GEOLOGY AND COAL QUALITY OF THE CADOMIN-LUSCAR COAL FIELD, ALBERTA

Open File Report 1989-9

WESTERN CANADA COAL GEOSCIENCE FORUM 1989

FIELDTRIP

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INTRODUCTION

The objective of this field trip is to examine Lower Cretaceous coal-bearing rocks in the Cadomin-Luscar area of central Alberta. Participants will have an opportunity to observe at first hand the lithology and complex structural relationships of the rock succession. Examples of deposition related to shallow marine, coastal plain, swamp, alluvial flood plain and alluvial channel environments will be observed and the evidence for this interpretation will be discussed. Fresh coal outcrops will be observed in the mine sites and results from recent coal quality studies will be discussed. The structure of the area will be explained with some excellent exposures and accompanying down-plunge cross sections.

The Cadomin-Luscar area is located in west-central Alberta, between latitudes 53° and 53° 8' and longitudes 117° 17' and 117° 34' (figures 1 and 2). The area forms part of the Cadomin (NTS 83F/3) and Miette (NTS 83F/4) map sheets and covers approximately 100 km^2.

The existence of the thick Jewel coal seam has been known since the turn of the century. An underground mine was developed at Cadomin in 1917 and at Luscar in 1921. These mines operated until the mid 1950's. Open pit mines were opened by Cardinal River Coals Ltd. at Luscar in 1970 and Gregg River Resources Ltd. in 1983.

The Cadomin area was mapped by the Geological Survey of Canada (MacKay, 1929 and 1930). Mountjoy (1959) mapped the Miette mapsheet. The area east of Gregg River was mapped by Hill (1980). The sections along the McLeod River at Cadomin have often been used in stratigraphic studies (e.g. Mellon, 1966,1967; McLean, 1982 and McLean and Wall, 1981). Petrographic characteristics (rank and composition) of the coals have been described by Kalkreuth (1988), Langenberg et al. (1989), Kalkreuth et al. (1989) and Kalkreuth and Leckie (in press).

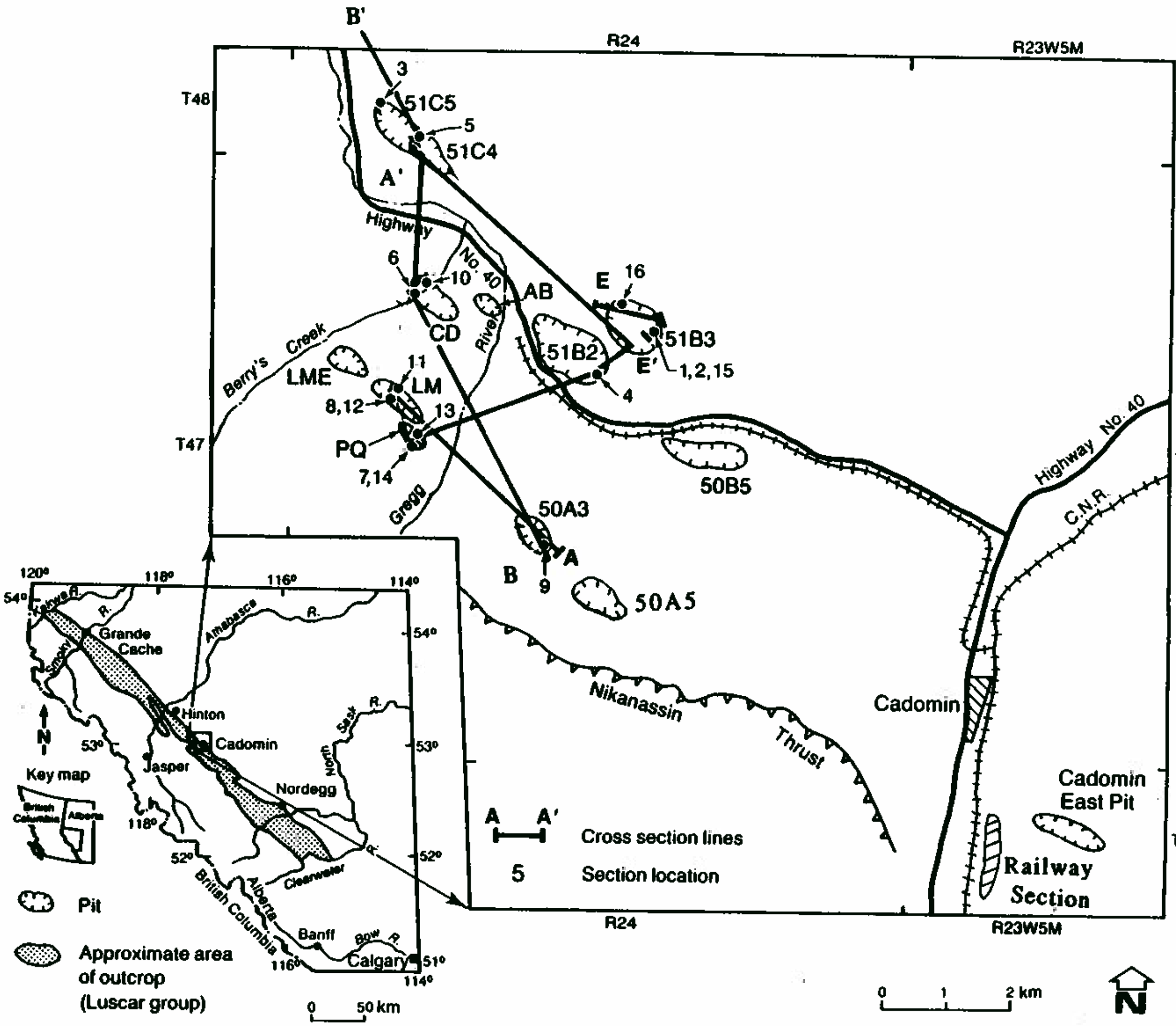

Figure 1. Location of Cadomin-Luscar coalfield with pits, stratigraphic cross sections and sections.

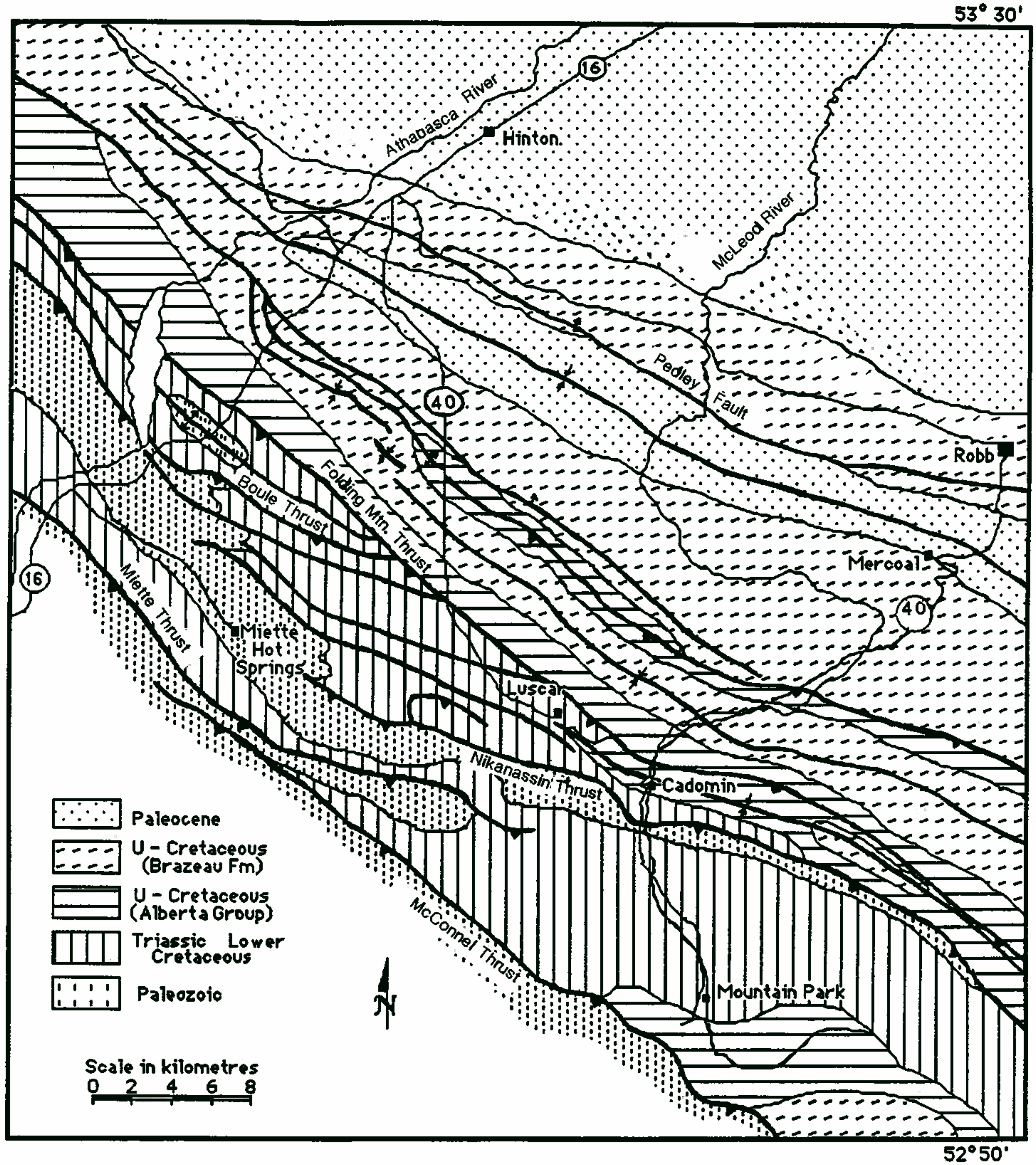

Figure 2. Regional geology of Cadomin area, modified from MacKay (1929).

GENERAL GEOLOGY

The Cadomin-Luscar coal field is situated in the Inner Foothills. The area is largely underlain by Lower Cretaceous rocks of the Luscar Group as defined by Langenberg and McMechan, 1985 (figures 3 and 4). The coal-bearing Luscar Group was deposited in an overall regressive sequence, during early Albian time. This sequence represents the second major, western sourced, Cretaceous clastic wedge to prograde into the Interior Cretaceous seaway. The first wedge is the Kootenay/Nikanassin succession. The Luscar Group consists of Cadomin, Gladstone, Moosebar and Gates Formations. The Cadomin Formation consists of alluvial conglomerates. The Gladstone Formation consists of alluvial sandstone, shale and minor coal and is of Aptian-Early Albian age. The Moosebar Formation contains marine shale and minor sandstone and is also of Early Albian age. The largely nonmarine Gates Formation consists of sandstones, shales and coal and can be divided into three members, i.e., the Torrens, Grande Cache and Mountain Park Members. The age of the Gates Formation ranges from Early to Middle Albian. The Torrens Member is defined by shallow marine (shoreface) sandstones. The Grande Cache Member shows coastal- and alluvial-plain sandstones, shales and major economic coal seams. It grades into the Mountain Park Member, which consists of fluvial, fining-upward sandstones, shales, and minor coal seams. Four regional marine sedimentation cycles can be distinguished in the transition from Moosebar to Gates Formations (Macdonald et al., 1988).

Two open pit coal mines (Cardinal River coals and Gregg River Resources) are presently producing from the Grande Cache Member. All production comes from the Jewel Seam at the base of this member and a total of 4.4 million tonnes of raw metallurgical coal was produced in 1987 (ERCB, 1987). The rank of the Jewel Seam is mainly medium volatile bituminous. The R seam (Rider Seam of Cardinal River and Ruff Seam of Gregg River) is situated about 60 meters stratigraphically above the Jewel Seam. The overlying strata of the Grande Cache Member contain additional, generally thin coal seams. In addition, the Torrens, Mountain Park, Nikanassin, Cadomin and Gladstone contain thin coal seams.

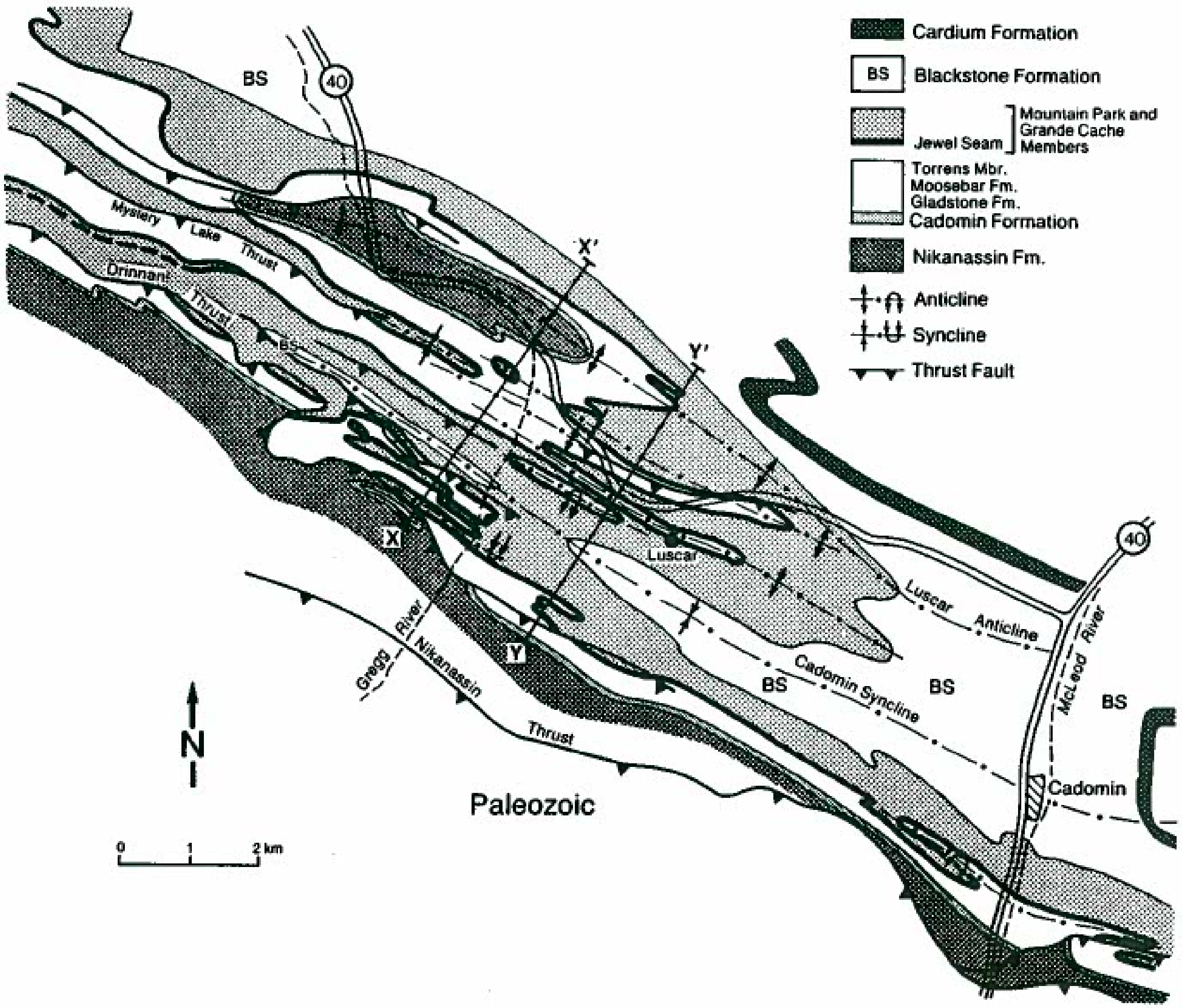

Figure 3. Simplified geological map of the Cadomin-Luscar coalfield, compiled and modified from Hill (1980) and Karst (Gregg River Resources, unpublished).

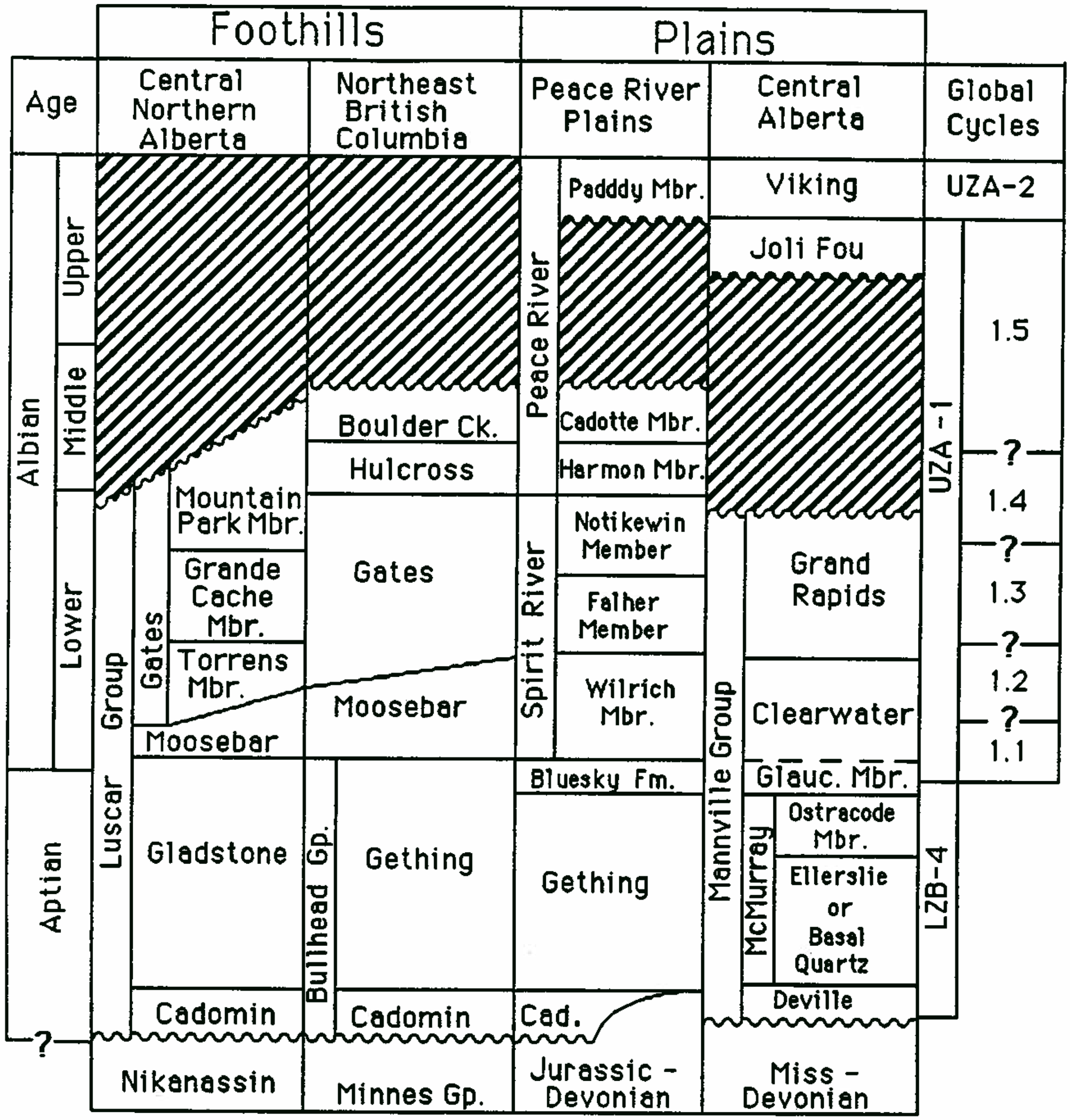

Figure 4. Lower Cretaceous stratigraphic nomenclature of northcentral Alberta and northeastern British Columbia.

The rocks of the area are highly deformed by folding and faulting, with major structures such as the Cadomin Syncline, the Luscar Anticline and the Drinnan Thrust (figures 5 and 6). The area is situated about 25 km southwest from the upper detachment, which is the Pedley Thrust near Coalspur (figure 5). The Coalspur Anticline (figure 5) defines the Triangle Zone in this part of the Foothills. In the south, the area is bounded by the Nikanassin Thrust, which forms the boundary between Foothills and Mountains in the region.

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS

NIKANASSIN FORMATION

The Nikanassin Formation straddles the Jurassic/Cretaceous boundary and is thought to represent the first western sourced clastics into the West Alberta foreland basin (Stott, 1984). The formation is generally divisible into a lower marine and an upper coastal and alluvial plain portion. The correlative Kootenay Formation, in central and southern Alberta, is coal-bearing and represents a more complete coastal plain to alluvial plain environment. At Cadomin, the upper Nikanassin is exposed immediately below the Cadomin Formation, along the McLeod River railroad section. Some gas is found in the Nikanassin in the Elmworth Deep Basin.

LUSCAR GROUP

The Luscar Group consists of the Cadomin, Gladstone, Moosebar and Gates formations. This group, which is equivalent to the Mannville Group of central Alberta (figure 4), shows both marine and non-marine sedimentary environments. In the Deep Basin (north of the Cadomin area), as many as eight marine cycles of marine sedimentation have been recognized in correlative strata of the Spirit River Formation (Cant, 1983; Smith et al; 1984). These include the Wilrich A and B cycles, the Falher A through G cycles and the Notikewin (figure 7). In the western

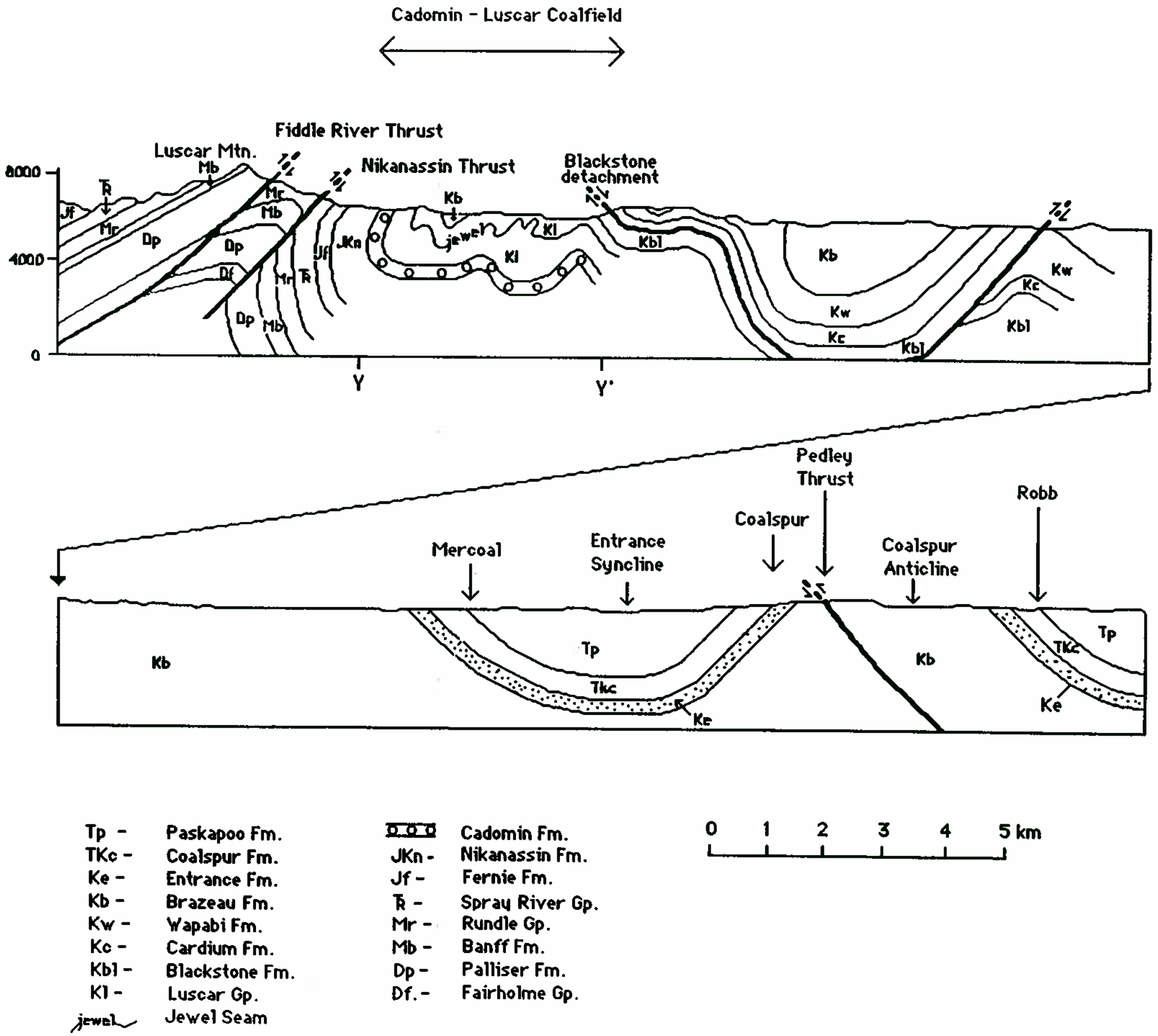

Figure 5. Regional structural cross-section from Cadomin to Robb area, modified from MacKay (1929).

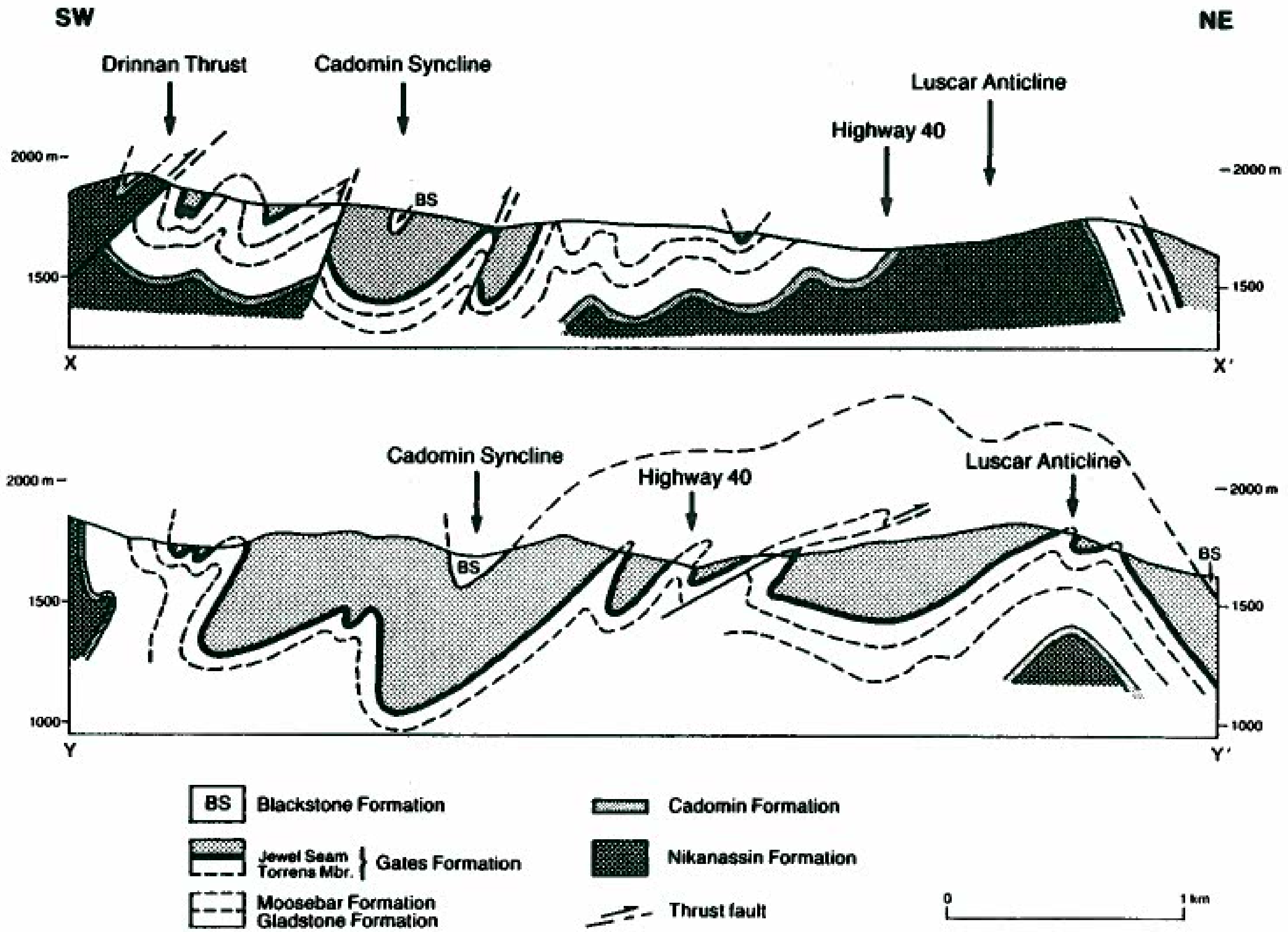

Figure 6. Cross sections XX' and YY' through the Cadomin-Luscar coalfield. Section XX' is on the Gregg River property (after Karst, Gregg River Resources Ltd., unpublished). Section YY' is on the Cardinal River property (modified from Hill, 1980).

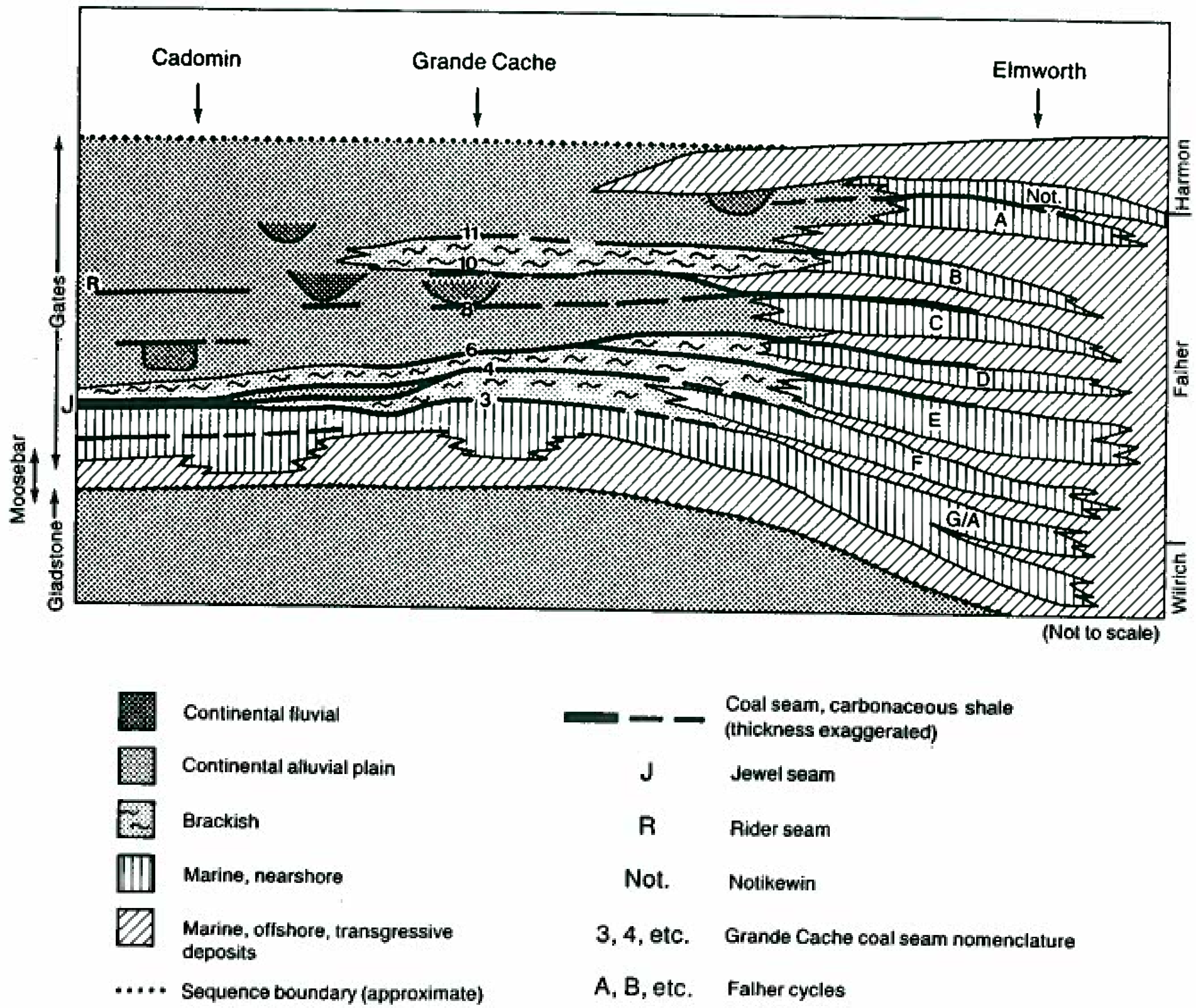

Figure 7. Schematic cross section of the Gates Formation clastic wedge, Cadomin to Elmworth area.

deformed part of the Deep Basin (Cadomin area), the Gates Formation is mostly nonmarine and it is not possible to recognize all of the Falher Member cycles (figure 7).

CADOMIN FORMATION

The Cadomin Formation was deposited in alluvial fans and on braided river pediment plains with chert pebble conglomerates, and is unconformably overlying the Nikanassin (McLean 1977, Gies, 1984). Much of the Cadomin that developed in the west as alluvial fans was transported and reworked into the northwest trending Spirit River channel that developed parallel to the foreland basin during the early Aptian. The Cadomin likely represents a major sea level lowering event and possibly a major sequence boundary.

Large reserves of gas are present in the Cadomin Formation in the northern Deep Basin region. At least one gas well, 10km east of Cadomin, encountered gas in the Cadomin Formation. The Cadomin Formation is an excellent marker horizon, both at the surface and in the subsurface.

GLADSTONE FORMATION

The Lower Cretaceous (Aptian-Albian) Gladstone Formation is equivalent to the coal-bearing Gething Formation in northeastern British Columbia and the oilsands-bearing McMurray Formation in northeastern Alberta. The formation lies conformably on the Cadomin with no apparent major stratigraphic break. The section at Cadomin shows a transition from well drained alluvial plain deposits with thin coals near the base, to coastal plain deposits with thicker coals near the top.

The Bluesky Member occurs at the top of the Gladstone as a near-shore marine transgressive, upward-coarsening sequence. Gas is produced from the northeast end of a barrier island or bar sand in the Bluesky in the Edson gas field. This bar sand extends to within 20km of the Cadomin area (Jackson, 1984), although it is not gas-bearing in this region.

MOOSEBAR FORMATION

Macdonald, et al. (1988) suggests that the marine strata of the Moosebar/Gates transition at Cadomin are likely correlative with the subsurface Wilrich and lower Falher cycles (figure 7). At Cadomin, these strata are divided into the 1st, 2nd and 3rd regional cycles (figure 8), forming a series of prograding shorelines and coastal plain deposits. A 4th cycle is present above the Jewel coal seam and is thought to represent a brackish water facies. More local scale cycles are also present in the outcrop area, probably representing local facies changes or subsidence events. The fully marine succession includes offshore to lower shoreface (with storm deposits) and shoreface to foreshore (and possibly beach, figure 8). It is uncertain, at this time, what type of prograding shorelines are represented in the Cadomin area. Very little evidence is present to support a tide or river dominated delta setting from sedimentological observations in the sections studied. McLean and Wall (1981) suggest a wave influenced strandline environment for the Cadomin area. In the subsurface to the east of Cadomin, Jackson (1984) suggests that southwest-northeast trending wave dominated shorelines were predominant during this time. There is general agreement amongst all workers that paleoflow was towards the north and Taylor and Walker (1981) argue specifically for a northwest paleoflow, parallel to the Cordillera, in the Nordegg area.

The lower Moosebar Formation (lower Wilrich or 1st cycle) in this area consists of a series of fine-grained mudstones interbedded with sharp based siltstones and thin sandstones (figure 8). A thin argillaceous coal is present, as well as Planolites and Skolithos burrows. The cycle terminates in a 3 m coarsening-up sequence that is capped by a thin rooted coal. Well preserved conifer cones and leaf impressions are present in a thin shale bed near the coal. This cycle is best exposed on the Cardinal River Coal property (50A3 pit), near the southwestern boundary of the Cadomin-Luscar coalfield (figure 1).

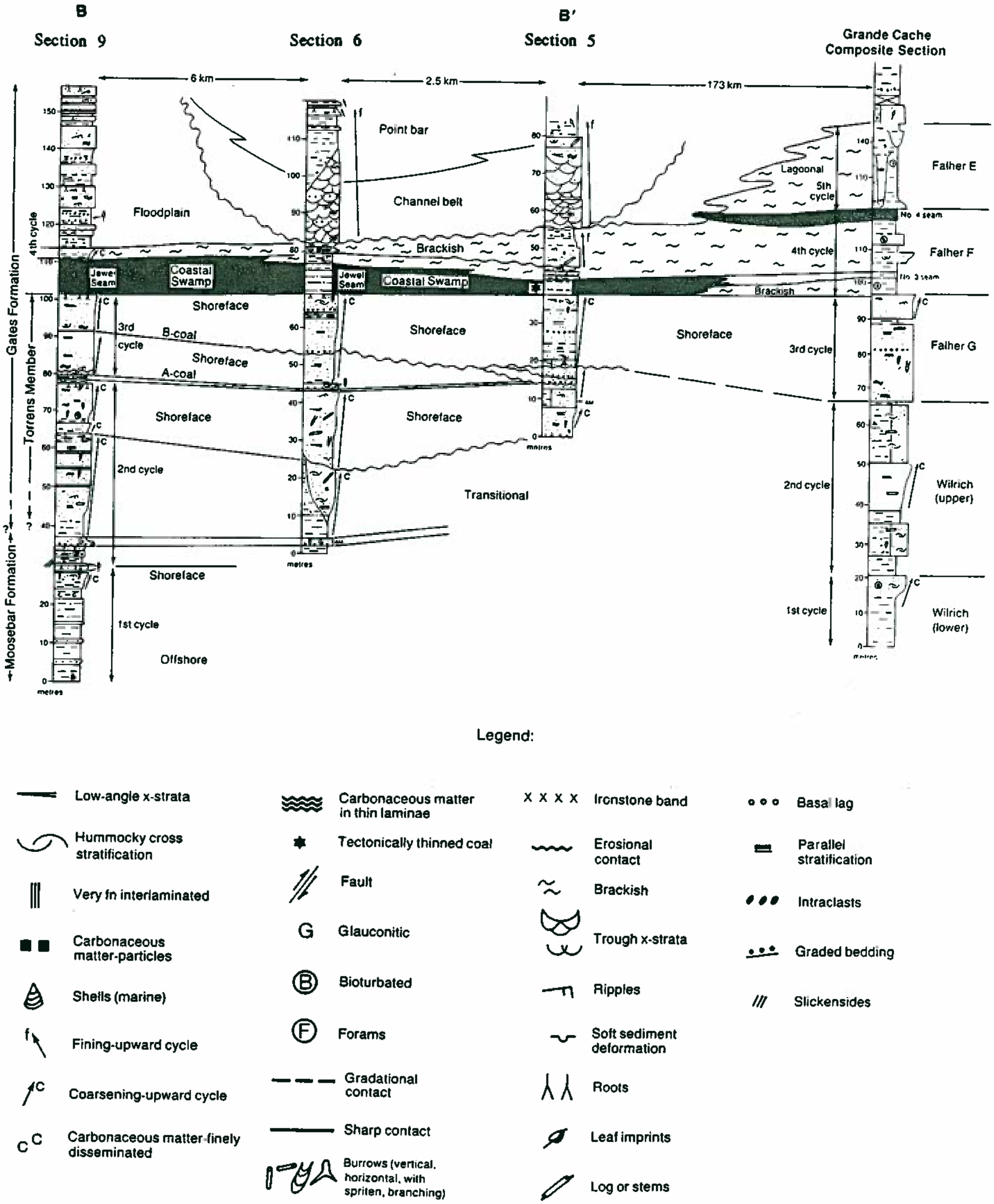

Figure 8. Cross section showing the marine to nonmarine transition, Cadomin-Luscar area.

This first cycle in the Moosebar Formation is interpreted to have formed in an offshore environment in which storm events periodically deposited thin sand units. In this area, the cycle terminated in an emergent offshore bar. A fairly major relative lowering of sea level, and consequent exposing of the shelf, is indicated by the preservation of well preserved plant fossils and the development of thin rooted coals.

The lower part of the 2nd marine cycle corresponds to the upper part of the Moosebar Formation. A glauconitic, sharp based pebble conglomerate bed, commonly graded, is found near the base of the cycle in Section 6 and 9 (figure 8) and is interpreted as an offshore transgressive deposit. It may in part represent very slow deposition of a condensed section as described by Haq et al. (1987). The presence of glauconite in the pebble beds supports this idea (Weimer, 1983). The boundary between Moosebar and Torrens is gradational and is somewhere in the 2nd cycle. Alternatively, it could be placed either at the top or the base of the 2nd cycle.

GATES FORMATION

The Gates Formation consists of the Torrens, Grande Cache and Mountain Park members. Both shallow marine and non-marine sedimentary environments are deduced for this formation.

TORRENS MEMBER

The base of the Torrens member is not well defined, but is somewhere in the 2nd marine cycle. The 2nd cycle is believed to correspond to one of the cycles in the Wilrich Member (figure 8). This cycle, at Cadomin, consists of two or more coarsening-up sequences stacked on top of each other. The coarsening up cycles are commonly heterolithic, with fine sand dominating. Hummocky cross stratification, soft sediment deformation, wave ripples, and parallel laminations are all found in this cycle. Trace fossils include Planolites, Diplocraterion and Skolithos. The second cycle is capped by a rooted coal or carbonaceous mudstone, herein called the "Torrens A-coal". This coal can be traced in the subsurface as far north as township 57 (south of Grande Cache), where it disappears in another coarsening up sequence (Macdonald et al., 1988). The Torrens A-coal is seen to vary from a 90 cm coal in the south (Section 9) to a carbonaceous shale at Section 6, and is locally eroded at Section 5 (figure 8).

The second cycle is interpreted to have formed, primarily, in the offshore to shoreface environments. The offshore/transgressive deposits of the Moosebar give way upsection to lower shoreface and finally foreshore sediments of the Torrens Member. The trace fossil assemblage is consistent with this interpretation. The hummocky cross stratification supports the storm deposited origin and has been found in other locations of the Moosebar to Gates transition (Leckie and Walker, 1982). The laterally extensive Torrens A-coal in the subsurface may suggest sea level lowering at this time (Macdonald, et al., 1988).

The 3rd marine cycle consists of massive (though occasionally thinly bedded), fine to very fine grained sandstone, which has been traditionally been called the Torrens member. Faint parallel laminations are the predominant structures, with some trough cross bedding and hummocky cross stratification also present (figure 6). Scour surfaces, with pebble lag deposits, are also common in the cycle. Mudstone is a very minor lithology in this cycle and is usually associated with the hummocky cross stratification. Trace fossils are particularly abundant near the top of the 3rd cycle and include Skolithos, Ophiomorpha, Planolites, and Diplocraterion. The sequence is capped by the thick Jewel seam. The sandstones below the coal seam are commonly well rooted and show a discoloration in the top 50 cm. Tree trunk impressions and root casts can be found on the uppermost bedding plane surface of these sandstones. A more medium-grained, intraclast rich, trough cross stratified facies occurs at one locality within this area.

The 3rd cycle is probably correlative with the Falher G or Wilrich A cycles in the Deep Basin (Macdonald et al., 1988). This cycle is interpreted to be a succession of two prograding shorelines sequences, with upper shoreface to foreshore environment transitions being present.

The thin Torrens "B-coal" that is present at Section 9, very likely represents a shifting away from this area of the prevailing sediment source and the development of a small lagoonal environment. This coal is not traceable throughout the Cadomin area (figure 8). The trace fossil assemblage is typical of the Skolithos ichnofacies, which is most commonly found in high energy beach or beach-like facies (Ekdale et al., 1984). The presence of hummocky cross stratification high up in the sequence precludes a true beach environment for parts of the Torrens, because these structures generally form below fair wave base (Walker, 1984). The more medium-grained, trough cross stratified facies is interpreted to be a later tidal channel deposit.

LOWER GRANDE CACHE MEMBER

The interval between the Jewel and R seams can be divided into five lithofacies units (figure 9). Lithofacies GC1 is the 10 m thick Jewel coal seam which overlies the Torrens Member, has a well rooted seatearth, which often contains log and root impressions (figure 8). The Jewel Seam forms the base of the Grande Cache Member. Macdonald et al. (1988) suggests that part of the Jewel seam is stratigraphically equivalent, though not necessarily time equivalent, to the No. 3 seam at Grande Cache. To the east, in the subsurface, the Jewel seam appears to be correlative with the Mannville "Medicine River coal marker" described by Strobl (1988). Farther towards the north, into the Deep Basin, the Jewel equivalent is seen to disappear into marine strata (figure 7). This evidence suggests a more landward position for the peat swamp development, perhaps up to 100km from the coastline on a coastal plain.

Englund et al. (1986) describe low ash, low sulfur, Pennsylvanian coastal coals, having no overlying marine strata, that are believed to be directly related to the development of peat swamps on top of abandoned delta lobes in an overall regressive sequence. McCabe (1987) describes coals from the Upper Cretaceous Horseshoe Canyon Formation and Judith River Group, forming in north-south belts parallel to the paleocoastlines

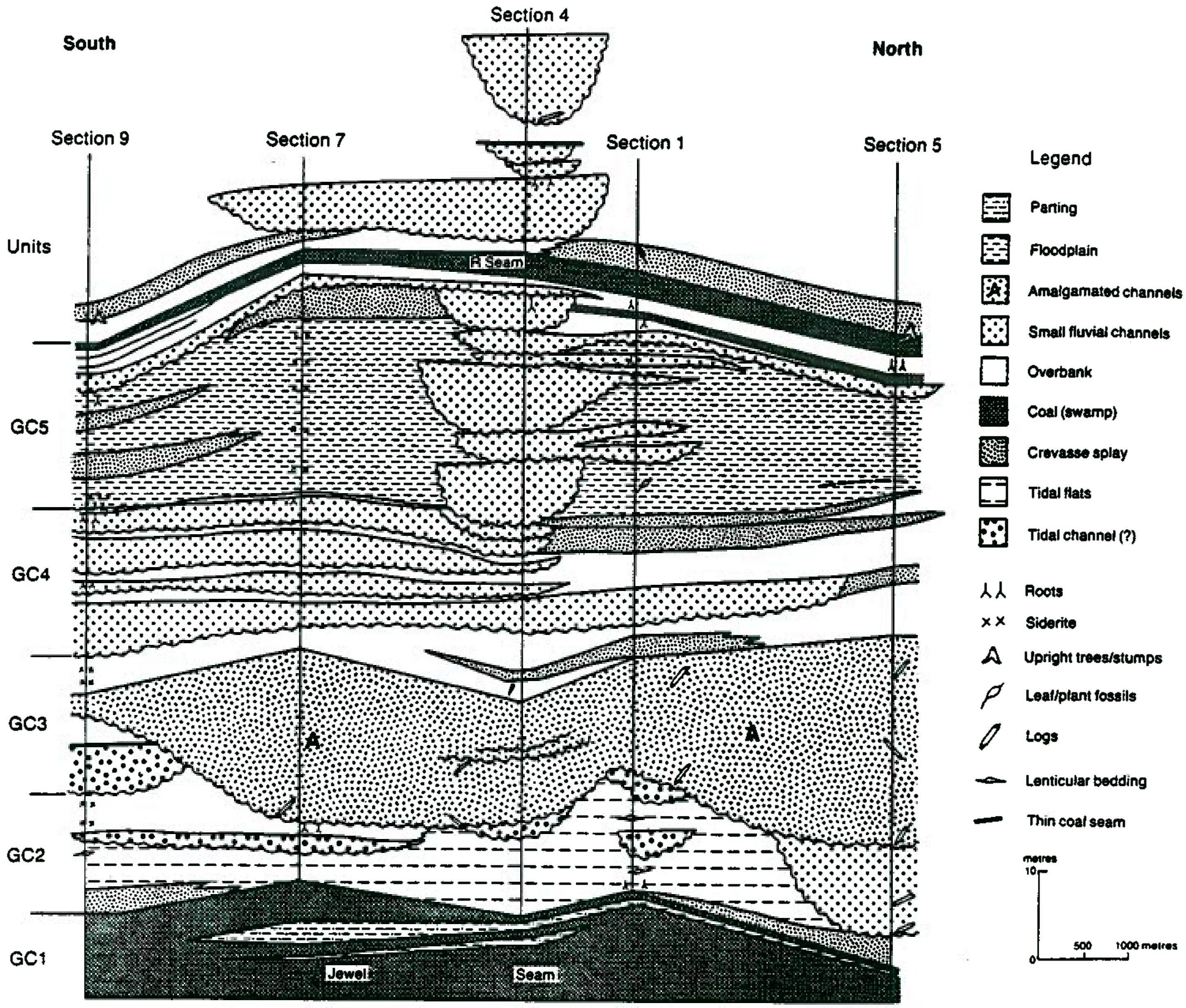

Figure 9. Stratigraphic cross section showing facies interpretation for the Grande Cache Member between the Jewel and R seams.

and having the thickest accumulation of peats (coals) some 40-80 km landward of the shoreline. The Okefenokee Swamp is cited as a modern day analog for the Upper Cretaceous coals by McCabe (1987), and this model may equally well apply to the Lower Cretaceous Jewel seam. McCabe (1984) has suggested that in order for thick, low ash coals to form in a low lying coastal plain swamp, they must be some distance landward from active shoreline processes, yet still maintain high watertables. This would seem to be the case for the Jewel seam at Cadomin. Because of the close connection with regionally extensive foreshore deposits below the coal, Kalkreuth and Leckie (in press, their figures 1 and 19) introduced the term strandplain coals for these coastal plain coals.

A 4th marine cycle (directly above the Jewel Seam) is designated as lithofacies unit GC2 and extends upsection until the first major fluvial sandstones are encountered (figure 9). A brackish water interpretation is based on the presence of trace fossils (Diplocraterion and Planolites) at Section 6, and the presence of lenticular bedding throughout this interval. Specimens of the siliceous forams Hippocrepina (?) sp., Miliammina (?) sp. and Saccammina sp. have been recovered from three locations above the Jewel seam in this area and are indicitive of ..."a shallow brackish (not normal marine) marine environment" (Wall, pers. comm.). The fourth cycle is thought to be related to the transgressive portion of the Falher F cycle in the Deep Basin further north.

The nonmarine sequence above the tidal flat facies GC2 (figure 9) is non coal-bearing or contains only very thin seams. No trace or hard-bodied marine fossils have been observed above the tidal flat facies, at least up to the R coal seam.

The GC3 lithofacies unit overlies the tidal flat unit and consists of thick, amalgamated, trough-cross stratified, log-bearing, fine-grained sandstones (figure 9). Some large lateral accretion bedding can be seen in the 51B2 pit at the Cardinal River minesite. The unit is interpreted to be a series of amalgamated fluvial channel deposits. A meandering system is suggested by the lateral accretion bedding.

The GC4 lithofacies consists of a series of thin, fining-upward sandstones and mudstones and some coarsening-upward sequences. A very thin (10-20cm) rooted coal caps this unit over most areas, except where channeling has removed the seam (figure 7). The GC4 lithofacies is interpreted to be a series of stacked, small fluvial channels, with associated crevasse splay deposits.

Over most of the area the Unit GC5 consists of fine-grained mudstones, thin discontinuous sandstones, the R seam capping the unit and minor coarsening up sequences. Section 4 (figure 9), in contrast, shows a series of fining up cycles, each about 2-6m thick. This unit is interpreted to be primarily a floodplain deposit, with one area of stacked, small fluvial channel deposits. Paleocurrent measurements are not available, but the cross-section F-F' orientation (figure 9), suggests either an east-west or northwest-southeast orientation for this channel system. The R seam is considered to be a typical alluvial plain coal, which was probably deposited contemporaneously with very small fluvial channels. It is possible, however, that the R seam is related to one of the Falher cycles (B or C?) during the post regression, coal forming period. The R seam does lie at about the same stratigraphic position as the #10 or 11 seam at Grande Cache (figure 6), both of which are thought to be associated with the Falher cycles in the Elmworth area (Macdonald et al., 1988).

UPPER GRANDE CACHE MEMBER

The upper Grande Cache member sequence above the R seam is much the same as seen in the lower portion. No significant change occurs in the interpreted depositional environment until the Mountain Park member is reached.

MOUNTAIN PARK MEMBER

The Mountain Park is generally defined as .."the first major greenish colored sandstone encountered going upsection" (McLean, 1977) for the purposes of field mapping in this area . These sandstones are interpreted to be large scale fluvial deposits and may occur at various stratigraphic levels, making the field mapping criteria somewhat arbitrary. The uppermost coal seam (> 0.6m thick) in the Grande Cache Member is alternately used, when no major greenish sandstone is present.

The contact between the Mountain Park Member and the overlying dark grey mudstones of the Blackstone Formation (Shaftesbury) is generally sharp and usually contains a thin transgressive pebble lag deposit. Thin upward-coarsening cycles are occasionally seen in the lower part of the Blackstone Formation. The Blackstone transgression may be related to the accretion of terrains during the Columbian Orogeny (Stott, 1984 and Monger, 1984). The Blackstone Formation may also be an important source rock for gas generation in this area.

COAL DEPOSITIONAL ENVIRONMENTS

The deposition of organic matter, which resulted in the generally thick coals of the basal Grande Cache Member, is closely related to the platform of underlying strandplain sandstones, such as those of the Torrens Member (Kalkreuth et al., 1989). These peats were probably situated inland and far removed from contemporaneous clastic depositional systems at the shoreline and can be classified as low-lying mires (McCabe, 1987).

Facies-critical macerals and a number of petrographic indices can be used to define coal facies and environments of coal deposition (Diessel, 1986). Macerals are defined as the microscopically recognizable constituents in coals. The term maceral was introduced as an analogy to the term mineral of inorganic rocks. The macerals are commonly classified in three groups: vitrinite, inertinite and liptinite. The relationships of coal macerals and depositional settings of the Lower Cretaceous Gates coals have been examined recently (Kalkreuth et al., 1989; Kalkreuth and Leckie, in press).

The proportions of the macerals in coals reflect the various organic source materials contributing to the accumulation of the ancient peat and the conditions prevailing during accumulation at or near surface; i.e. height of water table, pH, decay by aerobic and anaerobic bacteria, etc. Facies-critical macerals are components such as vitrintie A, which indicates on origin from wood-producing plants and liptinite macerals such as sporinite and cutinite, which refer to specific precursor materials. Others like alginite, semi-fusinite and fusinite are indicators of the relative position of the water table during peat accumulation. Petrographic indices such as the Tissue Preservation Index and the Gelification Index (Diessel, 1986) are used to assess the depositional environments, ie. mire types, height of water tables, preservation of cell-tissues, degree of oxidation and degradation due to transport mechanism (the Tissue Preservation Index, TPI, and Gelification Index, GI, are explained in figure 10).

Petrographic characteristics and coal depositional environments will be discussed in detail for a section from Gregg River's PQ and LM pits. The section sampled is shown in figure 10 and represents a composite of two sections separated by 650 m. Samples were collected from the Torrens A coal seam inbetween shoreface sandstones, the Jewel seam directly on top of the shoreface sandstones and the R seam (Ruff) from the non-marine environments (figure 9). Within this sequence, systematic trends in maceral contents, mineral matter content and in the petrographic indices are apparent (figure 10). The Torrens A seam has a very high vitrinite content (93 vol. %) while inertinite content is low (7 vol. %). Liptinite macerals were found only in traces. The mineral matter content is very high (47 vol. %). The samples collected from the Jewel seam show in contrast a drastic decrease in vitrinite contents (46 - 58 vol. %) while inertinite macerals account for 40 - 52 vol. %. Macerals of the liptinite group (sporinite) are still rare with up to 2 vol. % only. Mineral matter contents in the Jewel seam range from 2 - 23 vol. %. A return to a higher vitrinite content is indicated for the Ruff seam (96 vol. %) with only minor contributions of inertinite (3 vol. %) and liptinite (1 vol. %). The Ruff seam has at this location a mineral matter content of 21 vol. %. Within the group of petrographic indices many show distinct changes in respect of the stratigraphic position of the coal seams. Related to the overall contents of vitrinite and

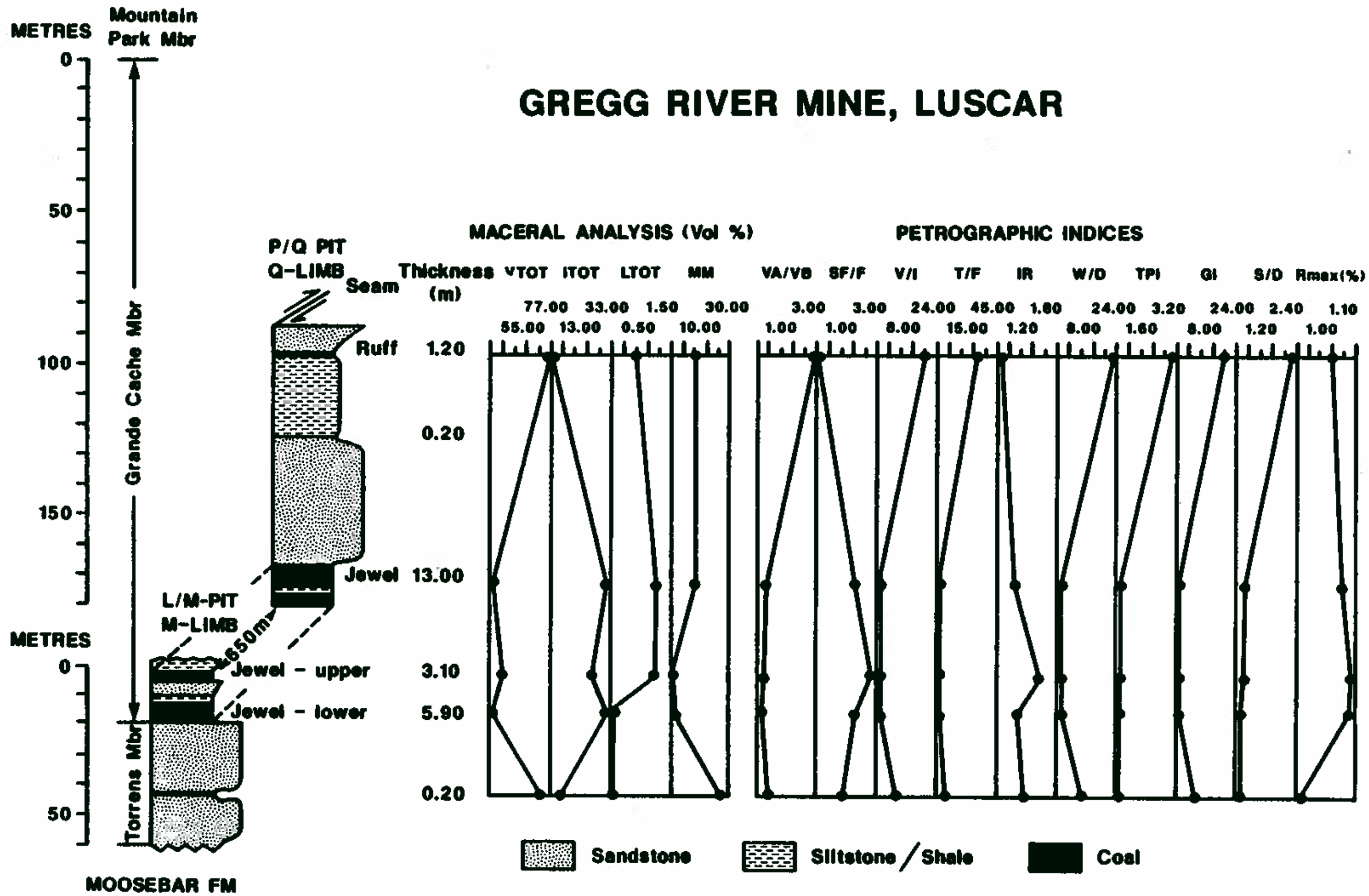

Figure 10. Maceral data, mineral matter contents and petrographic indices for Lower Cretaceous Gates coals, Gregg River Mine, Luscar (from Kalkreuth and Leckie, in press). Petrographic indices are: **VA/VB** ratio = Vitrinite A / Vitrinite B; **SF/F** ratio = Semifusinite / Fusinite; **V/I** ratio = Vitrinite / Inertinite; **T/F** ratio = Vitrinite / (Fusinite + Semifusinite); **IR** ratio = (Semifusinite + Fusinite) / (Inertodetrinite + Macrinite + Micrinite); **W/D** ratio = (Vitrinite A + Fusinite + Semifusinite) / (Alginite + Sporinite + Inertodetrinite); **TPI** ratio = (Vitrinite A + Fusinite + Semifusinite) / (Vitrinite B + Macrinite + Inertodetrinite); **GI** ratio = (Vitrinite + Macrinite) / (Semifusinite + Fusinite + Inertodetrinite); **S/D** ratio = (Vitrinite A + Fusinite + Semifusinite) / (Alginite + Sporinite + Inertodetrinite + Vitrinite B + Vitrodetrinite); **Rmax%** = Mean maximum vitrinite reflectance.

inertinite macerals, the Jewel seam has a very low V/I (vitrinite/inertinite) ratio while the Torrens A and the Ruff seams have high ratios. Preservation of the organic materials appears to be best in the Ruff seam which is characterized by a high vitrinite A/vitrinite B ratio, and a very high Tissue Preservation Index. In contrast, the Jewel seam appears to have a lesser degree of plant preservation, mainly because of substantial amounts of inertodetrinite and vitrinite B (low VA/VB ratio, figure 10). Within the inertinite group, semifusinite is the predominant maceral (22 - 24 Vol. %, high SF/F ratios, figure 10) while the total amount of structured inertinite (fusinite and semifusinite) is always greater than inertodetrinite (IR ratios = 1.35 - 2.02, figure 10).

Petrographic indices of 16 Jewel seam samples from the Cadomin-Luscar area (including the seams discussed previously) show that these coals form distinct groups, although considerable petrographic variation exists. In addition, some overlap of petrographic characteristics occur with the overlying coals from the non-marine environments. The V/I ratios range from 0.90 - 2.10 (mean = 1.39) and indicate, for most of the coals, the predominance of gelified components (vitrinite) over non-gelified (inerts). Within the vitrinite group the VA/VB ratio indicates a dominance of vitrinite B over vitrinite A (mean = 0.87) suggesting that substantial amounts of woody materials were decomposed prior to final deposition. The same holds true for the relatively high proportion of inertodetrinite derived from mechanical breakdown of fusinite and semifusinite precursors. The IR ratios (semifusinite + fusinite / inertodetrinite) of the Jewel Seam range from 1.20 - 2.30 with a mean of 1.58. That means that in all of these coals the sum of semifusinite + fusinite macerals is greater than inertodetrinite. IR ratios <2 were considered by Diessel (1982) to reflect hypauthochtonous and allochthonous conditions in the ancient peat swamps where redeposited semifusinite, fusinite and inertodetrinite would make up the bulk of the inerts. In other words, some transportation of the peat has taken place in the course of the accumulation of the Lower Cretaceous coastal plain coals.

Tissue preservation indices, such as T/F ratio and TPI ratio, are low to intermediate with values ranging from 0.50 - 1.60 for the T/F ratio (mean = 1.02) and from 0.80 - 1.54 for the TPI (mean = 1.12). These values indicate for the Jewel Seam a forest type swamp depositional environment with periods of low water tables during which substantial amounts of oxidized and partly oxidized materials were formed. The relatively high contents in the non-gelified macerals semifusinite, fusinite and inertodetrinite in respect to the gelified components vitrinite and macrinite leads to relatively low gelification indices ranging from 1.00 - 2.30 (mean = 1.55).

To assess the type of prevailing mire types during accumulation of the organic matter, the Gelification and Tissue Preservation Indices for the five coals have been plotted in a facies diagram (figure 11), as proposed by Diessel (1986). The three samples of the Jewel seam plot very close to each other, indicating a similar type of paleo-environment of deposition for these coastal plain coals (strandplain coals of Kalkreuth and Leckie,in press; see also figure 12). They must have been formed under relatively dry conditions as indicated by the high amounts of inertinite macerals (semifusinite, inertodetrinite, to a lesser extent fusinite). The major split of the seam, as illustrated in figure 10, might be a result of local flooding adjacent to fluvial/tidal channels or a result of lacustrine conditions caused by temporarily and locally increased subsidence rates. The Torrens A seam has a much higher Gelification Index (figure 10) due to a very high vitrinite content and low amounts of inertinite. The formation of the seam most likely reflects slight sea level fluctuations during deposition of the Torrens Member in which peat accumulated while a relatively high water table level was maintained as indicated by the large amounts of gelified plant remains. The Ruff seam in the Gregg River Mine area is highly variable in thickness, ash content and lateral continuity. The position in figure 11 shows very high Gelification and Tissue Preservation Indices due to the fact that the coal is made up almost entirely of vitrinite. As such, the Ruff seam might represent a locally flooded mire of the upper delta plain or alluvial plain with a substantial input of mineral matter associated with a relatively high water table.

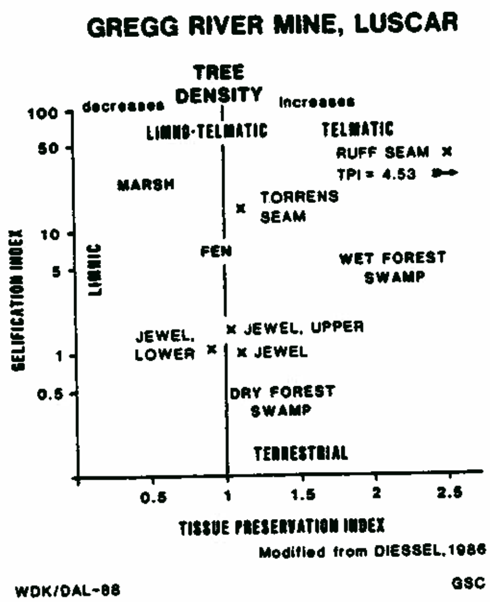

Figure 11. Facies diagram for Lower Cretaceous coals at Gregg River Mine, Luscar (from Kalkreuth and Leckie, in press).

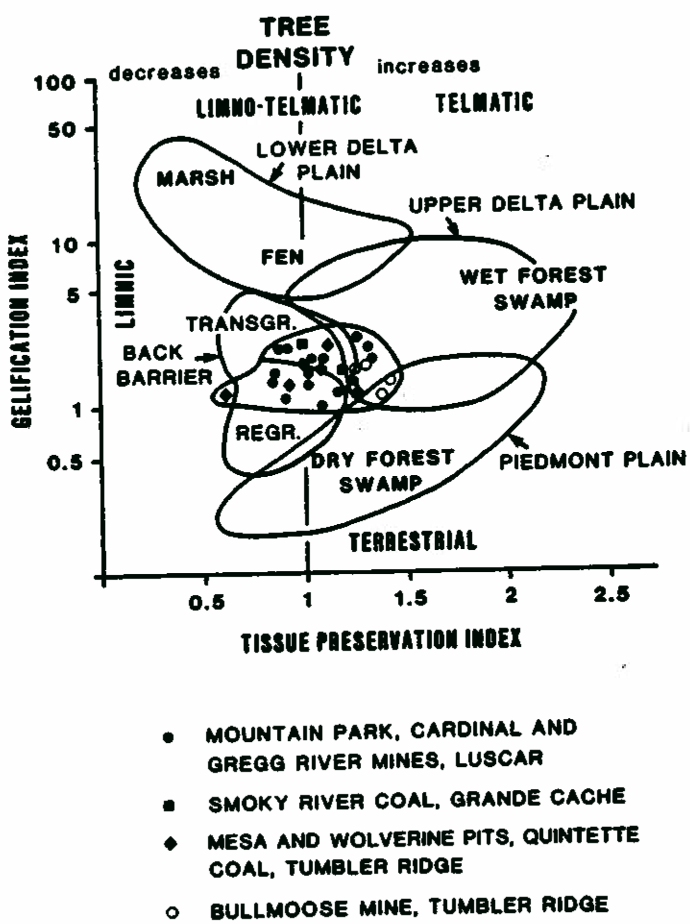

Figure 12. Coal facies and depositional environment for the lower Cretaceous coastal plain coals (modified from Diessel, 1986).

From the coal facies diagram (Diessel, 1986), a forest swamp environment of deposition is deduced for many of the coastal plain coals of the Lower Cretaceous (figure 12, see also Kalkreuth et al., 1989). For some coals, characterized by somewhat higher gelification indices (GI) while retaining similar tissue preservation indices (TPI), a shift to less forested fen-like depositional environments is indicated with a larger input of aquatic plants such as reeds and sedges.

STRUCTURAL GEOLOGY

The structure of the area is shown on the accompanying geological maps (figures 2 and 3) and cross sections (figures 5 and 6). The main structures in the Cadomin area are the Cadomin Syncline, Luscar Anticline, Drinnan Thrust and Nikanassin Thrust.

FOLDING

Many of the macroscopic folds have relatively straight limbs and short hinge areas, and could be classified as chevron folds. Folding is cylindrical on a local scale. This means that the folds can be described by the movement of a line (which is the fold axis) parallel to itself. This implies that a cylindrical fold does not change geometry in the direction of the fold axis. However on a regional scale folds change geometry in the direction of the fold axis and consequently they have to be considered non-cylindrical. This non-cylindricity resulted in the necessity to divide the Cardinal River property into 45 statistically cylindrical domains (Hill, 1980). These cylindrical domains enabled downplunge cross sections to be constructed. Cross section YY' (figure 6) is based on a composite downplunge projection of many cylindrical domains, similar to the cross sections constructed by Langenberg et al. (1987) in the Grande Cache area. This cross section shows overturned folds, which are generally open with interlimb angles of 120 to 40 degrees. However, several of the folds are tight with interlimb angles less than 30 degrees. The shortening can be measured to be around 50 percent, using the Jewel Seam as reference horizon.

The overturned southwest limb of the Cadomin Syncline is well exposed in Gregg River's PQ Pit, in Cardinal River's 50A3 and 50A5 Pits and along the McLeod River. The plunge of this fold is generally to the southeast, but several subsidiary folds plunging to the northwest indicate the non-cylindrical nature of the folding on a regional scale. Southeasterly plunging subsidiary folds are present in Gregg River's PQ and LM pits and Cardinal River's 51A3 Pit, while northwesterly plunging folds are found in Gregg River's LM pits and Cardinal River's 50A5 Pit.

A good cross section of the Luscar Anticline is provided by the 51B3 Pit. This exposure shows that folding has had a profound effect on coal quality by the resulting thickening in fold hinges. This process was described for the Grande Cache area by Langenberg et al. (1987). Most open pits are along the hinges of folds, indicating the economic significance of the thickening. Coal has flowed into these hinges from the nearby limbs. As a result, the folding of the Torrens sandstone is more open than the strata overlying the Jewel Seam (disharmonious folding). The plunge of the Luscar Anticline is generally to the southeast.

FAULTING

The Nikanassin Thrust is a major thrust fault, which in places thrusts Devonian strata (Palliser Formation) over Jurassic/Cretaceous strata (Nikanassin Formation). It forms the boundary between Foothills and Mountains in the region. The Drinnan Thrust, which is well exposed in Gregg River's PQ Pit, thrusts Nikanassin Formation over the Grande Cache Member with about 500 m of displacement. The Mystery Lake Thrust can be followed from Mountjoy's (1959) mapping in the Miette mapsheet to just west of a prominent syncline (figure 3). Consequently the fault has terminated and the shortening is transferred to the syncline. Coal in this syncline has been mined in Gregg River's AB Pit. Alternatively the fault in the southwesterly limb of the Luscar Anticline (named Luscar Thrust by Hill, 1980) could be an extension of the Mystery Lake Thrust. An unnamed fault places Nikanassin Formation over the Gladstone formation along the Gregg River, north of the Mystery Lake Thrust. Evidence for the presence of the Folding Mountain Thrust, mapped by Mountjoy (1959) in the northern part of the study area, is lacking at the surface.

Most of the faults are southwest dipping thrust faults, however in several of the pits, northeast dipping faults with hanging wall down can be observed. Hill (1980) suggested that these faults were pre-folding thrust faults. However, because these faults are not folded, they probably formed in a late stage of the folding process or post-folding. They might be a type of normal faults.

Another important structure is the Blackstone zone of detachment (figure 5), which is situated in the Blackstone Formation inbetween the disharmonious structures of the Cardium and Gates formations (Hill, 1980).

COAL QUALITY VARIATION

Coal quality variations have been discussed in detail by Langenberg et al. (1989). Coal quality was mainly determined by proximate and ultimate analyses and petrographic analyses using incident light microscopy.

In the context of this guidebook, coal quality variations will be discussed briefly in terms of ash and volatile matter contents obtained from proximate analyses, sulfur contents based on ultimate analyses, and vitrinite reflectance and maceral content based on petrographic analyses. Ash and sulfur contents and the variation in organic constituents (macerals) are largely determined by the original sedimentary environment, while volatile matter content and vitrinite reflectances are largely related to subsequent burial of the organic matter and to some extent to deformation.

ASH

Ash in the Jewel seam comes either from visible rock partings or from finely disseminated mineral matter within the coal. In places the disseminated ash content may have increased by tectonic shearing. Qualitative field observations suggest that the more highly sheared a coal is, the more likely it is to have elevated ash values. These factors make ash percentage prediction difficult. Average disseminated ash contents of the Jewel Seam is about 14 percent, although in-seam ash profiles show large variations from this average (figure 13). Vertical successions with upward increase in ash and low ash zones through the center of the seam can be explained by the original acidity of the swamp (Langenberg et al., 1989).

The overall depositional setting of the Jewel seam is believed to have been on a coastal plain, perhaps up to 100 Km inland from the shorelines. Thus the Jewel seam was allowed to attain its large thickness well removed from marine clastic influences. Smaller fluvial or tidal channels may have dissected or been adjacent to the Jewel swamp, providing the visible partings. For mining purposes, a 2m sampling interval of the Jewel Seam results in a good characterization of ash variation.

Ash values in R, Torrens and Moosebar coals all tend to be high, and are more likely related to nearby clastic environments than to the original acidity of the swamp.

VOLATILE MATTER

Volatile matter (dry and ash free) of the Jewel seam ranges from 19.3 to 39.8 percent, where the higher percentages represent oxidized coal. This range indicates largely medium volatile bituminous rank. There is a systematic variation of volatile matter in the study area, where the central part has the lowest percentages (see section on vitrinite reflectance).

SULFUR

Sulfur contents of the Jewel Seam are low compared to many other coal

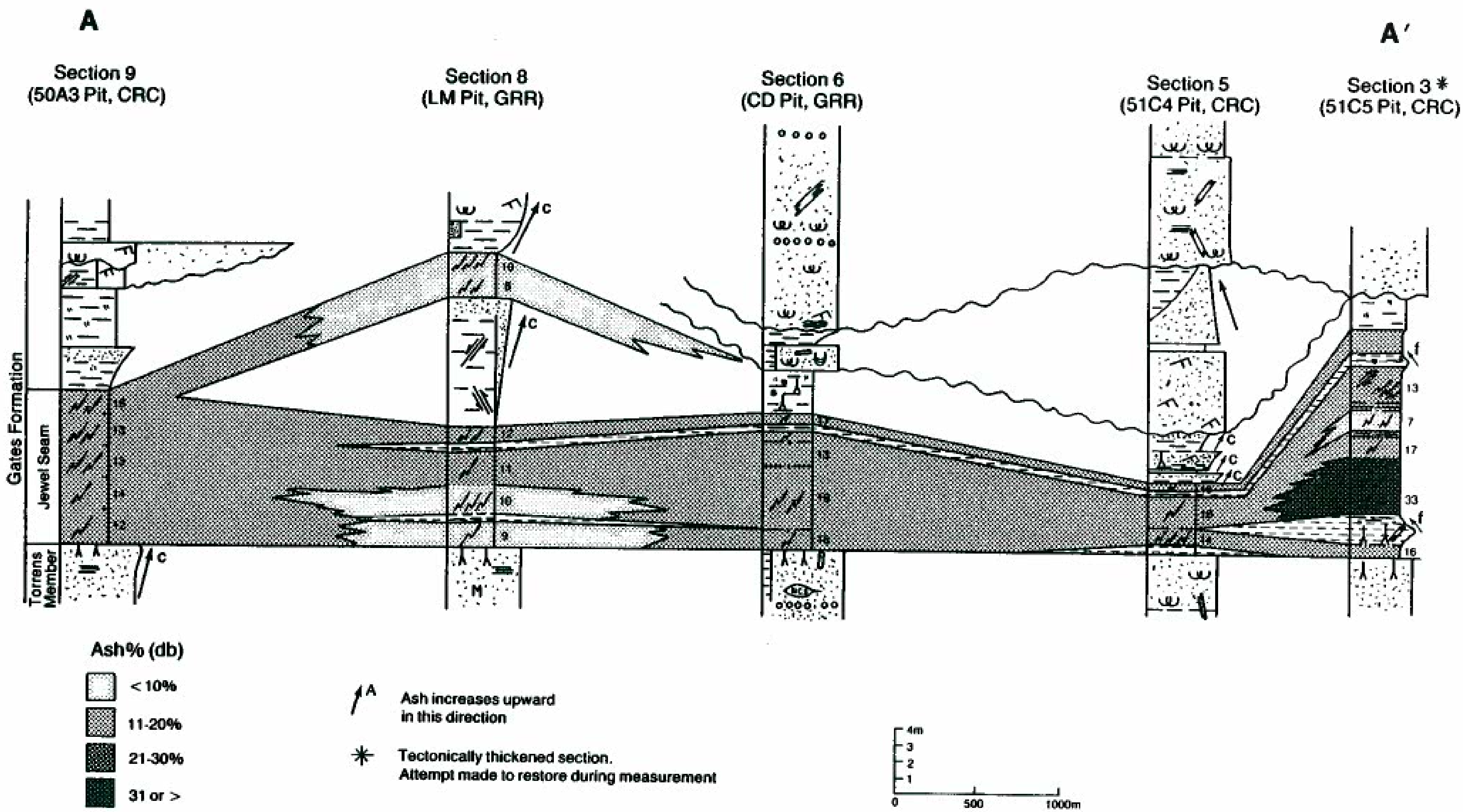

Figure 13. Stratigraphic cross section A-A' showing regional in-seam ash variations in the Jewel seam, throughout the Cadomin-Luscar area (see figure 1 for location).

deposits and average 0.3 percent. Low sulfur combined with moderate high ash and high inertinite contents point to acidic swamps, with intermittent aerobic conditions (Cecil et al., 1980). Sulfur, which is mostly organic in the Jewel seam, often shows elevated values at the base, and to some extent at the top of the seam. Basal elevated sulfur values can drop back to average values over short distances. Elevated sulfur values at the top of the seam may be related to overlying thick channel or brackish water deposits. A very low sulfur zone (i.e. < 0.2 percent dry) is often found in the middle of the Jewel seam, particularly when there are few partings.

Sulfur values in the R seam (alluvial plain setting) generally lie around 0.4 percent. Sulfur values in coals found in the Torrens Member and Moosebar Formation (marine to transitional environment) tend to be higher than the Jewel seam (i.e. > 0.7 percent dry) and support the general model of high sulfur coals associated with overlying marine strata.

MACERALS

Macerals (a term which was introduced as an analogy to minerals of inorganic rocks) are defined as the microscopically recognizable constituents in coals. The macerals are commonly classified in three groups: vitrinite, inertinite and liptinite. The proportions of the macerals in coals reflect the various organic source materials contributing to the accumulation of the ancient peat and the conditions prevailing during accumulation at or near surface; i.e. height of water table, pH, decay by aerobic and anaerobic bacteria, etc. The determination of macerals in coals is complicated by the fact that many undergo severe alterations during the course of coalification. For details the reader is referred to Stach (1982) and Bustin et al. (1983).

The Jewel Seam of the Cadomin-Luscar area is characterized by relatively low vitrinite contents ranging from 46 - 67 vol % with a mean of 56 vol % (based on 16 composite samples). In contrast inertinite contents are relatively high ranging from 32 - 52 vol % with a mean of 43 vol %. Within the inertinite group major components are semifusinite (range = 17 - 24 vol %, mean = 21 vol %), inertodetrinite (range = 8 - 19 vol %, mean = 14 vol %) and fusinite (range = 3 - 7 vol %, mean = 5 vol %). Liptinite content is in general low, ranging from nil to 2 vol % with an average of 1 vol %. The relatively low vitrinite contents and high amounts of inertinite macerals, in particular semifusinite and fusinite indicate rather low water tables during peat accumulation in which a substantial part of the organic matter was oxidized prior to final sedimentation. The optically determined mineral matter is in most coals low to moderate, ranging from 2 - 23 vol % with a mean of 9 vol %. These maceral contents are very similar to those of coal seams believed to have accumulated under similar environments to the north in the Grande Cache area, Alberta and Tumbler Ridge area, B.C. (figure 14). Petrographic indices, based on these maceral contents, were presented in the section on "coal depositional environments".

VITRINITE REFLECTANCE

Maximum vitrinite reflectance for the Jewel Seam ranges from 0.97 to 1.43 percent (figure 15). The highest rank is found in the central part of the study area, along the southwest limb of the Luscar Anticline. High volatile bituminous coals are present in the southeast. The rank variation indicates syndeformational coalification, although it can not be excluded that the central part of the coal field was buried somewhat deeper, resulting in the higher rank. However, the burial during sedimentation was probably also a result of deformation, which was taking place further west during the existence of the foreland basin. It should also be noticed that the highest ranks are not along the axis of the Cadomin Syncline as would be expected in the syndeformational coalification model, but along the southwestern flanks of the Luscar Anticline (figure 3). This might be explained by a late stage adjustment of the structure, where parts of the Cadomin Syncline have moved upwards by secondary folding and thrusting (Mystery Lake Fault and fault near Luscar).

A good linear correlation between maximum vitrinite reflectance and

MACERALS		**(Vol%)**	
	VITRINITE	**45-66**	**MEAN = 57**
	INERTINITE	**31-53**	**MEAN = 42**
	LIPTINITE	**NIL-9**	**MEAN = 2**
MINERAL MATTER		**2-11**	**MEAN = 6**
PETROGRAPHIC INDICES			
	V/I RATIO	**0.85 - 2.00**	**MEAN = 1.40**
	VA/VB-RATIO	**0.25 - 1.60**	**MEAN = 0.86**
	IR-RATIO	**1.16 - 2.64**	**MEAN = 1.58**
	SF/F-RATIO	**1.90 - 7.33**	**MEAN = 3.64**
	TPI-RATIO	**0.64 - 1.54**	**MEAN = 1.14**
	GI-RATIO	**1.00 - 2.27**	**MEAN = 1.59**

Figure 14. Petrographic characteristics of lower Cretaceous (Gates Formation) coastal plain coals. Means based on 26 samples from the Cadomin, Mountain Park and Grande Cache areas in Alberta and the Tumbler Ridge area in B.C.

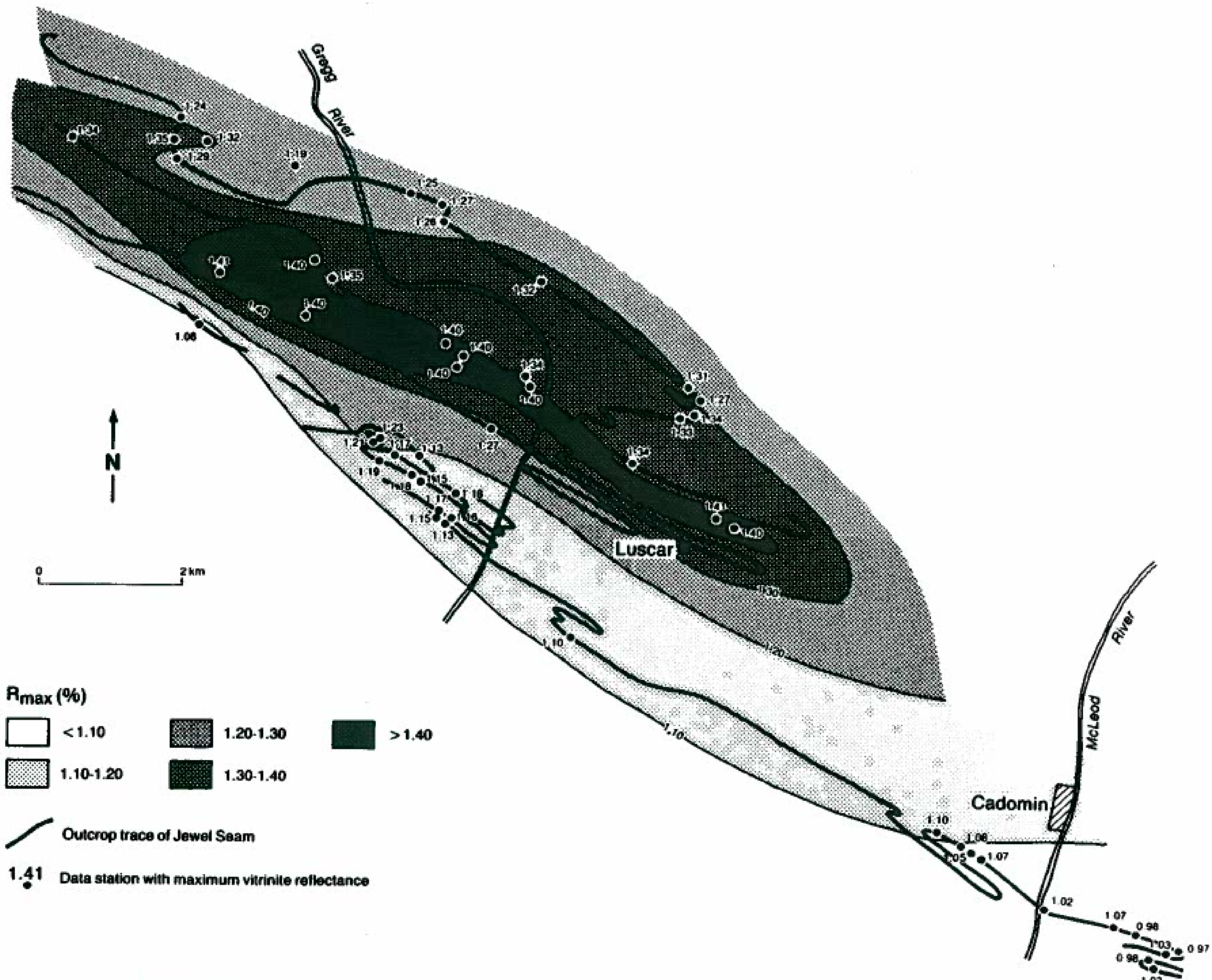

Figure 15. Regional vitrinite reflectance variations of the Jewel Seam.

volatile matter (dry and ash free) is observed, enabling volatile matter to be determined from vitrinite reflectance. The map of maximum vitrinite reflectance variation (figure 14) can be used to predict rank and volatile matter of the Jewel Seam for unexplored parts of the Cadomin-Luscar coalfield.

PETROGRAPHIC CHARACTERISTICS AND TECHNOLOGICAL PROPERTIES

Technological properties of coals are to a large extent a direct function of rank and composition of the parent coal. While no special requirements exist in terms of rank and composition for thermal coals used for generation of electricity, coking coals used in carbonization to produce metallurgical coke are restricted to a fairly narrow rank range, that is from high volatile A coal (Rmax >0.95%) to the transition from medium to low volatile bituminour coals (Rmax <1.50%, Jasienko (1978). The same is also true for conversion processes such as coal liquefaction, where optimum conversion rates are obtained using coals of high volatile bituminous rank (Whitehurst et al., 1980). Within the optimum rank ranges the maceral composition determines largely the nature and quality of the final products.

Technologically, the macerals of coals are generally classified as reactive or inert. The reactive group comprises macerals of the vitrinite and liptinite groups and a portion of the maceral semifusinite (30 - 50%). This group of macerals when exposed to processes such as carbonization will react in a sense that the organic material, depending on rank and experimental conditions used, will give rise to a variety of newly formed materials, i.e. liquids, gaseous products and residual material (cokes). The inert constituents are comprised of the macerals of the inertinite group including 50 - 75% of the maceral semifusinite. In terms of reflectance ranges, all samples from the Jewel Seam collected in the Luscar-Cadomin area fall well within the limits considered to be suitable for coke making (0.95 - 1.50% Rmax). Within this range the ratios of inert/reactive components will then define the quality of the final product (coke). There exists a number of empirical methods for the prediction of coke quality from petrographic analyses (Stach, 1982).

The petrographic data from 15 samples of the Jewel Seam have been plotted in a diagram modified from Pearson (1980). This diagram uses mean maximum reflectances of vitrinite and the contents in inert macerals to estimate coke stability factors. The dashed line indicates the optimum ratio of inerts to reactive macerals for producing the strongest coke for a given rank. The line of the 50 coke stability mark indicates the threshold separating strong cokes (>50) from those less acceptable (<50). From the graph shown in figure 16 it appears that the coke stability factors predicted for cokes from the Jewel Seam are close to or exceed coke stability factors of 50. This confirms the well known fact that coke produced from the Jewel Seam is of high quality.

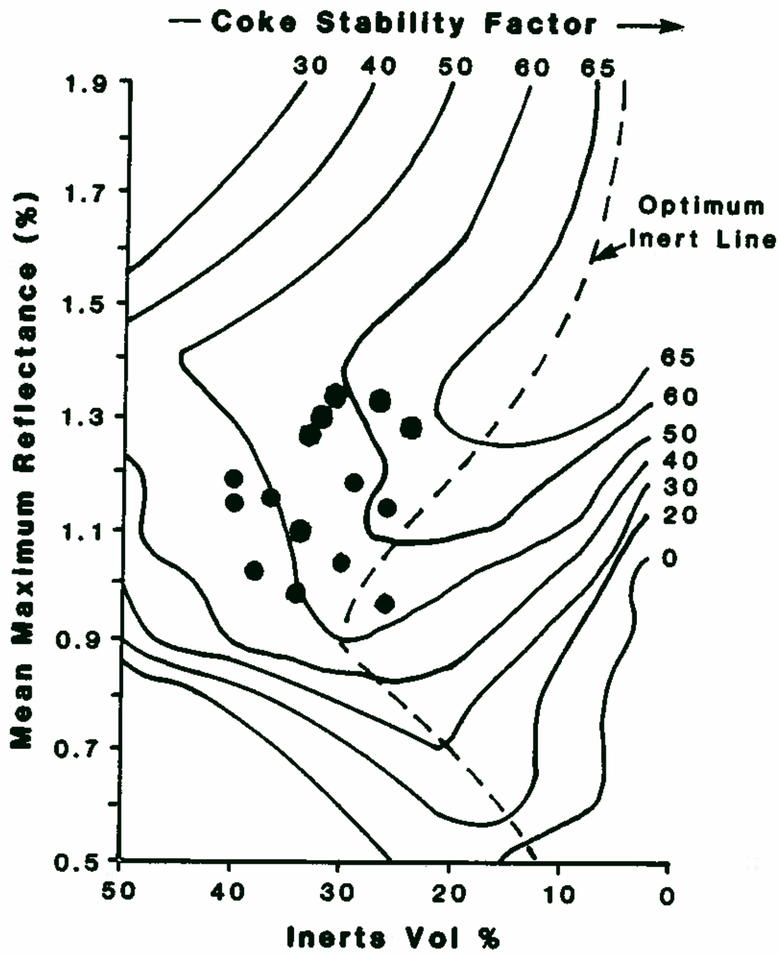

Figure 16. Prediction of coke stability factors from petrographic characteristics for Jewel Seam samples of the Cadomin-Luscar area. Data do not represent current production coal.

MATURATION AND HYDROCARBON POTENTIAL

The burial histories and the amount and type of organic matter in the sedimentary rocks determine the formation of oil and gas. Vitrinite reflectances determined on the coals from the Luscar area indicate that the maturation levels fall within the so called "oil window" concept, in which oil generation is believed to occur in the vitrinite reflectance limits of 0.5 - 1.3% (Dow, 1977). Leckie et al. (1988) showed that Lower Cretaceous strata to the north are characterized by the predominance of terrestrial organic matter, including the marine shales. This type of organic matter (kerogen III) will form gaseous products, when exposed to greater depths of burial. In other words, burial of the Lower Cretaceous strata in the Luscar area has most likely led to the formation of gas from the terrestrial matter in the shales and coal seams, while oil was not formed because of the lack of precurser materials (kerogen types I and II).

ROADLOGS AND STOPS

DAY 1

Road log between Edmonton and Edson

Kms.	
0	Start of Highway 16 West on 170th Street. Notice the flat topography caused by the clayey sediments of glacial Lake Edmonton. West Edmonton Mall on left.
4.0	Start of Acheson oilfield. Production is from the Devonian Nisku and Leduc formations.
6.5	Pitted delta of glacial Lake Edmonton.
9.0	Crossing the centre of the Acheson oilfield.
36.5	Highest point of the pitted delta. Deltaic sediments are over 100 m thick.
58.5	Wabamun Lake, which occupies a preglacial bedrock channel, which was a tributary to the preglacial North Saskatchewan River. TransAlta Ltd. coal fired power plant on left.
63.3	Whitewood surface coal mine on right. Six metres of subbituminous coals are mined from a 9 m thick interval of the Ardley Coal Zone of the Scollard Formation. This interval is equivalent to the Coalspur Formation of the Coalspur area (Stop 10).
72.5	Brown weathering sandstones of the Paskapoo Formation on left.
81.4	Glacially deformed bedrock with coal, overlain by till on right. We have now left the preglacial Lake Wabumun bedrock valley.
92.4	Old gravel pits (preglacial sands and gravel) left and right.
94.5	Pembina River at Entwistle. Outcrop of sandstone of the Paskapoo Formation along the river banks.
120.4	Glacially deformed bedrock, overlain by till.
168.7	Till exposed in road cuts. Till contains a large number of pebbles from the Canadian Shield.
174.1	Sandstone of the Paskapoo Formation on left.
186.2	McLeod River. Sandstones of the Paskapoo Formation along river bank about 1 km north of bridge.
191.7	Outskirts of Edson.
203.5	Turnoff to Robb.

Road log between Edson and Cadomin (Highways 47 and 40).

Kms.	
0	Turnoff overpass from Highway 16 onto Highway 47 - Robb road. View of the Front Ranges.
3.0	Railroad overpass.
8.0	Post-glacial dunefield exposed along the road for the next few kilometers.
13.0	McLeod River bridge.
18.0	Entering region of glacial lacustrine silt deposits.
31.5	Railroad crossing.
35.7	Small outcrop of Cordilleran till on right.
36.1	View of Nikanassin Range.
40.0	Roadcut exposing till, sand and volcanic ash - possibly glacially thrusted bedrock.
40.1	Prest Creek.

43.8 First view of Foothills.
47.2 Cordilleran till outcrop.
51.2 Turnoff to Robb (left) and Hinton (right).
52.0 Paskapoo Formation outcrops along the highway.
53.0 Glacial outwash sands with fine coal debris.
53.8 Northeast dipping Paskapoo Formation.
55.2 Northeast dipping Brazeau Formation outcrop. Palynological work indicates an Early to Middle Maastrichtian age.
56.2 Axial trace of Coalspur anticline exposed in Brazeau Formation roadcut to the right (north). The Coalspur Anticline defines the Triangle Zone in this part of the Foothills. Strata are roughly equivalent to the Plains Bearpaw Formation. However, the whole Brazeau Formation is continental in this area.
56.5 West dipping Brazeau Formation - west limb of Coalspur anticline.
56.8 Embarras River - Brazeau Formation.
58.4 Excellent exposure of the Coalspur Formation (Scollard equivalent) and a burning coal seam (Val d'Or seam). Palynological dating suggests an early Paleocene age, similar in age to the Ardley coal zone. The Cretaceous-Tertiary boundary is situated near the base of the Mynheer Seam, which is lower in the stratigraphy, but not exposed in this section. This section is described in Stop 10.
58.9 Highway takes a sharp turn to the left (southeast). Good view of abandoned coal mine on hillside above old town of Coalspur.
60.4 Turnoff to Cadomin via Highway 40. Embarras river and outcrops of Paskapoo Formation.
66.0 View of the Nikanassin range. Luscar Mountain (left), Mount Gregg (right).
67.1 Road to Mercoal village. Mercoal was the first opened and the last mining village to be abandoned in the Coal Branch area (1959).
68.5 Roadcut of east dipping Entrance conglomerate (roughly equivalent to the Battle Formation in the Plains).
70.2 Railroad overpass - Steeper siding.
71.0 Roadcut down into the McLeod River valley exposing Brazeau Formation.
73.6 View of Nikanassin Range with Cadomin Mountain.
76.5 Highway travels along the McLeod River valley, gravel outcrops are from associated terrace deposits.
79.4 Nikanassin Range. Leyland Mountain on left, Luscar Mountain in center.
81.0 McLeod River crossing, Brazeau Formation outcrops to the right along the river.
82.9 Brazeau Formation on left by railroad tracks.
85.3 Outcrops along Watson Creek, Brazeau Formation.
85.7 Watson Creek campground turnoff.
86.7 McLeod River bridge. At Hells Gate (1km upstream) contact of Wabiabi and Brazeau formations. Leyland Mountain straight ahead.
88.0 View of Inland Cements limestone quarry on Cadomin Mountain. Limestone is quarried from the Devonian Palliser Formation near the upper benches and is then dropped through a vertical shaft to a crusher located within the mountain. Crushed rock is then moved by belt conveyor, horizontally, out of the mountain to a rail load out facility.
89.2 Cardium Formation outcrops on the right (north) side of the highway. We are now on the map of figure 17.

90.1 Junction with Forestry Trunk road to Cadomin. Proceed to Cadomin.
91.5 Blackstone Formation, with the subsurface "second white specs" horizon, exposed almost continuously to the left along the railway.
92.5 Cadomin, general store and gas station.
93.3 Blackstone Formation with subsurface "Fish Scale horizon" exposed along railway tracks to the left.
93.4 Greenish weathering Mountain Park Formation exposed on the right. Approximately equivalent to the Harmon or Notikewin members of the Deep Basin area.
94.4 Old mine entances to Jewel Seam on both sides of river. Across the river to the left is an outcrop exposure of the Lower Cretaceous (Aptian) Gladstone to Moosebar, continental to marine transition that will be examined at Stop 1. This sequence is approximately equivalent to the McMurray to Clearwater transition in northeastern Alberta and the Gething to Wilrich transition in the northern Deep Basin.
95.7 Approximate trace of the Nikanassin thrust, which has brought Devonian Palliser and Mississippian Rundle Group strata on top of Jurassic to Cretaceous age Fernie and Nikanassin Formations.
95.9 Turnoff to Inland Cement quarry and bridge over McLeod River.
96.2 Road runs northward along CNR tracks, exposing progresssively younger strata in the southwest limb of the Cadomin Syncline (figure 17).
96.6 Thinly and rhythmically bedded Nikanassin Formation. In southern Alberta the correlative strata, Kootenay Group, is coal-bearing and consists of coastal plain to alluvial plain deposits.
96.7 Road passes over the Cadomin Formation (figure 17), which is a reliable mapping unit in this area. The Cadomin is thought to represent a series of alluvial fan to alluvial plain deposits that flowed, primarily, to the northeast from here towards the Boreal sea. The base of the Cadomin represents a major unconformity and perhaps a major sequence boundary between the Fernie/Nikanassin and Luscar/Mannville clastic wedge sequences.
97.2 Road passes by folded and faulted strata of the Gladstone Formation. The section of Stop 1 was measured along these exposures.
97.4 Old mine entrance in Jewel Seam above Torrens sandstone.

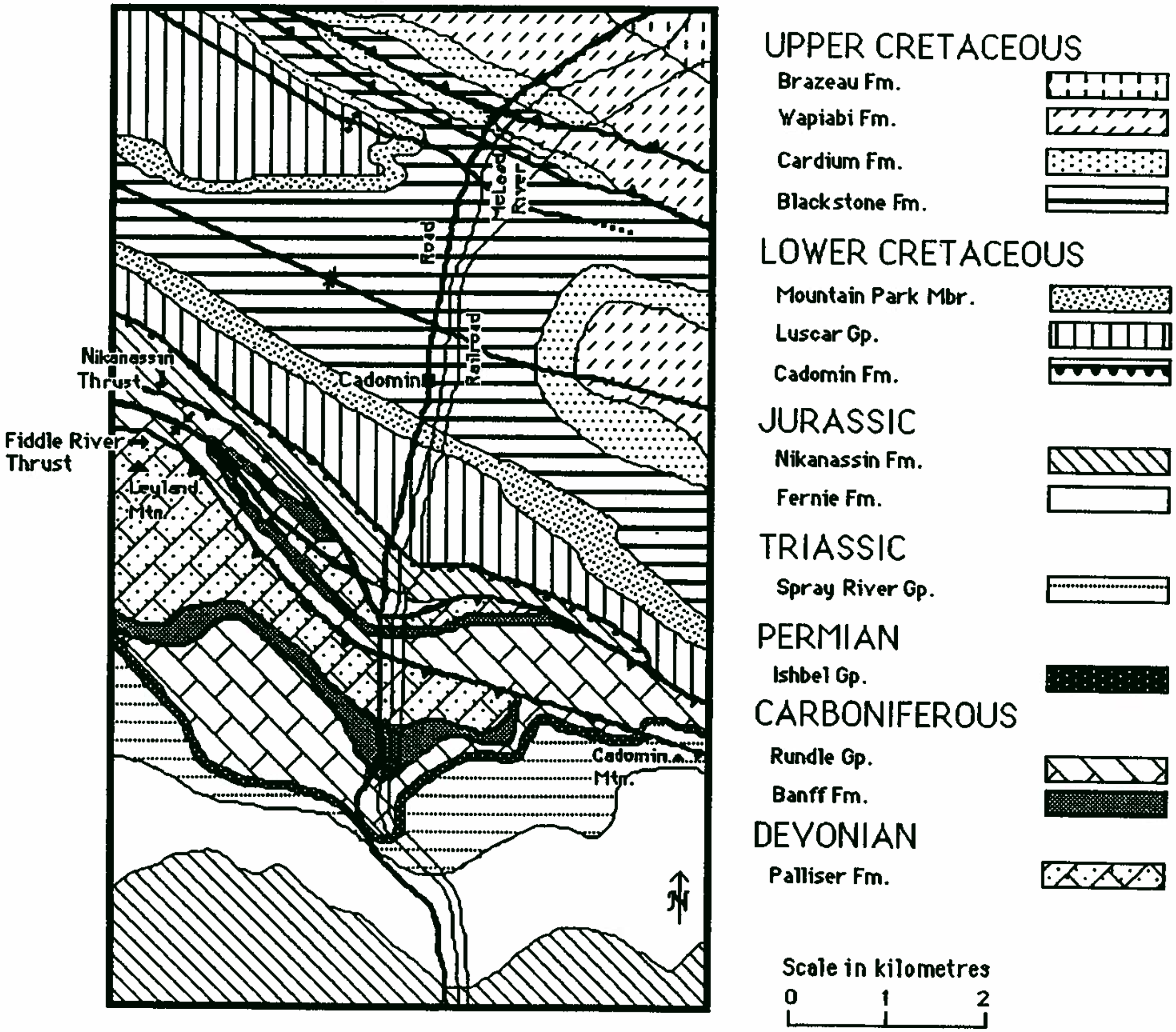

Figure 17. Geological map of the Cadomin area, modified from MacKay (1929).

STOP 1. COALS ASSOCIATED WITH A CONTINENTAL TO MARINE TRANSITION, TRANSGRESSIVE SEQUENCE - GLADSTONE TO MOOSEBAR FORMATIONS.

Objective: The objective of this stop is to demonstrate thin coals associated with the transgressive transition from continental alluvial plain strata of the Gladstone into the fully marine Moosebar Formation (figures 17 and 18).

Background: This section has been studied by several authors and microfossils have been collected from this section (McLean and Wall, 1981, Mellon, 1967). Some debate exists as to where to place the contact between the Gladstone and Moosebar Formations at this location. Examination of the section will show the difficulty, and perhaps somewhat arbitrary nature of any pick chosen.

Things to see:

1). In the lower portion of the section (between 12 and 24m) note the three lensoid shaped channel deposits. These channels tend to be small in size, are ripple laminated and contain abrupt abandonment overbank phases. Thin coals and carbonaceous mudstones are common (figure 20) and are typical of many poorly developed alluvial plain coals.

2). Up to the 85m level, note the abundant indicators of continental subaerial sedimentation in this part of the succession (rootlets, logs, paleosols, plant debris, possible dinosaur tracks - figure 21). Thin alluvial plain coals grade into thicker coastal plain coals (e.g. at 70 m).

3) Between 89 and 100m note the major upward-coarsening sequence, fewer continental indicators, and sudden presence of trace fossils. Brackish conditions are inferred from microfossils collected in this interval. The upward-coarsening cycle is thought to be the Bluesky member, which produces gas near Edson.

4) At 108m note the small fault that has repeated at least one of the upward-coarsening cycles above the Bluesky (figure 22).

5) Above 108m and till the end of the section, note the paucity of plant, root and other continental indicators and note the invertebrate fossil bed. Fully marine conditions have been inferred from foraminifera collected from this interval (McLean and Wall, 1981). Mellon (1967) and Mclean and Wall (1981) placed the base of the Moosebar at the invertebrate fossil bed. We would prefer to place it at the top of the Bluesky (figure 19), which is 2.5m below the fossil bed and above the highest sandstone bed. In this way the contact will conform to a major kick on geophysical logs.

6) Notice that only thin coals and carbonaceous shales are present in the marine part of the section.

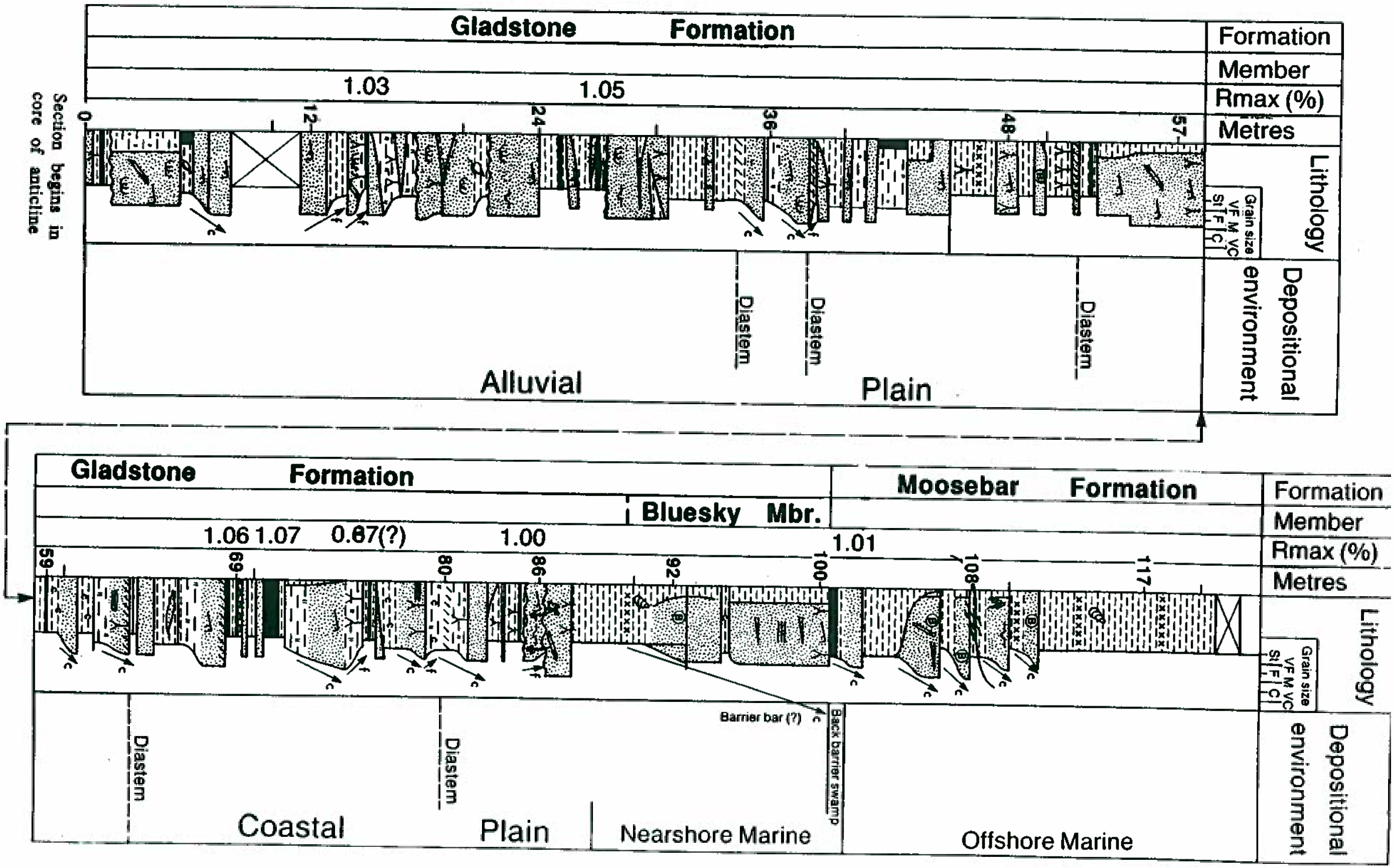

Figure 18. Stratigraphic section showing the Gladstone to Moosebar Formations transition, Cadomin railway section, Stop 1.

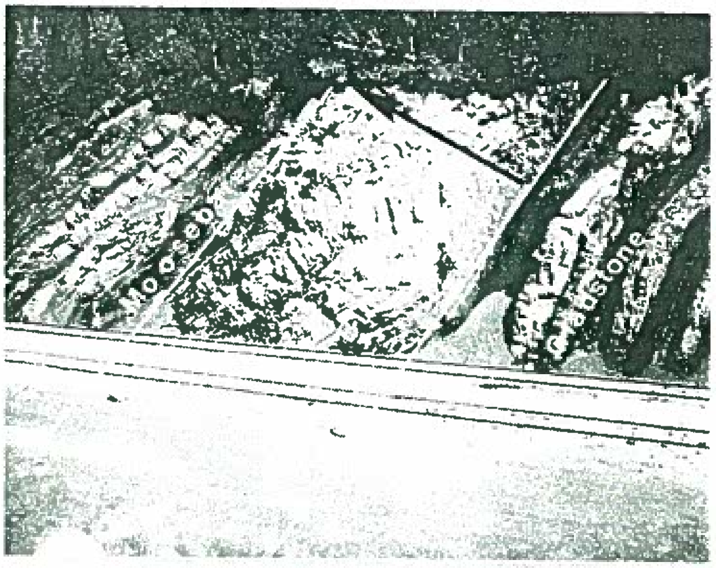

Figure 19. Gladstone and Moosebar formations, transition from alluvial plain to marine environments, Stop 1. Cadomin railway section.

Figure 20. Small lens shaped fluvial sandstones in the lower Gladstone Formation. Stop 1, 12 to 24m.

Figure 21. Log imprint and dinosaur cast (?) at the base of small fluvial channel, below the Bluesky member - Stop 1, 84m level.

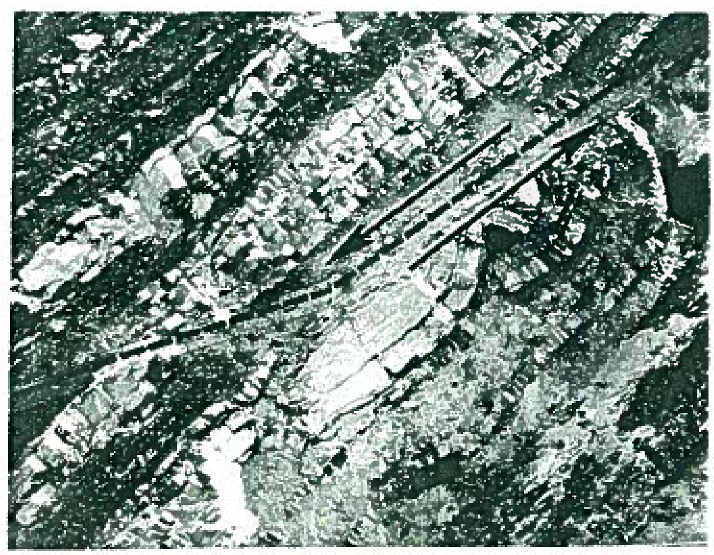

Figure 22. Small thrust fault repeating coarsening-up unit in the lower Moosebar Formation. Stop 1, near 108m level.

DAY 2

Road log from Hinton to junction with Cadomin Highway (47).

Kms.	
0.0	Turnoff from Highway 16 onto Highway 40
1.1	Outcrop on the left (northeast) is of the Entrance Formation. An alluvial fan or braided river environment is interpreted for the Entrance. The Entrance lies at approximately the same stratigraphic position as the Battle Formation in the Plains region and is close to the Cretaceous-Tertiary boundary.
3.7	Cold Creek crossing.
7.0	View of High Divide Ridge at 10 o'clock (northeast). This ridge is an erosional remnant of mainly Paskapoo and Coalspur Formations preserved in the core of the Entrance Syncline.
7.7	Outcrop of coal in the Coalspur Formation near Cold Creek. The Cretaceous/Tertiary boundary is thought to lie within coals in the lower part of the Coalspur Formation.
9.3	Roadcut exposure on the left of the Coalspur Formation. Note the thin coal seams and volcanic ash horizon. Strata dip northeast and occur along the southwest limb of the Entrance Syncline.
14.6	Wigwam Creek crossing.
17.2	Teepee Creek crossing.
18.3	Upper Cretaceous Brazeau Formation exposed on left.
19.8	Large scale trough cross-stratification in the Brazeau Formation on the right.
21.2	Descending into the Gregg River valley with a good view of the Nikanassin Range. Sphinx Mountain - straight ahead composed largely of Devonian Palliser Formation (equivalent to the Wabamun platform carbonates in the subsurface).
23.5	Gregg River crossing.
24.2	Brazeau Formation outcrop on the left.
28.5	Platy sandstones of the Brazeau Formation on the left.
28.9	Small waterfall over Brazeau Formation sandstone, on the right along the Gregg River, is reported to be an excellent trout fishing spot.
31.4	Wapiabi Formation mudstones and shales on the left. The Wapiabi is equivalent to that portion of the Upper Colorado above the Cardium in the subsurface.
33.2	Cardinal River Coals 51C5 pit exposed on the northeast limb of the Luscar Anticline.
34.8	Crossing the approximate trace of the 10m thick economic Jewel coal seam (Gates Formation).
36.4	Gregg River crossing and Jurassic-Cretaceous Nikanassin Formation exposed on left.
38.4	Nikanassin Formation exposed in the core of the Luscar Anticline on large outcrop to the left.
39.1	Gregg River Resources Limited minesite. Storage silo and load out facility visible from highway.
40.4	Cardinal River Coals Limited 51B2 pit. Mining is completed at this pit and waste rock from a developing pit to the east is now being backfilled into this pit. Pit shows the Torrens member (sandstone) on the extreme right, overlain by the Jewel coal seam, in turn overlain by the Grande Cache member. The thick

sandstone near the middle to top is the Mountain Park Formation.
41.8 Bedding plane view of Torrens member, footwall sandstone, steeply dipping to the northeast, right side of road.
42.4 Turnoff to Cardinal River Coals Limited mine.
43.9 Spoil pile being reclaimed by Cardinal River Coals.
44.3 From here to the Cadomin turnoff, there are several roadcut exposures of the marine Blackstone Formation (Lower Colorado/Shaftesbury equivalents).

In the morning the Gregg River Mine will be visited (Stops 2 to 7), followed by a visit to the Cardinal River Mine (Stops 8 and 9). Entering the Gregg River Minesite, the main haul road is followed crossing the Gregg River. We drive through the mined-out core of a coal-bearing syncline (AB Pit) and arrive in the CD Pit (Stops 2 and 3).

STOP 2. OVERVIEW OF THE END-WALL OF THE CD-PIT.
Objective: To demonstrate the structural style present in the Lower Cretaceous Luscar Group and the resultant effects on coal mining.

Background: Open to tight folds characterize the area, showing thickened coal zones in the hinges of anticlines and synclines. The open pit coal mines are generally along these thickened hinges. The present level of erosion at the Gregg River Mine results mostly in open pits along thickened syncline hinges. On the Cardinal River property open pits are located along thickened anticline and syncline hinges.

Things to see:
CD pit shows an anticline/syncline pair with a section of Moosebar to lower Grande Cache Member exposed (figure 23). This section will be examined in Stop 3. Coal is thickened along the hinge, but this feature is no longer exposed. The northeastern limb of the syncline has been mined, since the photograph of figure 23 was taken.

Figure 23. Anticline/syncline pair in CD Pit, with thickened Jewel Seam.

STOP 3. DEPOSITIONAL ENVIRONMENTS OF THE MOOSEBAR AND GATES FORMATION AND RELATED COAL QUALITY OF THE JEWEL SEAM, CD PIT.

Objective: To demonstrate the stratigraphic setting and depositional environments of coals in the marine to nonmarine transition from the Moosebar to Gates Formation and to discuss some coal quality parameters of the Jewel seam.

Background: This section (figure 24) shows a fully marine base and several coarsening-upwards cycles, which are often capped by carbonaceous mudstones or coals. The economic Jewel seam caps the marine sequence and is itself locally overlain by brackish water sediments. Wholly continental alluvial plain strata characterize the section up to the R seam.

Volatile matter contents (daf) are around 22% and Rmax is 1.40% (figure 15). In-seam ash and sulfur show predicatable vertical and lateral variations over less than 100m within this pit (figure 25). In-seam finely disseminated ash varies from 7 to 28% (db) and is thought to be related largely to the original swamp environment. In-seam sulfur is seen to be consistently low in the center of the seam and increases slightly towards the top and base of the seam (figure 26).

Lithotypes are defined as the macroscopically recognizable layers of different brightness in coal (Stach, 1982).They reflect variation in organic matter during deposition, as well as diagenetic changes. Figure 27 shows the "Australian" system of lithotype description, used in the Cadomin area. A macroscopic log (based on a minimum bandwidth of 1 cm) of the Jewel Seam of Stop 3 is shown in figure 28. Figure 28 shows that bright layers are enriched in vitrinite macerals, whereas the dull layers are rich in inertinite. This is summarized by figure 29.

Things to see:

1) The lowermost cycle, seen at other locations, is not present at the CD pit.
2) A glauconitic bed lies at 3 m from the base and may represent, in part, a transgressive condensed reworked shelf deposit. Look for bioturbation, graded-bedding, glauconite, and a pebble bed (figure 30).
3) The second marine cycle is characterized by offshore mudstones at the base and passing upwards into HCS storm units and finally into parallel laminated foreshore deposits. Look for trace fossils, HCS, scour surfaces, soft sediment deformation (figure 31) and carbonaceous mudstones (equivalent to Torrens coal of nearby sections) near the top.
4) The third marine cycle shows scour surfaces, bioturbation, HCS, and parallel laminations throughout. The Jewel coal seam caps this cycle.
5) Jewel coal seam showing approximate original stratigraphic thickness. Look for partings in coal, type of parting, and intensity of shearing in the coal. Try to identify the various lithotypes shown in figure 28.

6) The fourth cycle consists of the brackish unit immediately overlying the Jewel seam. Look for Diplocraterion traces, flaser bedding and tapering channel sandstones in this unit (figure 32).
7) Strata above the brackish interval is part of the amalgamated channel deposits (GC1 of Fig. 9). Look for trough cross-stratification, logs and the overall fining upward character.

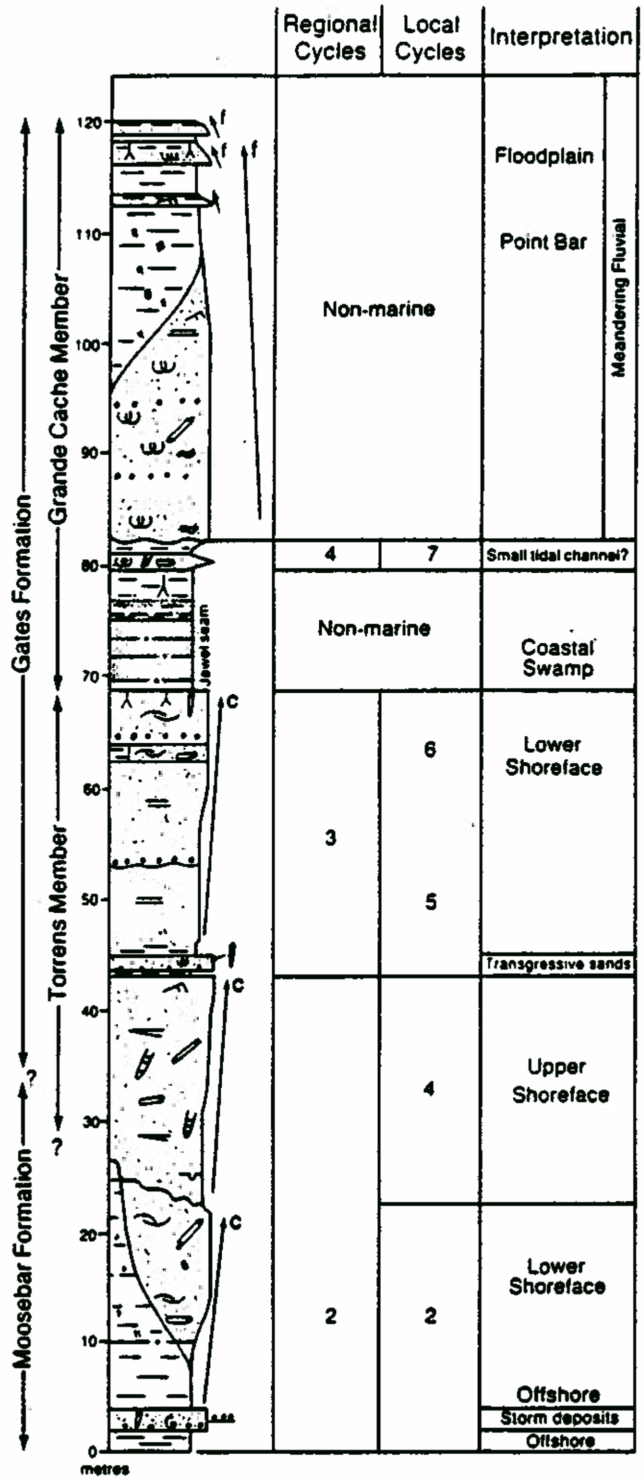

Figure 24. Stratigraphic section showing the Moosebar to Gates Formation transition, CD pit, Stop 3.

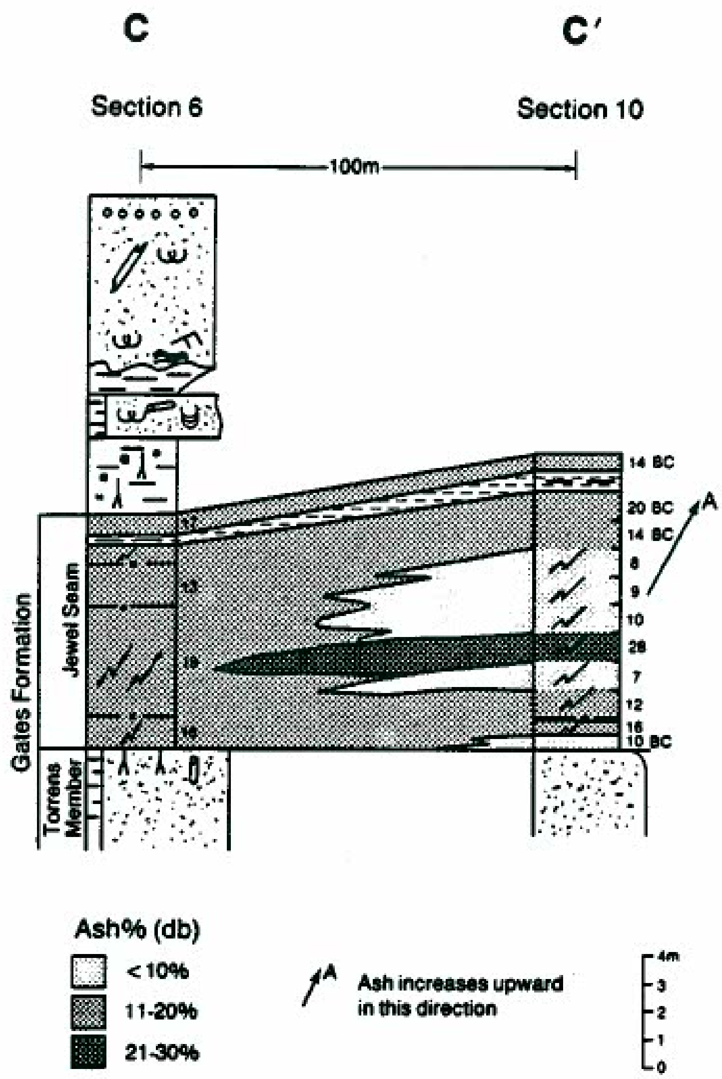

Figure 25. Stratigraphic cross section C-C' showing pit-scale in-seam ash variations in the Jewel seam, within the CD pit, Gregg River Resources Limited.

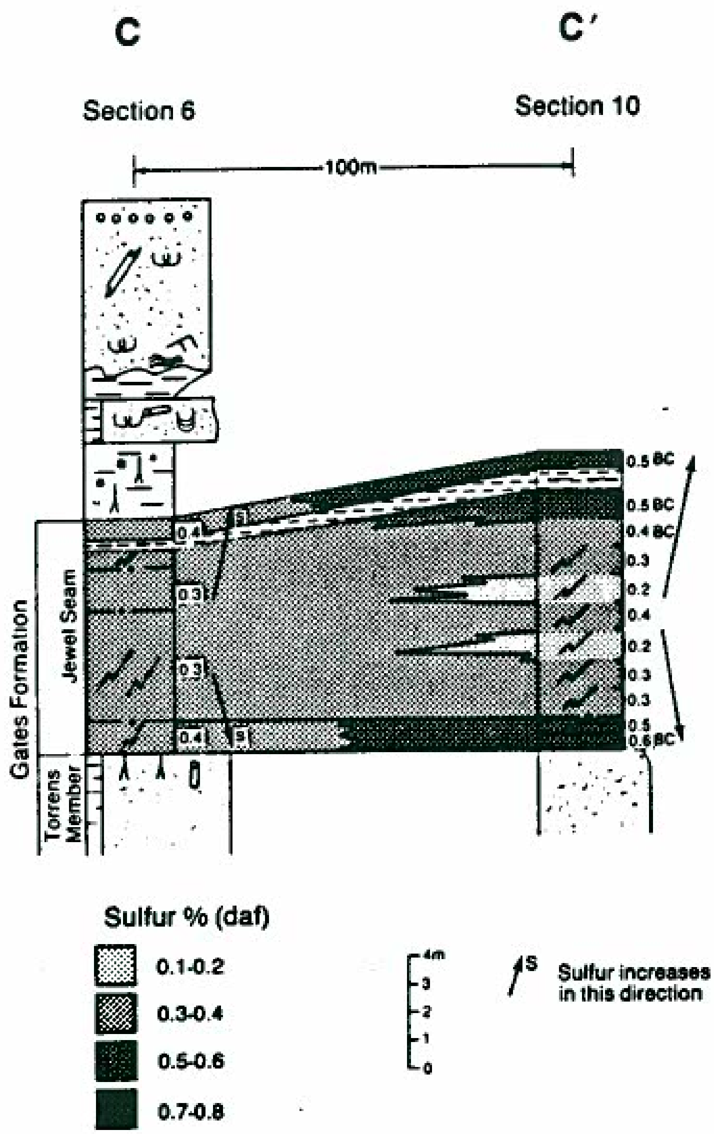

Figure 26. Stratigraphic cross section C-C' showing pit-scale in-seam sulfur variations in the Jewel seam, within the CD pit, Gregg River Resources Limited.

Divisions after Stopes	Divisions as used for Australian coals	Description
Vitrain	Bright coal	Subvitreous to vitreous lustre, or concholdal fracture <10 per cent dull
	Banded bright coal	Bright coal with some thin dull bands 10-40 per cent dull
Clarain	Banded coal	Bright and dull coal bands in equal proportion 40-60 per cent dull
	Banded dull coal	Dull coal with some thin bright bands 10-40 per cent bright
Durain	Dull coal	Matt lustre, uneven fracture <10 per cent bright
Fusain	Fibrous coal	Satin lustre, friable

Figure 27. Lithotypes division after Stopes and the "Australian" divisions, as used in the Cadomin area.

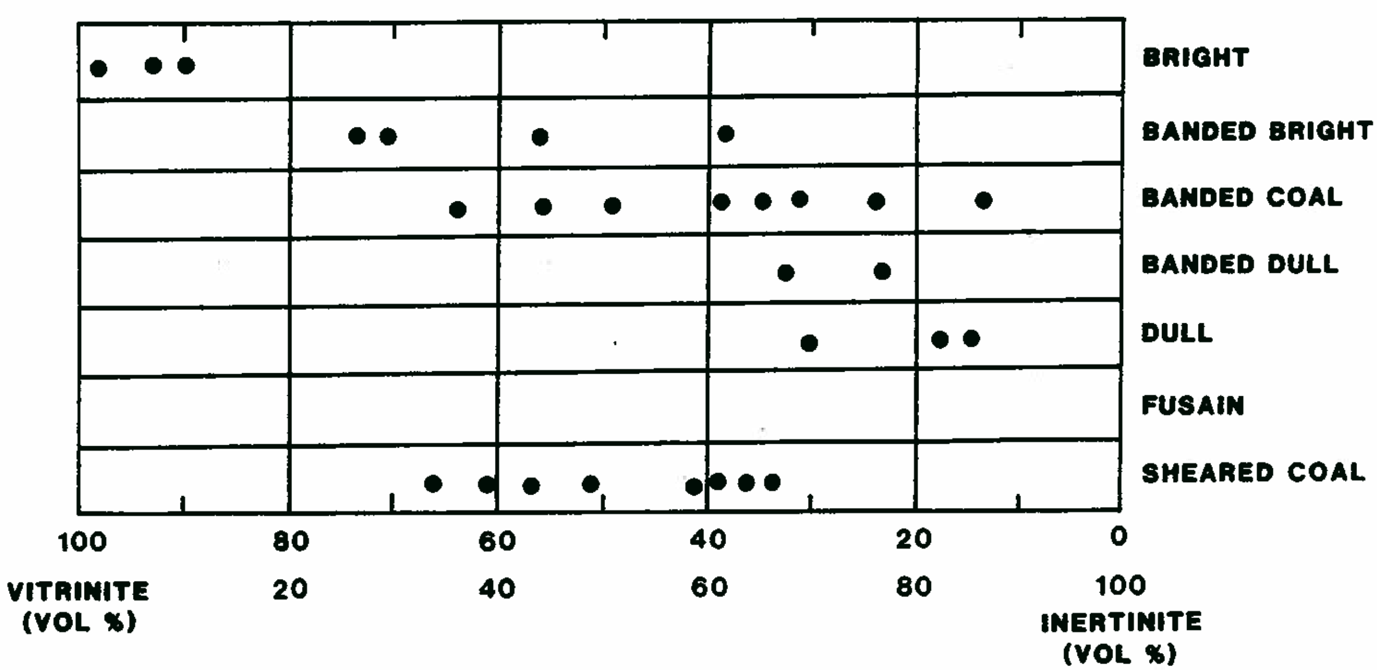

Figure 29. Ranges in vitrinite and inertinite contents for lithotypes identified in the Jewel Seam, CD Pit, D limb. Vitrinite and inertinite contents of sheared intervals are also shown. Data from Kalkreuth, Paul and Steller, unpublished.

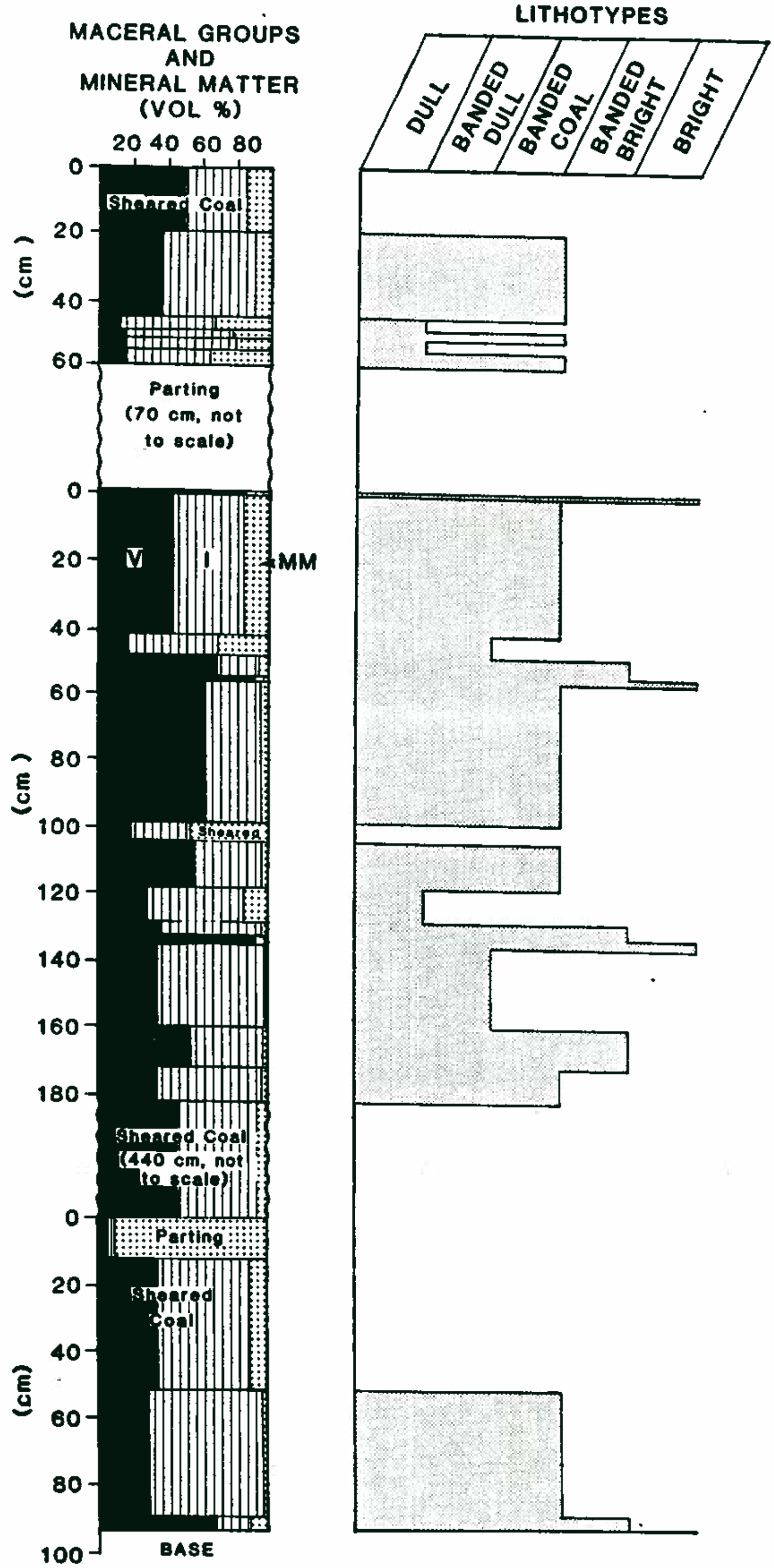

Figure 28. Macroscopic and microscopic log of the Jewel Seam, CD Pit, D limb. Right column shows lithotype variations for undeformed sections of the Jewel Seam. Abundance of lithotypes for this section: 2% bright, 10% banded bright, 69% banded, 12% banded dull and 7% dull coal. Left column shows contents of vitrinite (V), inertinite (I) and mineral matter (MM) for each lithotype. Data from Kalkreuth, Paul and Steller, unpublished.

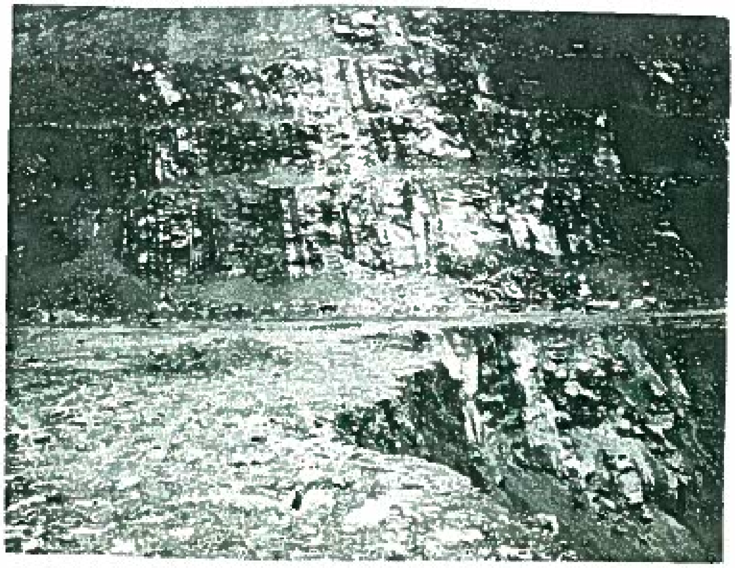

Figure 30. The lower part of the section of Stop 3, from base of the second cycle to top of Jewel Seam, CD Pit.

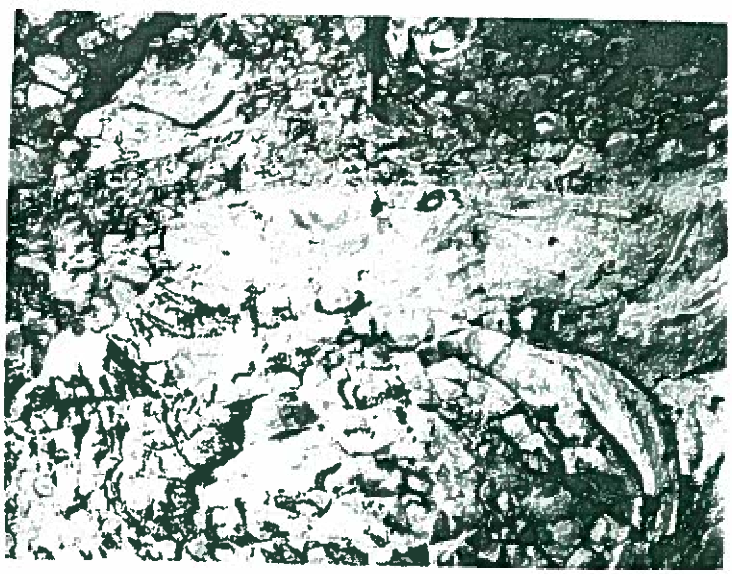

Figure 31. Soft sedimentary deformation at 25 m from base of section, CD Pit.

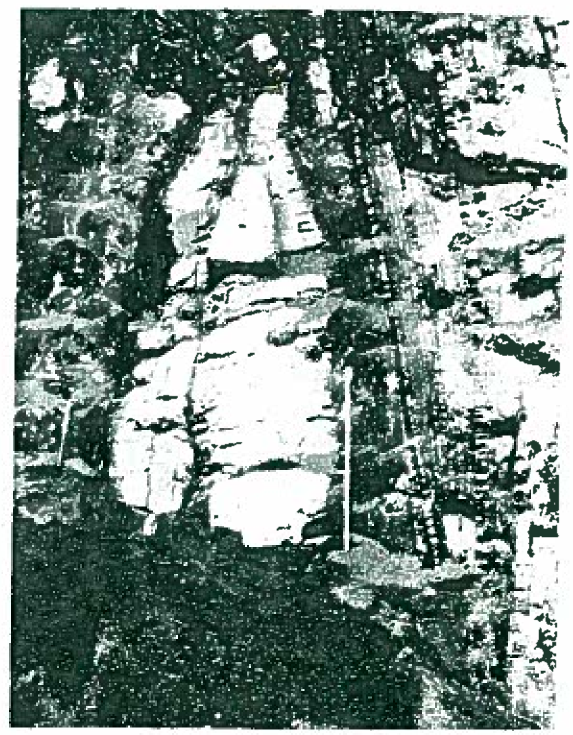

Figure 32. Small tidal channel above Jewel Seam, CD Pit.

STOP 4. COARSE GRAINED PEBBLE FACIES OF THE TORRENS MEMBER.

Objective: To illustrate a very coarse-grained facies of the third upward-coarsening cycle (strandplain sediments of the Torrens Member) upon which the Jewel coal seam developed.

Background: This section shows a fully marine base, which passes upward into the same series of upward-coarsening cycles as seen in Stop 3. The Jewel seam overlies the uppermost third cycle, however, most of the other carbonaceous shales and thin coals seen at the Stop 3, do not seem to be present here. This section is less than 1 km to the west from the CD pit (Stop 3), and probably lies due west along the inferred paleoshoreline. The coarse-grained Torrens section examined here is considered to be a beach conglomerate or alternatively a north-south trending fluvial channel mouth deposit.

Things to see:

1) The third marine cycle shows a very thick coarse-grained pebble conglomerate. Sorting tends to be very good and clasts are generally all well rounded and composed largely of chert.
2) Note the lack of trace fossils, bioturbation, HCS, and parallel laminations throughout this section, as was seen at Stop 3 at this stratigraphic level.
3) The Jewel coal seam is oxidized and poorly exposed here.

STOP 5. MAJOR PARTING IN THE JEWEL SEAM - HI 3 PIT.

Objective: To show the presence of a major clastic parting in the Jewel seam.

Background: Throughout most of the Cadomin-Luscar coalfield the Jewel seam is approximately 10m thick and only contains thin partings. Most of these partings are kaolinitic and are interpreted to be tonsteins, derived from volcanic ash that was blown into the swamp. The major parting in the middle of the seam (figure 33) is not volcanic, but is thought to have formed in a brackish-water environment.

Things to see:

1) HI 3 is an exploratory pit at the present time. Test production was performed by a front-end loader, which left the parting standing up like a fence.

2) X-ray diffraction on samples from partings in the Jewel seam of Pit HI 3 shows that the thinner partings are rich in kaolonite, indicating that they are tonsteins (vocanic ash). The major parting is rich in quartz and plagioclase and is heavily rooted. Although no diagnostic sedimentary structures were found, the parting is interpreted to have formed in brackish water.

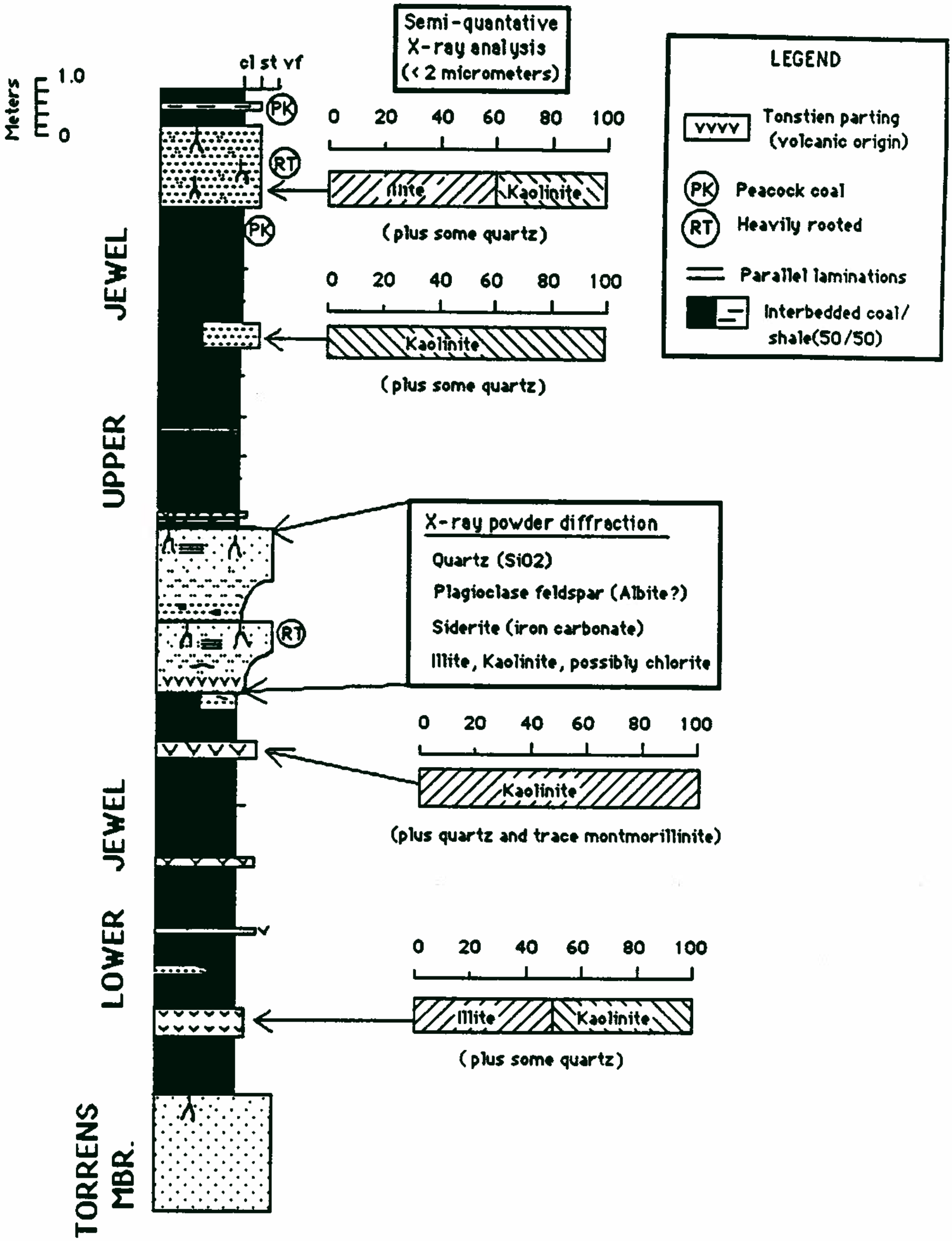

Figure 33. Stratigraphic section of the Jewel Seam in the HI 3 Pit, together with X-ray diffraction results.

STOP 6. PARTING IN THE JEWEL SEAM - LM PIT.

Objective: To show the changes in thickness of a major clastic parting in the Jewel seam.

Background: The parting thickens in this pit from 2.5 to about 10m (figure 34), and thickens to 30m about 0.5km to the northwest along strike.

Things to see:

1) Within the parting, two main lithostratigraphic units could be noted (figure 34): a) a fine-grained, well stratified lower unit and, b) a more homogenous, coarser-grained upper unit. The upper unit could be seen to be lensoidal in shape and cutting into the lower unit at several different levels. Unfortunately this exposure is not available anymore, because of mining.

2) The in-seam finely dissemenated ash content is lowest at the base of the lower Jewel (figure 13) and within the entire upper Jewel (<10%, db).

3) The in-seam sulfur content is lowest near the center of the lower Jewel (0.1-0.2%, daf), rises slighlty near the base of the major split (0.3-0.4%, daf) and at the base of the lower Jewel.

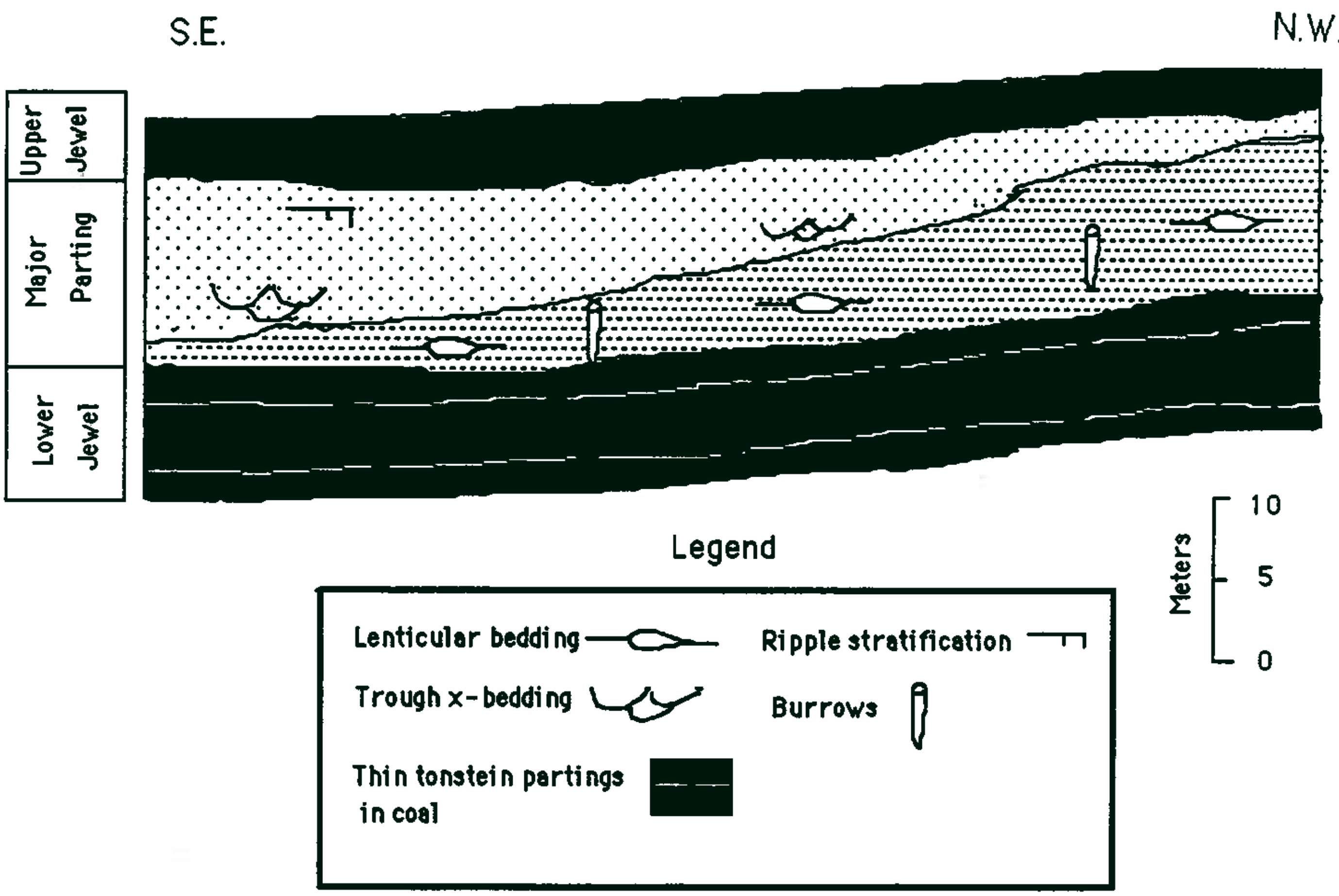

Figure 34. Field sketch of Jewel Seam in LM1 Pit, southeast to northwest along strike, showing major clastic parting. Scale is approximate.

STOP 7. STRUCTURAL STYLES IN THE PQ PIT

Objective: To demonstrate the effects of different structural styles on coal mining.

Background: The PQ pit is situated along the thickened hinge of a syncline, near the Drinnan Thrust (figures 1 and 3).

Things to see:

1) The disharmonious folding, expressed by the thickening of the Jewel Seam and tight folding of the Torrens sandstone (syncline-anticline-syncline train), results in an "H" shaped structure (figure 35).

2) The Drinnan Thrust is well exposed, with Nikanassin thrusted over Moosebar, Torrens and Jewel Seam.

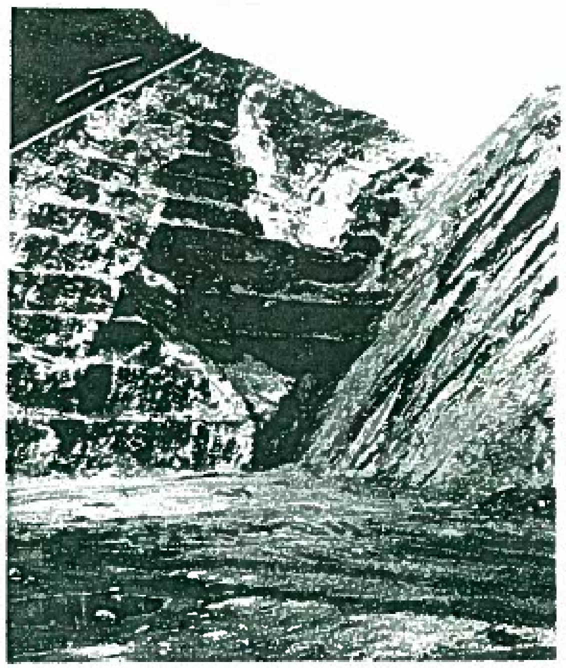

Figure 35. Disharmonious folding in PQ pit. The trace of the Drinnan Thrust is shown.

STOP 8. STRUCTURAL/STRATIGRAPHIC OVERVIEW (CARDINAL RIVER COAL 51B2 and 51B3 PITS).

Objective: To provide an overview of the structural and stratigraphic framework of the Grande Cache Member.

Background: The Cardinal River Coals 51B2 and 51B3 pits have collectively exposed almost 2km. of Grande Cache Member strata, perpendicular to the regional fold axis. The disharmonious folding style is plainly visible from the ridge as is the relationship between thickened coal and structure.

Things to see:

1) Thickened Jewel Seam above Torrens Member (figure 36).
2) Cylindrical folding of Torrens sandstone (figure 36).
3) Disharmonious folding as expressed by open folding of Torrens sand stone and tighter folding of strata above the Jewel Seam (figure 36 and 37).
4) Hinge collapse and resulting faulting (figure 36).
5) Roll-over folding in Torrens sandstone (figure 37).
6) Box fold in Rider Seam (figure 37).
7) Step faults in Torrens sandstone (figure 36).
8) Thrust fault bringing up the Jewel Seam (figure 37).
9) Several other faults, such as upthrusts, back thrusts and normal faults, which are probably related to the general folding (figure 37).
10) Combination of channel scour and thrusting (fig.37).

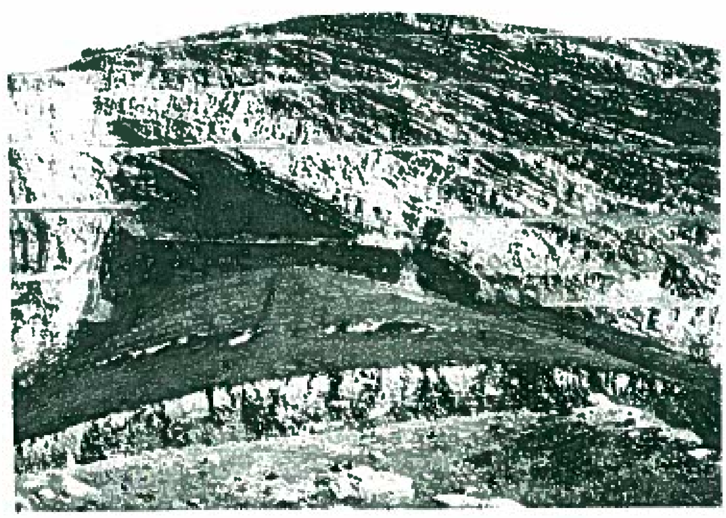

Figure 36. Anticline of 51B3 Pit, with disharmonious folding of Jewel Seam and nearby strata.

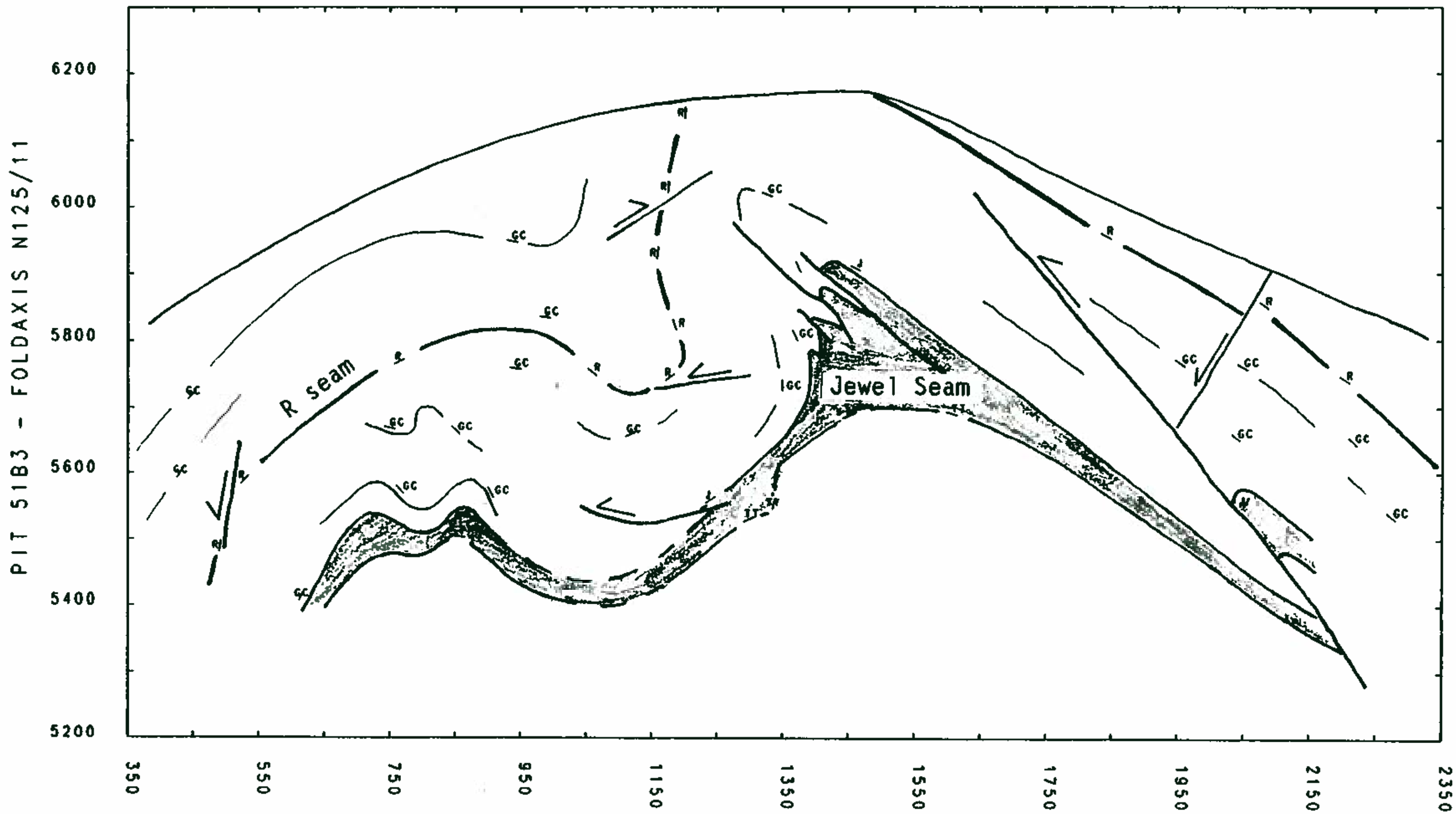

Figure 37. Vertical down-plunge cross section, perpendicular to the fold axis trend of N125E, through the end wall of the 51B3 Pit. For methodology of down-plunge cross section construction see Langenberg et al. (1987). TT=Top Torrens; J=Jewel Seam; GC=Grande Cache Member; R=R Seam. Sense of fault movement is indicated with arrows.

STOP 9: LARGE ASYMMETRIC ANTICLINE IN 50A5 PIT

Objective: To demonstrate the non-cylindrical nature of folding

Background: Folds are generally cylindrical on a local scale, as shown in the previous stop. However, on a regional scale folds change geometry in the direction of the fold axis and have to be considered non-cylindrical. The Cadomin Syncline is plunging to the southeast, but subsidiary folds such as the anticline in the 50A5 Pit plunge to the northwest. This change in plunge necessitates a change in geometry.

Things to see:

The large asymmetrical anticline is well exposed in the center of this pit and consists of Torrens Member (footwall) sandstone. The northwest plunge of the structure is well displayed (figure 38).

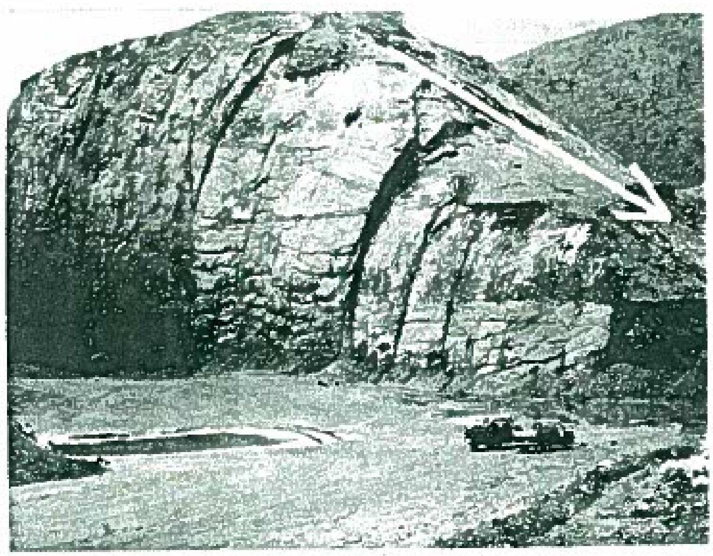

Figure 38. Exposed anticline in the Torrens member, Stop 3, 50A5 pit. The plunge is indicated. Trucks at lower left for scale.

STOP 10: COAL QUALITY VARIATION OF THE COALSPUR COALS, COALSPUR ROAD SECTION.

Objective: To contrast properties of lower Cretaceous coals from the inner Foothills with Paleocene coals from the outer Foothills.

Background:

The vicinity of outcrops of the younger Coalspur coals enables the discussion of differences in coal properties of the two major coal bearing stratigraphic units. Palynological dating suggests an early Paleocene age for the coals of the Coalspur Formation, similar to the age of the Ardley coal zone. In this road section the upper part of the Coalspur Formation, including the Val D'Or and Arbour seams (figure 39), is exposed. The Cretaceous-Tertiary boundary is situated near the base of the Mynheer Seam, which is lower in the stratigraphy, but not exposed in this section. Ash and sulfur contents for these two seams are shown in figure 39. Reflectance (figure 40B) indicates the high volatile C rank of the Coalspur coals. The high semifusinite ratios (figure 40C) are indicative of foreland basin coals (Hunt and Smyth, 1989). The depositional setting of these coals points to an alluvial plain (Jerzykiewicz and Langenberg, 1983).

Things to see:

1) Look for signs of burning coal.
2) The thick bentonite layer below the Arbour Seam allows correlation of this section with drill holes.
3) Notice crevasse splays in Val D'Or Seam and inbetween Val D'Or and Arbour seams.
4) Contrast these thick alluvial plain coals with the thick lower Cretaceous coastal plain coals. What differences do you see?

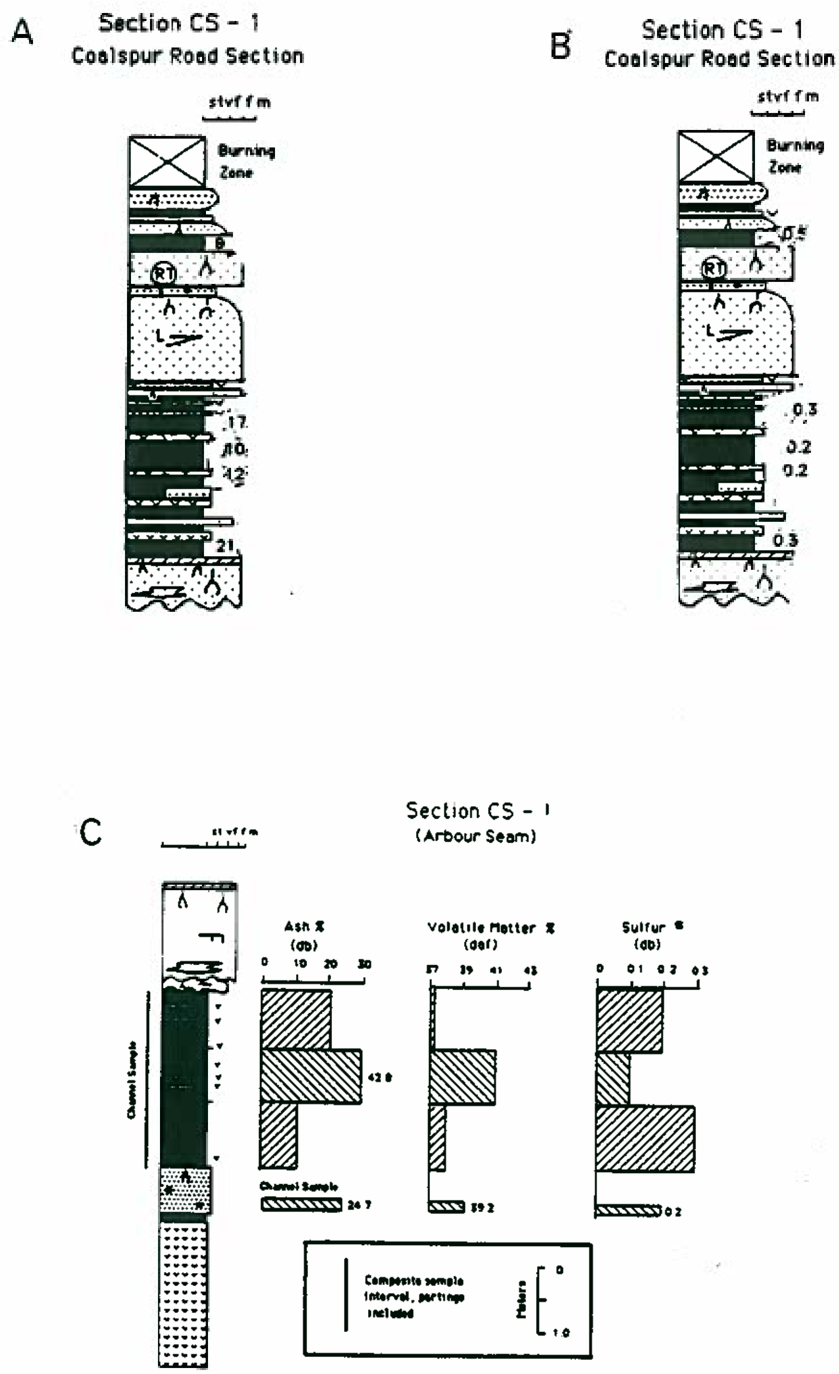

Figure 39. In-seam profiles of the Coalspur road section. A) Ash contents of the Val D'Or seam. B) Sulfur of the Val D'Or seam. C) Ash, volatile matter and sulfur of the Arbour Seam.

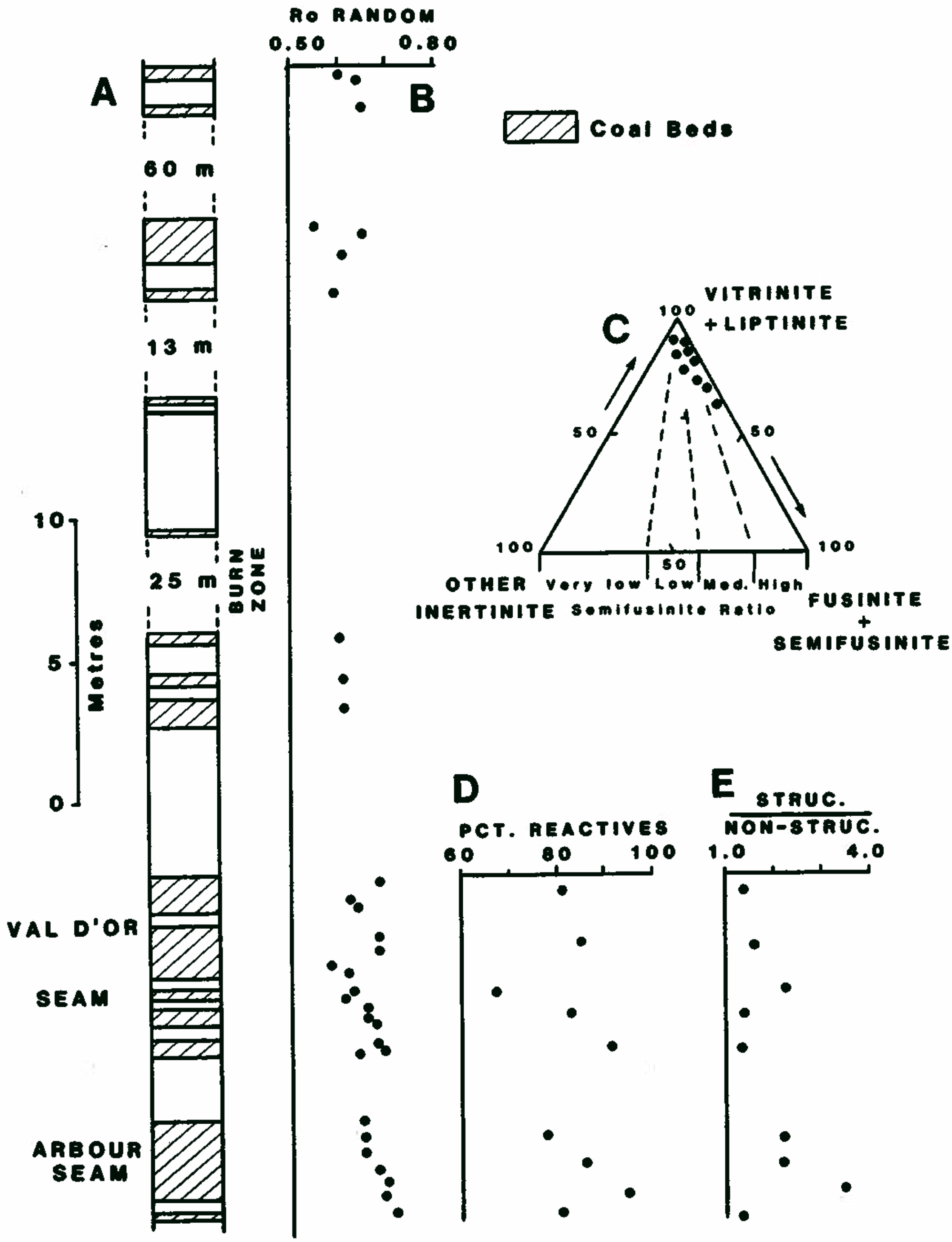

Figure 40. Compositional characteristics of Val D'Or and Arbour seams, Coalspur road section (data from Cameron, unpublished). A) Generalized section, showing the coal beds. B) Vitrinite reflectance (random) versus depth profile. C) Maceral distribution diagram (mineral matter free) for 9 coal intervals in the Val D'Or and Arbour seams. Diagram adopted from Hunt and Smyth (1989). D) Vertical distribution of reactive macerals of the 9 coal intervals. Reactives include vitrinite, liptinite and 1/3 semifusinite. E) Variation in ratio of structured/non-structured macerals for the 9 coal intervals. Structured macerals include telocollinite, semifusinite and fusinite; non-structured includes remaining macerals.

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APPENDIX

Legend:

- Sandstone
- Conglomerate
- Interbedded mudstone/coal (<25% coal)
- Clay-shale Claystone
- Siltstone Silshale
- Interbedded claystone Mudstone (<25% claystone)
- Mudstone Mudshale
- Interbedded sandstone Claystone (>50% sandstone)
- Interbedded sandstone Claystone (>75% sandstone)
- Paleosol
- Coal
- Low-angle x-strata
- Hummocky cross stratification
- Very fn interlaminated
- Carbonaceous matter-particles
- Shells (marine)
- Fining-upward cycle
- Coarsening-upward cycle
- Carbonaceous matter-finely disseminated
- Carbonaceous matter in thin laminae
- Scour and fill
- Sheared coal
- Large scale x-bedding

- Trough x-strata
- Ripples
- Soft sediment deformation
- Roots
- Leaf imprints
- Log or stems
- Basal lag
- Parallel stratification
- Intraclasts
- Graded bedding
- Slickensides
- Folding
- Fault
- G Glauconitic
- PY Pyrite
- B Bioturbated
- F Forams
- Gradational contact
- Sharp contact
- Burrows (vertical horizonta, with spriten, branching)
- Ironstone band
- Erosional contact
- Dinosaur track

- R Heavily rooted
- M Soil mottled
- Symetrical ripples
- Wavy bedding

Itinerary

April 22, 1989

1:00 p.m. Meet at Terrace Plaza office tower
3:00 p.m. Pit stop in Devon
4:30 p.m. Stop 1. Railroad section in Cadomin
5:30 p.m. Leave for Hinton
6:30 p.m. Arrive at Crestwood Hotel
7:00 p.m. Dinner

April 23, 1989

7:00 a.m. Breakfast
8:00 a.m. Leave Hinton
9:00 a.m. Arrive at Gregg River Mine
9:15 a.m. Stop 2. CD overview
9:30 a.m. Stop 3. CD Pit
10:30 a.m. Leave CD Pit
10:45 a.m. Stop 4. Haulroad to HI-3
11:15 a.m. Stop 5, HI 3 Pit
11:45 a.m. Arrive at Stop 6, split in LM Pit
12:15 a.m. Lunch near PQ Pit
1:15 p.m. Stop 7, PQ Pit
1:45 p.m. Leave Gregg River Mine
2:00 p.m. Arrive at Cardinal River Mine
2:15 p.m. Hike up Ridge to view structure in 51B3 Pit, Stop 8
3:15 p.m. Stop 9, 50A5 Pit
3:30 p.m. Leave Cadomin area
4:15 p.m. Stop 10, Coalspur
4:45 p.m. Leave Coalspur
5:30 p.m. Dinner in Edson
8:30 p.m. Return to Terrace Plaza office tower, Edmonton