DEPOSITIONAL ENVIRONMENTS AND PALEOCURRENT TRENDS IN THE GATES MEMBER NORTHEAST COALFIELD

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INTRODUCTION

The Lower Cretaceous Gates Member is an important coal-bearing stratigraphic unit in the Rocky Mountain Foothills of northeastern British Columbia. During the past two years, depositional environments in the Gates have been studied between the Wolverine River and the Mount Belcourt area, using outcrop, core, and geophysical log data. In this paper, some of the preliminary results of this study are presented.

LITHOSTRATIGRAPHIC NOMENCLATURE

The lithostratigraphic nomenclature of the Lower Cretaceous in the Foothills and the stratigraphic equivalents in the subsurface to the east, is illustrated on Figure 1. In the Foothills, south of the Pine River, the Gates, together with the Hulcross and Boulder Creek, are members of the Commotion Formation. In the subsurface to the east the stratigraphic equivalents to the Gates are the Falher and the Notikewan Members.

In recent years, two new terms have come into informal use: Transition Beds, to describe an interval of thinly bedded sandstones and claystones between the underlying Moosebar Formation and the Gates; and the Torrens Member, for a thick, regionally extensive, marine sandstone in the lower part of the Gates. Neither of these units has been formally described.

TECTONIC SETTING AND REGIONAL PALEOGEOGRAPHY

During Early Cretaceous time, northeastern British Columbia occupied part of the Rocky Mountain foredeep basin, a rapidly subsiding sedimentary trough that was bounded to the southwest by the Columbian Orogen and to the northeast by the Interior Platform. A thick sequence of molasse was deposited in the foredeep; it was derived mainly from the tectonically active area to the southwest. The sediments were deposited in both marine and non-marine environments.

During the Early Cretaceous, a major embayment of the Boreal Sea lay to the north (Douglas, et al., 1976). A series of major transgressive/regressive cycles show that this sea transgressed southward on several occasions. Wide areas of marine muds and silts were deposited during major transgressions whereas non-marine deposition was more widespread during regressions. The Gates Member, which consists of non-marine and

<table>
<tr><th colspan="2">PINE RIVER FOOTHILLS, BC.</th><th colspan="2">PEACE RIVER PLAINS, ALBERTA</th></tr>
<tr><td rowspan="5">COMMOTION FM.</td><td rowspan="2">BOULDER CREEK MBR.</td><td rowspan="3">PEACE RIVER FM.</td><td>PADDY MBR.</td></tr>
<tr><td>CADOTTE MBR.</td></tr>
<tr><td>HULCROSS MBR.</td><td>HARMON MBR.</td></tr>
<tr><td rowspan="2">GATES MBR.</td><td rowspan="3">SPIRIT RIVER FM.</td><td>NOTIKEWAN MBR</td></tr>
<tr><td>FALHER MBR.</td></tr>
<tr><td colspan="2">MOOSEBAR FM.</td><td>WILRICH MBR.</td></tr>
<tr><td colspan="2" rowspan="2">GETHING FM.</td><td colspan="2">BLUESKY FM.</td></tr>
<tr><td colspan="2">GETHING FM.</td></tr>
<tr><td colspan="2">CADOMIN FM.</td><td colspan="2">CADOMIN FM.</td></tr>
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Figure 1. Lithostratigraphic nomenclature of the Lower Cretaceous in the Foothills and the stratigraphic equivalents in the subsurface to the east; from Stott, 1968.

nearshore marine sediments, was deposited during a general period of regression.

DUMB GOAT MOUNTAIN SECTION

Dumb Goat Mountain* is located in the southern part of the area, approximately 3 kilometres northwest of Mount Belcourt. Outcrop is good and a fairly complete section was measured from the base of the Moosebar Formation to the top of the Hulcross Member (Figure 2). The intervals are described as follows:

(1) Moosebar Formation: Twenty-seven metres of grey, silty claystones, deposited in a marine environment. The lower contact with the Gething Formation is abrupt and represented by a thin, 10 to 20-centimetre-thick conglomerate overlying 1 metre of bioturbated sandstones. This conglomerate was deposited during the marine transgression which occurred at the base of the Moosebar.

*Dumb Goat Mountain - an informal name used by coal company geologists in the area.

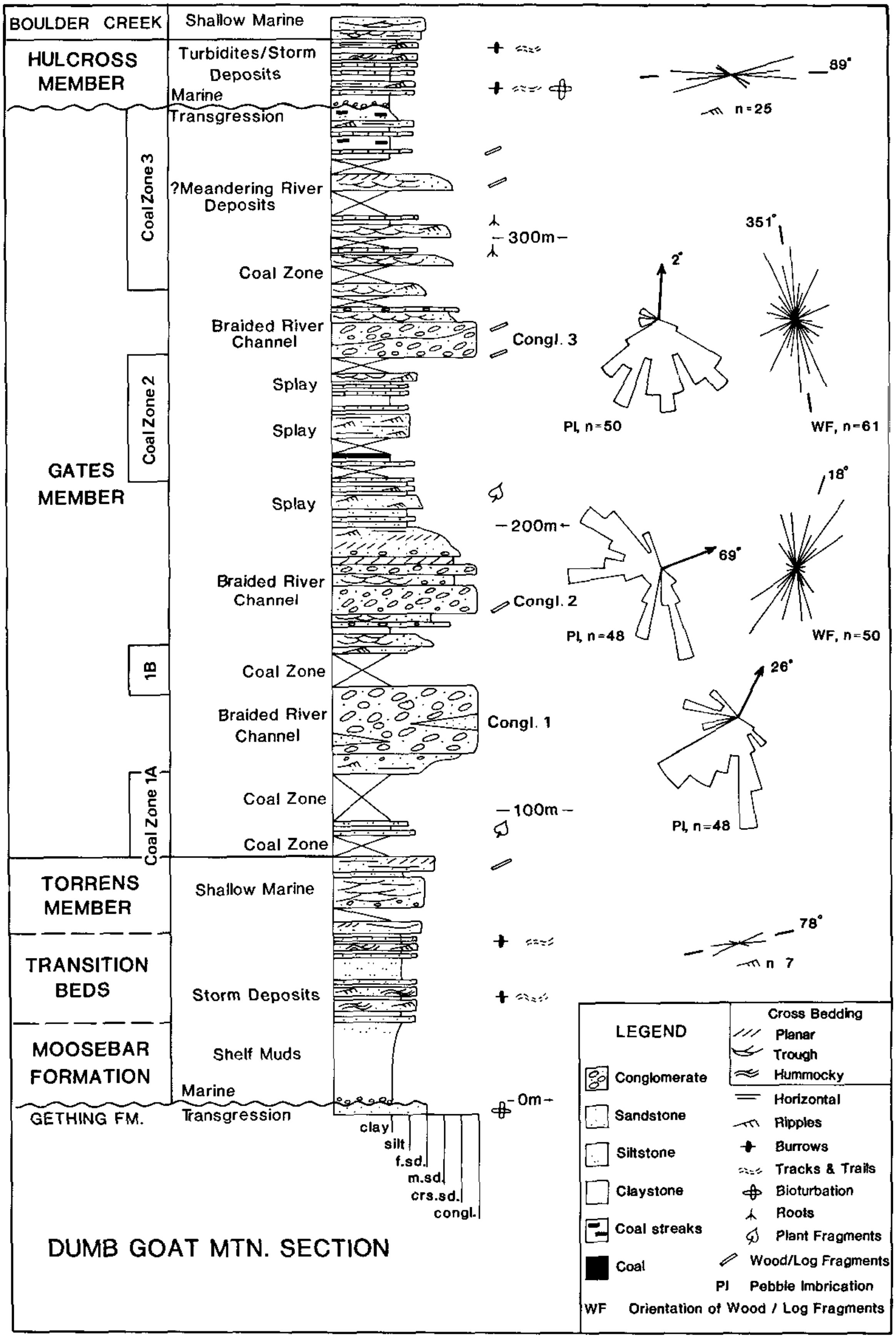

Figure 2. Moosebar, Gates, and Hulcross section on Dumb Goat Mountain.

(2) Transition Beds and Torrens Member: The Moosebar Formation is overlain gradationally by two major coarsening-up cycles in the Transition Beds and Torrens Member. The lowermost cycle consists of thinly bedded, very fine-grained sandstones, and interbedded, silty claystones. The sandstones occur as individual units 15 to 30 centimetres thick, or as composite units up to 2.5 metres thick. Contacts are generally abrupt or slightly erosional, as indicated by the presence of small clay rip-up clasts. Bedding is predominantly hummocky cross stratification (HCS) but there is some horizontal bedding. Symmetrical wave ripples are occasionally present on the top surfaces of the sandstones, as are burrows, tracks, and trails.

The second coarsening-up cycle consists initially of thinly bedded HCS sandstones and siltstones like those in the lower cycle, but they are overlain by a thick unit of fine to medium-grained sandstone. The thinly bedded sandstones and siltstones in the lower cycle and the lower part of the second cycle are assigned to the Transition Beds; the thick sandstone at the top of the second cycle is assigned to the Torrens Member. On the basis of sedimentary structures, three units are recognized in the Torrens. The lowermost is fine-grained sandstone that is 4.6 metres thick. It has large, shallow troughs, horizontal to low-angle bedding, and occasional planar crossbedding similar to swaley cross stratification (Walker, 1981). The overlying 10.8-metre-thick unit consists of large scale, trough crossbedded and horizontally bedded, fine-grained sandstones. It has occasional pebbly streaks near the base. The upper unit consists of 5.4 metres of horizontally bedded, and occasional planar crossbedded, medium-grained sandstone. Small wood fragments occur along the bedding planes.

The Transition Beds and Torrens Member are interpreted to be marine deposits formed during a period of coastal regression. Thin-bedded HCS sandstones in the lower part are interpreted to be offshore storm-generated deposits, whereas thick sands of the Torrens Member were deposited closer to shoreline.

(3) Non-Marine Part of the Gates: The main part of the Gates section is a 259-metre-thick sequence of non-marine sandstones, siltstones, claystones, and occasional coal seams (mostly covered), that includes three major conglomerate intervals.

The conglomerates occur as massive units 10 to 24 metres thick. Their lower contacts are erosional and impressions of large tree trunks are common near the base. Up section the conglomerates are interbedded with coarse, pebbly trough and planar crossbedded sandstones which grade upward into fine-grained rippled to horizontally bedded sandstones and siltstones. A coal seam generally caps these fining-up sequences.

The conglomerates are mainly clast supported with coarse sand in the matrix. Most of the pebbles are rounded and show considerable variation in size. The largest clast measured was 16 by 7 by 7 centimetres; the average pebble diameter is 1 to 3 centimetres. Bedding is uncommon but pebble imbrication zones are very common and locally impart a weak horizontal stratification.

Comparison with the Donjek vertical profile model (Miall, 1977) suggests that these conglomerates were deposited in a braided river environment. In the Gates, the conglomerates are associated with fairly thick overbank deposits. In braided river deposits, overbank deposits may result from lateral channel restriction on the floodplain, coupled with rapid subsidence (Miall, 1977).

In the upper part of the Gates, there are several fining-up sandstone units. Their vertical profile and sedimentary structures suggest that they are channel deposits. However, they represent a smaller and lower energy river system (? meandering) compared to the underlying conglomerate channels.

Although they are largely covered, coal seams in the section are inferred from coal bloom and occasional pieces of coal in float. The thickest coal zones are in the lower part of the sequence, above the Torrens Member. Above the upper conglomerate coals occur at the top of fining-up sequences. These coal seams appear to be thinner, but more numerous, than those in the lower part of the Gates.

(4) Hulcross Member: The marine transgression at the top of the Gates is marked by a 30-centimetre-thick, clast supported conglomerate. The conglomerate rests on a thin coal seam and is overlain by 2 recognized; the top cycle resulted in the development of a thick, fine to medium-grained marine sandstone (basal Boulder Creek unit).

The sandstones in the Hulcross are 5 to 50 centimetres thick and predominantly massive to horizontally bedded. They have abrupt bases and tops. Hummocky cross stratification is present in some and symmetrical wave ripples are common on the top surfaces. Small load structures may be present on basal surfaces. The thinly bedded sandstones are interpreted to be offshore storm deposits and turbidites, while the thicker sandstone at the top represents relatively nearshore conditions.

REGIONAL CORRELATION OF THE MOOSEBAR FORMATION, GATES AND HULCROSS MEMBERS

A regional correlation of the Moosebar Formation and Gates and Hulcross Members for a distance of 85 kilometres from Dumb Goat Mountain in the south to the Murray area in the north is shown on Figure 3. Marine and non-marine intervals in the Gates are shown on this section together with the locations of major non-marine conglomerates and the major coal zones. This correlation illustrates the following important points:

(1) The non-marine part of the Gates thickens to the south, while the marine Moosebar to Torrens and Hulcross intervals thin in that

direction. Also the number of coarsening-up marine cycles in the Transition Beds/Torrens Member increases from two on Dumb Goat Mountain to five in the Murray area.

(2) Two major marine transgressions are present within the Gates Member. Both come from a northerly direction and extended as far south as the Monkman area. These transgressions are essentially nondepositional, most of the marine sediments were deposited during the following phase of regression.

(3) Three major non-marine conglomerates are recognized. All occur at consistent stratigraphic levels throughout the area. In the case of conglomerates 1 and 3, deposition was followed by periods of marine transgression.

The marine unit in the upper part of the Gates has not previously been formally recognized or described. It is well developed in the Babcock and Murray areas, where it consists of a laterally extensive 25 to 40-metre-thick unit of sandstones with occasional conglomerates and thin claystones. These, together with the underlying non-marine conglomerate, form a distinctive lithological unit that Denison Mines' geologists call the Babcock Member.

Marine bivalves were found in the sandstones. Subsequently they were identified as pectinid bivalves, probably Entolium and Camptonectes by Dr. Paul Smith at the University of British Columbia. Further evidence for a marine depositional environment is provided by trace fossils, which are fairly common and easily recognized in cores. These include several distinctive types of marine burrows. The base of the marine sands is marked by a thin layer of very coarse conglomerate that is interpreted to be a marine lag deposit formed during the transgression. The overlying marine sandstones form a coarsening-up sequence, in which several lithofacies are recognized. Detailed core studies suggest that these were deposited in marine shelf and tidally influenced coastal environments.

COAL OCCURRENCES

Between the Monkman and Murray areas, four distinct coal zones* are recognized. The location of these zones is shown on Figure 3.

ZONE 1A: This zone occurs between two marine units in the lower part of the Gates and contains one or two thin coals. The coal is generally less than 1 metre thick; seams thicken to the south and pinch out to the north. Coals in this interval were deposited at the top of a regionally extensive, coarsening-up marine sequence during a short-lived regressive phase.

ZONE 1B: This zone occurs above the next coarsening-up marine unit and represents the beginning of the main phase of non-marine sedi-

*Coal zones: refers to an interval with one or more coal seams.

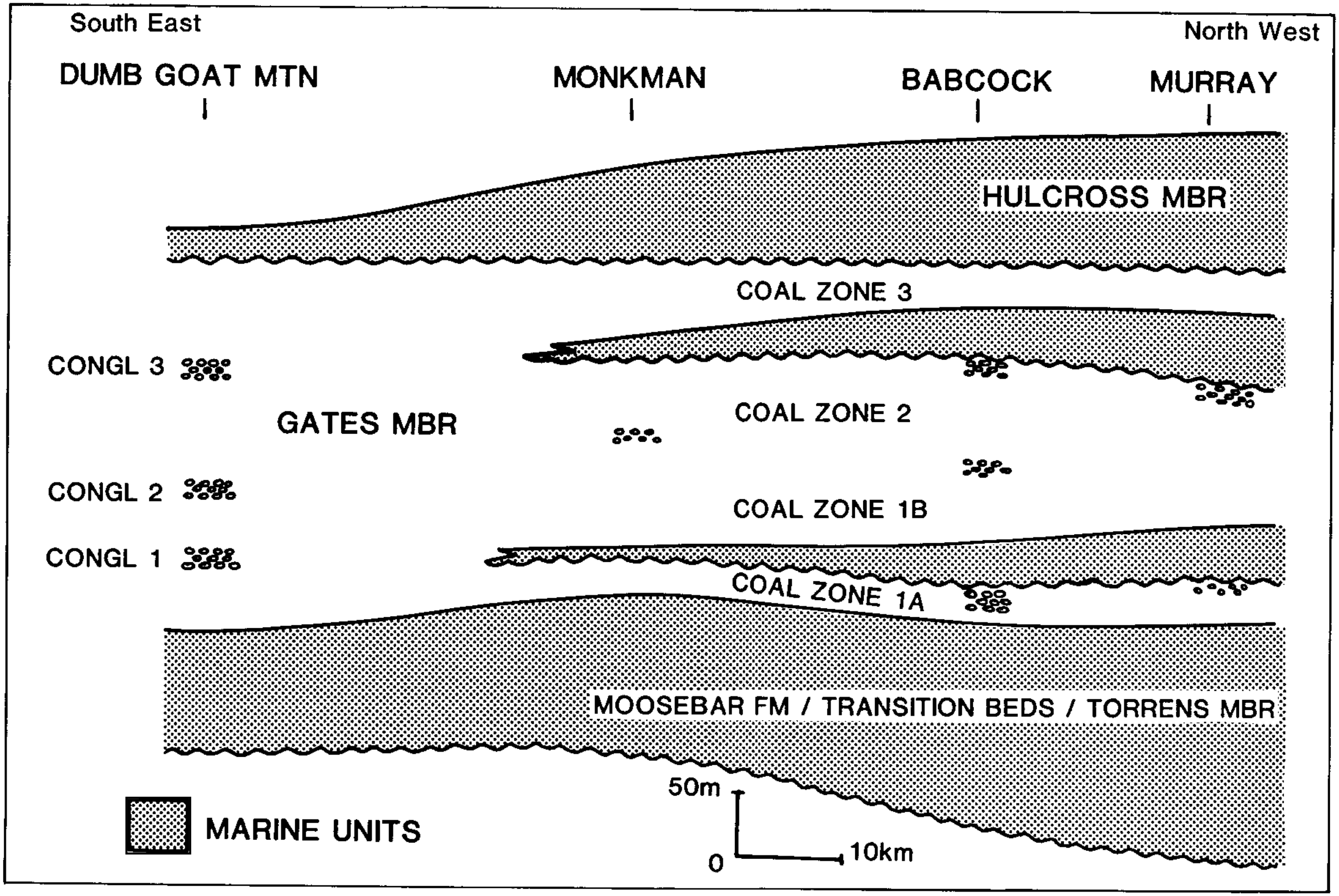

Figure 3. Regional correlation of the Moosebar Formation, Gates and Hulcross Members.

mentation in the Gates. In the Babcock area, up to three closely spaced seams are present in this interval. The thickest of these, seam J, has an average thickness of 6 metres.

ZONE 2: This zone occurs above zone 1B and below the marine unit in the upper part of the Gates. On Babcock, this zone contains four to five seams, each with an average thickness of approximately 2.5 to 3.5 metres. Typically, these coals are developed at the tops of fining-up cycles. On Babcock, two of the seams in this zone, seams E and G, wedge out laterally and are replaced by channel deposits.

ZONE 3: This zone occurs between the Upper Gates marine sands and the Hulcross Member. Coals in it are thin and not economically important. On Babcock there are three seams, A, B, and C, which rarely exceed 0.75 metre in thickness. Seam B, the middle seam, is the thickest and most persistent.

PALEOCURRENTS

Figures 4 to 7 show paleocurrent data, plotted as a series of rose diagrams, for the following intervals:

1) Transition Beds: Measurements in this interval were made on axes of symmetrical wave ripples, and flute and groove marks from thinly bedded sandstones that were deposited in the offshore area as a result of storm activity. The axes of symmetrical wave ripples give an approximate guide to the trend of the paleocoastline, while flute and groove marks indicate the direction of the paleoslope. This data suggests an average east-northeast - west-southwest orientation for the paleocoastline and a north-northwest - south-southeast paleoslope. The flute marks indicate that sediment was derived from the southeast.

2) 'Middle' Gates: Data is from fluvial sandstones and conglomerates in the non-marine part of the Gates between the Torrens Member and the conglomerate in the Upper Gates. Measurements were made of trough crossbedding, planar crossbedding, pebble imbrication, and the alignment of logs from the base of channels. The data indicates an average paleocurrent direction to the north-northeast although the range includes directions between northwest and east-northeast. Part of the spread in paleocurrent directions is from using different kinds of paleocurrect data for differrent types of fluvial systems in this interval.

(3) 'Upper' Gates Conglomerate: This map shows paleocurrent information from the conglomerate below the marine sands in the upper part of the Gates and from conglomerate 3 on Dumb Goat Mountain. Measurements are from pebble imbrication, log orientation, and planar cross-bedding. Conglomerate 3 on Dumb Goat Mountain shows a

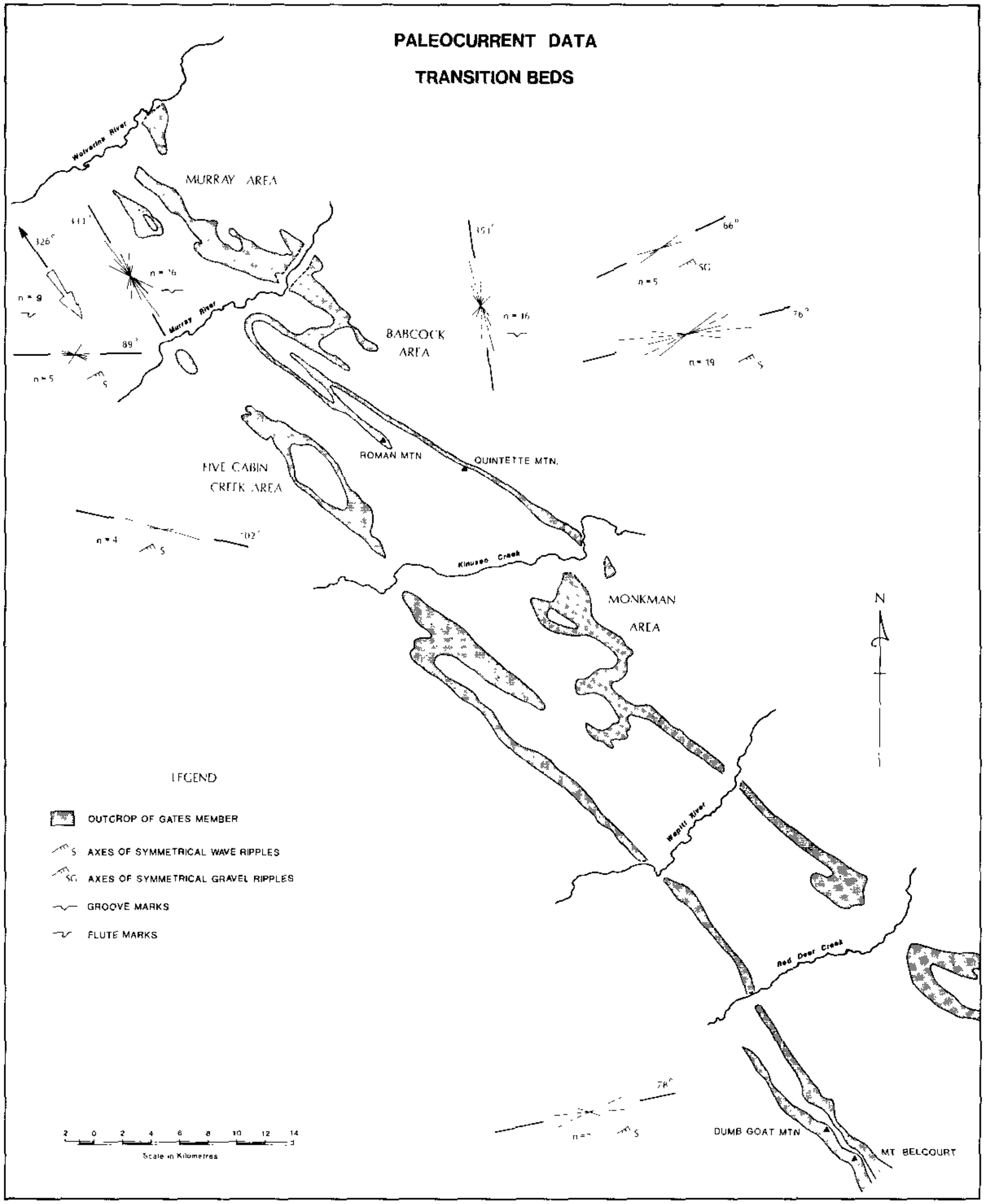

Figure 4. Paleocurrent data - Transition Beds.

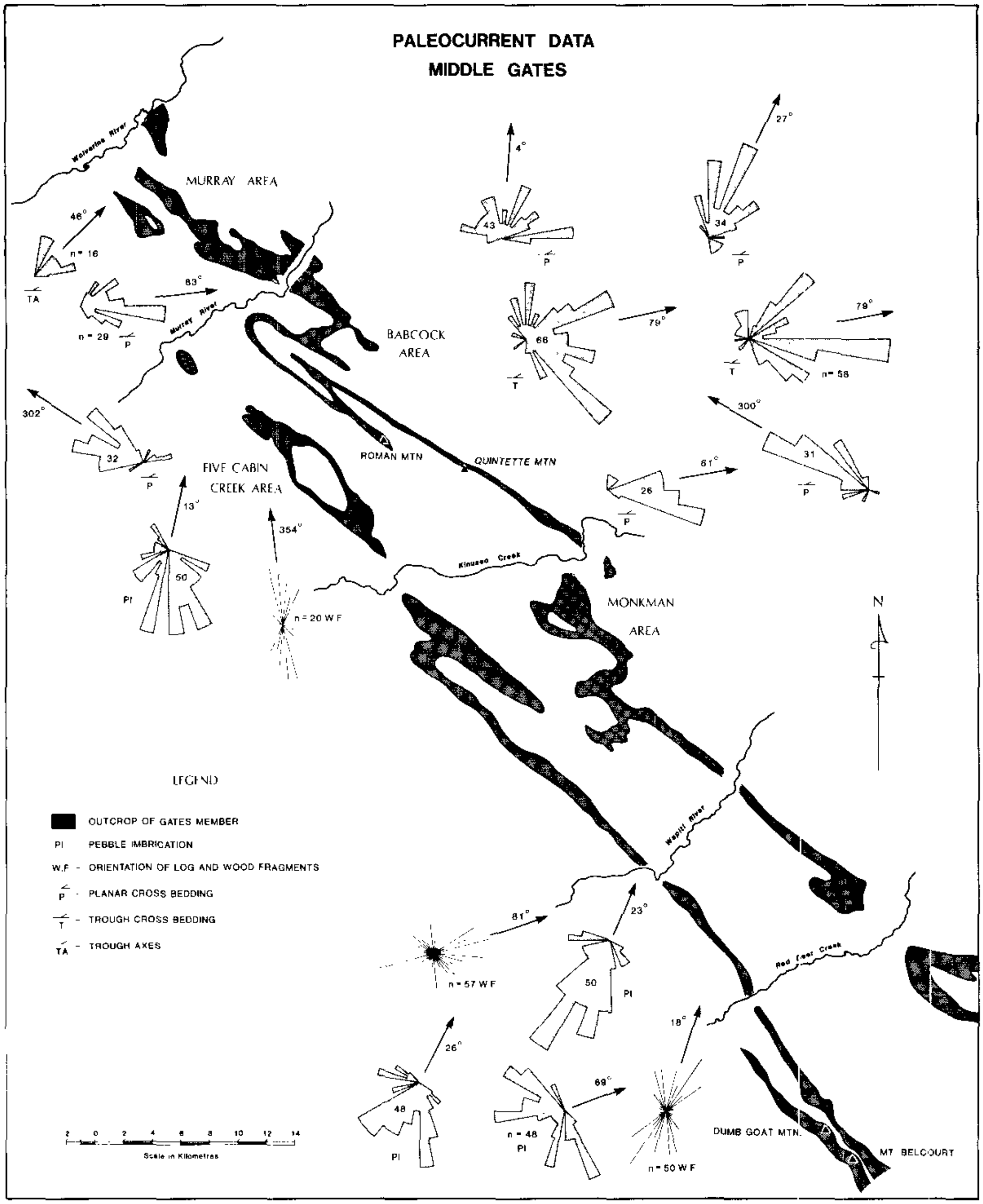

Figure 5. Paleocurrent data - 'Middle' Gates.

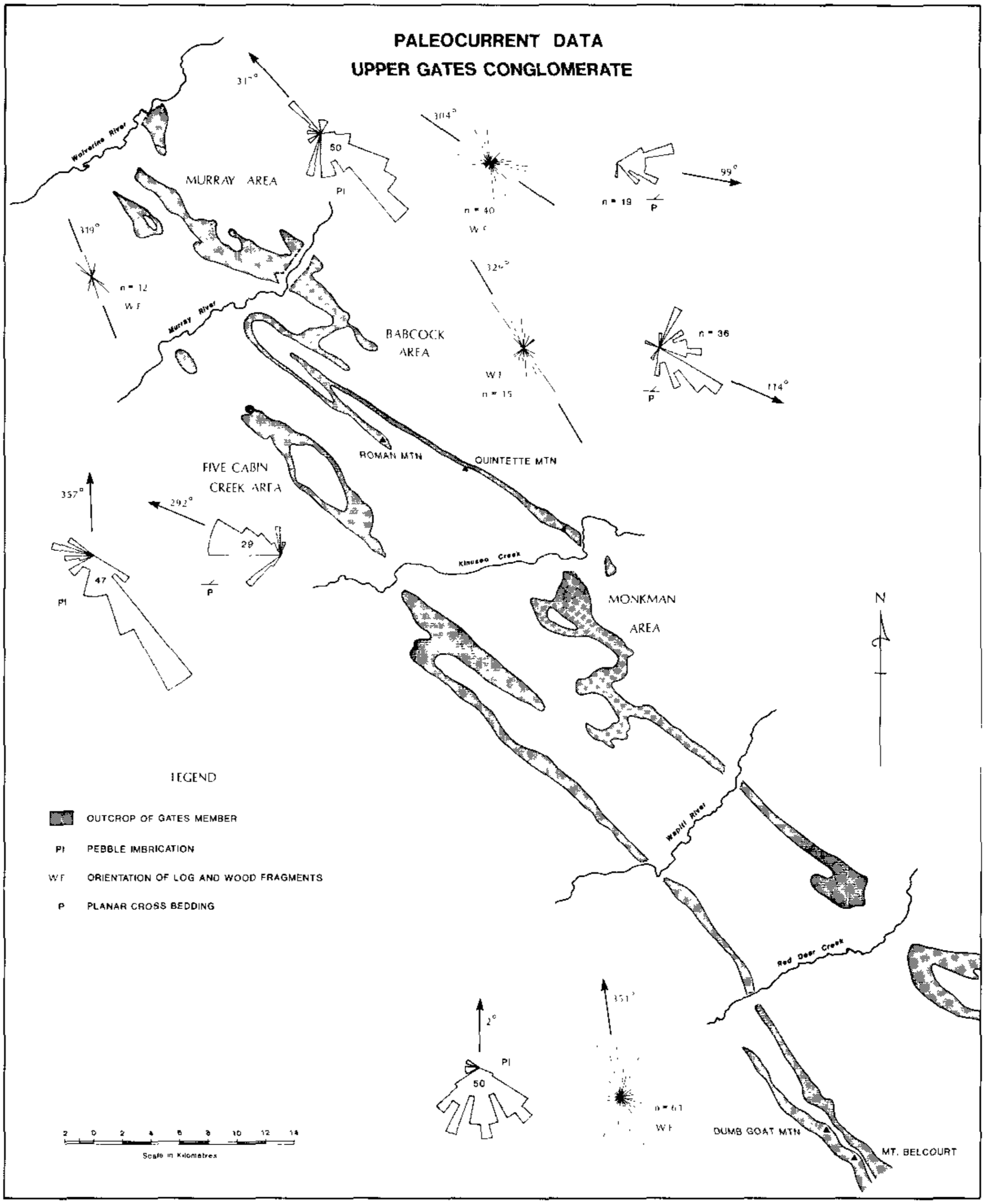

Figure 6. Paleocurrent data - 'Upper' Gates conglomerate.

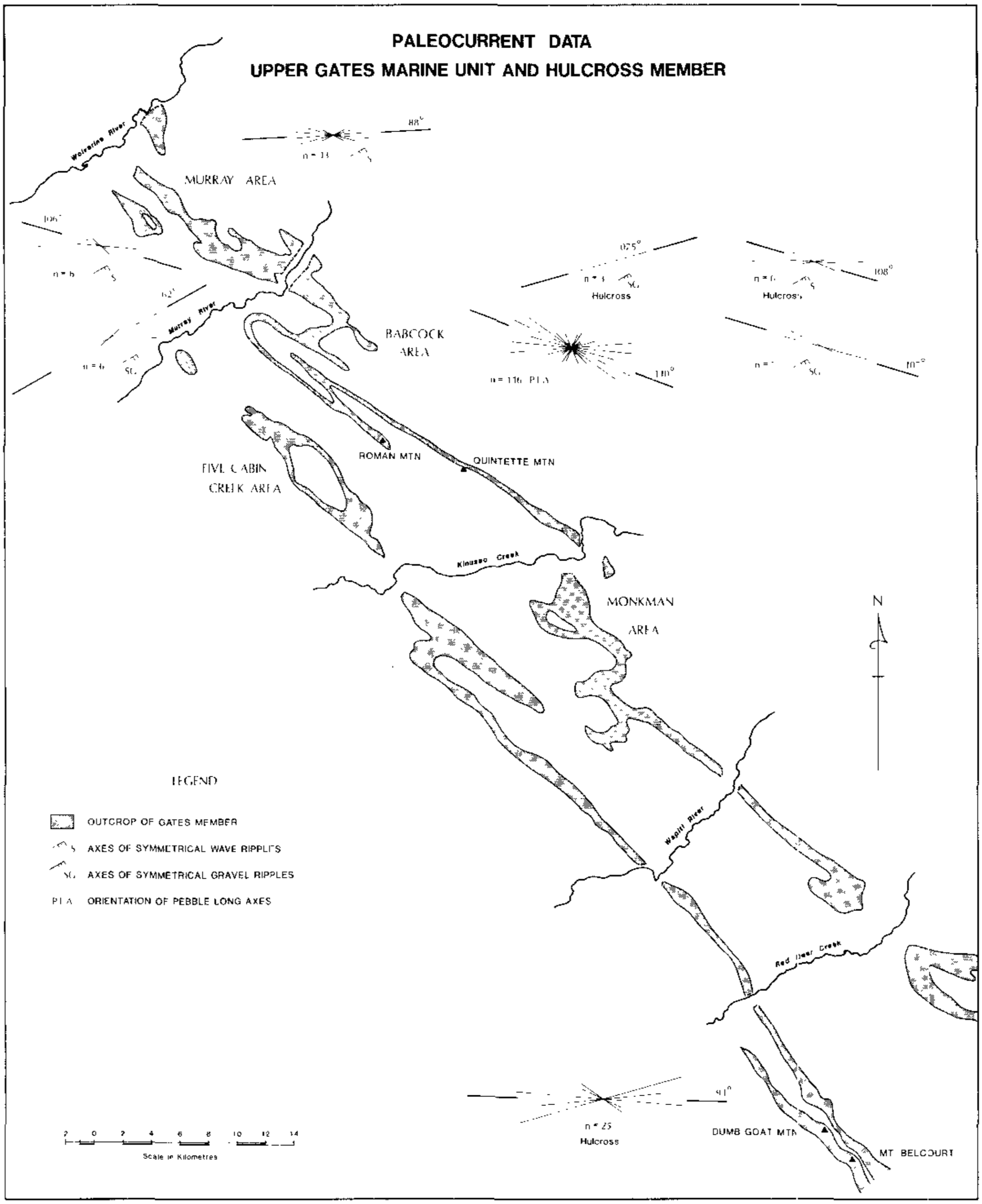

Figure 7. Paleocurrent data - 'Upper' Gates marine unit and Hulcross Member.

paleocurrent direction to the north, while further to the north the average direction is to the northwest. Planar cross-bedding from sandstones near the top of the conglomerate suggest currents in the opposite direction, toward the east-southeast. This is interpreted to represent deposition associated with the start of the marine destructive phase at the onset of marine transgression which occurs at the top of the unit.

(4) Marine Units of the 'Upper' Gates/Hulcross: Paleocurrent measurements from these intervals were made on the axes of symmetrical wave ripples from thinly bedded marine sandstones and conglomerates. The conglomerates occur at the base of the Upper Gates and Hulcross marine transgressions and are believed to be the result of marine processes. In addition, measurements were made on the long axis orientation of large pebbles in the 'lag' deposit at the base of the Upper Gates transgression on Babcock.

In the Babcock and Murray areas this data indicate an average east-west trend for the paleocoastline. On Babcock, the data suggest an east-southeast - west-northwest orientation for the Upper Gates paleocoastline.

DISCUSSION

(1) Gates Nomenclature

The last comprehensive description of Lower Cretaceous stratigraphy in the Foothills was that by Stott (1968). Since then, much new information has become available as a result of drilling by coal companies. Consequently, there is a need for a review of the stratigraphic nomenclature. Some of the problems with regard to the Gates nomenclature are as follows:

(a) The type section of the Gates (McLearn, 1923) is in the Peace River Canyon, east of Hudson Hope. The Gates there is predominantly marine and very different in character from the Gates further to the south along the length of the coalfield.

(b) The Gates in the Peace River area has formation status, but in the Pine Pass and the Foothills to the south, it is given only member status within the Commotion Formation.

(c) The Torrens Member is a name frequently used for a thick, relatively continuous marine sand in the lower part of the Gates. This unit, however, has not been formally described and there is some ambiguity in deciding which marine sand it refers to. For example, in the regional correlation section (Figure 3), does the Torrens Member refer to the sand above or below coal zone 1A, or both?

The following suggestions may be of value in a future revision of the nomenclature:

(a) The Gates is a sufficiently important interval for it to be given formation status along the length of the coalfield.

(b) Several marine units within the Gates can be recognized and correlated over a fairly large area. (Trace fossils are particularly useful in identifying these marine units). These units increase in number to the north and are replaced by non-marine sediments to the south. It is proposed that these marine units be given member status within the Gates Formation. The marine unit in the Upper Gates is particularly well developed in the Babcock area is referred to as the Babcock Member by Denison geologists. This unit is probably equivalent to part of the Notikewan Member in the subsurface to the east.

(2) Paleocurrents

Many of the published paleogeographic maps of the Lower Cretaceous show the main fluvial systems trending to the east or northeast, at right angles to the tectonic strike. These are frequently hypothetical directions and they differ from measured paleocurrent directions presented in this paper and those of Leckie (1981) for the Gates north of the Wolverine River. Both studies show a more northerly component for the fluvial paleocurrents and a paleocoastline oriented approximately east-west.

Measured paleocurrent data indicates, therefore, that the main drainage patterns in the Gates were longitudinal, subparallel to the tectonic strike. In the present day Himalayan molasse basin, the direction of flow of the major rivers is longitudinal, subparallel to the tectonic strike. It is not surprising, therefore, that similar drainage patterns are found in the Gates, which formed in a similar tectonic setting.

3) Conglomerates, Tectonics, and Marine Transgressions

The interdependence of sedimentation and tectonics in molasse basins has been described in some detail by Miall (1978). In the Gates, three major conglomerates are recognized at consistent stratigraphic levels throughout the area. These are interpreted as indicating three separate phases of tectonic activity in the source area.

In the Gates, deposition of conglomerates 1 and 3 was followed by marine transgressions. It is postulated that these transgressions resulted from isostatic adjustment and increased subsidence in the foredeep basin following periods of increased tectonic activity. Other factors such as sediment supply and eustatic sea level changes can also cause a marine transgression. The relative importance of these in the Gates has yet to be fully evaluated.

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