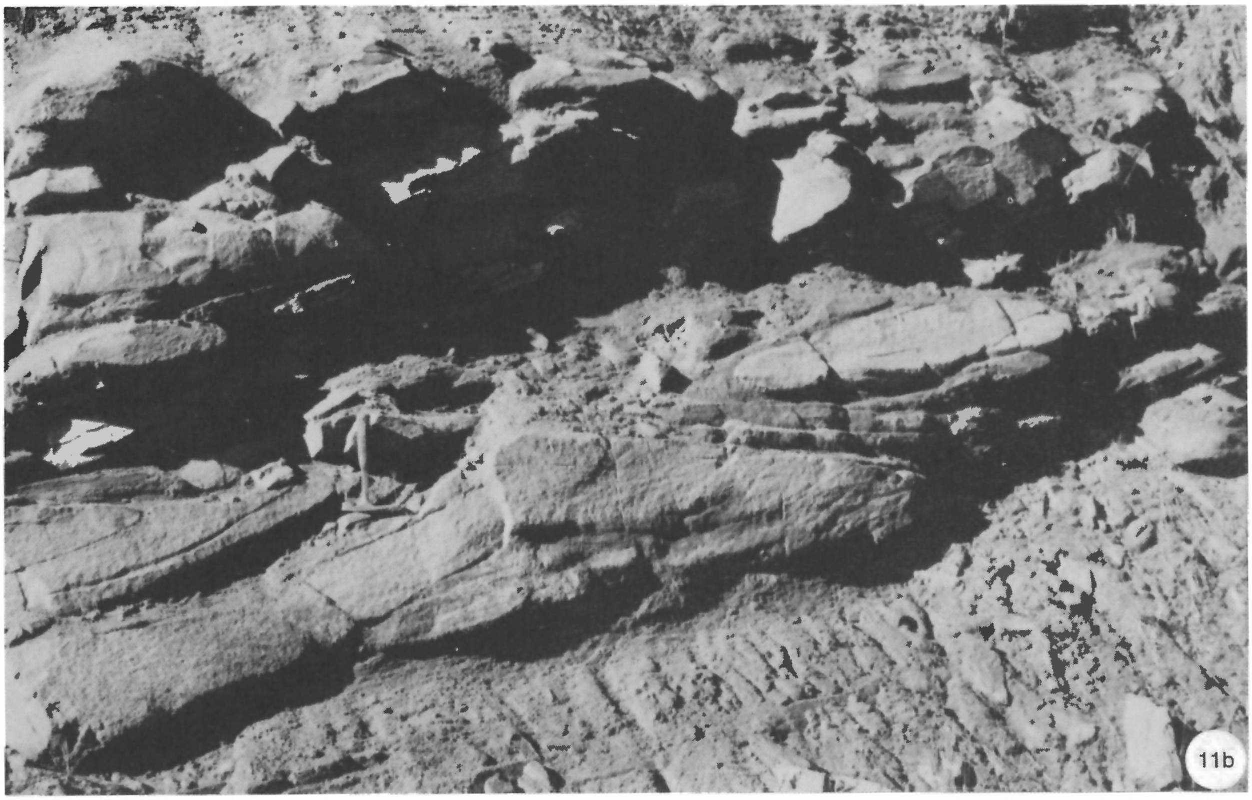


Plate 11

a. Outcrop 31. Fining-upward sandstone unit. A thick, medium- to coarse-grained planar crossbedded unit at the base (lithofacies Sp) is overlain by meidum- to fine-grained sandstone with low angle crossbedding passing laterally into horizontal bedding (lithofacies Sl).

b. Outcrop 36. Trough crossbedded unit (lithofacies St).

Plate 12

a. Outcrop 61. Co-set of planar crossbedded sandstone (lithofacies Sp) forming roof rock of Mynheer coal seam.

b. Outcrop 59. Trough crossbedded sandstone (lithofacies St) forming roof rock of Mynheer coal seam.

Plate 13

a. Outcrop 53. Massive and incline bedded sandstone (lithofacies Sh).

b. Outcrop 2. Channel deposit with lithofacies Gm, St and Sh.