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EDMONTON GROUP/ST. MARY RIVER FORMATION: SUMMARY OF LITERATURE AND CONCEPTS

By

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GENERAL TECTONIC AND DEPOSITIONAL SETTING

Foreland Basin Basics

In the Western Canada Sedimentary Basin (WCSB) the Foreland Basin Succession is the second of two major eastward-thinning wedges, is approximately equivalent to the Zuni Sequence of Sloss (1963), and is a direct result of the evolution of the Canadian Cordillera during Jurassic to Paleocene time (Porter *et al.*, 1982). Collisional accretion of microcontinents to the western margin of ancient North America compressed and detached the underlying Paleozoic miogeoclinal wedge, and telescoped and translated these strata as imbricate thrust sheets to form the thickened orogenic belt (Porter *et al.*, 1982). This thrust sheet load flexed the crust to form a deeply subsiding asymmetric foredeep, which migrated in front of the advancing thrust stack, and provided the source of detritus deposited in that foredeep. This led to a dramatic reversal of sediment dispersal, from generally westward off the craton, to generally eastward off the orogen as the miogeoclinal and earlier molassic strata were cannibalized. An enormous volume of synorogenic shallow marine and nonmarine sediments were deposited in asymmetric, generally regressive clastic wedges as a result (Leckie and Smith, 1993). Stratigraphic sequences in foreland basins are clearly controlled by regional tectonism, as evidenced by variation in sediment source, depositional regime and uplift/subsidence patterns between successive sequences (Embry, 1990; Miall, 1991).

Laramide Orogeny and Basin Infill

In mid-Cretaceous time a change from orthogonal to oblique northward convergence, caused western parts of the Cordillera to be displaced hundreds of km to the north (Monger, 1989). Late Cretaceous (Turonian/Cenomanian) docking of the oceanic Insular Superterrane (Alexander/Wrangellia Terranes), and others, (Monger, 1989; Cant and Stockmal, 1989; Stockmal *et al.*, 1993) led to rapidly intensifying tectonic loading, foredeep subsidence (creating accommodation space) and cannibalization of previous deposits. This resulted in Campanian to Paleocene rapid deposition of a series of generally regressive wedges of marine to nonmarine synorogenic molassic sediments (Jerzykiewicz, 1985) (Fig. 1). This composite coarsening-upward succession, up to 3.5 km thick, was deposited during 20-25 m.y. (sedimentation rate of about 175m/m.y.) and represents the final stage of Foreland evolution (Porter *et al.*, 1982).

Cant and Stockmal (1989) and Chamberlain et al (1989) noted the typical lag time between the increase in subsidence and the increase in sediment supply (here, up to 20 m.y. between Superterrane docking and the appearance of coarse clastic detritus in the preserved portion of the Foreland; Underschultz and Erdmer, 1991), creating generally coarsening-upward wedges. Jerzykiewicz and Labonte (1991) and Leckie and Smith (1993) noted that prevailing drainage in the proximal part of the post-Colorado foreland is perpendicular to basin axis in more proximal, coarser-grained phases and parallel to basin axis in more distal, finer-grained phases.

This last portion of the Zuni Sequence (Sloss, 1963; Porter *et al.*, 1982) represents an eastward-thinning wedge which extended into Manitoba (Taylor *et al.*, 1964) but was later partially eroded after thrusting ceased and crustal extension began in Eocene time (Monger, 1989), leaving only erosional remnants over the Plains. Most sediment was supplied through cannibalization of earlier Paleozoic/Mesozoic sediments from the emerging Rockies (Rahmani and Lerbekmo, 1975; Porter *et al.*, 1982; Stott, 1984; Jerzykiewicz, 1985; Mack and Jerzykiewicz, 1989).

Six coarsening-upward cyclothems, related to orogenic pulses, were identified in this succession in the central Foothills by Jerzykiewicz (1985): the Edmonton/St. Mary River/Eastend strata correlate to his Cycles II, III, and IV. Mack and Jerzykiewicz (1989) suggested that three main periods of thrusting are signalled by the sediments of the Belly River, lower Willow Creek and Paskapoo units in the Foothills, separated by two periods of relative tectonic quiescence represented by the St. Mary River and upper Willow Creek sediments. Campanian subsidence and sedimentation rate increased markedly in southwestern Alberta, but decreased northward, whereas in the Maastrichtian, these rates increased markedly in northwestern Alberta and decreased progressively southward (Chamberlain *et al.*, 1989). These effects presumably relate directly to geographically limited tectonic loading and creation of accommodation space, and resulting sediment dispersal patterns. Environments of deposition are generally nonmarine to the west and sediment-starved marine to the east (where preserved) (Leckie and Smith, 1993).

The Edmonton Clastic Wedge

The Saunders II, III and IV Cyclothems (Jerzykiewicz, 1985) and the equivalent Edmonton/St. Mary River/Eastend of the Plains represent part of a vast east or southeast-thinning wedge of generally nonmarine sediments deposited along the western or northwestern margin of a subsiding marine seaway which may have stretched from the Arctic to the Atlantic to the Gulf of Mexico (Gibson, 1977; Lerand, 1983). The Bearpaw Cycle of Weimer (1960) lasted about 5 Ma and includes the last major marine transgression preserved in the record. It was followed by an increase in sediment supply and volcanism which overwhelmed basin subsidence, allowing eastward progradation of the nonmarine wedge (Lerand, 1983). Initial rapid Bearpaw marine transgression was related to tectonically induced subsidence due to movement on major thrust sheets and tectonic loading, was diachronous in southwest Saskatchewan and extended to the northwest to somewhat beyond Edmonton and Pembina area, as well as north of Peace River Arch (Shepheard and Hills, 1970; Stelck *et al.*, 1976; McCabe *et al.*, 1986; Nadon, 1988).

The Bearpaw Formation marine shale thins to the west and north, but thickens to the east and south (Link and Childerhose, 1931) at the expense of the under and overlying clastic wedges to become part of the Riding Mountain and Pierre Formations (Caldwell, 1968; Shepheard and Hills, 1970; Stelck *et al.*, 1976). There are several sandy members in southern Alberta and Saskatchewan (Link and Childerhose, 1931; Clark, 1931; Caldwell, 1968). After isostatic relaxation and uplift, the subsequent rapid increase in sediment supply allowed progradation of the nonmarine clastic wedge and concomitant rapid eastward withdrawal of the Bearpaw sea, first from central Alberta, then from southwestern Alberta and finally from southeastern Alberta and Saskatchewan (Shepheard and Hills, 1970; Rahmani and Schmidt, 1975; McCabe *et al.*, 1986; Nadon, 1988). The resultant complex intertonguing of Bearpaw marine and Edmonton nonmarine sediments represents the beginning of the major regressive phase with many minor, but widespread, transgressive pulses. This created a transitional marine/nonmarine diachronous contact, with variable lithologies, between Bearpaw and Edmonton during the Maastrichtian (Link and Childerhose, 1931; Wall *et al.*, 1971; Shepheard, 1978; McCabe *et al.*, 1986).

The Edmonton/St Mary River/Eastend fluvio-deltaic clastic wedge (Fig. 2), of complexly interfingering fresh to brackish and nonmarine facies, thickens greatly to the west (including all portions of the wedge) and there is a great increase in the rate of thickening to the west (Elliot, 1960;

Yurko, 1976; Gibson, 1977). The wedge is characterized by great lateral and vertical variability in facies, general fine grain size, abundant thin coals, and abundant bentonites (Allan and Sanderson, 1945; Havard, 1971). The lower portion has the sedimentary and faunal characteristics of lower delta plain deposits with distributary channel, barrier island and backbarrier lagoon environments (Gibson, 1977), with deposition related to an embayed shoreline in estuarine and barrier island complexes (Rahmani, 1983). The shorelines are oriented WSW/ENE, with open sea to the south at Drumheller, but the overall progradational trend was punctuated by four rapid marine transgressions within the lower 50 m of transitional stratigraphy (Rahmani, 1983).

The upper portion of the clastic wedge is more like upper delta plain deposition with a system of large and small braided streams (Gibson, 1977). Rahmani and Schmidt (1975) and Rahmani and Lerbekmo (1975) postulated sediment transport to the east in short transverse drainage patterns which then connected to a basinwide NW to SE longitudinal drainage in the Plains from a positive source area in northern/central B.C. Penecontemporaneous volcanism was prominent. Conversely, Mack and Jerzykiewicz (1989) placed the Edmonton in their Petrographic Stage II with evidence of relative tectonic quiescence, wearing down of Rockies thrusts and decreasing importance of this sediment source, with reincorporation of predominant Omineca sediment sources. Again, volcanism was clearly prominent.

STRATIGRAPHIC SETTING AND BOUNDARIES

Relation to Other Units

The Bearpaw Formation in the Cypress Hills area was studied in detail by Lines (1963) who distinguished 5 members in ascending order: 1) Manyberries Member, dark grey shale and siltstone, 200 m thick, 2) Oxarart Member, medium sandstone, 36 m thick and thinning to the east, 3) Belanger Member, grey sandy siltstone, 21 m thick, 4) Thelma Member, fine sandstone, 12 m thick and thinning to the east, 5) Medicine Lodge Member, dark grey shale, 23 m thick, overlain conformably and gradationally by the Eastend Formation. In southwestern Alberta Link and Childerhose (1931), Clark (1931) and Lines (1963) identified thick dark grey shale with numerous thin bentonite beds and several sandy members (Magrath, Kipp, Ryegrass) overlain by the Blood Reserve Formation (Fox Hills Formation of Sanderson, 1931) sandstone (which Lines, 1963 and Furnival, 1950, equated to the Oxarart Member). All of these studies essentially identified three main coarsening-upward sequences in the Bearpaw of southern Alberta and Saskatchewan. It is not clear whether these denote laterally correlative sub-units.

In central Alberta the Bearpaw is thicker and shalier to the southeast, and sandier to the northwest, passing eventually into thin glauconitic sandstone with a sparse marine microfauna in the Edmonton area (Lines, 1963). Lines (1963) divided the Formation there into a lower Young Creek Member, 67 m thick, and a Paintearth Member, 55 m thick, both of dark grey shale with several sandy units.

In the central Foothills the Bearpaw Formation marine shale pinches out east of the Alberta Syncline axis (Jerzykiewicz, 1997). There, Cyclothems II, III, and IV of the upper Brazeau Formation of the Saunders Group (Jerzykiewicz, 1985) are approximately equivalent to the Edmonton and St. Mary River clastic wedge and define an overall coarsening-upward succession. Jerzykiewicz (1985) subdivided these cyclothems into lower coarser grained and upper finer grained units: IIa 34% channel sandstone plus overbank mudstone, IIb overbank mudstone plus coal, IIIa 68% channel sandstone plus overbank mudstone, IIIb overbank mudstone plus coal, IVa 71% channel sandstone plus overbank mudstone, IVb overbank mudstone plus bentonite (Battle-equivalent?) (Jerzykiewicz and McLean, 1980). This succession is abruptly overlain by the Entrance Conglomerate at the base of the Coalspur Formation. In the northern Plains the upper Wapiti is approximately equivalent to the Edmonton and is capped by a Battle-like unit with a tuff (Irish, 1970).

In the southern Foothills the Blood Reserve Formation (Fox Hills Formation of the U.S. and of Sanderson, 1931) has sharp but conformable upper and lower boundaries, overlying the Bearpaw marine shale and overlain by the St. Mary River Formation, and is actually a localized shoreline facies of the St. Mary River clastic wedge in southwestern Alberta (Russell and Landes, 1940; Glass, 1990; Jerzykiewicz, 1997). The overlying St. Mary River, first described by Dawson (1884), conformably overlies the Blood Reserve or Bearpaw and encompasses all continental rocks between the Bearpaw and the Willow Creek red beds (Williams and Dyer, 1930; Glass, 1990). The lower 60 m of the St. Mary River is approximately equivalent to the upper 60 m of the Bearpaw in Cypress Hills (Furnival, 1950). Tozer (1952) identified a white sandstone/mauve shale/tuff bed sequence at the top, directly correlative to the Whitemud/Battle/Kneehills Tuff of central Alberta. The St. Mary River can be mapped as intertonguing northward with the Horseshoe Canyon Formation in the area of Little Bow River (Twp 14, Rge 21-22W4), delineating an essential time-equivalence (Russell and Landes, 1940; Glass, 1990; Hamblin, 1998). It is conformably overlain by the Willow Creek on the west side of the Alberta syncline, but a disconformable relationship may occur at that contact on the east side of the syncline (ie. upper St. Mary River represents longer deposition than the upper Horseshoe Canyon?) (Russell and Landes, 1940; Glass, 1990).

Internal Subdivision

In central Alberta the Edmonton Series was first described by Tyrrell (1887) as the coal-bearing series well-exposed on Red Deer River between the Bearpaw marine shale and the Paskapoo sandstone (Williams and Dyer, 1930; Glass, 1990). Now referred to the Edmonton Group, this unit has a gradational base, a sharp disconformable top and correlates with the upper Wapiti/upper Brazeau/St. Mary River of the west and north, and the Eastend of the southeast (Glass, 1990), and comprises several formations. The initial subdivision by Allan and Sanderson (1945) (Fig. 3) from outcrop work in Red Deer River valley, identified A) a Lower Edmonton from Bearpaw to top of the conspicuous Drumheller Marine Tongue (about two-thirds of thickness from base) and including coal seams #0 to #10, B) a Middle Edmonton from the top of the Drumheller Marine Tongue to the top of the Battle Formation, including coal seams #11 to #12. The Upper Edmonton (Member E of some authors) has been formally named the Scollard Formation by Gibson (1977) who included it in the Edmonton, but in this review it is treated as part of a separate clastic wedge. Ower (1960) proposed a slightly different subdivision (Fig. 3) consisting of A) Member A of sandstone, shale and coal seams #0 to #7, B) Member B of green shale and sandstone and the Drumheller Marine Tongue in the middle but nearly barren of coal except for the minor seams #8 to #10, C) Member C of grey shale, sandstone and thick coal seams #11 and #12, and D) Member D of the Kneehills Tuff Zone (Whitemud and Battle Formations).

Elliot (1960) returned to the subdivisions of Allan and Sanderson (1945) but acknowledged that the Drumheller Marine Tongue pinches out northwest of Drumheller, is therefore difficult to use as a regional marker, and that the Kneehills Tuff Zone is the only persistent regional correlation unit. This sentiment was echoed by Campbell (1962) and Srivastava (1968) who both mentioned that the Kneehills Tuff Zone included the only floral/faunal break in the sequence. A macrofloral and dinosaur faunal break at the Battle Formation was confirmed by Srivastrava (1968, 1970) (Fig. 3) who also suggested that there was a floral distinction between those sediments below and above the Drumheller Marine Tongue. Ritchie (1960) gave radiometric dates for the Kneehills Tuff generally in the 66-67 Ma range, and Irish and Havard (1968) and Irish (1970) indicated that the Whitemud/Battle/Kneehills Tuff sequence was consistently present at the top of the Edmonton and represents a fundamental chronostratigraphic marker of regional extent.

Irish (1970) (Fig. 3) stated that Ower's subdivisions were based on outcrop and only useful locally, and suggested new type or reference sections for the three formations he defined in the Edmonton Group. The Horseshoe Canyon Formation includes all strata between the Bearpaw and the distinctive Whitemud sandstone, and so is equivalent to the Lower and Middle Edmonton of Allan and Sanderson (1945) and Members A, B and C of Ower (1960) (Irish, 1970). The Formation has a gradational base placed at the base of the lowest thick sandstone above the Bearpaw, a sharp to gradational conformable top with the Whitemud, and the Drumheller Marine Tongue is locally present about two-thirds up from the base (Stelck *et al.*, 1976; Glass, 1990). The type section (Fig. 4) designated was the entire Red Deer River Valley between East Coulee to the southeast (Twp 28 Rge 18W4) and Big Valley Creek (Twp 34 Rge 21W4), although the name "Horseshoe Canyon" comes from a nearby exposure area where only the upper portion of the strata are exposed.

Nurkowski and Rahmani (1984) (Fig. 3), studying the upper Horseshoe Canyon, described a lower fine-grained unit immediately overlying the Drumheller Marine Tongue, with bentonite time lines and no coal (equivalent to the lower Middle Edmonton of Allan and Sanderson, 1945, the upper Member B of Ower, 1960, and the formally-defined Tolman Member of Srivastrava, 1968) and an upper coal-bearing unit (Carbon/Thompson Coal Zone) immediately below the Whitemud and Kneehills Tuff time line (equivalent to the upper Middle Edmonton of Allan and Sanderson, 1945, the Member C of Ower, 1960, and the Eastend of Cypress Hills).

The Whitemud Formation, of white sandstone, conformably and gradationally overlies the Horseshoe Canyon and Eastend Formations, with a sharp but likely conformable top with the Battle, although it may be erosionally overlain by Frenchman/Paskapoo sandstone (Glass, 1990). The Battle Formation, of dark shale, has a sharp but conformable base and an upper contact which appears conformable with the Willow Creek in southwestern Alberta but is conformable to disconformable beneath pre-Frenchman/Paskapoo erosion in many areas (Glass, 1990). Conformably within the Battle in all areas, commonly in the upper half, are one to several thin tuff beds, the Kneehills Tuff (Allan and Sanderson, 1945; Glass, 1990).

Cypress Hills Stratigraphy

In Cypress Hills the Eastend Formation sandstone, siltstone and minor coal gradationally overlies the Bearpaw and is gradationally overlain by the Whitemud and Battle (Glass, 1990), and so occupies a similar stratigraphic position to that of the Horseshoe Canyon and St. Mary River Formations. However, it is much thinner and, based on the concept that the top of Bearpaw is diachronous but the Kneehills Tuff represents an approximate time line, the Eastend likely correlates to the upper Horseshoe Canyon of central Alberta (Russell and Landes, 1940), the upper St. Mary River of southwestern Alberta (Furnival, 1950) and the upper Bearpaw of southwestern Saskatchewan (Russell and Landes, 1940). Where deep pre-Frenchman erosion occurs the Battle/Whitemud may not be present and the Eastend is overlain by the Frenchman (Russell and Landes, 1940; Furnival, 1950; Glass, 1990). Lerbekmo (1985, 1987) published detailed magnetostratigraphic studies illustrating that the sub-Frenchman disconformity, with up to 70 m of relief, represents a hiatus of about 300,000 years and is represented in central Alberta by 50-60 m of upper Horseshoe Canyon strata. Lerbekmo (1985) was able to confirm that the Battle Formation is a slightly diachronous facies, older in the southeast.

AGE AND CORRELATION

The Edmonton Group of the Plains is underlain by the Maastrichtian Bearpaw Formation. The Campanian/Maastrichtian boundary is near the base of the Bearpaw (Srivastava, 1968) and the top of the Bearpaw is younger to the east (Russell and Landes, 1940). The Edmonton flora and fauna is Maastrichtian in age, the Kneehills Tuff at the top can be radiometrically dated to the late Maastrichtian and is overlain by the late Maastrichtian to early Paleocene Scollard Formation. The Edmonton has a conformable base and disconformable top, is approximately equivalent to the upper Brazeau of western Alberta, the upper Wapiti of northern Alberta, the St. Mary River of southwestern Alberta and the Eastend/Whitemud/Battle of southern Saskatchewan (Williams and Dyer, 1930; Rahmani and Lerbekmo, 1975; Glass, 1990). Near the top of the Edmonton the Whitemud Formation has been correlated to the Colgate Member of the Fox Hills Formation in northern U.S., due to similarity of lithology and petrography, and to the upper St. Mary River , by stratigraphic position (Russell and Landes, 1940; Furnival, 1950; Glass, 1990). The Kneehills Tuff, within the Battle Formation, at the top of the Edmonton is correlated to other tuff horizons identified at the top of the St. Mary River (Glass, 1990), upper Brazeau (Elliot, 1960), upper Saunders IVb (Jerzykiewicz, 1985), Battle Formation of the Cypress Hills (Furnival, 1950), and occurs throughout the Twp 1-67 area in outcrop (Irish and Havard, 1968). These ashfall beds have been dated at 75 Ma (Pb/Pb), 66-68 Ma (K/Ar on sanidine), 65 Ma (biotite from bentonite immediately above)(Ritchie, 1960), 66 Ma K/Ar (Dodson, 1971), 64-65 Ma (Williams and Burk, 1964), 66-67 Ma (K/Ar, Stelck *et al.*, 1976), 66 Ma (K/Ar dating by Folinsbee et al, 1961, as quoted by Srivastava, 1968), and a magnetostratigraphic date of 66.5-67 Ma (Lerbekmo and Coulter, 1985). The Ardley Seam of the overlying Scollard Formation yields a date of 63 Ma (K/Ar, Srivastava, 1970). Clearly the Edmonton Group is mid-late Maastrichtian in age, deposited shortly before the Cretaceous/Tertiary boundary. Through detailed magnetostratigraphic work, Lerbekmo (1985) showed that uneroded Battle was deposited during polarity chron 30r whereas the overlying lowest Frenchman was deposited during polarity chron 30, and the up to 70 m of erosional relief on the unconformity separating the two may represent only 300,000 years of time. In addition, the sub-Frenchman disconformity in Cypress Hills is represented by 50-60 m of Horseshoe Canyon/Scollard strata in central Alberta and the Battle Formation is 0.5 Ma younger in central Alberta than in Cypress Hills (ie. while the Battle was being deposited in Red Deer River valley, it was being eroded in Cypress Hills, Lerbekmo, 1985).

In the southern Foothills the Blood Reserve Formation is correlated to the Horsetheif Sandstone of Montana (Russell and Landes, 1940), the basal Horseshoe Canyon, but is older than the Fox Hills of North Dakota (Glass, 1990). It is likewise older than the Eastend and likely correlates to the Oxarart Member of the upper Bearpaw in Cypress Hills (Russell and Landes, 1940; Furnival, 1950; Lines, 1963). The overlying St. Mary River Formation is capped by a tuff bed and is correlated to Members A, B and C of the Horseshoe Canyon, and part of the upper Bearpaw and Eastend of Cypress Hills (Williams and Dyer, 1930; Ower, 1960; Rahmani and Schmidt, 1975). The St. Mary River passes northward into, and intertongues with, the Horseshoe Canyon in the Twp 10-17 area. There, the lower St. Mary River on Oldman River is very like the Edmonton, and on Little Bow River both the lower and upper portions are of Edmonton lithology separated by a middle St. Mary River zone (Russell and Landes, 1940; Glass, 1990; Hamblin, 1998).

In Cypress Hills the upper Bearpaw has several sandy members (Thelma, Belanger, Oxarart) separated by marine shale and the Oxarart is correlated to the Blood Reserve of southwestern Alberta whereas the upper 60 m of the Bearpaw is correlated to the lower 60 m of the St. Mary River Formation (Furnival, 1950). The overlying Eastend Formation, which thickens to the west and passes into Bearpaw marine shale to the east (Caldwell, 1968), is equivalent to the upper portion of the St. Mary River (Russell and Landes, 1940; Furnival, 1950) and to Member C of the Horseshoe Canyon Formation in central Alberta (Ower, 1960).

THICKNESS AND DISTRIBUTION

In the central Foothills Jerzykiewicz (1985) measured about 375 m of total thickness for Cyclothems II, III and IV, which approximate the Edmonton or St. Mary River. These include IIa=120 m, IIb=20m, IIIa=75 m, IIIb=25 m, IVa=75 m, IVb=50 m. In the southern Foothills the Blood Reserve Sandstone immediately overlies the Bearpaw Formation and thins northward from the U.S. border, from 30 m to 12 m at Oldman River (Young and Reinson, 1975; Glass, 1990), although Williams and Dyer (1930) listed 91 m on Little Bow River. The overlying St. Mary River Formation thickness has been variously given as 487 m on Oldman River and 914 m to the west (Williams and Dyer, 1930), up to 950 m (Rahmani and Schmidt, 1975), 240 m on Oldman River thickening westward to 450 m (Young and Reinson, 1975), 460-480 m (Yurko, 1976), 354 m on St. Mary River/457 m on Oldman River/762 m on Crowsnest River (Glass, 1990) and it extends north to about Twp 14. Furnival (1950) expressed doubt about the excessive 460-490 m thicknesses due to thrusting in the Monarch Fault Zone and suggested 275-300 m is more realistic.

In the Plains the Bearpaw marine shale is 220 m thick on St. Mary River (Young and Reinson, 1975), 150 m at Drumheller (Stelck *et al.*, 1976) and thins to the north and west to a pinchout near Edmonton (Caldwell, 1968; Shepheard and Hills, 1970; Stelck *et al.*, 1976). It thickens to the east at the expense of the underlying and especially the overlying clastic wedges and has marine sandstone tongues which feather into it from the Edmonton Group (Furnival, 1950; Lines, 1963; Stelck *et al.*, 1976).

The overlying Edmonton Group (excluding the Scollard Formation) is generally about 250-300 m thick along Red Deer River valley, thickening rapidly into the upper Brazeau to the west, thinning to the east (Allan and Sanderson, 1945; Ower, 1960; Gibson, 1977; Srivastava, 1970; Glass, 1990) and thinning to the south to 122 m on Little Bow River (Williams and Dyer, 1930).

Within the Edmonton Group, the Horseshoe Canyon Formation totals about 227-275 m, averaging 250 m (Irish, 1970; Stelck *et al.*, 1976; Gibson, 1977) and has been divided in several ways, using the Drumheller Marine Tongue (DMT) and Kneehills Tuff Zone (KTZ) as markers, which illustrate complex relationships (Irish, 1970; Stelck *et al.*, 1976). Ower (1960) identified several members with the following thicknesses, in ascending order: 1) Member A, 122-275 m, thickens rapidly to the north and west from 137 m at Drumheller to 222 m at Scollard Canyon, replacing upper Bearpaw, 2) Member B, 61-91 m green shale including the DMT at the base, 3) Member C, 21-55 m, including the Carbon/Thompson Coal Zone (Ower, 1960; Campbell, 1967; Yurko, 1976; Nurkowski, 1980). He termed the Battle/Whitemud or KTZ as Member D, 6-15 m thick. Several authors also simplified this as Lower Edmonton (Members A and lower B), and Middle Edmonton (Members upper B, C, D) (Allan and Sanderson, 1945; Elliot, 1960); the Upper Edmonton or Member E is equivalent to the Scollard Formation, treated as a separate clastic wedge. In the Cypress Hills the Eastend Formation, approximately equivalent to Horseshoe Canyon, is 36 m thick in southeastern Alberta, 19 m thick at Ravenscrag Butte and 21 m thick at Eastend (Furnival, 1950; Glass, 1990).

The Horseshoe Canyon is overlain by the Whitemud Formation, up to 23 m thick in Cypress Hills where pre-Frenchman erosion may cut it out completely, but generally 4-8 m thick over most of central Alberta (Furnival, 1950; Gibson, 1977; Glass, 1990). The overlying Battle Formation ranges 3-14 m, averaging 6m thick, but also may be partly to completely eroded by pre-Scollard/Frenchman downcutting (Gibson, 1977; Glass, 1990). The Kneehills Tuff within the Battle may be one bed 2.5-30 cm thick, or several thin beds within a 3.5 m interval and probably is not continuous throughout its vast area of occurrence (Ritchie, 1960; Glass, 1990).

COAL ZONES

There has been a long-term economic interest in the coals of the Edmonton Group, which account for most of the reserves on the Plains and are used for electrical generation (Yurko, 1976; McCabe *et al.*, 1986). They were first described by Tyrrell (1886). The coals are concentrated into 10 commercial zones between the base of the Horseshoe Canyon and the DMT (many coals in Member A, few in Member B), and 2 persistent horizons above the DMT (near the top of Member C) (Ower, 1960; Stelck *et al.*, 1976). The Horseshoe Canyon has about 19500 megatonnes of defined resource in 13 coalfields along the outcrop/subcrop belt (Dawson *et al.*, in press). The seams are thickest near the outcrop belt and thin rapidly to zero as the rank increases to the west (Yurko, 1976). There is rapid thinning and thickening of individual seams over short distances, making seam correlation difficult, although coal zones tend to be extensive and continuous (Allan and Sanderson, 1945; Yurko, 1976; McCabe *et al.*, 1986). Areas of thicker coal accumulation also generally have thicker seams (McCabe *et al.*, 1986).

The lower Horseshoe Canyon is most important for coal, with continuous seams which represent widespread peat accumulation due to *in situ* growth and minor aqueous transport and deposition, with clastic partings (Allan and Sanderson, 1945). The best coals are associated with the many tongues of marine influence which characterize the lower transitional 50 m of the Formation, hence the extent of the Bearpaw and DMT are important (McCabe *et al.*, 1986; Dawson *et al.*, in press). These coals were deposited in shoreline-parallel peat swamps 30-50 km back of the actual shoreline (McCabe *et al.*, 1986). Repeated transgressive-regressive phases resulted in extensive stacked coal seams with thicknesses over 2 m (McCabe *et al.*, 1986). These are organized into north/south trends, especially well-developed west of the outcrop belt (McCabe *et al.*, 1986). The coals are associated with three types of sandstone deposits, according to Gibson (1977): 1) coarsening-upward bayfill sandstone, 2) thick northeast-trending sandstone channels, 3) thin fining-upward crevasse splay sandstone.

Coals in the upper Horseshoe Canyon are encased in predominantly sandy fluvial sediments and are less continuous, except in locations far from major channels (McCabe *et al.*, 1986). Nurkowski (1980) and Nurkowski and Rahmani (1984) studied the coal-bearing unit 60-80 m thick at the top of the Horseshoe Canyon in central Alberta and described a general coarsening-upward, more fluvial-upward, succession deposited on a broad, low-lying coastal plain west and north of the retreating Bearpaw sea. This unit is under- and overlain by bentonitic markers interpreted to be synchronous time lines. The Carbon Coal Zone has thick channel sandstones, overbank laminated mudstones and coal seams up to 4 m thick, distributed in northwest/southeast trends beside and parallel to channel trends, and only correlatable along these trends. The overlying Thompson Coal Zone has coarser sandstone channels, mudstone and seams that likewise parallel the northwest/southeast channels in sinuous bands.

Horseshoe Canyon coals are distributed vertically in specific stratigraphic intervals (Fig. 3) as follows: 1) seams #0 and #1 in the basal transition zone, and seams #2 to #7 in the lower coaly unit (Member A of Ower, 1960), 2) a noncoaly unit overlain by seams #8 to #10 just beneath the DMT, and then overlain by the noncoaly green mudstone unit (all part of Member B of Ower, 1960), 3) seams #11 and #12 in the upper coaly unit (Member C of Ower, 1960) (Yurko, 1976). These seams are important for stratigraphic/sedimentologic analysis and the following is summarized from individual outcrop descriptions in the Red Deer River valley by Allan and Sanderson (1945) and Gibson (1977), in ascending order:

Seam #0, lowest, thin, thins to east, clean and vitreous, 0.2-0.8 m thick, 12-16 m above Horseshoe Canyon base.

Seam #1 (Drumheller Seam), carbonaceous shale and coal, vitreous with thin bentonite bed, 0.9-1.4-3.3 m thick, 18-27 m above base, thins to east, cut out by channel erosion in places, lowest mineable seam, commonly overlain by marine shale tongue.

Seam #3, thin, 0.2-0.7 m, 30-52 m above base and 2.5-4.0 m above #2, mostly carbonaceous shale.

Seam #4, thin, 0.2-0.5 m, 3-5 m above #3, eroded by channels in some places, vitreous to dull, good marker.

Seam #5 (Newcastle Seam), 0.3-2.0 m thick, 4-7 m above #4, vitreous with carbonaceous shale interbeds, exposed at Drumheller townsite level, entire stratigraphic interval #1-#5 thickens to southeast.

Seam #6, thin, 0.2-1.0 m, thickens to southeast, 14-22 m above #5, mostly carbonaceous shale with woody layer, good marker

***Seam** #7* (Daly Seam), 0.8-3.3 m thick, very variable but thickens to north, 6-8 m above #6 and 85 m above Horseshoe Canyon base, vitreous with carbonaceous shale lenses, generally present northwest of Drumheller.

Seam #8, 0.1-2.0 m splitting into 2 seams, 35-40m above #7, mostly carbonaceous shale with bentonite bed, distinctive marker.

Seam #9 thin, 0.1-0.7 m, 13-20m above #8, vitreous with bentonite bed, eroded by sandstone channel in places, exposed at Bleriot Ferry.

Seam #10 (Marker Seam), thin, 0-1m thick, brownish carbonaceous shale in greenish siltstone, 37-41 m above #9, approximately 180 m above Horseshoe Canyon base, passes to siltstone to the north, approximately at or immediately below DMT, exposed at top of Horsetheif Canyon.

Seam #11 (Carbon Seam), 0.2-1.6m thick, 53-62 m above #10, about 225 m above Horseshoe Canyon base, vitreous to dull with abundant carbonaceous shale, wood fragments and bentonite beds, extensively mined, exposed at Horseshoe Canyon and north of Morrin Bridge.

Seam #12 (Thompson Seam), 0.1-1.5 m thick, 7-16 m above #11 and immediately beneath the Whitemud Formation, vitreous with some carbonaceous shale, commercially mined, exposed at Horseshoe Canyon and north of Morrin Bridge.

CLIMATE

Deposition of the Edmonton/St. Mary River/Eastend clastic wedge occurred at a paleolatitude of about 60 N but the late Maastrichtian climate was warmer than the present-day climate at that latitude (Richardson *et al.*, 1988). Allan and Sanderson (1945), Furnival (1950), and Nurkowski and Rahmani (1984) all suggested a general warm humid to temperate climate, similar to the current Gulf of Mexico, as evidenced by the abundance of coal and dinosaur bones and the lack of evidence of desiccation. The Bearpaw sea, at maximum extent, occupied the southern half and northeastern quarter of Alberta and likely had a moderating effect on the climate.

Srivastava (1970) provided the most detailed paleoclimatic study of the Edmonton in central Alberta and its evolution through time. He interpreted lower Edmonton time as having a prevailing subtropical humid climate with rainforest vegetation, and middle Edmonton time with a subtropical humid climate becoming more temperate above the DMT. The Battle Formation was interpreted to represent a cooler climate with savannah vegetation. This upward increase in aridity was also noted in the St. Mary River of southwestern Alberta by Nadon (1988), based on the upward-increasing occurrence of paleosol horizons.

In the St. Mary River of the southern Foothills Jerzykiewicz and Sweet (1988) recorded a predominance of intermediate climatic indicators which pass upward into more arid climatic conditions of the overlying lower Willow Creek Formation. In the upper Brazeau Formation of the central Foothills the same authors found evidence of intermediate climatic conditions passing upward into a more humid, coal-bearing sequence and then back into the intermediate climatic facies of the lower Coalspur Formation. The geographical difference in climatic conditions was related to a difference in geographic distribution of topographic/orographic influence, whereas the vertical changes in climatic indicators within this wedge may relate to proximity to marine tongues/transgressions (Jerzykiewicz and Sweet, 1988).

The Whitemud/Battle Formations may represent unusual climatic or topographic conditions wherein rapid mechanical weathering and intense chemical diagenesis produced *in situ* kaolinitization of the feldspar grains in the Whitemud, with a rise in water table and widespread development of shallow lakes during Battle time (Lerbekmo, 1985).

PALEONTOLOGY

The paleontology of the Edmonton/St. Mary River/Eastend clastic wedge is very variable and has received little detailed study in recent years. In central Alberta, fossils in the Edmonton Group are only abundant at certain horizons in certain facies and are different from those of the Judith River, but similar to the overlying Scollard (Williams and Dyer, 1930). Most consist of freshwater and terrestrial gastropods and pelecypods, brackish water oyster/clam/gastropod beds, with minor wood fragments, fish and turtles (Williams and Dyer, 1930; Allan and Sanderson, 1945; Stelck *et al.*, 1976). Plants include ginkgoes, poplars, pines, sequoias, and cycads with a decided Lancian affinity and upright tree trunks occur above some coal seams (Williams and Dyer, 1930; Allan and Sanderson, 1945; Stelck *et al.*, 1976). The only major break in the pollen and dinosaur records occurs within the KTZ, suggesting a continuous depositional record through the Edmonton (Sternberg, 1947; Elliot, 1960; Srivastava, 1970) and the presence of abundant megaspores through most of the stratigraphy indicates a continental setting (Wall *et al.*, 1971). A lesser change in the flora occurs at the base of the DMT (Srivastrava, 1968). The DMT carries abundant marine to brackish water *Ostrea* and *Corbicula* beds, gastropods, bryozoans and a planktonic microfauna, but no fully marine ammonites as in the Bearpaw (Williams and Dyer, 1930; Allan and Sanderson, 1945; Stelck *et al.*, 1976; Gibson, 1977). The sandstones above and below the DMT contain some mammal bones and a diverse and characteristic dinosaur fauna dominated by Ornithischia, but with few Saurischia (Williams and Dyer, 1930; Allan and Sanderson, 1945; Stelck *et al.*, 1976). The occurrence of *Leptoceratops* is particularly diagnostic (Williams and Dyer, 1930).

Rahmani (1983) studied the intertonguing marine Bearpaw and lower Horseshoe Canyon shoreline sediments in central Alberta and found an abundant ichnofauna including *Ophiomorpha*, *Skolithos*, *Macaronichnus* and others associated with the shallow marine shoreface, barrier inlet and tidal inlet facies. Oyster bars, vertical burrows and *Teridolites* borings occur in the backbarrier facies. Thin shale tongues interbedded with the sandy facies yield marine forams (Wall *et al.*, 1971). The lower fine-grained unit of the upper Horseshoe Canyon yields abundant lacustrine/pond fern megaspores (Nurkowski and Rahmani, 1984).

The Whitemud Formation which overlies the Horseshoe Canyon has few fossils, consisting only of plant fragments, long tap roots, vertical burrows and casts of vertebrate coprolites and intestines suggesting a continental setting (Gibson, 1977; Glass, 1990). The Battle Formation, likewise, has no diagnostic fossils and the assemblage consists only of megaspores, algae, wood fragments, tap roots, bone and tooth fragments and one questionable *Haplofragmoides* specimen (Furnival, 1950; Irish and Havard, 1968; Binda and Lerbekmo, 1973; Gibson, 1977; Glass, 1990). The Formation is considered to be nonmarine. In southeastern Alberta and Saskatchewan the Eastend Formation contains poorly preserved marine and brackish water bivalves in its lower part and a few dinosaur teeth in its upper part (Russell and Landes, 1940; Furnival, 1950; Glass, 1990).

In the southern Foothills the Blood Reserve Formation forms the prograding shoreline facies overlying the Bearpaw and is characterized by the presence of *Ophiomorpha* burrows (Lerand, 1983; Glass, 1990), especially near the tops of tidal channel sandstones (Nadon, 1988). A few ammonites and rare *Macaronichnus* burrows are present in the prograding shoreline sandstones (Russell and Landes, 1940; Nadon, 1988), whereas brackish to freshwater pelecypods and gastropods, oyster beds and silicified wood are also present (Jerzykiewicz and Norris, 1992). In the overlying St. Mary River Formation, freshwater gastropods and pelecypods (particularly thick-walled *Unio* shells in fluvial sandstones), terrestrial molluscs, a few aquatic plants and rare dinosaur bones (including the diagnostic *Leptoceratops*) are characteristic (Williams and Dyer, 1930; Russell and Landes, 1940; Glass, 1990; Jerzykiewicz and Norris, 1992). Brackish water tongues with *Ostrea* and *Corbicula* coquinoid limestones are present near the base (Russell and Landes, 1940; Glass, 1990). Higher in the Formation, thin overbank sandstone beds typically host wood fragments, roots, horizontal and vertical burrows whereas associated mudstones have wood fragments, nonmarine pelecypods and nonmarine palynology (Rahmani and Schmidt, 1975; Nadon, 1988).

SEDIMENTOLOGY

Foothills

In the central Foothills Jerzykiewicz (1985) identified three two-part cyclothems of the upper Brazeau Formation of the Saunders Group, totalling 375 m thick in a coarsening-upward succession, which together approximate the Edmonton and St. Mary River of other areas. Cyclothem IIa (120 m thick) has a prominent 10 m thick, laterally persistent, multi-storied channel sandstone at the base and about 34% thin relatively fine-grained channel sandstone units with intraformational conglomerate lags at their bases. Overbank sediments are dark mudstone with splay and levee siltstone to very fine sandstone beds and a few thin bentonite beds. Cyclothem IIb (20m thick) is 88% overbank mudstone with coal and minor sandstone. Cyclothem IIIa (75 m thick) is 62% thick multi-storey channel sandstone with horizontal lamination, parting lineation and lags with tree trunks, passing upward into trough crossbedded and planar crossbedded sandstone. Cyclothem IIIb (25 m thick) is 74% overbank mudstone, carbonaceous shale and coal with minor thin splay sandstones. Cyclothem IVa (75 m thick) is 71% of very thick channel sandstones as above with 29% overbank mudstone without bentonites. Finally, cyclothem IVb (50 m thick) has 56% overbank coaly mudstone, and common bentonites (and is possibly equivalent to the Battle/Kneehills Tuff Zone).

In the southern Foothills and southwesternmost Plains, the Blood Reserve Formation (Fox Hills Formation of Sanderson, 1931 and Link and Childerhose, 1931) is a hard to soft, cliff-forming, light grey to buff, uniform, feldspathic fine to medium sandstone unit with calcareous to argillaceous cement (Young and Reinson, 1975; Lerand, 1983; Glass, 1990). It overlies a coarsening-upward Bearpaw sequence of dark grey, laminated mudstone and siltstone with marine forams, pelecypods, ammonites and pleisiosaur fossils (Link and Childerhose, 1931; Clark, 1931; Young and Reinson, 1975; Nadon, 1988). The Blood Reserve was deposited on the embayed western shoreline of the Bearpaw sea and prograded basinward as a coarsening-upward, tidally-influenced barrier island sequence overlain by minor backbarrier lagoonal coal and oyster beds (Young and Reinson, 1975; Lerand, 1983; Nadon, 1988). Lerand (1983) interpreted the barrier shoreline as oriented NE/SW with offshore to the southeast including tidal inlet channels, whereas Nadon (1988) inferred a more complex northwest/southeast barrier prograding into an east-west seaway embayment. Nadon (1988) described several facies associations as follows:

1) tidal channel fine to medium sandstone within the mesotidal barrier complex, erosional bases with lags of wood fragments and intraclasts, trough crossbedding, wave ripples, unidirectional northeastward flow, *Ophiomorpha* and *Rosselia* burrows near the top.

2) low-energy prograding shoreline very fine to fine sandstone, parallel lamination and minor scour surfaces, sharp top with wave ripples and bioturbation.

3)high-energy prograding shoreline and strandplain fine to medium sandstone, coarsening-upward from marine sediments with *Ophiomorpha* burrows to tidal crossbedded sandstone with bidirectional flows, to foreshore parallel and low-angle laminated fine to medium sandstone with *Macaronichnus* burrows.

The overlying and much thicker St. Mary River Formation represents the accompanying nonmarine clastic wedge, dominated by overbank fines and anastomosed fluvial channels which prograded from the southwest to the northeast (Lerand, 1983; Nadon, 1988). The formation is generally composed of interbedded siltstone, shale and sandstone, with minor bentonite, coal and freshwater mollusc-rich carbonates (Young and Reinson, 1975; Rahmani and Schmidt, 1975). Sandstones are greenish, calcareous, fine-grained and lenticular, interbedded with grey and green friable silty shale (Glass, 1990). The basal portion, up to 30 m thick, is fissile grey shale and siltstone with abundant wood fragments, brackish water coquinas up to 1m thick, thin coals, interpreted as brackish backbarrier lagoonal sediments (Young and Reinson,1975; Lerand, 1983; Glass, 1990). Minor broad, shallow burrowed and laminated fine sandstone channels with erosional bases and IHS lamination, or coarsening-upward splay sandstones are present throughout (Jerzykiewicz and Norris, 1992; Hamblin, 1998). The bulk of the unit is nonmarine, interbedded fine sandstone and siltstone with freshwater molluscs and dinosaur bones (Nadon, 1988; Glass, 1990). Poorly sorted mudflow deposits, interpreted as distal deposits at the periphery of alluvial fans, are present along Highwood River in the middle portion of the St. Mary River Formation (Jerzykiewicz and Norris, 1992). The following facies associations were described by Nadon (1988):

1) fluvial channel fine to medium sandstone in meandering point bar sheets up to 4.5 m thick with inclined heterolithic stratification (IHS) and clay plugs, or as multi-storied, erosionally-based fining-upward lenses (width:depth = 8-25:1) with trough crossbedding but no IHS or clay plugs and interpreted as anastomosing fluvial. Rahmani and Schmidt (1975) described classical fining-upward fluvial cyclothems up to 7 m thick.

2) proximal splay channel fine to medium sandstone in sharp-based lenses 2 m thick by 5 m wide, encased in mudstone.

3) crevasse splay calcareous siltstone to medium sandstone in thin, very extensive sheets with parallel lamination, climbing ripples, wave ripples and roots.

4) overbank dark to light grey laminated and rooted siltstone, lacustrine burrowed limestone

with shells and greenish paleosol siltstone with slickensides and nodular ironstone caliche limestone.

Plains

In central Alberta the Edmonton Group, first described by Tyrrell (1887), encompasses all nonmarine strata between the Bearpaw and Scollard Formations and is a variable sequence of complexly interfingering, fresh to brackish water sandstone, siltstone, sandy mudstone, coal and ironstone concretions which grades westward into the upper Brazeau Formation (Irish, 1970; Yurko, 1976; Gibson, 1977; Glass, 1990). The depositional setting is generally fluvio-deltaic (Yurko, 1976) and the relatively thin sandstones represent shoreline and fluvial channels whereas mudstones represent overbank floodplain environments (Williams and Dyer, 1930). There is one significant marine tongue known in the middle of the formation. In addition, there is less coal and more lacustrine shale to the west (Williams and Dyer, 1930). All sediments are very bentonitic, usually calcareous, and uniformly fine-grained: no conglomerate or coarse sandstone is present (Srivastava, 1968; Glass, 1990). It has been divided, in ascending order, into the Horseshoe Canyon, Whitemud and Battle Formations (Fig. 3).

The Horseshoe Canyon Formation is generally characterized by a variable sequence of interbedded nonmarine greenish to greyish, sandstone, siltstone and shale with numerous coal and bentonite beds, plus ironstone concretions, deposited in a fluvio-deltaic setting (Irish, 1970; Havard, 1971; Gibson, 1977; Shepheard, 1978; Glass, 1990). Bedding is typically lenticular, with rapid lateral facies changes and discontinuous interfingering beds, so that two measured sections are never the same (Irish, 1970; Shepheard, 1978; Glass, 1990). The basal portion represents a marine-nonmarine transition from the Bearpaw, followed by predominantly fluvial sediments, then the marine to brackish DMT (in outcrop at Red Deer River), followed by fluvial and lacustrine sediments, and more fluvial deposits beneath the Whitemud Formation. The formation generally thins to the southeast from the base (Ower, 1960), and includes Members A, B, C of Ower (1960) and the Lower and Middle Edmonton of Allan and Sanderson (1945). Sandstone beds are soft, light grey to greenish grey, feldspathic and bentonitic, poorly sorted and argillaceous, very fine to medium grained (never coarse grained) (Allan and Sanderson, 1945; Irish, 1970). They occur in fining-upward lenticular beds with abundant trough crossbedding, planar tabular crossbedding, oscillation ripples, mudcracks and a few burrows (Allan and Sanderson, 1945; Irish, 1970; Gibson, 1977; Glass, 1990). Mudstones are grey-green or brown, argillaceous and bentonitic, and carbonaceous (Gibson, 1977). They usually contain abundant wood fragments, bentonite beds, thin coaly streaks, ironstone concretions and beds with plant and dinosaur fossils, and minor oyster beds near the base and in the DMT (Irish, 1970; Gibson, 1977; Glass, 1990).

The Bearpaw/Horseshoe Canyon transition has been extensively studied in outcrop on Red Deer River. It encompasses a shallow marine to shoreline and continental coastal plain transition interpreted as representing rapid deposition in low-energy, unstable environments of an embayed, tidally-influenced barrier island/estuarine shoreline oriented NE/SW with the offshore direction to the southeast (Shepheard and Hills, 1970; Irish, 1970; Shepheard, 1978; Rahmani, 1983). The following is a summary of the facies associations, depositional environments and transgressive-regressive history, in ascending order, from the very detailed studies of Shepheard and Hills (1970) and Rahmani (1983):

1) coarsening-upward delta-front interbedded sandstone and siltstone, and erosionally-based tidal channel sandstones, and tidal flat mudstones.

2) basal transgression, coarsening-upward barrier island sandstone trending northeast/southwest, backbarrier sandstone or mud-filled tidal channels trending northwest/southeast, swamp coal.

3) backbarrier brackish lagoonal mudstone with thin coarsening-upward sandstone shoals, swamp coal, wide and deep mud-filled and sandstone-filled channels trending north/south.

4) mesotidal barrier island coarsening-upward sandstone, erosionally-based tidal channels trending northwest/southeast, backbarrier mudstone, coal and coarsening-upward splay sandstone with lenses of glauconitic oyster-filled sandstone.

5) basal transgression, erosionally-based meandering fluvial channel sandstone trending east/west, coarsening-upward splay sandstone, nonmarine overbank mudstone and bentonite, swamp coal.

The rest of the thick lower Horseshoe Canyon is dominated by nonmarine grey shale and channel sandstone with abundant, laterally continuous coal zones and bentonites deposited on a rapidly-prograding, low-topography coastal plain with (?)braided distributary channels and vast overbank areas (Gibson, 1977; Ower, 1960). Large scale crossbedding and most of the Edmonton dinosaur fossils are typical of this portion of the Formation (Allan and Sanderson, 1945). About 185 m from the base in Red Deer River valley is the Drumheller Marine Tongue (DMT), a thin but extensive marine to brackish zone including one to several hard thin lenticular beds of fossiliferous arenaceous limestone, containing pelecypod shells, separated by bluish grey calcareous siltstone (Allan and Sanderson, 1945; Ower, 1960; Srivastava, 1968; Gibson, 1977; Glass, 1990). It pinches out to the north (north of Twp. 32) and west and was not recognizable in the subsurface of Twp 25 Rge 25W4 by Ower (1960) or Havard (1971) but clearly represents the distal portion of an extensive Bearpaw marine transgressive tongue from the southeast, which must have been an event of regional significance.

Immediately above the DMT is a distinctive thick unit of greenish mudstone with no coal, typically 35-60 m thick in outcrop; the formally-defined Tolman Member of Srivastava (1968) or the "fine-grained unit" of Nurkowski and Rahmani (1984), and also noted by Gibson (1977). It comprises pale green, calcareous, argillaceous to sandy siltstone with minor sharp-based, fining-upward rippled, very fine to fine sandstone, arranged in coarsening-upward sequences between laterally extensive, thin bentonite beds (Nurkowski and Rahmani, 1984). Plant fragments, freshwater fern spores and burrows are abundant, but there is no coal, and these sediments are interpreted as lacustrine (Nurkowski, 1980; Nurkowski and Rahmani, 1984). The unit generally occurs between coal seams 10 and 11 (Gibson, 1977).

Between the lacustrine mudstone and the Whitemud Formation is the "coal-bearing unit" of Nurkowski and Rahmani (1984), or Member C of Ower (1960), or "coaly member" of Srivastrava (1968), characterized by thick channel sandstones trending NW/SE, thin grey shale, bentonite and the Carbon/Thompson Coal Zones, also trending NW/SE. This unit has an overall coarsening-upward, more fluvial-upward trend (Nurkowski, 1980). Nurkowski and Rahmani (1984) defined a lower silty and non-coaly member deposited in sinuous mixed load channels, a middle very coaly member due to a dominance of high sinuosity suspended load channels, and an upper member dominated by very linear thick sandstone trends deposited in less sinuous, bed load-dominated fluvial channels due to an increase in channel gradient (?tectonic influence). The DMT to "fine-grained unit" to "coal-bearing unit" succession can be interpreted as the result of southeastward progradation of a marine-lacustrine-fluvial system of a broad, low-lying, meandering coastal plain on a Bearpaw shoreline (Nurkowski, 1980; Nurkowski and Rahmani, 1984).

The Whitemud Formation comprises distinctive white-weathering, light grey, kaolinite- and montmorillonite-rich sandstone with lesser siltstone and shale deposited in a fluvial setting on an extensive floodplain (Furnival, 1950; Campbell, 1962; Irish and Havard, 1968; Irish, 1970; Yurko, 1976; Gibson, 1977). The sandstone is fine to medium grained, arkosic, fining-upward, bentonitic and massive with trough and planar tabular crossbeds and minor pebble lenses (Furnival, 1950; Campbell, 1962; Irish, 1970; Binda and Lerbekmo, 1973; Gibson, 1977; Lerbekmo, 1985). Subordinate mudstone is green or grey, sandy, bentonitic and kaolinitic, with plant fragments, vertical burrows, parallel lamination and ripple cross lamination (Gibson, 1977; Lerbekmo, 1985). Three zones have been identified in Cypress Hills: 1) lower fining-upward, erosionally-based, crossbedded sandstone, with paleoflow to the north, east and south. 2) thin, brown to black, fissile carbonaceous shale with thin lignite seams, thin lenticular sandstone beds, a freshwater macroflora and deep tap roots. 3) upper thinly interbedded grey and mauve claystone with tap roots, which appears to represent interfingering with the overlying Battle Formation (Furnival, 1950; Campbell, 1962; Lerbekmo, 1985; Glass, 1990). These members are not distinctive in central Alberta (Glass, 1990). To the southeast, in Saskatchewan the Whitemud is represented only by thin white kaolinitic clay (Caldwell, 1968). Deposition occurred in slow-moving, low-energy channels on an extensive floodplain far from the sediment source, and the increase in volcanic detritus and decrease in sediment supply suggests subsidence was dominant (Binda and Lerbekmo, 1973; Gibson, 1977). The kaolinite-rich sediments are the product of intense chemical diagenesis and *in situ* kaolinitization (Furnival, 1950; Lerbekmo, 1985).

The overlying Battle Formation (or Blackmud Member of Srivastrava, 1968) is one of the most distinctive units in the stratigraphy and comprises purple to mauve weathering, greenish grey to dark brown to black, thin bedded, bentonitic silty mudstone with scattered sand grains and abundant organic matter (Srivastrava, 1968; Irish, 1970; Gibson, 1977; Glass, 1990). One to several distinctive hard, silicified, pale grey tuff beds occur near the top (Irish and Havard, 1968; Irish, 1970; Gibson, 1977). This thin, areally extensive unit was previously considered as the upper member of the Whitemud (Furnival, 1950). The Battle is predominantly decomposed ash, has no diagnostic fossils, but some mudcracks and a continental microflora and algae (Irish and Havard, 1968; Binda and Lerbekmo, 1973; Glass, 1990). In Cypress Hills Furnival (1950) defined a lower dark bentonitic shale member conformable with the Whitemud, and an upper member of thinly interbedded greenish sandstone, siltstone and shale with bentonite, and an erosional top. The Battle is highly siliceous and montmorillonitic, representing a volcanic maxim, but has no evidence of extensive kaolinitization like the Whitemud (Furnival, 1950). It represents very slow aggradation of airborne ash in extensive, calm, shallow lakes and swamps on a floodplain, due to a marked rise in water table (Irish and Havard, 1968; Binda and Lerbekmo, 1973; Lerbekmo, 1985).

The Kneehills Tuff(s) in the upper part is pale grey, hard, massive, uniform, siliceous and bentonitic claystone with opal/chalcedony-filled vugs (Allan and Sanderson, 1945; Srivastrava, 1968; Ritchie, 1960; Irish, 1970; Glass, 1990). There are fresh angular quartz and feldspar fragments, with some rounded zircon grains and some parallel lamination suggesting that the ash was windblown and deposited in fresh water with some detrital material (Allan and Sanderson, 1945; Ritchie, 1960; Gibson, 1977; Lerbekmo, 1985). The Tuff may be represented by several thin beds. It is nearly continuous over much of Alberta and is a very good time-stratigraphic marker (Allan and Sanderson, 1945; Ritchie, 1960; Irish, 1970; Lerbekmo, 1985). It is possible that major ashfalls occurred on a frequency of 100's to 1000's of years but were only preserved as individual beds in coal swamp and lake environments as in the Battle (Lerbekmo, 1985). The radiogenic age of the Kneehills Tuff is given as 66 Ma by Folinsbee *et al.* (1961).

Cypress Hills

In Cypress Hills the Horseshoe Canyon-equivalent is the Eastend Formation, the marine to nonmarine shoreline transitional unit from the underlying Bearpaw. It approximately correlates with the upper Horseshoe Canyon and is overlain by the Whitemud and Battle Formations (Russell and Landes, 1940; Furnival, 1950; Caldwell, 1968). The Eastend generally comprises yellow to buff to grey sandstone and coarse siltstone with a sparse marine molluscan fauna near the base and minor lignite/carbonaceous shale near the top (Russell and Landes, 1940; Furnival, 1950; Glass, 1990). Sandstones are fine to medium grained, coarsening-upward, silty, feldspathic, limonitic, with concretions, lenticular bedding and crossbeds (Russell and Landes, 1940; Furnival, 1950; Caldwell, 1968; Glass, 1990). Thin beds of grey to dark green siltstone are present, especially near the top (Furnival, 1950). Russell and Landes (1940) described a typical upward sequence of thick crossbedded sandstone, to thinly interbedded sandstone and siltstone, to massive sandstone, to thinly interbedded sandstone, mudstone and lignite, to buff-coloured siltstone. The Eastend generally becomes finer grained and dominated by siltstone to the east in southern Saskatchewan (Caldwell, 1968).

PETROGRAPHY

In the central and southern Foothills Mack and Jerzykiewicz (1989) identified Petrographic Stage II of the post-Wapiabi succession as representing the upper Brazeau/St. Mary River sequence. Compared to underlying sediments it is characterized by an increase in metamorphic rock fragments and a decrease in carbonate and chert sedimentary rock fragments, interpreted to represent a decline in the influence of the Rockies Thrust Belt sediment source and an increase in the influence of the Omineca Belt sediment source, plus significant volcanism. In the central Foothills the upper Brazeau has plagioclase plus volcanics=56-76%, polyquartz plus metamorphics=10-20%, monoquartz plus sedimentary=13-21%, indicating a major dominance of a volcanic sediment source, probably to the west in the now-eroded roof rocks of the Omineca Belt (Mack and Jerzykiewicz, 1989). In the southern Foothills the St. Mary River has plagioclase and volcanics =30%, polyquartz plus metamorphics =25%, monoquartz plus sedimentary =45%, suggesting more balance between input from the Omineca and the Rockies Belts (Mack and Jerzykiewicz, 1989). The Blood Reserve Formation is characterized by very quartzose medium sandstone with calcareous or argillaceous cement (Russell and Landes, 1940; Lerand, 1983; Glass, 1990). The overlying St. Mary River Formation has very calcareous fine to medium sandstone and silty shale (Russell and Landes, 1940; Glass, 1990).

In the Plains the Edmonton Group is generally composed of calcareous, argillaceous fine sandstone with no coarse grained material (Allan and Sanderson, 1945; Glass, 1990). Sandstones have fair to poor sorting, and are arkosic with 40-65% of fresh to angular grains of plagioclase, plus quartz and minor biotite/muscovite (and a few heavy minerals) set in a bentonitic clay matrix comprising up to 35% of the rock (Allan and Sanderson, 1945). Rahmani and Lerbekmo (1975) identified two heavy mineral provinces of zircon/apatite in the south, west and southeast, and garnet/apatite/sphene in the northeast. They related these to northwest-to-southeast transport from a positive source area in northern and central B.C. These authors also noted that the Edmonton has a distinct lack of hornblende, epidote, clinozoisite and plutonics and low metamorphic content, but is dominated by volcanic and sedimentary detritus, again through input from the Omineca and Rockies Belts. The lithic sandstones in the Horseshoe Canyon are typically very fine to medium grained, graded, argillaceous and feldspathic, and dominated by sedimentary rock fragments, quartz, chert, plagioclase and K-feldspar with cements of montmorillonite, kaolinite, illite and calcite (Irish, 1970; Gibson, 1977). There is a striking bimodality of grain size (sandstone vs. clay) but some of the argillaceous material results from diagenesis and, in fact, secondary calcite replaces much of the clay and shale rock fragments (Shepheard and Hills, 1970). In southeastern Alberta the equivalent Eastend Formation comprises fine to medium grained, feldspathic, argillaceous sandstone dominated by volcanic lithic fragments (Furnival, 1950; Glass, 1990).

Overlying the Horseshoe Canyon Formation, the Whitemud/Battle Formations, or Kneehills Tuff Zone, have received some attention because of their unusual lithologies. The very fine to coarse grained (generally fine to medium) sandstones of the Whitemud are feldspathic, arkosic, kaolinitic and bentonitic (Glass, 1990; Gibson, 1977). Grains are subround-subangular, with mono-and polyquartz = 25-60%, feldspars = 5-20%, rock fragments = 30-60%, whereas fines range 4-43%, average 22%, mostly montmorillonite and kaolinite (Binda and Lerbekmo, 1973; Gibson, 1977). The kaolinite is derived from intense *in situ* chemical diagenesis of the feldspar-rich sediments (Binda and Lerbekmo, 1973; Lerbekmo, 1985). The Battle Formation dark, bentonitic mudstones are mostly montmorillonite (decomposed volcanic ash, Irish and Havard, 1968), with minor kaolinite, illite, chlorite and abundant organic matter (Gibson, 1977; Lerbekmo, 1985). Up to 10% of the rock is sandstone and siltstone grains of quartz, feldspar, chert and euhedral zircon with accessory heavy minerals (Gibson, 1977; Glass, 1990). Within the Battle , commonly near the top, are one to several ashfall beds, known as the Kneehills Tuff (Ritchie, 1960). It is composed mainly of angular fresh quartz, feldspar and glassy volcanic shards set in an isotropic groundmass of opaline silica and montmorillonitic clay (Ritchie, 1960; Gibson, 1977; Nurkowski, 1980; Glass, 1990). The overall composition is greater than 90% silica (Ritchie, 1960).

PALEOCURRENTS

There is a paucity of paleocurrent data for the Edmonton Group, except in a few specific areas where modern sedimentological studies have been conducted. The underlying Bearpaw shale is thickest to the east and south, and thins and pinches out to the north and west near Edmonton, although it also apparently flooded the area north of Peace River Arch (Caldwell, 1968; Stelck *et al.*, 1976). When it withdrew, it did so toward the south and southeast (Rahmani and Schmidt, 1975). The lower Horseshoe Canyon in the Drumheller area has been intensively studied several times in the past 30 years. Shepheard and Hills (1970) suggested that the shorelines were oriented N/S and sediment was supplied from west to east. From heavy mineral analysis Rahmani and Lerbekmo (1975) concluded that sediment dispersal proceeded from the northern and central B.C. area to the east or southeast in central Alberta. Rahmani (1983) provided the most comprehensive treatment of the Bearpaw/Horseshoe Canyon transition in this area and described the following paleocurrent relations. Most channel-related sedimentary structures indicate flow to the southeast or south-southeast (although some near the base have northeastward flow), interpreted to represent shorelines with a west-southwest/east-northeast trend. Open sea was to the southeast, backbarrier areas were to the northwest and successive progradations extended further to the southeast through time. Hamblin (1998) presented a detailed measured section and paleocurrent data from the Little Bow River illustrating that the Bearpaw/Horseshoe Canyon transition was typified by southeastward transport, but overlying and intertonguing St. Mary River facies underwent northeastward transport. In the upper Horseshoe Canyon, sandstone channel units trend northwest/southeast, in a paleodrainage system with flow from the northwest (Nurkowski, 1980; Nurkowski and Rahmani, 1984), complementing the conclusions of Rahmani (1983).

The comparable marine-nonmarine transition in the southern Foothills is represented by the Bearpaw-Blood Reserve-St. Mary River transition. Lerand (1983) suggested the Blood Reserve shoreline was oriented NE/SW with offshore to the southeast, as at Drumheller. In the same area a more detailed study by Nadon (1988) delineated a much more complex setting with tidal channels in the Blood Reserve flowing to the northeast while overlying St. Mary River fluvial channels flowed north or northeast, suggesting a totally different depositional system from that of the Horseshoe Canyon. Nadon (1988) delineated sources of Bearpaw-age sandstone to the north, west and south of a deeply subsiding marine trough trending east-west, centred on Twp 4, as the main control on sedimentation in the area.

In the central and northern Foothills, Jerzykiewicz and Labonte (1991) have summarized their paleocurrent data for the entire post-Colorado succession, including 146 readings from the St. Mary River/upper Brazeau sequence, mostly of trough crossbedding from fluvial channels. These indicate a diverse paleodrainage pattern but most give paleoflow to the southeast quadrant, ie. parallel to the inferred early Maastrichtian deformational front. Some actually define flow components to the southwest, suggesting the drainage area extended much farther west than the present edge of the deformed belt, and the authors caution that paleoflow directions may have been different in the Plains beyond their study area (Jerzykiewicz and Labonte, 1991).

HYDROCARBON POTENTIAL

General

The Edmonton Group contains a small share of the gas reserves of the post-Colorado strata in a small number of pools in the west-central Alberta Plains. These reside primarily in sandstones of the lower, shoreline-related facies and in sandstone channels of the middle-upper, fluvial-related facies (Fig. 5). The group is predicted to include a very modest proportion of the total gas resource to be found distributed through a large number of small, shallow pools (Hamblin and Lee, 1997). However, this clastic wedge, the intertonguing Bearpaw Formation to the south and east, and the correlative St. Mary River Formation to the south, are not as well understood as the underlying Belly River

Group, and further study may elucidate additional possibilities. The following play descriptions are summarized from the work of Hamblin and Lee (1997).

Lower Horseshoe Canyon Formation, Shoreline

This established, mature play includes gas-bearing pools and prospects in nearshore-shoreline sandstones of the lower Edmonton Group, including those related sandy tongues which extend basinward into the marine Bearpaw. It includes a large area in west-central and northwestern Alberta. This play area is defined on the west and southwest by the limit of deformation, and on the east and north by the outcrop belt of the unit. The lower portion (lower Horseshoe Canyon/Blood Reserve/Eastend) includes a series of sandy tongues which extend basinward into the Bearpaw. These are lower delta plain/estuary/shoreline complexes related to an embayed shoreline, oriented WSW/ENE, with open sea to the southeast (Gibson, 1977; Rahmani, 1983).

Lower Horseshoe Canyon shoreline deposits are present in the subsurface from about Twps 5 to 55, Rge 15W4 to the disturbed belt in the west (Fig. 6). Minor gas reserves are contained in a small number of small pools. The overlying nonmarine fine grained deposits and the thin marine shale tongues which separate the shoreline-related sandstone tongues are the vertical seal for the pools, and updip to the east or southeast, the pinchout of clean sandstone may also create stratigraphic traps. The source of hydrocarbons may be the underlying Bearpaw Formation marine shales, or the adjacent nonmarine, coal-bearing strata.

The initial discovery well was drilled in Sylvan Lake Field in 1960. Discovered gas pools are concentrated in the Leo, Bashaw and Pembina fields. The largest discovered pool (Bashaw, Edmonton pool No. 1) has initial in-place volume of 862 x 10^6m^3. The mean pool area is 1146 ha, mean net pay is 3.3 m, mean porosity is 23.8%, and mean pool depth is 446 m. There have been a total of 18 pools discovered in this play (Fig. 6) and the total discovered in-place volume is 1 237 x 10^6m^3, with a mean in-place pool size of 72 x 10^6m^3.

Estimates of the expected potential for this play (Fig. 6) indicate an in-place volume of 9 714 x 10^6m^3 representing approximately 89 % of the total play resource, assuming a total population of 580 pools, with an in-place volume for the largest undiscovered pool of 324 x 10^6m^3 (Hamblin and Lee, 1997). The potential gas resources in this play will likely be found in small pools located in west-central Alberta.

Middle-Upper Horseshoe Canyon Formation, Fluvial

This established, mature play includes gas-bearing pools and prospects in fluvial channel sandstones of the middle and upper Edmonton Group. It includes a large area in west-central Alberta. This play area is defined on the west and southwest by the limit of deformation, and on the east and north by the outcrop belt of the unit. Most of the Horseshoe Canyon Formation of central Alberta, and the St. Mary River Formation in southwestern Alberta, include upper delta plain interbedded thick fluvial channel sandstones and overbank mudstones with thick coals deposited behind the shoreline complexes of the lower portion of the Edmonton clastic wedge (Gibson, 1977). Throughout much of southern Alberta these deposits are blanketed by the argillaceous sandstone of the Whitemud Formation and the bentonitic mudstone of the Battle Formation (Irish, 1970).

Middle and Upper Horseshoe Canyon fluvial deposits are present in the subsurface beneath all of western Alberta, from about Twps 5-60, Rge 23W4 to the disturbed belt in the west (Fig. 7).

Minor gas reserves are contained within a few small pools. The overlying and interbedded nonmarine fine grained deposits within the Horseshoe Canyon and Battle formations are the vertical seal for the pools in fluvial channels which create stratigraphic traps. The source of hydrocarbons may be the underlying Bearpaw Formation marine shales, or the interbedded nonmarine, coal-bearing strata.

The initial discovery well was drilled in the Bigoray Field in 1958. Discovered gas pools are scattered through central Alberta. The largest discovered pool (Pembina, Edm) has initial in-place volume of 128 x $10^6 m^3$. The mean pool area is 203 ha, mean net pay is 5.5 m, mean porosity is 24.8%, and mean pool depth is 525 m. There have been a total of 17 pools discovered in this play (Fig. 7) and the total discovered in-place volume is 532 x $10^6 m^3$, with a mean in-place pool size of 31 x $10^6 m^3$.

Estimates of the expected potential for this play (Fig. 7) indicate an in-place volume of 5 834 x $10^6 m^3$, representing approximately 92 % of the total play resource, assuming a total population of 600 pools, with an in-place volume for the largest undiscovered pool of 335 x $10^6 m^3$ (Hamblin and Lee, 1997). The potential gas resources in this play will likely be found in small pools situated in the Plains of west-central Alberta.

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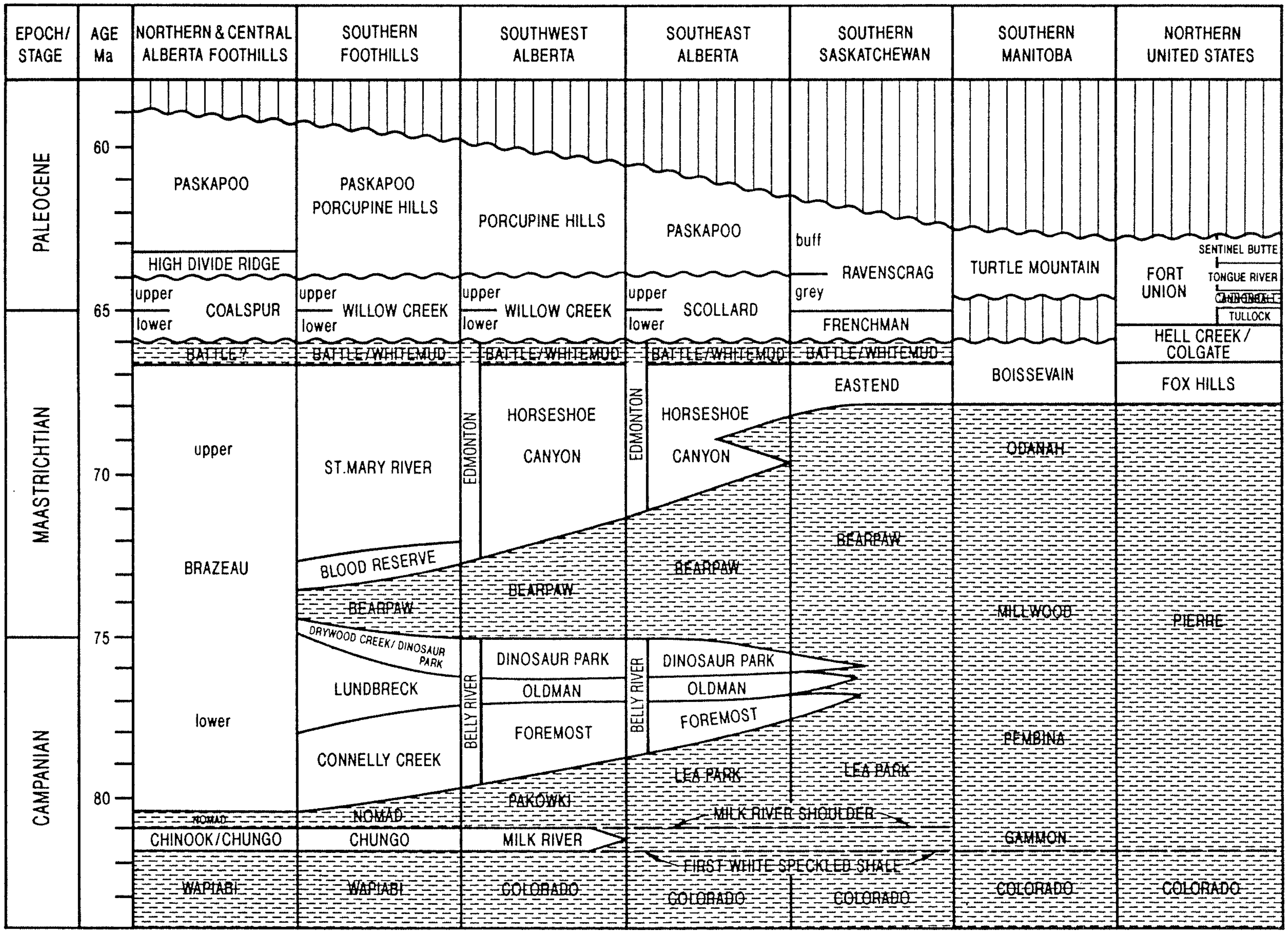
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NORTHERN & CENTRAL ALBERTA FOOTHILLS
SOUTHERN FOOTHILLS
SOUTHWEST ALBERTA
SOUTHEAST ALBERTA
SOUTHERN SASKATCHEWAN
SOUTHERN MANITOBA
NORTHERN UNITED STATES
PALEOCENE
MAASTRICHTIAN
CAMPANIAN
60
65
70
75
80
PASKAPOO
HIGH DIVIDE RIDGE
upper
lower
COALSPUR
BATTLE ?
upper
BRAZEAU
lower
NOMAD
CHINOOK/CHUNGO
WAPIABI
PASKAPOO
PORCUPINE HILLS
WILLOW CREEK
BATTLE/WHITEMUD
ST.MARY RIVER
BLOOD RESERVE
BEARPAW
DRYWOOD CREEK/ DINOSAUR PARK
LUNDBRECK
CONNELLY CREEK
CHUNGO
PORCUPINE HILLS
EDMONTON
HORSESHOE
CANYON
DINOSAUR PARK
OLDMAN
FOREMOST
BELLY RIVER
PAKOWKI
MILK RIVER
COLORADO
SCOLLARD
LEA PARK
MILK RIVER SHOULDER
FIRST WHITE SPECKLED SHALE
buff
RAVENSCRAG
grey
FRENCHMAN
EASTEND
TURTLE MOUNTAIN
BOISSEVAIN
ODANAH
MILLWOOD
PEMBINA
GAMMON
FORT UNION
SENTINEL BUTTE
TONGUE RIVER
TULLOCK
HELL CREEK / COLGATE
FOX HILLS
PIERRE

FIGURE 1

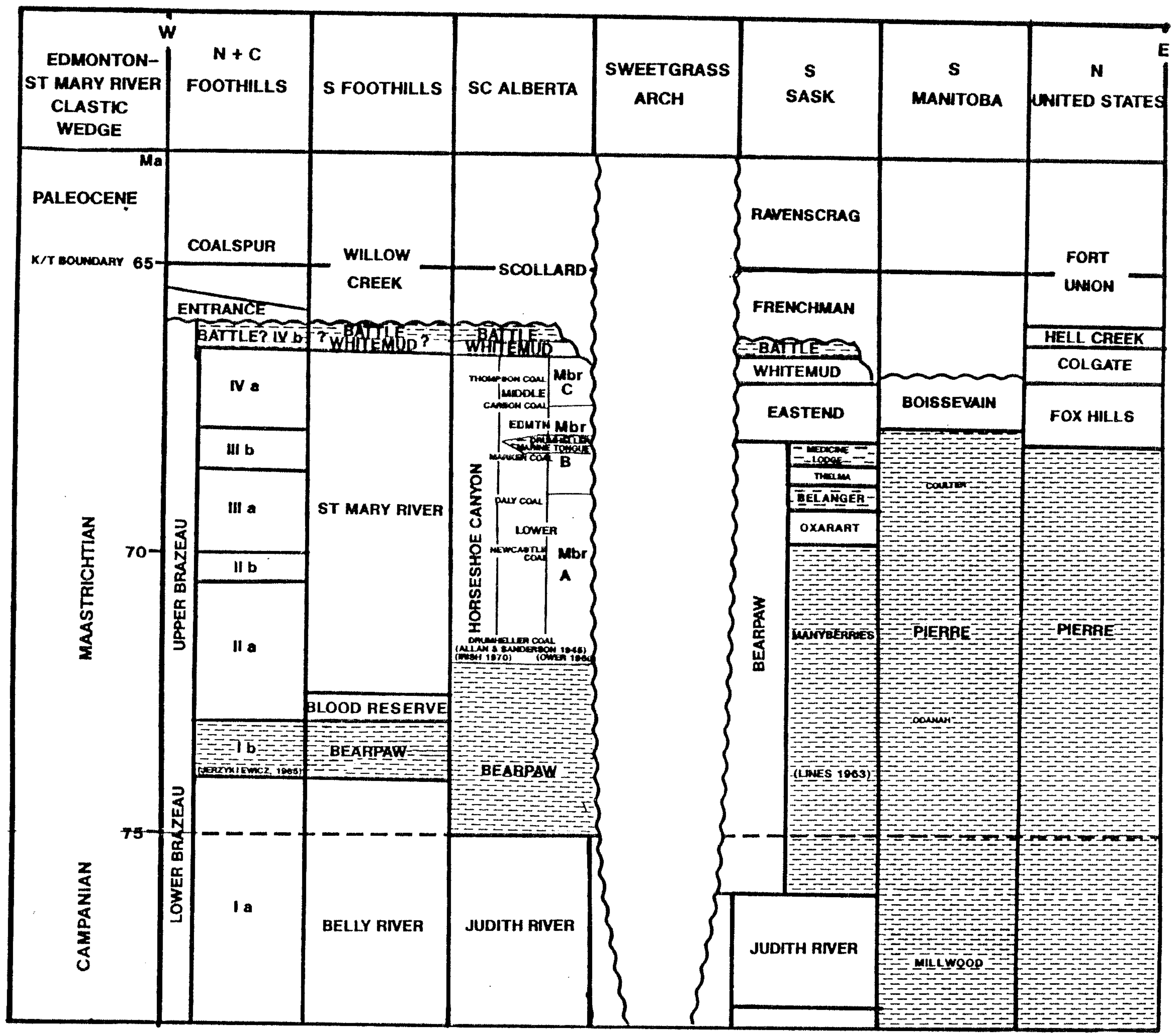

W
E
EDMONTON–ST MARY RIVER CLASTIC WEDGE
N + C FOOTHILLS
S FOOTHILLS
SC ALBERTA
SWEETGRASS ARCH
S SASK
S MANITOBA
N UNITED STATES
Ma
PALEOCENE
K/T BOUNDARY
65
70
75
MAASTRICHTIAN
CAMPANIAN
UPPER BRAZEAU
LOWER BRAZEAU
COALSPUR
ENTRANCE
BATTLE? IV b
IV a
III b
III a
II b
II a
I b
(JERZYKIEWICZ, 1985)
I a
WILLOW CREEK
? BATTLE ? WHITEMUD ?
ST MARY RIVER
BLOOD RESERVE
BEARPAW
BELLY RIVER
SCOLLARD
BATTLE
WHITEMUD
THOMPSON COAL
MIDDLE
CARBON COAL
Mbr C
EDMTN
Mbr B
MARINE TONGUE
MARKER COAL
DALY COAL
LOWER
NEWCASTLE COAL
Mbr A
HORSESHOE CANYON
DRUMHELLER COAL
(ALLAN & SANDERSON 1945)
(IRISH 1970)
JUDITH RIVER
RAVENSCRAG
FRENCHMAN
EASTEND
MEDICINE LODGE
THELMA
BELANGER
OXARART
MANYBERRIES
(LINES 1963)
BOISSEVAIN
COULTER
ODANAH
MILLWOOD
PIERRE
FORT UNION
HELL CREEK
COLGATE
FOX HILLS

FIGURE 2

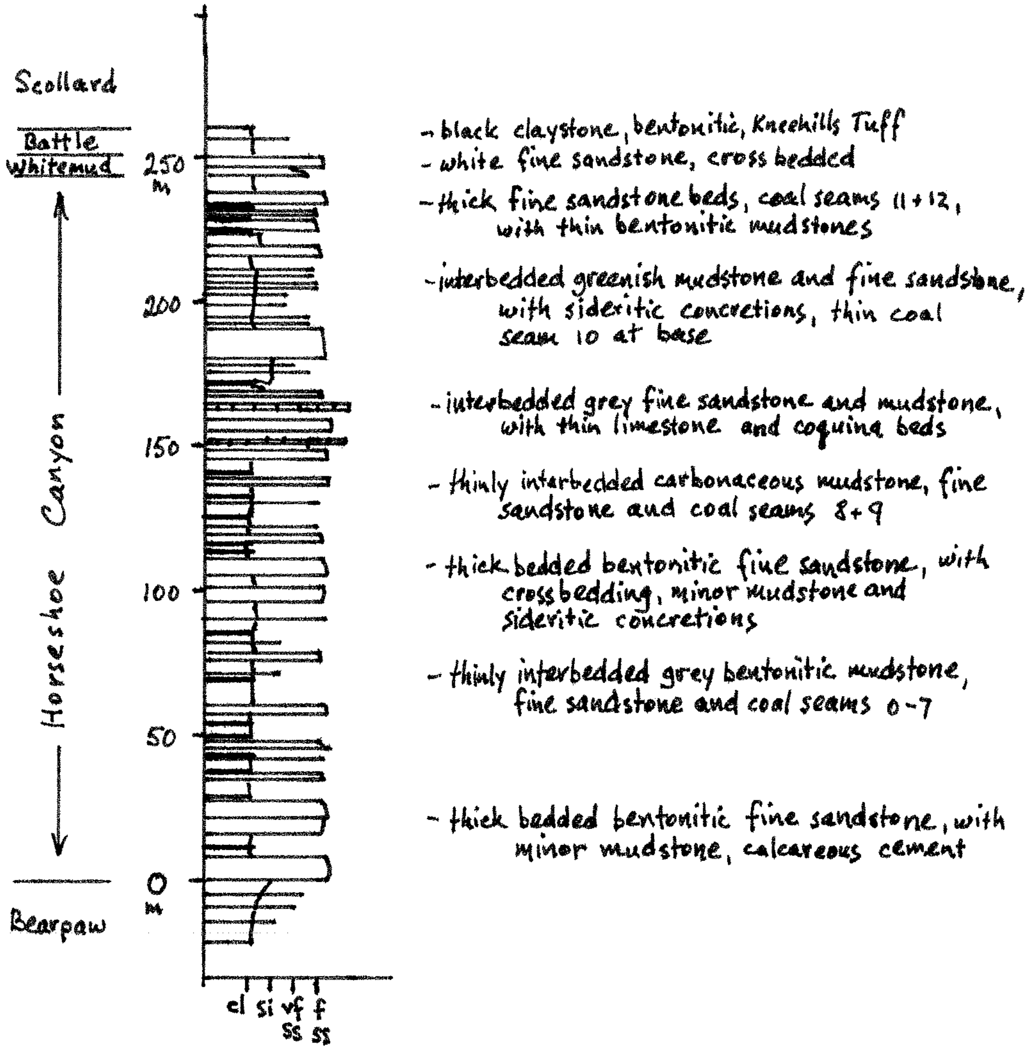
Allan and Sanderson (1945) (outcrops, Red Deer River)	Ower (1960) (outcrops, Red Deer River)	Srivastrava (1968) (outcrops, Red Deer River)	Irish (1970) (outcrops, Red Deer River)	Gibson (1977) (outcrops, Red Deer River)	Nurkowski (1980) (subsurface, central Alberta)	McCabe et. al. (1986) (subsurface, central Alberta)
Upper Edmonton	Member E	Nevis Member Mammal Member	Scollard Formation	Scollard Member	Scollard Formation	
Kneehills Tuff Zone	Member D	Blackmud Mbr.	Battle Fm.	Battle Mbr.	Battle Fm.	Battle Fm.
		Whitemud Mbr.	Whitemud Fm.	Whitemud Mbr.	Horseshoe Canyon Formation: Thompson Coal Zone	Horseshoe Canyon Formation: Carbon-Thompson Coal Zone
Middle Edmonton	Member C	Coaly Member	Horseshoe Canyon Formation	Horseshoe Canyon Formation: seam 12 seam 11	Carbon Coal Zone	
	Member B	Tolman Member		green siltstone unit seam 10	upper fine unit lower fine unit	Upper Horseshoe Canyon Weaver Coal Zone
Drumheller Marine Tongue		Drumheller Member		Drumheller Marine Tongue	Drumheller Marine Tongue	
Lower Edmonton		Non-Coaly Member		seam 9 seam 8		Lower Horseshoe Canyon
	Member A	Coaly Member		seam 7 seam 6 seam 5 seam 4 seam 3 seam 2 seam 1		
		Transition Member		seam 0		

FIGURE 3

Horseshoe Canyon Formation

Composite Type Section (Irish, 1970)

Red Deer River Valley between
T. 28 R. 18 W4 and T. 34 R. 21 W4



drawn and summarized from information presented by Irish (1970)

FIGURE 4

TYPICAL GAMMA RAY - POROSITY LOG, EDMONTON GROUP
10 - 29 - 19 - 24W4

FARROW FIELD
EDMONTON UNDEFINED POOL

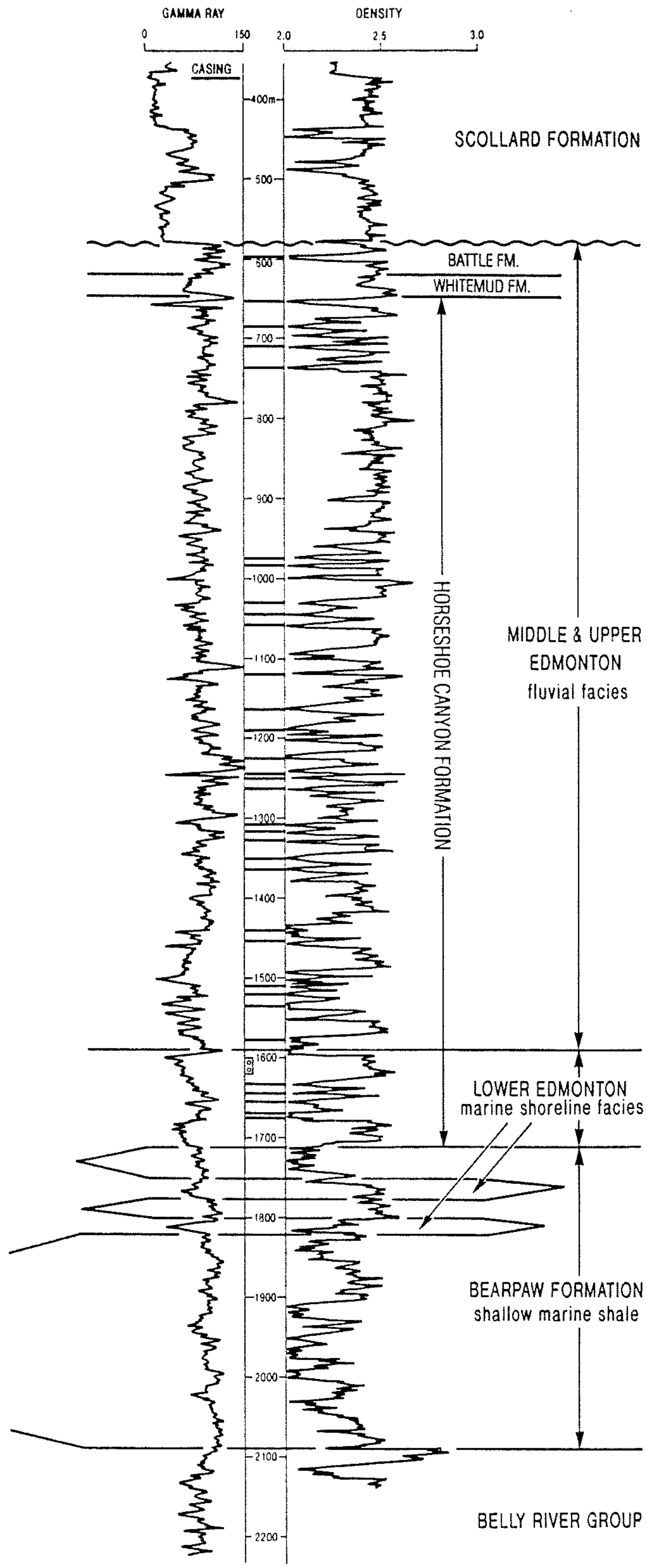
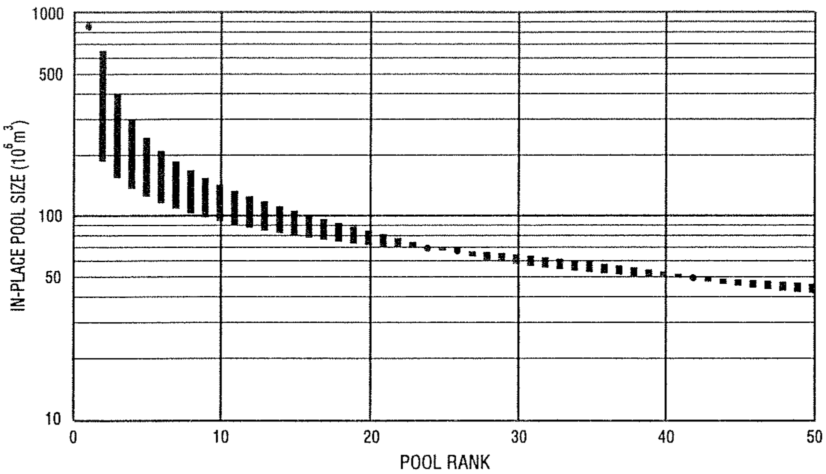


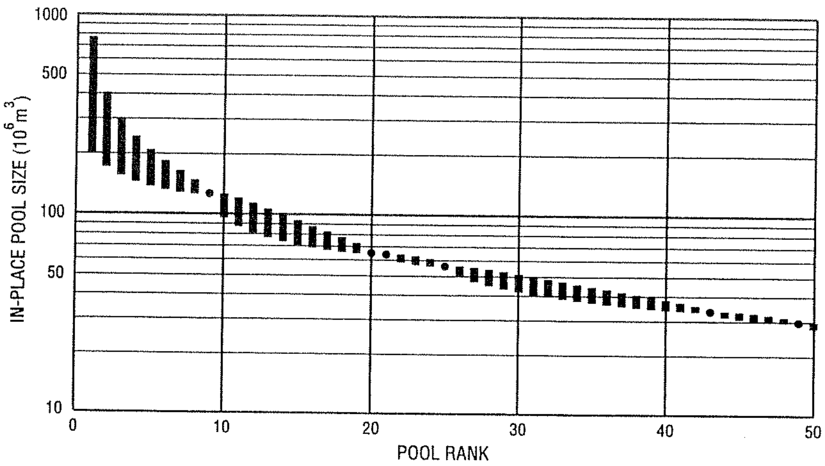
FIGURE 5



Pool rank	Field/Pool Name	Pool type	Discovered in-place volume (x 10^6 m^3)	Discovery date
1	Edmonton Pool No. 1	NA	862	79/10/26
24	Sylvan Lake, Edmonton	NA	70	60/12/01
26	Link, Edmonton B	NA	68	85/11/29
42	Pembina, Edmonton	NA	50	77/08/26
109	Pembina, Edmonton	NA	25	79/03/01
114	McLeon, Edmonton	NA	24	79/12/02
185	Michichi, Edmonton	NA	15	89/06/01
186	Pembina, Edmonton	NA	15	82/11/15
210	Fenn West, Edmonton	NA	13	89/10/06
211	Link, Edmonton A	NA	13	85/09/13
241	Michichi, Edmonton	NA	11	77/12/11
242	Michichi, Edmonton	NA	11	89/07/31
259	Farrow, Edmonton	NA	10	74/08/05
260	Leo, Edmonton	NA	10	79/12/07
280	Cessford, Edmonton A	NA	9	81/01/02
327	Coral, Edmonton	NA	7	78/03/05
426	Farrell, Edmonton	NA	4	84/08/25
Initial in-place volume (discovered) (10^6 m^3)			1 237	
Initial in-place volume (potential) (10^6 m^3)			9 714	
Per cent play resources undiscovered			89	
Total pools discovered			18	
Total pool population			580	

NA, nonassociated gas

FIGURE 6



Pool rank	Field/Pool Name	Pool type	Discovered in-place volume (x 10^6 m^3)	Discovery date
9	Pembina, Edmonton	NA	128	78/11/08
20	Bigoray, Paskapoo	NA	66	58/11/13
21	Ferrier, Edmonton	NA	65	85/10/13
25	Minnehik-Buck Lake, Edmonton	NA	57	78/01/22
43	Davey, Edmonton	NA	34	77/08/03
49	Pembina, Edmonton	NA	30	88/02/20
60	Ferrybank, Edmonton	NA	24	79/11/01
65	Chickadee, Edmonton	NA	22	80/04/23
71	Leaman, Edmonton	NA	20	77/08/27
73	Minnehik-Buck Lake, Edmonton	NA	19	79/12/28
74	Morkill, Edmonton	NA	19	77/01/01
86	Bigoray, Edmonton	NA	16	78/03/02
96	Ferrybank, Edmonton	NA	14	77/07/03
146	Pembina, Edmonton	NA	8	80/10/02
197	Morningside, Edmonton	NA	5	80/08/13
224	Bigoray, Paskapoo A	NA	4	71/05/28
397	Chickadee, Edmonton A	NA	1	80/10/02
Initial in-place volume (discovered) (10^6 m^3)			532	
Initial in-place volume (potential) (10^6 m^3)			5 834	
Per cent play resources undiscovered			92	
Total pools discovered			17	
Total pool population			600	

NA, nonassociated gas

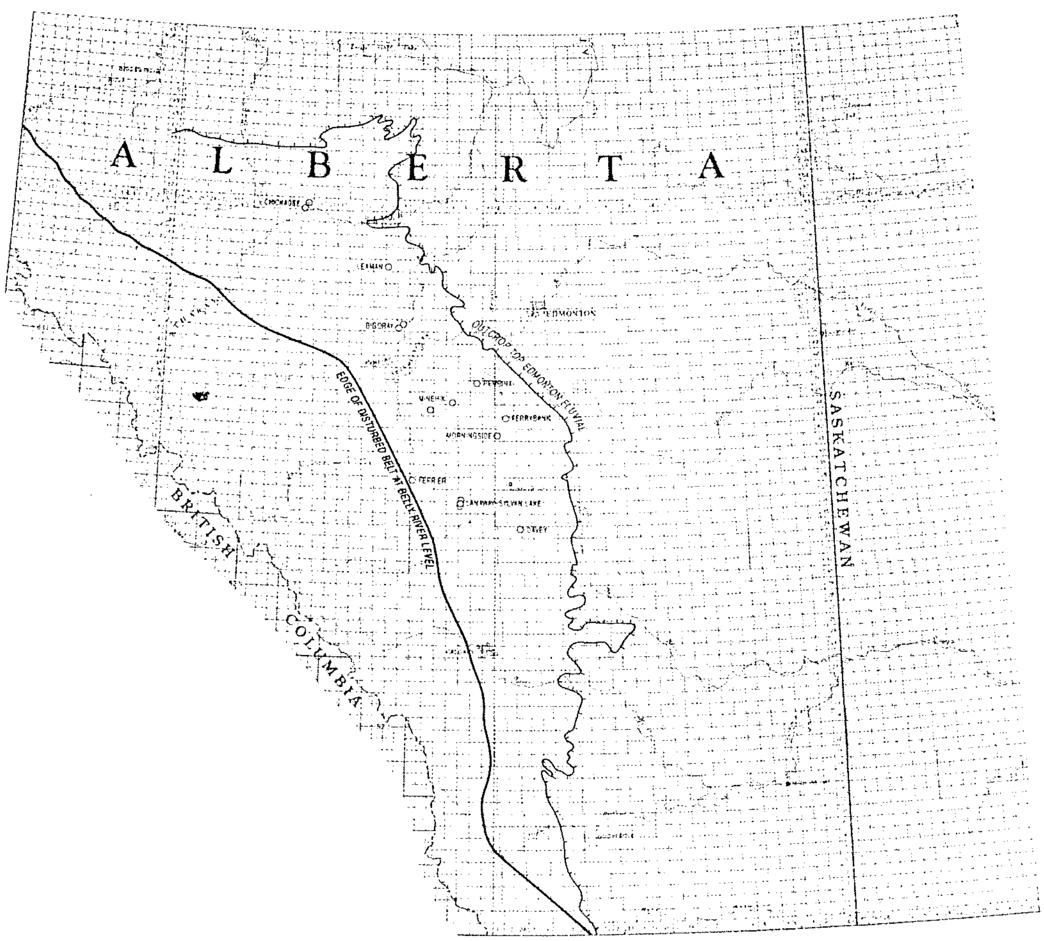


FIGURE 7