GEOLOGICAL
SURVEY
OF
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DEPARTMENT OF ENERGY,
MINES AND RESOURCES

PAPER 69-7

THE BANFF AND EXSHAW FORMATIONS IN THE WABAMUN LAKE AREA, ALBERTA (83 G)

(Report and 9 figures)

H. L. Martin

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ABSTRACT

In the Wabamun Lake area the combined Banff and Exshaw Formations form a wedge which thins from more than 600 feet in the northwest to zero in the northeast owing to erosion in late Paleozoic and post-Paleozoic times. As a result, progressively older Mississippian rocks underlie the sub-Mesozoic unconformity from west to east.

The black,radioactive Exshaw shale is overlain by carbonates, shales, siltstones, and minor amounts of sandstone of the Banff Formation. The latter formation is divided into three stratigraphic units which, in turn, are further subdivided into ten lithofacies that reflect their depositional environments.

Oil and gas are obtained from the middle Banff dolomitized micritic-skeletal limestone. Erosion has produced scarps of porous dolomite, and hydrocarbons are trapped at the updip edge by the overlying Lower Cretaceous shales.

INTRODUCTION AND ACKNOWLEDGMENTS

The Wabamun Lake area, located immediately west of the city of Edmonton, is a region of about 4,000 square miles. Its eastern boundary is the fifth meridian and it extends westward to include range 14. The south and north boundaries are townships 50 and 58, inclusive.

Oil and gas are obtained from rocks of Cretaceous, Jurassic, and Mississippian ages in the region. Commercial production from the Mississippian Banff Formation comes from two fields, Glenevis and Cherhill, and from 10 wildcat completions in the surrounding areas.

The purpose of this study is to provide useful information on the distribution of rock types within the Banff Formation and, particularly, on the relationship of the different rock types to the occurrence and entrapment of oil and gas.

The writer is indebted to Professor B.L. Mamet of the University of Montreal and the University of Brussels, Belgium, for his identification of Foraminifera found in collections from the base of the Banff Formation. He also wishes to thank Dr. A.E. Foscolos of the Geological Survey of Canada, Calgary, for providing the X-ray diffraction and chemical analyses on rock samples.

METHODS

Data available as of November 30, 1968, from 225 wells drilled into and through the Mississippian Banff or Devonian Wabamun rocks were used in this study. Thin sections were prepared from sample cuttings because cores of the lower Banff were not available. The method of thin section preparation listed below is not entirely new, but most of the steps indicated are improvements which allow the preparation of high quality, permanent thin sections.

1. Coat a glass slide and an aluminum ring, ½-inch deep and ½-inch in diameter, with ordinary beeswax.

2. Place the ring on the coated slide and then put the rock chips into the ring and adjust them to obtain the largest rock surface area face down on the glass slide. Rock chips should not lie in contact with each other.

3. Heat the glass slide gently so the wax melts; the rock chips and ring will then be held in contact with the glass.

4. Prepare a plastic mounting medium by mixing Fiberlay resin and catalyst (obtained from Fiberlay, Inc., Seattle, Washington) according to the manufacturer's directions. Pour this mixture into the aluminum ring, filling it at least half full.

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5. Put the specimen into an oven at 150°F for 15-20 minutes to set the Fiberlay mixture. Then remove from oven and allow to cool at room temperature.

6. Remove the aluminum ring and glass slide leaving a plug of rock chips in plastic.

7. Polish the surface of the plug on a grinding wheel using 220 grit silicon carbide to expose the maximum surface of the rock chips, and then polish with 600 grit silicon carbide on a glass plate. The surface should be perfectly flat, i.e., no relief between the rock chips and Fiberlay.

8. Let the plug dry thoroughly at room temperature or heat in an oven for about 30 minutes at 125°F. This is important because if moisture is present in the plastic or rock chips, air bubbles will be present in the final thin section.

9. Frost a glass slide by holding it on a grinding wheel with 400 grit silicon carbide for a few seconds.

10. Heat the slide gently and apply epoxy resin to the prepared surface of the plug. Note: Easypoxy, obtained from Conop, Inc. Allegany, N.Y., is recommended as some epoxies react with Fiberlay causing shrinkage which shatters the glass slide.

11. Mount the plug on the heated slide and eliminate air bubbles by applying slight pressure and moving the slide in a circular manner.

12. Let the epoxy set for 24 hours at room temperature. This process may be hastened by placing the mounted specimen in an oven at 150°F for 20-30 minutes but, even with Easypoxy, there is danger that the glass slide will shatter. If the oven is used, remove the slide and cool to room temperature.

13. Secure the mounted specimen in a jig such as Buehler's AB Resectioning vise, and cut the plug with a diamond saw to minimal thickness (about 1/8-inch or less). If a jig is not available, the plug can be thinned on a grinding wheel but a substantial amount of time is necessary owing to the hardness of Fiberlay.

14. Grind the mounted specimen on a grinding wheel and glass plate to the desired thickness (30 microns or less), using 220 and 600 grit silicon carbide.

The thin sections were stained with Alizarin Red S solution to differentiate between calcite and dolomite. For a description of Alizarin Red S stain, its preparation and use, see Warne (1962)[1].

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[1] Briefly, dissolve 0.1 g of Alizarin Red S in 100 ml of 0.2% cold HCl (0.2% HCl = 2 ml of commercial grade concentrated HCl with 998 ml of distilled water). Calcite turns a deep red whereas dolomite is unaffected.

X-ray diffraction and chemical analyses were used to investigate troublesome Banff lithologies as detailed below.

STRATIGRAPHY

Mississippian strata in the Wabamun Lake area are divided into four formations following the usage of Penner (1958). These are, in ascending order: Exshaw, Banff, Pekisko, and Shunda Formations. Late Paleozoic and post-Paleozoic erosion (Macauley, et al., 1964) bevelled the Mississippian strata so that the Mesozoic formations overlie progressively older rocks from west to east (Figure 1). In the extreme northeastern corner of the study-area, Mississippian rocks have been completely eroded and Lower Cretaceous strata unconformably overlie Upper Devonian rocks of the Wabamun Group.

The Exshaw Formation is either Late Devonian or Early Mississippian in age (see Warren, 1937, 1956; Warren and Stelck, 1950; Crickmay, 1952, 1956; Pamenter, 1956; Harker and McLaren, 1958; Folinsbee and Baadsgaard, 1958; Schindewolf, 1959; Macqueen and Sandberg, 1968). The Banff Formation is Kinderhookian, the Pekisko is Osagean, and the Shunda Formation ranges in age from Osagean to earliest Meramecian (Macqueen and Bamber, 1967). This report deals only with the Exshaw and Banff Formations.

In the Wabamun Lake area the thickness of the combined Banff and Exshaw Formations, where they have not been truncated by erosion, ranges from 542 to 607 feet (Figure 2). The maps showing structure contours on top of the Devonian Wabamun Group (Figure 3) and on top of the intervals which subdivide the Banff (Figures 4, 5, and 6), as well as the structural cross-section (Figure 1), show essentially the same attitudes for all surfaces. The strike of the strata is northwest and the dip increases from 40 feet per mile near the eastern edge of the mapped area to 60 feet per mile near the western edge. The -3,500-foot contour shown on Figure 3 marks the approximate position of a hinge line that passes through the centre of the study-area. During the periods of erosion, north-northeasterly flowing streams established drainage channels and formed the irregular surface of the sub-Mesozoic unconformity. The scarps and outliers of porous strata created by these deeply incised channels form some of the reservoirs that contain the hydrocarbon reserves in this area.

Exshaw Formation

The name Exshaw Formation was given by Warren (1937) to about 30 feet of black, fissile shale at the base of the Mississippian Banff Formation that overlies Upper Devonian Limestones, near Exshaw, Alberta. Warren believed that this shale represented the uppermost Devonian strata in that area and, as it differed in physical characteristics from the rest of the Banff Formation, he introduced the new formational name. Later, Clark (1949) included 30 feet of overlying argillaceous limestone within the Exshaw; Harker and McLaren (1958) and Macauley (1958) also included siltstone and silty limestone beds which overlie the black shale in parts of western Alberta.

Macqueen and Sandberg (1968) redefined Warren's type section as follows: 31 feet of black shale grading upward into 2½ feet of dark grey, silty limestone which, in turn, grades upward into 127 feet of calcareous siltstone. Sandberg (1965) correlated the basal part of the Sappington Member of the Three Forks Formation of Montana and Wyoming with the Exshaw black shale and overlying siltstone of Alberta and, in turn, correlated this unit with the lower black shale and medial siltstone of the Bakken Formation of southeastern Alberta and Saskatchewan. Warren (1937) also had considered the Exshaw shale and Three Forks shale of Montana to be correlative because of their similar stratigraphic relationships. The siltstone overlying the Exshaw shale is present only in the western half of the Wabamun Lake area, and is overlain by oolitic and bioclastic limestones which are discussed below. Therefore, in this report it was found most convenient to adhere to Warren's original lithologic definition of the Exshaw although for mapping purposes it is grouped with the Banff Formation. The Exshaw Formation of this report is an extremely radioactive, homogeneous, dark brown to black, non-calcareous shale with a characteristic brown streak. Its typical thickness is about 10 feet, and it is easily identified in sample studies and on gamma ray logs throughout the area. This usage of the term was followed also by Moore (1958) and, as mentioned by Penner (1958), also is used in this sense by industry.

The contact between the Exshaw Formation and the underlying Upper Devonian Wabamun Group is sharply defined owing to the abrupt downward change from shale to a clean, light brown carbonate. It is thought that this abrupt change in lithology represents a disconformity. The uppermost Wabamun beds are generally composed of pelleted or sparsely fossiliferous, light brown, partly siliceous, and rarely dolomitic, micritic limestone. In the northeastern part of the map-area, the uppermost Wabamun limestone is not present and the shale rests on porous sucrosic dolomite. The contact relationships of the Exshaw shale and the overlying Banff Formation are discussed below.

Banff Formation

The term Banff Formation was introduced by Shimer (1926) for about 1,200 feet of Mississippian calcareous shale and argillaceous limestone in the Lake Minnewanka region near Banff, Alberta.

The carbonates, shales, siltstones, and sandstones recognizable in the Banff Formation are thought to have been deposited under shallow-water conditions; an initial transgressive phase with minor regressive cycles in earliest Banff time was followed by a dominantly regressive phase. These two phases established three main stratigraphic units referred to as lower, middle, and upper Banff, which have been recognized in both surface and subsurface studies by Warren (1927), Clark (1949), Macauley (1958), Macqueen and Bamber (1968), Martin (1967a, 1967b), and others, but formal nomenclature has not been established. In the Wabamun Lake area, the three units are recognized in the western half of the study-area where the Banff is conformably overlain by the Pekisko Formation. In the eastern part of the area, where the Banff subcrops at the sub-Mesozoic unconformity, the lower unit remains largely unchanged. But, it was necessary to combine the middle and upper units in some areas (Fig. 6) because of the rapid disappearance of these owing to erosion and because of thickening and irregular dolomitization of the middle unit.

The lower, middle, and upper Banff are here subdivided into ten lithofacies that reflect a variety of marine environments; figures 7 and 8 are cross-sections showing this stratigraphic and lithologic subdivision of the Banff. The lithofacies are discontinuous and a complete vertical section showing all ten has not been found.

Lower Banff

Lithofacies 1. The lower Banff ranges in thickness from 250 feet in Mobil Home Peers N 10-19-54-14 well to 358 feet in Blue Ridge No. 5-14 well in lsd 5-14-58-8W5. It is composed either predominantly or completely of cherty, dolomitic, micritic limestone which is here designated as lithofacies 1. This rock is dark grey-brown owing to the presence of abundant organic matter and has a significant clay- and silt-sized quartz content as discussed below. Siliceous monaxon spicules, dark grey to black nodular chert, often spicular, and pyrite, are common. In the northeastern quadrant of the study-area, the dark grey-brown colour changes to light brown, and chert and siliceous spicules are absent; this non-cherty rock was observed only in the small area where the lower Banff subcrops at the sub-Mesozoic unconformity.

Examination of thin sections prepared from well cuttings indicated the presence of some skeletal debris, but other than rare ostracods and siliceous spicules, constituents could not be identified because of their fine, fragmentary nature. It is suspected, however that some of the debris is of calcareous algal origin. The contribution of organisms to the rock is difficult to assess because the fine-grained carbonate does not show recognizable features that would enable one to distinguish between skeletal and non-skeletal origin (for a discussion of this problem in fine-grained sediments, see Feray, et al., (1962).

The abundant organic matter found in this lithofacies presented some difficulty in rock classification. Examination of well cuttings under a binocular microscope showed little, if any, textural difference between rock chips treated with dilute HCl (1:7) which (a) disaggregated completely; (b) left insoluble residues that retained their forms but broke up easily using a probe; and (c) retained their forms and were difficult to crush with a probe. The latter two types of residue were then boiled in HCl to ensure removal of all the carbonate but the residues appeared as before. Studies of thin sections from this interval indicated that clay was not present and that the quartz content was probably less than 20 per cent. Rock chips representing a ten-foot interval of the lower Banff were carefully picked from each of three wells in the study-area for semiquantitative identification of minerals by x-ray diffraction. The results were as follows:

Well Name	Location	Depth	Mineralogical Analyses	
St. Ann 1	9-28-55-4W5	4620-30	Calcite	65%
			Dolomite	32%
			Quartz	3%

Well Name	Location	Depth	Mineralogical Analyses	
Imp. et al. Mahaska E	4-13-57-12W5	6,830-40	Calcite	50%
			Dolomite	35%
			Quartz	14%
			Illite	1%
			Feldspar	trace
Hudsons Bay Chip Lk 1	4-22-55-11W5	6,750-60	Calcite	40%
			Dolomite	30%
			Quartz	27%
			Siderite	2%
			Illite	trace
			Feldspar	trace

The lack of clay minerals and the relatively small percentage of quartz suggested that organic matter was contributing to the insoluble residues (amorphous organic matter cannot be detected by X-ray diffraction methods). A sample was then collected from St. Ann 1 well in the interval 4,700-4,800 (10 rock chips were selected from each five-foot interval), and also from Imp. et al. Mahaska E well where interval 6,700-6,800 was sampled by picking 20 rock chips from each ten-foot interval. The samples were thoroughly washed and qualitative and quantitative mineralogical identification of the two samples was made by X-ray diffraction methods followed by chemical analyses supplemented by further X-ray diffraction and differential thermal analysis.

Two minor components found in the insoluble residues, and observed under binocular microscope examination of well cuttings, were pyrite and siliceous monaxon spicules; a few rock chips actually showed an interlocking framework of spicules after dissolving the carbonate matrix. In rare cases, pyrite was found to have partly replaced the spicules. For X-ray and chemical analyses, samples without visible pyrite were selected but, as etching is necessary to show the presence of spicules, some of the quartz content shown in the analyses is probably from that source, and the amount of quartz silt could be substantially below that shown in Table 1.

Pettijohn (1957, p. 154) stated "the average near-shore sediments have 2.5 per cent and the deposits of the open ocean average approximately 1 per cent organic matter." He also indicated (p. 599) that an abnormally high content of organic matter is greater than 2 or 3 per cent. Thus a content of greater than 6 per cent organic matter, as shown in Table 1, indicates a strongly reducing environment with shallow, quiet water conditions for the lower Banff micritic limestone.

Table 1 indicates the percentage of minerals and organic matter in the samples obtained by chemical and X-ray analyses. Note that the organic matter content is almost the same in both wells.

Table 1

	St. Ann 1			Imp. *et al.* Mahaska E		
		X-ray			X-ray	
Component	Chemical	Uncorrected	Corrected *	Chemical	Uncorrected	Corrected *
$CaCO_3$	76.0	81.5	76.0	55.7	59.6	55.7
$CaMg(CO_3)2$	9.3	6.7	6.4	21.1	20.7	19.4
SiO_2	8.3	11.8	11.0	16.4	19.7	18.3
Organic matter xx	6.4			6.8	-	-
TOTAL	100.0%	100.0	93.4	100.0%	100.0	93.4

* As amorphous organic matter cannot be detected by X-ray diffraction methods a correction factor of (100-6.4) /100 for St. Ann 1 and of (100-6.8) /100 for Mahaska E was used from the chemical analysis to correct the values obtained by X-ray diffraction.

xx The amount of organic matter was calculated by taking the difference between the initial weight of the sample minus the total weight of the calcite, dolomite, and silica as determined by chemical analysis.

Lithofacies 2. Throughout most of the region a dark grey-brown to black, calcareous shale, which resembles the Exshaw shale in appearance, underlies lithofacies 1. Its radioactive content approaches that of the Exshaw Formation and it is usually picked on the second scale of the gamma ray log. In the western half of the study-area, this shale overlies lithofacies 3 but, in the east, it is either absent and the entire lower Banff is represented by lithofacies 1, or it directly overlies the Exshaw. Where present, the shale ranges from 6 to 70 feet in thickness.

Lithofacies 3. In the west half of the map-area, lithofacies 2 is underlain by 6 to 14 feet of oolitic limestone, here referred to as lithofacies 3. This limestone is readily identified on gamma ray logs by its low radioactivity; it stands out as a pronounced peak on the curve (Figure 7 and 8). Examination of thin sections prepared from well cuttings indicates that the individual oolites (or ooids) are as much as 2.5 mm in diameter. These accretionary particles show several well-developed shells having concentric structure, and the few nucleii observed consist of rounded calcitic grains. Extensive recrystallization is shown by some oolites where the nucleus and inner shells consist of a coarse mosaic of calcite (with the coarsest development in the centre) although the outer shell retains its form. Scattered dolomite rhombs are found in some grains, and the oolites and matrix show traces of silica replacement.

The rock is cemented with sparry calcite near its eastern limit, but lime mud, slightly dolomitized, forms the matrix in the western part of the area. In Union Ang Kroy Stan Shin Bnk 16-23 well, in lsd 16-23-56-14W5, the characteristic gamma ray curve is present but sample examination indicates a lateral facies change to 10 feet of micritic limestone with some algal? structures (poor sample quality and partial dolomitization prevented a positive identification), but oolites were not observed. This distinctive limestone was traced beyond the study-area to the north and south, but is not present in the west.

Lithofacies 4. An approximate north-south line in range 9 delineates the eastern margin of lithofacies 4, a light to medium brown dolomitic siltstone, that directly overlies the Exshaw shale (Figure 5). This siltstone unit is included in the Exshaw by some workers as previously discussed. Staining with Alizarin Red S solution indicated that the carbonate cement is almost entirely dolomite with traces of calcite. The siltstone ranges from 13 to 45 feet in thickness.

Lithofacies 5 and 6. In the Wabamun Lake area, an anomalous basal lower Banff facies developed in an elongated pattern extending from township 55, ranges 8 and 9, to township 59 beyond the edge of the map-area; its maximum width is about 11 miles (Figure 5).

At the southern end of this rock unit, in Imperial Paddle River 1 well, in lsd 5-17-56-8W5, 160 feet of light coloured, crinoidal, spar cemented limestone with lesser intraclasts and coated grains overlies 20 feet of siltstone of lithofacies 4 and is, in turn, overlain by 30 feet of dark grey calcareous shale (lithofacies 2). This bioclastic limestone is classed as lithofacies 5. The crinoidal debris and rounded intraclasts of lime mud are as much as 1.2 mm in diameter; rare, coarse, lime mud aggregates with irregular boundaries also were observed. Some samples contain trace amounts of green shale which suggests the presence of thin, probably irregular, shale laminae. Incipient dolomitization has occurred; fine dolomite rhombs replace some of the comminuted debris and single dolomite rhombs were seen in a few of the larger crinoid fragments. Insoluble residue consists of small amounts of very fine (less than 0.08 mm), clear quartz grains.

Near the north end of this anomalous clastic development, 100 feet of very fine, well-cemented sandstone (upper 10 feet calcareous, remainder dolomitic) with pyrite inclusions directly overlies the Exshaw shale. This sandstone is found in Blue Ridge No. 5-14 well, in lsd 5-14-58-8W5, and is classed as lithofacies 6. It is contiguous with the siltstone of lithofacies 4 and is overlain by the oolitic limestone of lithofacies 3.

Middle Banff

Throughout most of the study-area, the middle Banff is mainly a micritic-skeletal limestone here classed as lithofacies 8. In the western part of the area, this rock type is normally underlain by a siliceous, crinoidal and cherty limestone here called lithofacies 7. In the north-central part of the area, the micritic-skeletal limestone has been largely dolomitized and cannot be separated into upper and middle Banff and is, therefore, mapped as "combined middle and upper Banff" (Figure 6) and classed as lithofacies 9. The middle Banff is also dolomitized at its subcrop near the deeply incised channel shown on Figure 6 and forms the reservoir rock for oil and gas accumulation in the area.

The average thickness of the middle Banff limestone is about 100 feet, but it ranges from 48 feet in Mobil CS McLeod N 10-6-56-13 well to an extreme of 223 feet in Muskeg A-1 Sangudo 2-18-57-6 well (Figure 6). The upper and lower boundaries are gradational and consistent boundary definitions are not always possible which may account for some of the thickness variation.

Lithofacies 7 is a siliceous, crinoidal, and cherty limestone with some dolomitized intervals. No cores were cut in this unit and the 10-foot sample intervals are a mixture of the following:

(a) Crinoidal debris as much as 2 mm in diameter cemented by sparry calcite.

(b) Silicified crinoidal limestone where complete replacement of the above preserved the textural details resulting in blue-grey silicified crinoids in a white siliceous ground mass. Intermediate stages of silicification are seen also where the crinoids were silicified but the spar was not replaced.

(c) Dolomitized crinoidal limestone where replacement by finely crystalline dolomite varied from moderate to almost complete with only a few crinoid fragments, either calcitic or siliceous, still recognizable. Some beds are completely dolomitized and have vuggy porosity owing to leaching of the skeletal debris. Drillstem tests conducted in this interval recovered only salt water.

(d) White or light tan coloured chert fragments with no discernible texture.

Fragments of brachiopod shells, ostracods, and siliceous monaxon spicules are rare; pyrite and glauconite are also rare. A few well cuttings are large enough to show contacts between the various lithologies and it is thought that the silica replacement is nodular in form. This lithofacies occurs only in the western half of the study-area where it either represents the entire middle Banff or is overlain by the micritic-skeletal limestone of lithofacies 8.

Lithofacies 8 is a micritic-skeletal limestone containing sparse crinoidal debris, rare ostracods and brachiopods, and some pellets; a few light coloured chert inclusions also are present. At and near the middle Banff subcrop, this limestone displays some poor pin-point porosity and contains some dark brown tarry oil residue. Although the thickest complete section of this lithofacies is now found near its subcrop in Muskeg A-1 Sangudo 2-18-57-6 well (223 feet), the thickest development of the lithofacies occurred in its present subcrop area where lithofacies 9, its dolomitized equivalent, is 224 feet thick in Ashland Cdn-Sup Glenevis 13-13-56-5 well. Erosion has removed an unknown amount of section above this lithofacies and its original thickness could have been substantially greater. St. Ann 1, a well drilled in the subcrop area in lsd. 9-28-55-4W5, encountered 190 feet of micritic-skeletal limestone with minor amounts of chert replacement of the crinoidal debris. Quartz silt residue was estimated to be less than 10 per cent of the rock. Partial to almost complete dolomitization of the matrix has resulted in the sequence limestone-dolomitic limestone-calcareous dolomite-dolomite. The latter has good vuggy porosity owing to the leaching of the skeletal debris.

Lithofacies 9. Complete dolomitization of lithofacies 8, the micritic-skeletal limestone, resulted in a finely sucrosic dolomite which is here termed lithofacies 9. Medium and dark brown tarry oil staining occurs as irregular patches, whereas the unstained dolomite is light greenish grey and contains as much as 15 per cent quartz silt.

This dolomite is the reservoir rock in the Glenevis and Cherhill oil fields, and in wildcat oil and gas completions near these fields. Texaco Glenevis No. A-1 well, in lsd. 7-35-55-4W5, the discovery well of the Glenevis field, is a typical well penetrating this reservoir rock in the area. There, the partly eroded middle Banff consists of 177 feet of light brown and grey dolomite with irregularly brown-stained intervals and good vuggy and intercrystalline porosity. The uppermost 50 feet is light brown with a high lustre and contains about 5-10 per cent quartz silt; interlocking dolomite crystals are less than 0.08 mm in size. The vugs were formed by leaching of the skeletal debris. The lower 127 feet consists of finely sucrosic dolomite with small amounts of brown oil staining and good porosity. Scattered pyrite cubes are present and the insoluble residue consists of about 10 - 15 per cent quartz silt.

In the Cherhill field, the section is not completely dolomitized and intervals of dolomitic limestone with vuggy porosity are found interbedded with the dolomite, but this lithology comprises less than 20 per cent of the section and the middle Banff is still classed as lithofacies 9 in this area.

Upper Banff

The thickness of the non-eroded upper Banff is represented by one lithofacies unit and ranges from 112 feet in Imperial Northville No. 15-2-52-10 well to 204 feet in Grt Plns *et al.*, Peers 10-35-54-14 well; the typical thickness is about 150 feet.

Lithofacies 10. In the western half of the study-area, the upper Banff consists of a silty, finely crystalline and sucrosic dolomite, grading into or interbedded with dolomitic siltstone; it is here referred to as lithofacies 10. The rock is light grey or brown, pyrite inclusions are common, and irregular green shale beds as much as 6 inches thick normally occur in the uppermost 50 feet. A few beds of light brown, micritic limestone with some vague pelleted texture, rare "birdseye" structure, and scattered calcispheres were observed but their occurrence is erratic and sparse.

MICROPALEONTOLOGY

Thin sections from the grain-supported lower Banff limestone and the micritic limestones of the uppermost Devonian were sent to Dr. B.L. Mamet of the University of Montreal for micropaleontological identification. Except for the red alga Parachaetetes sp., all of the following are foraminifers.

(1) Cities Service Mayerthorpe 1, lsd. 12-14-57-8W5
top lithofacies 5 5,168
top Devonian Wabamun Group 5,374

Depth	Fossils	GSC Location No.
5,160-5,170	Latiendothyra sp.	C-2345
5,180-5,190	Umbella sp. Latiendothyra sp.	C-2346
5,370-5,380	Archaesphaera sp. Parathurammina sp. Vicinesphaera sp.	C-2347

(2) Imperial Paddle River 1, lsd. 5-17-56-8W5
top lithofacies 5 5,682
top Devonian Wabamun Group 5,870

Depth	Fossils	GSC Location No.
5,700-5,710	Latiendothyra sp. Umbella sp.	C-2348
5,710-5,720	Latiendothyra sp.	C-2349
5,720-5,730	Umbella sp. Septaglomospiranella sp.	C-2350
5,740-5,750	cf. Tournayella sp.	C-2351
5,780-5,790	Earlandia sp.	C-2352
5,790-5,800	Umbella sp. Parachaetetes sp.	C-2353
5,820-5,830	Umbella sp.	C-2354

(3) Zapata B.A. Blue Ridge 10-14-58-8, lsd. 10-14-58-8W5
top lithofacies 3 5,104
top Devonian Wabamun Group 5,228

Depth	Fossils	GSC Location No.
5,100-5,110	Earlandia elegans (Rauzer-Chernoussova)	C-2355
5,110-5,120	Paracaligella sp.	C-2356

(4) Blue Ridge 8-11, lsd. 8-11-58-8W5
top Devonian Wabamun Group 5,238

Depth	Fossils	GSC Location No.
5,240-5,250	Umbella sp.	C-2357

Dr. Mamet stated that there were practically no foraminifers in the thin-sections and he saw only scattered fossil debris which, with one exception, was not identifiable on a species level. He concluded that "The microfauna of the Banff seems similar to that of the Banff in southwestern Alberta; if this assumption is correct, although based on very meagre evidence, the microfauna would belong to the lower part of zone 7; this is the lower part of the Middle Tournaisian". For the relationships between the standard European succession and the Mississippi Valley sequence, see Mamet and Mason, (1968, p. 159).

GEOLOGICAL HISTORY

The various lithofacies in the Banff Formation reflect the depth and turbulence of the water in which the sediments were deposited. The black, organic-rich Exshaw shale is thought to have been deposited in stagnant, shallow water which produced a toxic reducing environment on the sea floor. The initial Banff sediments, the siltstones of lithofacies 4, were deposited following minor uplift of a land mass some distance northeast of the study-area and which supplied the detritus. The absence of terrigenous clastic rocks at the base of the Banff in the eastern part, and their presence in the western part of the study-area, suggests emergence of this eastern region above sea level for a short period of time. The rapid disappearance of the Banff strata owing to erosion toward the east and northeast makes it impossible to determine the areal extent of the emergence. The sandstone accumulation of lithofacies 6 that passes laterally into the skeletal sparry limestone of lithofacies 5 in the north-central part of the area represents a local shoal area of high wave and current energy.

An increase in water temperature and salinity, coupled with very shallow, turbulent water conditions led to the deposition of the oolitic limestone of lithofacies 3. The westward increase of lime mud and corresponding decrease of spar cement indicate less turbulent and deeper water conditions in that direction.

A return to conditions similar to those prevailing during deposition of the Exshaw shale led to the deposition of the dark shale of lithofacies 2. The environment was not as strongly anaerobic as the previous one because the shale is slightly calcareous and dark grey-brown instead of black.

Transgression then occurred and the dark grey-brown, cherty, micritic limestone of lithofacies 1 was deposited. The rock type is thought to have been deposited below wave base in shallow, quiet waters where anaerobic conditions prevailed. Thus, much of the organic matter was preserved and this resulted in the dark grey-brown colour of the rock.

Regression or shallowing of the sea followed, and open marine shelf conditions prevailed. The skeletal sparry limestone of lithofacies 7 and the micritic-skeletal limestone of lithofacies 8 indicate high and low energy conditions respectively, and reflect slight changes in sea level.

Continued regression or shallowing of the sea resulted in the deposition of the uppermost siltstones, silty dolomites, and micritic limestones of lithofacies 10. These suggest deposition in a low-energy, tidal flat environment where the quartz silt was brought to the site of deposition by winds.

ECONOMIC GEOLOGY

In the Wabamun Lake area, two oil fields with production from the Banff Formation have been designated by the Oil and Gas Conservation Board of Alberta (Figure 9). The first, Glenevis, was discovered in 1954. As of November 30, 1968, there were 8 wells capable of producing oil, and two wells that were formerly oil producers had been recompleted to salt water disposal. The maximum gross pay is in the Texaco Glenevis No. A-10-35 well, in lsd 10-35-55-4W5, where 75 feet of lithofacies 9 is found above the oil/water interface at 1,950 feet. The porosity is about 11 per cent, and the gravity of the oil is 20°API.

The Cherhill Field was designated by the Board in 1968. As of November 30, 1968, there were 6 wells capable of oil production from the Banff Formation. The gas/oil interface is at -1,961 feet, and the oil/water contact is at -2,043 feet. The maximum gross pay is in the Ashland Cdn Sup Glenevis 4-24-56-5 well where 23 feet of gas column and 88 feet of oil column are present. Average porosity is about 17 per cent.

Another pool was found in 1968 where 6 oil wells were completed in the Banff Formation. It is located due south of Cherhill and due west of Glenevis (Figure 9). Cores, samples, and logs were still confidential in November 1968.

Texaco Majeau Lake B1 well, in lsd. 3-25-56-4W5, is a potential Banff gas well completed in 1951 with an initial potential of 9.5 mmcf/d. The gas/water contact is at -1,918 feet, and 74 feet of gross pay are present.

Three wells in the Barrhead area (township 55, range 5W5) were completed in the Banff Formation in 1949 and 1950. Two were completed as oil wells (23° API) with a maximum 18 feet of gross pay above the oil/water contact at -1,746, and the third is a gas well with 24 feet of gross pay.

The variable oil/water and gas/oil contacts indicate several small separate reservoirs. Porosity development is largely the result of secondary dolomitization and leaching of the skeletal debris which is related to the sub-Mesozoic unconformity. Erosion has produced scarps of porous dolomite and hydrocarbons are trapped at the updip edges by the overlying Lower Cretaceous shales. Exploration for additional reserves must, therefore, be aimed at delineating other topographic highs in lithofacies 9 at the sub-Mesozoic unconformity.

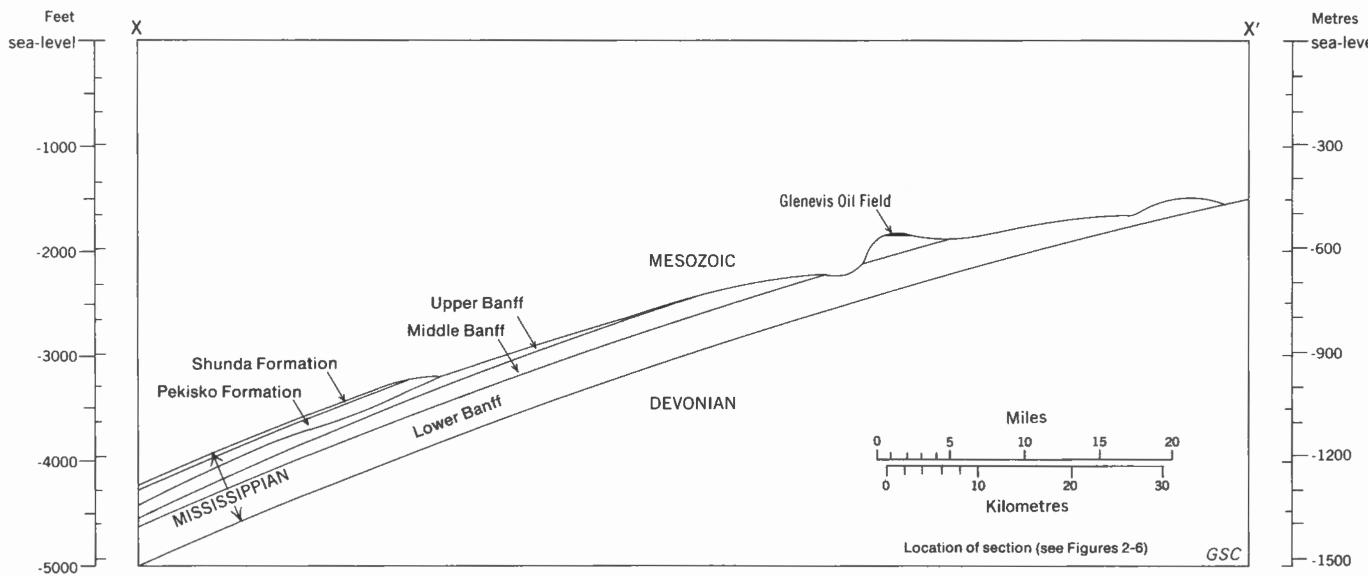
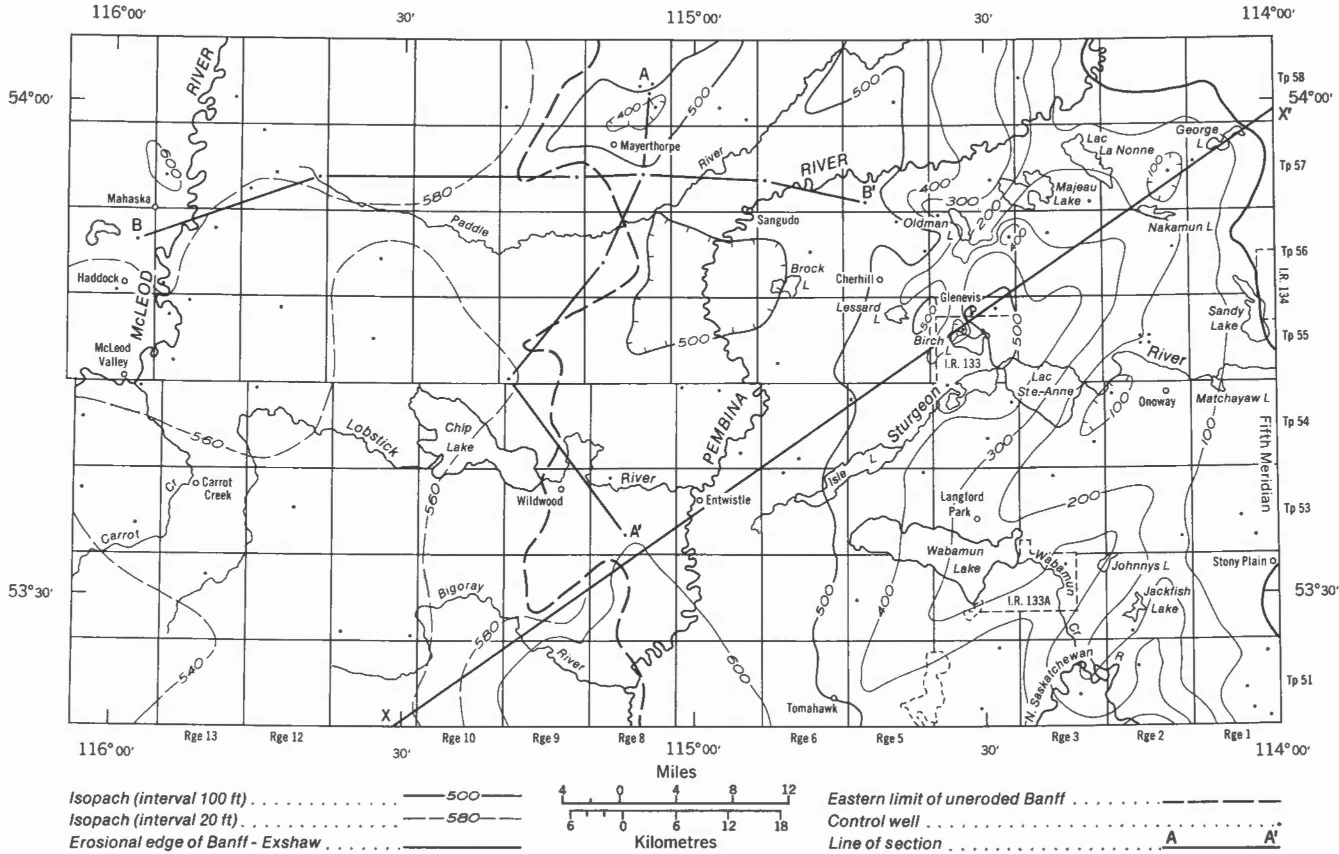


Figure 1. Structure cross-section X-X'



Note: well control as of November 30, 1968

GSC

Figure 2. Isopach map of the Banff and Exshaw Formations

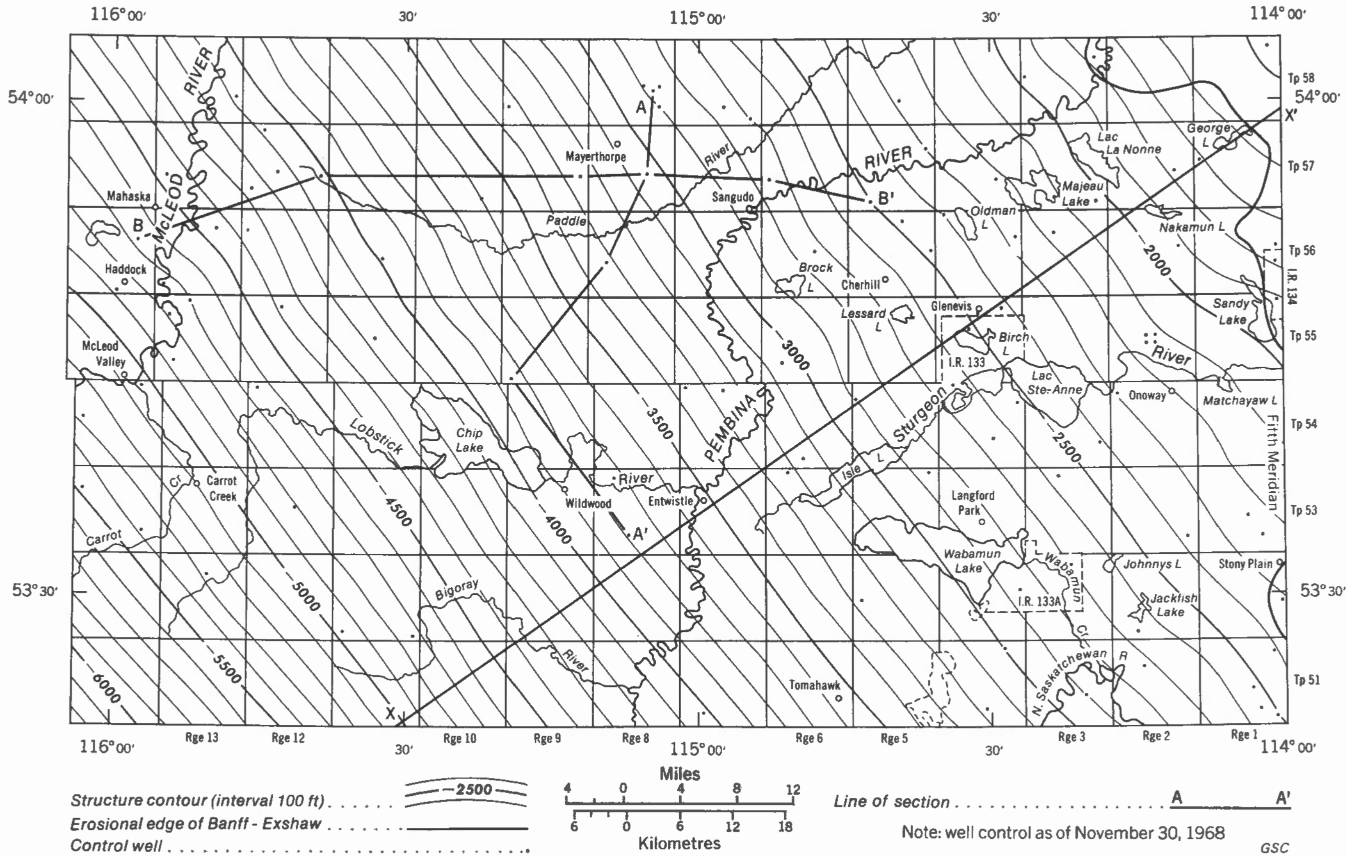
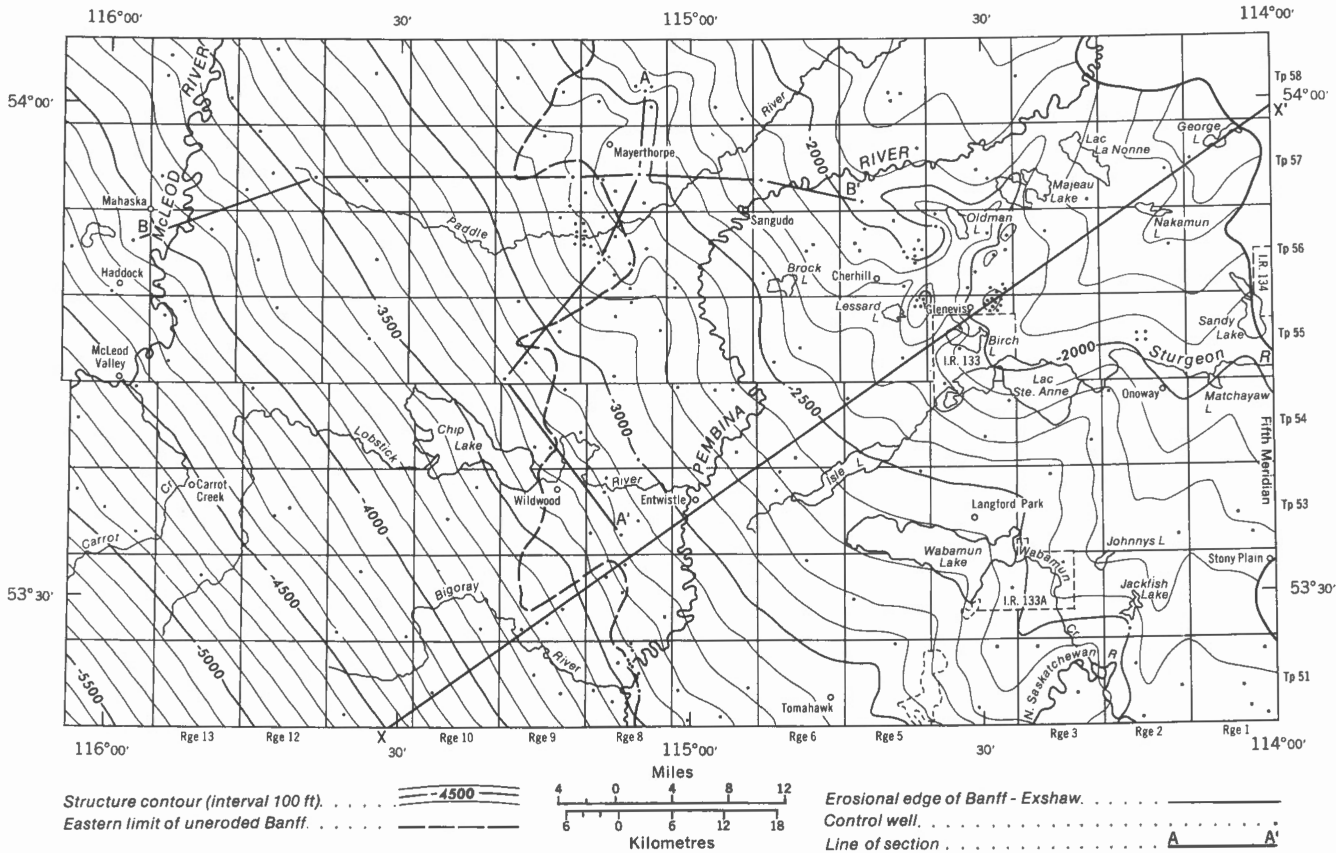


Figure 3. Structure contours on top of the Devonian Wabamun Group



Note: well control as of November 30, 1968

GSC

Figure 4. Structure contours on top of the Banff Formation

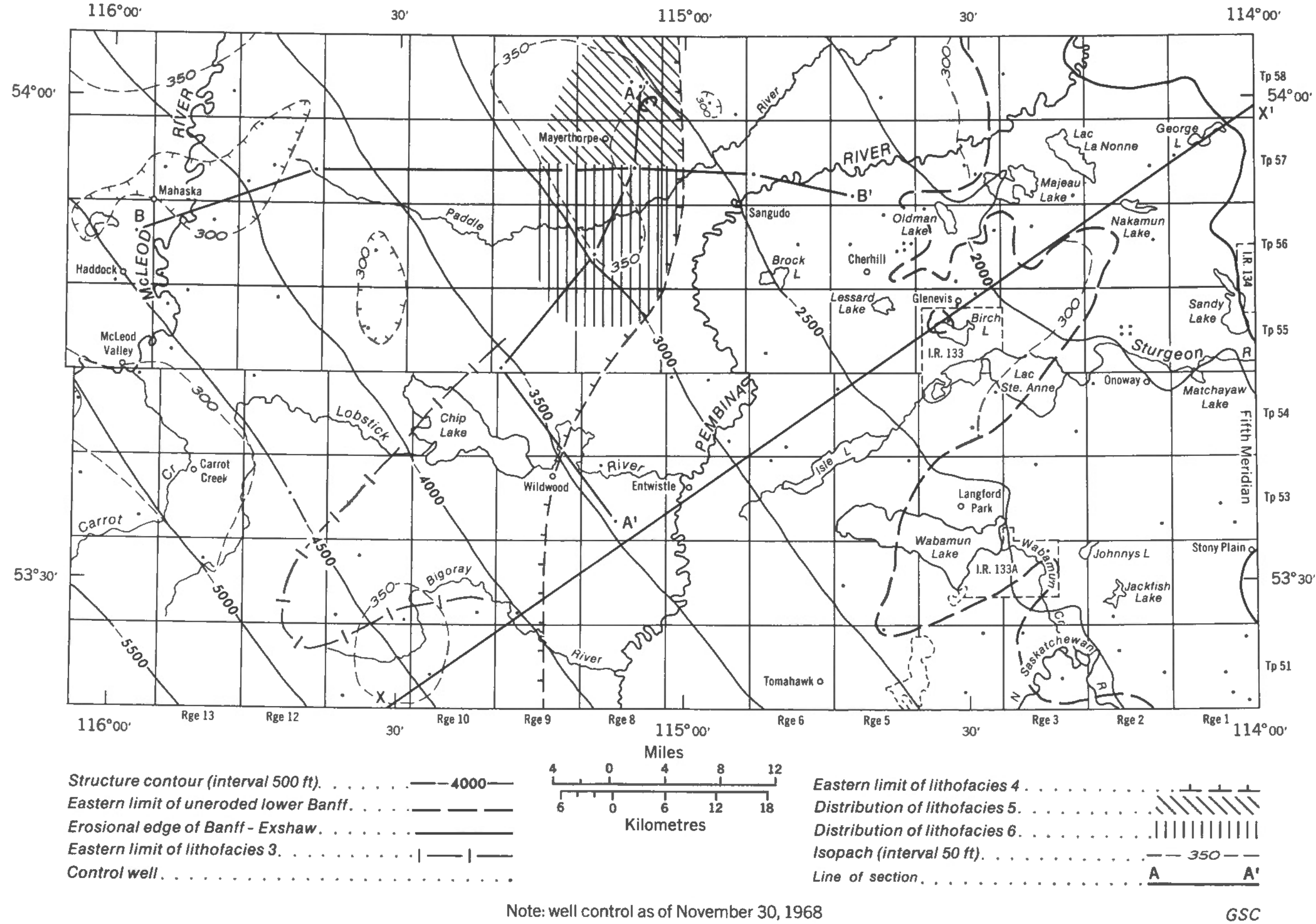


Figure 5. Structure contours, isopachs, and lithofacies distribution of the lower Banff

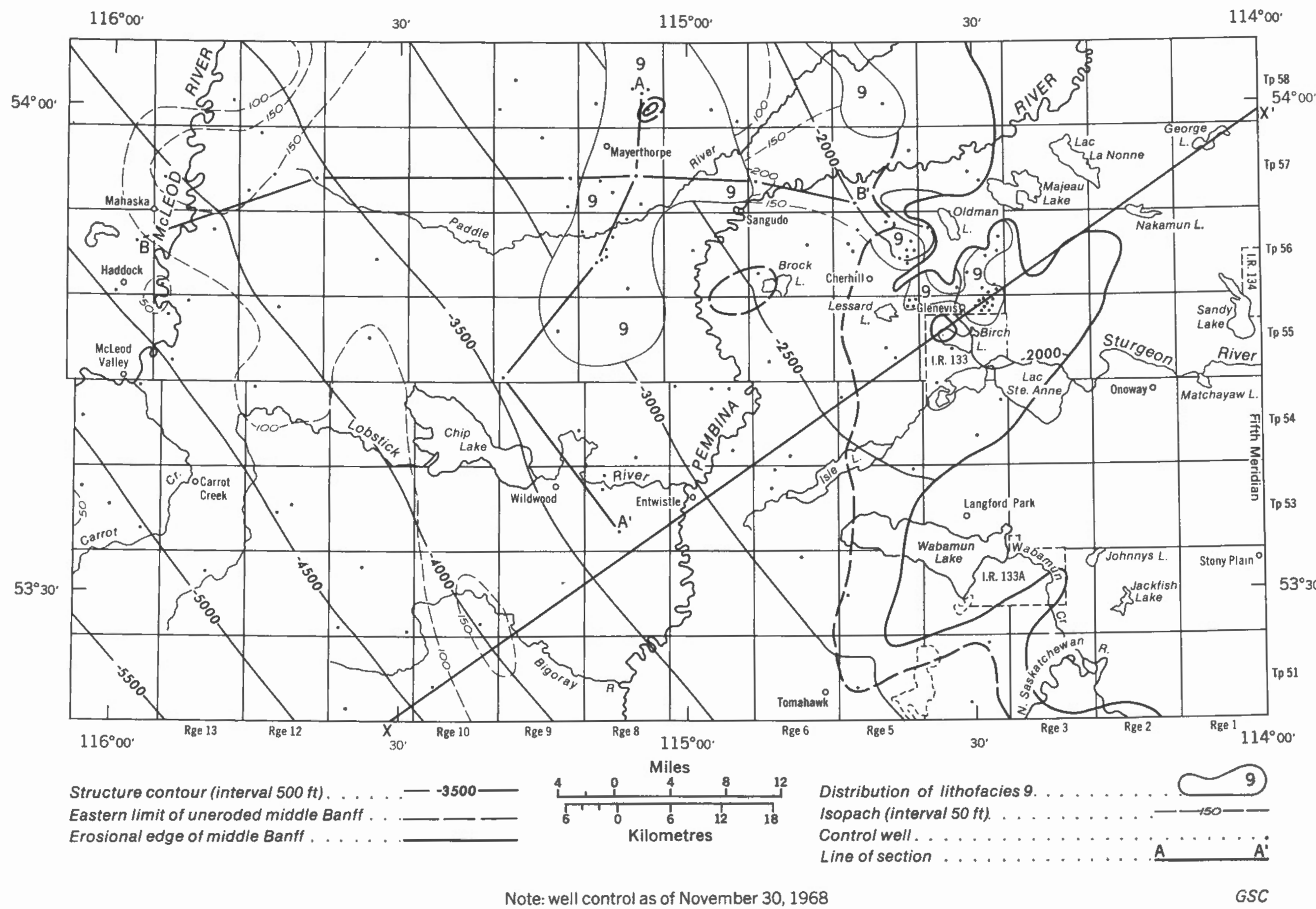


Figure 6. Structure contours, isopachs, and lithofacies distribution of the middle Banff

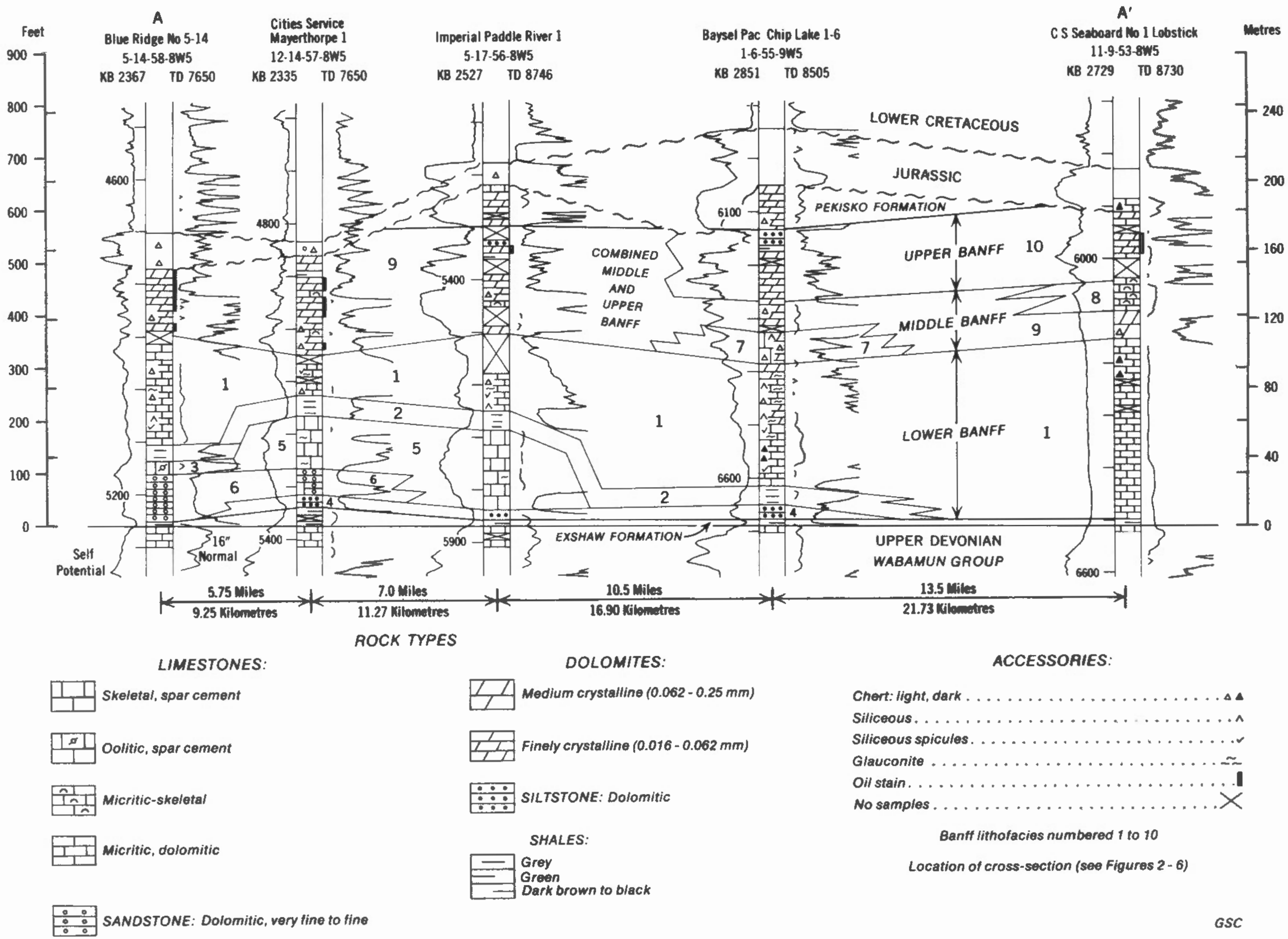


Figure 7. North-South stratigraphic cross-section

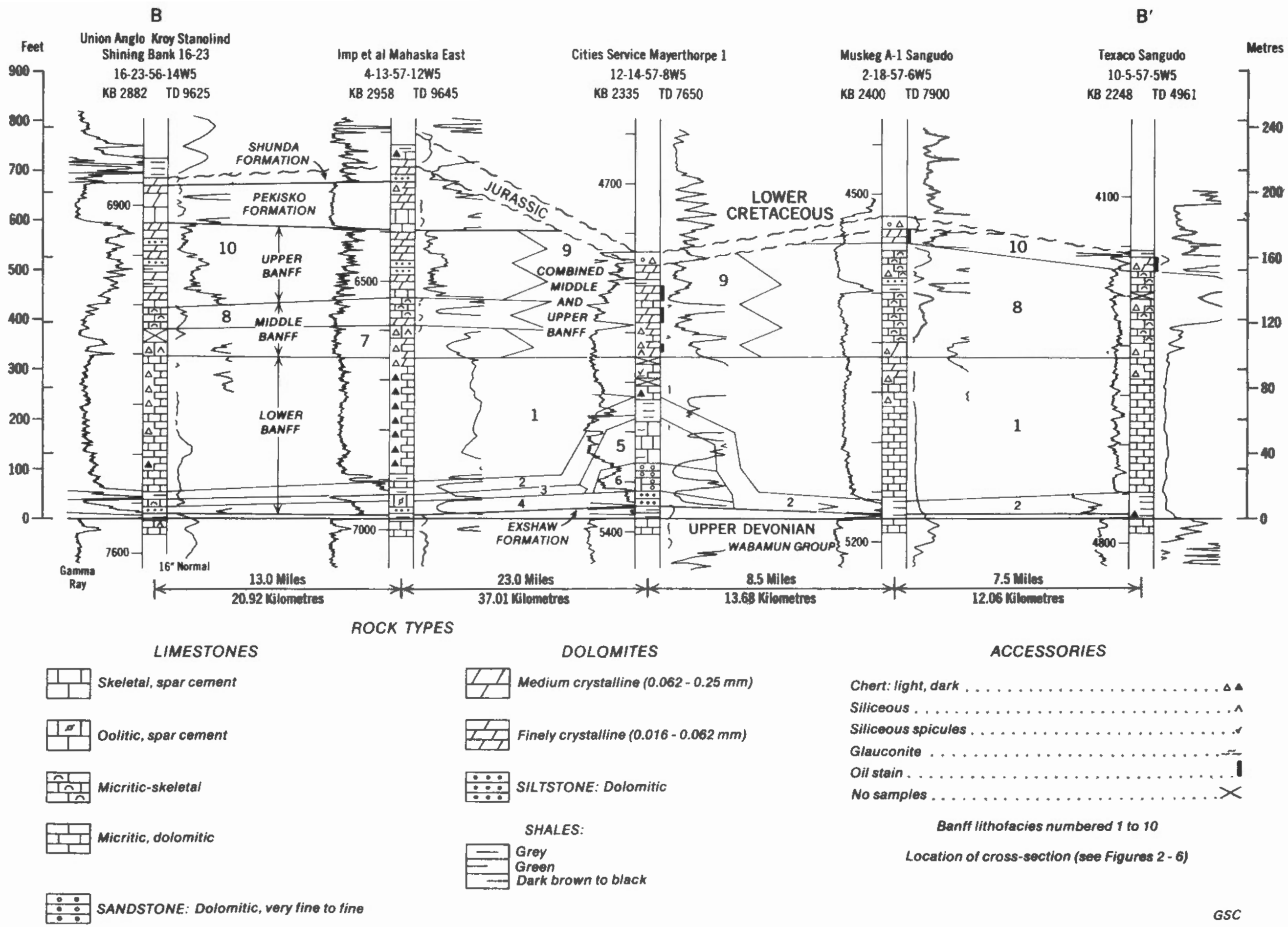


Figure 8. East-West stratigraphic cross-section

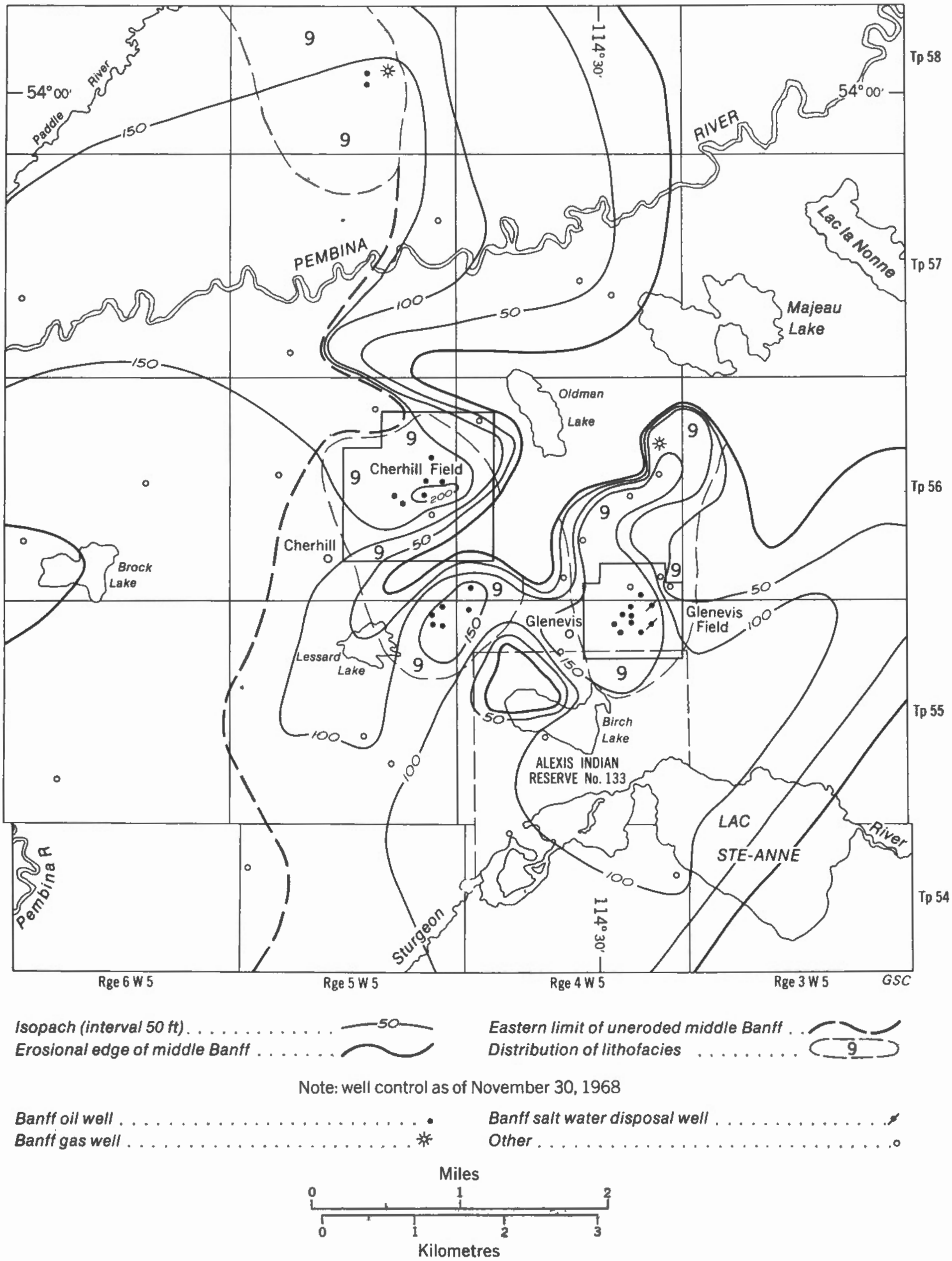


Figure 9. Isopachs and lithofacies distribution of the middle Banff, Cherhill - Glenevis area

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