FIELD TRIP GUIDEBOOK

'SEDIMENTOLOGY OF THE UPPER CRETACEOUS JUDITH RIVER (BELLY RIVER) FORMATION, DINOSAUR PROVINCIAL PARK, ALBERTA'

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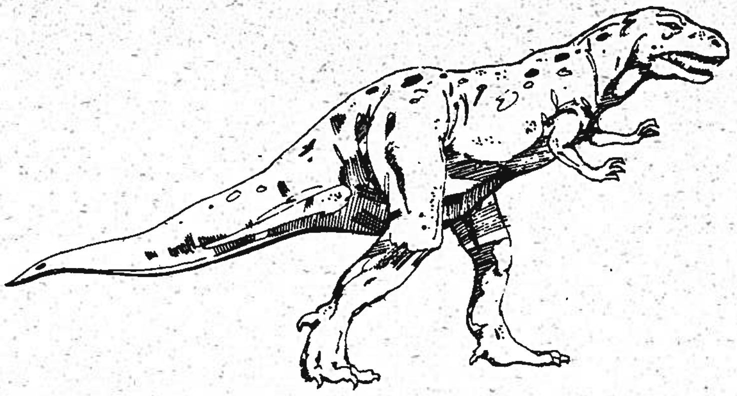
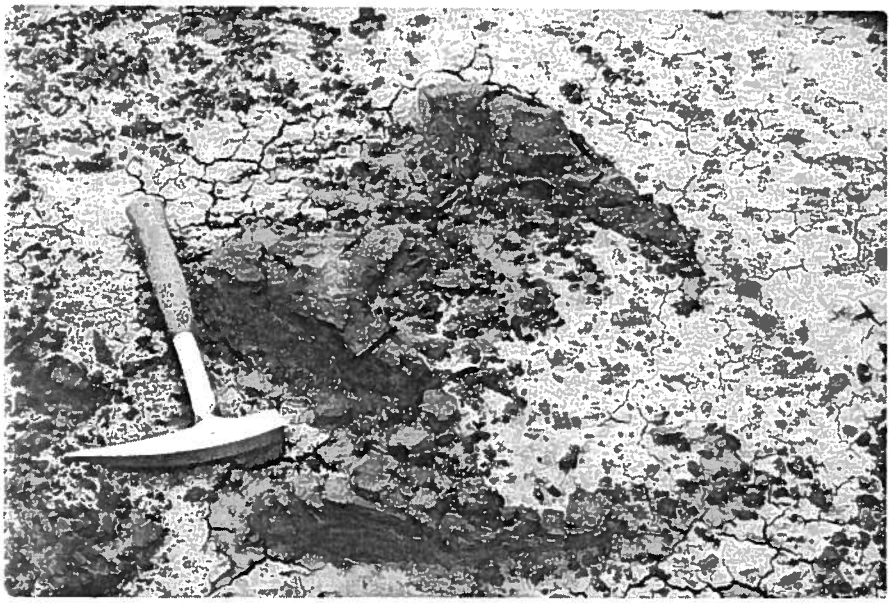
Alberta's World Heritage Site



"Dinosaur Provincial Park represents the most important remaining fragment of the dinosaurian world known to mankind."

Dr. Dale A. Russell, chief of the paleobiology division of the Canadian National Museum of Natural Sciences, Ottawa, in a written statement on the scientific significance of Dinosaur Provincial Park in southern Alberta.

A staff member of the Tyrrell Musem of Palaeontology and a volunteer doing excavation work in a dinosaur quarry.



The first dinosaur footprint found in the Park (Quarry No. 155), belonging to the Ichnogenus Amblydactylus. The print is about 60 cm in length and was left by a hadrosaur. Paleontologists consider that the rarity of footprints in the Judith River Formation is related to the unconsolidated nature of paleochannel sequences which tend to erode in vertical sections.

FOREWORD

The Park, which contains an unsurpassed amount of outcrop for any Plains' formation, has somehow evaded geological attention until very recently. Yet it holds promise of being a valuable new 'laboratory' for the evaluation of some current key sedimentological concepts. It is also logistically convenient for Calgary-based resource geologists - who will perhaps find the complexities of three-dimensional exposure a 'sobering thought' to interpretations that may otherwise emanate from one-dimensional core and/or geophysical log data from the same formation. Sedimentological fieldwork in the Park also contributes, particularly as the area is now designated a World Heritage Site by UNESCO, to improvements in its educational value to the thousands of summertime public visitors and the information base for future planning by Alberta Recreation and Parks. Another goal of current sedimentological field research is to attempt elucidation of the paleoenvironmental aspects that were ecologically suited to vertebrates: no other area (on a global scale) has produced such a diverse, abundant assemblage of dinosaurian remains.

Field excursions are typically run to areas where synthesis and interpretation of field data have reached a fairly advanced, or concluding stage. It is intended that by running a field excursion to the Park at this time, light will be shed on evolving interpretations and combinations of features which presently seem enigmatic. Participants are therefore encouraged to contribute their ideas to the discussions at outcrop and in other opportunities during the excursion.

I very much hope you find the weekend amidst paleochannels and dinosaurs to be a fascinating and stimulating one! Your interest and input are appreciated.

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1.0 PREFACE

The late Jurassic to Paleogene stratigraphic record of foreland molasse wedges intercalated with epeiric marine episodes, along the western interior of North America, has been the subject of an enormous amount of geologic attention over the last hundred years. Perhaps no other geologic province in the world has stimulated such a massive volume of interdisciplinary literature that is so well communicated across international borders (Caldwell, 1975).

An intensive search for hydrocarbons and regional surface/subsurface stratigraphic work occurred in the wake of early geologic mapping. This pre-1950 body of literature was followed by a growing series of site-specific studies. Sedimentological interest accelerated during the 1970's and particularly in the present decade, due partly to a rejuvenated interest in coal resources and further recovery of hydrocarbons. In turn, process-orientated field excursions have occurred with increasing frequency, and the associated research papers have reaped considerable benefits for the overall advance in knowledge of interdisciplinary sedimentology.

The Alberta segment of the Western Interior Seaway has certainly shared in the above-mentioned trends. However, one could argue that the field excursions run in conjunction with the AAPG/SEPM 1982 Calgary meeting, the 1982 IAS Congress in Hamilton, this CSPG Mesozoic Conference, as well as several other regional meetings over recent years, have all contributed to an enhanced profile for the current variety of detailed sedimentological and paleontological research being conducted in the plains and disturbed belt. Additionally, the field areas increasingly serve to integrate the interests of the Calgary resource industry with the work of universities and federal/provincial research agencies.

In actual fact, this recent body of work has been primarily concerned with transitional sequences between marine and coastal margin paleoenvironments within the foothills (Fernie/Kootenay, Wapiabi/Belly River, Bearpaw/St. Mary River). Alluvial processes apparently predominated during the accumulation of molasse wedges during regressive phases of the Seaway (Walker, 1982; Fig. 1). However, as Walker and Cant (1979; p. 31) pointed out:

> "....There is an astonishing absence in the Canadian literature of detailed interpretations of ancient sandy fluvial depositional environments ...... There are, of course, many examples described as fluvial, with some petrographic and paleocurrent information. However, none contains the necessary data on sedimentary structures and their sequence, integrated with paleoflow data in such a way that they contribute to sandy fluvial facies models...."

Notable initial steps to remedy this situation have been by Walker (1982) on the lowermost Belly River Formation at Ghost Dam, and by Waheed (1983) on the higher parts of the Horseshoe Canyon Formation exposed around Drumheller. Also, a good understanding of the anastomosed channel type has emerged in recent years using several modern and ancient Canadian examples (Smith and Putnam, 1980).

Rahmani's work (Walker, 1982; p. 31-60) on the lowermost Horseshoe Canyon Formation at Drumheller has triggered an awareness of tides as an Interior Seaway process. Given the extensive, gently-sloping nature of bordering coastal plains, his conclusions serve to remind researchers working on the main 'internal' parts of clastic wedges in the plains of the likelihood that paleodrainage courses became estuarine below high tide limits located quite far inland. Presently unknown for Judith River time is the abundance and length of any intertidal inlet channels without river connection.

The 1980's is an exciting, vital period for work on fluvial sequences. The First International Fluvial Conference in Calgary, 1977 (Miall, 1978) was characterized by presentations on a limited number of broadly applicable facies models. Its successor in 1981 at Keele, England (Collinson and Lewin, 1983) witnessed a general realisation that a 'cookbook' style of interpretation in fluvial sequences was intractable.

The locally excellent exposures of molasse units in the badlands of the plains and in outcrops of the disturbed belt provide valuable opportunities to advance the degree and quality of knowledge in fluvial sedimentology. This excursion to Dinosaur Provincial Park, with its unsurpassed circumstances for detailed sedimentological research in western Canada, will hopefully demonstrate one example of how sedimentology may be profitably linked with resource evaluation and dinosaur taphonomy.

2.0 DINOSAUR PROVINCIAL PARK

2.1 Introduction

The term 'badlands' was first used in North America by early French trappers who described the semi-arid, rocky terrain along the White River in what is now South Dakota as the 'mauvaises terres' (Beaty, 1975a). Traditionally, the Drumheller area is Alberta's best known area of badlands because the town is a popular tourist stop on the major route linking Saskatoon on the Yellowhead Trail with Calgary and the TransCanada Highway. As the Red Deer River flows south-eastward from Drumheller perpendicular to the strike of the Alberta syncline, it descends stratigraphically from the Horseshoe Canyon Formation through the Bearpaw Formation into the Judith River Formation of Campanian age. Along the Red Deer River, 40 km northeast of Brooks, an oil and agricultural supply town on the TransCanada Highway 186 km east from Calgary, lies Dinosaur Provincial Park (Fig. 1). Located in the heart of the largest and most impressive expanse of badlands, exposures in the Park are distributed along a 23 km reach of the river, locally extending up to 5 km away from the banks, for a total area of approximately 96 km^2 (Fig. 2).

The extensive, and often three-dimensional exposures of upper Judith River (Campanian) strata in the Park are unsurpassed in terms of quantity and good preservation of a diverse vertebrate fossil assemblage. In recognition of its outstanding scientific value, the United Nations' Educational, Scientific and Cultural Organization (UNESCO) declared these badlands as a World Heritage Site in 1979. With this new status, the Park boundary underwent slight changes to exclude privately owned lands. Alberta Recreation and Parks is responsible for the management, protection and interpretation of resources within the Park (originally established as a Provincial Park in 1956), but works cooperatively with staff at the Tyrrell Museum of Palaeontology at Drumheller (formerly part of the Provincial Museum in Edmonton) who excavate and study the dinosaurian and other fossil remains.

In recent years, taphonomy (by P. Dodson of University of Pennsylvania) has become an important new aspect of paleontological research in the Park (coordinated by P.J. Currie). That is, to deduce the sedimentological and ecological conditions surrounding animal death and preservation has become an addition to the taxonomic work, anatomical studies and display mounting that characterised the endeavour of previous decades. It was in the context of this new thrust of paleontological research that the Alberta Geological Survey was invited by the Provincial Museum in December 1980 to examine the stratigraphy and sedimentology of the Upper Cretaceous sequence in the Park. Since this kind of study would complement the ongoing research program of the Alberta Geological Survey to identify and interpret Alberta's shallow coal resources in the Plains' region (under contract from the Department of Energy and Natural Resources), the invitation was accepted. The most logical place to start investigation of this coal-bearing formation within the study area, which extends from the U.S. border north to Township 25, and the Saskatchewan border west to Range 25, west of the 4th meridan, was the extensive fine outcrop in Dinosaur Provincial Park (Figs. 1 and 2).

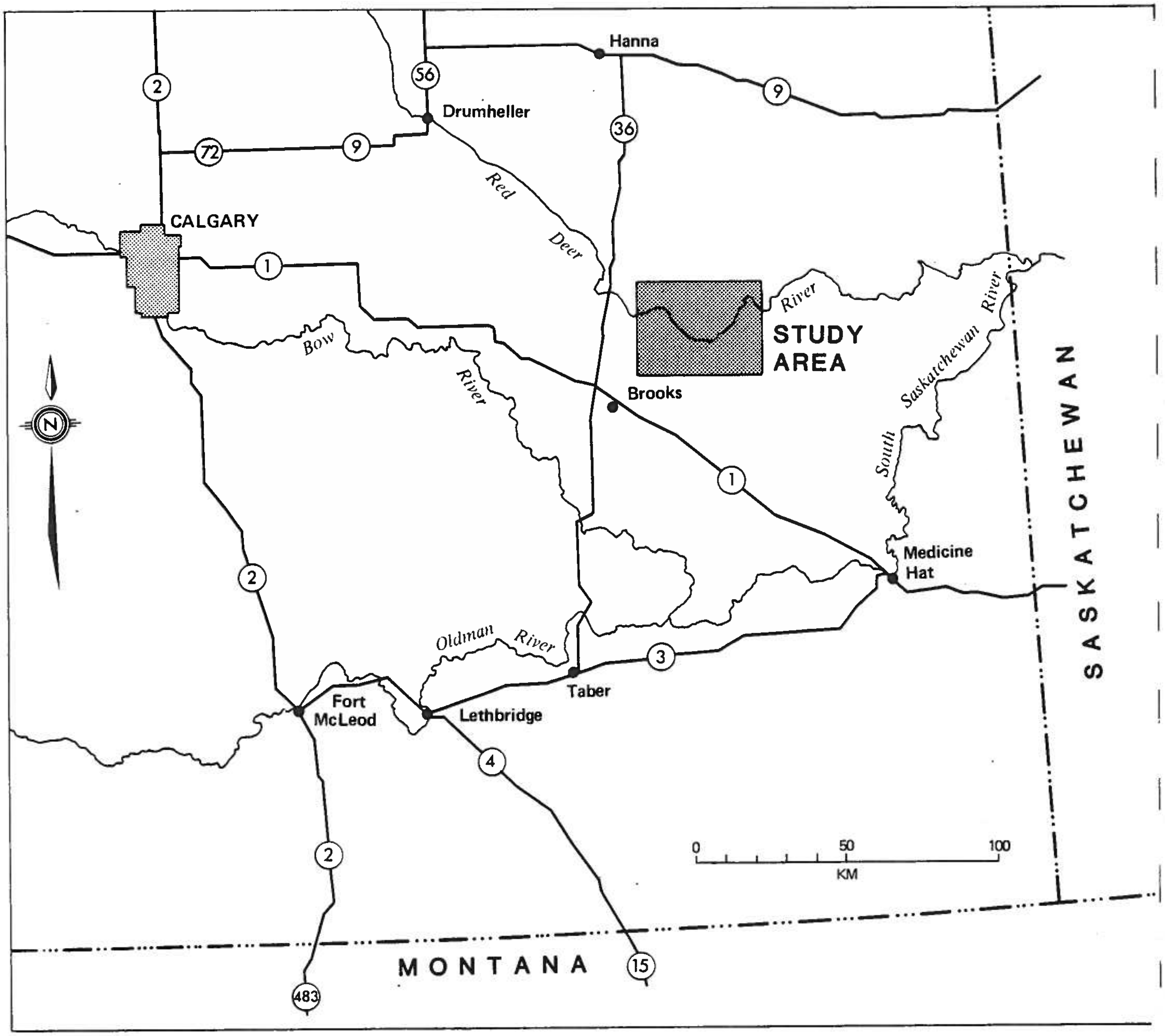


Figure 1. The south-eastern corner of Alberta showing highway access routes. Details of the study area are shown in Figure 2.

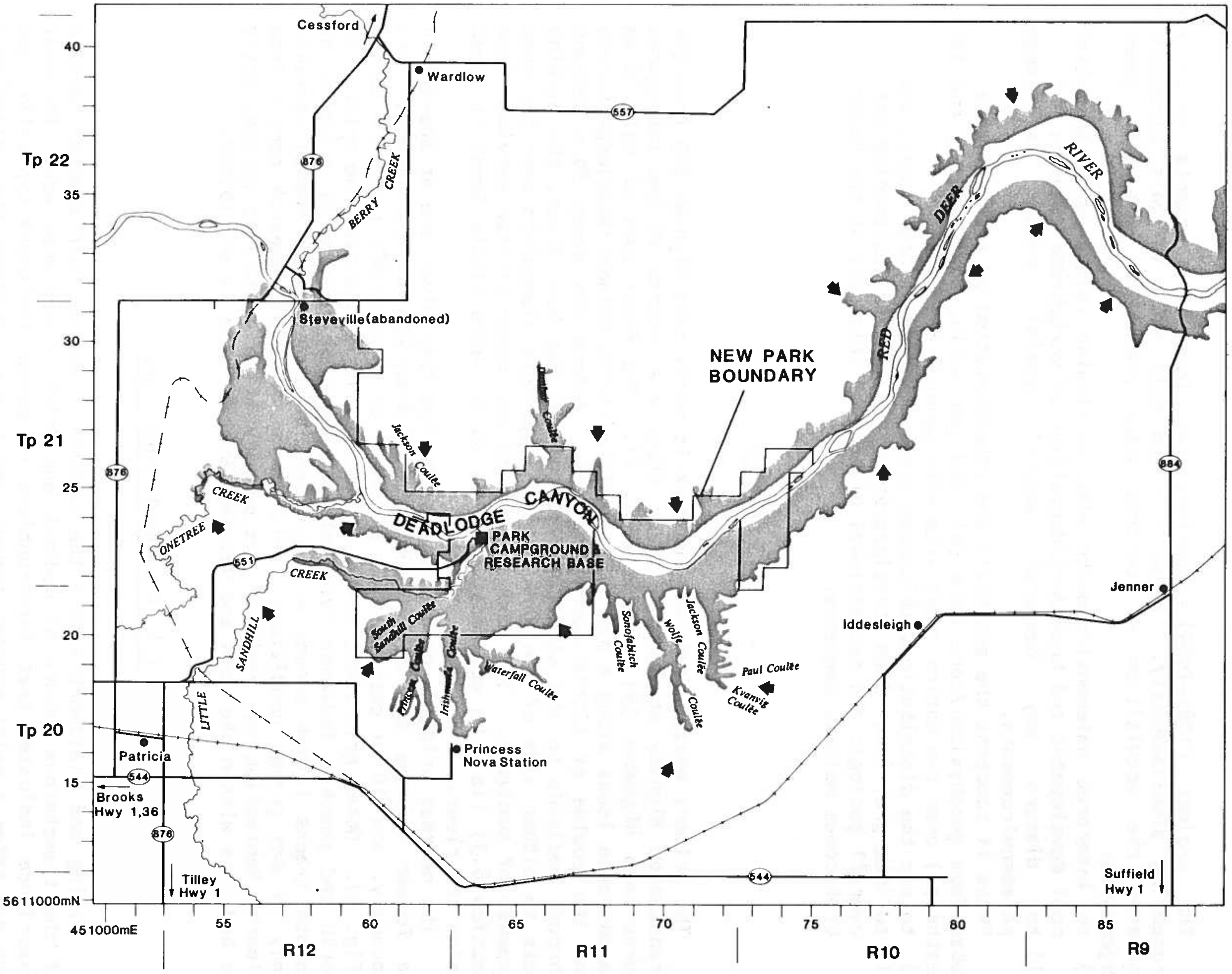


Figure 2. A detailed map of the study area showing local access and the extent of the badlands (shaded). Arrows indicate access points by unpaved tracks to the prairie edge. Capitalized coulee names are those which appear on NTS map sheets; those in lower case are names

2.2 Overall Project Objectives

The project (1981-1985) comprises two integrated aspects which are proceeding simultaneously. Phase I - the main topic of this guidebook - concerns the acquisition of outcrop data from the Park with general objectives:

i) to interpret paleoenvironments with particular reference on potential coal development and transport/deposition of vertebrate remains; and

ii) to discern any temporal and/or spatial trends in these paleoenvironments.

Phase II concerns the synthesis and interpretation of all available subsurface geophysical/core data (oil and gas wells, coal company and ARC testholes) over the entire study area with general objectives:

i) to map the distribution, thickness and continuity of coal seams; and

ii) to interpret inter-seam stratigraphy with a view to deciphering the overall geologic and depositional history of this part of the Upper Cretaceous molasse sequence.

2.3 Access

The primary access route to the Park is north onto Highway 873 from the TransCanada Highway at Brooks. Park signs are located at the subsequent turns onto Highways 554 and 551 (Fig. 2). The final part of this 48 km paved route leads along a narrowing prairie divide between Deadlodge Canyon and the coulee of Little Sandhill Creek. Before the steep 80 m descent through badlands to the alluvial flats of the Red Deer River, the parking lots to either side of the Park gate are splendid viewpoints over the huge expanse of badlands. The Park campground and other visitor services (see Section 8.3) lie 1 km northeast of this point where Little Sandhill Creek joins the river.

The nearest bridging points across the Red Deer River are at Steveville (a former village and ferry point) on Highway 876 at the western Park boundary, and 30 km east outside the Park on Highway 884 north of Jenner (Fig. 2). Other grid roads serve to enclose the Park across the prairie to north and south. Badlands lying elsewhere can be reached by a number of remote tracks (ranch access or petroleum industry service roads) passable only in dry ground conditions. Without an official research permit from Alberta Recreation and Parks or the company of an authorized person, entry to badlands within the Park and Natural Reserve Areas is prohibited.

2.4 Fieldwork Conditions

Hiking and fieldwork within the badlands requires fair weather because of the treacherous nature of bedrock and drift slopes when wet. Personal experience indicates that interruptions to summer fieldwork typically last one day after a brief thunder shower, and as much as three days following a prolonged frontal rain. Storm runoff is fairly immediate, but the rate at which bedrock surfaces dry to allow sufficient traction depends largely on precipitation being followed by windy, sunny weather. Colour contrasts in stratigraphic sections are inverted in wet weather, and trenching and sampling operations are impractical on damp slopes. Suitable conditions for fieldwork are when successive lithofacies are outlined by sharp colour contrasts. However, heavy rain has two desirable repercussions from the sedimentological standpoint. Firstly, sandstone slopes are commonly stripped of their thin weathering rind to reveal faint signs of sedimentary structures, that otherwise are discernible only in differentially-weathered concretionary horizons. Secondly, pediments become veneered with new sediment and thus provide potential new collecting ground for vertebrate fossil fragments.

Annual precipitation averages 32.5 cm, and almost 4 cm typically falls in July amidst the wetter period which lasts from May until September. July is also, on average, the hottest month. Although the monthly average is 19°C, daytime maximum shade temperatures commonly exceed 30°C . Since commonly there is no shade available, working temperatures may approach 50°C.

Given the weather conditions, the following precautions are advised:

1. Enter the badlands only under conditions of dry ground when there is no forecast or sign of imminent rain.
2. Wear sturdy boots with 'vibrasole'-type tread.
3. Wear light-colored, loose clothing and carry water.
4. At the first sign of approaching rain, leave the badlands and get your vehicle onto blacktop roads.

Fieldwork can then be safely conducted providing you:

1. Inform Park officials or other colleagues of your intended work area to minimise search delays in the event of a disabling accident. Hiking alone in the more remote areas is not advised.
2. Mind your step on the steeper slopes for the deep vertical 'pipes' that mark the beginning of local underground conduits for storm runoff.
3. Watch out for rattlesnakes and scorpions, although relatively few are seen.
4. Beware of sudden movements by wildlife such as deer, antelope, hares, rabbits and predatory birds when you are otherwise occupied on steep slopes.

3.0 REGIONAL GEOLOGY

3.1 Stratigraphic Nomenclature

Canadian nomenclature of stratigraphic sequences bordering the Western Interior Seaway is characterised by:

1) differences across Alberta between the indurated outcrops of the disturbed belt and the less consolidated counterparts of the plains' region;
2) differences between nomenclature in Montana (Fig. 3) and Alberta;
3) differences in usage by successive workers in the same area;
4) exchange of Canadian terms with American equivalents;
5) problems in recognising outcrop-based divisions in regional down-dip subsurface studies; and
6) rejections by some workers of previously recommended refinements published in accordance with the International Stratigraphic Guide (Hedberg, 1976).

While this type of situation commonly prevails in a geologic province, its inconvenient repercussions should be recognised. Furthermore, any formal nomenclatural revisions aimed at reducing confusion and enhancing communication deserve support by subsequent researchers.

Previous sedimentological and paleoecological studies in Dinosaur Provincial Park have employed the term Oldman Formation (e.g. Dodson, 1971; Beland and Russell, 1978). This nomenclature reflects the traditional usage across the southern Alberta plains in which mid-Campanian non-marine strata have been divided into the Foremost (below) and Oldman Formations (e.g. Russell, 1940; Crockford, 1949): geological maps reflect this tradition (Section 8.1).

Earlier work often referred to the Oldman unit as the Pale Beds (e.g. Powers, 1931). Further inconsistences arose in the work of Williams and Dyer (1930) who assigned the Foremost Beds and Pale Beds to the Belly River Formation, and Dowling (1917) who extended the base of his Belly River Series to include the Milk River Sandstone. Other early regional studies elected to recognise numerous named members in the Belly River Series or Group (e.g. Allan, 1919; Nauss, 1945).

For a comprehensive review of these nomenclature problems, the reader is referred to McLean (1971, 1977). Earlier disputes over correlation with sequences in Montana have been recalled by Waage (1975). By the turn of the century, Stanton and Hatcher (1905) had shown conclusively that the Belly River beds of southern Alberta were correlative with the Judith River Formation in Montana.

McLean's (1971, Table 2) literature review demonstrates considerable disagreement in distinguishing characteristics of the Foremost-Oldman division. Concensus was restricted to four points, in that the Foremost sequence is generally darker, and contains more coal/carbonaceous beds, brackish-water fossils, and less cross-stratification. Given the ideal criteria for defining a formation (Hedberg, 1976), and the desirability of being able to recognise a formation in the subsurface, there appears to be a weak basis for perpetuating the Foremost-Oldman division.

Powers (1931; p. 84) claimed that the boundary between the Foremost and Oldman Formations is clearly defined by the Taber coal zone. However as McLean (1971; p. 32) pointed out, the type locality for the Foremost in Chin

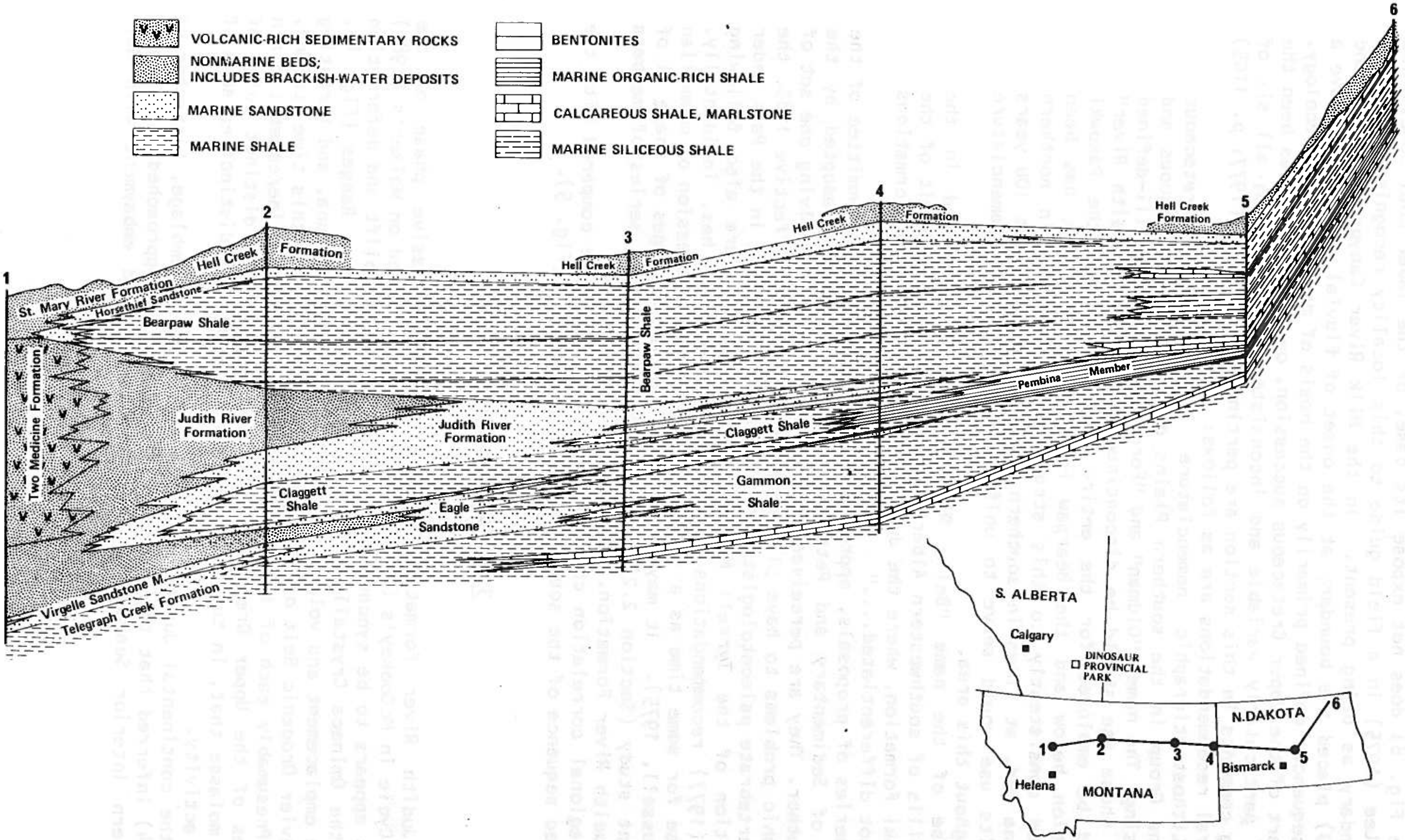


Figure 3. Fence diagram running west to east across the foreland basin south of the U.S. border. Redrawn from McGookey (1972).

Coulee (see Fig. 8) does not expose its base, or the Taber coal zone. Yet Shawa and Lee (1975) in a field guide to this locality recognised the formation boundary as being present. In the Milk River Canyon, Speelman and Hills (1980) placed the boundary at the onset of fluvial conditions above a shoreline sequence, defined primarily on the basis of megaspore paleoecology.

This part of the Upper Cretaceous succession, one concludes, has been the subject of particularly variable and inconsistent nomenclature; all six of the opening comments in this section are pertinent. McLean's (1977; p. 1105) nomenclatural recommendations are as follows:

> "....Lithostratigraphic nomenclature in the Upper Cretaceous Montana Group in the southern Plains of Alberta is ambiguous and confusing. The names "Oldman" and "Foremost" are vague, ill-defined terms whose use should be discontinued. The name "Judith River" should be employed for the entire interval between the Pakowki Formation below and the Bearpaw Formation above. It has been applied consistently to this stratigraphic interval in northern Montana and, at times in southern Alberta, for the past 100 years and its use would serve to unify and simplify the nomenclature throughout this area.
>
> Use of the name "Belly River" should be retained in the Foothills of southwestern Alberta, beyond the western limit of the Pakowki Formation, where the Judith River and Milk River Formations are not differentiated...."

This series of proposals, approved by the Stratigraphic Committee of the Institute of Sedimentary and Petroleum Geology, have been adopted by the present author. They are perceived as a prudent step in resolving one set of stratigraphic problems to have plagued Alberta geology. Effective 1983, the team of vertebrate paleontologists and taphonomists working in the Park under the direction of the Tyrrell Museum of Palaeontology are also following McLean's (1977) recommendations. The term 'Judithian' has, incidentally, been in use for some time as a stage in the regional succession of mammalian faunas (Russell, 1975). It may prove useful in later stages of Phase II of the present study (Section 2.2) to recognise an informal series of members for the Judith River Formation, as done by McLean (1971).

The regional correlation chart in Figure 4 should be compared with the interpreted sequence of the southwest Alberta foothills (Fig. 5).

3.2 Paleogeography

The Judith River Formation represents the regressive phase of the Claggett Cycle in McGookey's (1972) terminology, and based on Walker's (1982) synthesis appears to be synchronous with the onset of uplift and deformation east of the Omineca Crystalline Belt as far as the Front Ranges (Fig. 4). Batholith emplacement and volcanic activity in western Montana, and thrusting in the Sevier Orogenic Belt of Utah were also occurring at this time (Lerand, 1982). Presumably each of the four coarsening-upward, marine/coastal plain megacycles of the Upper Cretaceous (Fig. 4) represent a distinct pulse of foreland molasse that, in turn, each relate to an equally distinct episode of orogenic activity.

For the continental Judith/Belly River-Paskapoo assemblage, Eisbacher et al. (1974) inferred that the hinterland paleodrainage approached the lingering Western Interior Seaway (by now a long northward embayment with Gulf

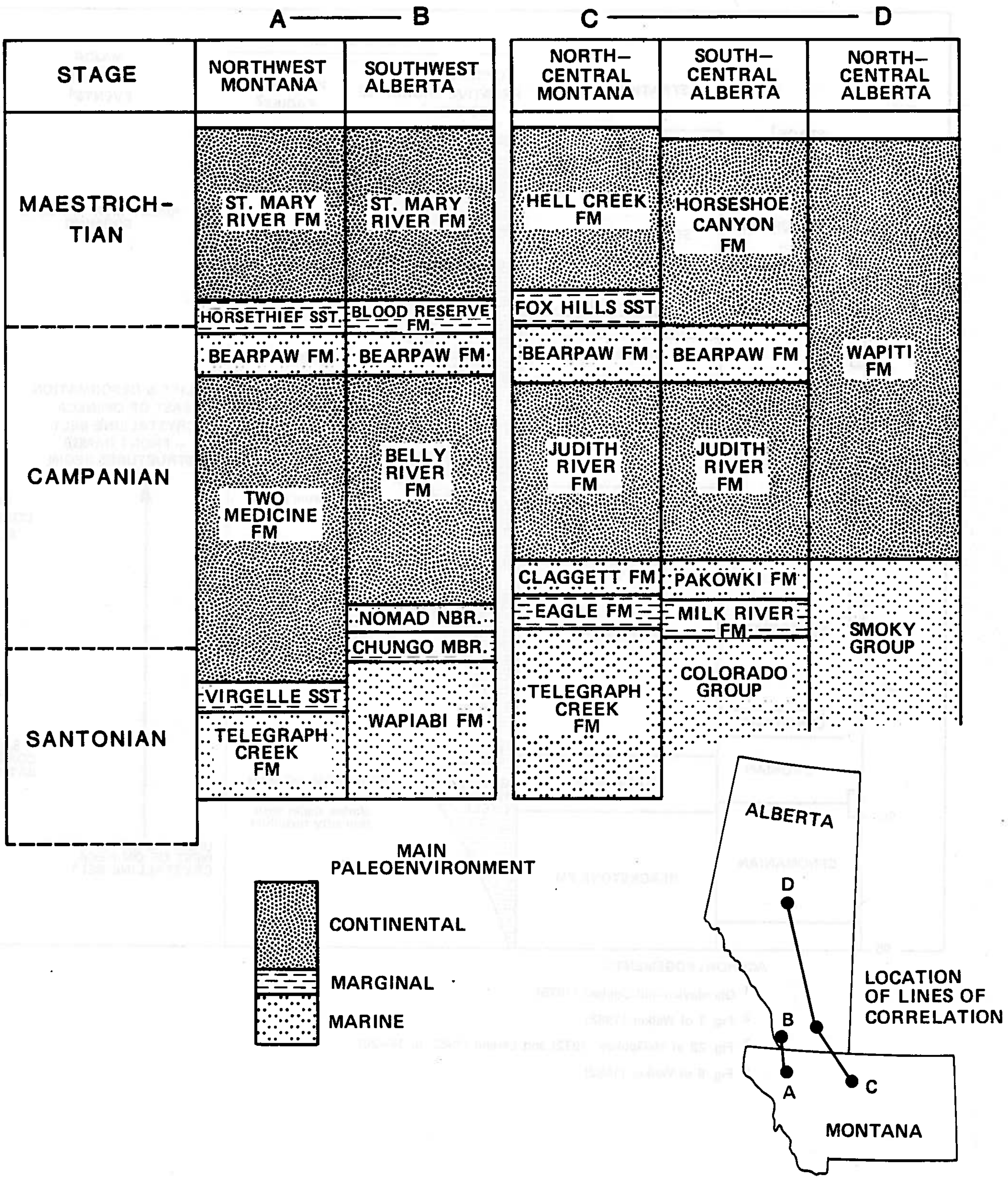
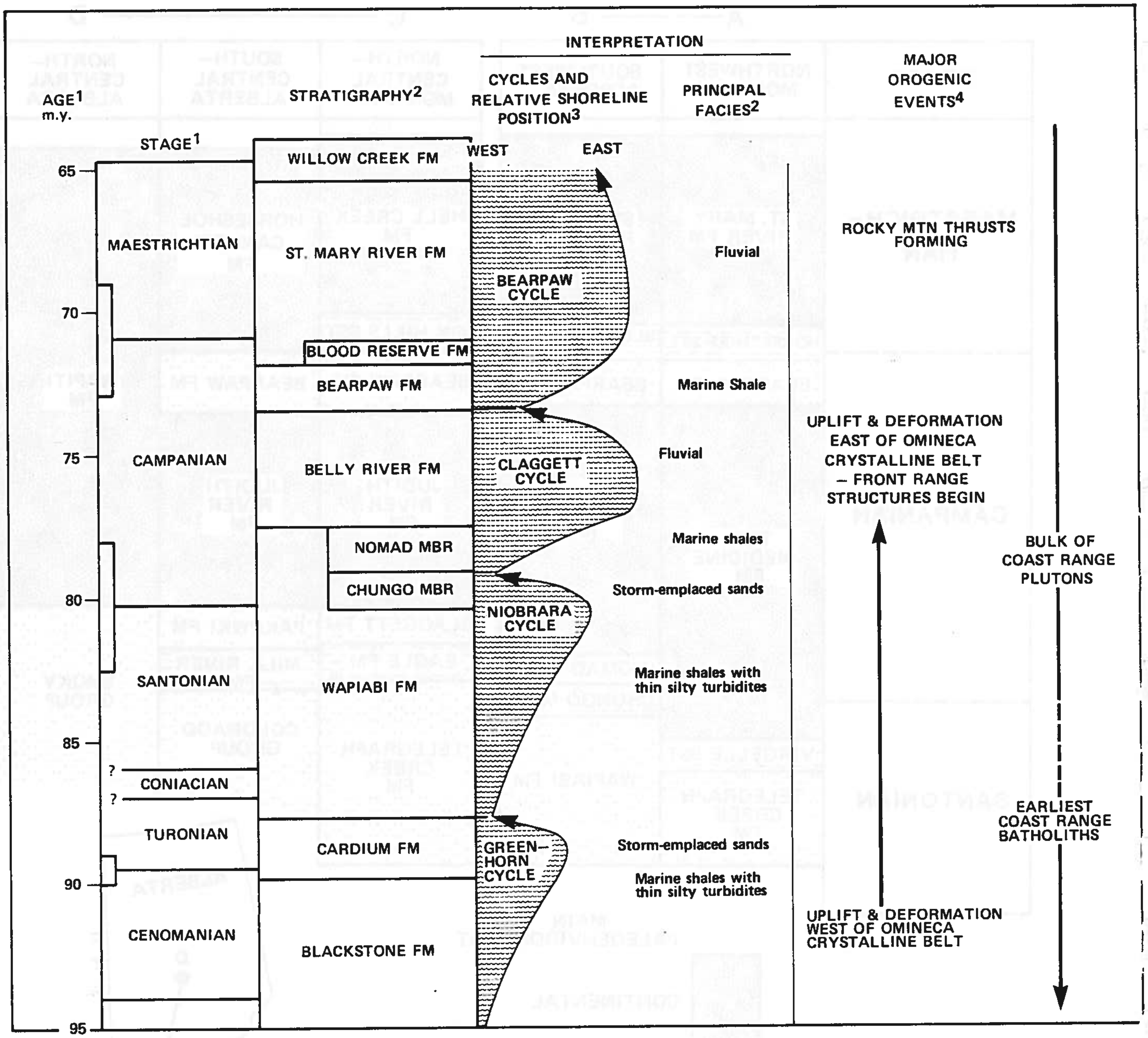


Figure 4. Regional correlation chart for the late Cretaceous showing stratigraphic nomenclature in northern Montana and south-central Alberta. Based on information presented by McLean (1971), McGookey (1972) and Lerand (1982).



ACKNOWLEDGEMENTS:

1 Obradovich and Cobban (1975)
2 Fig. 1 of Walker (1982)
3 Fig. 23 of McGookey (1972) and Lerand (1982, p. 14–20)
4 Fig. 6 of Walker (1982)

Figure 5. Interpretation of Upper Cretaceous stratigraphy in the Foothills' region of south-western Alberta. The boxed age-intervals in the first column indicate uncertainty over exact chronostratigraphy of stage boundaries.

connection) via already-established structural re-entrants in the Front Ranges. Accordingly, they considered that the western Alberta plains' area was undergoing fan-shaped fluvial activity that radiated from these mountain passes. Beyond the distal limits of these giant coalescing fans, the coastal plain was occupied by eastward and south-eastward flowing larger rivers. This scenario was subsequently confirmed for mid-Campanian time by Rahmani and Lerbekmo (1976) who analysed the distribution of heavy mineral suites across Alberta and southeast Saskatchewan. It will be seen in Section 4.4 that these conclusions are firmly supported by paleocurrent distributions in Dinosaur Provincial Park.

Transgressive shorelines of the preceding Pakowki/Nomad and ensuring Bearpaw phases of the ever-fluctuating Western Interior Seaway both reached close to the B.C. border in southwestern Alberta (Williams and Burk, 1966; Figs. 12-17 and 12-21). Figure 6 applies to the maximum regressive phase of Judith River deposition and incorporates the paleogeographic evidence of the above-noted work, as well as the cross-sectional data of McLean (1971) and McGookey (1972). The prevailing continent-wide paleogeography for mid-Campanian time is shown in Text-figure 7 of Williams and Stelck (1975). During the Cretaceous Period, North America lay further east and was twisted clockwise in comparison to its present configuration, because of the progressive northward advance of sea-floor spreading in the North Atlantic. During the late Cretaceous, southern Alberta had an approximate paleolatitude of 57°N (Marsaglia and Klein, 1983), 6-7° further north than at present.

3.3 Paleoclimate

The main climatic variables are temperature (mean annual, seasonal variation) and precipitation (mean annual, seasonal variation and its ratio with evapotranspiration). Specific combinations characterise different climatic types.

Sedimentologists infer past climates, typically in a piecemeal fashion, by an uniformitarian approach to such features as paleosols, floral/faunal paleoecology, paleohydrology, coastal evidence of storms, mineralogy of sandstones and mudrocks. However, the climatic type of a particular (paleo-) region is basically the collective result of three geologically-controlled factors - namely, latitude, proximity to an ocean and to high relief (particularly in the source direction of prevailing winds). Superimposed on these factors is variation in the average latitudinal temperature gradient caused by the heat balance effects of the changing extent of marine areas and associated land distribution (Barron et al., 1980). An apparently more equable poleward temperature gradient with a concomitant latitudinal compression of high-latitude climatic belts during the Cretaceous is generally ascribed to the lower percentage of land within the subtropical belt (Thompson and Barron, 1981). To an increasing extent, these variables have been semi-quantified for Cretaceous time (e.g. Lloyd, 1982), thereby allowing an independent check on local outcrop-based evidence.

For the Upper Cretaceous, the following paleoclimatic evidence derives from previous work as cited.

Seasonality:

- annual rings in petrified wood (Dodson, 1971; p. 35);
- growth rings in vertebrae of Champsosaurus (ibid.);
- periodic stage variation in paleochannels (see Section 4.4).

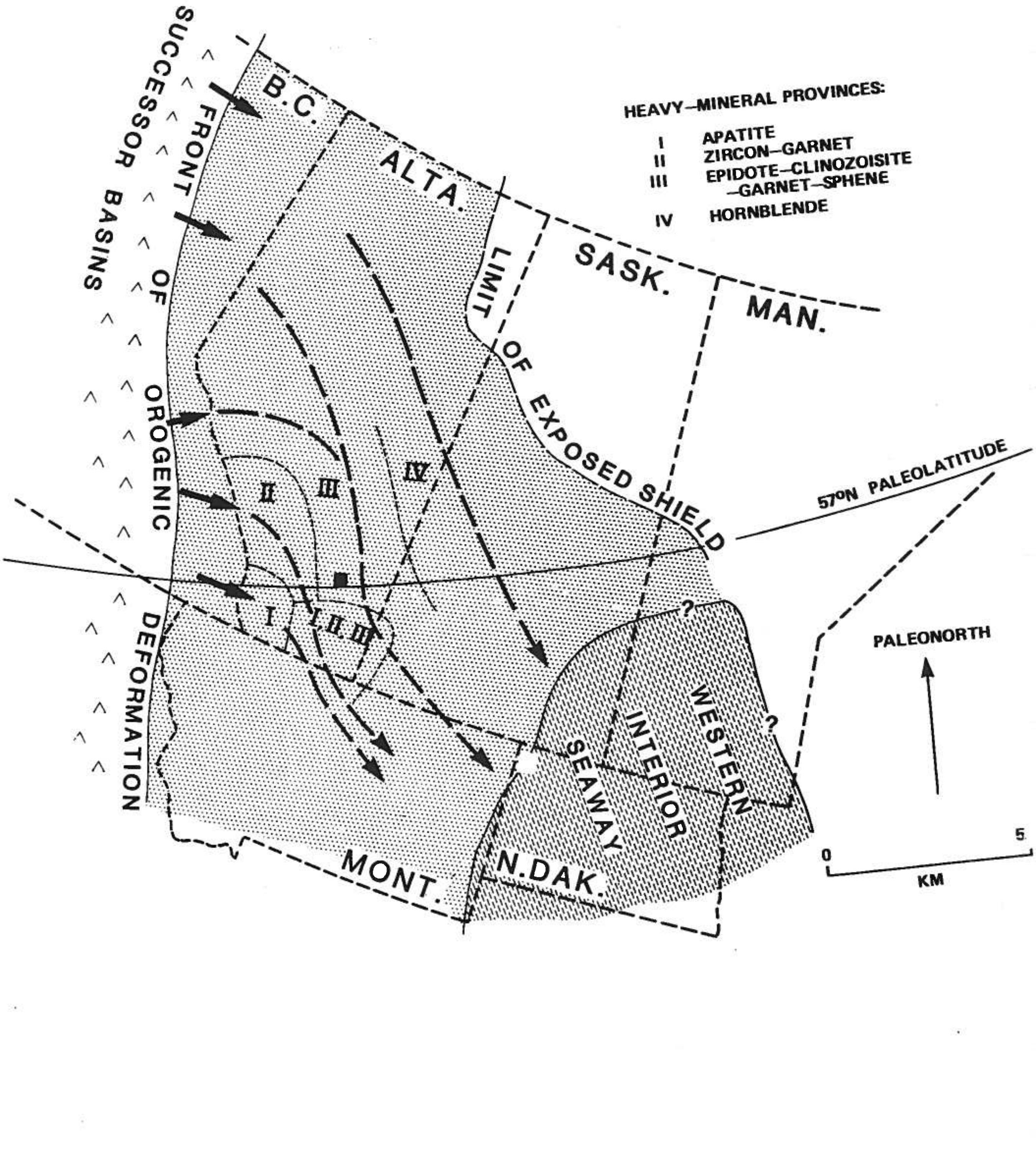


Figure 6. Mid-Campanian paleogeography of the Plains' region. Arrows from the hinterland indicate drainage outlets according to Eisbacher et al. (1974); heavy mineral analyses are from Rahmani and Lerberkmo (1976); other sources of information are indicated in the text.

Moderate-high precipitation:

- Taxodioxylon wood, metasequoian foliage and Sequoites cones indicating mean annual rainfall of at least 1200 mm (Beland and Russell, 1978; p. 1019);
- inferred herbivore biomasses of at least 20t/km on alluvial soils enriched by volcanic ashfalls require mean annual rainfall of at least 1000 mm (ibid.);
- perennial flow in deep paleochannels (see Section 4.4).

High precipitation/evapotranspiration ratio:

- frequent, widespread paralic conditions with preservation of carbonaceous mudrocks and coal;
- rich flora required for abundant herbivorous fauna preserved in Dinosaur Provincial Park (Dodson, 1971; Beland and Russell, 1978);
- absence of reports of any evaporitic paleosol types.

Winter storm activity:

- interpretation of hummocky and swaley cross-stratification along the coast of the Western Interior Seaway (Walker, 1982; p. 22-30) by Marsaglia and Klein (1983);
- floods in paleorivers (see Section 4.4).

Moderate-high temperature:

- 17-27°C paleotemperatures of water in the adjacent Bearpaw Sea (Forester et al., 1977).

These numerous, independent lines of evidence collectively indicate a warm, moist paleoclimate, with rather pronounced seasonality and occasional winter cyclonic disturbances. Prevailing winds were westerly (Lloyd, 1982) with the proportion of orographic to leeside (i.e. foreland) precipitation presumably increasing in proportion to the growing scale of mountainous relief along the Pacific rim. Foreland drainage was undoubtedly perennial and with relatively high density: it also seems plausible that the main fluvial systems emerging from the front ranges received tributary input from within the foreland. The rather immature mineralogy of Belly River sandstones in the foothills (Lerbekmo, 1963) is attributed to short transport distance and their probable first cycle nature, rather than a specific climate.

3.4 Structure and Outcrop

The Judith River Formation, across southeastern Alberta, directly underlies Pleistocene drift in a broad arcuate tract, 29,500 km^2 in size and typically about 150 km in east-west width, that has the Sweetgrass Arch structure as a medial line (Fig. 7). The bedrock surface is traversed by a dendritic network of preglacial valleys (Stalker, 1961).

With the Red Deer River valley forming a northern limit, the strata of interest are occasionally overlain by outliers of Bearpaw and younger formations along the Saskatchewan border (principally the Cypress Hills). In a north/northeast line linking the Milk River Ridge, Lethbridge, Bow City and Brooks, the Judith River Formation becomes concealed in the east limb of the main Alberta Syncline. Along the U.S. border, older formations are exposed along the Milk River area between Ranges 6 and 16. Between these contacts, exposures are sporadically distributed as badlands along the Red Deer, Bow, Oldman and Milk Rivers and the network of coulees between Taber and Manyberries.

McLean (1971) gave a thorough review of various workers' definitions for

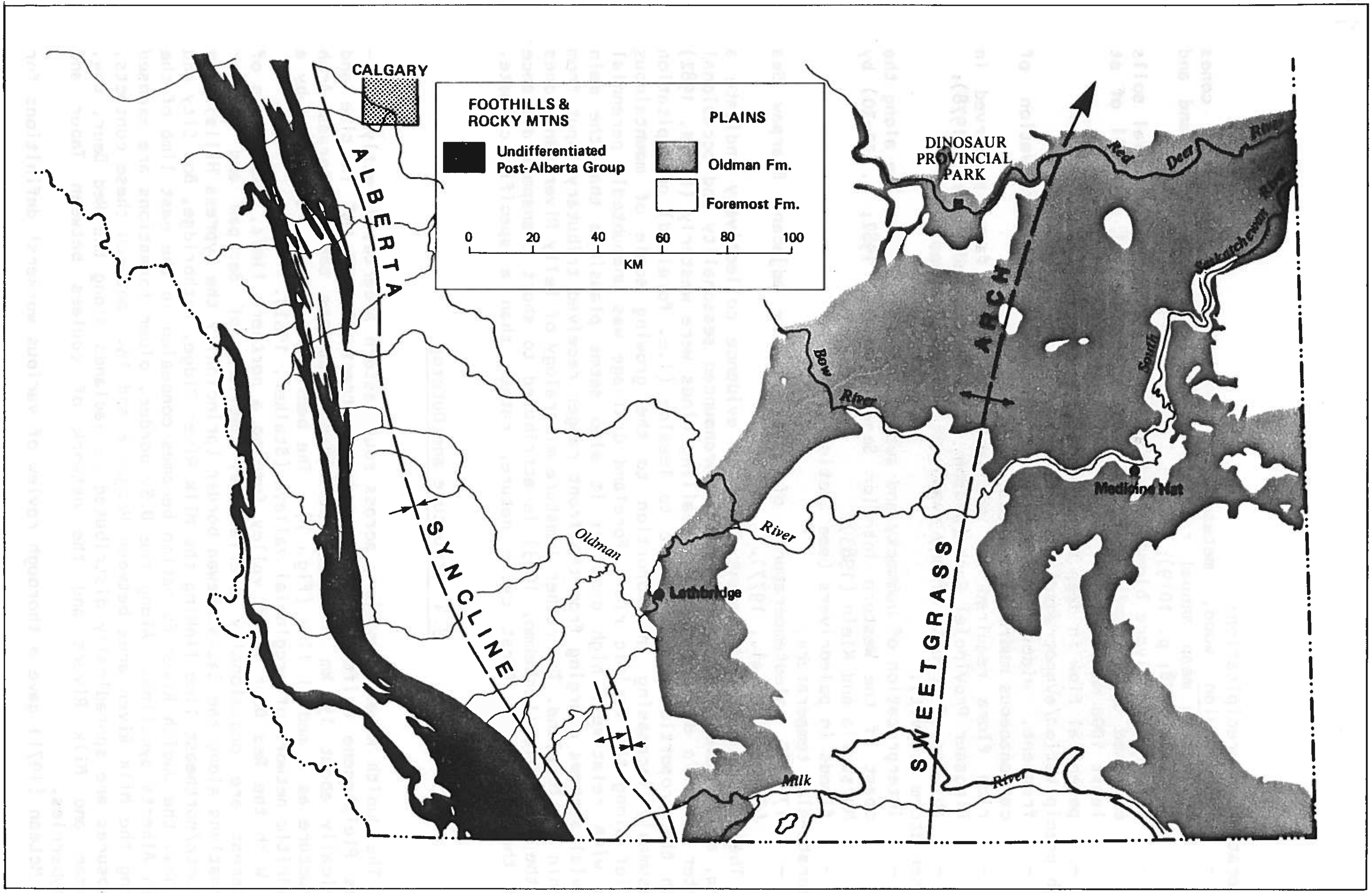


Figure 7. A simplified geological map of southern Alberta showing the traditional nomenclature of strata time-equivalent to the Judith River Formation. and principal tectonic elements

the base and top of the Judith River Formation. Concerning the basal transition from the Pakowki Formation, the upper limit of a series of coarsening-upward, progradational cycles beneath the McKay coal zone seems to be the most logical one. The Judith River/Bearpaw contact is typically abrupt (Habib, 1981) and has caused relatively little debate. Defined in the above manner, the Judith River Formation in the study area thins eastwards and north-eastwards from ca.450 m in the extreme southwest to ca.280 m beneath the Cypress Hills and ca.325 m in Township 23, Range 16, east of which oil and gas wells are spudded below the Bearpaw base.

The north-northeastward plunging Sweetgrass Arch is clearly the predominant structure in the region (Williams and Burk, 1966). According to Tovell (1958), it is a composite feature linking the neighbouring Kevin-Sunburst dome in Montana with the Bow Island arch north of the point of confluence of the Bow and Oldman Rivers. Down-plunge, its axis crosses the Red Deer River immediately east of Dinosaur Provincial Park. Axial plunge decreases northward from 3.4 to 0.8 m/km south and north of Township 12, respectively. Regional dips vary from a maximum of 4 m/km east of the Sweetgrass Arch, west along Township 12, to more than 16 m/km where the main synclinal axis is nearby (Fig. 7). Minor near-surface flexures in the southwestern corner of the study area were noted by Irish on his 1:500,000 map of the southern plains (see Section 8.1).

Active since the Paleozoic, it is a conspicuous feature on structure contour maps of the top of the Milk River Formation where it has the form of a mild anticlinorium (Meyboom, 1960; Fig. 7). Its influence on late Cretaceous sedimentation is uncertain partly because of the depth of erosion over its axial region: the report by Wells (1957) concluded that movement continued into the early Tertiary. The regional subsurface study of the Judith River Formation by the present author, presently underway, is attempting to discern the time-space distribution of any intra-Campanian influences. Meanwhile, outcrop data will be used to check Beland and Russell's (1978) suggestion that paleorivers in the Dinosaur Provincial Park area had steepened gradients over the Arch. As McLean (1971) notes, the term Sweetgrass or Bow Island 'Arch' may be a misnomer in that it appears to have separated two more rapidly subsiding areas on its flanks - namely the Alberta and Williston Basins.

3.5 Important Previous Sedimentological Work

Figure 8 indicates the geographic location of major post-1960 contributions to a sedimentological understanding of the Belly/Judith River Formations across southern Alberta. However because of location or the specific stratigraphic interval of interest, little of this previous work bears directly on the upper part of the Formation exposed in Dinosaur Provincial Park. The regional stratigraphic investigation of McLean (1971) therefore remains a prime reference article. As pointed out by Walker and Haywick (1982; p. 151), "there is no summary article on the general depositional facies and paleocurrent trends of the Belly River Formation".

Studies in the foothills' belt, typically on steeply-dipping gorge exposures, have been generally concerned with the transition zone between the Wapiabi and Belly River Formations. There appears to be a growing concensus that the regressive phase of the Wapiabi sea accumulated upward-coarsening cycles of burrowed mudrocks below wave-base, and storm-emplaced sands (see

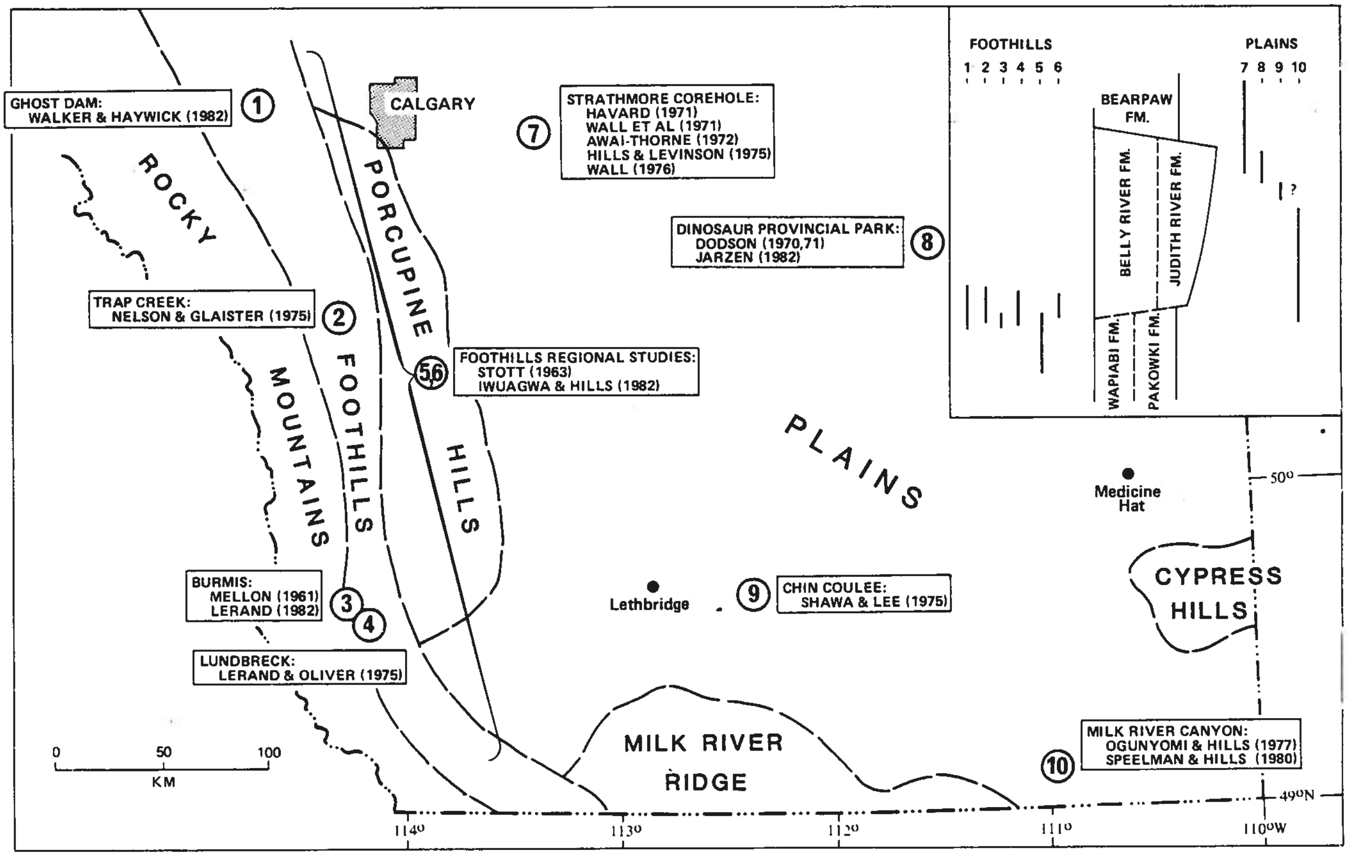


Figure 8. Map of southern Alberta showing locations of important post-1960 sedimentological research with respect to physiographic regions. The inset shows stratigraphic coverage of these studies with respect to the Belly/Judith River Formation boundaries.

Walker, 1982). Marsaglia and Klein (1983) in a recent global synthesis of occurrences of swaley and hummocky cross-stratification conclude that the southwest Alberta area was affected by winter storm weather at 57°N paleolatitude.

The Wapiabi/Belly River boundary is sharply defined by the abrupt onset of fluvial paleoenvironments. At Ghost Dam, Walker and Haywick (1982) recognised eleven fining-upward paleochannel sequences in the basal 122 m of the Belly River Formation. With some direct evidence of lateral accretion, these units average 2.9 m thick (maximum 4.2 m) and have vertical sequences from trough cross-bedding to ripple cross-lamination. Flow directions are clustered between northeast and southeast, and the rate of channel to overbank sediments is approximately 3:1. In conclusion, Walker and Haywick were uncertain how this Ghost Dam sequence sits with respect to the overall scale of contemporaneous fluvial activity.

In the plains region, Ogunyomi and Hill's (1977) study in the Milk River area on the correlative Pakowki-Foremost transition recognised a cyclic sequence of lagoonal and barrier-bar sediments. No fluvial sequences were found, so that their vector mean of 040° possibly represents the direction of longshore sand transport - a process which they envisaged. Their comparison of this transport direction with Dodson's (1971) 085° vector mean from channel-related cross-beds in Dinosaur Provincial Park therefore seems inappropriate. At Chin Coulee where a middle portion of the Judith River is exposed, Shawa and Lee (1975) deduced a southerly vector mean from freshwater cross-beds. The large volume of interdisciplinary work on the Strathmore corehole (Tp. 25, R. 25 W4), which penetrated the upper ca. 20 m of the Judith River Formation, revealed an abrupt basal contact with the overlying Bearpaw Formation. The Alberta Research Council's 1983 corehole in Tp 20 R. 12 W4 down to the Pakowki contact south of Dinosaur Provincial Park (see Fig. 12) will add considerably to our subsurface sedimentologic knowledge of the Judith River Formation.

As far as the Park is concerned, the work of Dodson (1970, 71) remains a useful summary account, although some intrepretations are judged erroneous by this author (e.g. lateral-accretion bedding as a result of progradation into standing water bodies). His ongoing major contributions in the field of dinosaur taphonomy (e.g. Dodson, 1983) will shortly be integrated with this author's sedimentological work. Recent research progress by the Provincial Government's paleontologists is summarised by Currie et al. (1981) and Currie (1982a). Useful manuals for the identification of fossil plants/invertebrates and vertebrates are Stanton and Hatcher (1905) and Johnson and Storer (1974), respectively. Bibliographic information on vertebrate fossils is provided by Davis (1980) and Russell (1976). Some palynological work has been done by Jarzen (1982) using matrix sediment from excavated turtle carapaces. Lastly, one of the more recent publications arising from ongoing geomorphological research in the Park is that by Bryan and Campbell (1980).

3.6 Resources

3.6.1 Coal

The first coal production in Alberta was from upper Judith River strata near Lethbridge in 1872 to supply customers in Montana, and later in Medicine

Hat. Synthesising data from Campbell's (1964) catalogue of larger-scale registered mines in the plains indicates that Judith River coal exploitation reached its peak in the early 1920's (Fig. 9a): worked seams were commonly about 1 m thick (Fig. 9b). Although no mining operations are presently underway, Petro Canada and Fording Coal/Idemitsu Kosan (Japan) have advanced plans for large underground mines in high-volatile bituminous C resources at Kipp and Shaughnessy, north of Lethbridge. The most recent operation at the Taber Ajax mine was still active in 1974.

The Energy Resources Conservation Board (1982a) currently recognises twelve coalfields within the Judith River Formation (Fig. 10, Table 1). Collectively they account for 6.6% of the plains' total of in-place reserves, but this low proportion is counteracted by the fact that no other alternative shallow resources exist across southeast Alberta. Eleven coal companies presently hold leases in the study area (Fig. 11), but these are largely contained within landblocks withdrawn from disposition by the Alberta Government (1976), pending revision of its Coal Development Policy.

Data from 41 samples ranging in depth from 51-250 m acquired during ARC's 1976 regional drilling program has been synthesised by Nurkowski (1983). Judith River seams average 0.66% sulfur, 16.6% ash, equilibrium moisture 13.9% and 20,104-29,356 kg/kj in calorific value (moist, ash-free basis). These coals therefore range in rank from sub-bituminous C to high-volatile bituminous C.

Virtually all of the Formation's coal occurs in three zones, each separated by several 100 metres of barren strata. In stratigraphic order, the common nomenclature applicable to the western plains (Holter and Chu, 1978) is McKay (immediately above the Pakowki/Judith River transition), Taber, and Lethbridge (immediately below the Judith River/Bearpaw contact) dominated by the Galt seam. In eastern areas, Holter and Chu noted that diachronism in the Judith River base causes the Taber to become the lowest coal zone. Neither of the studies by Yurko (1976) or Holter and Chu (1978) had sufficient data bases to allow reserve estimates. However, such was possible for the area enclosing the Cypress Hills by Campbell (1974). Figure 9a of the Energy Resources Conservation Board (1982a) traces the outcrop and approximate 600 m structure contour of the upper two coal zones across the southern plains.

Refining this earlier evaluation is a major related objective of the sedimentological research in Dinosaur Provincial Park. Given that systematic subsurface studies are still in progress, a regional paleoenvironmental summary is here stated in a tentative manner.

Sporadic development of coal zones appears to be a repercussion of channels having been densely distributed in time and space. Paludal environments therefore had a low probability of being either sustained for sufficiently long periods or being adequately remote from channel activity. The basal McKay seams developed in a delta-top situation (cf. Ryer, 1981) whereas the uppermost widespread Lethbridge zone reflects the imminent submergence by the relatively rapid Bearpaw transgression. In between, the Taber zone is speculated to have been the result of a change in rates of regional tectonics/subsidence and/or hydrologic regime.

Current emphasis in prospective coal development is on strippable reserves for on-site conversion or nearby generation of electricity (Campbell and du Plessis, 1982). The Brooks/East Brooks' fields contain 79% of the surface Judith River resources (Table 1), and are proposed by Campbell and du Plessis as a possible site for a mated power/pyrolysis industry. In consideration of these factors, and with a view to integrating the results of

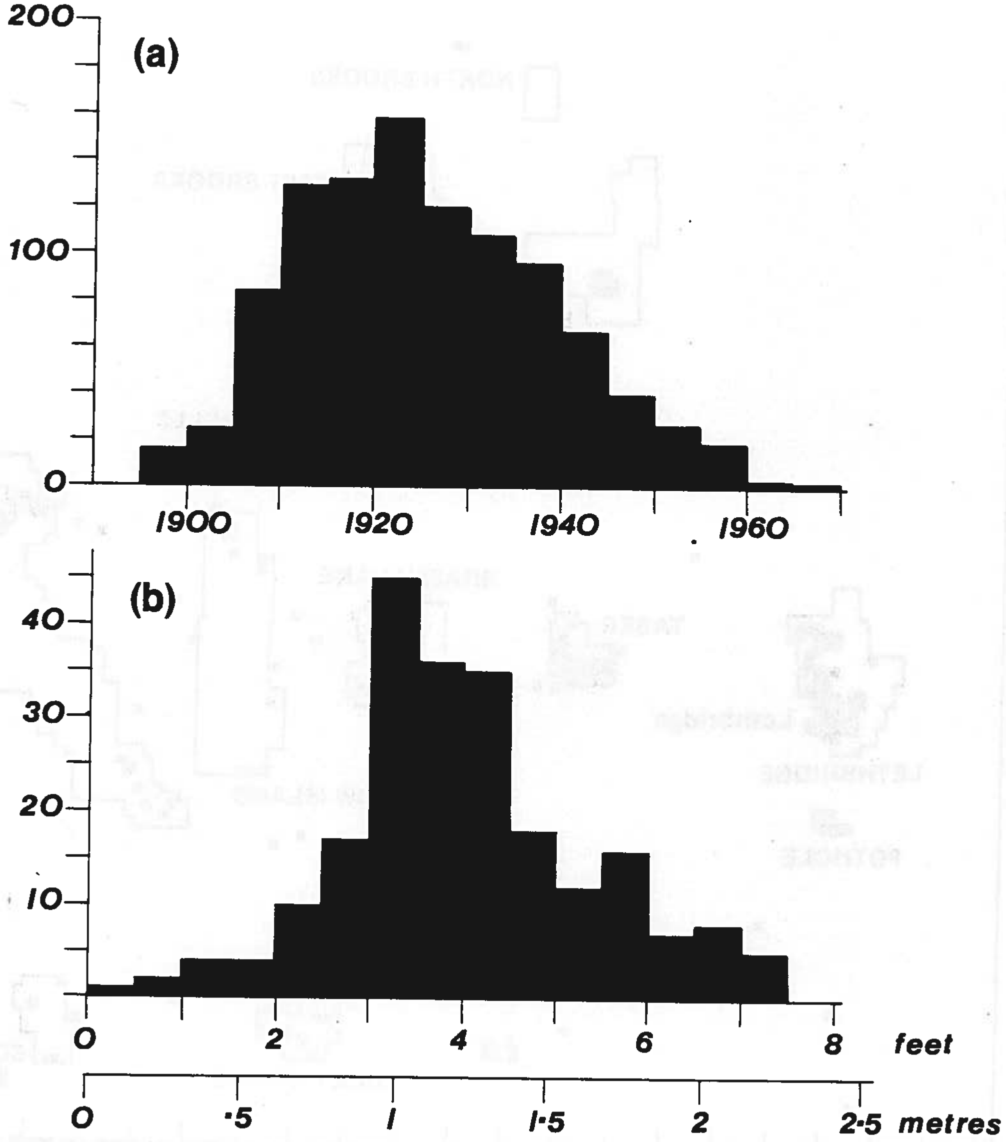


Figure 9. (a) The volume of coal-mining activity across southern Alberta earlier this century in the Judith River Formation, expressed as the number of mining permits issued per year. (b) Frequency distribution of coal seam thicknesses encountered in these early mines. Both sets of data are processed from Campbell (1964).

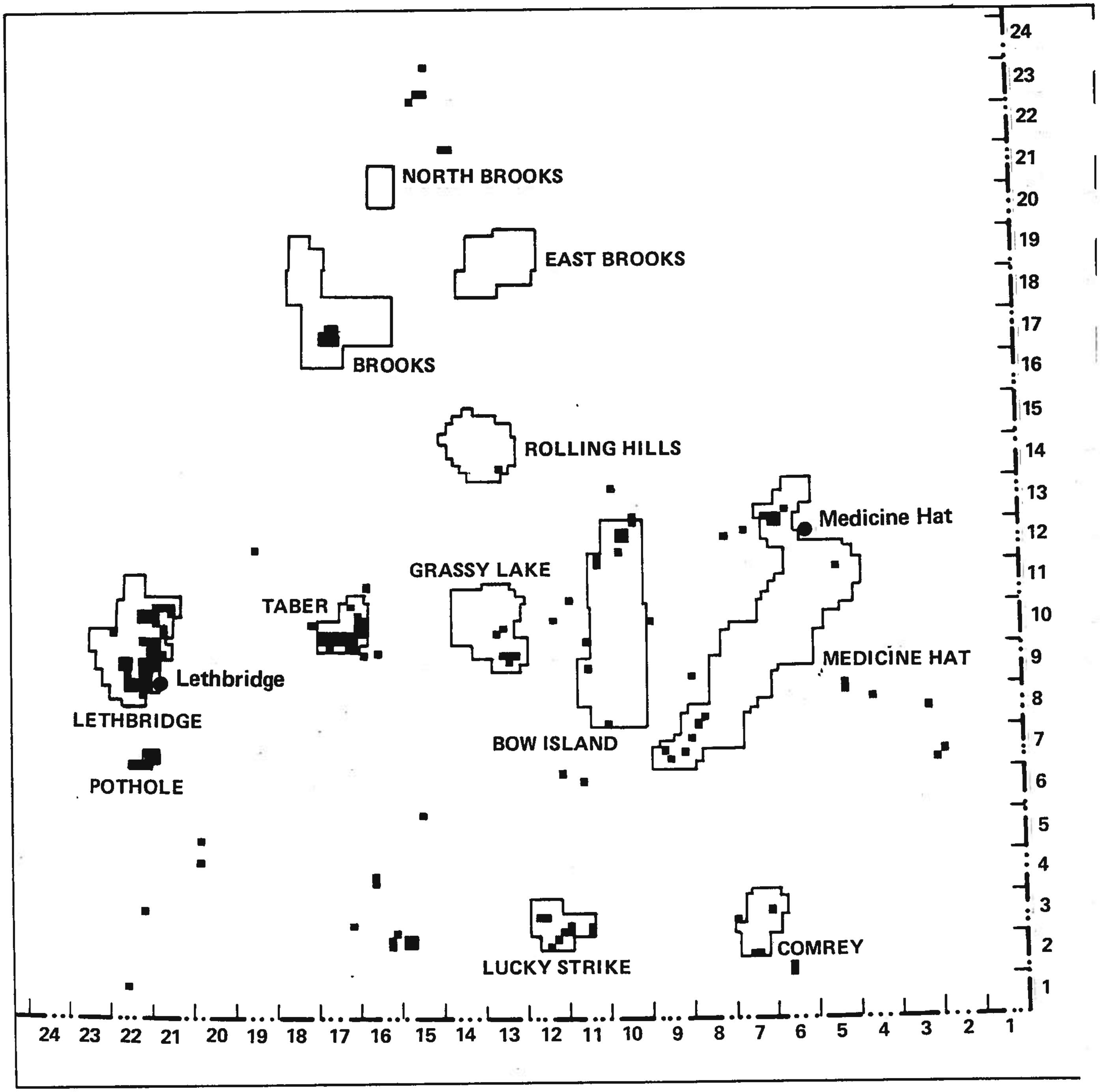


Figure 10. Potential surface-mineable coal fields in the Judith River Formation, according to the Energy Resources Conservation Board (1982a). Black shaded areas are legal subdivisions in which there was former mining activity (Campbell, 1964).

TABLE 1. RESOURCES (megatonnes) OF JUDITH RIVER COALFIELDS ACCORDING TO THE ENERGY RESOURCES CONSERVATION BOARD (1982a).

FIELD	IN-PLACE	RECOVERY[1] RATIO	SURFACE	UNDERGROUND	RANK
BOW ISLAND	300	0.06	11	2	Subbituminous B/C
BROOKS	340	0.34	67	38	Subbituminous A/B
COMREY	38	0.10	4	0	Subbituminous B/C
EAST BROOKS	190	0.39	76	0	Subbituminous B/C
GRASSY LAKE	100	0.15	15	0	Subbituminous B
LETHBRIDGE	490	0.34	0	130	High vol. bituminous B
LUCKY STRIKE	29	0.18	5	0	Subbituminous A
MEDICINE HAT	560	0.26	0	120	Subbituminous B/C
NORTH BROOKS	26	0.00	0	0	Subbituminous B
POTHOLE	16	0.00	0	0	High vol. bituminous B
ROLLING HILLS	380	0.24	0	94	Subbituminous B
TABER	35	0.14	4	0	Subbituminous A
SUB-TOTAL	2504		182	384	
PLAINS' TOTAL	37760		6990	6000	
%	6.6		2.6	6.4	

[1] Considers parts of field that are non-recoverable due to other land use, old mine workings, and local resources discontinuous with main body.

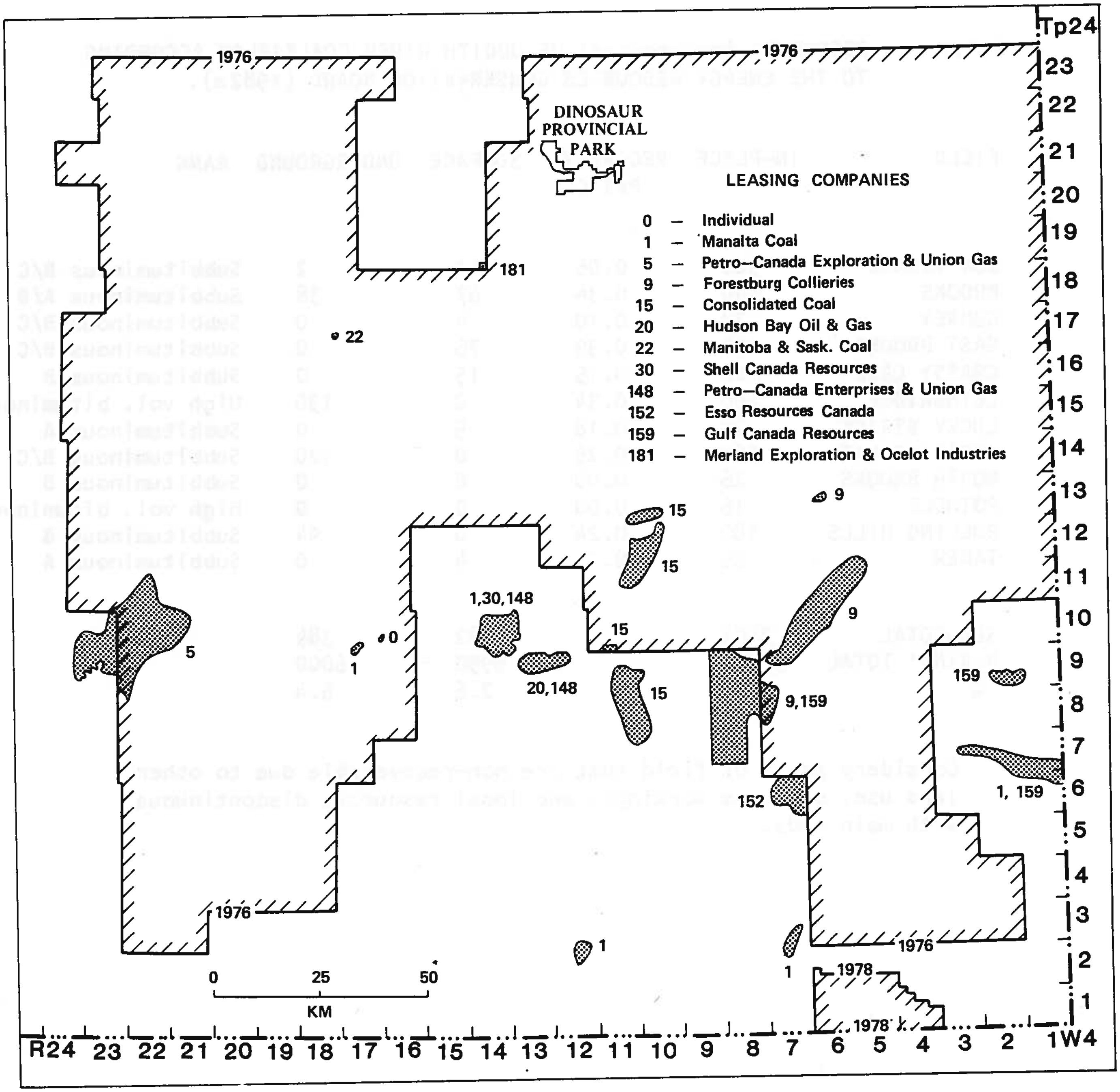


Figure 11. Generalized current lease areas by companies with potential interest in Judith River Formation coal, according to Alberta Energy and Natural Resources. The large H-shaped block represents the area in which permits for mine development are not being currently issued, pending release of a revised Coal Policy for the Province of Alberta.

fieldwork in the Park to the overall regional subsurface study across southeast Alberta, the area between the Red Deer and Bow Rivers through Brooks has been selected for ARC's 1983 coal drilling and coring program (Fig. 12). The strategy of hole locations is to elucidate the depositional framework responsible for the typically patchy time-space distribution of Judith River coal resources. With the exception of the most northeasterly corehole which will penetrate the entire Formation to approximately 400 m depth, all holes will be less than 80 m to characterise the near-surface Lethbridge Coal Zone (Fig. 13).

3.6.2. Hydrocarbons

The intent of this section is to briefly review published data on hydrocarbon reservoirs in Judith River strata (Fig. 14), as background to sedimentological research in the Park.

It would however be remiss not to firstly mention the Milk River gas pool across southeastern Alberta (see Fig. 4), because it dominates the petroleum geology of Upper Cretaceous strata. Possibly, the largest single gas field in aerial extent across western Canada (Herbaly, 1974), the Energy Resources Conservation Board (1982b) estimates 253,300 x 10^6 m^3 of marketable gas of which a quarter has been exploited since 1970. Myhr and Meijer-Drees (1976) provide a sedimentological account of the Milk River Sandstone reservoir.

The Judith River Formation is generally the youngest hydrocarbon producing formation in Alberta. Shouldice (1979) recognised an eastward increase in porosity across the plains' limb of Alberta syncline, and concluded that traps occur as 1) updip marine pinchouts into marine shale, 2) gentle structures involving widespread sands, and 3) fluvial paleochannel sands. The first two types predominate (cf. the Pembina field described by Iwuagwu and Lerbekmo (1981)) and characterise the basal part of the unit above the Pakowki Formation. Of relevance to work in the Park are the limited gas accumualations in paleochannel sandstones higher in the Formation, but Shouldice also detected a few east-west trending sandbodies of much greater extent. An example of early exploitation of Judith River hydrocarbons on the western limits of Dinosaur Provincial Park is provided by Stewart (1941).

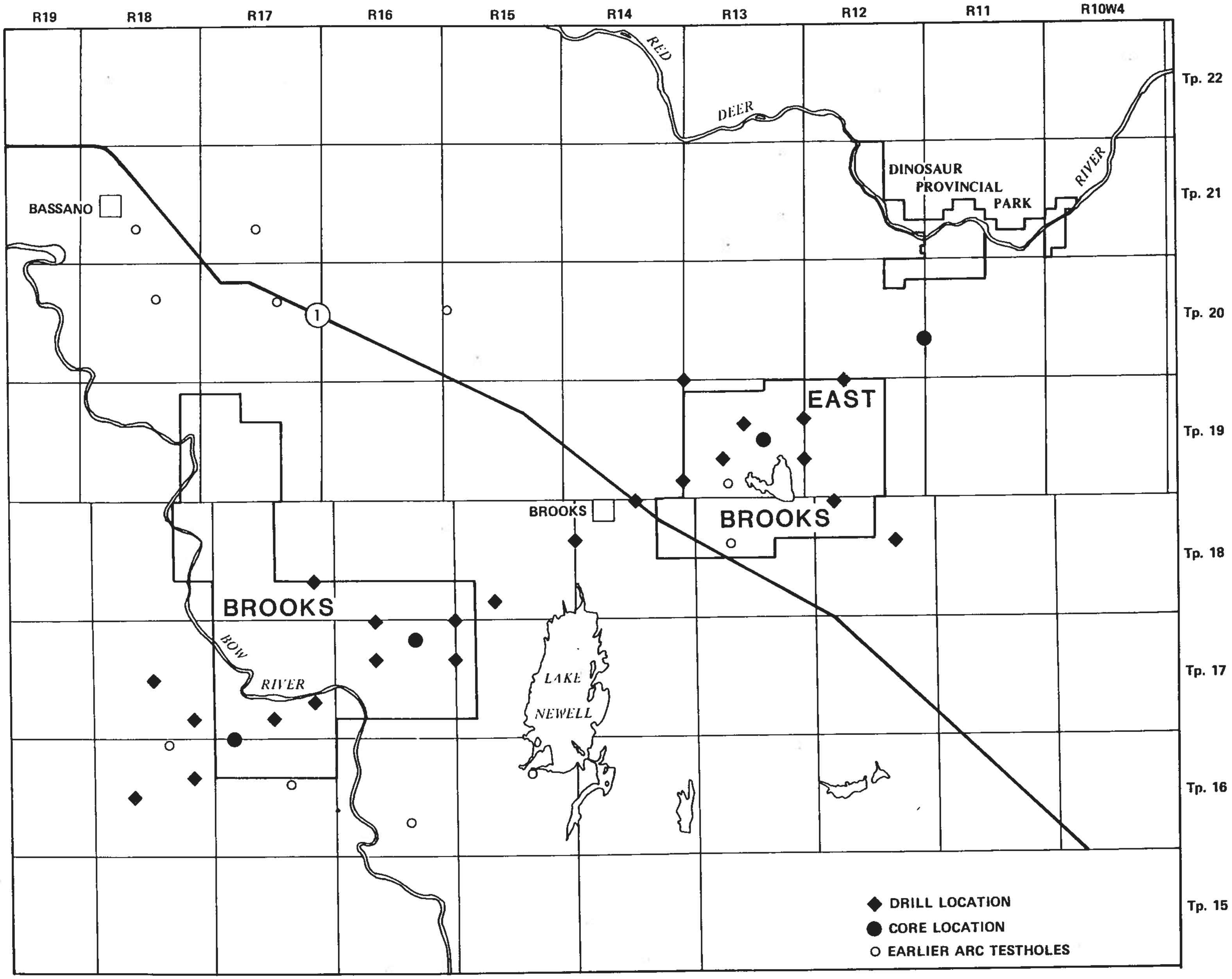


Figure 12. Layout of the Alberta Geological Survey's 1983 drilling/coring program southwest of Dinosaur Provincial Park.

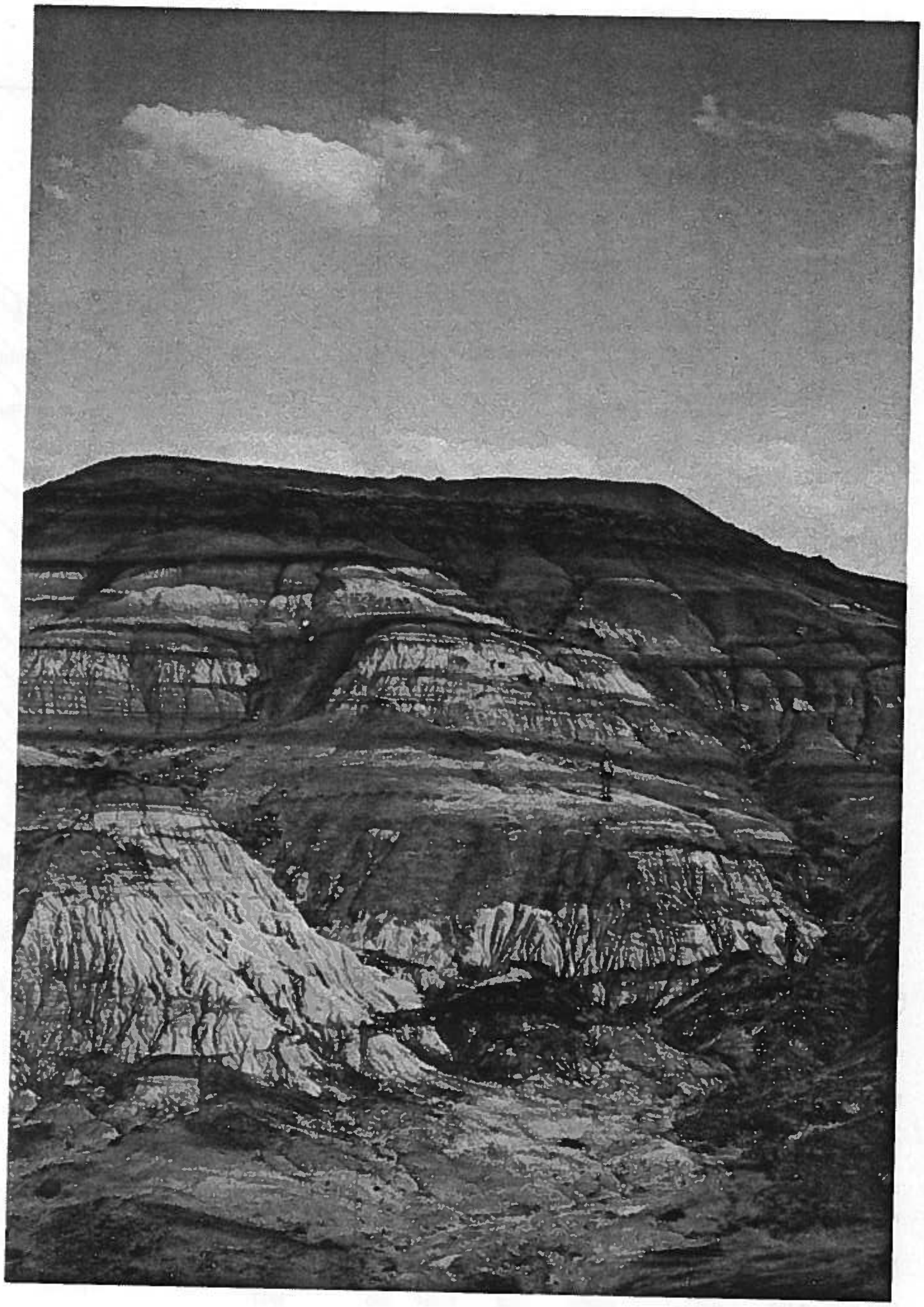
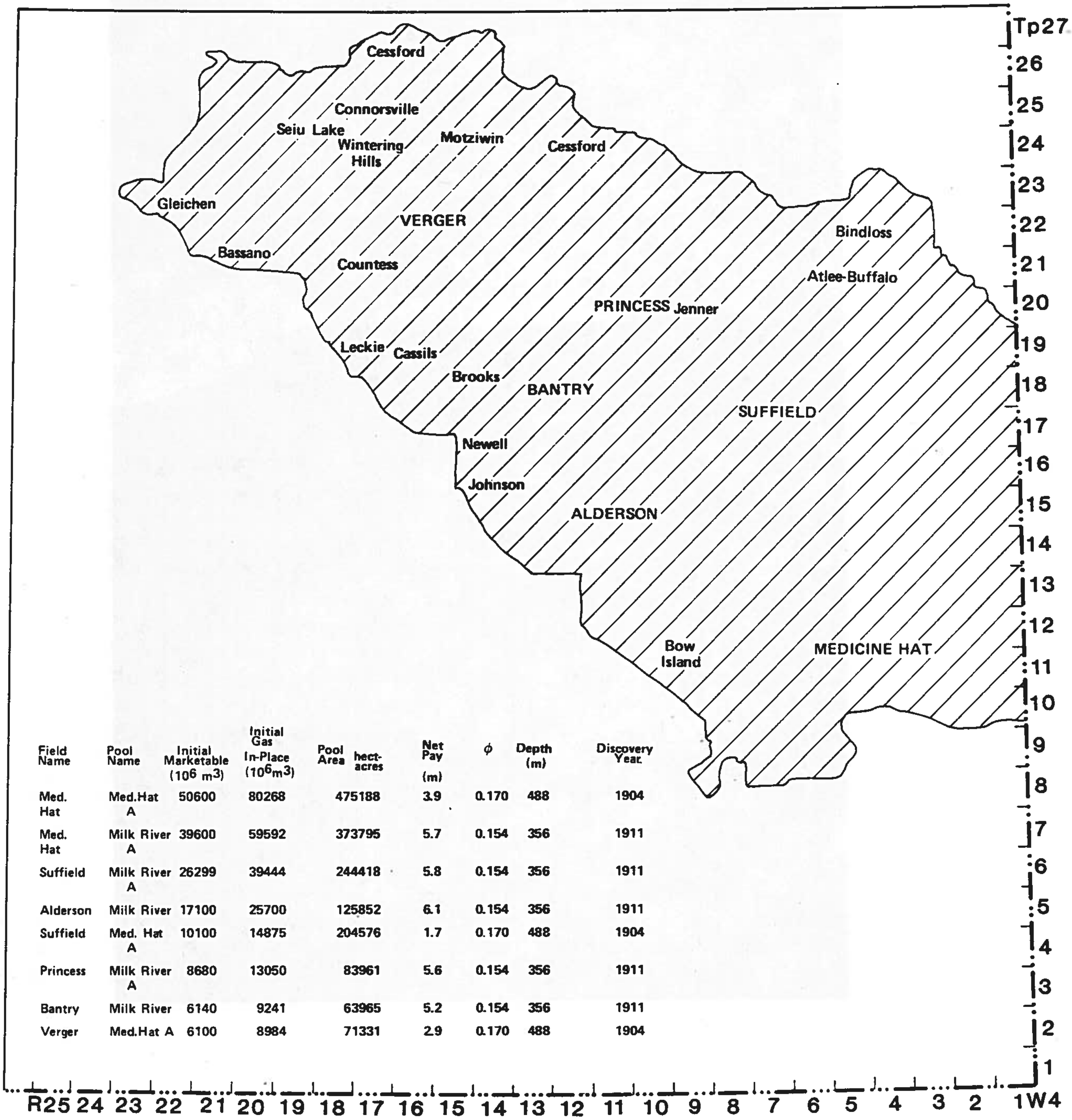


Figure 13. The Lethbridge coal zone just below the prairie surface here overlies a 31 m thick sequence of variegated, bentonitic floodplain sediments interrupted by three low-sinuosity paleochannel units, although the middle one appears to be partially amalgamated with one containing vague lateral accretion. Several crevasse-splay units, less than 1.5 m thick are present in the upper portion. [5626740mN; 455160mE / basal elevation 679 m a.s.l.]



Field Name	Pool Name	Initial Marketable (10^6 m^3)	Initial Gas In-Place ($10^6 m^3$)	Pool Area hect-acres	Net Pay (m)	ϕ	Depth (m)	Discovery Year
Med. Hat	Med.Hat A	50600	80268	475188	3.9	0.170	488	1904
Med. Hat	Milk River A	39600	59592	373795	5.7	0.154	356	1911
Suffield	Milk River A	26299	39444	244418	5.8	0.154	356	1911
Alderson	Milk River	17100	25700	125852	6.1	0.154	356	1911
Suffield	Med. Hat A	10100	14875	204576	1.7	0.170	488	1904
Princess	Milk River A	8680	13050	83961	5.6	0.154	356	1911
Bantry	Milk River	6140	9241	63965	5.2	0.154	356	1911
Verger	Med.Hat A	6100	8984	71331	2.9	0.170	488	1904

Figure 14. The distribution of Upper Cretaceous gas pools in southeastern Alberta. Major pools are capitalized and data for these are provided in the table. Information taken from GSC Map 1558A (1981).

4.0 LOCAL GEOLOGY

4.1 Sedimentological Background

All previous sedimentological work on the Judith River Formation away from its boundary transitional zones into marine settings have concluded a fluvial paleoenvironment (Section 3.5). This also applies to the outcrop of the upper ('Oldman') part in Dinosaur Provincial Park (Dodson, 1971, 1983; Beland and Russell, 1978). There are, however, several emerging lines of evidence that suggest close proximity of the encroaching Bearpaw Sea, and perhaps even a tidal influence in some paleochannels (see Section 1.0). The former receives support from the following (Dodson, 1983):

- disarticulated remains of euryhaline fish such as gars (*Lepisosteus*), sturgeons (*Acipenses*) and batoid (*Myledaphus*)
- remains, including a partial skeleton, of plesiosaurs.

Although plesiosaurs are generally considered to have had a marine habitat, Dodson (ibid, p. 91) suggests that "just as certain whales and sharks do today, plesiosaurs occasionally entered estuarines and came upstream in search of novel food or perhaps to shed infestations of marine ectoparasites".

A tidal influence is suggested by two independent properties:

- Dinoflagellates and acritarchs are occasionally present in sediment samples taken from turtle carapaces (Jarzen, 1982) and 'overbank' mudstones (C. Singh, written communication, 1983). Singh strongly favours reworking from earlier formations, but the author contends than the 'protected' preservational environment of a carapace opens up the possibility of contemporaneous plankton drift up channels, and destruction in parts of the sequence more exposed to diagenesis.
- The style of lateral-accretion bedding in high-sinuosity paleochannels bears a strong resemblance to that observed in certain Recent intertidal meandering channels (e.g. de Mowbray, 1980) and the basal parts of the Horseshoe Canyon Formation at Drumheller (Rahmani, 1982). This sedimentological aspect is addressed further in Section 4.4.2.

Unfortunately, it is difficult to independently assess the distance to the prevailing shoreline. The overlying Bearpaw Formation overlies the highest exposures in the western end of the Park within ten or so metres and although the transgression is known to have been very rapid with respect to ammonite zonation (Caldwell et al., 1978), the absence of isochronous marker features within the Judith River Formation precludes a detailed time-space plot of its shoreward pinchout to the east. It is hoped that further light will be shed on this important problem as the regional subsurface study and Park fieldwork are expanded eastwards, and the cores from the Brook/Bow City 1983 drilling program (Section 3.6.1) become analysed.

Meanwhile, it is important to keep in mind that while the high-tide limit up an estuary is an easily defined point, the downstream change from fluvial to tidal dominance is transitional. Both in terms of paleohydrology, fossil assemblages and the character of point bar and overbank sequences, seaward trends will be especially gradual under conditions of very low coastal plain slope. As one calculated example, the perhaps extreme combination of a 6 m tidal range and a coastal plain slope of 0.0001 would cause the tidal limit to be located approximately 60 km inland; this assumes no local augmentation of tidal range due to narrowing embayments.

As mentioned in the preface to this guidebook, fluvial sedimentology is currently undergoing somewhat of a renaissance, in which some traditional concepts are now considered less generally applicable and a considerable volume of new data has yet to be thoroughly synthesised.

Without too much simplification, alluvial sediments (and their possible downstream tidal extensions) conveniently divide into coarse and fine members - respectively the response to channel and interchannel processes. Although sedimentologists increasingly draw attention to the relative lack of attention to vertically-accreting interchannel sediments (Potter et al., 1980), channels as the arteries of sediment transport from hinterland to base level are deservedly the focal point of interest in geologic- and resource-related aspects of basin analysis.

Channel classification therefore emerges as a fundamental issue in fluvial sedimentology. Clearly the major basis for such schemes are that channel types be classified according to morpho-genetic variables in a manner meaningful to the interpretation of ancient alluvium. Rust's (1978) review of earlier key work by Schumm, and Leopold and Wolman concluded that braiding (defined so as to be independent of river stage) and sinuosity parameters can quantitatively define four channel types. Low- and high-sinuosity systems, with sinuosity of 1.5 as a tentative divider, may be single or multi-channel in form. However the single-channel, high-sinuosity (i.e. meandering) and multiple-channel, low-sinuosity (i.e. braided) types are more abundant than the anastomosing (or straight) forms. Rust (ibid.) recognised that his classification can not yet be rigidly applied in interpretative work on paleochannel systems, but that all available sedimentological data will generally allow at least a qualitative assessment of degrees of overall sinuosity versus interchannel braiding. However Walker (1978, p. 5; 1979) reminded us that paleochannel classification is an initial step to formulation of facies models which ideally serve a four-fold purpose - namely to act as a

1) norm for purposes of comparison,
2) guide to future observations,
3) predictor in new situations, and
4) basis for an overall interpretation.

The factors governing which channel form prevails in time and space are incompletely known. However, the general concensus for braided versus meandering channel forms is that the former develops under conditions of greater slope, discharge variability, bank erodibility and supplies of non-cohesive sediment (Walker, 1979). These variables are in turn controlled by a complex set of extrabasinal (i.e. tectonics, climate, provenance) and intrabasinal (e.g. downstream hydraulic geometry, base level) factors. Accordingly, braided and meandering systems may co-exist in a proximal-distal trend (e.g. Schwartz, 1978), supercede one another stratigraphically (e.g. Nami and Leeder, 1978), or (? more rarely) co-exist in the same part of the basin (e.g. Baker, 1978). The most common situation favouring anastomosed systems in a foreland molasse setting appears to be a rapid subsidence and/or base level rise (Smith and Putnam, 1980).

Criteria to distinguish coarse-member deposits of braided versus meandering systems are discussed in a rather massive volume of literature over the last decade or so; accordingly, only the salient points are briefly discussed here. One of the earliest noteworthy contributions was by Moody-Stuart (1966), who considered that diagnostic characters are:

- overall geometry,
- presence or absence of epsilon cross-stratification,
- presence and extent of vertically-accreted channel fills,

- position and extent of levee deposits, and
- paleocurrent pattern.

The increasingly-detailed studies since the early 1970's have inevitably evolved a more comprehensive, hierarchical approach to the problem, viz. -

- a facies assemblage defined mainly on the basis of lithology, and structures (Walker, 1979), integrated with paleocurrent data (Miall, 1976);
- vertical, and where possible lateral, facies relationships (Stewart, 1981);
- the scale of paleocurrent structures with respect to their position in the fluvial system (Miall, 1974);
- overall coarse-member geometry (Friend et al., 1979) and paleohydrology (Ethridge and Schumm, 1978); and
- coarse-member density and 'interconnectedness' (Leeder, 1978).

Of the above criteria, the significance of lateral-accretion bedding is presently rather controversial. Because it is so abundant in one category of Judith River Formation paleochannels, the main elements of the controversy are briefly reviewed here for convenience.

Jackson (1978) and others have cautioned that the mere presence or absence of lateral-accretion bedding in fluvial deposits is an unreliable indicator of channel form. It is, for example, a common structure in low-sinuosity systems due to progradation of large-scale bedforms (e.g. Allen, 1983). In contrast, point-bar migration in meander belts (which generates the epsilon cross-stratification (ECS) in Allen's (1963) classification) involves lateral accretion that combines greater horizontal extent and vertical dominance within the paleochannel body. Apart from these aspects which Allen (1983) discusses, the facies assemblage and azimuths of lateral accretion should be regarded as additional vital criteria in attempts to discriminate paleochannel form at outcrop. Absolutely unequivocal interpretations are perhaps only possible where exposures are sufficiently extensive and three-dimensional (e.g. Nami, 1976; Friend et al., 1979) to allow integration of the above data with mapped paleochannel margins. Correct assignment of lateral-accretion bedding to a high- or low-sinuosity channel form has obvious major repercussions for deductions of paleoflow regime and alluvial architecture.

Point bars themselves are not diagnostic of fluvial meandering channels. They also typify the lower estuarine reaches of meandering hinterland rivers (Rahmani, 1982) and intertidal mudflat channels (Bridges and Leeder, 1976). In subsiding coastal plains that border foreland molasse environments, the point at which undirectional flow in fluvial channels becomes increasingly influenced by bi-directional tidal influences is highly significant sedimentologically. Tidal ranges and coastal plain slope collectively determine how far inland the tidal limit penetrates. According to S.G. Pemberton (oral communication, 1983), the intermediate zone of brackish water is usually represented by a peak in trace fossil occurrence. The ratio of spores and pollen versus marine microfauna is often used as a relative indicator of shoreline position (e.g. Wall et al., 1971), but the lack of an exact reciprocal relationship suggests that this parameter's ability to locate a tidal limit is questionable.

In fluvial point bars, lateral-accretion bedding develops upon initial waning in stage from competent flood discharge. Flow is perennial and the minimum recurrence interval of such events is typically annual. Hydraulic geometry is such that bankfull depth is accompanied by maximum velocity. In contrast, the diurnal ebb-flood cycles of tidally-influenced channels involve maximum velocity at intermediate-high depths and widths, and slack water at maximum stage. Distal reaches of intertidal mudflat channels empty during ebb tidal stages.

Given these considerations of marked differences in fluvial versus tidal regimes, clear contrasts in sedimentary sequences between each point bar environment are expected. Barwis (1978) and de Mowbray (1980) address this problem using some specific examples, but the present author contends that contrasts are yet to be comprehensively assessed. Tentatively, it seems reasonable to suggest that the classical fining-upward, sand-dominated cycle is the result of a typical fluvial regime where fines remain in suspension. At the other extreme, the regular alternation in velocity of tidal channel flow results in a more uniform but slower rate of point-bar migration by deposition of thin laminated units separated by clay drapes.

4.2 Joints, Drainage and Orientation Exposures

A striking geomorphological aspect of the badlands in Dinosaur Provincial Park is the rectilinear network of drainage. This warrants study because it is useful to know which sections are likely to be most perpendicular to, and parallel with average paleochannel directions established from initial studies. Straight segments of drainage range in length from 9.3 km along parts of the Red Deer River valley to as little as 270 m in 4th order coulees and gullies. Figure 15 depicts the orientation of all obviously linear reaches (n = 180) determined from a 1:30,000 air photo mosaic of the Park.

Alignments of geomorphological features developed in undisturbed strata are commonly related to fracture systems. The general study of Ozoray (1972) substantiated this for the Alberta plains, although preferred coulee alignment in the Lethbridge area is apparently a repercussion of chinook winds (Beaty, 1975b). In drift-covered terrain, the degree of control by bedrock joint sets on surface linear features is somewhat controversial (Babcock, 1974). However, the Park area is only thinly veneered with till and glaciolacustrine deposits - hence the ease of badland development. The Red Deer River valley [having originated as a spillway upon deglaciation, cf. (Kehew, 1982)] would have, in any case, facilitiated direct access to jointed bedrock for headwardly-eroding tributary systems.

Babcock's (1973) study of joint orientations in bedrock across the southern Alberta plains revealed a complex pattern comprising three orthogonal systems (Fig. 16a) as follows:

S_1,T_1 The predominant system striking ca. 065° and 155° respectively, which both parallels structural undulations in major Phanerozoic stratigraphic surfaces (Robinson et al., 1969), and the alignments of maximum/minimum horizontal stress with respect to the Rocky Mountain foldbelt as detected by 'borehole breakouts' (Bell and Gough, 1981).

S_2,T_2 A subordinate system S_2,T_2 striking ca. 005° and 095°, respectively, roughly parallel and perpendicular to the crest of the Sweetgrass Arch (Tovell, 1958).

S_3,T_3 A local set oriented at ca. 045° and 135°, respectively, (of uncertain cause) which predominates northeast of Medicine Hat.

Ozoray (1972) found that linear geomorphic features in Alberta display evidence of two structurally-controlled orthogonal systems. The first, aligned 054° and 134°, appears to be a hybrid of sets S_1,T_1 and S_3,T_3 in

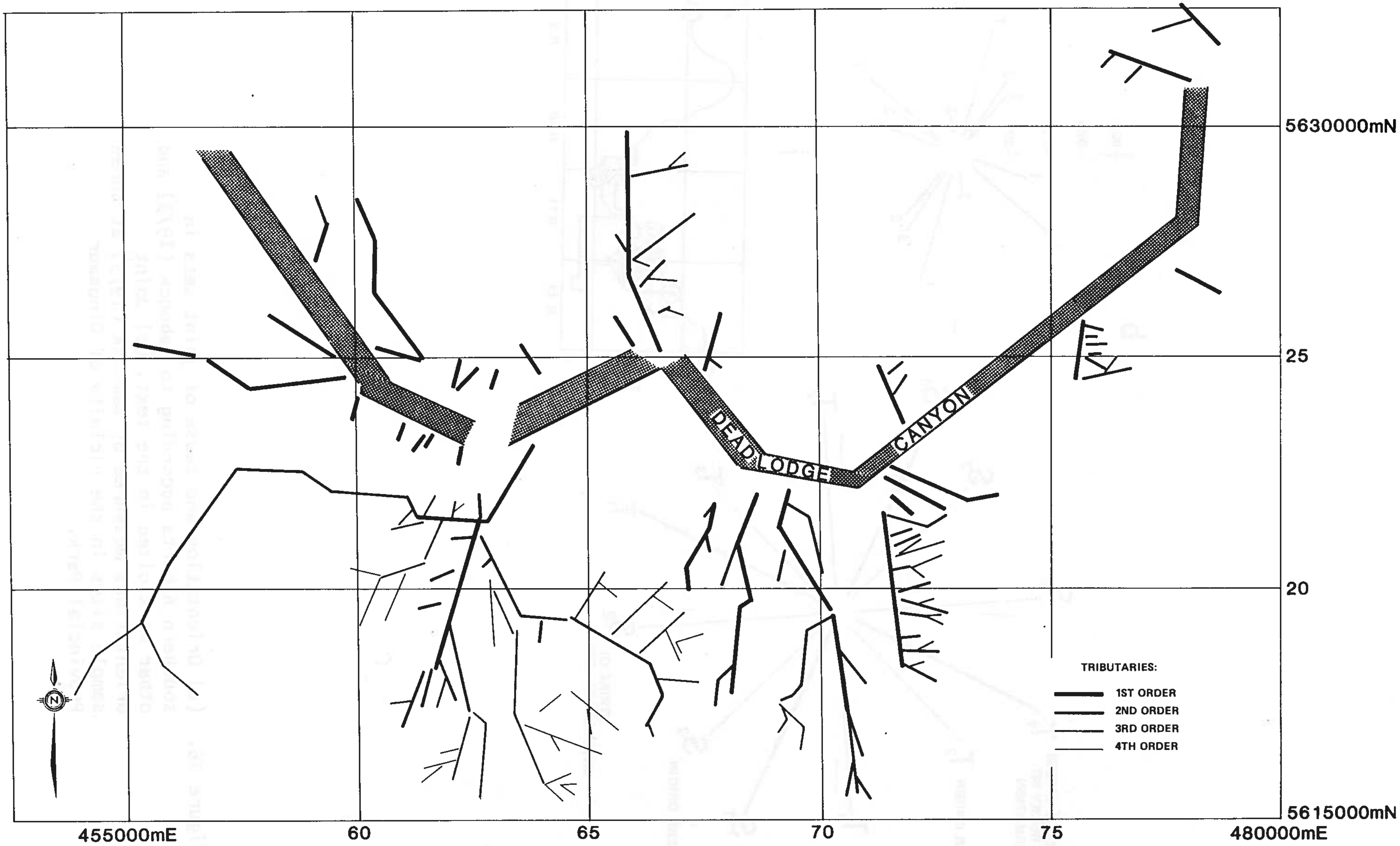


Figure 15. Traces of linear segments of coulees within the badlands of Dinosaur Provincial Park, categorized according to stream order. The course of the Red Deer River is shaded.

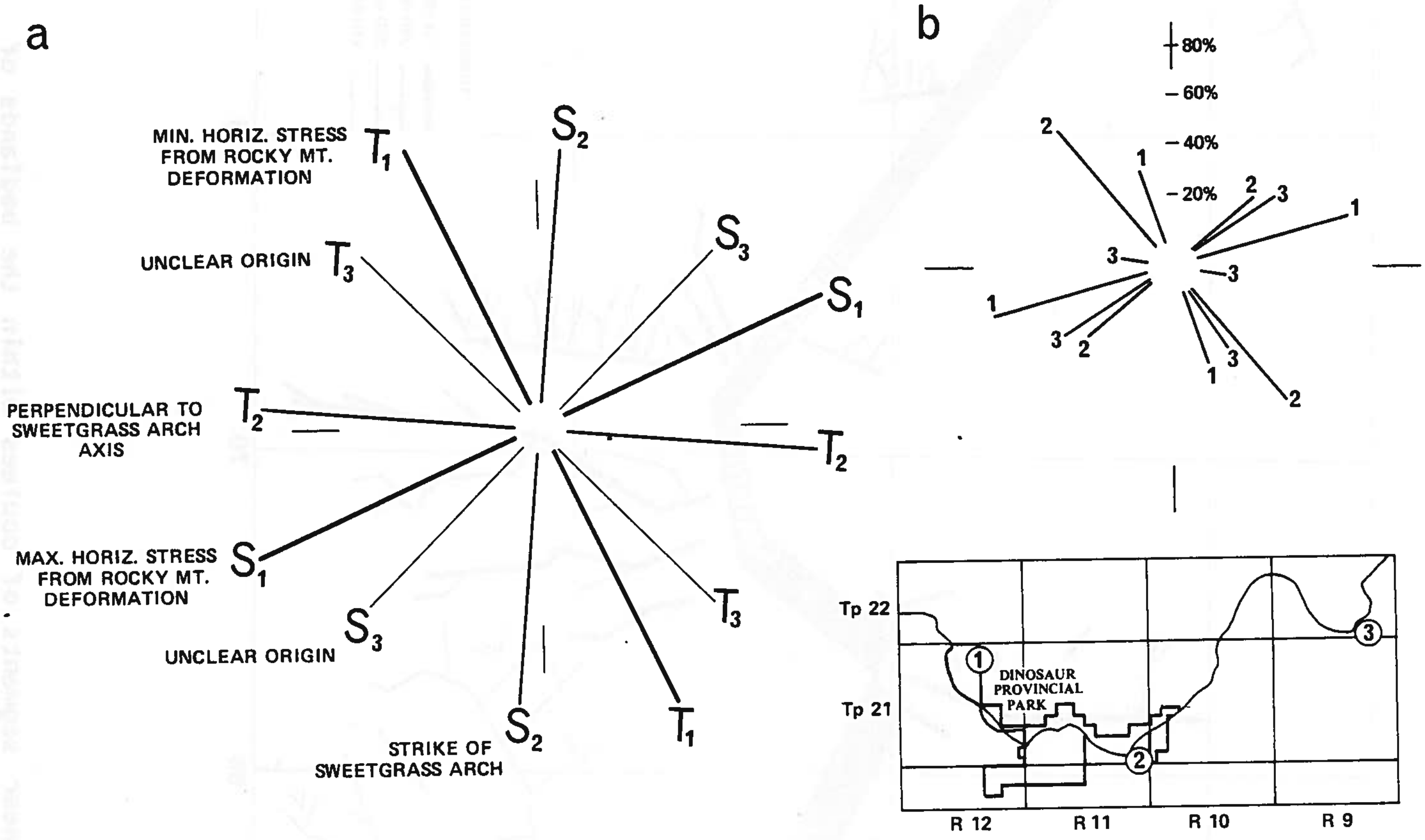


Figure 16. (a) Orientation and cause of joint sets in southern Alberta according to Babcock (1973) and other work cited in the text. (b) Joint orientations measured by Babcock (1973) at three sample sites in the vicinity of Dinosaur Provincial Park.

Babcock's (1973) study. Ozoray's second set was described as meridional and latitudinal, and thus appears to relate to S_2,T_2.

Three of Babcock's sample sites were located in badlands along the Red Deer River valley enclosing the Park (Fig. 16b). In downstream order, the mean orientations parallel 1) S_1,T_1, 2) S_3,T_3 and 3) $S_1,T_1/S_3,T_3$ hybrid and T_2. One joint orientation was found to predominate at each site, and inter-site variability in joint patterns is evidently typical (Babcock, 1974; Fig. 4). The question arises, are these bedrock joint sets replicated by the network of coulees?

Using a 10° sector scale, the rose diagram of the raw frequency data (Fig. 17a) is clearly polymodal but χ^2-test reveals that the observed pattern does not depart significantly from a random distribution. However, weighting of the orientation data according to segment length (Fig. 17b) accentuates the modes and produces a statistically-significant degree of preferred orientation at the 95% probability level. Comparing the principal alignments of drainage in Figure 17b with Babcock's local joint orientation modes indicates a pronounced parallelism for T_1, S_2 and S_1/S_3. Thus, the direction of minimum compressive stress within the Alberta syncline and the strike of the Sweetgrass Arch structure emerge as the probable principal orientations on badland drainage patterns. Inspection of Figure 17 reveals that the mode at 075° comprises a relatively high number of short segments. Since none of the reported joint sets have this specific orientation, this mode may relate to the action of prevailing winds (cf. Beaty, 1975b).

Partitioning of the bulk drainage data according to stream order reveals marked differences in preferred orientation (Fig. 18). The precursor spillway, now Deadlodge Canyon, was clearly guided in its course by the regionally predominant set S_1,T_1. Subsequently evolution of tributaries, which the author envisages to have occurred at an exponentially declining rate during the Holocene, has been guided mainly as follows: 1st order - S_2, 2nd order - S_1, 3rd order - S_1/S_3 and S_2, 4th order - T_3. Undoubtedly, this differentiation partly reflects spatial/stratigraphic variation in the prevalence of joint sets, but it also may indicate a chronologic progression in the geomorphic influence of different joint systems during postglacial isostatic rebound. The data suggests that the alignments of minimum compressive stress and the Sweetgrass Arch probably exerted a strong influence on early drainage development, followed by the enigmatic system developed northeast of Medicine Hat. A minor influence by the orthogonal orientations in each of these joint sets for all stream orders is also suggested.

To conclude, stratigraphic section and correlation work in coulees should recognize the control by regional joint sets on preferred orientation of continuous outcrops. First order tributaries have the highest probability of best exposing the true dip of lateral accretion surfaces of high-sinuosity paleochannels (see Section 4.4.2). On the other hand, profiles across the average direction of low-sinuosity paleochannels (Section 4.4.3) are comparatively uncommon. The exposures within the heavily dissected tracts of badlands at Steveville, and around the Park headquarters, are sufficiently three-dimensional that these problems are alleviated. These findings have influenced the methodology of fieldwork reported in this guidebook.

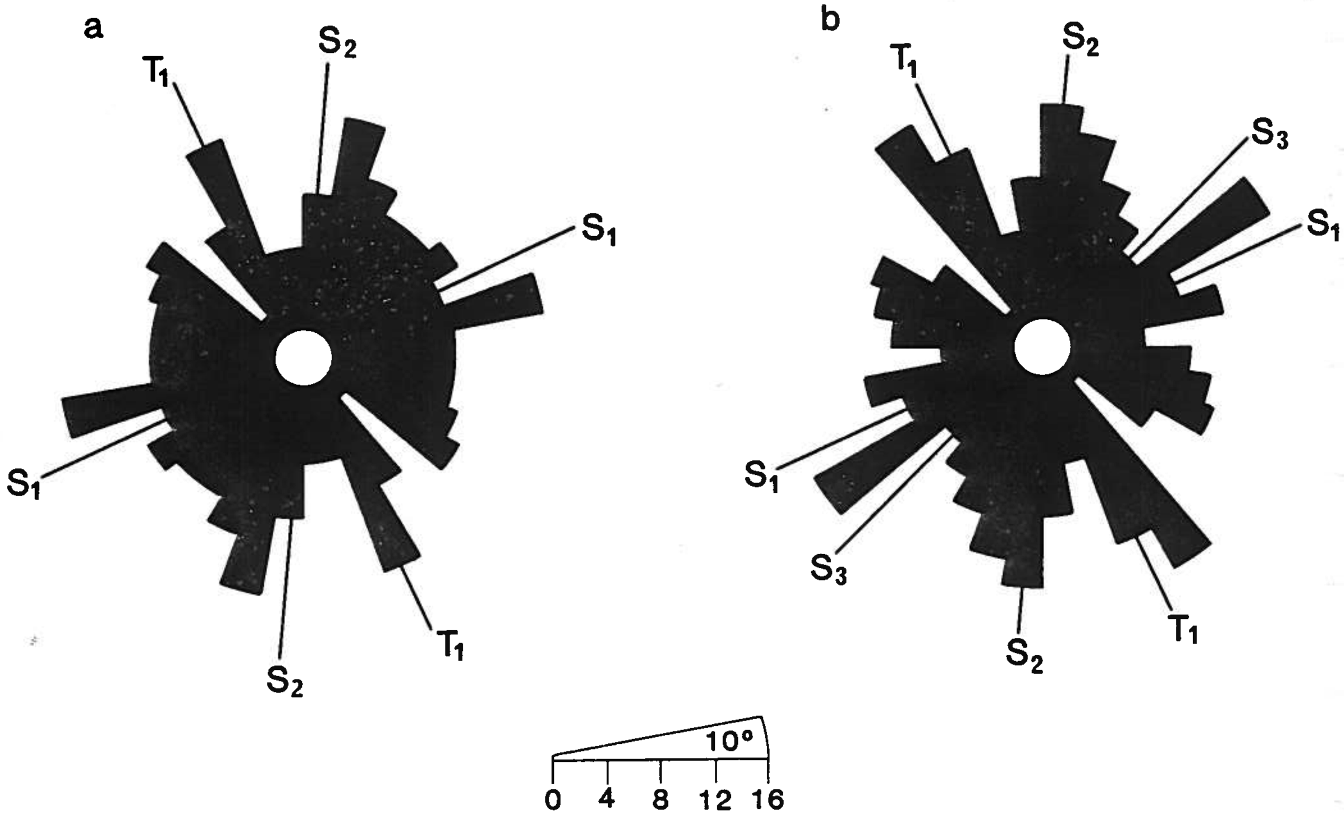


Figure 17. Rose diagrams of the data shown in Figure 15, superimposed on selected southern Alberta joint sets (Figure 16a). (a) Raw data of orientations. (b) Data weighted according to segment length.

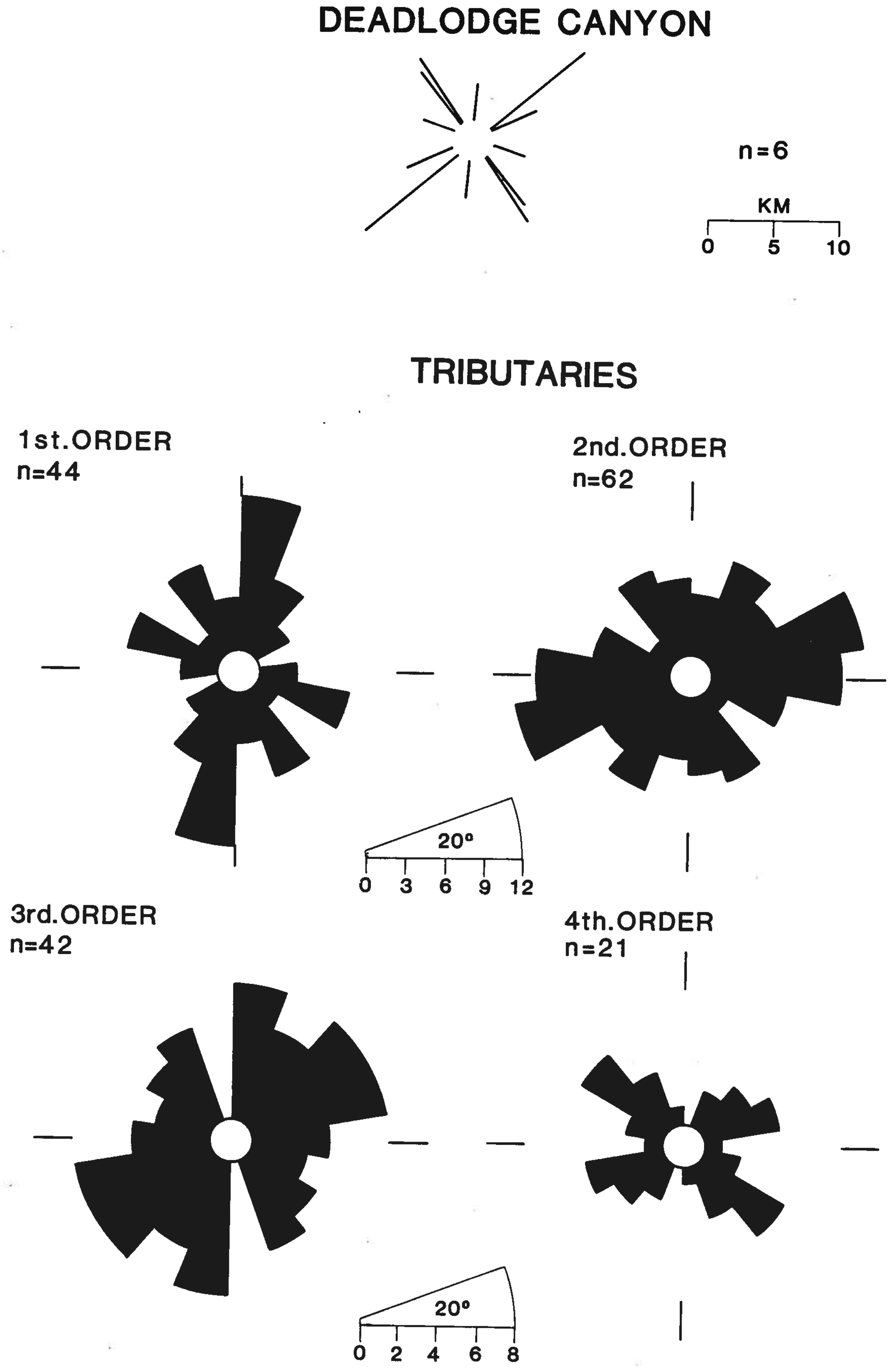


Figure 18. Rose diagrams of the data in Figure 15 partitioned according to the scale of their associated drainage elements. The one for Deadlodge Canyon shows the distance of individual reach orientations: the four for tributaries show raw data. These should be compared with the orientation of joint sets displayed in Figure 16a.

4.3 Objectives, Methodology and Progress

Although facies' definition is the fundamental step in modern sedimentological process-response research after familiarisation with the given outcrop, the scale of subdivision depends on one's objectives, time and abundance of apparent facies' criteria (Walker, 1979; p. 1).

Given the need to systematically examine the huge expanse of exposure in the Park area, these factors required careful assessment in the initial planning stages of fieldwork (Koster, 1982). Good sections are ubiquitious, and opportunities for lateral tracing in many orientations with respect to local paleocurrent direction(s) are abundant. Also taking into account the project schedule, manpower and overall objectives (i.e. to elucidate the time-space distribution of paleoenvironments with particular reference to regional coal resources and local vertebrate fossil assemblages), it was decided that a statistical approach to the spatial frequency of data acquisition would be necessary. This kind of strategy has been advocated for surface sedimentological research by McCammon (1975), even when patterns of variability are previously unknown.

Evenly-spaced (i.e. random) north-south traverses across segments of badlands between the bounding prairie limits enable:

1) the east-west extent of the Park to be covered within the time-frame available to this phase of the project;
2) a basis for selecting some key areas for subsequent site-specific work with detailed facies subdivision;
3) elucidation of regional and stratigraphic trends in lithology subjacent to the Lethbridge coal zone as interpreted from geophysical well/testhole logs;
4) answers to the Tyrrell Museum's basic questions concerning the sedimentological framework of vertebrate fossil distribution; and
5) an update of geologically-related parts of present literature and field displays for public interpretation of the Park.

Vantage points from which a camera could pan a lengthy uninterrupted panorama as an aid to between-section correlation (cf. Rahmani, 1982) are relatively few because the topography, even along main coulee walls, is dominated by irregular buttes. Accordingly, two-man field operations geared to the attainment of these five objectives are as follows. Northings in the military coordinate system (Fig. 2) are the traverse lines, commencing at the western limit of badlands (i.e. most proximal paleoenvironments). Lines of traverse were first marked in the field by a series of flag markers, using transparent copies of the 1:10,000 topographic maps on air photos of the same scale (Section 8.2). This navigational stage, which typically proceeds at 1 km per 1-2 hours, also provides the opportunity for general reconnaissance, and preliminary trenching in argillaceous units. The second, major stage is to generate a stratigraphic profile of the traverse. Using the above-mentioned maps and air photos to determine location (to the nearest 10 m) and elevation (to the nearest 2 m), a Jacob's staff is used to measure the vertical sequence at frequent points along the traverse (Fig. 19). Appropriate distances between such points are determined on-site mainly on the basis of outcrop continuity and thickness variation of major units, but rarely exceed 250 m. Rates of progress of this data-gathering stage vary greatly at 1 km per 1-4 days. Major emphasis is placed on the vertical and lateral extent of paleochannel sand bodies (Koster, 1983) in terms of their sequence, lithology, grain-size, structures, paleocurrent information and macrofaunal/floral contents. Conspicuous features of intervening overbank units are also recorded. After preliminary plotting of this data, the traverse is walked for a third time to verify major elements

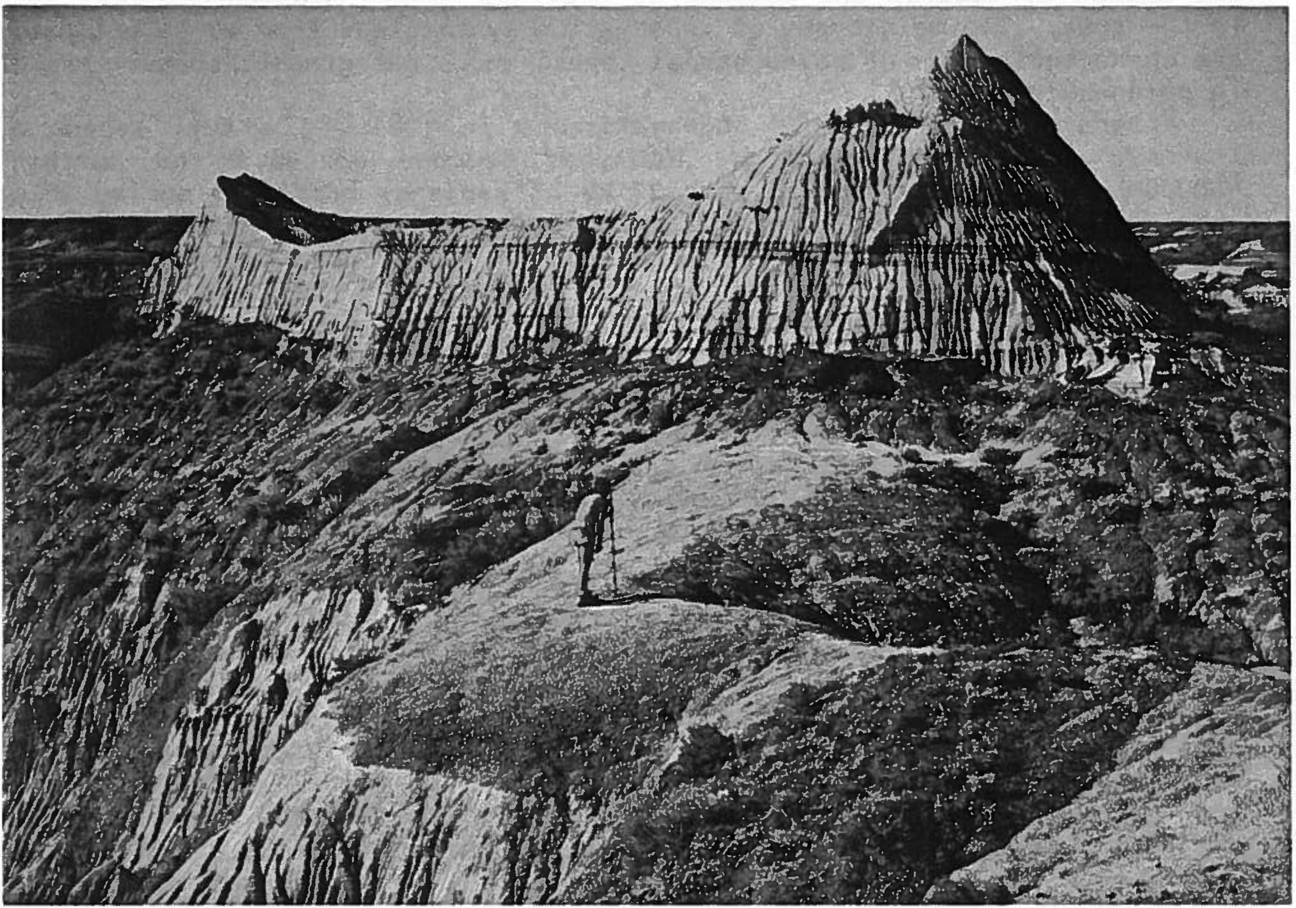


Figure 19. Traversing of the badlands in South Sandhill Creek coulee. The assistant is using a Jacob's staff to measure a 3.8 m thick mudstone which underlies a butte-forming, low-sinuosity paleochannel sequence. [5621980mN; 460020mE / elevation of contact 682 m a.s.l.]

and to sample for texture and microfaunal/flora contents.

A detailed facies' subdivision is precluded by the weathered nature of inter-channel sequences and the fact that cross-bed sets are often discernible only within concretions, but in any case impractical because of the extent of outcrop and absence of previous modern sedimentological work in the area. The main types of information synthesised from these traverses are characterisation of paleochannel types, and stratigraphic/spatial trends in paleoenvironments.

Progress to date, after reconnaissance in 1981 and a full season of traverse and related work in 1982 has reached eastwards to northing 460000mE. This has involved some 12 km of badlands profiling during which over ninety channel cross-sections have been measured with approximately 270 within-channel directions or orientations for paleocurrent determinations. In addition, detailed transit surveys of channels further east and mosaic photography of 17.5 km along the north wall of Deadlodge Canyon downstream from Steveville have also been conducted.

4.4 Facies Assemblages - Description and Interpretation

4.4.1 Introduction

Geomorphology of the badlands accentuates the fact that Judith River strata are readily divisible into 'coarse and fine members', as conventionally defined (Fig. 20). Sequences appear cyclic, but traverse data reveal that coarse-member geometry is laterally variable; coarse-fine member ratios range vertically between 0.4 and 2.9. Dodson (1971) considered that sandstone units comprise about 70% of the Park sediments, and by synthesising earlier data found that all but one of the 84 then known dinosaur quarries were located in coarse members. Although fine units are on average subordinate, amalgamation of coarse members is surprisingly uncommon.

To facilitate description and interpretation, it is convenient to recognise that sequences comprise three principal types of genetic units. Terminology of these facies' assemblages reflects characteristic features that are conspicuous at outcrop. In view of Dodson's (1971) earlier account of lithologic features, the following descriptions are brief and emphasise those aspects of paleoenvironmental significance.

4.4.2 Laterally-accreted, upward-fining, heterolithic sequences

a) Description:

Almost 70% of the coarse members so far encountered fall into this category. Their most prominent feature is lateral-accretion bedding (Fig. 21), conspicuously outlined by sloping sand-mud couplets and/or, less commonly by ironstone horizons. The nature and degree of textural heterogeneity varies considerably, as demonstrated by Figure 22. Individual couplets (usually on a scale of decimetres) may fine-upward, coarsen-upward or be sharply segregated; ratios vary widely from 10-90%. Upward-coarsening couplets, usually well laminated, typically contain an increasing percentage of coarse-grained intervals as the sand-dominated upper part of the cycle is approached. Couplets which fine upward are typically capped by more massive mudstones.

The sandstone layers are very fine to fine grained, and contain rippled

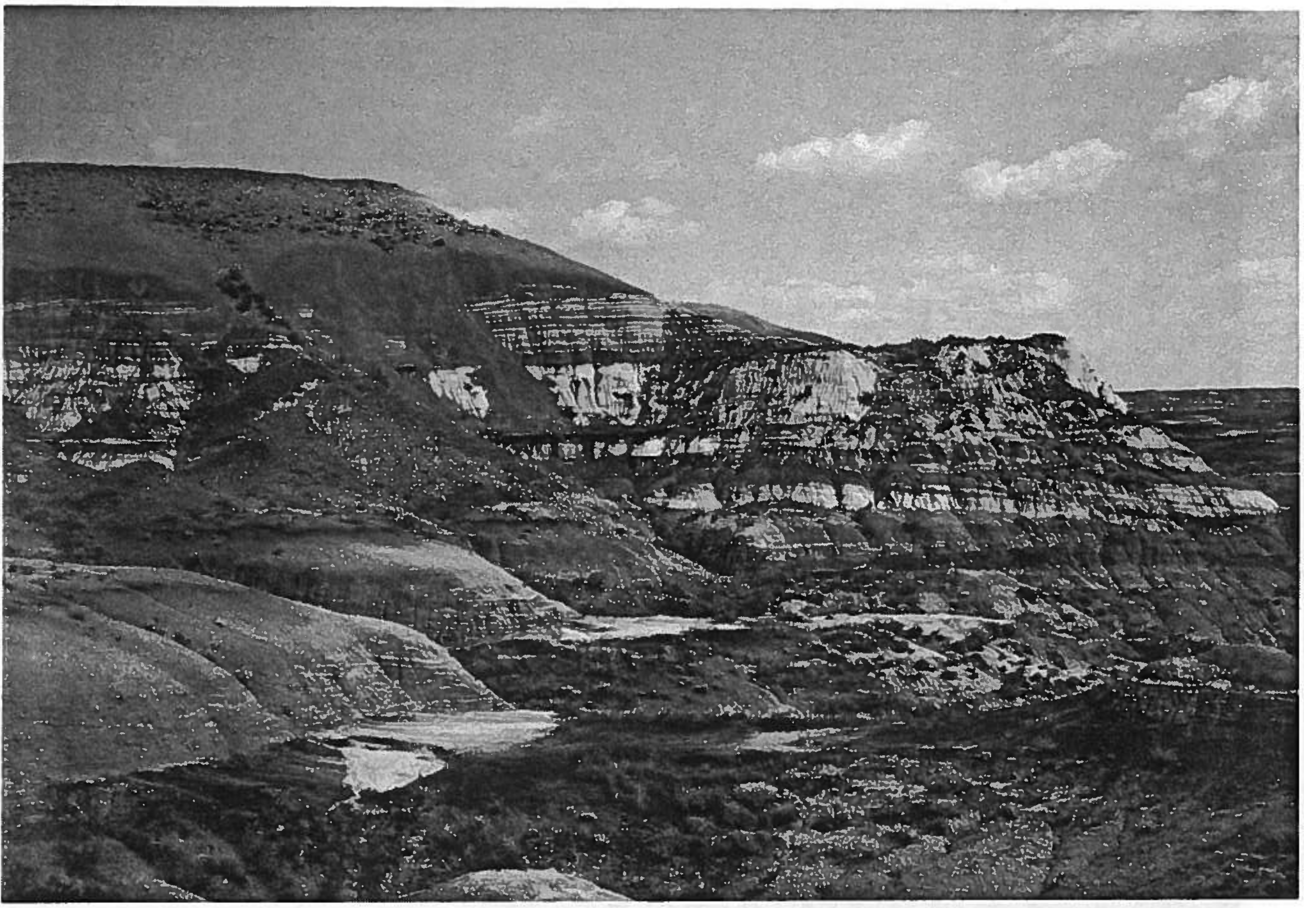


Figure 20. An excellent exposure immediately beneath prairie level that demonstrates an alternating sequence of 'coarse and fine members', typical of the Judith River Formation in the Park. The 'coarse members' comprise both laterally-accreted and vertically-aggraded paleochannel sequences. [5628920mN; 456020mE / basal elevation of view approx. 676 m a.s.l.]

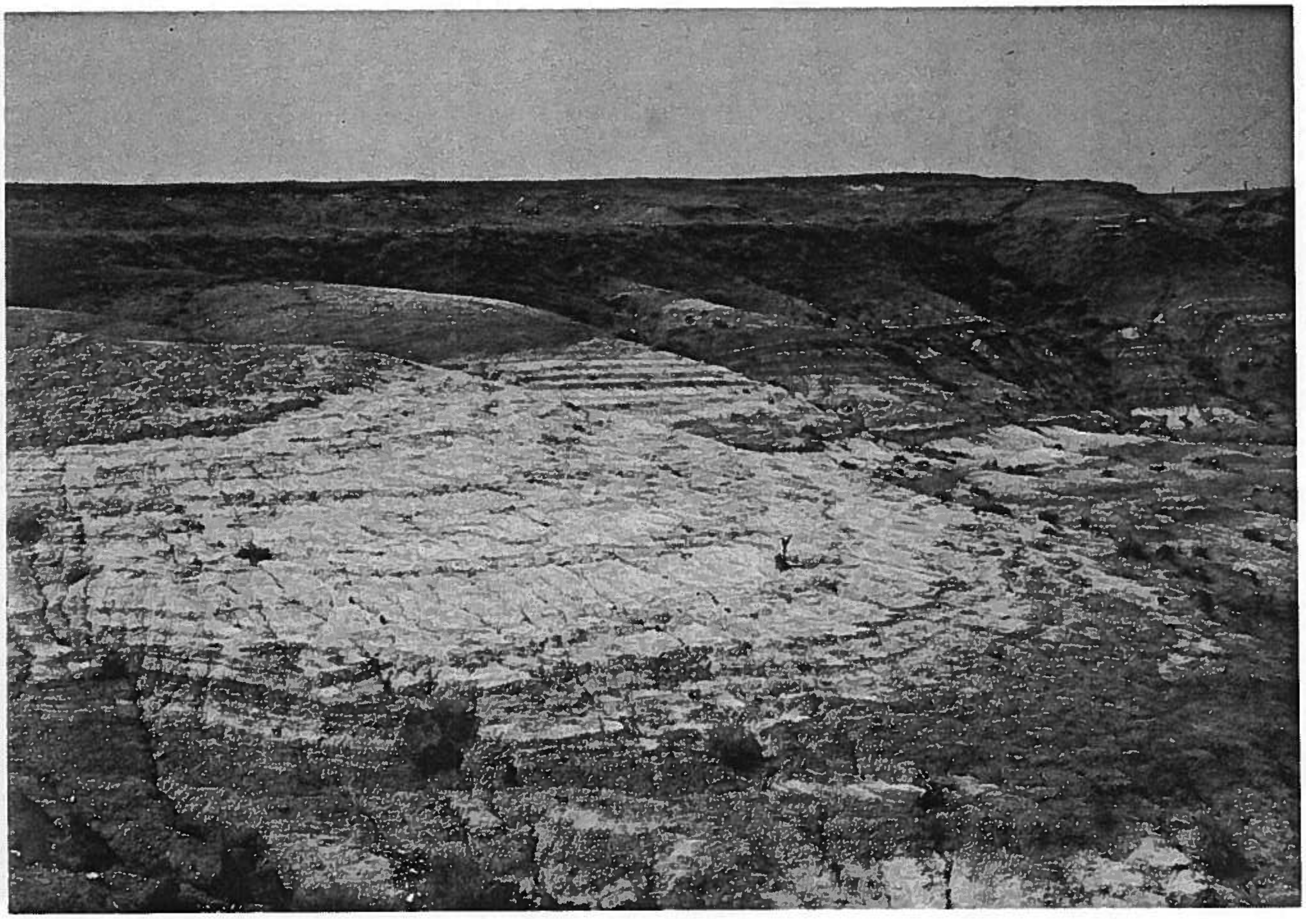


Figure 21. Panorama looking west of a 3.1 m thick, laterally-accreted sequence with a 200° spread in direction of 4° accretion clockwise from 043° in the foreground, to 242° in the distance. The argillaceous component of sloping sand-mud couplets increases in the same direction.
[5626670mN; 454900mE / basal elevation of unit 702 m a.s.l.]

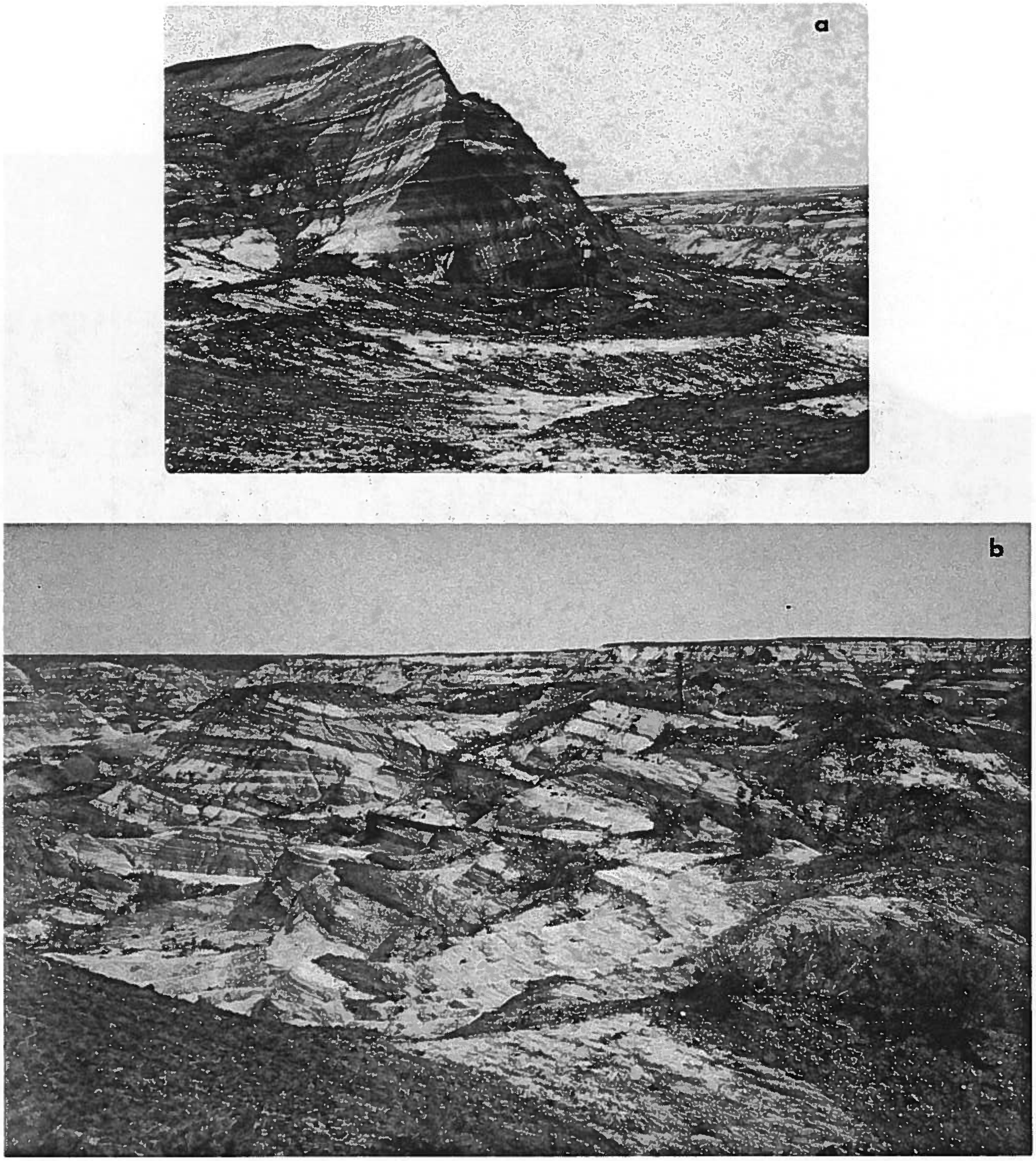


Figure 22. Examples of (a) upward-fining, (b) upward-coarsening and (c) sharply segregated sand-mud couplets in laterally-accreted paleochannel sequences (overleaf). (a) is 9.3 m thick and dips at 11° towards 207° [5629500mN; 456000mE / 678 m a.s.l.]. (b) is 3.9 m thick, with maximum dip of 12° towards 155° [5621220mN; 460080mE / 704 m a.s.l.]. (c) is 7.5 m thick and dips at 11° towards 192° [5626570mN; 455000mE / 702 m a.s.l.]


c

horizons (or rarely climbing-ripple) units - but these are often not discernible. Most bedding planes are smothered with carbonised plant debris that may, because of their bentonitic[1] non-concretionary nature, display strong preferred orientation. The intervening 'mudstone' units are bentonitic, rich in well-preserved palynomorphs, and invariably dark grey and carbonaceous. Couplets lack trace fossils[2], (apart from rare signs of small-scale burrowing) and evidence of dessication. Lithologically, they are either massive mudstone but more commonly, finely interlaminated mud-sand intervals. Iron-cemented siltstones, on the other hand, commonly contain vertical rootlet markings that are occasionally made obvious by small-scale differential weathering around stem positions, thickness of such units seldom exceeds 15 cm.

Lateral-accretion bedding occupies the full depth of nearly all units. The basal part of thicker ones may be, alternatively, sand-dominated in which case there is an up-slope intercalation of sand-mud couplets (Fig. 23). In the latter case, concretionary cosets of planar cross-beds up to 70 cm and trough-shaped sets several metres wide are common. Vector means of such structures (available sample size rarely exceeding 10) deviate from the dip direction of accretion bedding above by between 68° and 141°, but the average is 94°. Isolated vertebrate bone fragments and pebble-sized mudstone intraclasts are invariably aligned perpendicular to adjacent cross-bed azimuths.

Irrespective of the downward extent of lateral-accretion bedding, accretion surfaces are planar or mildly concave-upward. However, the inclination of sand-mud couplets is occasionally interrupted by steeper reactivation surfaces and/or by local chaotic masses of slumped sediment. Basal surfaces are sharp and planar over observed distances of at least 120 m; gradational upper boundaries are ubiquitous, and they are commonly underlain by ball-and-pillow structures.

In the 65 laterally-accreted units thus far encountered, data on thickness and inclination are log-normally distributed. The average sequence is 3.8 m thick and dips almost at 7°, but units approaching 20 m have been sighted off traverses (Fig. 24). Vectors of lateral-accretion bedding are distributed with modes between 330-060° and 120°-240° (Fig. 25a), and there is no obvious tendency towards a different spatial configuration for the thicker units (Fig. 25b). The vector mean of 63 contained cross-beds is 084° with a magnitude of 51%. Although the lateral extent of accretion bedding commonly exceeds 200-300 m, several localities at which the structure ultimately pinches out are known (Fig. 26).

b) Interpretation and paleohydraulic reconstruction:

The geometry and laterally-accreted nature of this coarse member type attests to accumulation as point bars in single-channel, meandering systems. The term 'epsilon cross-stratification' abbreviated ECS, is therefore appropriately applied (Jackson, 1978). The structures in certain sand-mud couplets and the overall style of the ECS resemble those of meandering tidal channels (Terwindt and Breusers, 1972; Visser, 1980; de Mowbrey, 1980). Also, the complete repetitious coverage of fine-grained sediment drapes on point bar surfaces is not easily resolved with fluvial velocity-stage relationships. Slack water conditions with bankfull flood tidal stages can more simply explain

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[1] term used synonymously with montmorillonitic to refer to disseminated volcanic ash-fall sediments.

[2] based on the observations of the author, and those by S.G. Pemberton, Alberta Geological Survey, in a segment of a eastern traverse.

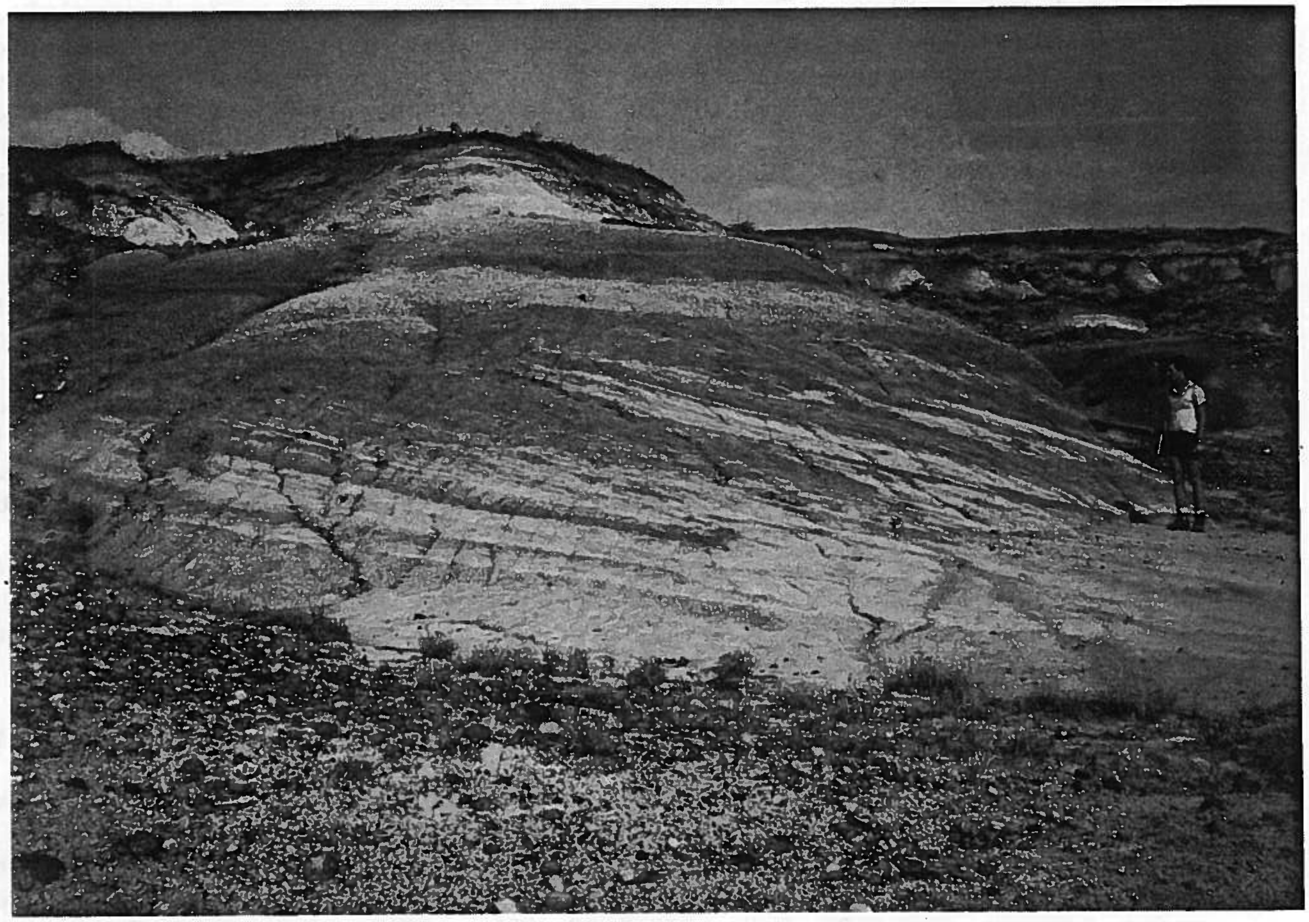

Figure 23. Upslope intercalation of sand-mud couplets in a fining-upward, laterally-accreted paleochannel sequence. The unit is 2.2 m thick and dips at 12° towards 044°.
[5627450mN; 455020mE / 688 m a.s.l.]

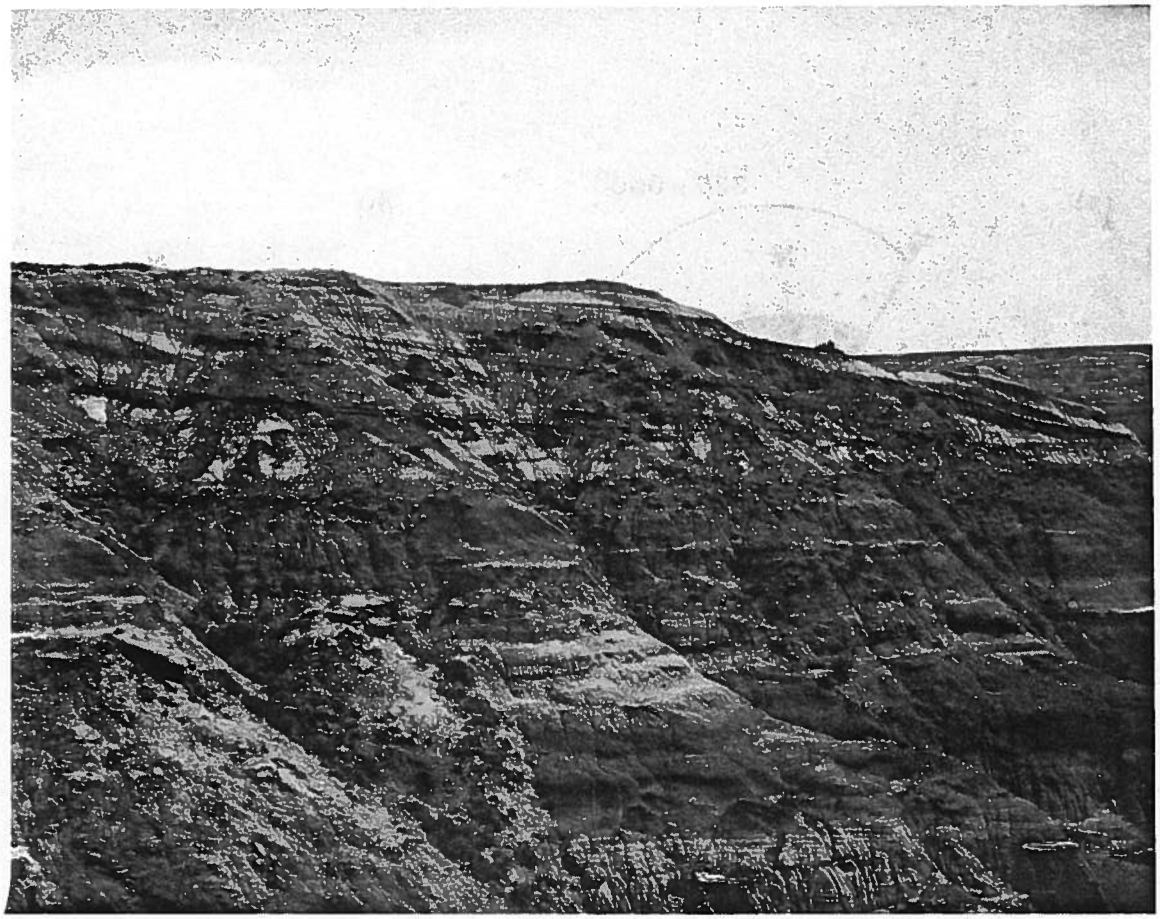

Figure 24. View of approx. 18 m thick point-bar sequence that apparently correlates with Figure 22a. The unit dips westwards and displays good upward-fining from a sand-dominated basal part, through sloping ironstones and sand-mud couplets to the overlying mudstone. [5629500mN; 455600mE / prairie elevation 698 m a.s.l.]

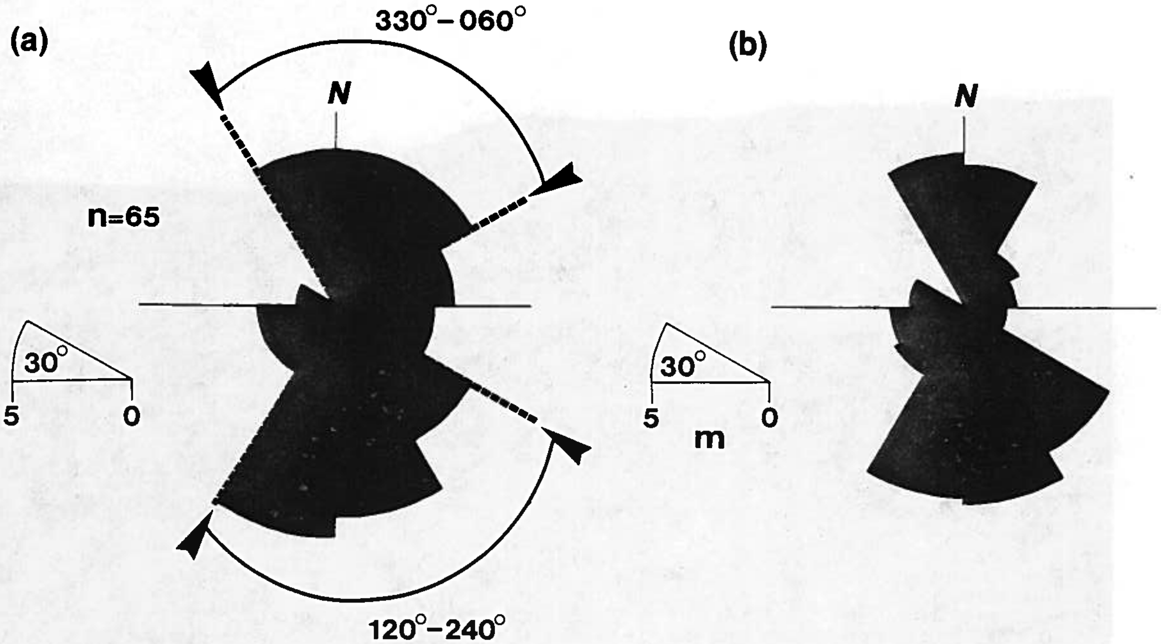

Figure 25. Rose diagram of unweighted (a) and weighted (b) data on vectors of lateral-accretion surfaces. In (a), the preferred directions of point-bar migration direction are highlighted.

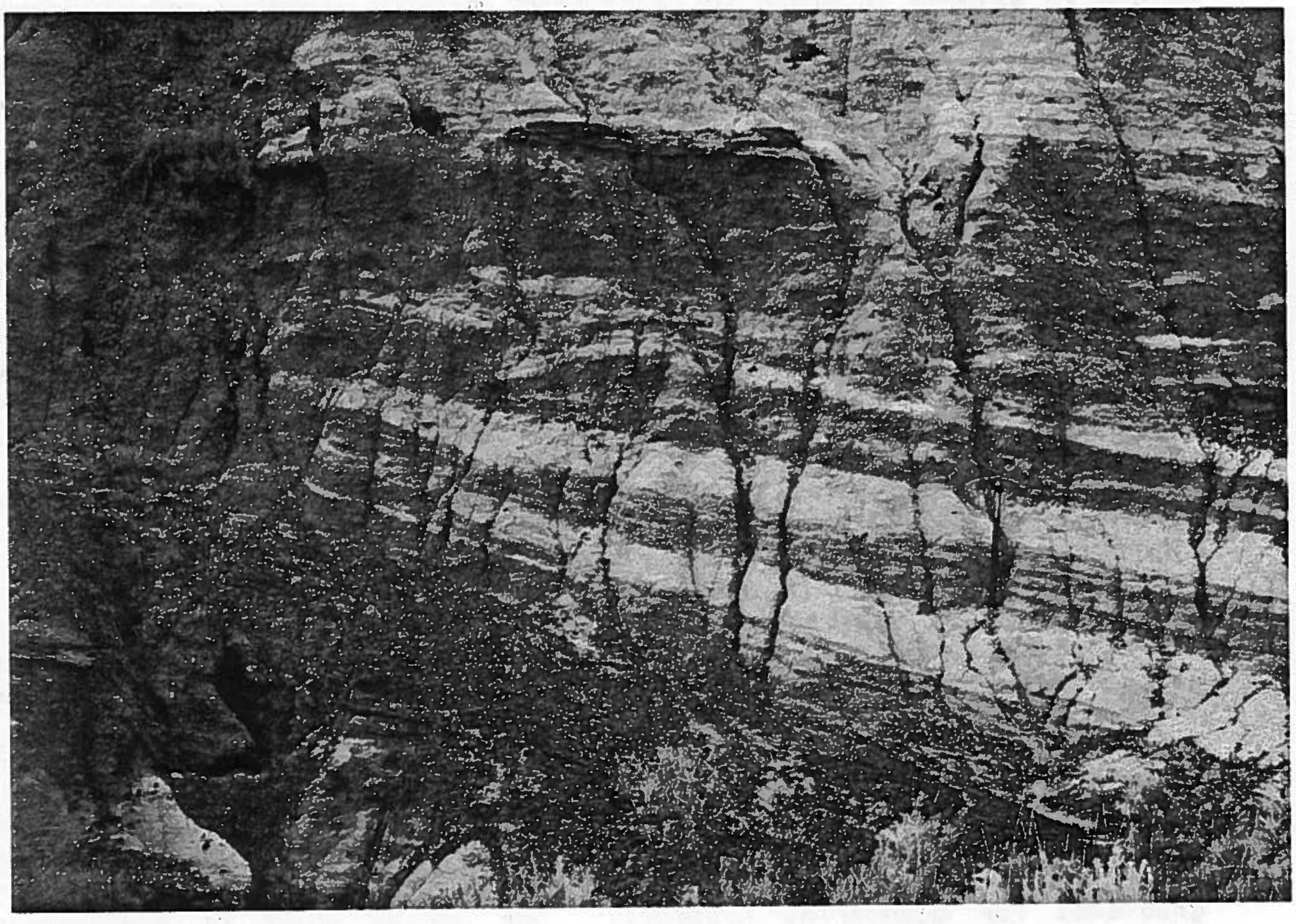

Figure 26. The up-dip pinchout of lateral-accretion bedding with a ca. 40 cm scale to sand-mud couplets. Unit thickens to 6.1 m and dips at 17° towards 231°. [5630040mN; 456000mE / 669 m a.s.l.]

surfaces is not easily resolved with fluvial velocity-stage relationships. Slack water conditions with bankfull flood tidal stages can more simply explain this feature. However, other authors (e.g. Meulen, 1982; Mossop and Flach, 1983) ascribe a similar set of point bar features to a fluvial origin. Further work is needed to clarify the origin(s) of heterolithic ECS: for now, a fluvial origin is assumed in order to reconstruct meander geometry and paleohydraulic conditions.

Migration geometry of individual fluvial point bars evolves by expansion, rotation and translation, or some combination thereof (Daniel, 1971). Jackson (1976) subsequently recognised five typical categories of meander growth - viz. expansion, translation, expansion + rotation, expansion + translation, expansion + rotation + translation [his order]: this sequence is one of increasing complexity. An alternative approach is to recognise that simple expansion and translation probably represent end-members in a continuum, governed primarily by the overall system gradient from low to moderate levels, respectively. Increasing slope obviously limits the degree to which a migratory channel can increase its thalweg sinuosity, and thereby favours a downstream component to point bar growth. Given this line of thinking, rotation is an intermediate mode, and thus Jackson's (1976) meander category 'expansion + translation' seems an unlikely combination.

Figure 27 schematically presents several repercussions of this proposed continuum in meander geometry which have considerable sedimentological significance. Perhaps the salient one concerns the probability that meander bends are prone to ultimate neck cut-off, leading to vertically-accreted channel fill sequences. This event occurs when the increasing sinuosity of an individual meander bend produces such a low-gradient, tortuous course that flood discharges seek a more direct course between adjacent channel reaches. General reference articles on fluvial sedimentology (e.g. Walker and Cant, 1979) usually assume, albeit implicitly, that all meanders are subject to a neck or chute type of abandonment. However, Figure 27 predicts that neck cut-off would rarely occur with meanders that migrated principally by translation, because this migration geometry entails a limiting value of sinuosity. Such systems would probably be typical of moderately high paleoslopes (within the range of gradients for meandering systems). The second point of sedimentological interest relates to the distribution of point bar growth directions. Meander expansion results in a symmetrical bimodal trend, where paleoslope would have to be determined from within- channel structures. In contrast, meander translation results in a downstream clustering of modes.

The distribution of Judith River ECS vectors (Fig. 25a) and the occurrence of neck cut-off fills combine to indicate that paleochannels migrated primarily by sideways expansion.

Reconstruction of paleohydrologic conditions for fluvial meandering systems is an increasingly popular field of fluvial sedimentology (Ethridge and Schumm, 1978). Its protagonists (e.g. Dott, 1983) view it as a major advance, whereas others claim that background assumptions and error margins in estimates render current methodology to be of questionable value (e.g. Jackson, 1978). Recognising its limitations, and the problem of error propagation, the present author perceives this facet of fluvial research as a valuable conceptual aid to basin-scale analysis of fluvial sequences - providing exposure is adequate to allow confident measurement of base variables.

Paleohydrologic analysis of single-channel, high-sinuosity fluvial channels initially follows one of two basic methods, depending on the presence or absence of lateral-accretion bedding (Leeder, 1973). The quality of paleochannel exposures in the Park and the conspicuous presence of ECS allow the

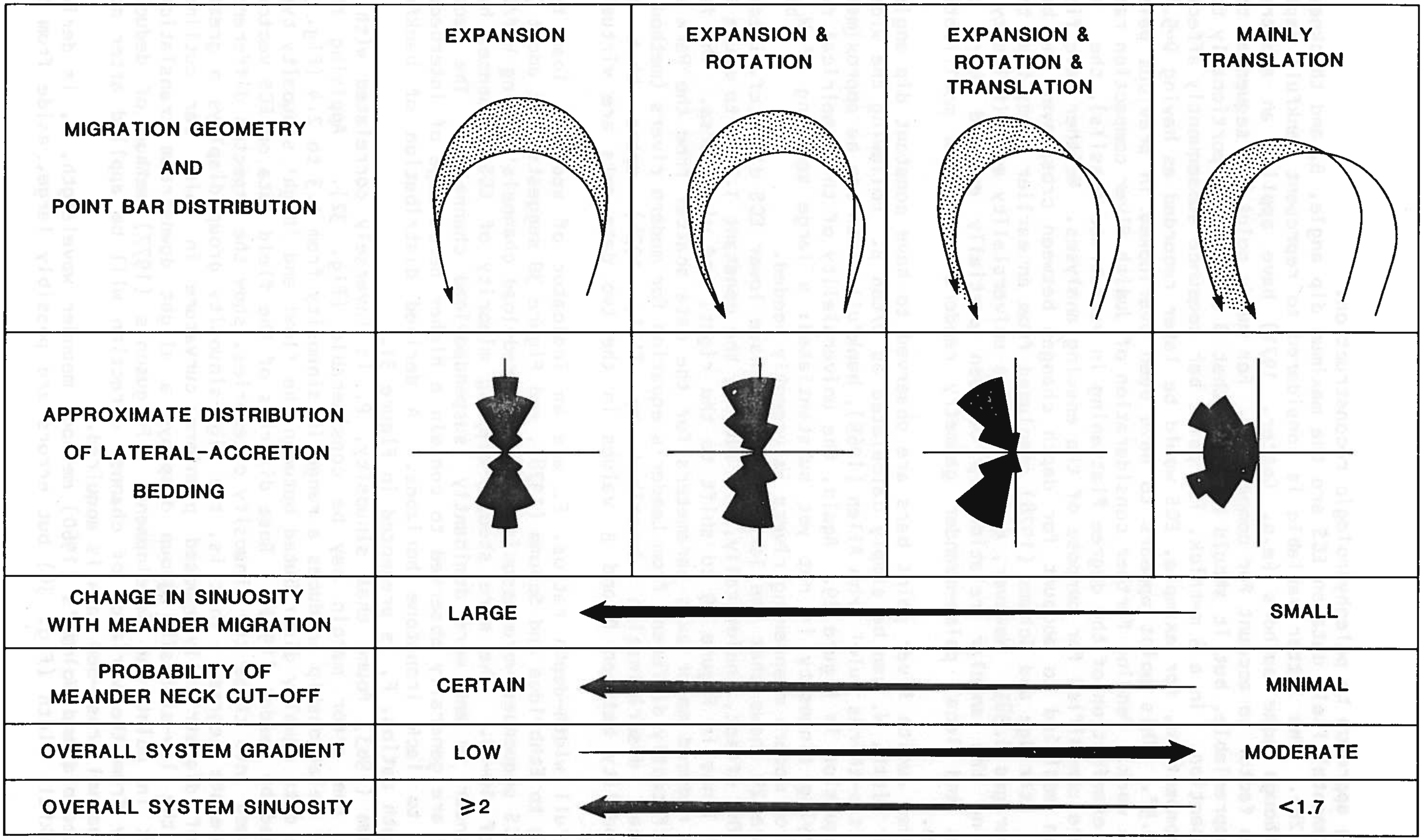

Figure 27. A theoretical attempt to predict aspects of meandering channel form and process from a consideration of the geometry of point-bar migration. Column categories based on work by Daniel (1971) and Jackson (1976).

following approach to paleohydrologic reconstruction.

Fundamental field data on ECS are the maximum dip angle, β, and thickness, D (Fig. 28). The latter variable is considered to represent bankfull depth, D_{bf}, although some authors (e.g. Cotter, 1971) have applied an arbitrary reduction factor to account for compaction. For muddy point bar sequences this may be appreciable, but it should be noted that β declines proportionally to D with compaction. In a 6 m-thick, 12° point bar seqeunce subsequently affected by 10% compaction, for example, ECS would be later recorded as having D=5.4 m and β=10.5°. This point appears to have been overlooked in previous paleohydraulic work. Pending further consideration of Judith River compaction rates (e.g. by examination of the degree flattening in vertebrate fossils), the and D data are unmodified for purpose of the ensuing analyses. Neither have field data been modified to account for depth changes between cross-over and bend reaches. Ethridge and Schumm (1978) concluded from an earlier study that this ratio averages 0.585. However, doubt over its universiality and difficulty in deciphering the angular relationship between partially exposed point bar sequences and local paleo-meander geometry renders any depth modification uncertain.

Because Judith River point bars are observed to have constant dip angles, point bar width, W, can be simply calculated as D/tan β. Following the widely adopted 'two-thirds rule' from Allen (1965), bankfull width can be approximated by the equation in Figure 29. Again, the universiality of this empirical rule with varying sinuosity is not yet substantiated: a large sampling of W_{bf}:W ratios from modern meandering rivers is urgently needed.

Figure 29 shows that the larger channels have lower ECS dips (cf. Leeder, 1973). The effect, incidentally, of reducing the constant 1.5 is to cause the field of lines in Figure 29 to shift to the right, and vice versa. The fact that the reduced major axis parameters for the data scatter from the Park are not significantly different from Leeder's equation for modern rivers (method of statistical discrimination described by Till, 1974) means that the proportionality between D and β values in the two data sets are virtually identical.

Bankfull width-depth ratios, F, are an indicator of sediment load type according to Ethbridge and Schumm (1978), and Figure 30 suggests that about 70% of the ECS sequences were associated with 'mixed-load channels' having Wbf/Dbf ratios of 10-40. The more steeply-dipping minority of ECS sequences have ratios under 10 and were dominantly 'suspended-load channels'. The second category are generally observed to contain a higher percentage of interbedded mud and to lack ironstone horizons. A derived distribution of bankfull width/depth ratios, F, is presented in Figure 31.

Schumm (1963) found that sinuosity, P, is inversely correlated with F, although the error margin may be considerable (Fig. 32). Applying this empirical relationship produces a range in sinuosity from 1.3 to 2.4 (Fig. 33) with the data equally distributed between the 'low' and 'high' sinuosity types as defined by Leeder (1973). Rose diagrams of the field data on ECS vectors, partitioned into these two sinuosity categories, show the expected differences to a moderate degree. That is, the high-sinuosity group displays a greater amount of diametrically-opposed planform curvature in point bar outlines, whereas the low-sinuosity group displays a slight downstream translational component in point bar development. Ferguson's (1977) method of deducing sinuosity from the variance of channel direction will be applied after more within-channel cross-bed data is acquired.

By Leopold and Wolman's (1960) method, meander wavelength, L, is derived from bankfull width (Fig. 34) but errors are possibly large, aside from the

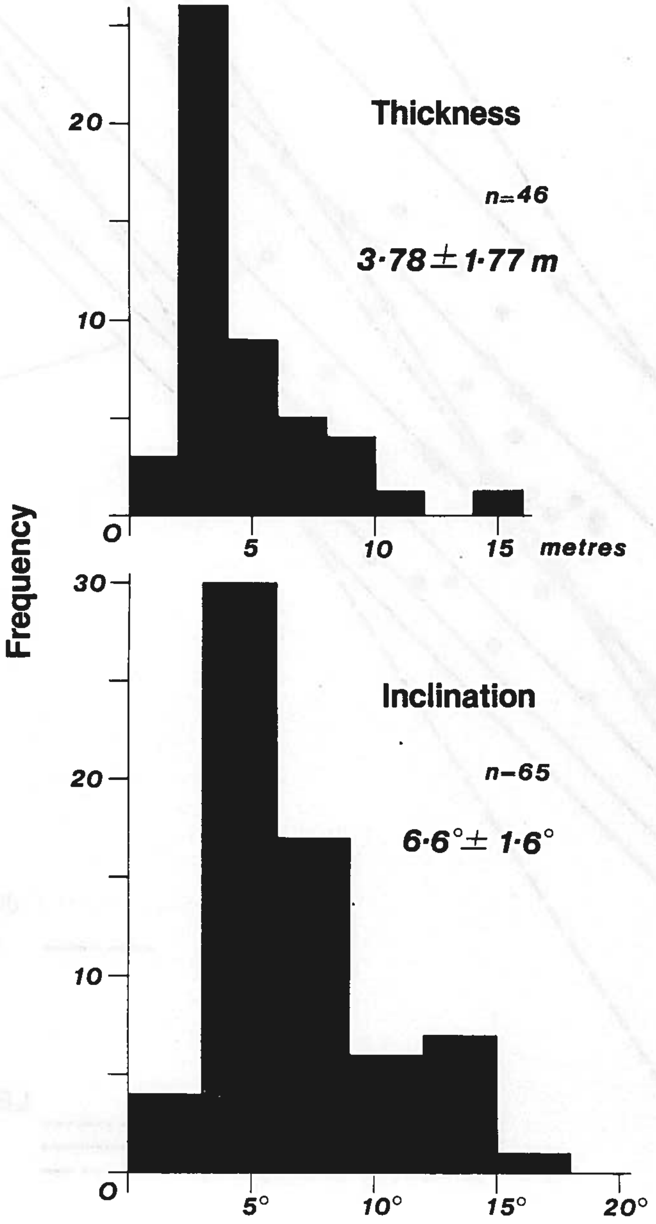

Figure 28. Histograms of thickness and maximum dip angle for measured point-bar sequences. Because of their log-normal distributions, mean and standard deviations were calculated using log to the base 10 transforms of the data.

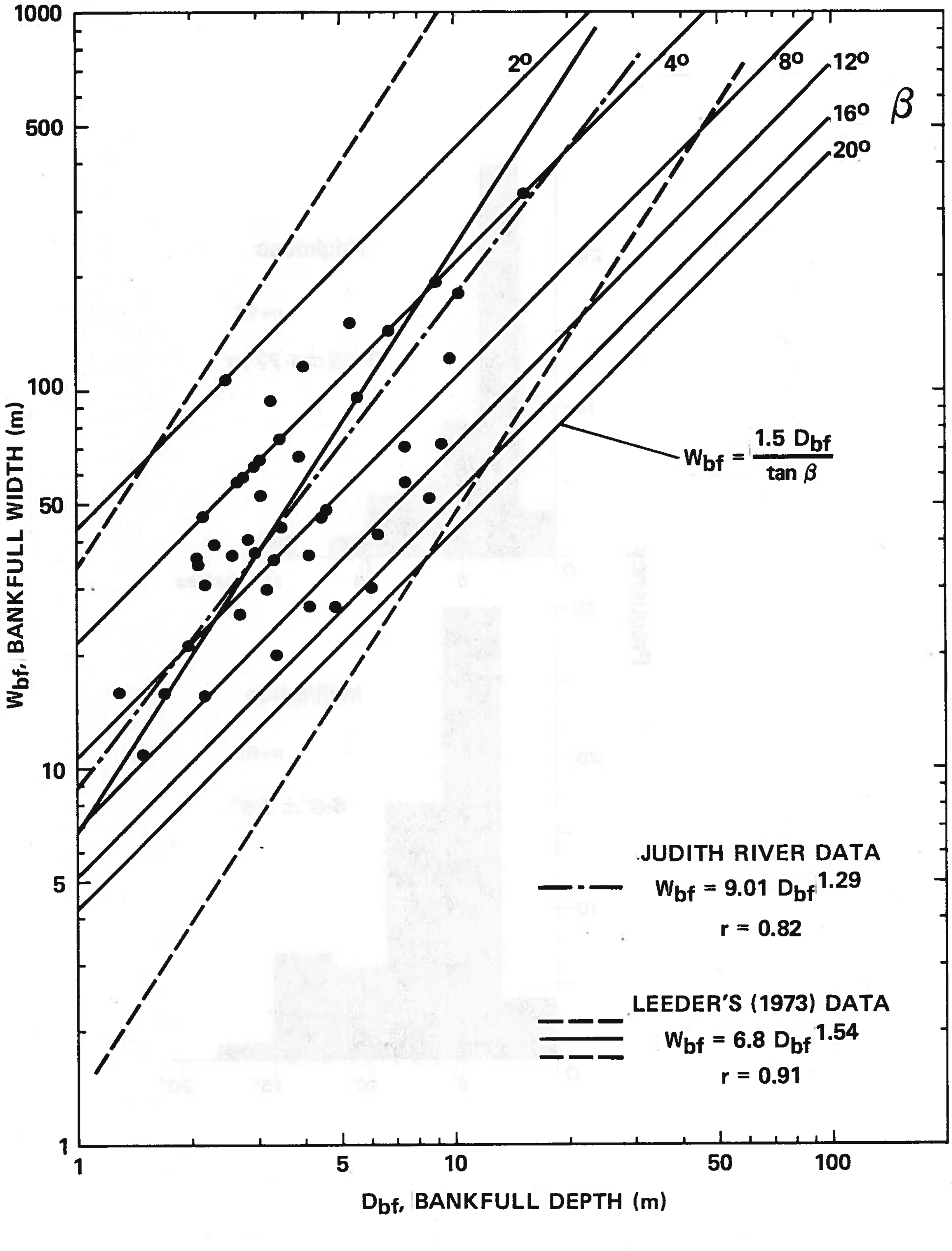

Figure 29. The relationship between inferred bankfull depth and bankfull width, calculated from field data by the equation given in the upper right. The parallel set of sloping lines are for point bar slopes at 4° intervals (cf. Leeder, 1973). Judith River data is shown in relation to Leeder's relationship for modern high-sinuosity rivers. Reduced major axis regression (Till, 1974) is applied.

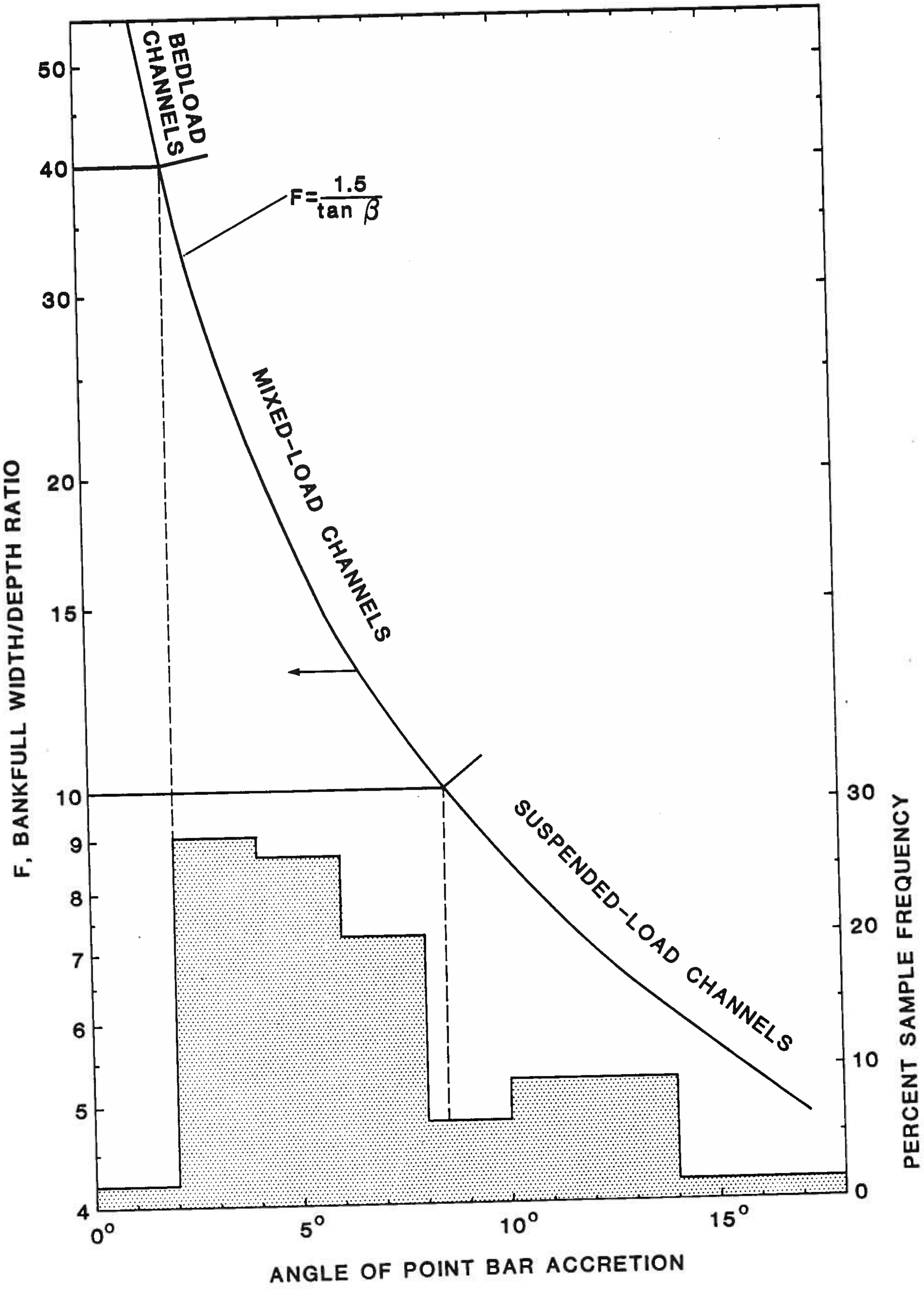

Figure 30. Relationship between bankfull width-depth ratio and angle of point bar accretion in relation to Schumm's classification of channel types. The histogram of point bar dip data is repeated to show that 70% of the ECS sequences apparently developed in 'mixed-load' channels with bankfull width/depth ratios between 10 and 40.

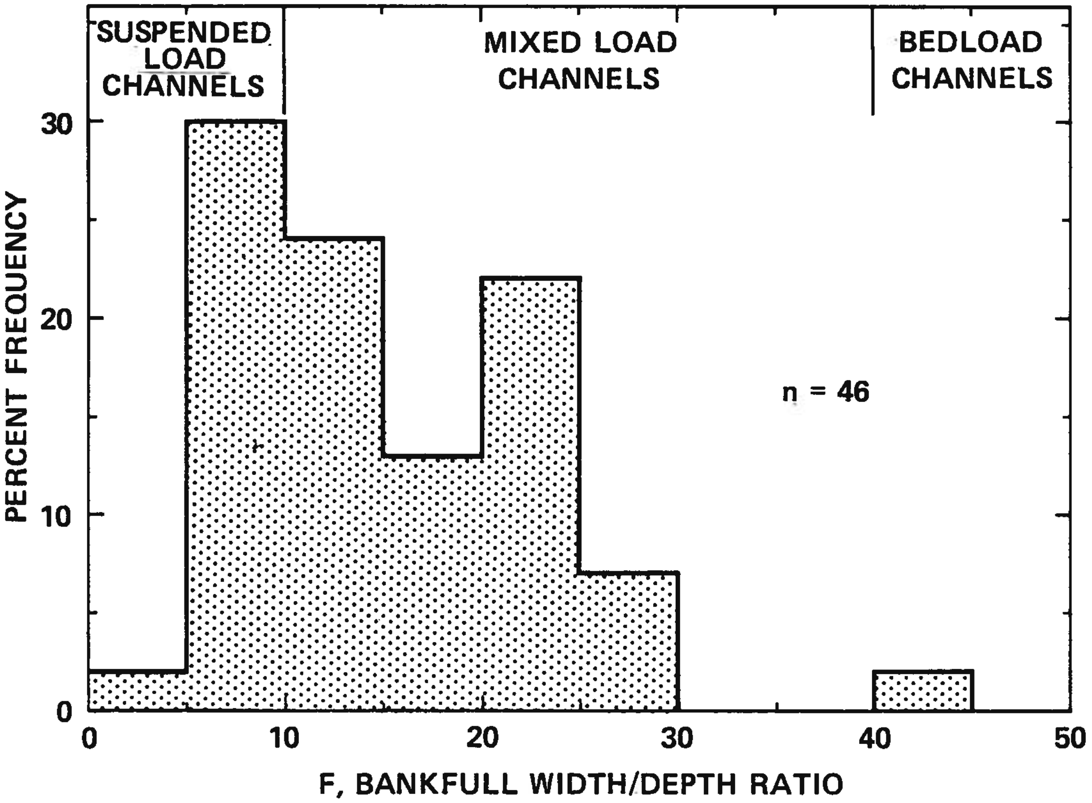

Figure 31. Histogram of bankfull width-depth ratios derived by the equation shown in Figure 30.

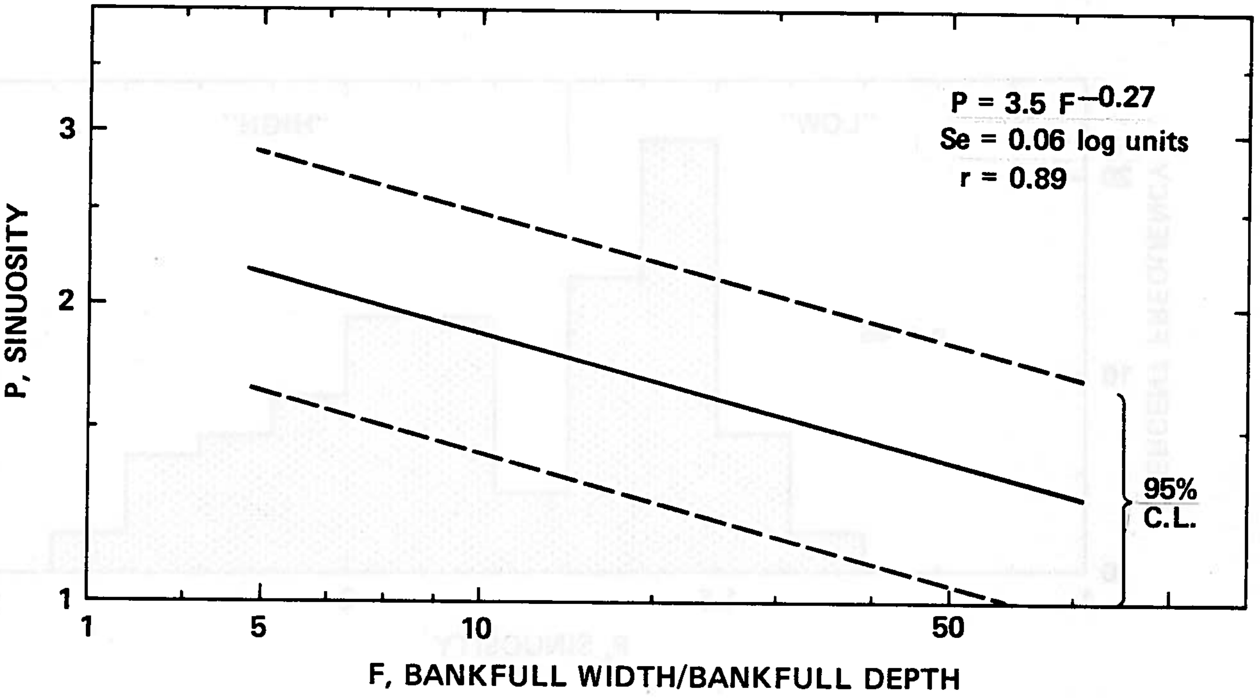

Figure 32. Schumm's (1963) empirical relationship to predict sinuosity from bankfull width/depth ratio. C.L. denotes 95% confidence limits of prediction using the least-squares regression line.

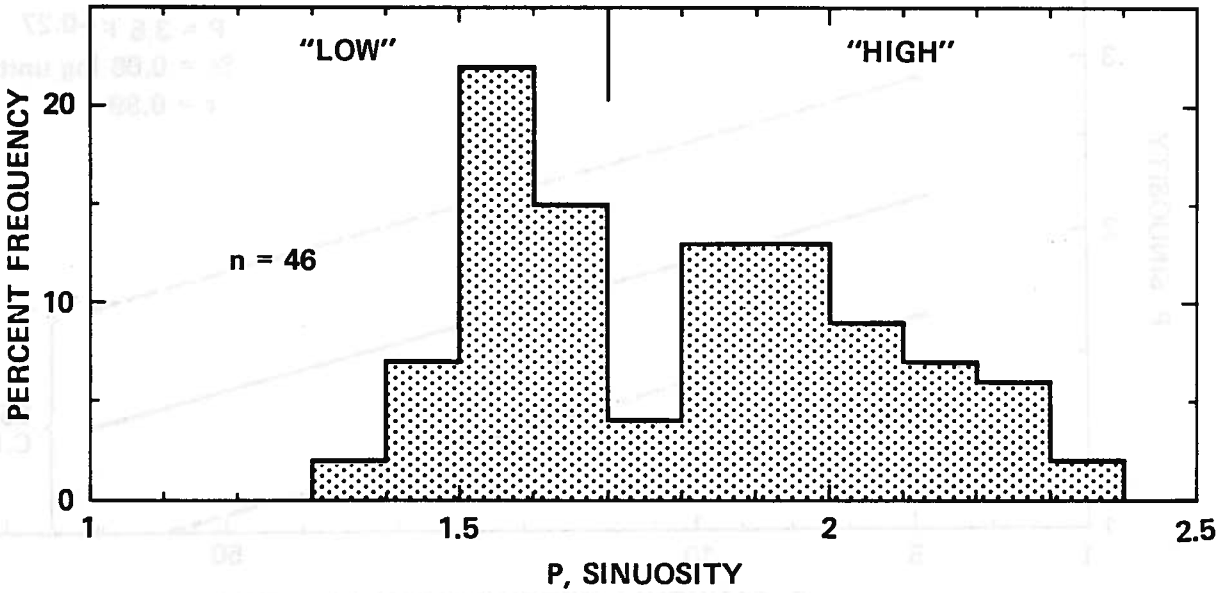

Figure 33. Histogram of sinuosity values derived from the relationship in Figure 32.

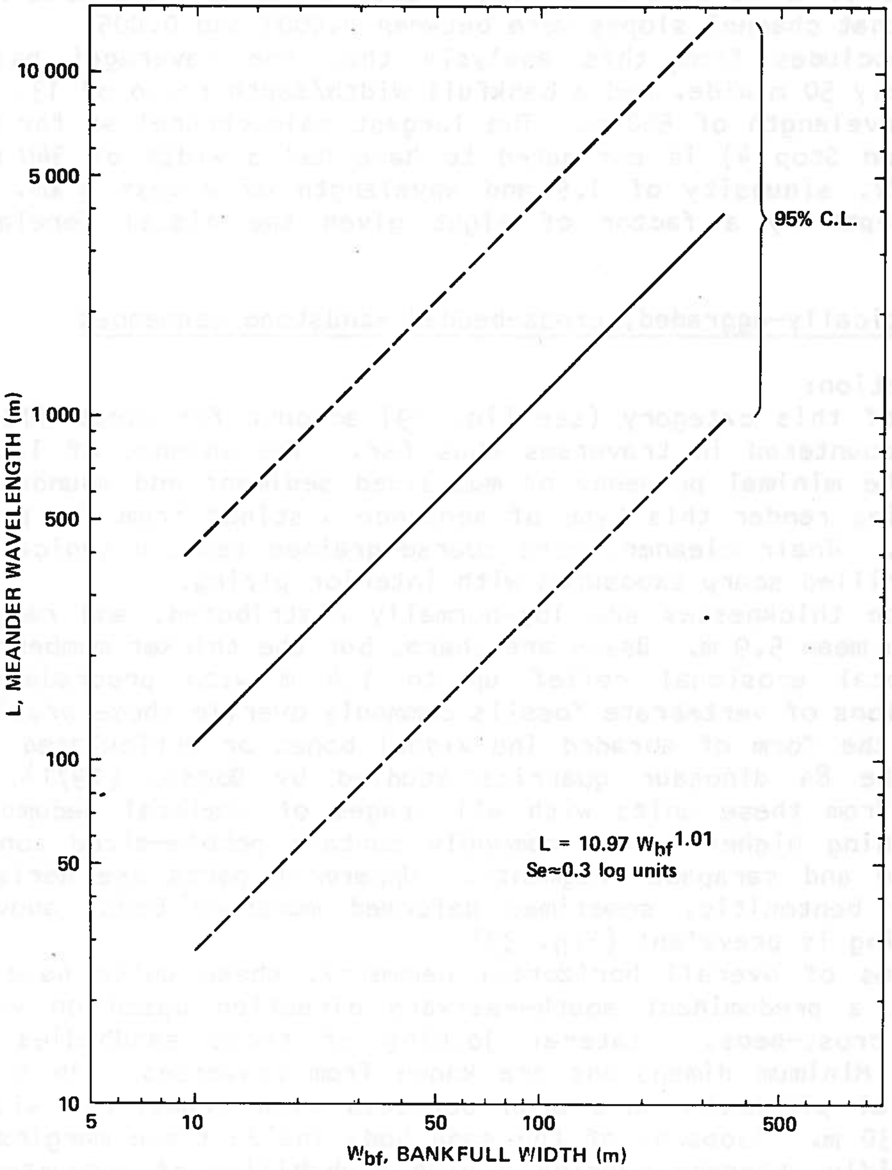

Figure 34. Leopold and Wolman's (1960) empirical relationship to predict meander wavelength from bankfull width data. C.L. as defined in Figure 32.

quality of the W_{bf} estimate itself. The resulting histogram (Fig. 35) suggests that only 20% of the meanders had wavelengths exceeding 1 km. Error propagation in using Carlston's (1965) method to deduce mean annual discharge from values of L is considered too great to warrant application. Figure 36 concludes that channel slopes were between 0.0003 and 0.005.

One concludes from this analysis that the 'average' paleochannel was approximately 50 m wide, had a bankfull width/depth ratio of 13, a sinuosity of 1.75 and wavelength of 560 m. The largest paleochannel so far measured (Unit V, Excursion Stop 4) is estimated to have had a width of 340 m, width-depth ratio of 22, sinuosity of 1.5 and wavelength of almost 4 km. Variation in bankfull depth by a factor of eight given the distal foreland setting is puzzling.

4.4.3 Vertically-aggraded, cross-bedded sandstone sequences

a) Description:

Units of this category (see Fig. 19) account for about 30% of the coarse members encountered in traverses thus far. The absence of lateral-accretion bedding, the minimal presence of mud-sized sediment and abundant, large-scale cross-bedding render this type of sequence distinct from the preceding facies assemblage. Their cleaner, more coarse-grained texture typically contributes to steep, rilled scarp exposures with interior piping.

Sequence thicknesses are log-normally distributed, and range from 1.4 to 12.6 m with mean 5.9 m. Bases are sharp, but the thicker members, occasionally exhibit local erosional relief up to 1.4 m with progradational infills. Concentrations of vertebrate fossils commonly overlie these erosional contacts, either in the form of abraded individual bones or articulated skeletons. In fact of the 84 dinosaur quarries studied by Dodson (1971), 81% had been excavated from these units with all stages of skeletal decomposition noted. Rills draining higher levels commonly contain pebble-sized concentrations of teeth, bone and carapace fragments. Uppermost parts are horizontally-bedded with minor bentonitic, sometimes deformed mudstone beds, above which rapid upward-fining is prevalent (Fig. 37).

In terms of overall horizontal geometry, these units have linear ribbon form, with a predominant south-eastward direction based on vector means of contained cross-beds. Lateral joining of these sandbodies has not been observed. Minimum dimensions are known from traverses. In a few instances, both lateral pinchouts have been detected with transverse widths of approximately 230 m. Isopachs of the sand body inside these margins reach maximum values rapidly, thereby causing a high probability of encountering a uniform unit thickness in traverses. Within outcrop limits, lengths of units with above average thickness have been found to exceed 1.3 km, but considerably greater dimensions are anticipated.

Cross-bedding is abundant in the lower-to-middle-levels of these units but a consistent vertical organisation in scale and/or type appears to be lacking. However, an overall upward-fining trend from medium to fine or very fine-grained sandstone is discernible in about a third of the examples. Planar tabular or wedge-shaped sets range from 5-140 cm in thickness, with dips averaging 18° with a maximum of 32°. Foresets are occasionally gypsiferous, but are quite commonly draped with thin laminations of carbonaceous and/or bentonitic mudstone. Alternatively, they are sometimes conglomeratic with mudstone intraclasts: extremely rare are lenses of extrabasinal small pebbles. Cosets of nested trough cross-beds commonly dominate lower levels (Fig. 38) with a range in preserved widths from 80 cm to 19.5 m. Pediment exposures

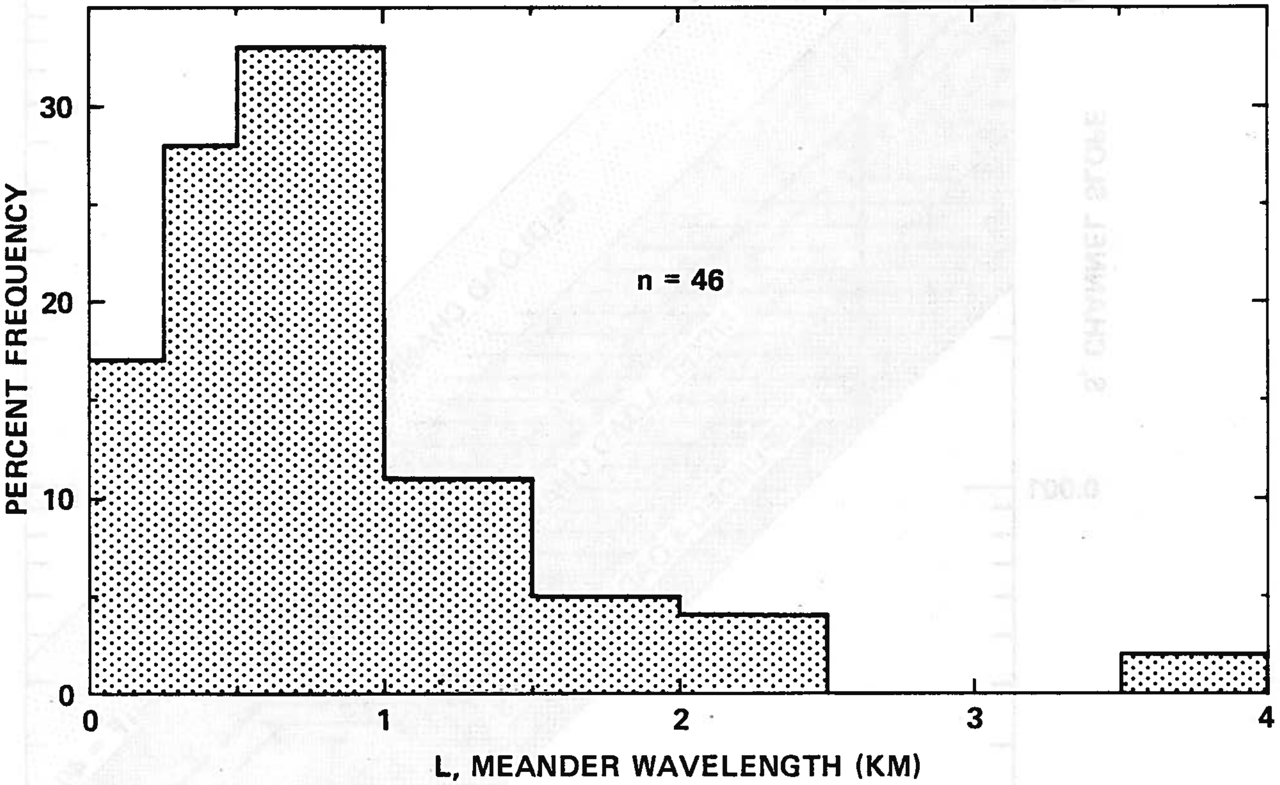

Figure 35. Histogram of meander wavelength values derived from the relationship in Figure 34.

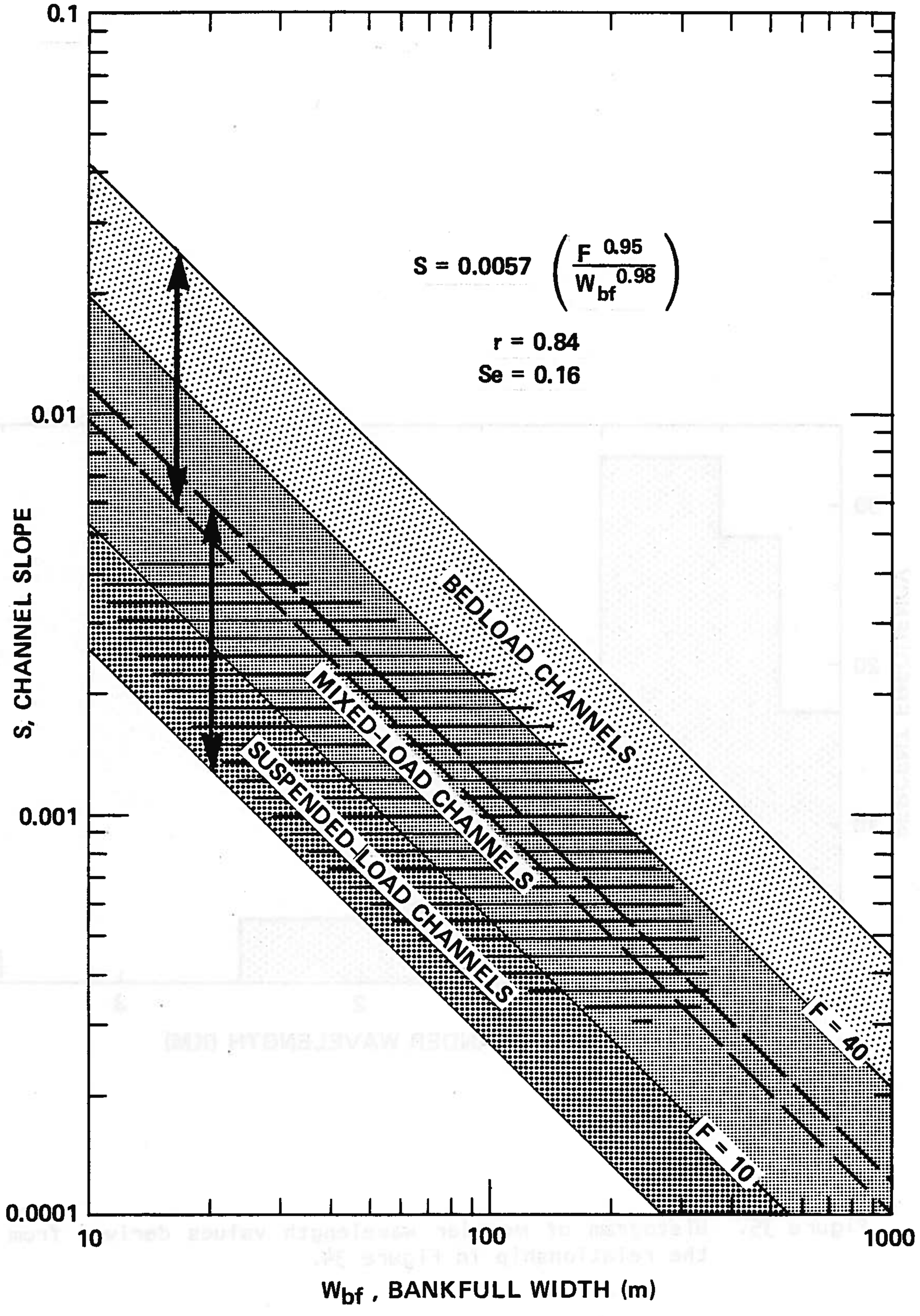

Figure 36. Schumm's empirical equation (see Ethridge and Schumm, 1978) to predict channel slope from data on bankfull width and depth. It is used to derive boundaries with 95% confidence limits (arrowed ranges) for channel types according to Schumm's classification. The cross-hatched oval area encompasses the scatter of data for the observed meandering paleochannels.

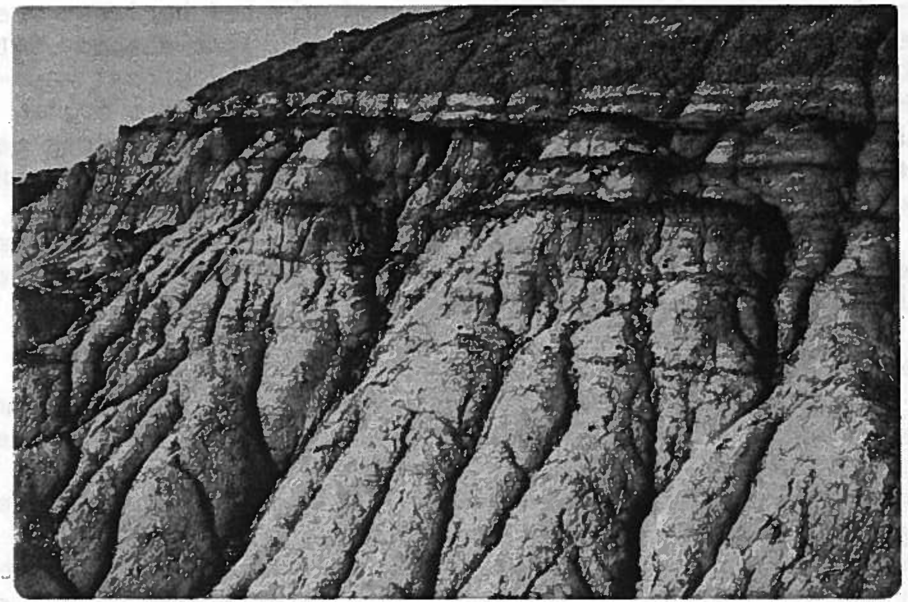

Figure 37. Vertically-accreted upper part to a low-sinuosity paleochannel sequence. The sands lack discernible cross-bedding and are bentonitic. Hammer at left centre in rill for scale. [5626740mN; 455160mE / 690m a.s.l.]

display upto 18 m of trough progradation, and some foresets show evidence of extremely regular, episodic deposition (Fig. 39). Sloping erosional set boundaries are often lined with lags of current-normally aligned intraclasts of mudstone (Fig. 40), or undulatory thin ironstones. Evidence of scour infilling is reasonably common: these appear either as concave-upward, longitudinal scours or have deep, asymmetric lower boundaries (Fig. 41). Geometry of the fill sequence is respectively vertical and progradational, with carbonaceous shaley mudstone clasts at basal levels. In general, current structures are discernible only in Ca- or Fe-concretionary masses in which foreset laminations are differentially weathered: alternatively, a faint iron-staining highlights the foreset configuration. Ripple cross-laminated horizons are rare.

Directions of foreset dips in wedge/planar-shaped sets and axes of symmetrically-filled troughs generate virtually identical east-southeast vector means (Fig. 42). The fact that the latter group have higher vector magnitude is not unusual (e.g. Dott, 1973). Weighting of planar cross-bed data according to set thickness only slightly improves vector magnitude, probably because of the frequency with which upper set boundaries are truncated. When cross-bed data is grouped according to host units (Fig. 43), the resultant mean trend is 120°: weighting of the data according to unit thickness indicates that the larger units have a more clustered mode.

b) Interpretation:

The evidence for vertical aggradation by cross-bedded sandstone in units that have ribbon or sheet-like geometry indicates that these coarse members originated as wide low-sinuosity, non-migratory channels of high energy. A multi-channel form is normally associated with such features (Rust, 1978). Braiding is, in fact, suggested by abundant, thick planar cross-bed sets, representing bars (Smith, 1972a; Walker and Cant, 1979) and the occurrence of large, three-dimensional dune fields in intervening channels (Allen, 1983). However, unequivocal evidence for frequent subaerial exposure of bar-complexes is lacking.

Separate development of nomenclature for modern bedforms versus ancient bedding structures hinders the interpretation of braided channel sequences. An additional difficulty is that modern braided rivers for which sedimentological processes have been investigated in detail, for example the Platte (Blodgett and Stanley, 1980) and South Saskatchewan (Cant, 1978), are in valley settings. As such, they do not elucidate the genesis of a network of aggrading channel units on open alluvial plains. Presently enigmatic therefore are the reason(s) why this coarse member type repeatedly became entrenched and then vertically-aggraded (cf. Bluck and Kelling, 1963): presumably, an avulsion event then followed. Their geometry more closely resembles the confined low-sinuosity systems described by Moody-Stuart (1966) than the amalgamated complexes in Campbell's (1976) study.

The thickness of each paleochannel sequence compared to its largest contained planar cross-bed set is considered to be an approximate indicator of the number of aggradational cycles needed to complete channel fill. Such ratios range from 2 to 7. The fact that fill sequences contain current structures in their lower parts, and vertically-accreted muddy fills at their tops, suggest that channels become progressively shallower after the initial erosive, avulsion event. As such, there is no obvious similarity between the vertical sequences of these channels and the 'type' examples for sandy braided systems put forward by Miall (1977).

Fluctuating discharge is indicated by 1) occasional deposition of cohesive sediment and its subsequent local redistribution while still wet, as mudstone

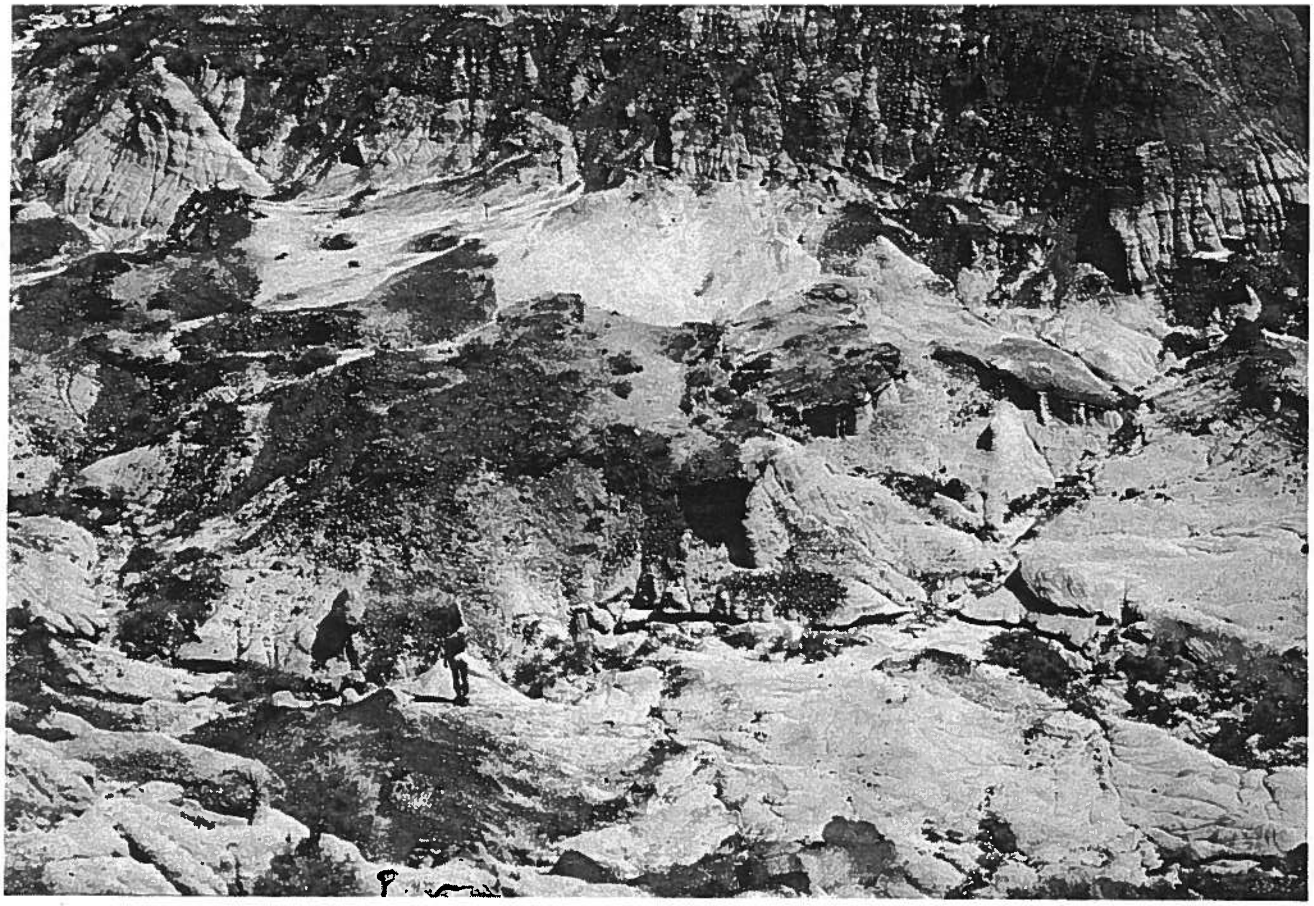

Figure 38. View downwards onto an exposure showing a giant coset of nested trough cross-beds up to 12 m wide, all directed east-southeast. Thin ironstones coincide with upper set boundaries.
[5621660mN; 459920mE / 668m a.s.l.]

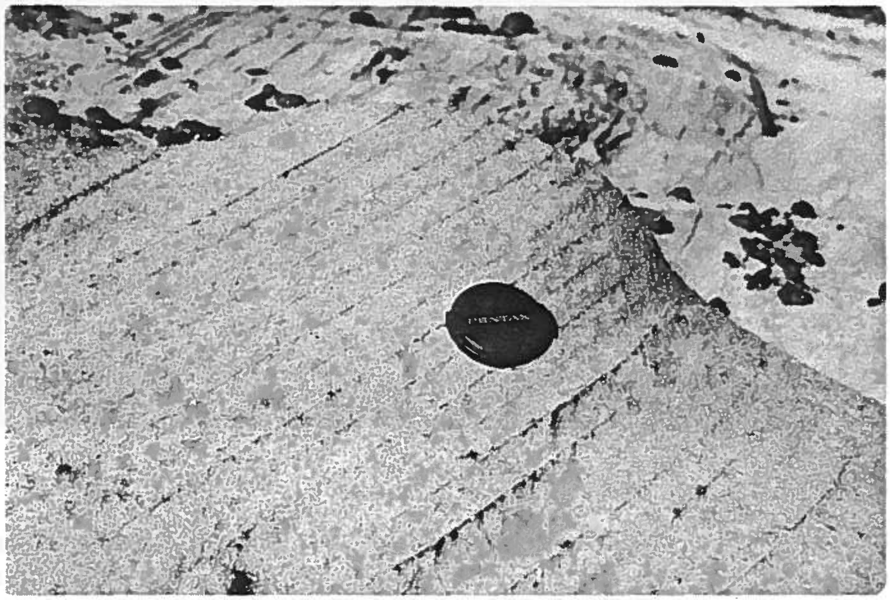

Figure 39. Extreme regularity of 2 cm-thick, 29° foreset laminae separated by 1 mm thin mudstone drapes in a 11.75 m wide trough set, directed 163°.
[5628570mN; 455960mE / 654m a.s.l.]

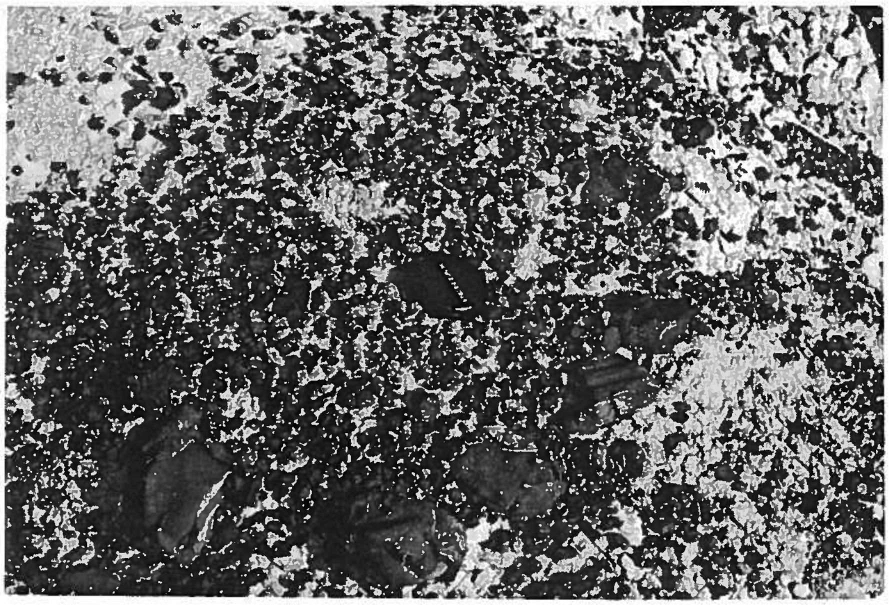

Figure 40. Bimodal size distribution of intraclasts of ferruginous mudstone in a low-sinuosity paleochannel sequence. The larger cobble-size mode are prone to spheroidal weathering; the more abundant and well-sorted pebbly mode are very well rounded. [5626730mN; 455320mE / 679m a.s.l.]

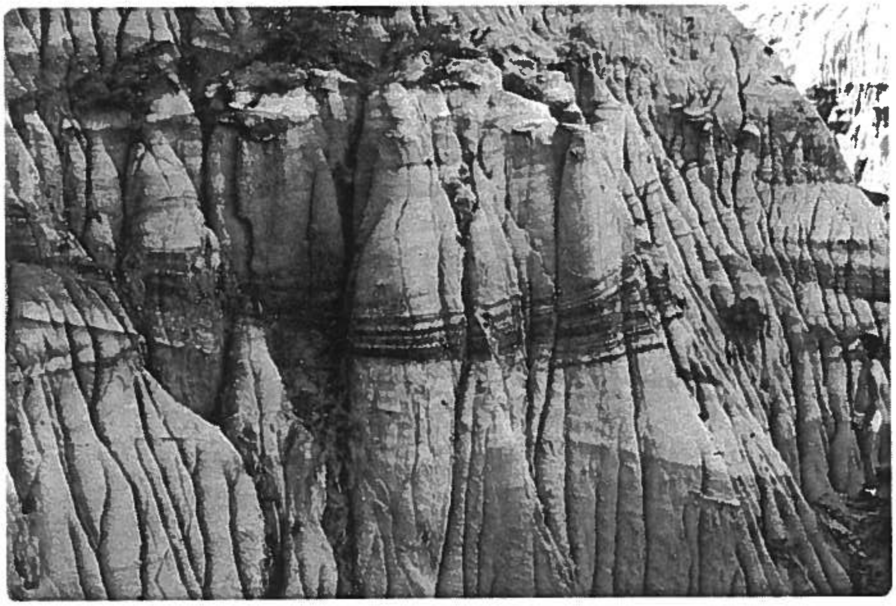

Figure 41. Large asymmetric scour fill at the mid-level of a low-sinuosity paleochannel sequence (person at lower right). Tangential bottomsets are made conspicuous by thin-bedded, carbonaceous mudstones. The 1.8 m thick cross-bed set above is almost perpendicular to the vector mean of adjacent cross-beds. [5621620mN; 600200mE / 677m a.s.l.]

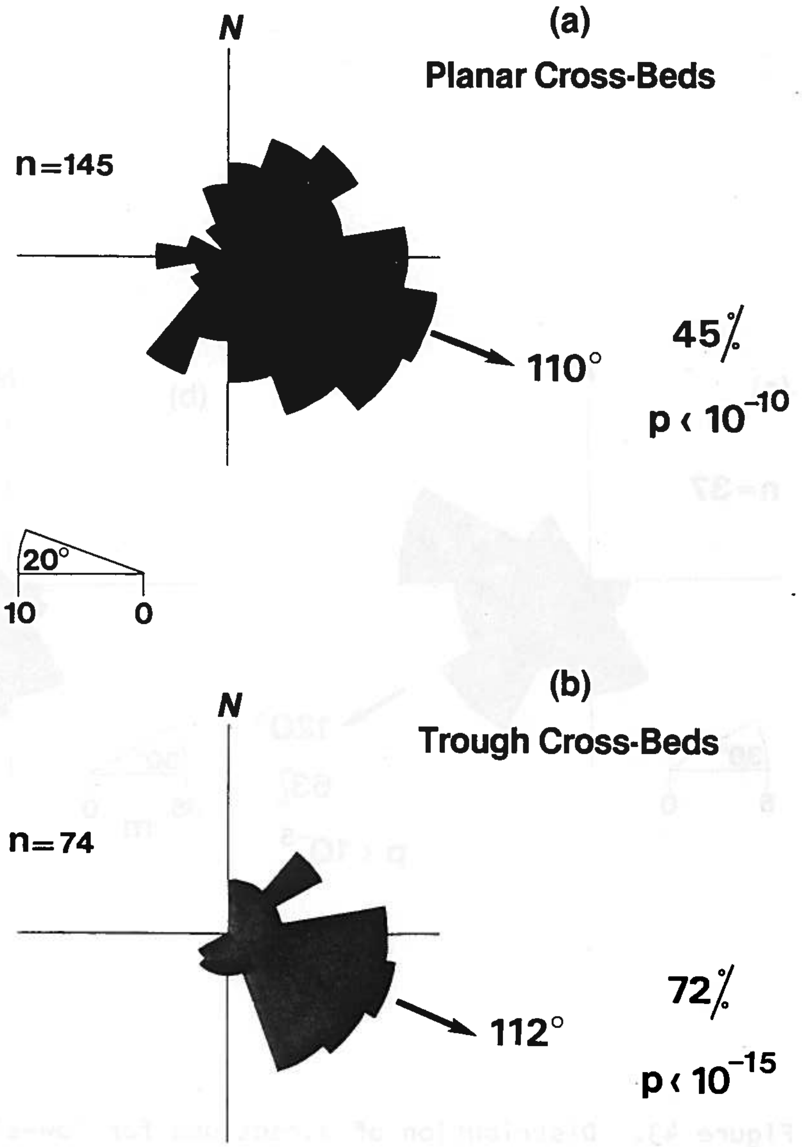

Figure 42. Rose diagrams of planar and trough cross-bed vectors from low-sinuosity paleochannel sequences. The vector mean, vector magnitude and probability, p, of the observed distribution deriving from a randomly-directed population (Curray, 1956) are given for each.

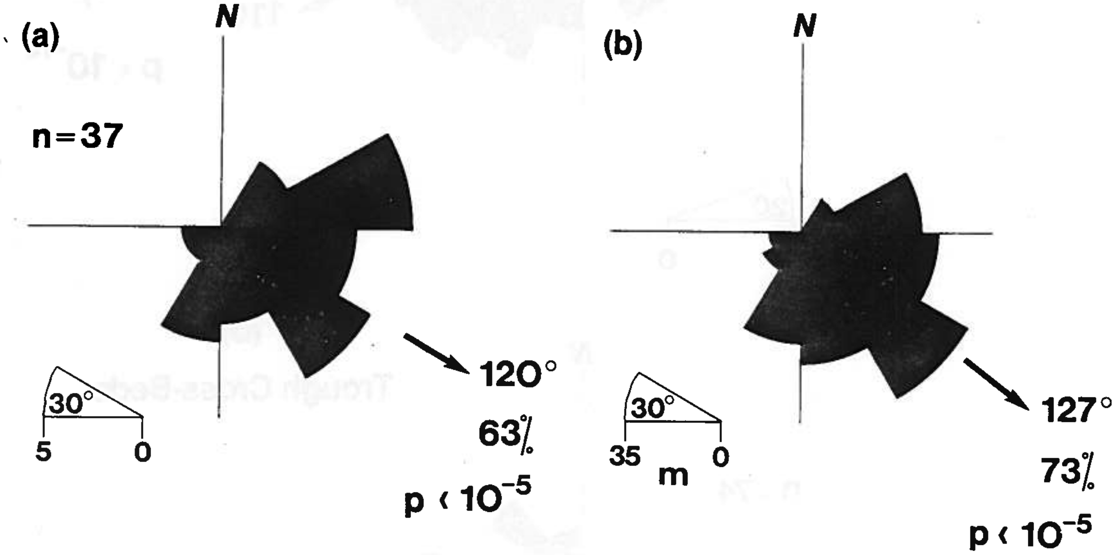

Figure 43. Distribution of directions for low-sinuosity paleochannels deduced from vector means of contained cross-beds. (a) raw data; (b) data weighted according to thickness of host units. Statistics as in Figure 42.

intraclasts (Smith, 1972b), 2) the extensive angular truncation of upper boundaries in large cross-bed sets, and 3) the lack of preservation of intact vertical sequences. In sequences containing transported large dinosaur carcasses, flow depth must have exceeded the animal's girth (up to 1.5 m). Actual competence levels of paleoflows were considerably higher than those needed to transport the bedload of predominantly fine sand and to generate large bedforms. This is indicated by traction transport of rounded mudstone intraclasts upto cobble size (ca. 700 g) and isolated limb bones commonly up to 1 m long (ca. 22 kg), both with current-normal alignment.

4.4.4 Vertically-accreted, bentonitic mudstone sequence

a) Description:

This facies assemblage (Fig. 44) envelops, in a three-dimensional sense, the coarse-member paleochannel sequences. Local thickening to a maximum of 18 m has been noted, but intervals of 3-6 m are typical.

Detailed examination of these sequences requires considerable trenching because of deep weathering. This arises from a high percentage of montmorillonite (up to 65% in Belly River Formation mudstones of the foothills, according to work by Lerbekmo (1963)), which readily absorbs precipitation causing disruption of near-surface fabrics. When dry, surfaces become rough and crumbly (so-called 'popcorn' texture). Because the prime interest of fieldwork lies in the much better exposed paleochannel sequences, mudstone intervals are not regularly subject to detailed examination during traverses.

Palynological anlaysis of 24 samples collected at random show a well-preserved assemblage, identical in composition to that recorded by Tschudy (1973) from the Judith River Formation of Montana. However, very occasional damaged specimens of acritarchs (Pterospermella sp.) or dinoflagellates (Bacchidinium polypes, Cleistosphaeridium sp.) were also spotted. Petrified logs of Taxodioxylon gypsaceum (Dodson, 1971) occur sporadically, but never in growth position. While articulated skeletons are virtually absent, isolated limb bones for example have been located (Fig. 45).

With 'mudstone' being used as a general convenient term, typical lithologic properties are as follows. Bedding appears massive with prevalent blocky fracture. Although weathered surfaces have a tendency to appear grey, trenching reveals considerable variability in colour (GSA's Rock Colour Chart used), with respect to floral content and grain-size (Fig. 45). This ranges from unfossiliferous grayish-orange silty units, through yellowish-brown intervals with disseminated tiny remains of carbonised plant debris, to olive- or brownish-grey units with large volumes of coaly plant fossils. Fissility increases noticeably with the darker facies but colour changes are generally gradational. Fissile, brownish-black shales with partings coated with carbonised plant debris are rarely developed, except where associated with thin sub-bituminous seams at high stratigraphic levels in the vicinity of the Lethbridge coal zone. Bentonite beds appear very rarely and are laterally discontinuous.

Slightly bentonitic, very fine grained sandstones up to 1.5 m thick appear randomly, but the lack of internal concretions usually prevents their small sets of cross-beds from being fully deciphered. These are also laterally discontinuous over distances of 100 m or so. Heterolithic intervals frequently contain deformed bedding (cf. McKee and Goldberg, 1969) and/or horizons of ironstone concretions (Fig. 46). The latter often underlie the erosional base of paleochannel sequences.

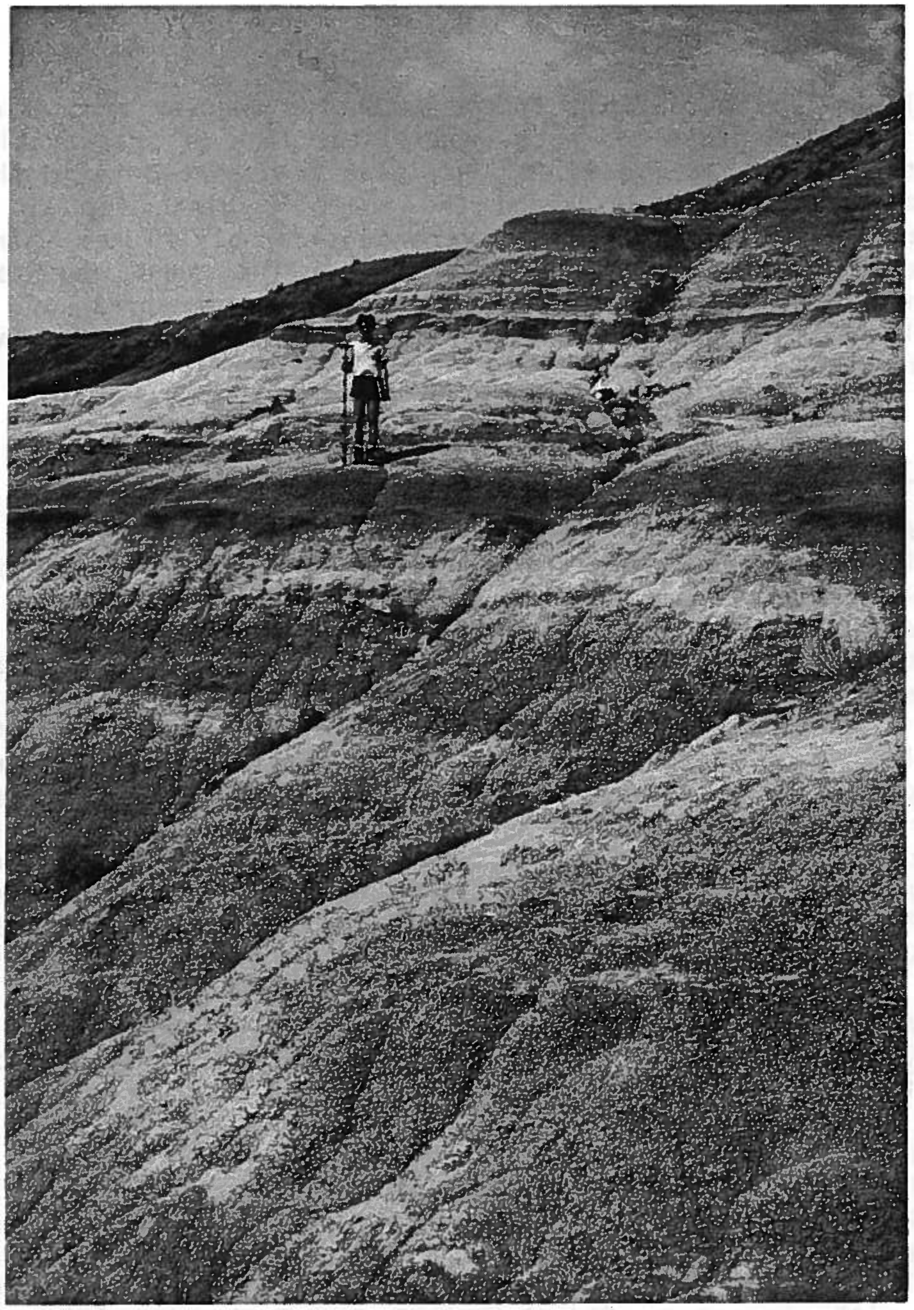

Figure 44. Sequence of various overbank facies, defined primarily on the basis of texture, colour and macrofloral remains - as discussed in the text. [5626740mN; 455150mE / 686-697m a.s.l.]

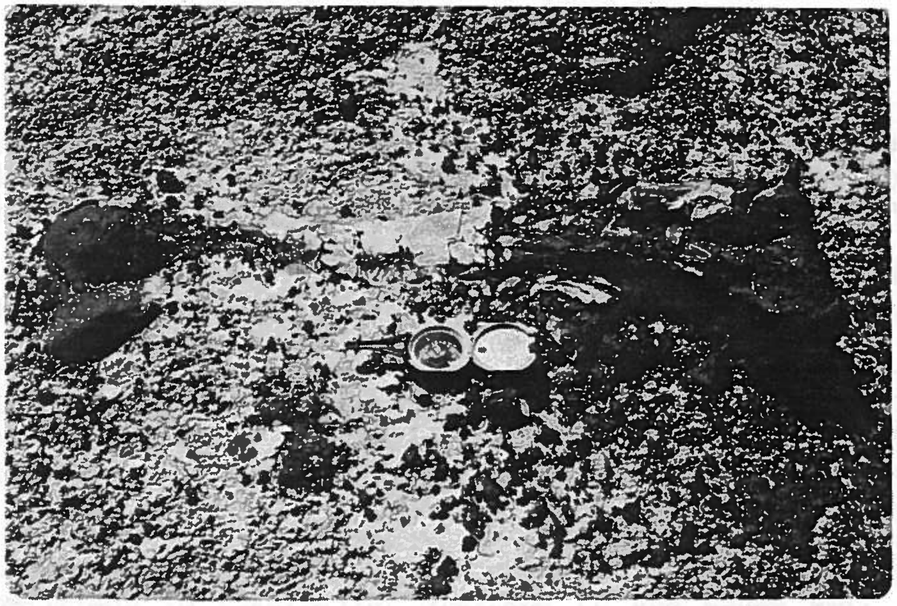

Figure 45. One of a sub-parallel pair of 92 cm-long dinosaur limb bones resting in mudstone. Orientations are 124° and 144°.
[5628970mN; 456020mE / 687m a.s.l.]

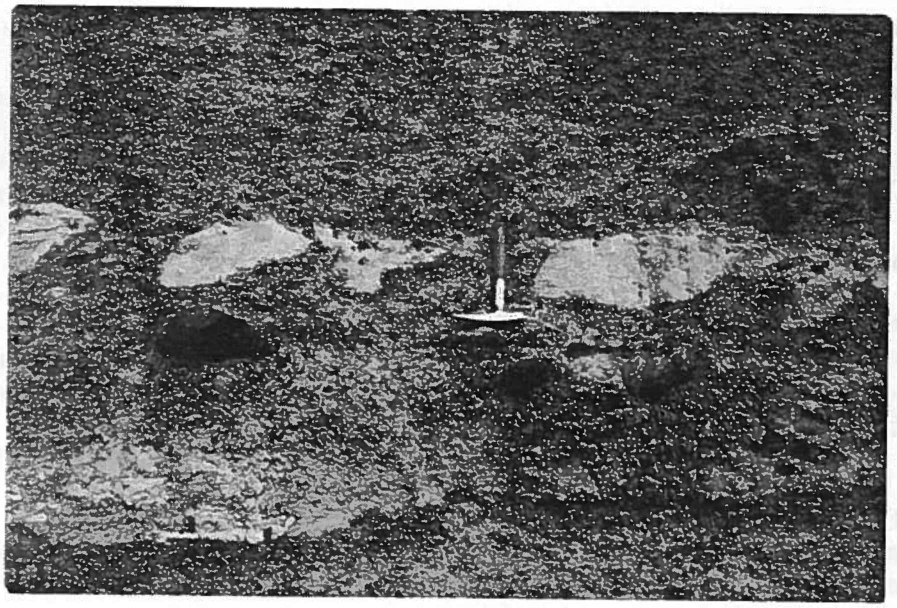

Figure 46. A 20-25 cm thick splay unit in bentonitic mudstones. Due to differential loading and/or dewatering, the bed of very fine sand has undergone early deformation. Ironstone concretions appear to be located on foundered blocks.
[5622000mN; 466890mE / 685m a.s.l.]

There are no obvious signs of pedogenesis having affected this facies assemblage. Lastly, weathering out of gypsum crystals, primarily from the darker mudstone intervals, appears to reflect a surficial geochemical process.

b) Interpretation:

Deposition in fresh water is indicated by 1) the formation of siderite (Postma, 1982), 2) a well-preserved continental microflora (C. Singh, written communication, 1983), 3) the abundance of macrofloral remains, and 4) juxtaposition with paleochannel sequences having unidirectional flow indicators. Trampling of sediment by vertebrates was undoubtedly widespread.

Aggradation in overbank areas appears to have been fairly steady, given the apparent lack of paleosols or desiccation features. Also, the water column was rarely static judging by the 1) constant dispersal of volcanic ash, 2) abundance of lightish mudstones, 3) floating in of logs, 4) traction of dinosaur limb bones and 5) possible intraclasts of coalified peat. However, cyclic changes in water depth are suggested by upward-fining trends toward darker, more fissile units. The thin sandstones are considered to have originated as crevasse-splays from nearby channels; irrespective of their specific subenvironment, sand deposition commonly triggered the development of deformational structures in subjacent beds. The erosional downcutting phase of interstratified paleochannel sequences apparently had similar repercussions.

4.4.5 Time-space trends in sedimentation

Because the fieldwork is not yet complete, comprehensive reconstruction of the overall depositional framework in the upper 70 m or so of the Judith River Formation in the Park is premature. On the basis of the preceding description and interpretation of facies assemblages produced by overbank areas and two types of paleochannels, the following brief statements can be made.

1) That a network of sinuous, migratory single-channel systems, with a four-fold depth variation, flowed eastwards. Flow velocity fluctuated regularly, without causing much change in stage below bankfull.
2) That a concurrent less numerous network of vertically-aggrading, wide channel systems had on average, an east-southeasterly flow direction. Carcasses of dinosaurs were frequently transported and then stranded on the beds. These probably host the small gas pools described by Shouldice (1979).
3) That both these channel types were flanked by muddy overbank areas which were frequently inundated with low energy flows ('low' because of the relative scarcity of splay and desiccation events). Instability of overbank surfaces was such that peat accumulations were rarely developed or preserved.

In the case of the high-sinuosity group of paleochannels, point bar geometry shows rather distinct vertical trends (Fig. 47). Thickness is an indicator of channel scale, while point bar slope angle reflects the bankfull width/depth ratio. In turn, the second parameter varies inversely with sinuosity. Given these relationships in channel form, Figure 46 suggests the following temporal changes.

1) In the vicinity of 660 m, 680 m and above 705 m a.s.l. (i.e. the Lethbridge Coal Zone), laterally-migrating channels were rare; those that did occur were unusually shallow and relatively wide.
2) Just above 650 m and in the vicinity of 668 m a.s.l. laterally-migrating

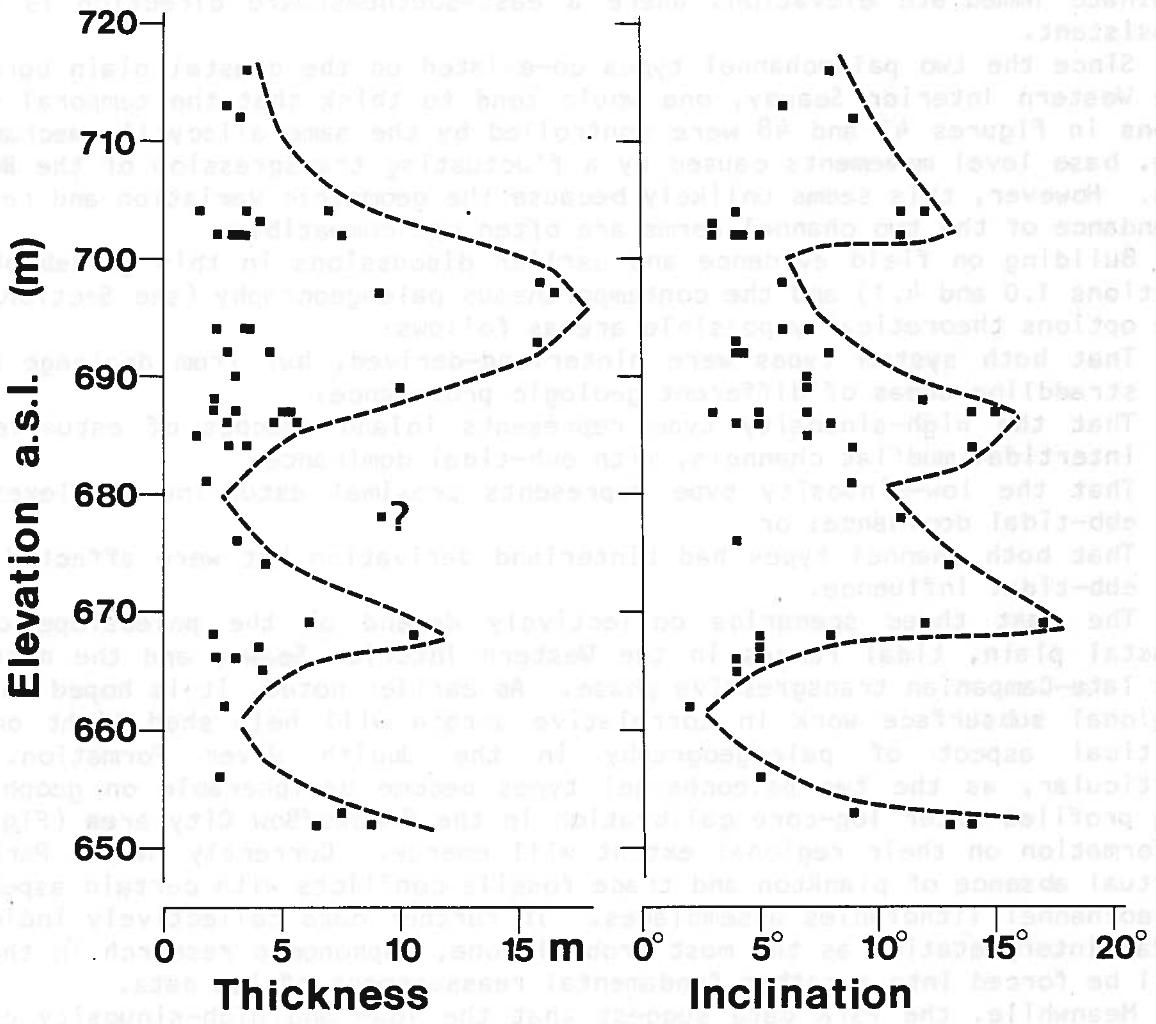

Figure 47. Point bar geometry with respect to elevation in the Park. Each point represents the basal elevation of a laterally-accreted unit measured in the course of north-south traverses. The dashed lines enclose the sequence of maximum values.

channels had above-average depth and point bar slope values.

3) At above 685 m and between 690-700 m a.s.l. channels again had above-average depth but moderately high sinuosity.

The low-sinuosity category of paleochannels also indicates vertical trends not only in scale but also in their direction (Fig. 48). The thicker units dominate immediate elevations where a east-southeastward direction is rather consistent.

Since the two paleochannel types co-existed on the coastal plain bordering the Western Interior Seaway, one would tend to think that the temporal variations in Figures 47 and 48 were controlled by the same allocyclic mechanism - e.g. base level movements caused by a fluctuating transgression of the Bearpaw Sea. However, this seems unlikely because the geometric variation and relative abundance of the two channel forms are often not compatible.

Building on field evidence and earlier discussions in this guidebook (see Sections 1.0 and 4.1) and the contemporaneous paleogeography (see Section 3.2), the options theoretically possible are as follows:

1) That both system types were hinterland-derived, but from drainage basins straddling areas of different geologic provenance;
2) That the high-sinuosity type represents inland reaches of estuaries, or intertidal mudflat channels, with ebb-tidal dominance;
3) That the low-sinuosity type represents proximal estuarine complexes with ebb-tidal dominance; or
4) That both channel types had hinterland derivation but were affected by an ebb-tidal influence.

The last three scenarios collectively depend on the paleoslope of the coastal plain, tidal ranges in the Western Interior Seaway and the nature of its late-Campanian transgressive phase. As earlier noted, it is hoped that the regional subsurface work in correlative strata will help shed light on this critical aspect of paleogeography in the Judith River Formation. In particular, as the two paleochannel types become decipherable on geophysical log profiles after log-core calibration in the Brooks/Bow City area (Fig. 12), information on their regional extent will emerge. Currently in the Park, the virtual absence of plankton and trace fossils conflicts with certain aspects of paleochannel lithofacies assemblages. If further data collectively indicate a tidal interpretation as the most probable one, taphonomic research in the Park will be forced into a rather fundamental reassessment of its data.

Meanwhile, the Park data suggest that the low- and high-sinuosity channel types tend to occur in mutually exclusive time-space intervals. That is, one envisages that at any one time each channel type was clustered in a southeast trending belt. The research literature offers little insight into this style of arrangement of paleochannel units.

Figure 49 presents the available data on combined spatial/chronological changes in sediment transport direction for the western end of the Park. Vertically, paleocurrent means rotate from south to east, but no consistant spatial trend from west to east appears to exist. Whether the former represents any 'diverting influence' by the Sweetgrass Arch structure (Section 3.4) can not yet be ascertained.

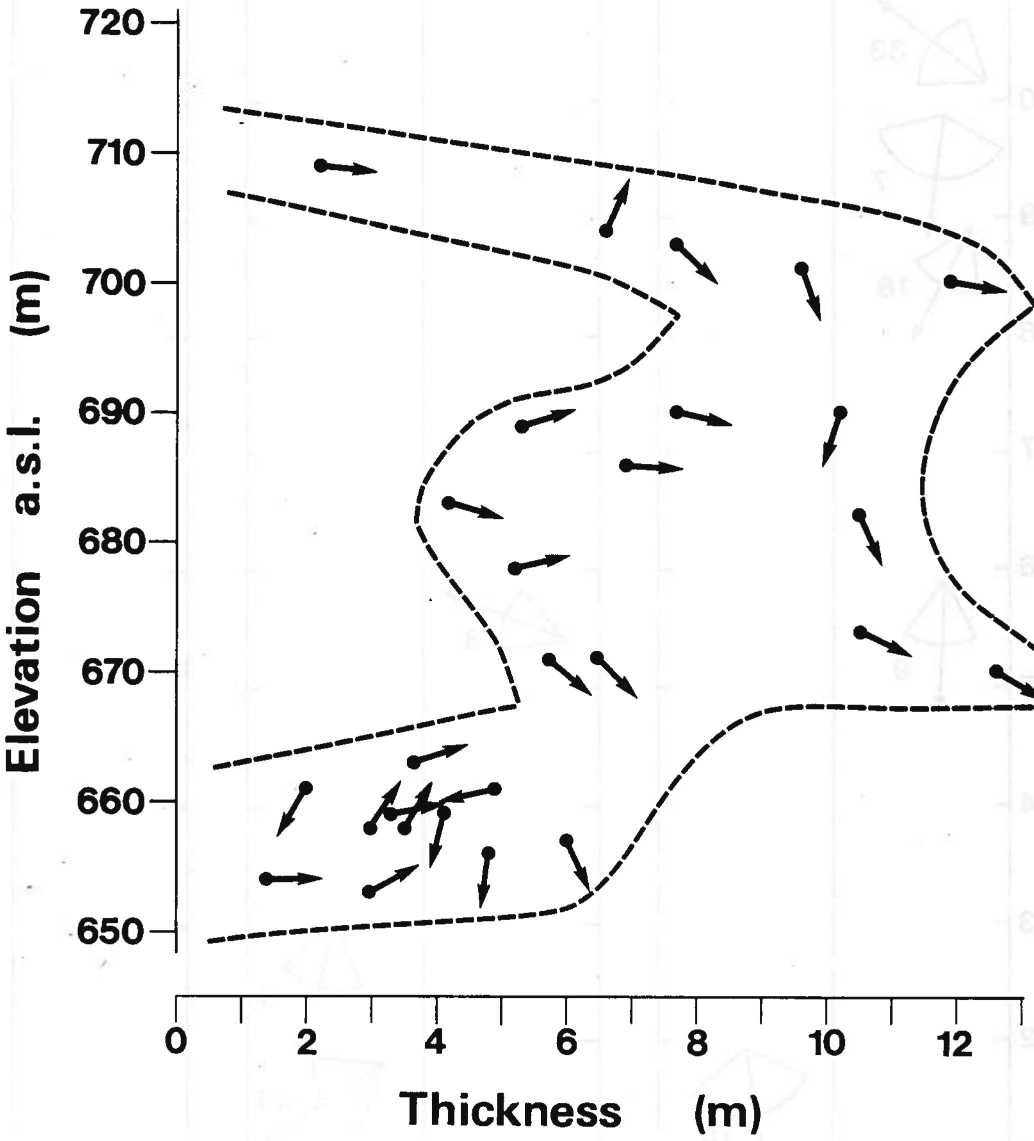

Figure 48. As a counterpart of Figure 47, this shows the vertical distribution of low-sinuosity paleochannel units: arrows indicate the vector mean of contained cross-beds.

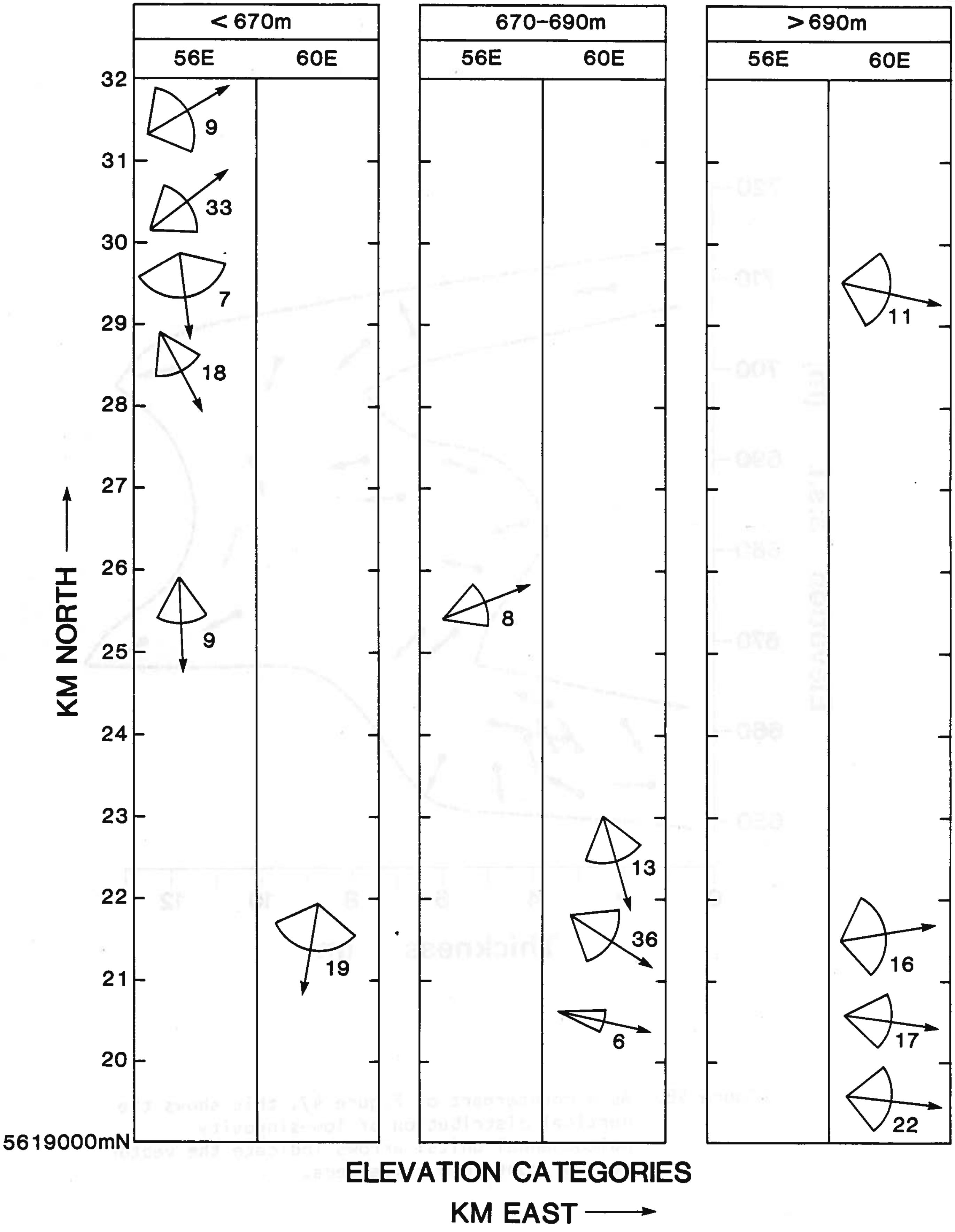

Figure 49. Cross-bed vector means with standard deviation (Till, 1974), partitioned according to elevation and location. Each of the three columns presents data for two northings in intervals of elevation that increase to the right. The spread of data indicates the geographic extent of badlands traversed by the northings, 456000mE and 460000mE

5.0 EXCURSION STOPS

5.1 Introduction

As mentioned in Section 2.4, vehicle access to the prairie edge and hiking within the badlands are possible only under dry conditions. To the extent possible, this excursion's schedule of stops has been arranged so as to minimise travel on unpaved routes. Hopefully, the logistic inconvenience of late impromtu changes will not arise - if they do prove necessary, it will simply be to avoid stuck vehicles and hazardous hiking conditions! An overview of the planned schedule follows. We will be accompanied by Dr. Philip Currie (Assistant Director of the Tyrrell Museum of Palaeontology) and John Walper (a geology undergraduate, now a Park Interpreter).

Most of the first morning is intended as background, with three stops in the vicinity of the Park headquarters. After discussion of some introductory points at a splendid viewpoint (Stop 1), there will be an opportunity to briefly view two in situ dinosaur displays: these are located along two Park trails. The second one winds southwards and facilitates a valuable quick overview of a typical degree of stratigraphic complexity through 50-60 m of truly spectacular remote badlands. We will pause during the descent and take a short hike eastwards to view a prolific bonebed currently under excavation by the Tyrrell Museum (Stop 2). The morning will conclude back near the viewpoint, with examination of a detailed transit survey of two low-sinuosity paleochannel fills (Stop 3).

The remaining stops each involve upto two hours hiking to examine mixed paleochannel sequences exposed along a north-south series of three traverses coincident with the military grid coordinate 460000mE (Fig. 2). During traverses, we will examine the facies sequence and geometry of each paleochannel unit in some detail. Stratigraphic sections are provided for each traverse as background to brief descriptive notes which are illustrated by selected field photographs. During these hikes it is important, for reasons of safety and schedule, that everyone remain in sight of the rest of the group and move forward when signalled. In the first afternoon, the sequence exposed in the rugged terrain of Little Sandhill Creek coulee will be examined. 1.3 km wide and 60 m deep, we will look at the north slope first (Stop 4) and then, depending on the creek level, drive around, or 'jump across' to the south side (Stop 5). The next day, continuing the same style of investigation, we will move 1 km south and visit South Sandhill Coulee, 0.9 km wide and 35 m deep (Stop 6). To conclude the excursion, we will then move 9.5 km northwards to examine a portion of the Steveville badlands where disection is 35 m deep and spans 0.55 km (Stop 7).

Time permitting and with completely dry ground conditions, there may be the opportunity to fit in one or more extra short stops to examine certain other specific sedimentary features.

5.2 #1: Park Viewpoint

[5622350mN; 462990mE/712m a.s.l.]

The parking lots to either side of Highway 551 immediately inside the Texas gate marking the Park entrance are splendid viewpoints over the badlands. From this landmark, we will deal mainly with those aspects of the area's geomorphology that influence the methodology of sedimentological field studies (Fig.50).

In a proglacial setting that postdated the youngest drift sequence, about 13,000 yrs. B.P. (Westgate, 1967), glacial diversion near the town of Red Deer of the former headwaters of the Battle River led to the development of a spillway, now the Red Deer valley (Bayrock and Broscoe, 1972). Probably of a catastrophic nature (Kehew, 1982), the Deadlodge Canyon reach was deeply eroded from prairie level at ca. 705 m locally to 620 m a.s.l. McPherson's (1966) boreholes in the floodplains below this viewpoint record subsequent alluviation to the 635 m level. Across the typically 700 m wide valley floor, lines of cottonwood and other arborescent flora delineate subtle scroll-bar relief between the slightly sinuous modern channel (sinuosity ca. 1.1, wavelength ca. 3.5 km) and coulee walls. Channel migration, up to 250 m since the 1880's (McPherson, 1966), is mainly translateral producing lens-shaped point bars that shift incrementally downstream.

The preglacial Bow Valley, occupied now by the Bow River west of Bassano and by the Red Deer River east of Jenner lies to the north of Deadlodge Canyon (Stalker, 1961). However through the Park area, bedrock joint sets trending parallel and perpendicular to the Rocky Mountains appear to have directed the linear course of the spillway (Section 4.2). As a result of the canyon's configuration with respect to the preglacial Bow Valley, the Park straddles a bedrock 'high' - a feature that favours development of badlands (Bayrock and Broscoe, 1972). This relationship is demonstrated by the absence of badlands on the opposite side of the valley from the viewpoint where the drift sequence thickens in a tributary preglacial valley.

During the Holocene, the spillway walls have become heavily dissected due to the processes of scarp retreat, piping and pediment widening. The prairie edge is now farthest from the main valley line where the drainage density of joint-controlled tributary coulees is greatest. Although Holocene climatic change has undoutedly varied (? net deceleration) the rate of badland development, measurements show that modern scarp retreat proceeds at 1-2 cm/year (Bayrock and Broscoe, 1972) with computed minimum denudation rates averaging 0.83 m/1000 years (Campbell, 1970). Typically 10% of the annual precipitation arises from the heaviest summer convective storm (ibid.) causing erosion to be periodically intense.

From this viewpoint, the field procedure (Section 4.3) will then be briefly reviewed and later excursion stops located.

5.3 #2: Centrosaurus bonebed

[5622350mN; 465950mE/673m a.s.l.]

From Stop 1, we will descend into Deadlodge Canyon through the public campground area and proceed onto the two tour roads within this central part of the badlands. These brief tours will serve to familiarise you with some general aspects of the vertical succession, the nature of badland terrain and provide an opportunity to examine a dinosaur bonebed in these related contexts.

From the Park headquarters' area, where time may permit a brief pause to view public fossil exhibits, we will proceed east and circle the one-way public 'loop road', approximately 3.2 km long. Notice the different degree of exposure on the south- and north-facing slopes - the latter retain moisture and support a vegetation cover. At the eastern extremity of the loop road, an in situ hadrosaur fossil will be viewed (Display No. 2; Quarry No. 126). Found by

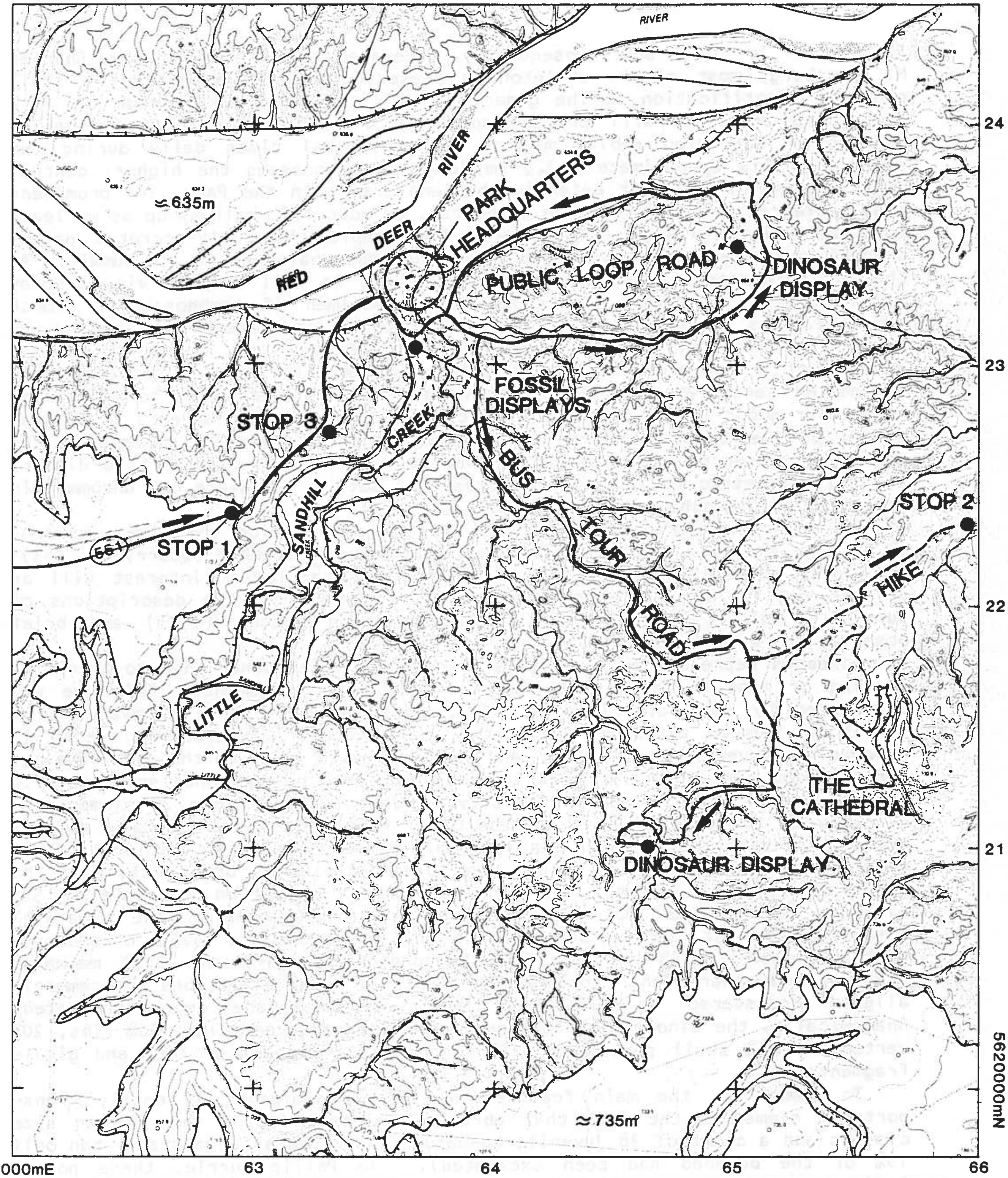

Figure 50. Location map for Excursion Stops 1-3 superimposed on a portion of Sheet 4 of the Parks Division 1:10,000 topographic map series (see Section 8.1). The contour interval is 4 m, but on steep slopes these are omitted between the thicker 20 m intervals.

R. Fowler in 1961 and subsequently excavated and described by Charles M. Sternberg, most of the skeleton is preserved but the absence of a skull prevents identification to the generic level. Passing back through the Park campground area, we will proceed south up the 'Bus Tour Road' (so-called because of scheduled public minibus tours several times daily during the summer). This approximately 3.8 km long route accesses the higher, central parts of one of the most extensive badland tracts in the Park. The prominent mesa, referred to locally as The Cathedral, on your left halfway up as we leave an intermediate grassy pediment area has complex laterally-accreted paleochannel sequences at its base and the Lethbridge coal zone at its summit. At the top turn-around point, at elevation 688 m, we will stop to view Display No. 4 (Quarry No. 128). This hadrosaur specimen of Lambeosaurus, almost complete, was dynamited from the precipitous sandstone ridge behind by Sternberg in 1964 and lowered to its pediment display site. The unit is a good example of a non-accretory, high energy system with both articulated and fragmented vertebrate fossils: cohesive sediment is restricted to scattered, lenticular scour fills. However, the capping overbank unit appears to be just missed by the present erosion level, judging by the vertical trends in the preserved sequence. The dearth of concretions makes it difficult to discern the full geometric relationship of cross-bed sets - a feature not uncommon in this type of paleochannel unit.

On the return trip, we will park at 678 m elevation and hike eastwards ca. 1.5 km and view the much-publicised Centrosaurus bonebed (Quarry No. 143). En route, several sedimentological features of particular interest will be pointed out. The following brief overview stems from the descriptions of Currie et al. (1981), Currie (1982a, b), and Dodson (1971) and brief observations by myself.

Bonebeds represent accumulations of disarticulated bones, due to hydraulic sorting or mass mortality with minor in situ rearrangement. This one was discovered by Park officials in 1977, and systematic grid excavations by Provincial Museum personnel began two years later. Excavations are still proceeding. Covering ca. 3,300 m^2 and spanning up to 1.5 m in the upper fining, carbonaceous part of a 7 m thick laterally-accreted paleochannel sequence with rooted ironstones, the spatial density of bone averages some 20 elements/m^2 (locally up to three times this density). Most bone is horizontal, and its skewed size distribution averages 17.3 cm. Between 80-90% of the identifiable material is ceratopsian in nature, and diagnostic skull bones belong to the genus Centrosaurus - hence the bonebed's name. Based on a sample of 525 elements (as of the 1981 field season), the composition of the remaining assemblage is 5% carnivorous dinosaur, 3.5% hadrosaur, 1.5% champosaur, 0.5% ankylosaur, 0.5% turtle, 0.5% Myledaphus (a ray) and 2.5% mammals, lizards, and other fish. Long bone elements at lower elevations are commonly aligned transverse to flow, and some vertebrae are even imbricated. Anatomically, the dinosaurian component of the bonebed comprises 50% ribs, 20% vertebrae, 15% skull parts, 10% limbs, and small numbers of foot and girdle fragments.

To summarise, the main features are the predominance of easily transportable elements, the fact that abrasion mainly affected the smaller size classes and a count of 38 juvenile-to-mature individuals (at a stage when only 10% of the bonebed had been excavated). To Philip Currie, these points indicate that the bonebed originated as a herd that suffered mass mortality by perhaps drowning, subsequent scavenging and trampling by therapods, then minor wasting after skeletal disarticulation. After presentation of this site by Philip Currie, we will proceed north, and then east to Stop 3.

5.4 #3: Paleochannel transit survey
[5622800mN; 463310mE/645-673m a.s.l.]

This stop concerns a detailed transit survey of a sequence, comprising two vertically-aggraded, fine to very fine grained sandstones (see Section 4.4.3) separated by highly bentonitic mudstones over a rectangular area (220 by 150 m) lying mainly to the southeast of the Park entrance road halfway between prairie and river levels (Fig. 50). This location was selected as a test site for detailed examination because of its logistic convenience and the comparatively excellent exposure of structures on pediments and walls of enclosing buttes.

The prime objective was to generate a map of each sandbody showing overall geometry and internal paleocurrent distribution. This was achieved by two transit locations at elevation 661 m from which the bearing, distance and elevation of unit contacts (at a minimum spacing of 10 m, supplemented with Jacob's staff) and sedimentary structures (n = 158) were accurately determined. McKee and Weir's simple, non-genetic classification of crossbed types is used (see Fig. 5-2 of Blatt et al., 1980) Weighting of cross-beds vectors according to set thickness (Miall, 1974) was carried out, but in no case produced an increase in vector magnitude. This is attributed to the common truncation of set upper boundaries. As is typical for other exposures, cross-bedding directions were mostly obtained from differentially-weathered concretions. The fact that individual sets, and parts of cosets, are not commonly traceable along outcrop unfortunately precludes the possibility of comprehensive lithofacies' profiles. However the large amount of spot survey data is considered to provide a valuable insight into aggradational processes.

The configuration of the outcrop and basic succession are depicted in Figure 51, and Table 2 summarises basic data for the two sandstone units. The latter are of fluvial origin given that intervening mudstone samples contain (C. Singh, written communication, 1983) terrestrial proportions of palynoflora, and only three (? reworked) specimens of microplankton (1 acritarch, 2 dinoflagellates). Sand body geometry, assemblages of rank 3-6 structures (Miall, 1974) and their directional properties combine to indicate deposition by high-energy braided systems of low sinuosity (Section 4.4.3). Principal outcrop observations (Figs. 52-54) are briefly summarised as follows.

a) 'Lower sandstone' (Figs. 53, and 55a)

Outcrop follows an irregular outline across a partly concealed pediment and around the lower gullied slopes of the coulee. In terms of overall geometry, an eastward-sloping left-bank pinchout slightly oblique to the unit vector mean of 067° is exposed at two locations. Subparallel 1, 2, and 3 m isopachs occur south of this line within 35 m, beyond which the sharp base is consistently ±3 m below a horizontal, slightly gradational upper surface. Internally, the unit is dominated by tabular and wedge cross-beds, exposed sporadically in calcareous concretions. Trough cross-beds up to 6.5 m long in preserved downstream extent are mostly discernible on the pediment surface. The vertical succession contains an upward swing in the strongly clustered mean paleocurrent directions from east-northeast to north-northeast. Superimposed on this trend, are several, fairly distinct cycles of increased scale in cross-bedding with carbonaceous foreset laminae. Large trough cross-beds occur at spaced intervals in the lower parts of these cycles.

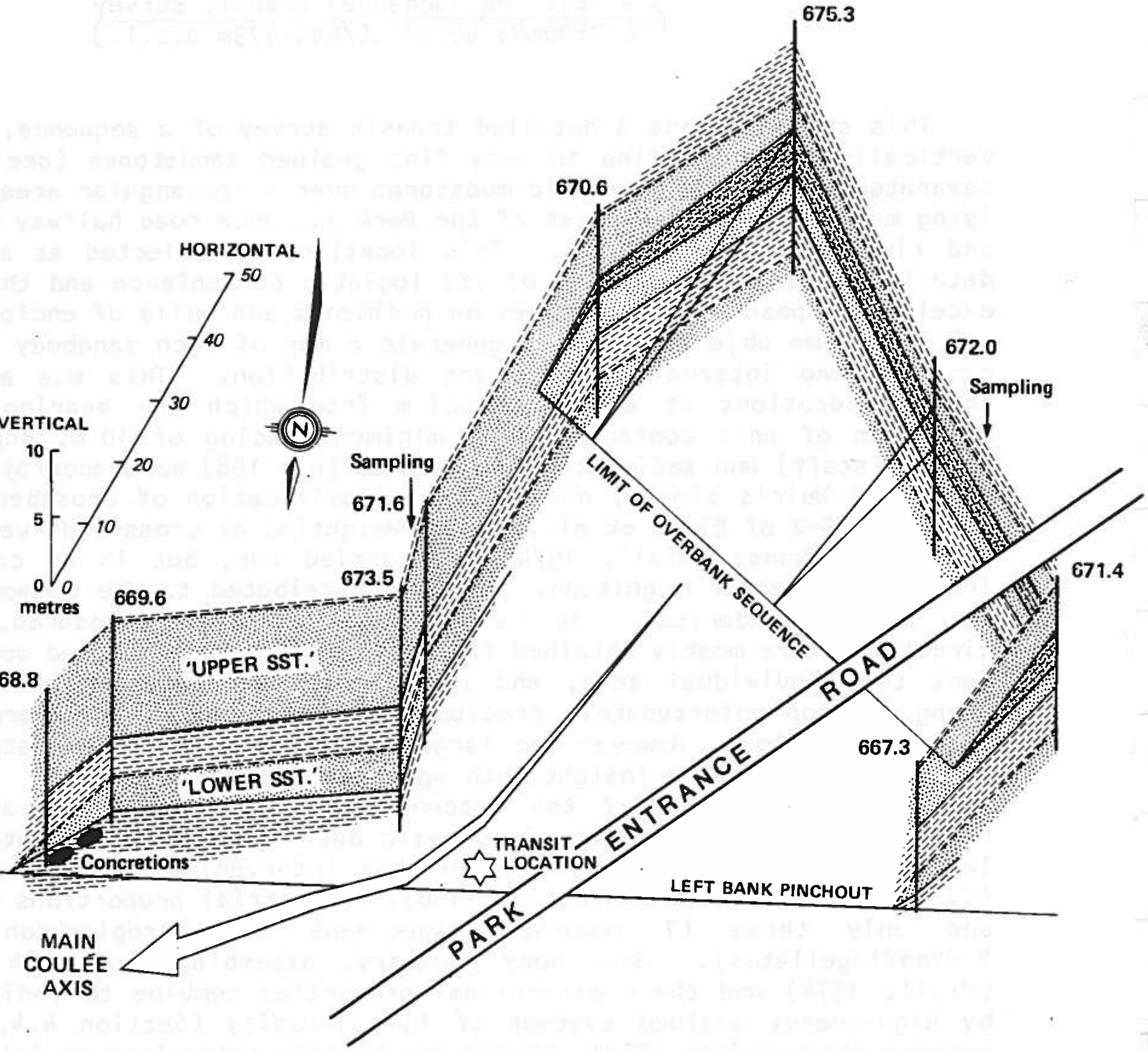

Figure 51. Fence diagram of sequence to be examined at Stop #3. Numbers above measured sections are elevations (m) above sea level.

TABLE 2. TRANSIT SURVEY OF TWO VERTICALLY-AGGRADED SANDSTONES AT 5622800mN; 463310mE.

(a) BASIC DATA SUMMARY

UNIT	THICKNESS (m)	WIDTH (m)	MIN. NO. OF AGGRADATION EPISODES[1]	VECTORIAL STATISTICS[2]			CROSS-BEDS (% CONCRETIONARY)	SURVEY STATIONS		
				MEAN	MAGNITUDE	PROB[3]		RIPPLES[4]	INTRACLAST ORIENTATION[4]	SCOURS
UPPER	7.0-9.5	≥240	6	143°	72%	$<10^{-10}$	61 (49%)	1 (7)	3 (27)	5
LOWER	0-3.1	>100	4	067°	75%	$<10^{-10}$	52 (60%)	1	0	0

(b) DESCRIPTIVE AND VECTORIAL STATISTICS OF CROSS-BED DATA

	%	DIP		THICKNESS (cm)			WIDTH (m)	VECTORAL STATISTICS		
		MODE	RANGE	MODE	RANGE	MEAN	RANGE	MEAN	MAGNITUDE	PROB.
UPPER UNIT:										
TABULAR	46	19-21°	11-27°	20-40	15-84	n/a	n/a	133°	68%	$<10^{-5}$
WEDGE	46	16-18°	12-26°	40-60	9-165	n/a	n/a	150°	79%	$<10^{-5}$
TROUGH	4	i/d	11-25°	i/d	22-73	i/d	1.8-4.9	145°	98%	<0.05
LOWER UNIT:										
TABULAR	29	19-21°	11-25°	10-30	8-75	n/a	n/a	058°	80%	$<10^{-4}$
WEDGE	52	10-12°	9-25°	10-20	9-65	n/a	n/a	073°	75%	$<10^{-5}$
TROUGH	19	i/d	12-20°	i/d	16-58	1.8	0.9-3.1	067°	71%	<0.01

Footnotes:

[1] Ratio of maximum unit thickness/thickest planar cross-bed set

[2] Vectorial statistics calculated according to Curray (1956)

[3] Probability that sample-based distribution stems from a randomly-directed population

[4] Number of sample stations (aggregate sample)

i/d - insufficient data

n/a - not applicable

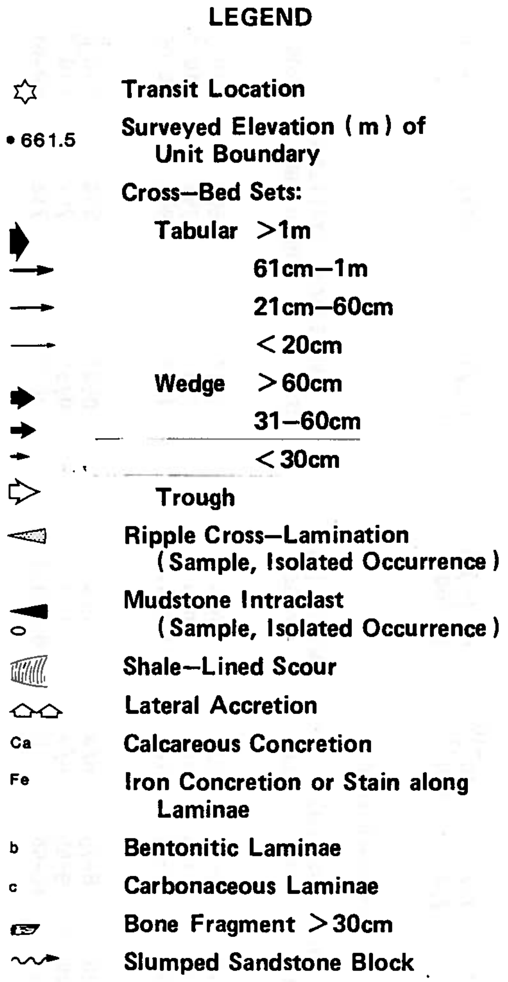

Figure 52. Legend for Figures 53 and 54.

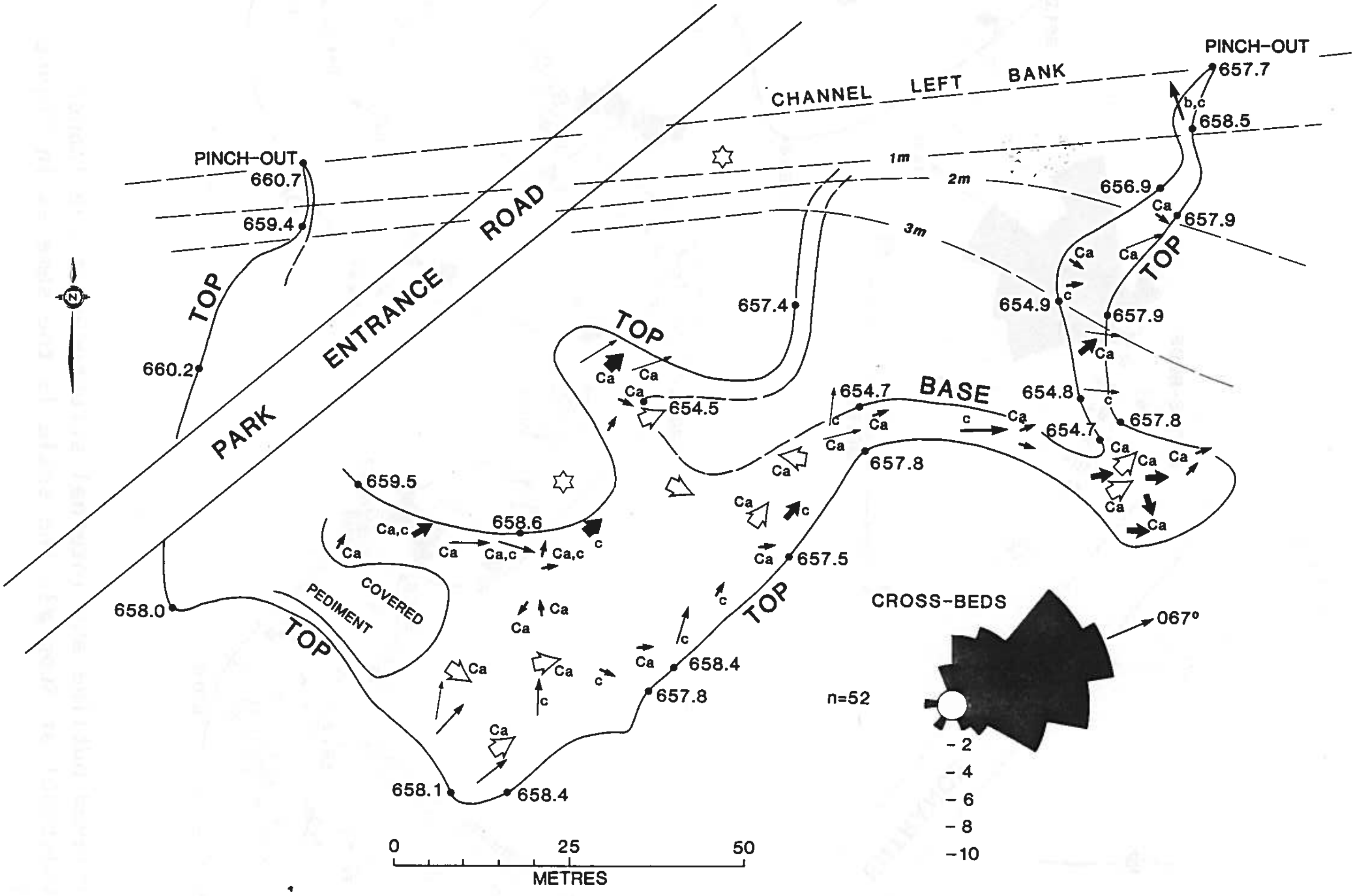

Figure 53. Surveyed outline and internal structures of the 'lower sandstone' at Stop #3. Symbols are explained in Figure 52.

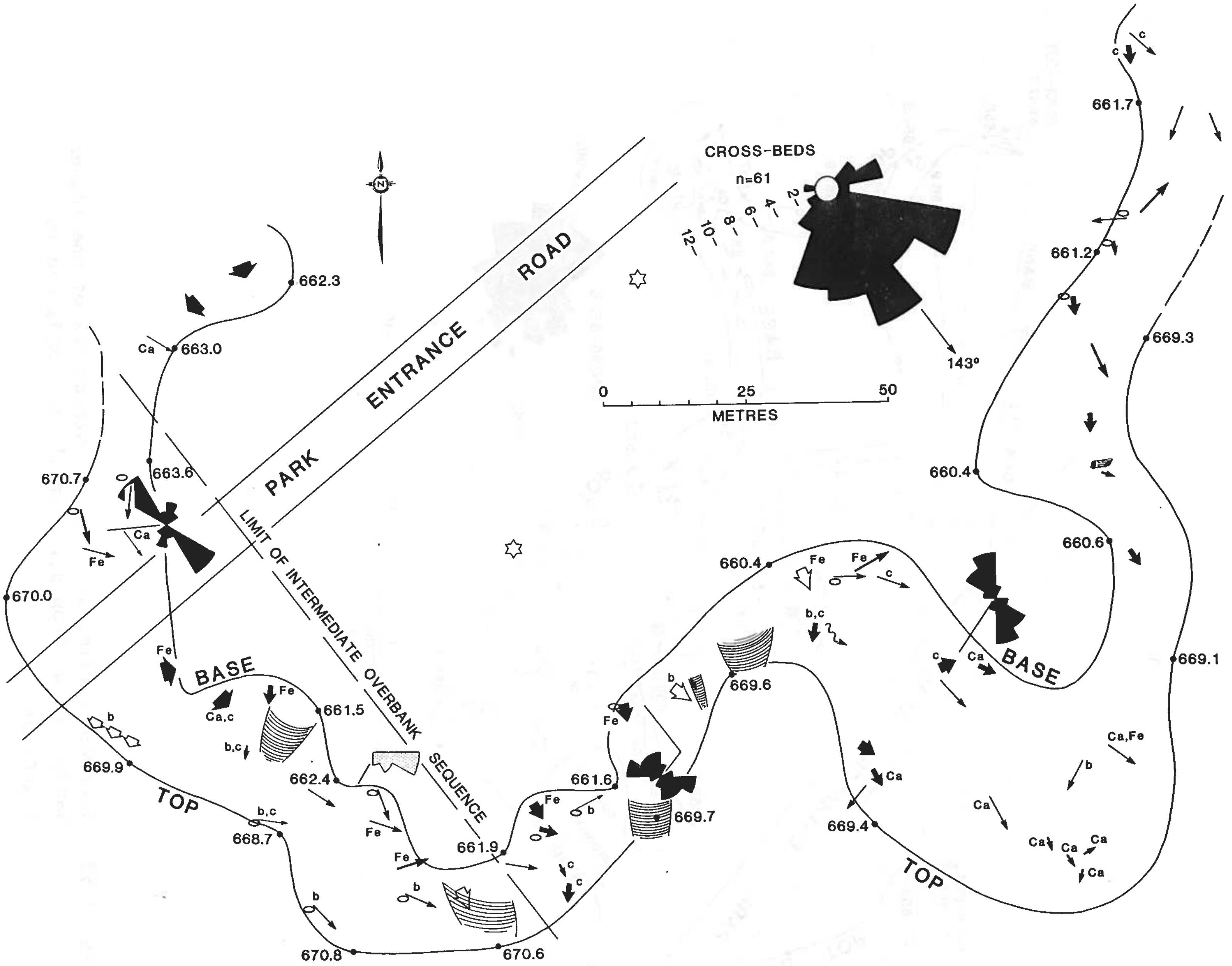

Figure 54. Surveyed outline and internal structures of the 'upper sandstone' at Stop #3, the scale is the same as in Figure 53.

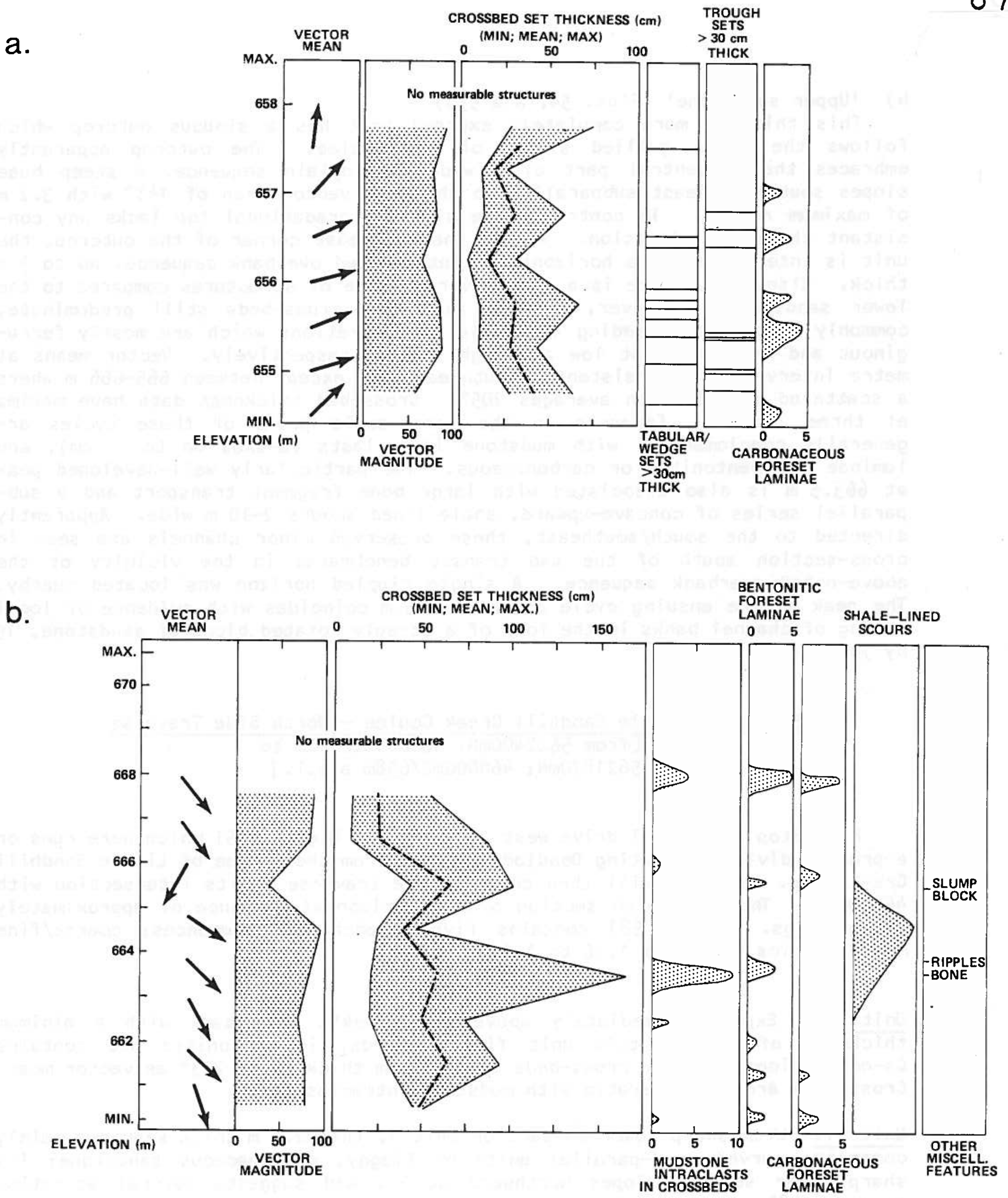

Figure 55. Vertical sequences of paleocurrents and structures in the (a) lower and (b) upper sandstones at Stop #3. Vector mean and magnitude are calculated using Curray's (1956) method.

b) 'Upper sandstone' (Figs. 54, and 55b)

This thicker, more completely exposed unit has a sinuous outcrop which follows the upper gullied slopes of the coulee. The outcrop apparently embraces the subcentral part of a wider braidplain sequence. A steep base slopes south-southeast subparallel to the unit vector mean of 143° with 3.2 m of maximum relief. In contrast, the slightly gradational top lacks any consistant change of elevation. Across the southeast corner of the outcrop, the unit is interrupted by a horizontally interbedded overbank sequence, up to 3 m thick. Elsewhere, there is a more diverse suite of structures compared to the lower sandstone. However, tabular and wedge cross-beds still predominate, commonly in cosets exceeding the scale of concretions which are mostly ferruginous and calcareous at low and high levels, respectively. Vector means at metre intervals are consistently south-eastward except between 665-666 m where a scattered distribution averages 205°. Cross-bed thickness data have maxima at three levels. Foresets in the large-scale peaks of these cycles are generally conglomeratic with mudstone intraclasts (a-axes up to 11 cm), and laminae are bentonitic or carbonaceous. The particularly well-developed peak at 663.5 m is also associated with large bone fragment transport and a subparallel series of concave-upward, shale-lined scours 2-10 m wide. Apparently directed to the south/southeast, these preserved minor channels are seen in cross-section south of the two transit benchmarks in the vicinity of the above-noted overbank sequence. A single rippled horizon was located nearby. The peak of the ensuing cycle close to 666 m coincides with evidence of local caving of channel banks in the form of a steeply rotated block of sandstone, 19 by 74 cm.

5.5 #4: Little Sandhill Creek Coulee - North Side Traverse

[from 5622400mN; 460000mE/712m to
5621870mN; 460000mE/658m a.s.l.]

From Stop #3 we will drive west 2.9 km along Highway 551 which here runs on a prairie divide separating Deadlodge Canyon from the coulee of Little Sandhill Creek (Fig. 56). We will then commence the traverse at its intersection with 460000mE. The 54 m high section over a horizontal distance of approximately 550 m (Figs. 57 and 58) contains five paleochannel sequences; coarse/fine member ratios vary from 1.16 to 1.37.

Unit I: Exposed immediately above the creek's left bank with a minimum thickness of 4.9 m, this unit fines upwards, is bentonitic and contains Ca-concretionary planar cross-beds upto 110 cm thick, with 253° as vector mean. Cross-beds are conglomeratic with mudstone intraclasts.

Unit II: With sharp lower contact on Unit I, this 2.1 m thick sequence mainly comprises curved, non-parallel units of flaggy, carbonaceous sandstone; its sharp upper surface slopes northward at 5°, and suggests lateral accretion towards 348°.

Unit III: This abruptly overlies a 2.0 m thick upward fining overbank sequence, which contains ironstone concretions at mid-level. The base of this 10.5 m thick, upward-fining sandstone appears erosional with fairly abundant broken bone and vertebrae. Ca-concretionary planar cross-bed sets, 17-68 cm

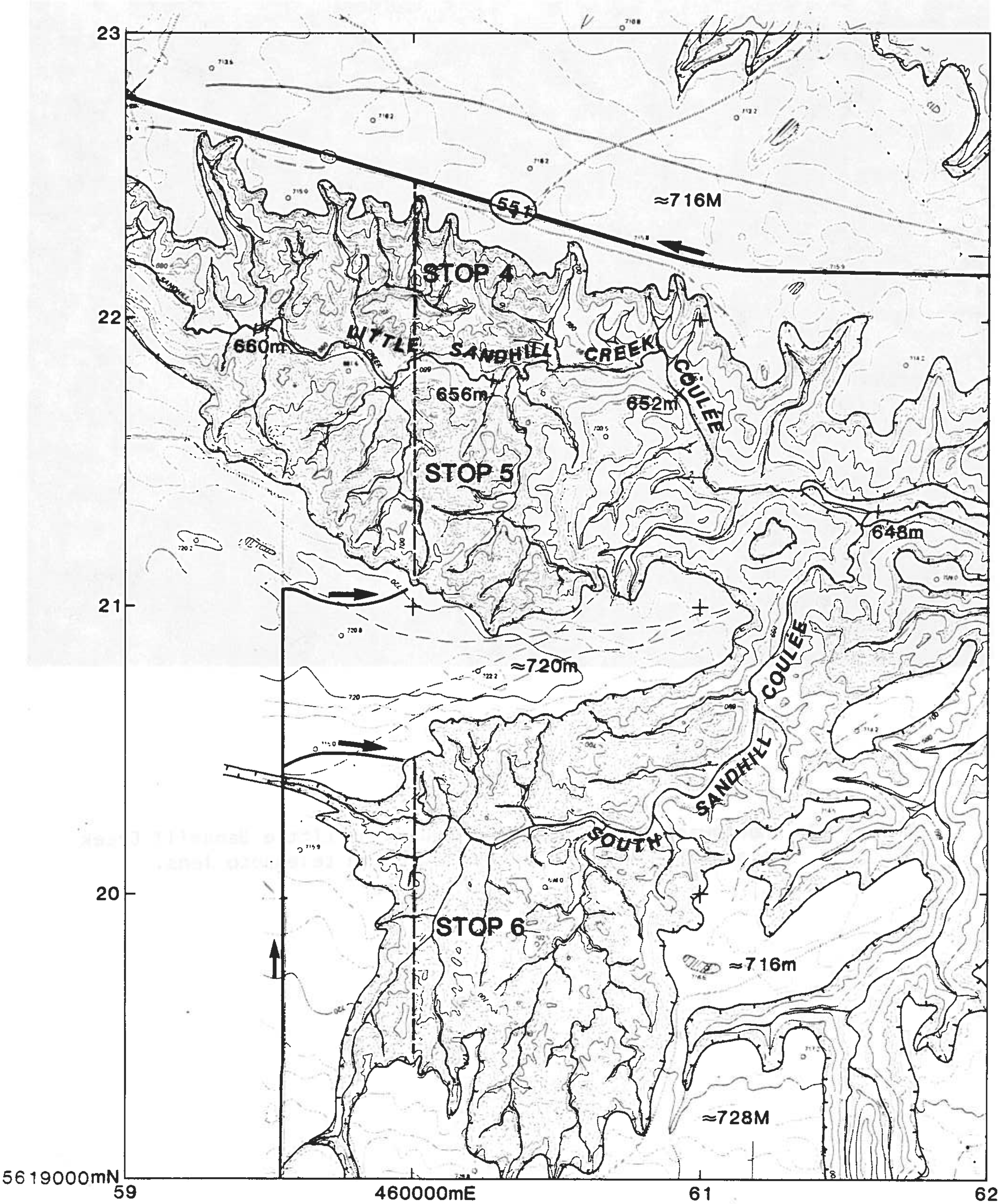

Figure 56. Location map for Excursion Stops 4–6. See Figure 50 for details.

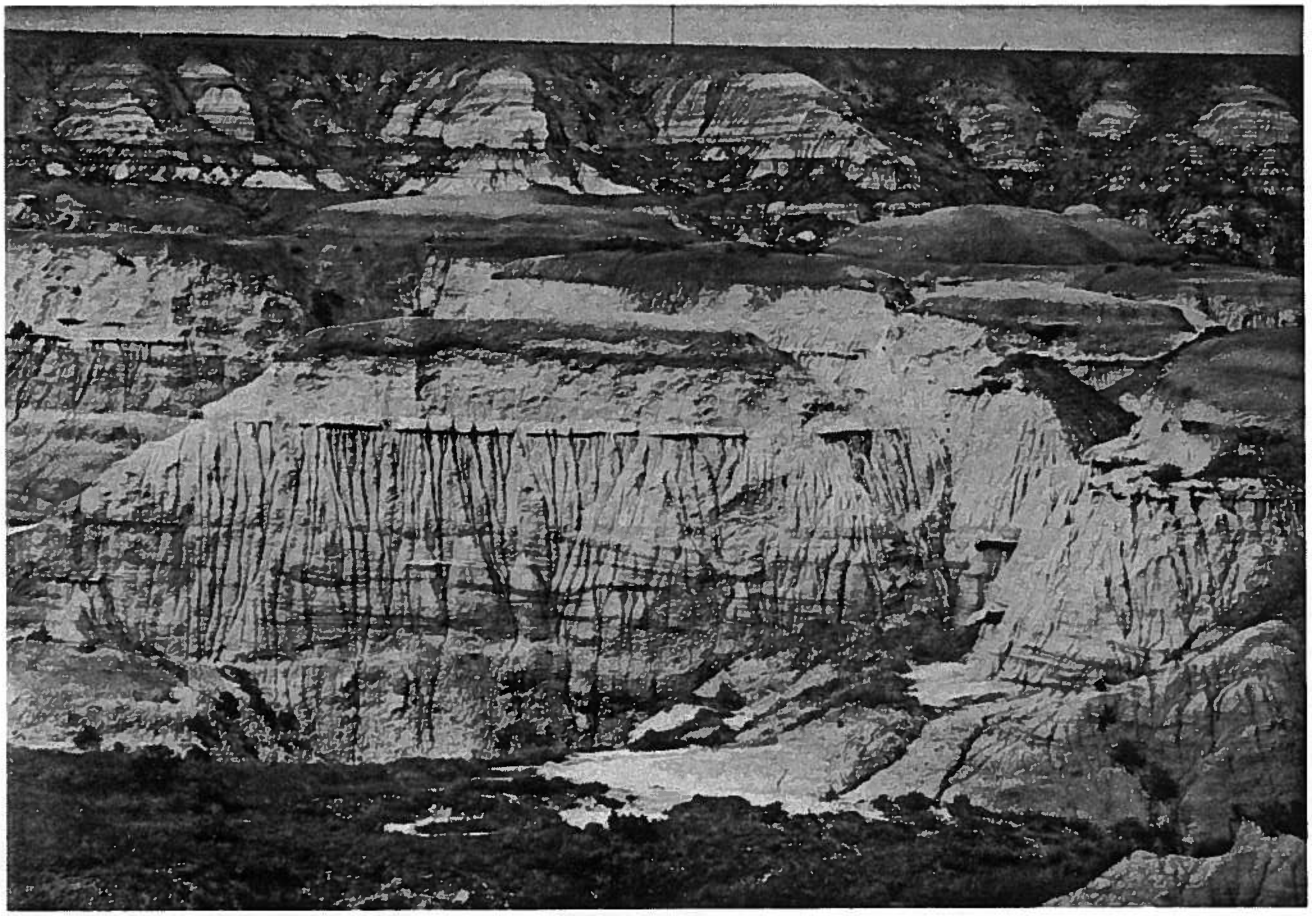

Figure 57. Northward view across the coulee of Little Sandhill Creek along 460000mE, taken with a 200 mm telephoto lens.

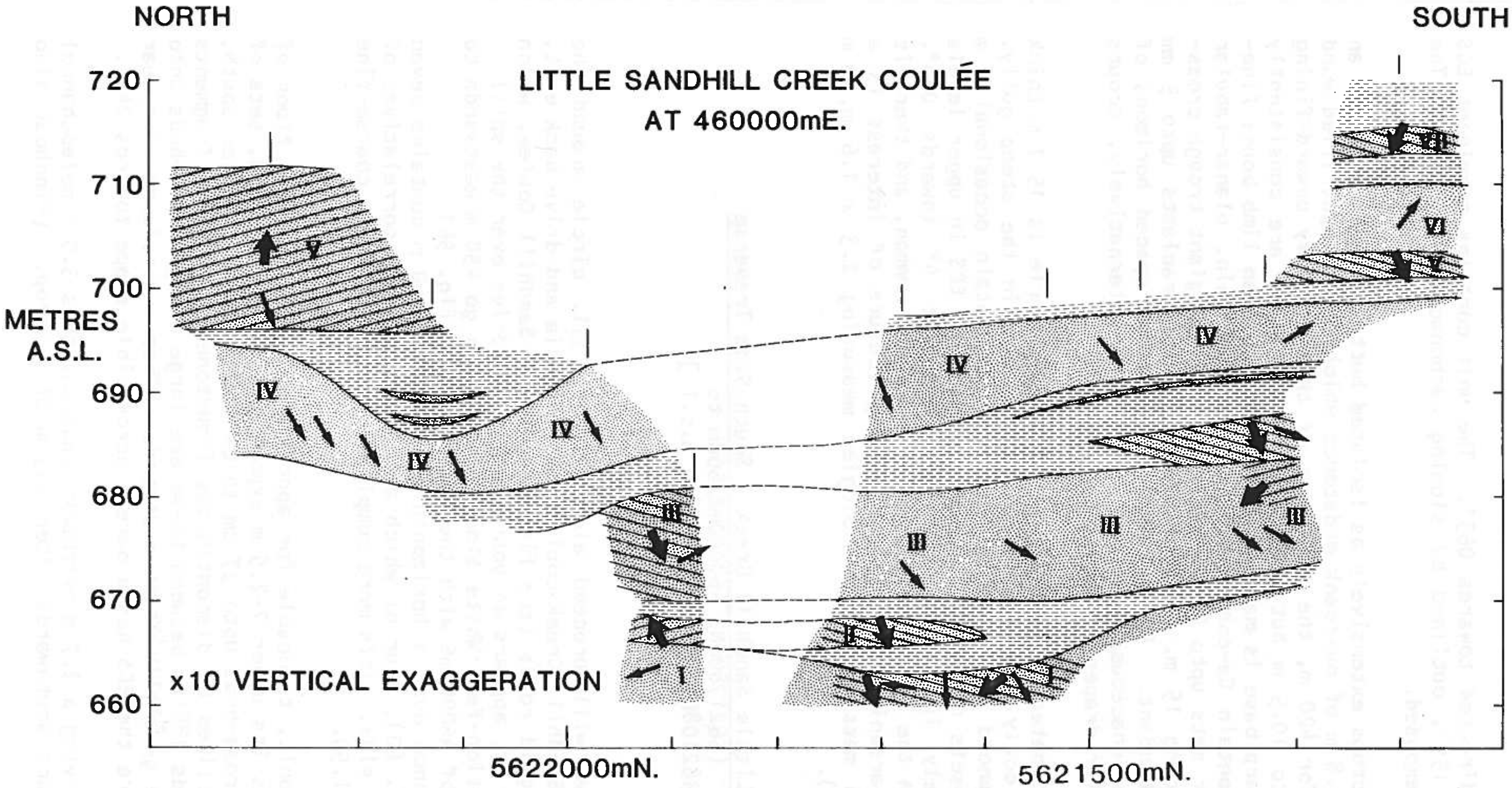

Figure 58. Stratigraphic cross-section pertaining to Excursion Stops 4 and 5. Laterally-accreted sequences are shown by the sloping line ornament (Section 4.4.2); vertically-aggraded sequences by stipple-tone (Section 4.4.3); overbank mudstones and thin sands by shale and sandy-shale symbols (Section 4.4.4). Short vertical lines above the profile indicate measured sections. Paleochannel units are numbered with Roman numerals in stratigraphic order: note that these numbers do not necessarily correlate at high elevations. Short, thick arrows denote the dip direction of lateral-accretion bedding; smaller arrows denote vector means of cross-bed samples.

thick, are on average directed towards 063°. The unit contains prominent ECS dipping at 5° towards 159°, outlined by sloping carbonaceous horizons. The upper part is not well exposed.

Unit IV: This unit outcrops extensively as isolated buttes (see Fig. 19 for an example): it overlies 3.8 m of overbank mudstones which contain petrified wood fragments. Traceable for 420 m, the thickness of this slightly upward-fining unit varies from 4.9 to 10.5 m but cross-bed vector means are consistently east-southeast. Its sharp base is marked by occasional broken limb bone: fine-grained lower levels contain Ca-concretionary cosets of thin, planar-tabular cross-beds, wedge-planar sets upto 68 cm, as well as a few giant trough cross-beds with widths exceeding 15 m. Layers of mudstone intraclasts upto 5 mm diameter are locally abundant. 5% of the unit comprises spaced horizons of horizontally-bedded, carbonaceous/bentonitic sandstone; alternatively, scours are filled with lenticular drapes of the same lithology.

Unit V: This prominent heterolithic unit beneath the prairie is 15.7 m thick and overlies 1.5 m of coaly mudstone where best exposed in the steep gully. Upward-fining is pronounced above lower levels which contain occasional 1 m thick planar-tabular cosets directed just east of south. ECS in upper levels (Fig. 59) dips obliquely into the east gully wall at 4° towards 008°. Reactivation surfaces in the lateral-accretion bedding are common, and there is an overall down-dip coarsening trend. A puzzling feature of interest is a sharply-bounded jumbled mass of ECS lithologies measuring 2.3 x 1.6 m, 9 m above the base (Fig. 60).

5.6 #5: Little Sandhill Creek - South Side Traverse

(5621780mN; 460000mE/660m to
5621080mN; 460000mE/716m a.s.l.]

Leaving Stop #4, we will proceed along Highway 551, circle around the upstream end of Little Sandhill Creek coulee near Patricia and drive back east, then north on unpaved grid roads (see Fig. 2). South Sandhill Coulee, which will be visited as Stop #6, appears on your right as we drive over the spill off channel from irrigation-fed 'White Slough'. We then go 450 m eastwards to reach the intersection of 460000mE with the prairie edge (Fig. 56).

The 56 m high sequence over a horizontal distance of 640 m contains seven paleochannel units (Fig. 60), four of which are almost certain correlatives of Units I-IV on the north side. This more complex stratigraphy has a coarse-fine member ratio averaging 1.50.

Unit I: This complex unit, traceable for approximately 525 m up the floor of the tributary coulee has its upper 2-2.5 m exposed. At the north end, sets of westward wedge-planar cross-beds upto 37 cm thick predominate. Further south, ECS develops and is outlined by discontinuous ironstones with plant fragments that slope ca. 8° towards 188° - between these are large trough cross-beds upto 12 m across that plunge generally south-eastwards. These macroforms disappear still further south where the ECS has a barely perceptible slope towards 245°.

Unit II: Abruptly overlying a 2.7 m overbank sequence, this 3.0 m paleochannel unit thins and disappears southwards after 155 m of outcrop. (Pinchout also

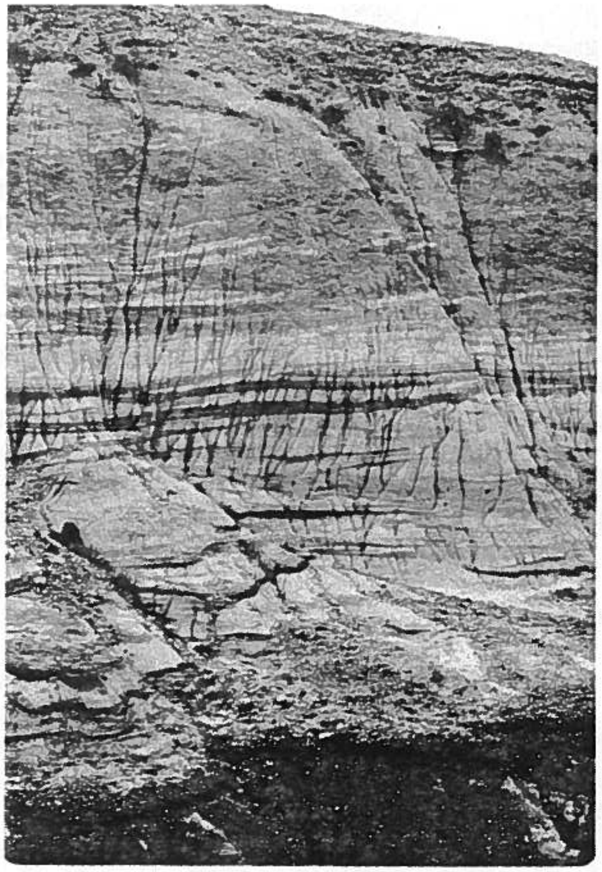

Figure 59. Eastward view of Unit V on the south gullied wall of South Sandhill Creek coulee, at 460000mE. The upward-fining 15.7 m thick unit displays prominent low-angle lateral-accretion bedding to the left.

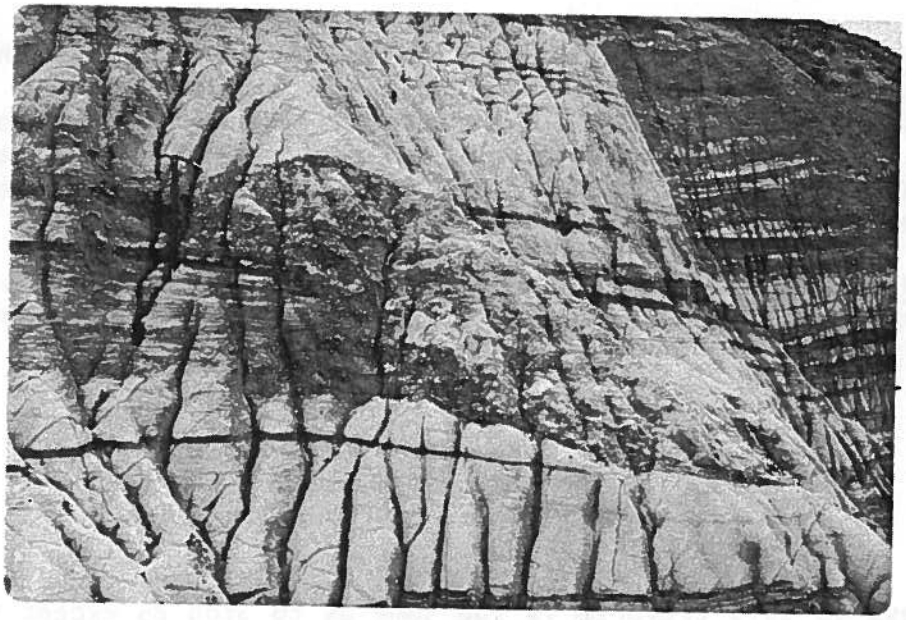

Figure 60. A (?)slumped deposit in Unit V, measuring 2.3 x 1.6 m and containing rotated sandstone blocks upto 40 cm. Figure 59 was taken just to the right. Note the down-dip coarsening trend of the ECS.

occurs at 5621640mN; 459880mE, west of the traverse line.) ECS is heterolithic and principally outlined by sloping ironstones. Near the second location, the unit lacks ECS and comprises nested cosets of giant trough cross-beds, directed east-southeast (see Fig. 38).

Unit III: Abruptly overlying 2.3 m of mudstones, this vertically-aggraded unit is dominantly composed of planar tabular and wedge-shaped cross-beds, 45-70 cm thick, that are consistently directed southeast. The unit fines upwards and thickens southwards from 6.5 to 12.6 m where progradational scour infills are present (see Fig. 41); lower levels contain abundant mudstone intraclasts and bone fragments. As the southern limit of exposure is approached, the upper part of the unit appears to become progressively amalgamated with an overlying laterally-accreted unit in which the ECS dips southward (Fig. 61).

Unit IV: Separated from Unit III initially by a 9.2 m overbank sequence, locally containing a thin crevasse-splay unit, Unit IV above has difficult access. Near the tops of flanking buttes, it contains troughs upto 14 m wide and horizons of ripple cross-lamination, both directed south-eastwards. Southwards, the underlying mudstone thins and locally pinches out, but its main feature is that it develops a complex vertical facies sequence that grades into southwardly directed ECS (not shown on Fig. 58).

Unit V: This unit thickens eastward from 1.5 to 3.5 m, both because of a sloping lower contact into a mudstone sequence below and erosional truncation by the overlying Unit VI. ECS is made prominent by carbonaceous sand-mud couplets, the higher parts of which show deformational structures. Further eastwards (see Fig. 22b), the ECS becomes very prominent and contains upward-coarsening mud-sand couplets that are erosionally truncated in several places. Bedding planes are strewn with carbonised, randomly-orientated plant and twig debris. Any current structures in bentonitic sand layers are difficult to discern.

Unit VI: With an erosional base on Unit V, this 6.6 m thick unit mainly contains sets of wedge-planar cross-beds, directed to the northeast, with abundant bone, jaw and turtle carapace fragments. Drapes on lower foreset laminae are generally carbonaceous and bentonitic, with gypsum rosettes upto 8 cm weathering out. Upwards, the carbonaceous grey mudstone layers become more abundant, but are affected by ball-and-pillow structures.

Unit VII: This 2.6 m thick unit between mudstones, and 5 m beneath prairie elevation, contains mud-dominated ECS sloping 6° towards 196°. The unit curiously appears to coarsen upwards.

5.7 #6: South Sandhill Coulee Traverse

[from 5620500mN; 460000mE/712m
to 5619400mN; 460000mE/720m a.s.l.]

Access to this traverse is the same as to Stop #5 except that a turn east onto prairie is made immediately north of the incised spill-off channel leading from White Slough. At 460000mE, South Sandhill Coulee is 1.08 km wide and has a ca. 40 mm range in elevation. Although local relief between coulees and intervening buttes is moderate, correlation of the principal paleochannel units

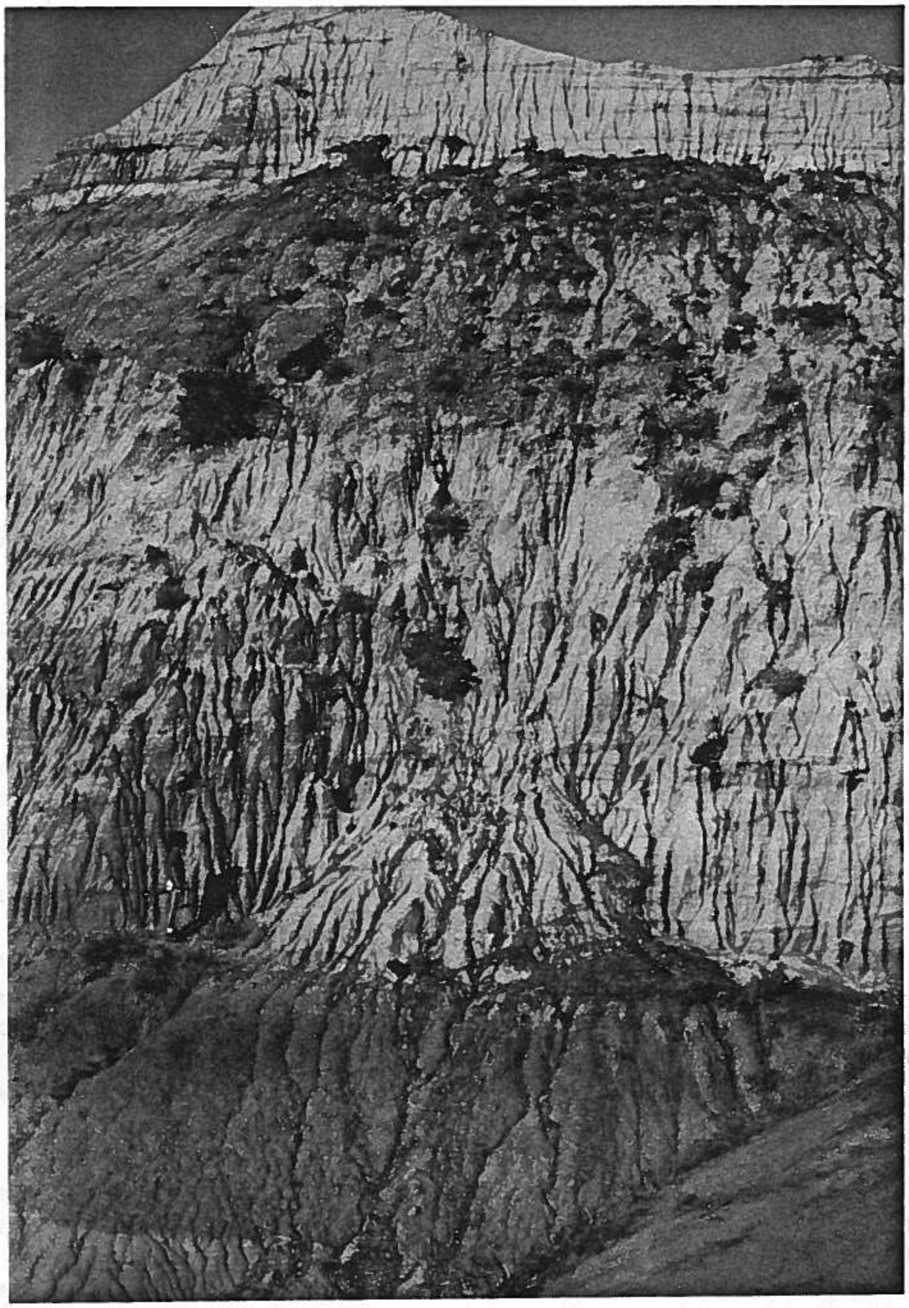

Figure 61. View west across tributary coulee showing southward, sand-dominated lateral accretion in Unit III which is 9.7 m thick (person standing on lower sharp contact). The top of Unit I and the basal portion of Unit IV are also seen: these three paleochannel sequences are separated by overbank mudstones.
[5621350mN; 459920mE / basal contact of Unit III at 702 m a.s.l.]

appears straightforward (Fig. 62). Coarse-fine member ratios range from 0.40 to 1.49; particular interest lies with Units II and III. The first, a vertically-aggraded sequence has good three-dimensional exposures of its ribbon form; the second displays lateral variability south from a well-exposed pinch-out.

The first 100 m of the traverse has outcrop of a 13 m thick overbank sequence containing three crevasse-splay units, each less than 1 m thick. The latter consist of carbonaceous, flaggy very fine-grained sandstones interbedded with laminated grey mudstone intervals. 60 m east of the traverse, this sequence incorporates a 4.5 m heterolithic ECS unit dipping 8° at 018°: the upper sand-mud couplets show ball-and-pillow structure, while lower levels contain unusual clast-supported clay-flake conglomerates. This whole sequence is capped, beneath prairie level by a 6.8 m thick ECS unit that dips 4° towards 145° and shows a good upward-fining trend. Further eastwards, the unit thickens and develops a cleaner sand base above which heterolithic ECS is still prominent.

Unit II: This mud-free vertically-aggraded unit, upto 6.9 m thick, is almost 400 m wide in north-south section. Left-bank pinchouts are clearly seen by looking down the main coulee towards 5620200mN; 460240mE, 5620300mN; 460450mE and 5620180mN; 460090mE. From these points, the unit base quickly drops in elevation to 686 m a.s.l. Above the sharp base, isolated and articulated dinosaur bone are fairly abundant. The latter includes Quarry No. 141 (found in 1974 and excavated in 1981), the skull of Leidyosuchus canadensis, and a hadrosaur with 23 caudal vertebrae discovered last year by the Alberta Geological Survey. On the traverse line, and in the central portion of this unit, the sequence is completely composed of nested large troughs with preserved widths of between 4.35 and 17.8 m (Fig. 63). Good directional data was obtained from 18 of these structures - all levels show eastward transport (with vector magnitude over 90%). Southward the unit thins, contains small troughs and occasional current-normally aligned log fragments upto 8 cm diameter. A right-bank pinchout is observed at 5619890mN; 460000mE.

Unit III: With northward pinchout at 5620200mN; 460000mE, this unit is separated from the preceding one by upto 3.6 m of overbank mudstone. It rapidly thickens to 10.6 m, thick and contains prominent south-westward ECS outlined by ironstones dipping at 4-6°. Mudstone intraclasts and ironstone concretions are locally abundant. Southwards, the ECS becomes confined to the central part of the unit. Below the laterally-accreted interval, a mud-free sandstone contains trough cross-bed sets directed southeast with non-carbonised wood fragments. Thin cosets of planar-tabular cross-beds occur above the ECS with similar directions, but bedding is commonly disrupted by ball-and-pillow structures. Still further southwards, the ECS portion disappears and the bone-bearing erosional base of the unit climbs several metres. Here the unit comprises a variety of Fe-concretionary, dominantly planar, cross-beds and local progradational scour fills upto 70 cm deep. The mudstone immediately beneath Unit III has numerous ironstone concretions and petrified log fragments. Finally at the southern limit of South Sandhill Coulee, Unit III splits on account of a 2.1 m thick mudstone. The lower sandstone contains upto 30% bentonitic, occasionally carbonaceous, mudstone with east-northeast current indicators: the upper part is less muddy, and contains 30 cm thick planar-tabular units with mudstone intraclasts.

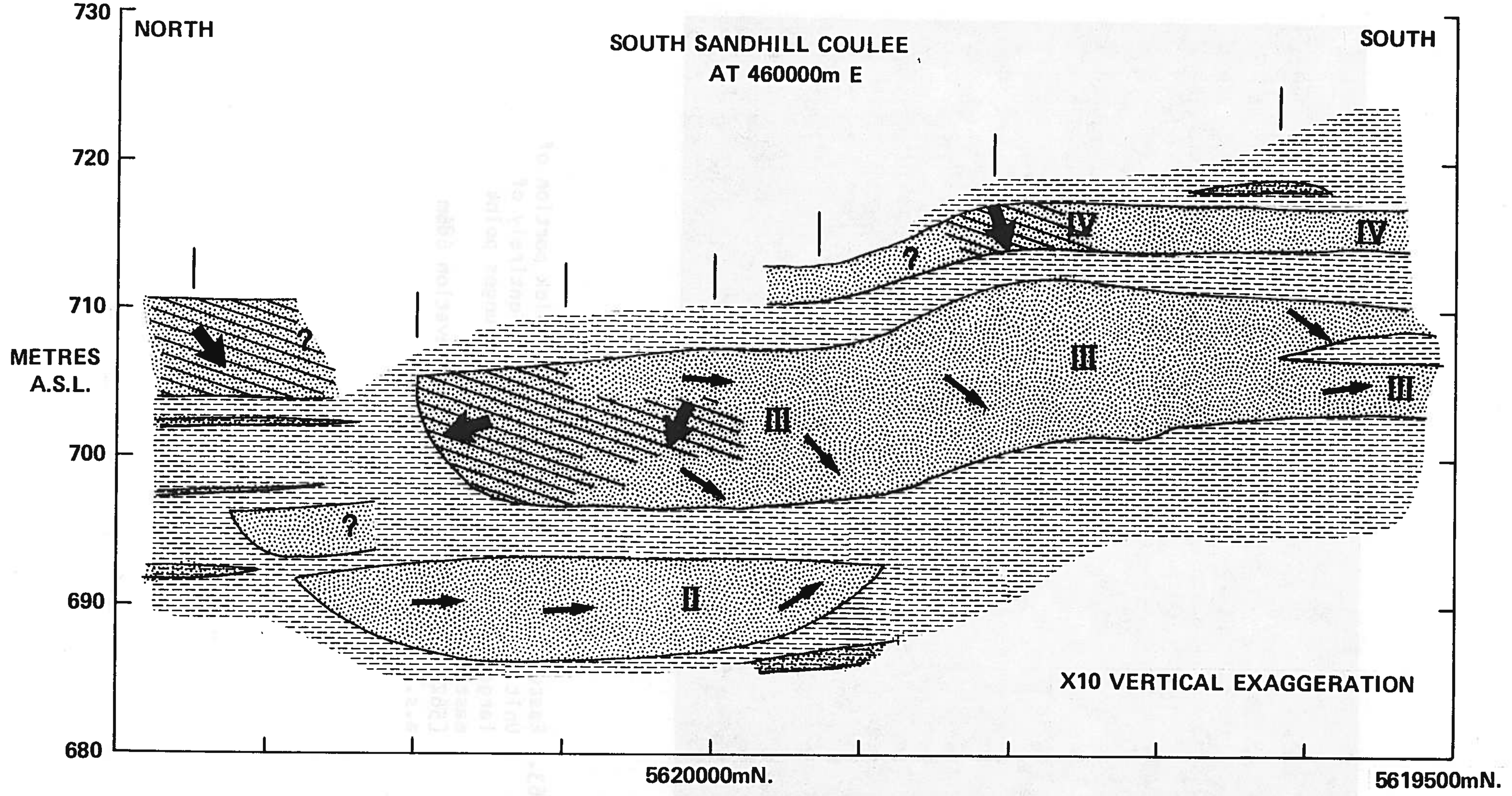

Figure 62. Stratigraphic cross-section north to south across South Sandhill Coulee (Stop #6). See Figure 58 for explanation of symbols.

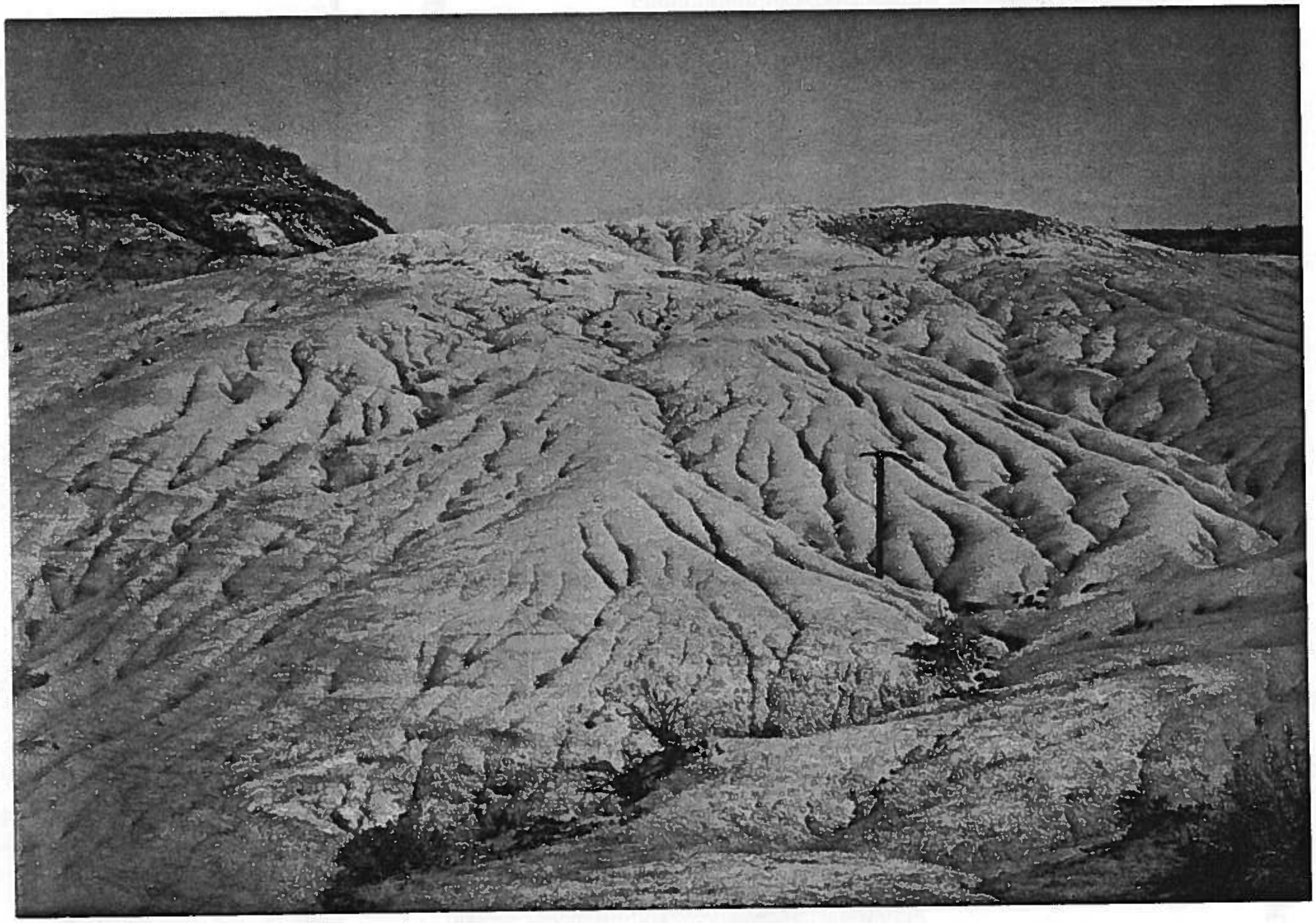

Figure 63. Eastward view into the central, thick portion of Unit II at Stop #6 which consists entirely of large trough cross-beds; axial plunges point eastward.
[5620200mN; 460110mE / basal elevation 686m a.s.l.]

5.8 #7: Steveville Badlands Traverse

[from 5628950mN; 460000mE/706m
to 5629500mN; 460000mE/708m a.s.l.]

Access from the Patricia area is north along Highway 876 across the Red Deer River at Steveville (see Fig. 1). From here, we will turn right onto Highway 557 which ascends to prairie level and strikes due east. A right turn onto an unpaved grid road leads to the eastern limit of the Steveville badlands (Fig. 64). We will traverse this remote segment of badlands (Fig. 65) from south to north, and spend some time attempting to unravel the north slope which is capped by a representative of the Lethbridge Coal Zone (Fig. 66). Local relief totals 33 m. Paleochannels in this section are almost entirely of the lateral-accreting type (Fig. 67), and vertebrate fossils are scarce. Coarse-fine member ratios average 0.42 but this relatively low value largely reflects a basal, poorly exposed overbank sequence of at least 13.5 m.

Unit I: The base is not clearly exposed, but the unit thins northward from 5.6 to 2.1 m. When first encountered at the southern limit of exposure, heterolithic, low-angle ECS directed south is a prominent feature. Within-channel current structures are not discernible in the 30-40 cm sand-mud couplets, or between thin discontinuous ironstone horizons.

Unit II: This unit, generally 3.6 m thick and overlying a 1.8-2.6 m mudstone interval, contains prominent ECS sloping northwards upto 7°. It is dominantly mudstone, with occasional beds and concretions of ironstone. Thin sandstone intervals contain eastward ripple cross-lamination and scattered small bone fragments. At the top, sand-mud couplets are intensely deformed by ball-and-pillow structures (Fig. 68). Northwards, the ECS pinches out.

Unit III: This unit is confined to the south end of the traverse where it appears that mud-dominated ECS begins abruptly above an exhumed point bar surface (Fig. 69).

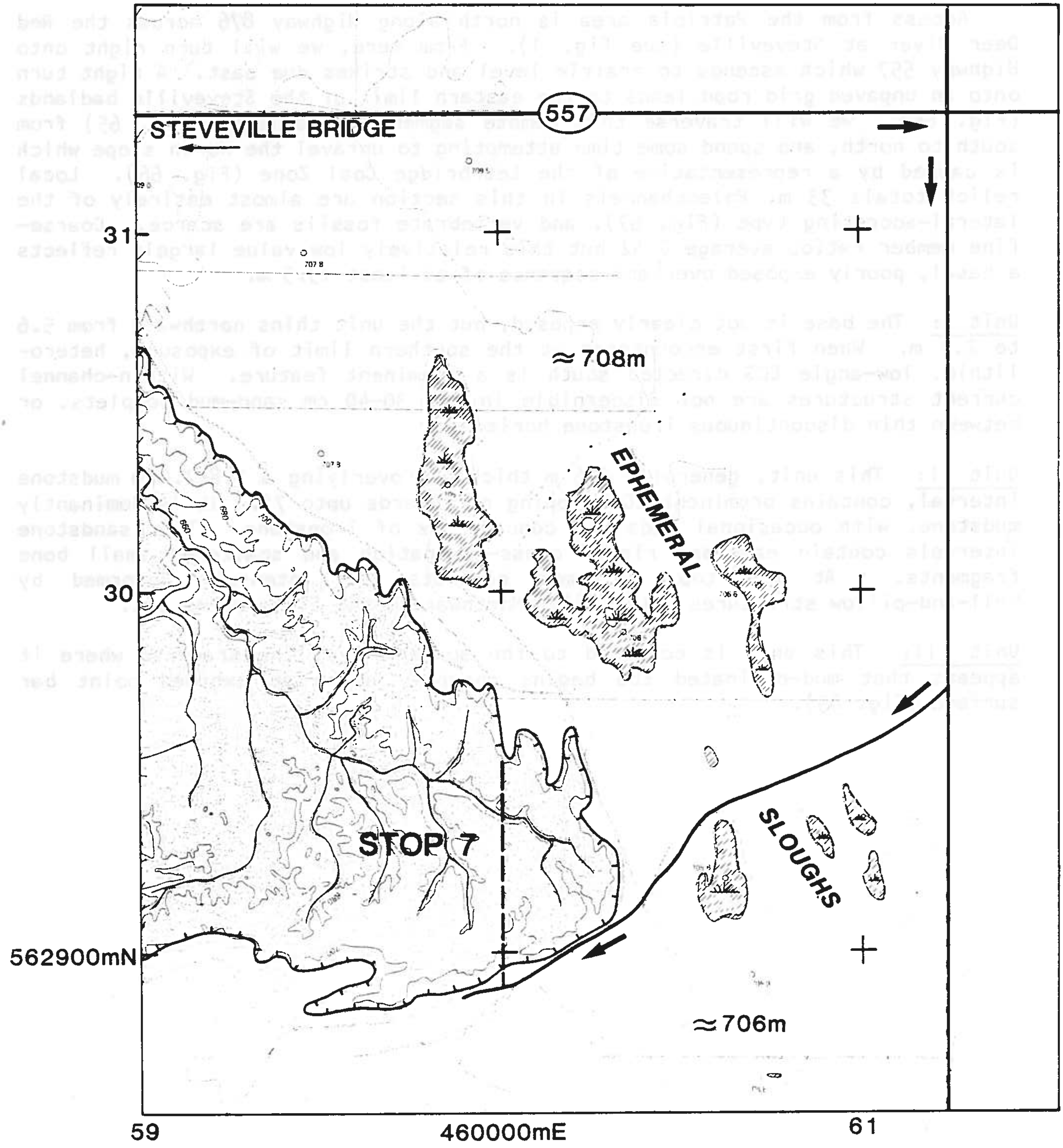

Figure 64. Location map for Excursion Stop #7 in the Steveville badlands at 460000mE.

Figure 65. View west into the main tract of the Steveville badlands. Shallow paleochannels with prominent heterolithic lateral-accretion bedding, separated by thin overbank units, predominate at higher levels.

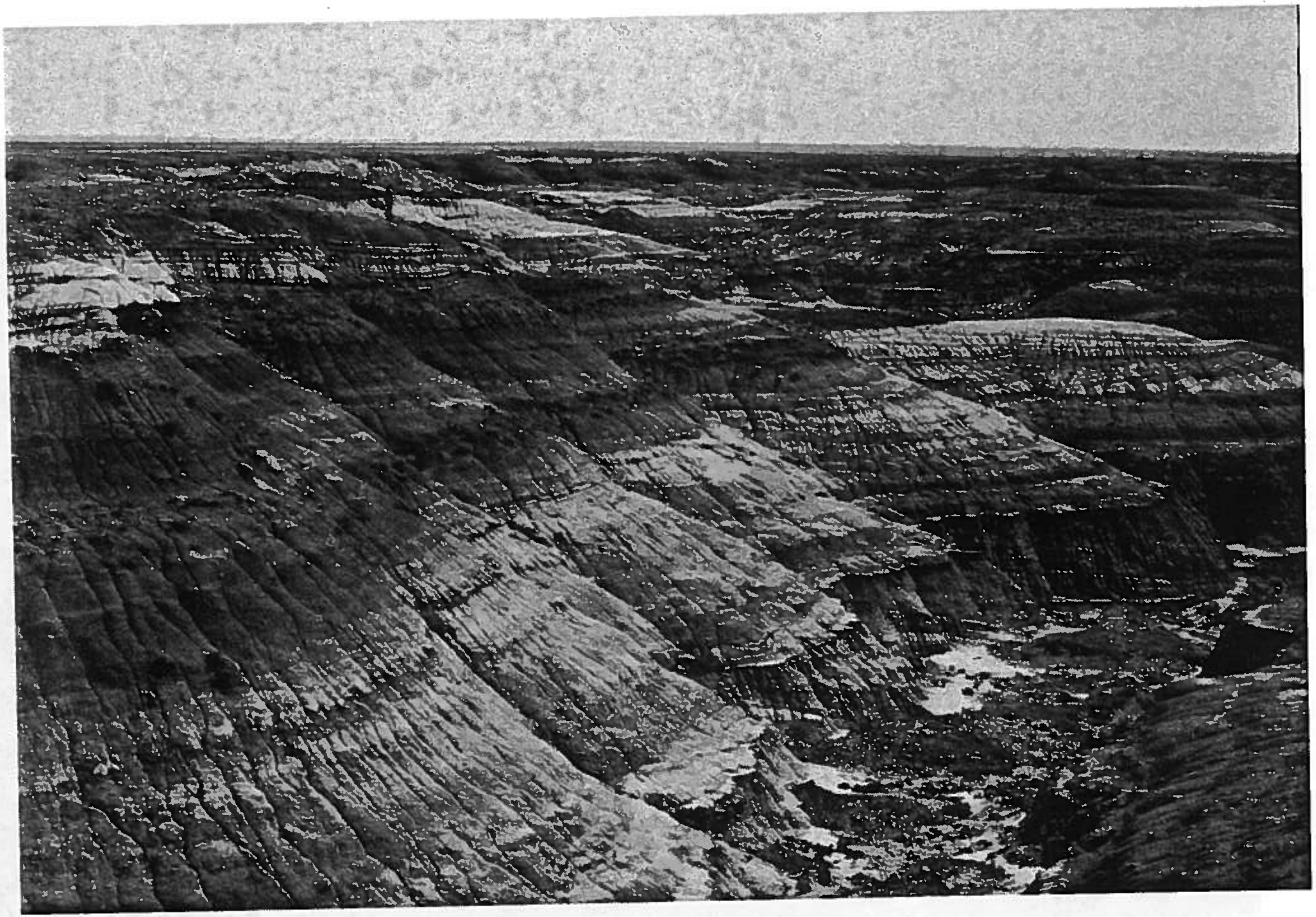

Figure 66. Eastward view at the north end of the traverse at Stop #7, Steveville badlands. It comprises a horizontally stratified, upward fining sequence from mudstones containing thin bentonitic sandstones to a black carbonceous shale sequence with coal seams. A sandstone with evidence of lateral accretion caps this sequence.

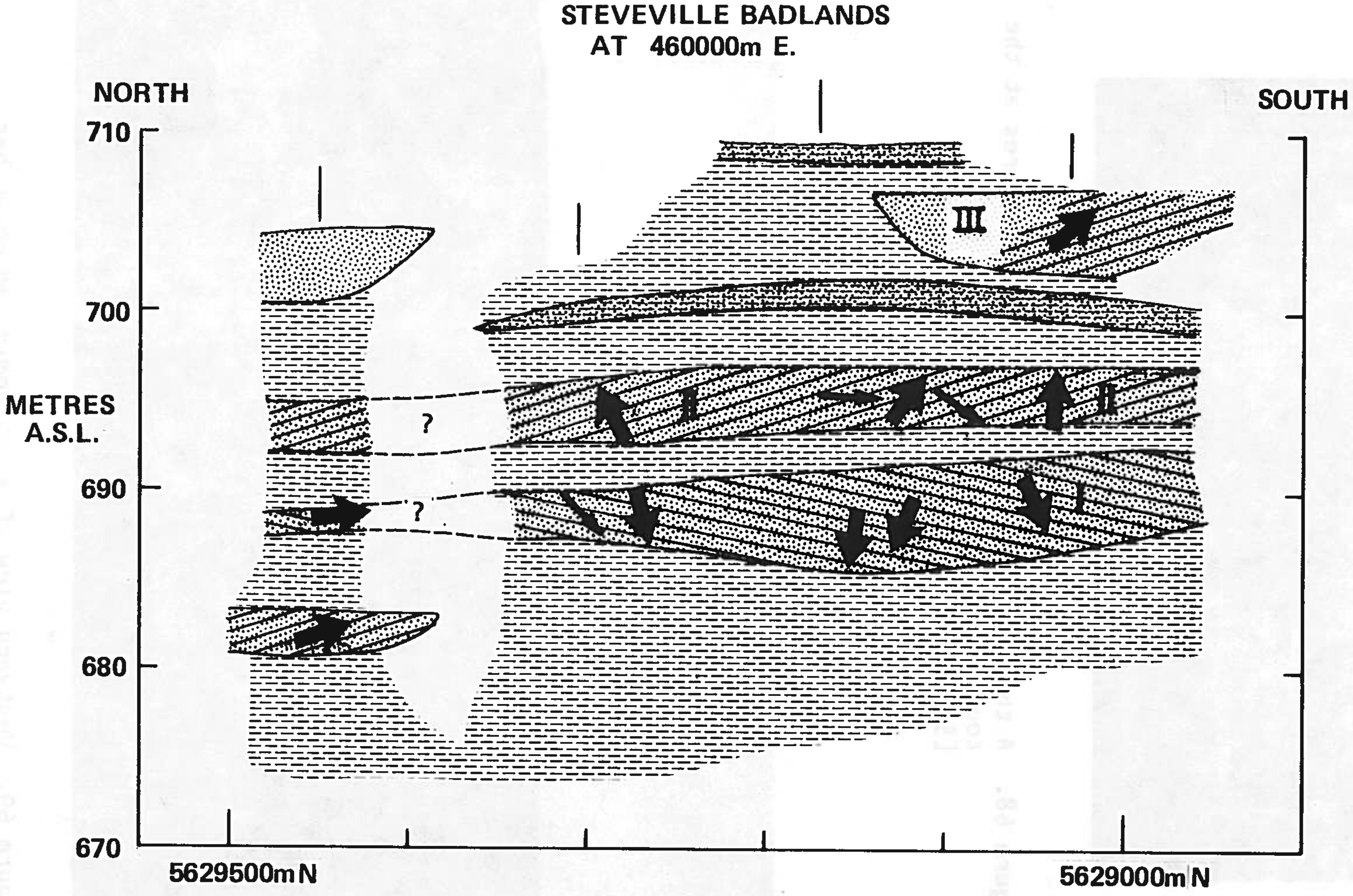

Figure 67. Stratigraphic cross-section from north to south across the Steveville badlands at 460000mE (Stop #7). See Figure 58 for explanaton of symbols.

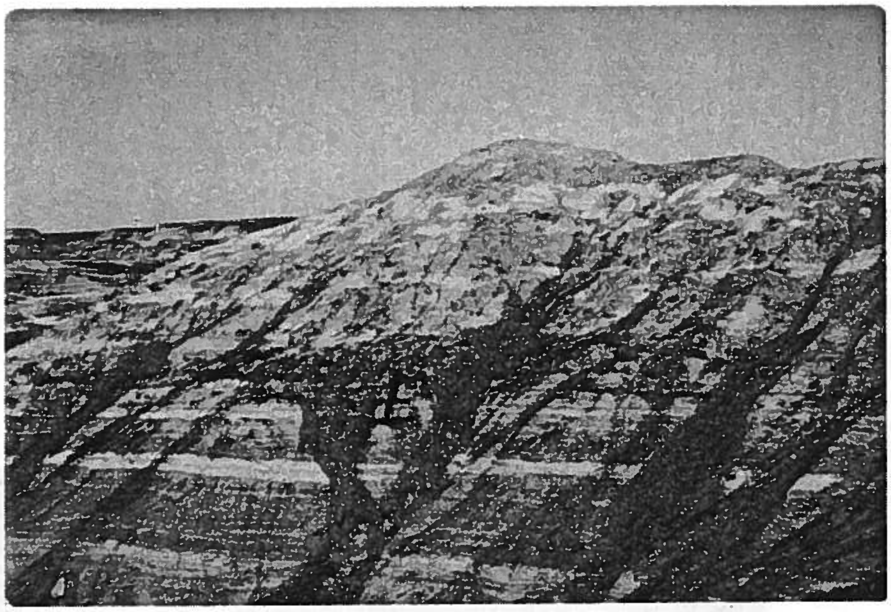

Figure 68. A thick zone of ball-and-pillow structures at the top of Unit II at Stop #7. [5629050mN; 459980mE / 696m a.s.l.]

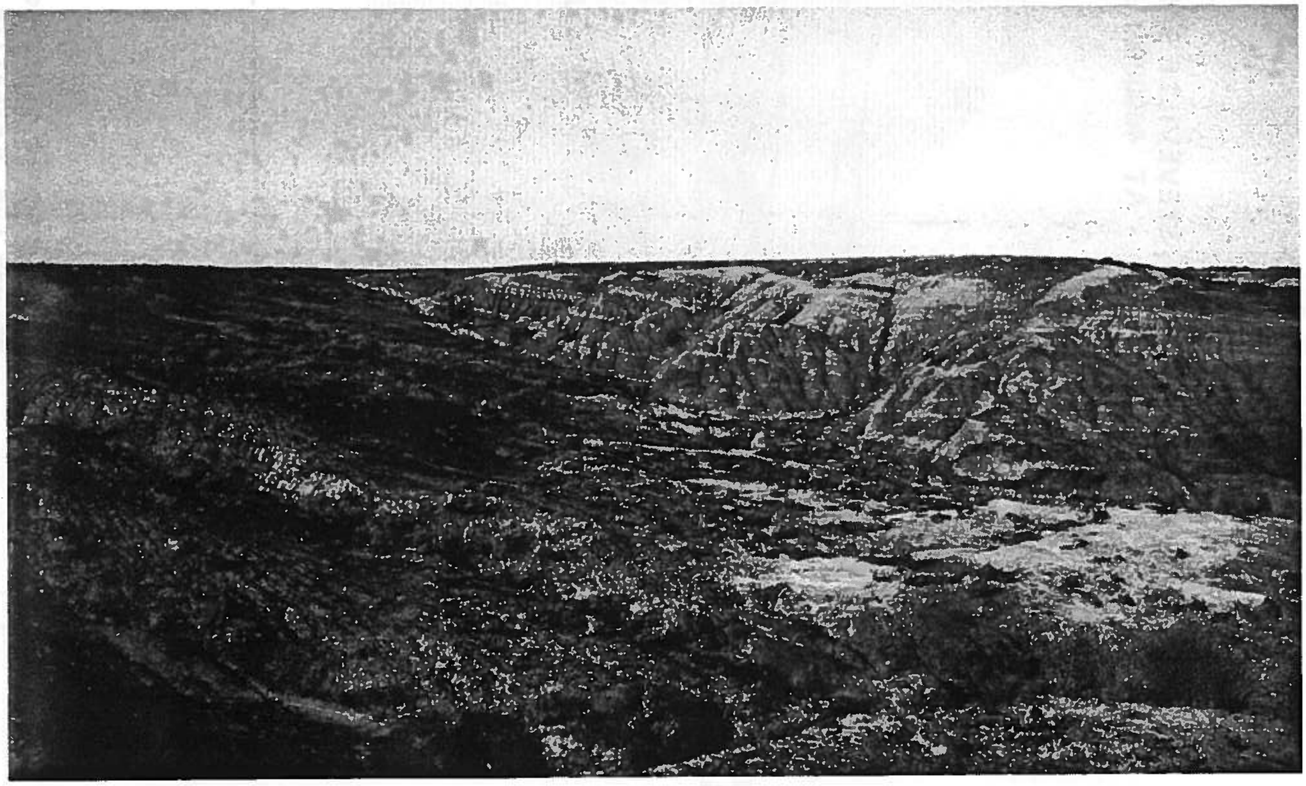

Figure 69. Westward view of a mud-dominated point bar sequence (Unit III at Stop #7), one surface of which appears to be exhumed. Taken with a wide angle lens, person at upper left. 5629030mN; 460150mE / 703m a.s.l.]

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8.0 APPENDICES - DINOSAUR PROVINCIAL PARK

8.1 Area Map Coverage

TOPOGRAPHY

Surveys and Mapping Branch, Canada Department of Energy, Mines and Resources -
1:250,000 NTS Sheet 72L, Medicine Hat (1967)

1:50,000 NTS Sheets 72L/11, Jenner (1975)
72L/12, Brooks (1975)
72L/13, Wardlaw (1975)
72L/14, Halsbury (1975)

Parks Division, Alberta Parks and Recreation -
1:10,000 Dinosaur Provincial Park and Area (1979)
2 m contour interval

Sheets		
1	5615000-5618500mN;	467000-473000mE
2	5615000-5618500mN;	460000-467000mE
3	5621500-5627000mN;	454400-458500mE
4	5618500-5627000mN;	459000-467000mE
5	5618500-5626300mN;	467000-475500mE
6	5627000-5629700mN;	464200-467400mE
7	5627000-5633100mN;	454400-461300mE

BEDROCK GEOLOGY

Mines and Geology, Branch, Canada Department of Mines and Resources -
1:253,440 (1 inch to 4 miles) Map 695A, Brooks (1942) with descriptive notes; geology by J.S. Stewart.

Geological Survey of Canada, Department of Energy, Mines and Resources -
1:253,000 (1 inch to 4 miles) Map 21-1967, Medicine Hat (1968) with descriptive notes, geology by E.J.W. Irish.
1:500,000 Map 1286A Southern Plains of Alberta (1971) with descriptive notes; geology by E.J.W. Irish.

SURFICIAL GEOLOGY

Alberta Research Council, Edmonton -
1:250,000 NTS 72L, Medicine Hat (1972) with descriptive notes; geology by T.E. Berg and R.A. McPherson.

BEDROCK TOPOGRAPHY

Geological Survey of Canada, Department of Energy, Mines and Resources - 1:1,267,000 (1 inch to 20 miles) Map 47-1960 to accompany GSC Paper 60-32, Buried valleys in central and southern Alberta (1961), geology by A. MacS. Stalker.

Alberta Research Council, Edmonton - 1:250,000 NTS 72L, Bedrock topography of the Medicine Hat map area (1970) with descriptive notes; geology by V.A. Carlson.

VERTEBRATE FOSSIL LOCALITIES

Geological Survey of Canada, Department of Mines and Technical Surveys - 1:31,680 (1 inch to 1/2 mile) Map 969A, Steveville/Dinosaur Provincial Park (1950), with notes on dinosaur quarries by C.M. Sternberg.

8.2 Park Aerial Photo Coverage

Air Photo Distribution Office, Alberta Energy and Natural Resources -

1:30,000 (B & W), AS 1658 (1978):	Line 2,	Nos. 185-195
	Line 3,	Nos. 201-208
	Line 4,	Nos. 213-224
	Line 5,	Nos. 232-243
1:10,000 (B & W), AS 1576 (1977):	Line 5,	Nos. 113-129
	Line 6,	Nos. 140-164
	Line 7,	Nos. 173-199
	Line 8,	Nos. 210-237
	Line 9,	Nos. 247-274
	Line 10,	Nos. 300-326

National Air Photo Library, Ottawa -

1:10,000 (Colour), P1107 by Machair Surveys Ltd. (1977):

MA1121,	Nos. 87-106, 172-190
MA1122,	Nos. 70-85, 154-176
MA1123,	Nos. 32-47
MA1132,	Nos. 69-74, 88-90, 151-155
MA1133,	Nos. 65-71, 86-87, 135-152

8.3 Visitor facilities

The following information derives from a brochure produced by Alberta Recreation and Parks and is quoted here for the convenience of prospective visitors.

> ".....Natural Preserve
> A vast Natural Preserve, encompassing most of the park, protects fossilized bones and related resource attractions. The preserve is regularly patrolled by park rangers. A jet boat and park vehicles are employed to provide complete coverage. Visitors are permitted access to the Natural Preserve only through conducted hikes and tours. These activities are available daily from May 1 through the Labour Day weekend in September. Look for posted schedules and times.
>
> Recreational Opportunities
> Day and evening interpretative programs, available to park visitors May 1 through Labour Day weekend, are designed to maximize enjoyment and to present interesting and informative stories focusing on dinosaurs and related attractions. Hikes, guided walks, children's activities, audio-visual productions, bus tours, and drama presentations are offered. Posted schedules provide times and locations for these activites. Visitors are also encouraged to pursue leisure-time activities on their own. These include:
>
> Summer
> - Camping
>   Campsites nestled among shady cottonwood trees provide shelter and cool areas during warm summer days.
> - Picnicking
>   Picnic tables, covered camp kitchens with wood stoves, fire pits and available wood are provided.
> - Hiking
>   The "Badlands Interpretive Trail" and an accompanying brochure are available to visitors who wish to travel a short loop trail with the aid of a text keyed to features along the footpath. Brochures are available at the trailhead. Informal trails wind through the badlands, along Little Sandhill Creek and the Red Deer River.
> - Dinosaur Displays
>   Dinosaur displays reveal fossilized dinosaur bones which have been prepared for public viewing.
> - Nature Observation, Photography and Painting
>   The park is a preserve where plants, animals and other resource attractions can be viewed in their natural habitat. Visitors will enjoy the sights of numerous bird species and colourful badland plants.
> - Canoeing
>   Canoeists travelling along the Red Deer River use Dinosaur as a point to begin or end a trip. A canoe launch is provided

near the confluence of the Red Deer River and the Little Sandhill Creek. Note: Camping in the park is limited to the formal camping area.

- Fishing

The Red Deer River offers seasonally good fishing for walleyes, northern pike and goldeyes. A provincial fishing licence is required.

Winter

- Nature Observation, Photography and Painting

A colourful setting of snow-covered formations greets the winter visitor.

You can watch the silent flights of snowy, great-horned and short-eared owls as they hunt for small birds and mammals. Everywhere there are signs of life and the mornings and evenings are usually filled with coyote song.

- Cross-Country Skiing and Snowshoeing

The loop road allowing access to dinosaur displays is unplowed and offers seasonally excellent skiing, or you can strike out on your own through the badlands and along the river.

- Picnicking

Covered camp kitchens with wood stoves and firewood are provided.

- Camping

Limited facilities are provided. Water, during the winter months is not available....."