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STRATIGRAPHY AND CHARACTER OF THE BLUESKY FORMATION (94A, B, H, G; 93I, O, P)

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INTRODUCTION

Lower Cretaceous Bluesky sediments found in the Northern Rocky Mountain foothills can be traced into the subsurface of the plains of northeastern British Columbia. In the plains region, the unit produces significant quantities of oil and gas from a series of structural-stratigraphic traps; equivalent strata in northwestern Alberta also contain large hydrocarbon reserves. The Bluesky Formation is used as a lithostratigraphic datum in the correlation of coal seams in the Peace River Coalfield. Despite economic interest in the succession, no detailed investigation of its distribution or character in northeastern British Columbia has been published.

This paper is a preliminary account of the distribution, stratigraphy, and lithology of the Bluesky Formation. Much of the information is based on drill core, outcrop, and geophysical log examinations. A petrographic study has not yet been completed. The recognition of several major environments is based on comparison with modern environments.

From previous work on the Bluesky Formation, it is evident that discrepancies as to its stratigraphy, regional relationships, and interpretations of depositional environments still exist. Traditionally, the Bluesky has been considered a nearshore lag deposit formed during the early transgressive stage of the Moosebar/Clearwater Sea (Pugh, 1960; Rudkin, 1964; White, 1983). Stott (1968) considered the unit to be a lateral facies equivalent of the uppermost Gething Formation. In the Sukunka-Wolverine area, Duff and Gilchrist (1983) documented the presence of a marine tongue which divides the Gething Formation into two coal-bearing zones — the lower Gething, and the upper Chamberlain members. The marine tongue and Chamberlain member were considered to be lateral equivalents of the Bluesky in the plains regions. Southeast of the Wolverine River, where the Gething marine tongue is thought to pinch out, the upper Chamberlain member merges with the lower Gething Formation. This then suggested that south of the Wolverine River the Bluesky, which overlies the lower Gething Formation, was not present. However, from boreholes logged as part of this study: (1) only the marine tongue and not the Chamberlain member should be considered part of the Bluesky, (2) the marine incursion can be traced as far south as the Belcourt River, and (3) the continental Chamberlain member was deposited at the same time as active Bluesky deposition in the plains, but in different environments. Kilby (1985) documented the presence of two prominent bentonite bands in the Moosebar Formation. These volcanic ash 'time lines' can be used to establish the complex sequence of events for Bluesky deposition.

METHODOLOGY

Oil and gas well core and coal exploration diamond-drill core were examined during the 1985 field season at the British Columbia Ministry of Energy, Mines and Petroleum Resources core storage facility in Charlie Lake. Core from 88 petroleum wells and 41 diamond-drill cores were examined; a total of 1490 discrete rock units were measured. Information from the drill holes was entered into a computer data base system using the CAL DATA LTD. Geological Analysis Package and a Kaypro II 64K microcomputer.

LITHOFACIES DESCRIPTIONS

The Bluesky Formation is a lithologically diverse unit containing three major lithofacies; all are distinct but genetically related. It includes: (1) basal chert pebble conglomerates and conglomeratic to coarse-grained sandstones ('C' facies); (2) middle bioturbated, interbedded siltstones and mudstones ('B' facies); and (3) upper glauconitic argillaceous sandstones, siltstones, or mudstones ('A' facies; Fig. 23-1).

The chert pebble conglomerate/sandstone or C facies unit contains three distinct subfacies: 'C1,' chert pebble conglomerate with mud matrix; 'C2,' medium to coarse-grained sandstone of three varieties: bioturbated, glauconitic sandstone; micaceous quartzose sandstone; planar crossbedded sandstone; and 'C3,' chert pebble conglomerate with coarse sand matrix.

Subfacies C1: Chert pebble conglomerate with mud matrix, is generally confined to the uppermost beds of the Bluesky throughout the study region. The clasts are composed predominantly of chert or quartzite; most of the chert is black, white, grey, or pale green. The clasts vary from subangular to well rounded with most being subrounded. The pebble-size clasts are embedded in a dark grey to black mudstone matrix. Larger clasts may be found at the top as well as the bottom of the unit; sorting is generally poor. In some beds, the mud merely fills the space between touching pebbles, whereas in others the pebbles are matrix supported. In most units stratification is fairly obscure. Glauconite content can vary up to 60 per cent but averages 15 per cent.

Subfacies C2: Three types of medium to coarse-grained sandstones are common in the Bluesky. The first type is a highly bioturbated, glauconitic sand where bedding is destroyed. Burrows are mainly round, vertical tubes averaging 1 centimetre in diameter and 2 to 15 centimetres in length. Burrow orientations range from subvertical to subhorizontal. Those burrows, which are mud-lined and infilled with a similar material to the surrounding matrix, are the trace fossils *palaeophycus*, which are considered to be open burrows occupied by suspension feeders which were infilled by passive sedimentation after desertion (Pemberton and Frey, 1982). Burrows that are subvertical shafts are the trace fossil *skolithos*. Bioturbation gives the unit a distinct mottled appearance. Composition of the sand averages 80 per cent quartz plus chert, 10 per cent dark fines, and 10 per cent glauconite. Contacts are generally gradational. Burrowing activity decreases as the contacts are approached. Beds may range up to 10 metres in thickness. Porosity is fair to good. This rock type is only found in the plains, especially in 94H and the eastern portion of the 94A block.

The micaceous quartzose sandstone in C2 is composed of clear, subangular to subrounded quartz grains; glauconite is sparse. Authigenic white kaolinite platelets commonly occupy the pore spaces.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

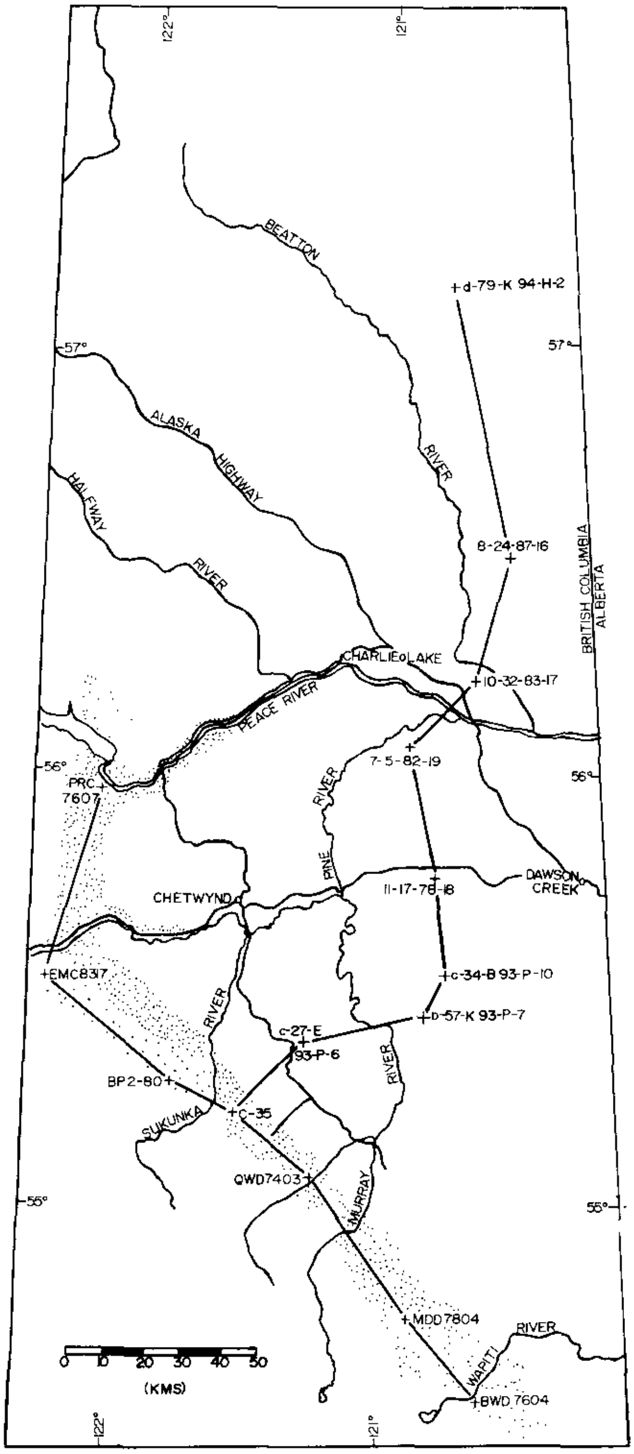


Figure 23-1. Generalized sequence of Bluesky facies in the back barrier section of the formation.

The unit is always tan-brown in colour, non-bioturbated, and poorly cemented. Porosity is good to excellent. Bedding is faint to massive.

The third and most common variety of sand in C2 is a planar crossbedded sandstone. Crossbeds are generally low angle and thinly laminated. Glauconite, if present, occurs along the basal planes of crossbeds. The sand is generally clean, non-bioturbated, well sorted, and tightly packed. Porosity ranges from fair to good. Crossbeds, generally small scale, range from weakly to well developed. Occasional dark laminae are composed of silt or concentrated finely macerated carbonaceous debris. Trough crossbedding was found in only two wells (d33J-94H7 and d59L-94A13).

Subfacies C3: Chert pebble conglomerate beds with a sand matrix, occur sporadically throughout the formation in the plains region but are confined to the lowermost beds in the Peace River foothills. Clast size and composition are generally identical to those in facies C1; however, in the Crassier Creek area boulders to 20 centimetres in diameter were noted. Pebbles are embedded in a medium to coarse-grained sandstone matrix composed mainly of chert or quartz grains. Some of the conglomerates have a strong bimodal grain size distribution, the chief mode being pebble size material, and the secondary mode being coarse grain sand. An interesting feature of the Bluesky unit is that although the sand matrix conglomerate may grade vertically upward into the mud matrix conglomerate type, there is no decrease in pebble size.

Packing of the clasts becomes very tight with many sutured clast contacts. This tight packing decreases the porosity of the unit. The conglomerates generally exhibit some cross-stratification, although bedding is faint to fairly obscure. Prominent low-angle, planar crossbedding was noted in the Willow Creek area. Planar crossbeds are more common than trough crossbeds. Glauconite content averages 5 per cent. The bases of many beds are scoured; they are sharply discordant and appear to be lensoidal. Beds occur in 0.1 to 2-metre units.

Marine mudstone and siltstone/sandstone interbeds (B facies) lie conformably above the basal C conglomeratic facies. A rhythmic or cyclic development occurs within this unit; mudstones grade upward into siltstone-sandstone-mudstone interbeds. This coarsening upward sequence is also reflected in geophysical logs (Kilby, 1984). The cycle may be repeated several times in the section. Thick accumulations of this unit occur in the Falls Mountain to Sukunka area but rarely in the plains region. Sandstones of this facies are fine grained, commonly with well-developed, low-angle laminations, and often have scoured bases with abundant load casts. Individual sand beds show distinct grading upward to clay size material. The mud beds show varying degrees of bioturbation. Burrows which are mainly horizontal, unlined, and infilled with sand are the trace fossil *planolites*. In places the burrows are pyritized; they are usually 2 to 4 millimetres across and oval in cross-section. Small (1 to 2-millimetre), subhorizontal burrows with tight meanders, and composed of the same mud as the surrounding host, are the trace fossils *helminthopsis*. Laminations in the mudstones are virtually absent and stratification is indicated only by thin silty streaks. The mudstones are similar to the Moosebar/Wilrich mudstones which resemble Recent offshore clays. The mudstones weather to rusty, small blocky pieces. The siltstones/sandstones are platy to blocky weathering. Marine fossils have been documented in this horizon by Duff and Gilchrist (1983).

Extremely glauconitic mudstone to sandstone (A facies) forms a diagnostic unit at the top of the formation. The unit ranges from 0.1 to 2.0 metres in thickness. In most places the contact with the overlying Moosebar shale is abrupt. Glauconite content varies from scattered grains to about 60 per cent where the unit forms a coarse gritty sand. Bioturbation was not seen in the cores. In some places there are a few scattered floating pebbles; they are usually black or white chert.

REGIONAL RELATIONSHIPS

The regional stratigraphic variations within the Bluesky Formation are illustrated in a series of columnar sections (Figs. 23-2 to 23-4). The main datum used is the base of the Bluesky Formation. Figures 23-3a and 23-3b depict the vertical stacking of Bluesky and Chamberlain member sequences in the Sukunka-Wolverine area.

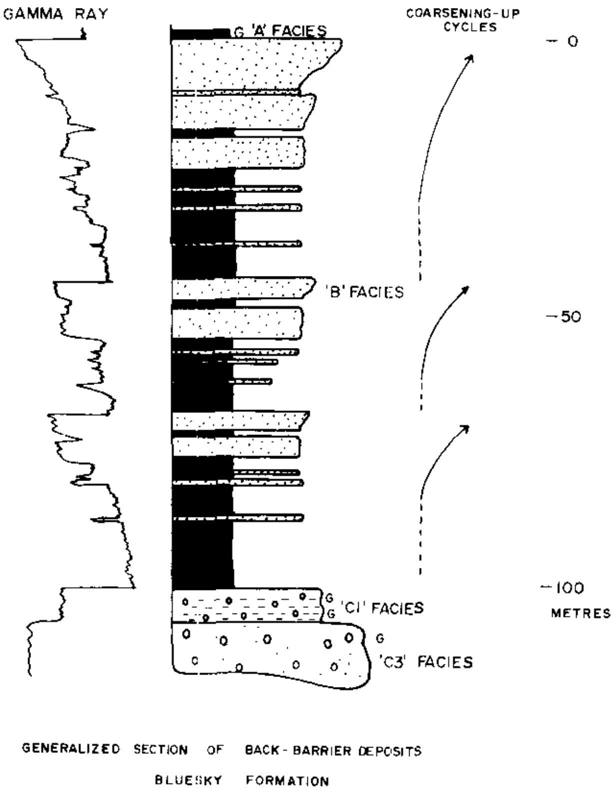


Figure 23-2. Well location map and outline of study area in northeastern British Columbia. Shaded area outlines Lower Cretaceous outcrop.

Although the diagram suggests high relief in this area compared to adjacent areas, the reader should note the vertical exaggeration incorporated in the diagram. The paleoslope is estimated to be less than one degree.

The three lithofacies described previously can be found throughout most of the foothills belt. The unit ranges in thickness from 5 to 85 metres. It is conformably overlain by the Moosebar Formation in the Peace River region and to the south in the Sukunka-Wolverine-Belcourt areas by the Chamberlain member of the Gething Formation. From the foothills toward the plains this tripartite division is replaced laterally by a succession of thick sandstone or conglomerate beds. Two prominent bentonite horizons distinctly 'frame' the Bluesky throughout the region. One bentonite occurs in the Moosebar and the other in the lower Gething Formation. Kilby (1985) correlated these over considerable distances in which the lower bentonites maintained a parallel relationship with the top of the lower Gething. This implies that at the close of lower Gething time the entire area was a continuous coastal swamp of very little relief (Kilby, 1985). As the source area for Gething sediments was reduced in elevation, less material was contributed to the continually subsiding basin which eventually led to rapid flooding of the upper Gething delta by the Clearwater Sea. Bluesky deposition marks the early stages of this transgression.

ENVIRONMENTS

The sandstone facies of the Bluesky Formation are mainly shallow marine in origin. The presence of glauconite, good sorting, uniform grain size, and *skolithos* and *palaeophycus* trace fossils all point to an offshore to nearshore environment. Although much of the sandstone appears to be sheet-like, it may be a composite of smaller sand bodies. Correlation of any one bed between neighbouring wells is difficult. Such shallow marine deposits are similar to Recent tidal/barrier island sand bodies or areally extensive offshore bars. The occurrence of the severely bioturbated sandstone unit may represent the lower to middle shoreface facies during fair weather, when biogenic activity is allowed to proceed. However, with storm activity, large clouds of sand are put into suspension and redeposited along the shoreface. The quartzose sandstone unit, with very low glauconite content, may represent this type of deposit. The cross-stratified, coarse-grained sandstone with good glauconite development may indicate tidal inlet channels. The unit has large to small-scale planar crossbeds, no bioturbation, erosional bases, and is often overlain by a coarse lag deposit.

In a westward direction, the sands pass into marine siltstones with intercalated beds of marine shale (B facies) over a conglomeratic base. This characteristic coarsening upward sequence may represent part of the back barrier facies bordering a pebble beach strandline. Typically lagoonal sediments consist of coarsening upward sequences of clays and silts complicated by influxing channel fill detritus from a tidal delta on the landward side (Reinson, 1984). This may result in brackish water conditions for the lagoon and a regressive sequence in the section. The individual sand beds of the back barrier zone may represent washover storm deposits from the barrier side into the lagoon. This is evidenced by the fining upward cycle in which the size of material in suspension changes from coarse to mud-sized particles, and also by the occurrence of a scour base. With the return of fair weather, biogenic activity returns, along with normal mud deposition. As the flood-tidal delta matured and stabilized, peat marshes developed. The Moosebar Sea by this time had begun to encroach landward toward this delta complex. Evidence of periodic flooding of the delta is found in the Chamberlain member. The glauconite or A facies found in the Peace River region may mark rapid incursion of the Moosebar Sea where flooding conditions brought about chemico-physico conditions to favour glauconite development.

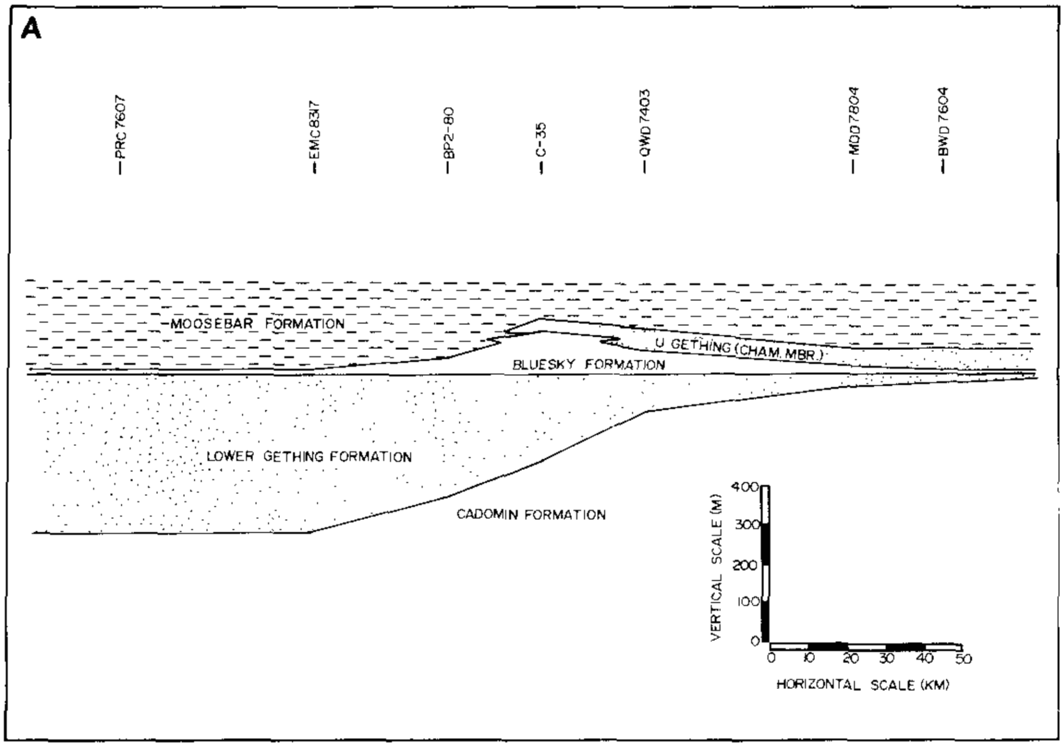
The final episode was the complete and rapid flooding of the entire study area by the Clearwater Sea forming a deep quiet basin into which the Moosebar bentonite was deposited.

PETROLEUM OCCURRENCES

Oil and gas accumulations in the Bluesky Formation occur in well-sorted, clean, porous sandstone units. The deposits are found in both stratigraphic and stratigraphic/structural traps. Suitable source beds are present in the Jurassic and Cretaceous marine shales and Gething Formation coal beds. Marine Moosebar shales cap the Bluesky sands, forming an effective seal for hydrocarbon entrapment.

Yield from the sandstone reservoirs will undoubtedly vary as the permeability changes with the type of sandstone. The severely bioturbated sandstone has high glauconite and fine sediment content which reduces the intergranular and dissolution porosity significantly. Extensive cementation occurs in this and the crossbedded sandstone unit lowering their permeabilities. The third type of sandstone, the poorly cemented, quartzose sandstone, should have a higher primary porosity and permeability than the bioturbated and crossbedded units. Porosities up to 15 per cent and permeabilities to 1 darcy can be expected. A complete petrophysical examination of the sandstone units would reveal their ratings and diagenetic history.

The conglomeratic facies may also contain hydrocarbons, depending upon their diagenetic history. Compression and local recrystallization structures have been noted in some cores, especially in zones with a low sand content matrix. Sutured contacts and quartz overgrowths effectively cut off the pore throat apertures, thereby



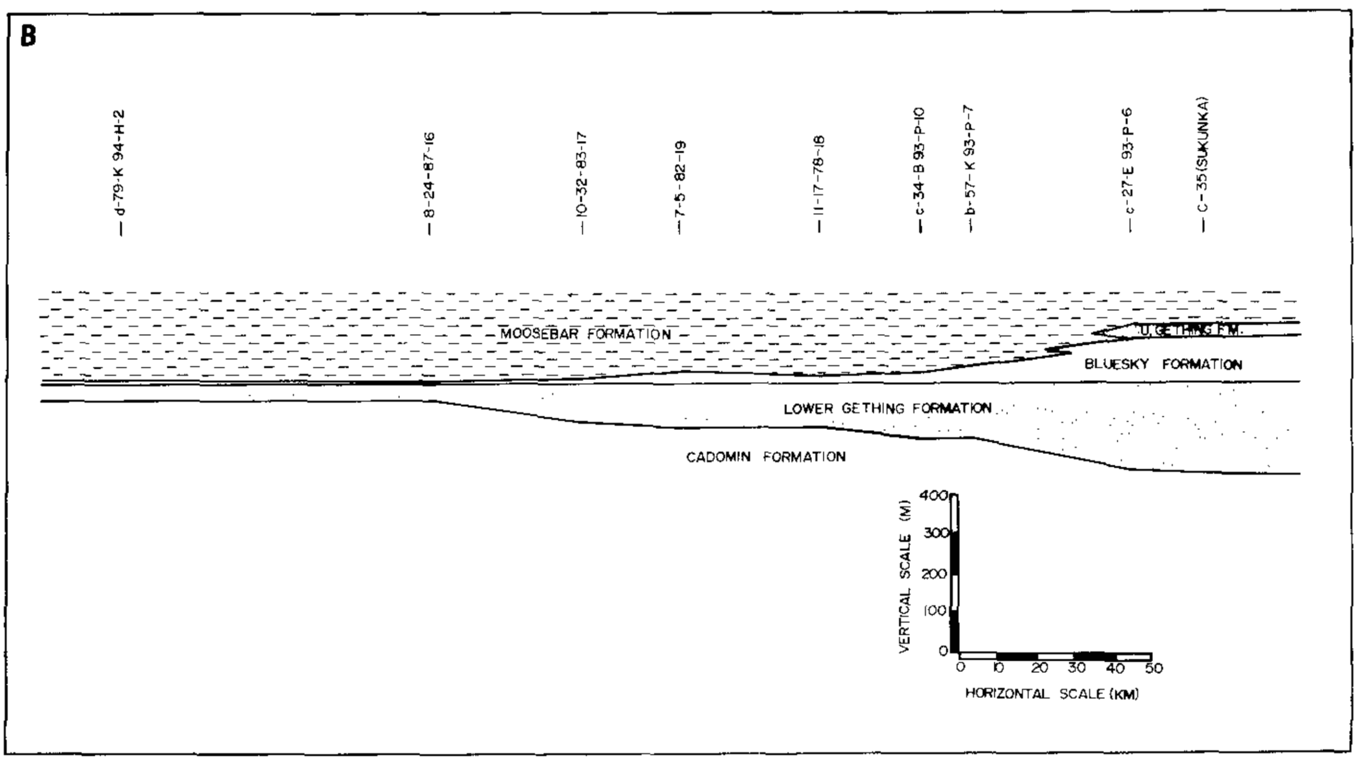


Figure 23-3. (a) Stratigraphic relationships of Bluesky sediments along a northwest-southeast section line. *See* Figure 23-1 for borehole locations. (b) Stratigraphic relationships of Bluesky sediments along a northeast-southwest section line.

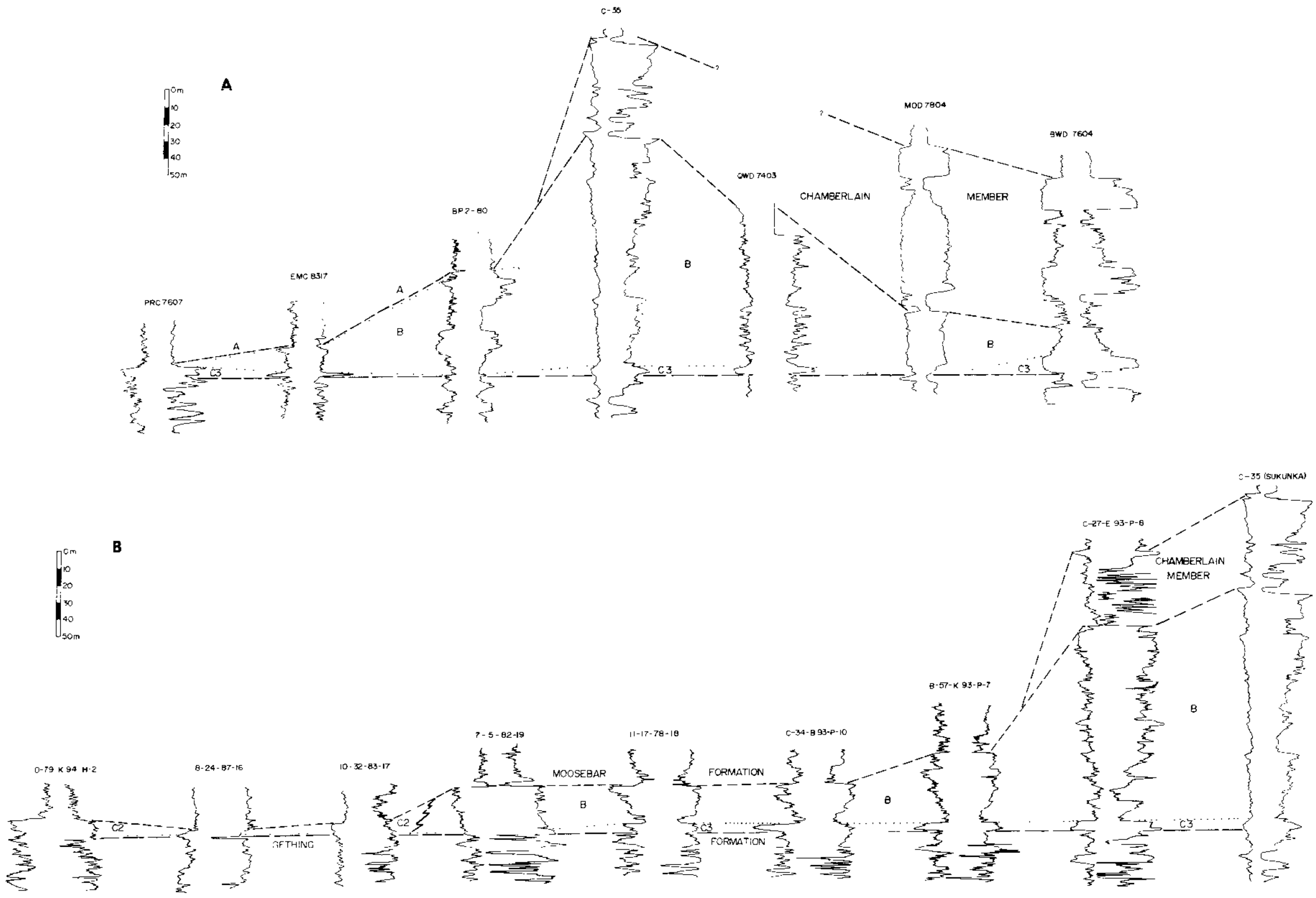


Figure 23-4. (a) Gamma and neutron geophysical log correlation of Bluesky Formation along a northwest-southeast section line. *See* text for explanation of facies codes. (b) Gamma and sonic geophysical log correlation of Bluesky Formation along a northeast-southwest section line. *See* text for explanation of codes. *See* Figure 23-2 for well locations.

reducing porosity and permeability. These deposits are also complicated by irregular thicknesses and lateral extent and thus, would be difficult to predict with any certainty.

The geometry of the quartzose sandstone units should be easier to predict. Being storm generated, their outlines will be elongate normal to shoreline. Therefore, as a storm wanes, the sediments are deposited seaward. These deposits should be sizeable but still limited in extent. Trapped gas or oil reserves could be found near their pinch-out points. A regional hydrodynamic study would probably uncover several pressure systems influenced by these facies variations.

CONCLUSIONS

Investigation into the Bluesky stratigraphy is at a preliminary stage. Further work into the time relationship of the Gething-Bluesky-Moosebar contacts is needed to sort out the sequence. Detailed petrographic studies and ichnofacies correlations for the units should reveal a more definitive answer for the depositional history. To date the study has shown (1) that the occurrence of the Bluesky can be extended southeastward to the Wapiti River; (2) the formation can be subdivided into three distinct facies; (3) the Bluesky is a barrier island/offshore bar complex with back barrier deposits; and (4) a close genetic relationship exists between the back barrier deposits and the emerging Chamberlain delta.

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