PROVINCE OF ALBERTA

RESEARCH COUNCIL OF ALBERTA

BULLETIN 7

OCCURRENCE AND STRATIGRAPHY OF SOME GYPSUM AND ANHYDRITE DEPOSITS IN ALBERTA

by

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Edmonton
Printed by L. S. Wall, Queen's Printer for Alberta
1961

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ABSTRACT

The origin, occurrence, and utilization of gypsum and anhydrite minerals are described briefly; data on Canadian production and use of gypsum are given.

Triassic gypsum deposits are present at Mowitch Creek and Fetherstonhaugh Creek in the Rocky Mountains north of Jasper; both these deposits are tentatively correlated with the subsurface Upper Triassic evaporitic Charlie Lake formation of the Peace River area. Drill-hole data are used in geological sections to illustrate this correlation.

Middle Devonian gypsum deposits occur at Peace Point and along the Salt, Slave, and Little Buffalo Rivers, and subsurface at McMurray. The lower gypsum bed along the Salt, Slave, and Little Buffalo Rivers is correlated with the Chinchaga formation of northwestern Alberta, the second, third, and fourth salt beds in central Alberta, and the Meadow Lake formation of Saskatchewan. The McMurray deposit is correlated with the Pine Point and Presqu'ile formations in the Northwest Territories (also with an upper gypsum bed along the Little Buffalo River), the Muskeg formation of northwestern Alberta, possibly the lower part of the Peace Point gypsum deposit, the first salt of central Alberta, and the Prairie evaporite of Saskatchewan. At least the upper part of the Peace Point deposit is correlated with the Fort Vermilion member of the Slave Point formation, and is possibly equivalent to the upper part of the McMurray deposit (upper Dawson Bay equivalent). These correlations are illustrated by geological sections, isopach maps, and an interpretive facies section.

A small gypsum deposit of Upper Devonian age occurs at Head Creek in the Highwood Range of southern Alberta.

Chemical analyses are given for many of the deposits, and the possibility of economic development is discussed from the point of view of markets, utilization, location, transportation facilities, quality, reserves, and possible extensions of the deposits. It is concluded that the Fetherstonhaugh Creek and Peace Point deposits are the most suitable for development in the conditions now existing. A more suitable deposit might be revealed by prospecting between McMurray and Lake Claire.

Appendix A discusses the possibilities of the presence of potassium salts in Middle Devonian strata in Alberta; Appendix B discusses the age of the Devonian evaporitic deposits and nomenclature of the strata.

INTRODUCTION

With the advent of major oil discoveries during 1947 and succeeding years, Alberta has become a wealthy province, ranking third in total mineral production in Canada. In the wake of wealth came increased population with its accompanying demands for homes, roads, and manufactured products. It is in this economic climate that industrial minerals become of major importance, an importance that is demonstrated by an increase in their value of over fivefold since 1946, a value which for several years has greatly exceeded that of coal production. In a province where two industries—petroleum and agriculture—account for almost all the wealth and employ directly or indirectly most of the population, it is an advantage if industrial minerals can be produced within the provincial borders, thus providing a desirable diversification of the economy.

Alberta is not outstandingly rich in high-grade mineral deposits; one possible exception to this generalization is gypsum, which occurs in large quantities at several localities, and which is not yet developed. These gypsum deposits were reviewed briefly in 1958 (Govett and Byrne, 1958) on the basis of existing published data. Since that time deposits at Fetherstonhaugh Creek and at Head Creek have been investigated by the writer, and some additional data on the Peace Point deposit have been obtained by M. A. Carrigy and L. B. Halferdahl of the Research Council. These additional field data, together with the study of subsurface data obtained by the oil industry which are now available, have led to the compilation of this report.

This is primarily an economic report on gypsum, but much stratigraphic information is included to enable a better understanding of the origin and correlations of the various deposits. Also, two appendices have been included: Appendix A is a brief review of the possibility of deposits of potassium salts being present in the Middle Devonian evaporites in Alberta; Appendix B presents some notes upon the terminology and correlation of Middle Devonian evaporitic rocks.

Acknowledgments

Thanks are extended to the geological staffs of Imperial Oil Limited and Shell Oil of Canada, Limited, and to G. G. L. Henderson of California Standard Oil Company, for useful discussions upon the Triassic stratigraphy and gypsum deposits in the Rocky Mountains. Grateful acknowledgment for lithologic subsurface data of the Triassic system is given to the following oil companies: Amerada Petroleum Corporation, British American Oil Company, Pan American Petroleum Corporation, Phillips Petroleum Company, Richfield Oil Corporation, Shell Oil of Canada, Texaco Canada, Texaco Exploration Company, and Triad Oil Company.

Acknowledgment is also made to the various organizations and individuals listed below: Pacific Petroleum Company gave permission to take chip samples from the cores of Bear Vampire No. 2 and Bear Westmount No. 2 wells; the Alberta Oil and Gas Conservation Board permitted the use of drill-hole data for the compilation of some figures;

D. I. Istvanffy of the Alberta Government Bureau of Statistics supplied miscellaneous statistics; Dr. L. B. Halferdahl (Research Council of Alberta) provided some of the information used in the account of the gypsum deposit at Peace Point; the chemical analyses of new samples were performed by H. Wagenbauer (Research Council of Alberta) and the Technical Service Laboratories, Toronto; the diagrams were drafted by J. Groot (Research Council of Alberta). Dr. G. R. Pearson (Geologist, Research Council of Alberta) accompanied the writer to Fetherstonhaugh Creek and assisted with sampling and mapping; D. Clements (Field Assistant) was of great service in all phases of the field work; Dr. R. Green aided in discussion and literature research upon the subject of the Devonian evaporitic succession.

GYPSUM AND ANHYDRITE—DESCRIPTION, ORIGIN, OCCURRENCE, AND UTILIZATION

Chemical and Physical Description

Gypsum—$CaSO_4.2\ H_2O$

Gypsum is hydrated calcium sulfate which, when pure, contains 32.57 per cent calcium oxide, 46.50 per cent sulfur trioxide, and 20.93 per cent water. It crystallizes in the monoclinic system, and crystals are flattened parallel to the clinopinacoid which is also a cleavage plane. Common twins are the arrowhead type and the swallowtail type. The mineral has a hardness of 1.5 to 2.0 on Mohs' scale and may be scratched readily by the fingernail; the specific gravity is 2.3 to 2.4; when pure it is white, but impurites may color it various shades of red, pink, brown, or grey.

Well-formed crystals known as *selenite* are colorless and transparent. Most of the larger deposits are of a massive variety consisting of an aggregate of small, normally microscopic, mutually interfering crystals. Other forms of gypsum are *satin spar* which has a fibrous texture, and a pure, fine-grained, compact, marble-like variety known as *alabaster*.

Gypsum is soluble in pure water to the extent of about 2 grams per litre, although this solubility is increased considerably in the presence of certain salts, notably sodium and magnesium chlorides; it is readily soluble in dilute hydrochloric acid. When heated to 120 to 130°C. three-quarters of the water is expelled resulting in the formation of the hemihydrate, $CaSO_4.\frac{1}{2}\ H_2O$, although prolonged heating at lower temperatures will result in the loss of some water; all the water is lost at 163°C. and dissociation to CaO and SO_3 begins at 400°C. Apart from the instability of water of crystallization, gypsum is chemically inert.

Anhydrite—$CaSO_4$

Anhydrite is the anhydrous form of calcium sulfate, and when pure contains 41.19 per cent calcium oxide and 58.81 per cent sulfur trioxide. It crystallizes in the orthorhombic system, crystals being tabular or prismatic. Cleavage is parallel to the three pinacoids and cleavage fragments are thus rectangular. This mineral has a hardness of 3 to 3.5 on Mohs' scale and, since it cannot be scratched with the fingernail, is readily distinguished from gypsum; the specific gravity is 2.92 to 2.98; the color typically is white, but may be pale grey, blue, or pink. Crystals are rare and it normally occurs in the massive form.

The solubility of anhydrite in water is somewhat less than that of gypsum; it is soluble in boiling hydrochloric acid.

Origin and Occurrence of Gypsum and Anhydrite

Gypsum occurrences may be divided into three main classes dependent upon the origin of the gypsum. By far the most important class of gypsum is that which has been precipitated through evaporation of bodies of saline water. This type of gypsum occurs in rocks of all ages—from the Precambrian as in Arctic Canada (Blackadar and Fraser, 1960) to the Pleistocene as in Kenya (Groves, 1958)—but is especially prevalent in rocks of Permo-Triassic and younger ages. These deposits are commonly extensive; for instance, in what is probably the largest known deposit—in that area of Somalia formally administered by Britain—beds of gypsum and anhydrite 100 to 2,000 feet thick outcrop over an area of at least 14,000 square miles (Groves, 1958). The rocks normally associated with gypsum are limestone, shale, clay, marl, and especially salt and other evaporites; in many places gypsum is found associated with petroleum source-rocks (Groves, 1958).

Gypsum will crystallize from a body of water where evaporation exceeds accession of fresh water, provided that calcium sulfate is present in sufficient concentration in the water. The normal order of precipitation of salts from sea water is calcium carbonate, calcium sulfate, sodium chloride, magnesium sulfate and magnesium chloride, and finally potassium salts and double salts. The question of whether calcium sulfate is deposited as gypsum or anhydrite is the subject of debate: the general opinion (as summarized by Green, 1961) is that gypsum will crystallize from sea water only below 34°C., whilst MacDonald (1953) states that in solutions saturated with sodium chloride gypsum can form only at temperatures below 14°C.; on the other hand Conley and Bundy (1958) consider it unlikely that anhydrite will be deposited from sea water at temperatures less than 42°C. A review of current opinion concerning the formation of evaporites, together with a survey of evaporitic deposits with respect to age and location, is given by Green (1961).

The second class of gypsum is that formed by interaction of sulfuric acid (commonly formed from iron pyrite) and lime salts such as limestone; the presence of small selenite crystals which abound along the bedding planes in Cretaceous, Tertiary, and Recent clays and shales in Alberta is probably accounted for in this manner. In some areas hydrothermal solutions and volcanic activity are responsible for the formation of gypsum as, for example, on Sheep Mountain 90 miles northwest of Anchorage in Alaska where hydrothermal solutions have altered Jurassic volcanic rocks to gypsum, greenstone, and quartz-sericite rock (Eckhart, 1951).

The third class consists of secondary gypsum that is formed by disintegration of existing deposits followed by deposition of the debris as dunes, such as the gypsum dunes of the Tularosa desert in New Mexico (Groves, 1958). The surficial accumulations of unconsolidated gypsum mixed with clay and other contaminants—gypsite—may also be considered in this class, although gypsite probably owes its origin in some cases to chemical action of circulating groundwater. This type of deposit is prevalent in lowlands and old creek channels, particularly in areas where there is a bedrock source of gypsum or anhydrite; such deposits are found in the southwestern United States (Groves, 1958) and in British Columbia (Cole, 1930).

An important economic consideration is the depth to which gypsum can exist without changing to anhydrite. MacDonald (1953) has deduced transition curves which depend upon the concentration of sodium chloride in groundwater and, of course, pressure and temperature which are dependent upon depth of burial and physical character of the superincumbent and underlying strata. This matter will be considered in relation to gypsum deposits in Alberta in the section on McMurray (p. 28), and it is sufficient to note here that surface calcium sulfate deposits exposed to normal atmospheric pressures, and temperatures below about 40°C. will exist largely as gypsum.

Utilization of Gypsum

The modern uses of gypsum have been treated ably by Groves (1958) and will be summarized here only as two broad groups—calcined gypsum and raw gypsum.

Calcined Gypsum

The outstanding property of gypsum is its ability to lose about three-quarters of its water on heating to form the hemihydrate $CaSO_4 \cdot \frac{1}{2} H_2O$; when water is added to the hemihydrate a plaster is formed which may be molded to any desired shape and which, on setting, will revert to gypsum. This plaster, which is manufactured by heating gypsum to 150 to 190°C., has the advantage of being chemically inert, and fire resistant. The major uses of calcined gypsum are in the manufacture of plaster of paris, plasterboard, lightweight gypsum blocks, high-temperature lagging and fireproofing, acoustic plaster, asbestos and other insulating boards, molding and casting plaster, dental and surgical plasters, in the dehydration of oil, and in filtering.

Raw Gypsum

In the uncrushed state the alabaster variety of gypsum is used for interior statuary and decorative utilitarian items such as bookends, particularly in Italy and the United Kingdom; most of the gypsum of commerce, however, is used in the crushed state.

Cement and Chemical Industries

The greatest volume is consumed by the portland cement industry; the addition of 2 to 3 per cent gypsum to cement causes retardation of the setting time. A number of chemicals may be manufactured from gypsum, such as sulfuric acid, calcium sulfide, elemental sulfur, and lime.

Agriculture

Agricultural practice has included the use of gypsum since the Greek and Roman periods, and in modern times gypsum has been used successfully as a soil conditioner and reclaimer in many parts of the world, such as the western United States, Egypt, and Russia (Greene, 1948). The action of gypsum upon soil is to cause a change from sodium-clay (which gives rise to high alkalinity and poor soil structure) to a calcium clay, thus

$$\text{Sodium clay} + CaSO_4 = \text{Calcium clay} + Na_2SO_4.$$

An efficient drainage system is necessary to carry away the resultant sodium sulfate. Gypsum may also be added advantageously to irrigation waters that are high in sodium salts (Groves, 1958).

Other Uses

As a filler, gypsum may be used in chemicals, insecticides, drugs, and cotton goods; it may be used as an alternative to kaolin in paper, is a base for many paints, and is used in rubber. Other uses of crushed gypsum are in the glass and ceramic industry, for filtering and refining of oils, purification of water, and in chalks and crayons.

Utilization of Anhydrite

This mineral is commonly thought of as being of no value—perhaps because of its lack of use in North America—but it has wide application in Europe, particularly in the United Kingdom.

Chemical Industries

The major use is in the manufacture of sulfuric acid and cement clinker—an application which is now widespread in the United Kingdom (Groves, 1958)—by roasting anhydrite with coke, sand, and clay; about 1.66 tons of anhydrite yields 1 ton of sulfuric acid and 1 ton of cement clinker.

Another use is in the manufacture of ammonium sulfate fertilizers (Groves, 1958).

Plaster

Anhydrite was used in various types of plasters in the United Kingdom prior to 1939. These plasters require the addition of inorganic salts to accelerate the setting time, but the resulting plaster has great hardness, and a shorter drying time than gypsum plasters. The inclusion of colored anhydrite aggregate in the plaster provides a cheap decorative alternative for tiles, marble, and terrazzo (Groves, 1958).

Other Uses

Finely ground anhydrite may be used instead of gypsum in agriculture; it serves as a filler in roofing felts and paints.

Canadian Occurrences, Production and Utilization of Gypsum and Anhydrite

General

Gypsum deposits occur in all but two (Saskatchewan and Prince Edward Island) of Canadian Provinces, but is produced in six provinces only—Newfoundland, Nova Scotia, New Brunswick, Ontario, Manitoba, and British Columbia. Canada is the world's second-largest producer with an output about half that of the United States (table 1), but is the world's largest exporter. Canadian production, import, and export figures for 1959 are shown in table 2. The major utilization of gypsum in Canada is for the manufacture of plaster, plasterboard and related products, and in the cement industry.

Anhydrite finds no use in Canada at present despite an intensive investigation by Cole and Rogers (1933) into the use of this mineral. These investigators concluded that Canadian anhydrite is admirably suited for the manufacture of sulfuric acid, portland cement, and ammonium sulfate, and also as a retarder in cement. Encouraging results were obtained on tests for its suitability in the manufacture of plasters, whilst it was also found suitable as a filler for certain grades of paper.

A small quantity of anhydrite is mined in Nova Scotia and exported to the United States for use as a fertilizer.

Alberta

The quantity of gypsum utilized in Alberta continues to increase: 65,331 tons in 1956, 67,750 tons in 1957, 78,177 tons in 1958, and 96,276 tons in 1959. The mineral is brought into Alberta from Gypsumville, Manitoba and Windermere, British Columbia to manufacturing plants in Calgary where gypsum lath, tile, wallboard, and plaster are produced.

No gypsum is produced in Alberta, although considerable reserves exist in the Province. Two deposits occur in Triassic strata of the Rocky Mountains, one at Mowitch Creek, the other at Fetherstonhaugh Creek. The remaining deposits occur in rocks of Devonian age: Middle Devonian deposits at Peace Point, a subsurface deposit in the vicinity of McMurray, and smaller, related deposits have been noted along the Salt and Slave Rivers; an Upper Devonian deposit at Head Creek in the Highwood Range of the Rocky Mountains. Occurrences of gypsite have been recorded in some areas, but none of economic importance.

The locations of the deposits are recorded in figure 1 and are described below.

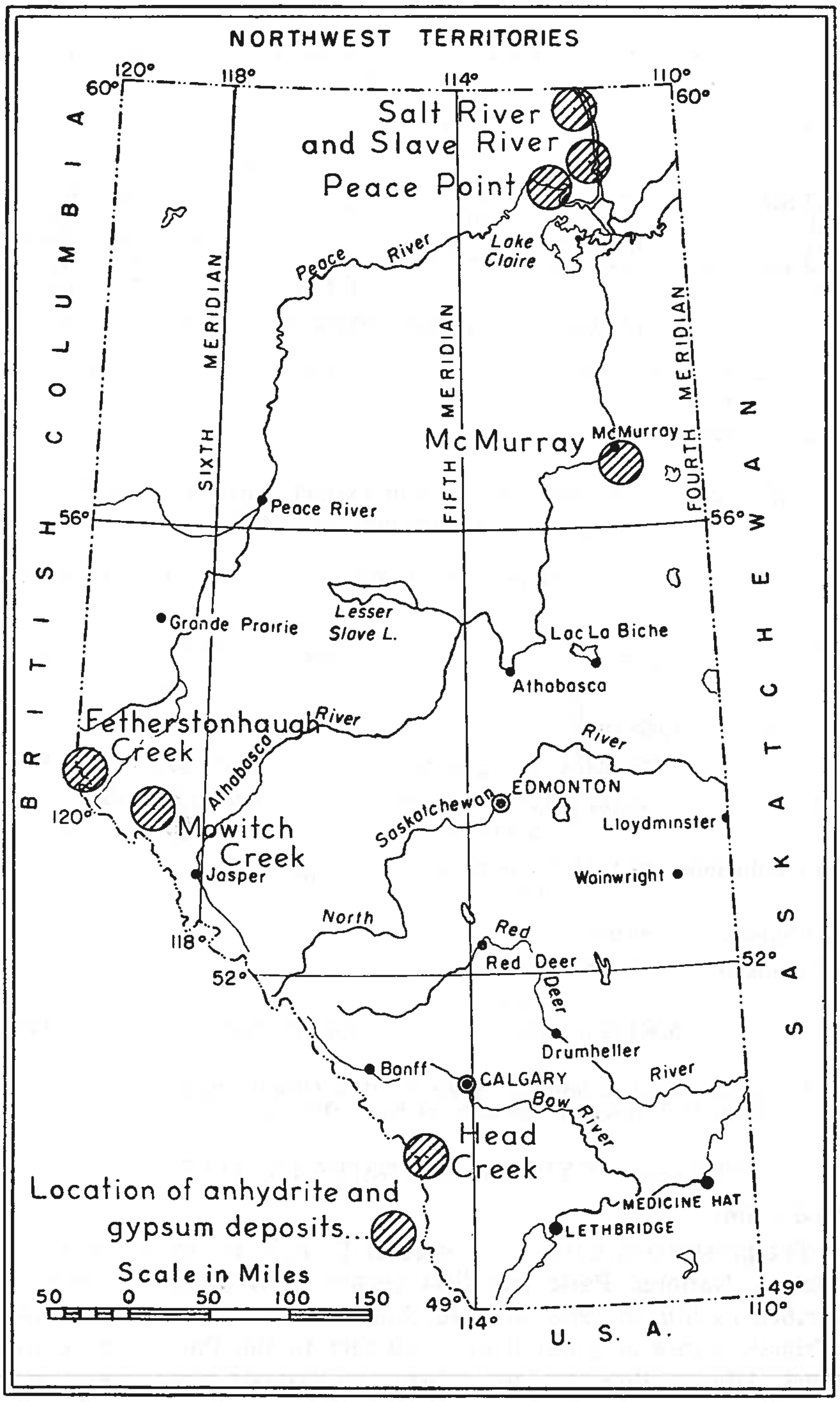


FIGURE 1. Location of gypsum and anhydrite deposits in Alberta

Table 1. Production of gypsum for five leading producers[1]

No data are available for U.S.S.R., Bulgaria, Rumania, China, Korea, Mexico, Cuba, and others.

Country	1938	1946	1950	1953	1956
	SHORT TONS				
United States	2,396,612	5,026,248	7,314,844	7,404,354	9,207,843
Canada[2]	1,008,799	1,810,937	3,666,336	3,841,457	5,192,805
France[2]	1,292,300	1,718,794	2,234,486	2,850,818	3,542,000
United Kingdom[2]	1,092,395	1,687,968	2,206,263	2,674,030	3,334,200
Spain	----	----	2,609,000	1,035,657	1,157,046
Total	7,000,000	12,700,000	20,800,000	21,600,000	27,000,000

(1)—Statistics for Canada from Dominion Bureau of Statistics (1957); other countries from Groves (1958)

(2)—Including anhydrite

Table 2. Production, import, and export statistics, for the Canadian gypsum industry 1959[1]

Production		Imports (all provinces)		Exports (all provinces)	
Province	Crude Gypsum, short tons	Item	short tons	Item	short tons
Nova Scotia	5,093,960				
Ontario	415,088	Crude gypsum	117,930	Crude gypsum	4,848,576
Manitoba	198,104	Plaster of paris wall plaster	17,757	Plaster of paris wall plaster	373
British Columbia	98,104	Wallboard and lath	1,988		
New Brunswick	96,067				
Newfoundland	40,000				
Total	5,941,323	Total	137,575	Total	4,848,949

(1)—From Canadian Mineral Industry—1958 (Preliminary); Dept. of Mines and Technical Surveys, Ottawa

TRIASSIC GYPSUM DEPOSITS IN ALBERTA

Introduction

The presence of gypsum in rocks of Triassic age at Mowitch Creek in Jasper National Park was first recorded by Allan in 1929, and described by him in 1933; in 1940, Allan and Stelck recorded gypsum in Triassic strata at a depth of 5,120 feet in the Pouce Coupé River district, Alberta. Recently, the subsurface Triassic stratigraphy of the Peace River area of Alberta and British Columbia has been described

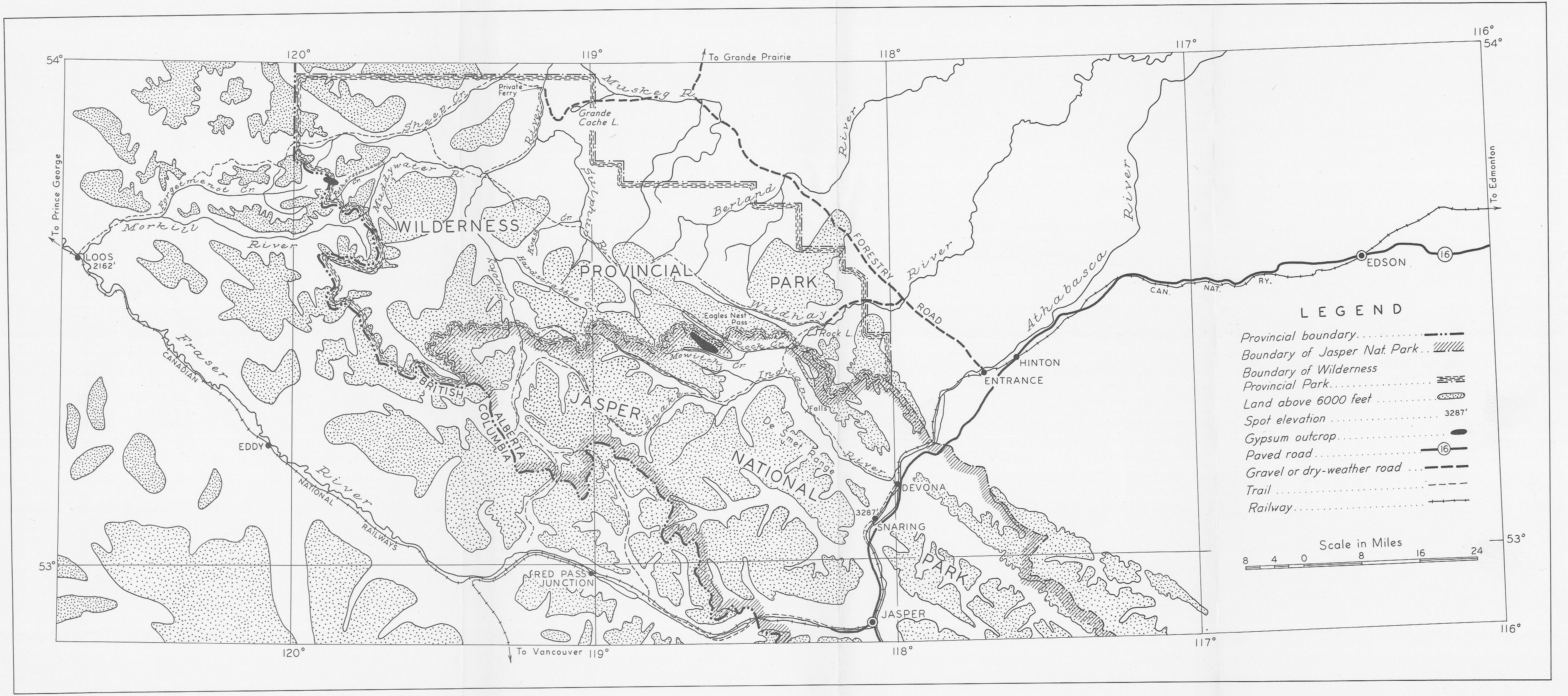


FIGURE 2. Location of the Mowitch Creek and the Fetherstonhaugh Creek Triassic gypsum deposits

by Hunt and Ratcliffe (1959); the evaporitic sequence, which they show to be extensive, is placed in the upper Triassic (Karnian) and assigned as the Charlie Lake formation.

In 1956, G. G. L. Henderson reported to the Research Council the presence of gypsum at the headwaters of Fetherstonhaugh Creek. Henderson was engaged upon a helicopter-survey and was only able to spend one hour examining the deposit to which he tentatively assigned a Paleozoic age. This data was first published by the Research Council (Govett and Byrne, 1958). During August, 1959, the writer travelled by pack-train from Rock Lake, up the Wildhay and Berland Rivers, down the Sulphur River, up Kvass Creek, across the Smoky River, up the Muddywater River, Dry Canyon, and up Sheep Creek to Fetherstonhaugh Creek deposit where one day was spent examining the gypsum deposit and its stratigraphic relations to other strata. The return trip was made by way of Sheep Creek, Dry Canyon, Muddywater River, Smoky River as far as Gustavs Flats, and thence eastwards past Grande Cache Lake and up the Muskeg River to the Entrance-Grande Prairie forestry road (Fig. 2). On the basis of this field work the Fetherstonhaugh Creek deposit is here assigned to the Triassic system.

There are no published geological maps for part of the country travelled by the writer, and therefore observations made en route to and from the Fetherstonhaugh Creek deposit are combined with data from Geological Survey of Canada maps, and are compiled to form the map included in this report (Fig. 3, in pocket). This map is necessarily incomplete and should be regarded only as an indication of the general geologic features. Much of this area has been mapped in much greater detail by some oil companies, but such data remain unpublished.

Fetherstonhaugh Creek

Location and Access

The gypsum beds outcrop in Sec. 20, Tp. 55, R. 13, W. 6th Mer. (about 53°45′ N. and 111°53′W.), forming a small hill some 6,500 to 7,000 feet above sea level, straddling the Continental Divide between the eastward-flowing Sheep and Fetherstonhaugh Creeks, and the westward-flowing Forgetmenot Creek. At the time of the investigation the nearest road in Alberta terminated at the privately owned ferry across the Smoky River at Gustavs Flats (Fig. 2); it is understood that this road now has been extended by mining interests to Sheep Creek. The distance between Fetherstonhaugh Creek and the ferry by horse trail along the Sheep Creek, Muddywater River and Smoky River is 50 to 60 miles. The distance between the ferry and Entrance is 95 to 100 miles. The deposit is about 40 miles northeast of Loos, British Columbia, a stop on the Canadian National Railways line from Prince Rupert to Edmonton.

Stratigraphy and Structure

The gypsum-bearing strata structurally overlie rocks of Permian age, and although the lack of continuous exposures and diagnostic fossils did not allow detailed stratigraphic relationships to be proved, it is considered almost certain that the gypsum is Triassic in age (regional correlations in a later section support this). The succession may be divided into three main units which have a total thickness exceeding 2,100 feet. These are, in descending order, as follows:

Unit 3: limestones, vuggy limestones and dolomites, and gypsum beds. This series passes downwards through vuggy dolomite and banded siltstones into unit 2.

Unit 2: grey, fossiliferous limestones. The fauna consists of poorly preserved brachiopods and crinoid ossicles, algae, ostracods, and echinoids.

Unit 1: dolomitic and siliceous siltstones, some sandstones and shales. The weathering to brown-colored flaggy slabs is characteristic of lower Triassic strata.

No exposures of the immediately overlying beds were located, although it is possible that low-lying ground west of the deposit is underlain by Fernie shales, intervening between the gypsum series and the overthrust Lower Paleozoic (?) strata. The underlying strata consist of massive blue chert beds, and yellow and grey limestones containing nodular chert. The presence of fusulinid Foraminifera (*Schwagerina* sp.) in the limestone is indicative of Permian age (Forbes and McGugan, 1959). The general stratigraphical correlation of this area with other strata in Wilderness Provincial Park is shown in figure 3.

Description of the Gypsum Unit

The major outcrop of gypsum extends about 1,000 yards in a northwesterly direction, and about 180 yards in a northeasterly direction. Sink holes are evident for a distance of 1,000 yards north and a mile to the east of the main outcrop. No complete section of gypsum was found within the area of outcrop, and the section given in table 3 is composite. The succession is complicated by severe contortion, collapse structures, the common occurrence of sink holes, and the presence of limestone scree. It is uncertain whether the scree is derived from underlying beds or has been "let down" from above by solution of the gypsum.

Details of the gypsum series are recorded in table 3. A thickness of 180 feet of gypsum is recorded (excluding a lower 90 feet of strata obscured by sink holes which may or may not represent gypsum). The calculation of this figure involves an assumption of a regular 30 degree dip to the south (as found in underlying strata). It is possible that the total given may include some duplication due to difficulty of tracing any one bed. Despite these reservations, it is probable that a minimum thickness of 50 feet is present, as indicated from sections in sink holes.

Excluding dolomite and limestone of probable evaporitic origin, gypsum is the only evaporite evident in the deposit. No anhydrite was observed in either hand specimen or thin section. The quality and character of the gypsum appears, from field evidence, to be remarkably constant: the major variation is between a massive type and a laminated or banded type. The laminated variety shows individual laminations from 3 to 6 mm. thick which do not normally persist laterally for more than several inches. This type of gypsum gives a distinctive ribbed appearance on weathered surfaces; although a characteristic of the deposit, it was not determined whether it is typical of the deposit as a whole. When examined by the microscope the laminated gypsum is seen to be composed of small crystals having a maximum diameter of 0.025 to 0.035 mm. The crystal margins are ragged, and the texture an intricate "jig-saw" of sutured crystals. There are zones of larger crystals (0.05 to 0.10 mm.) parallel to the direction of lamination in places filling definite cracks in the rock. In some samples the remnants of earlier and larger crystals are discernible. These remnants vary in size up to about 1.5 by 0.3 mm., are oriented parallel to the laminations, have irregular margins, and have been recrystallized into sutured crystals up to about 0.02 mm. diameter which themselves have no definite orientation. All laminated gypsum exhibits strain extinction in thin section, and contains small discrete crystals (0.04 mm. maximum diameter) of carbonate—probably dolomite. Some dolomite is concentrated along cracks in the rock.

Table 3. Description of gypsum (unit 3), Fetherstonhaugh Creek

Thickness, feet	Lithology	Bed Designation and Analysis No. (see table 4)
	Limestone, pale buff, vuggy	
8	Gypsum, obscured by sink holes	
30	Gypsum, white and pink, poorly laminated in part	Bed A, 1, 2, 3
24	Gypsum, massive, white	Bed B, 4
23	No exposures	
30	Gypsum, white and massive; some pink, grey, buff bands; thin shale layers (up to several inches) in places	Bed C, 5, 6, 7, 8
16	Gypsum, white; thin limestone and gypsiferous limestone	Bed D, 9
14	Scree, grey limestone	
125	Limestone, grey, some honeycomb weathering	
90	No exposures, sink holes; gypsum	
250 ± 50	Dolomite, vuggy, passing down into dolomite and siliceous siltstones	
	Underlying formation: limestone of unit 2	
610 ± 50	Total unit 3.	

Table 4. Chemical analyses of gypsum from Fetherstonhaugh Creek Analyzed by H. Wagenbauer, Research Council of Alberta.

Theoretical composition of gypsum: CaO, 32.57%; SO_3, 46.50%; H_2O, 20.93%

Sample No.	Bed[1]	Sample type	COMPOSITION, PER CENT WEIGHT										
			SiO_2	R_2O_3[2]	CaO	MgO	Na_2O	K_2O	SO_3	H_2O^-[3]	L.O.I.[4]	Total	H_2O^+[5]
1	A	Specimen, top of bed; white, massive, with a faint mottle	n.d.[6]	0.27	32.64	0.58	n.d.	0.03	45.61	0.04	21.51	100.68	20.34
2	A	Composite: top 5 ft. of bed; white to pink, massive	0.05	0.18	32.79	1.77	0.02	n.d.	45.10	0.05	21.38	100.34	20.28
3	A	Composite: basal 10 ft. of bed; massive, large scale (0.5-0.75 in.) mosaic mottle	n.d.	0.30	32.74	0.75	0.03	0.02	44.88	0.08	21.84	100.64	19.90
4	B	Specimen, base of bed; white massive, irregular mottle	n.d.	0.30	32.63	0.17	0.03	0.02	46.03	0.05	21.21	100.44	20.53
5	C	Composite: top 2 ft.; white, massive, mosaic mottle	n.d.	0.19	32.84	0.41	0.01	n.d.	45.49	0.05	21.48	100.47	20.51
6	C	Channel: over 1 ft. from base of 5; buff to grey, with brown streaks	0.20	0.54	32.60	0.71	0.02	n.d.	44.60	0.09	21.35	100.11	20.07
7	C	Channel: over 1 ft. from 1 ft. below base of 6; pink with greenish streaks	0.65	0.56	32.52	0.25	0.07	0.10	45.56	0.05	20.79	100.55	20.16
8	C	Specimen: base of bed; white, massive	n.d.	0.20	32.90	0.32	0.02	n.d.	45.81	0.10	20.93	100.28	20.46
9	D	Specimen: top of bed; impure limy gypsum rock band	0.13	0.45	32.53	3.22	0.04	0.05	38.01	0.12	25.67	100.22	16.82

(1)—Refers to beds in table 3
(2)—R_2O_3=Al_2O_3, Fe_2O_3, TiO_2, P_2O_5
(3)—H_2O^- determined at 43° C
(4)—L.O.I. = loss on ignition
(5)—H_2O^+ determined at 200° C
(6)—n.d. = not detected

The macro-features of the massive variety are, in general, unremarkable; at most, the gypsum shows a coarse irregular polygonal mosaic, with a maximum diameter of the polygons being about 22 mm. Some samples show a faint grey mottling against the normal white background. Thin section examination shows large subhedral lath-shaped crystals which have a mottled surface, and are streaked with inclusions of a carbonate (dolomite?) parallel to the long axis of the crystal. The crystals range in size from 0.7 by 0.4 mm. down to small crystals having a diameter of 0.02 mm.; the smaller crystals are packed between the larger. There is no definite orientation of either large or small crystals.

The remarkable uniformity and high quality of the gypsum is confirmed by the chemical analyses which are recorded in table 4. The sulfur trioxide varies only between 44.60 and 46.03 per cent (compared with a theoretical 46.5 per cent for pure gypsum) in eight samples which include picked specimens, composite, and channel samples. The lowest recorded gypsum content (38.01 per cent sulfur trioxide, sample 9, table 4) is a picked specimen of one of the thin limy bands which are present in places.

Mowitch Creek

Location and Access

According to Allan (1933), the Mowitch Creek deposit is situated "towards the north end of township 51 and the south part of township 52, in range 5, west of the 6th meridian"*. The locations of old gypsum claims are shown on figures 2 and 3. The deposit may be readily reached by pack-train from Rock Lake, a distance of 18 miles. Rock Lake is 35 miles by road from Entrance. An alternative route is by pack-train from Devona, a distance of about 35 miles. Both Entrance and Devona are on the main Canadian National Railways transcontinental route.

Stratigraphy and Structure (after Allan, 1933)

The gypsum-bearing rocks are exposed on a ridge between Rock Creek and a branch of Mowitch Creek; the ridge rises to a maximum elevation of 9,000 feet. The strike of the strata is reported to be northwest, with steep dips of 35 to 78 degrees to the west. The rocks have been divided into four units; the succession, as determined at the northern end of the deposit (McDonald Gulch) is given in descending order:

Unit 4: grey, hard marine limestone and standstones; over 25 feet thick.

* It is possible that this location is inaccurate (Mountjoy, pers. comm.).

Unit 3: soft yellow, buff, and pinkish shales, containing some granular gypsum and pinkish shaly limestone; 67 feet in measured section.

Unit 2: red, buff, and yellow shales, interbedded with gypsiferous beds, dolomitic limestone, and cavernous lime-limestones; 165 feet thick.

Unit 1: gypsum series: gypsum beds, with gypsiferous limestones, limestones and shales; the thickest gypsum bed is 12 feet, and the lowest bed in the succession is a cross-bedded sandstone.

Table 5. Description of Gypsum Unit at McDonald Gulch, Mowitch Creek (after Allan, 1933)

Thickness		Lithology	Analysis No. (see table 6)
feet	inches		
2	0	Yellow beds	
1	0	Gypsum, white	
3	5	Red to yellow beds	
2	7	Gypsum, white	
11	8	Gypsum rock, cherty	
9	5	Gypsum rock, white	1, 2, 3
3	7	Gypsum and cherty rock	
7	11	Limestone, yellow lenses; 1 ft. gypsum lens	
12	0	Gypsum and gypsum rock; 1 ft. limestone at base	
9	7	Gypsum rock, dark grey	4, 5
22	11	Gypsum, mottled, cherty	
2	5	Limestone, cherty	
12	8	Gypsum and gypsum rock	
5	0	Gypsum and limestone	
3	0	Gypsum, white saccharoidal	6
1	0	Shale	
3	0	Gypsum, white, banded	7
2	0	Limestone	
12	0	Gypsum, white, shale lenses	8
5	0	Gypsum rock and cherty limestone	
7	0	Gypsum, white	9
9	5	Gypsum, gypsum rock, gypsiferous limestone	
13	0	Limestone, thin bedded; buff to yellow gypsum	
23	0	Limestone, cherty; gypsum	
22	0	Limestone, cherty; 2 ft. gypsum 5 ft. from base	
10	0	Sandstone, buff, massive, cross-bedded	

The overlying beds are said to be Fernie shales, but no data are reported (Allan, 1933) concerning the underlying strata. Moreover, no diagnostic fossils were found.

Description of the Gypsum Unit

The gypsum occurs as beds of pure white gypsum and lenses of gypsum which are interbedded with impure gypsum, shale, colored limestones, siliceous and cherty limestones, and quartzite. The purest gypsum occurs as lenses and the thickest bed of gypsum measured was 12 feet. The deposit in general is characterized by mottled gypsum and fragments of dolomitic limestone. The succession at the northern end of the deposit is recorded in table 5. The general character of the deposit as determined at McDonald Gulch persists two miles to the southeast where the following section was measured in Corser Gulch:

200 feet:	folded and faulted gypsum, interbedded with siliceous limestone
40 feet:	impure cherty gypsum
290 feet:	gypsum (maximum thickness 13 feet), cherty limestone, sandstone, and shale
50 feet:	siliceous dolomitic limestone, thin bedded

Allan reports that some of the gypsum lenses have a dune-like character; he suggests that the gypsum crystals were exposed to aeolian action long enough for a winnowing effect and the formation of gypsum dunes.

Examination of a thin section made from the only remaining specimen of gypsum from Mowitch Creek (McDonald Gulch) collected by Allan shows the rock to be even textured, made up of stubby subhedral crystals of gypsum up to about 0.05 by 0.02 mm. A few larger crystals up to about 0.15 mm. in diameter are present, particularly along cracks. A number of small, euhedral crystals are present; crystal suturing is not conspicuous. There are relatively more dolomite crystals within the rock than in specimens from the Fetherstonhaugh Creek deposit.

Chemical analyses of the gypsum at McDonald Gulch (table 6) show that some pure gypsum is present: seven out of nine samples contain more than 41 per cent sulfur trioxide. The gypsum at the southern end of the deposit (Corser Gulch) shows a marked decline in quality, the sulfur trioxide content in five samples being quoted as 44.58, 1.72, 30.80, 17.30, 36.31 per cent. This southeastward deterioration in the quality of the gypsum is maintained as far as the east side of Cinquefoil Mountain where 1.22 per cent sulfur trioxide is reported in samples (Allan, 1933).

Table 6. Chemical analyses of gypsum from McDonald Gulch, Mowitch Creek (Allan, 1933)

Theoretical composition of gypsum: CaO, 32.57%; SO_3, 46.50%; H_2O, 20.93%

Sample Number[1]	Sample type	Composition, per cent weight					
		SiO_2[2]	$Fe_2O_3 + Al_2O_3$	CaO	MgO	SO_3	L.O.I.[3]
1	Channel sample	1.51	0.49	31.90	1.41	43.28	21.51
2	Average sample, upper part of bed	0.89	0.00	32.22	0.00	46.02	20.90
3	Average sample, lower part of bed	0.82	0.00	32.28	0.00	45.91	20.80
4	Specimen sample	3.10	0.00	32.40	2.31	41.42	20.70
5	Average sample	1.91	0.32	32.02	0.00	45.83	20.00
6	Channel sample	1.51	0.59	32.12	1.10	43.38	21.40
7	Channel sample	3.40	0.81	31.39	5.40	35.71	23.20
8	Specimen sample	2.02	0.90	31.21	0.78	44.34	20.90
9	Channel sample	11.91	0.40	27.80	1.51	38.42	19.90

(1)—Numbers shown refer to beds tabulated in table 5
(2)—Reported as "siliceous residue" in Allan, 1933
(3)—Loss on ignition

Age, Correlations, and Possible Extensions of Triassic Gypsum Deposits

General Stratigraphy

The Triassic rocks of Alberta strike in a general northwesterly direction with a dip (which increases towards the Foothills) to the southwest; the same strike is maintained in the Mountains. In the Foothills and Mountains between Jasper and Banff two members are recognized which together comprise the Spray River formation. The lower, or Sulphur Mountain, member consists of dark-grey, laminated, sandy and calcareous shales, with fine-grained, silty dolomites and limestones. The upper, or Whitehorse, member comprises light-grey limestones, sandy limestones, and sandstones. Warren (1945) states that the Sulphur Mountain member contains a Lower Triassic fauna, whilst the Whitehorse member contains fossils of Middle Traissic age, and he suggests that there may be an unconformity between these two members. The Whitehorse member is overlain, disconformably, by beds of Jurassic age. The Sulphur Mountain member disconformably overlies strata of Permo-Pennsylvanian or Mississippian age.

Northwards from Jasper there is a much expanded Triassic sequence (Hunt and Ratcliffe, 1959) which is shown by the isopach map, figure 4. In the Peace River area of Alberta and British Columbia the lowest units are the Toad and Grayling formations which consist of grey calcareous siltstones with minor sandstones, dark-grey shales and dark limestones. These are believed to be equivalent in age to the

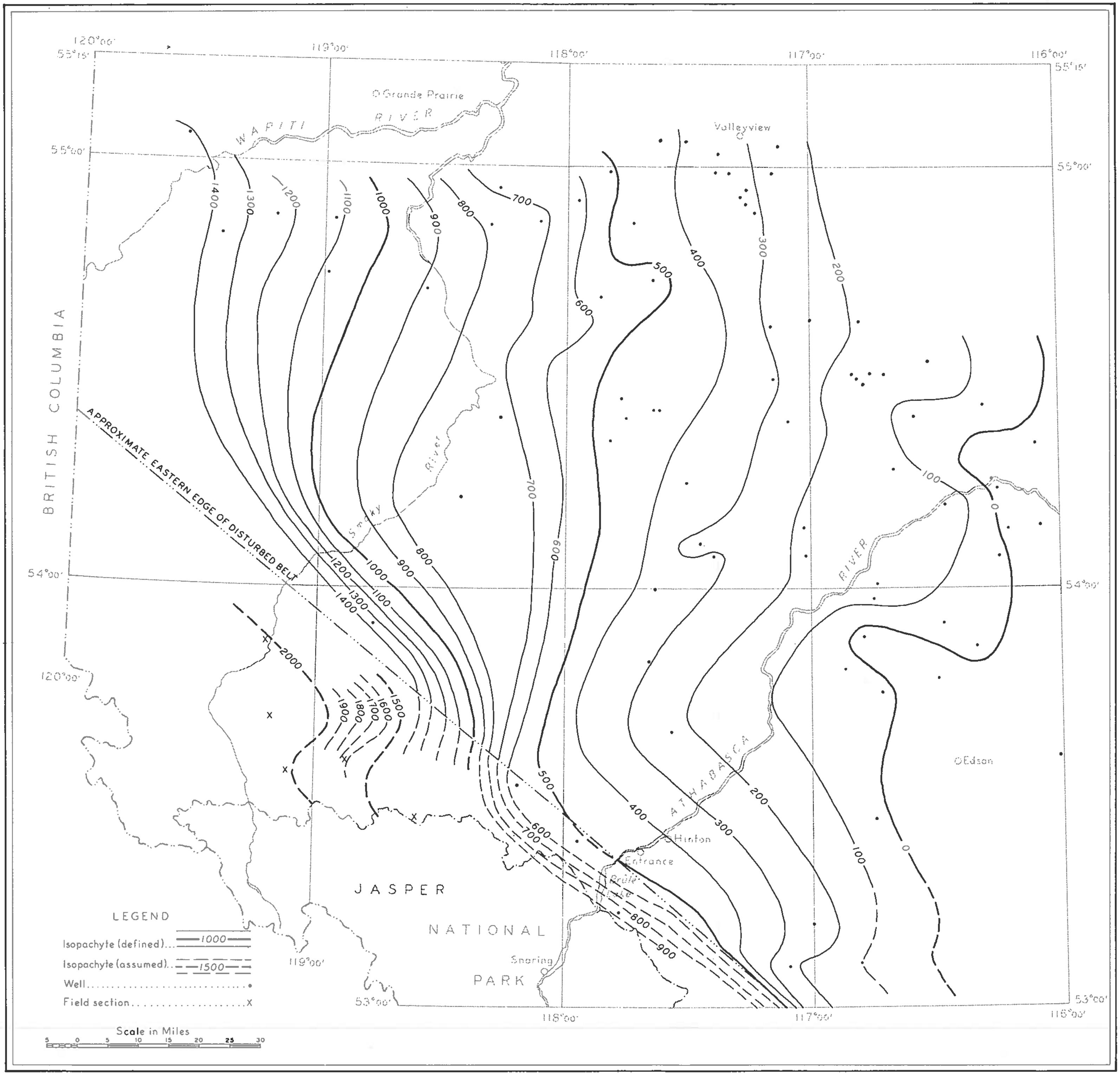


FIGURE 4. Isopachs of the Triassic system in part of western Alberta

Sulphur Mountain and perhaps to at least part of the Whitehorse member (McLearn, 1953; Hunt and Ratcliffe, 1959; Fig. 5). There is probably a break between the (upper) Toad and the (lower) Grayling corresponding to the postulated Sulphur Mountain-Whitehorse hiatus. The upper limit of the Toad-Grayling formations is placed at the Middle Triassic unconformity where there is a sharp break between the siltstones of the Toad-Grayling and the calcareous sandstones of the overlying Halfway formation of the Schooler Creek group; in the western Peace River area this contact is conformable (Hunt and Ratcliffe, 1959).

Conformably overlying the Halfway formation is the Charlie Lake evaporitic formation. This consists of massive anhydrites, red dolomitic siltstones, buff and grey dolomites, interbedded anhydrites and minor amounts of salt. Towards the east there is a facies change to evaporitic "red beds" and towards the west a facies change to marine sandstones (Hunt and Ratcliffe, 1959).

The Charlie Lake formation is overlain conformably by buff, grey and brown, fossiliferous dolomites (Baldonnel formation). In British Columbia, at least, the equivalent beds ("Grey Beds", Fig. 5) are overlain by calcareous shales, siltstones, limestones, and calcareous limestones of the Pardonet formation which, belonging to the Norian stage, represent the youngest Triassic now known in Western Canada.

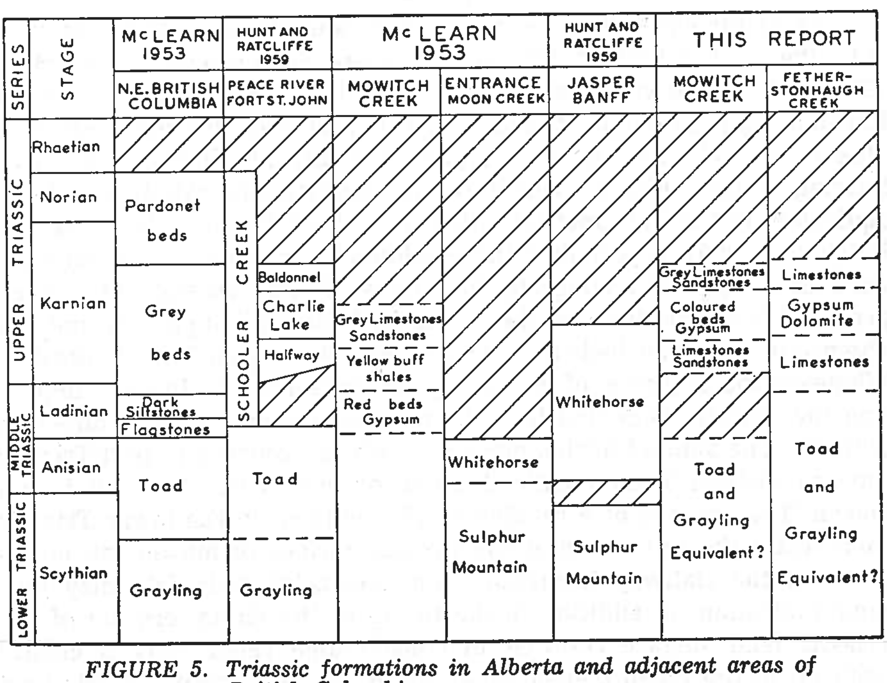


FIGURE 5. Triassic formations in Alberta and adjacent areas of British Columbia

Summary of Historical Geology

Throughout Triassic time there was a long, narrow geosyncline along the site of the present Rocky Mountains and Foothills (McLearn, 1953) with a continental land mass to the east and a volcanic archipelago to the west (Warren and Stelck, 1958). Following a period of erosion during late Pennslyvanian and Permian times, the Triassic sea transgressed eastwards resulting in the onlap of the Toad-Grayling formations against the continental land mass. A westward recession caused the deposition of the Toad being restricted to the western part of the Peace River area (Hunt and Ratcliffe, 1959). Renewed transgression eastwards of the Triassic sea in late Triassic (Karnian) time led to the deposition of the Halfway formation, followed by a rapid change in environment resulting in the evaporitic conditions of Charlie Lake time. The red beds of the latter formation were deposited along the eastern shoreline under arid or semiarid conditions. The elongate evaporitic basin seems to have had its centre near Dawson Creek, the axis trending northwest, passing through the locality of Northern Foothills Agreement Muskeg Number 1 well (situated in Lsd. 15, Sec. 13, Tp. 57, R. 6, W. 6th Mer.): the increase in thickness of evaporites in a northwesterly direction is shown in figure 6. The evaporitic conditions extended westwards until communication with the main Triassic sea was established, and the Baldonnel sediments and, in the west, the Pardonet sediments were deposited.

An hiatus exists between the Triassic and Jurassic strata throughout Alberta. The earliest Jurassic strata are Sinemurian in age (Best, 1958), whilst the youngest Triassic proved to exist in Alberta are of Karnian age, although Parajas (1931) reported the occurrence of *Monotis* cf. *M. subcircularis* (upper Norian) at Vine Creek (near Snaring station, Fig. 2) which would indicate the extension of the equivalent of the Pardonet formation to at least this locality. Hunt and Ratcliffe (1959) report that the Baldonnel formation shows an eastward thinning, which suggests that the westward recession of the sea preceded the deposition of the Pardonet beds—although this and the absence of Pardonet beds may be due entirely to post-Triassic erosion. Whatever the sequence of events, by the beginning of Jurassic deposition the Triassic beds had been tilted in a general westerly direction (Fig. 7). The amount of this movement which occurred in post-Triassic time as distinct from middle Triassic or even early Triassic is not known. The absence of a reliable marker-horizon in the lower Triassic complicates the separation of the various periods of movement; correlation of the Halfway formation from electrolog well data may give some indication. In addition to the tilting of the strata, erosion of the Triassic land surface resulted in considerable relief; this is clearly depicted in the reconstructed contours of the post-upper Triassic land

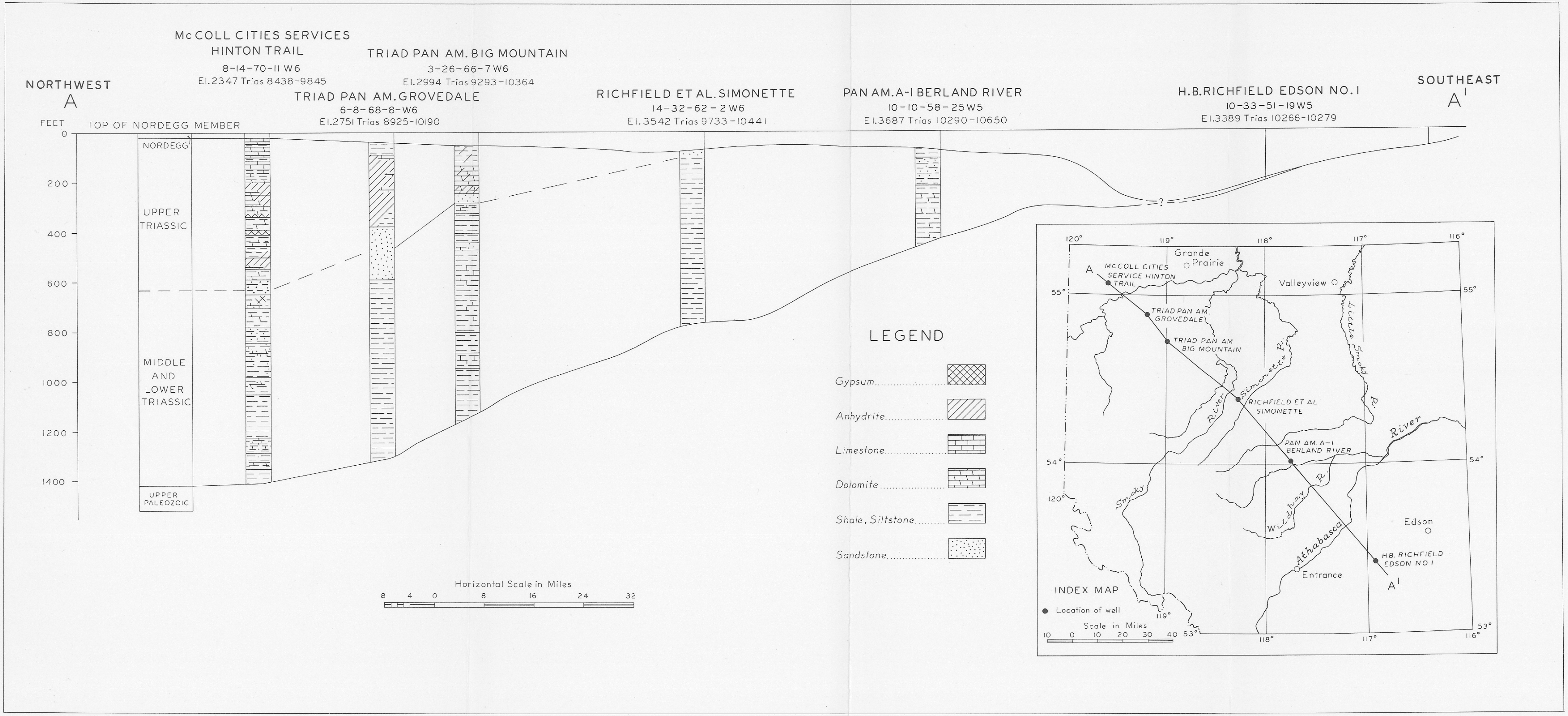


FIGURE 6. Geological cross-section A—A' of Triassic formations

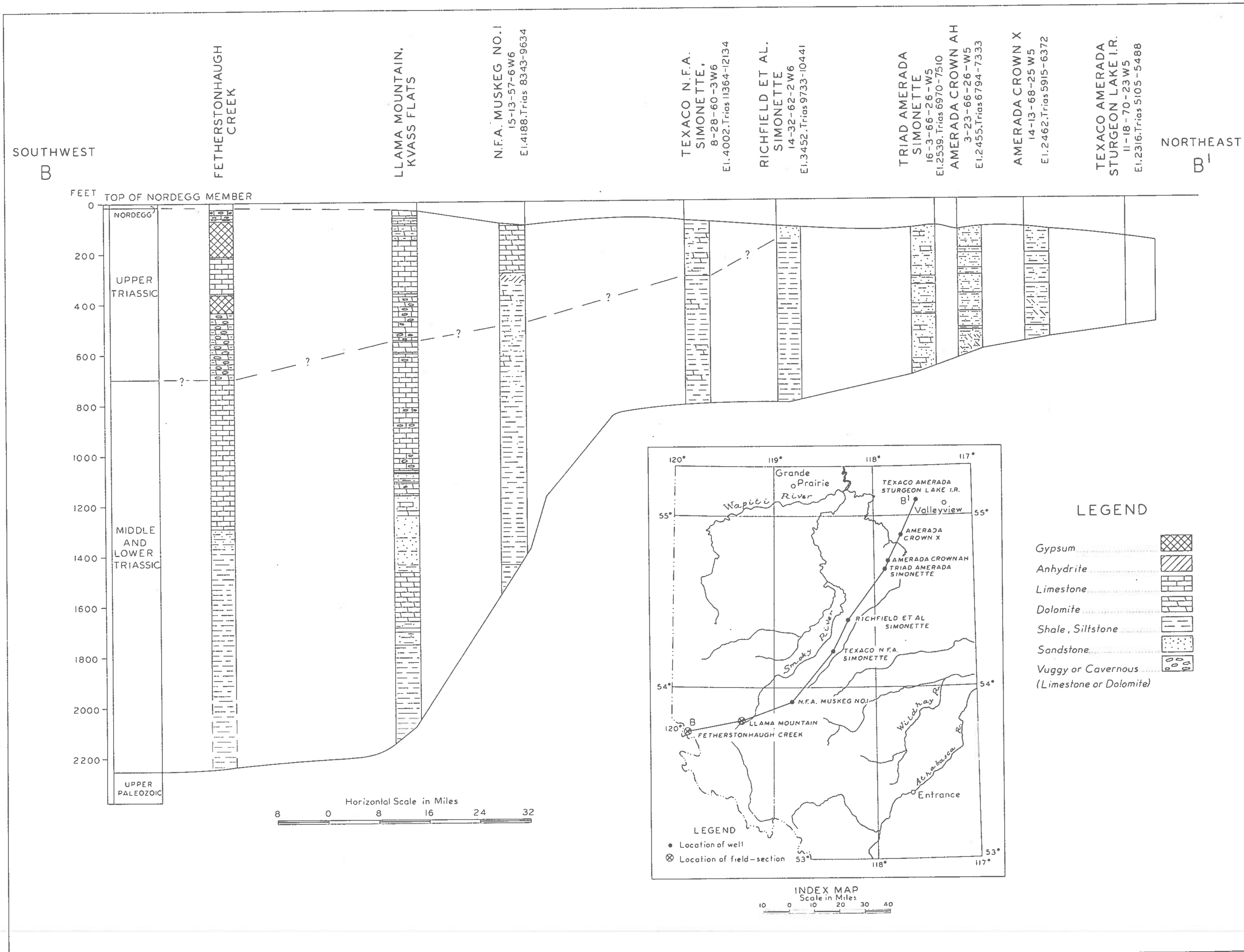


FIGURE 7. Geological cross-section B—B' of Triassic formations

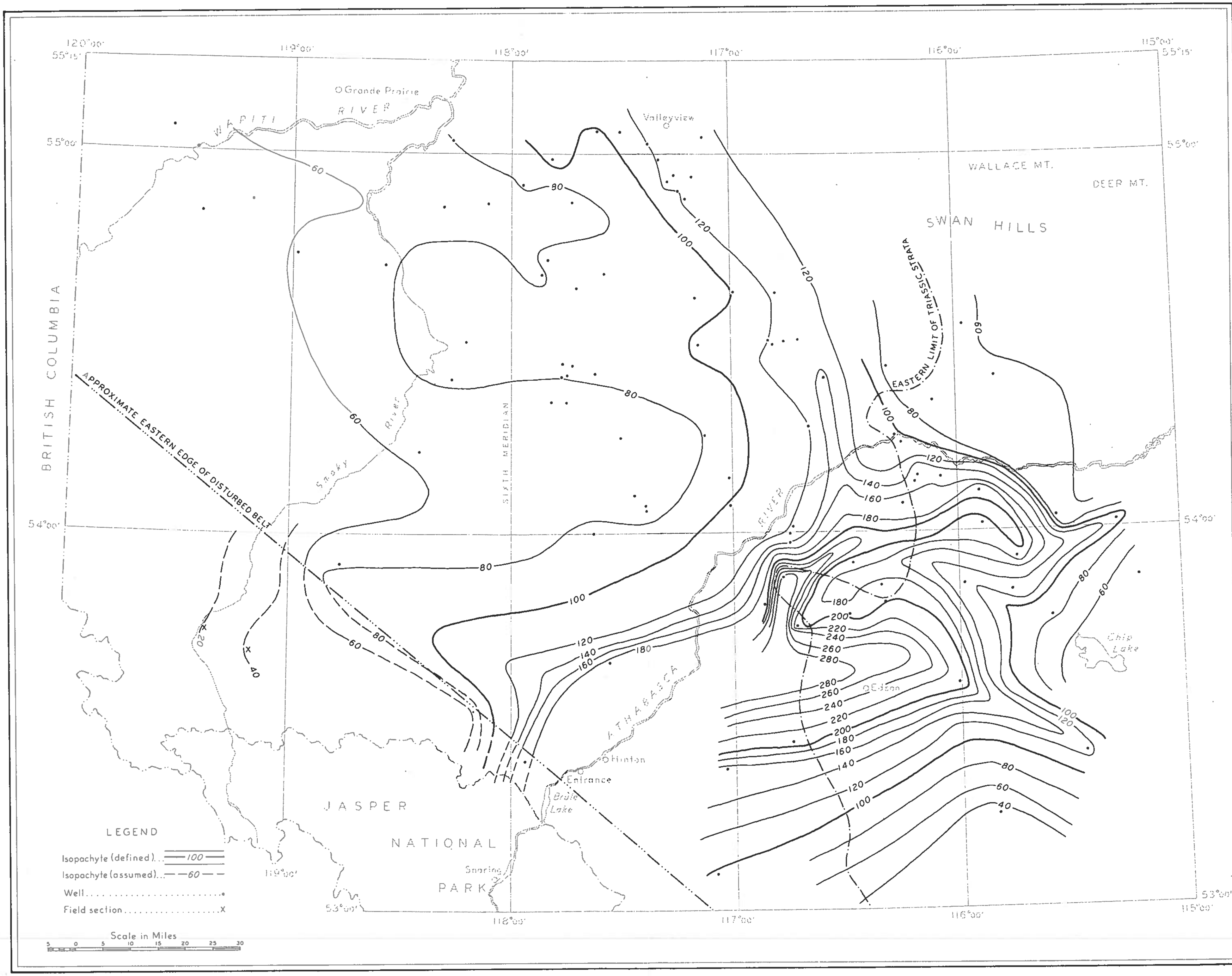


FIGURE 8. Isopachs of the Nordegg member of the Fernie formation, showing topographic features in late Triassic times

surface relative to the datum of top of Nordegg member of the Fernie formation (Fig. 8). The outstanding feature of this land surface is a deep valley in the vicinity of Hinton, with major tributaries in the southeast from Edson, and in the east from Mayerthorpe (southeast of Whitecourt); a smaller, though persistent, tributary enters from the north through Valleyview. The main valley floor at Hinton is at least 200 feet below the general level of the land surface (Triassic) towards the northwest, and most or all of Triassic strata have been removed. Paucity of data precludes accurate location of this valley in the Mountains, although it is possible that it turns southward following approximately the route of the present Athabasca River.

Correlation of the Triassic Gypsum Deposits and Their Possible Extensions

Recent work on the subsurface Triassic strata has placed the evaporitic rocks of northern Alberta in the Upper Trias (Charlie Lake formation, Hunt and Ratcliffe, 1959), and there is no unequivocal evidence to suggest that there was more than one period when evaporite conditions were extant during Triassic time. It is, therefore, reasonable to assume that the Mowitch Creek and Fetherstonhaugh Creek evaporites are also late Triassic in age and that they should be correlated with the Charlie Lake formation. Moreover, as pointed out by McLearn (1953), inasmuch as true evaporitic deposits have not been reported from the Alberta Foothills where the youngest Triassic strata are of the Whitehorse member (Anisian age—early middle Triassic), it is possible that the Mowitch Creek deposits are post-Anisian in age.

Allan, unfortunately, does not give a complete section for the Mowitch Creek area, but examination of some of his field notes for 1929 to 1931 has yielded some additional informaiton. At Snake Indian Falls (Fig. 1) on the Snake Indian River 18 miles southeast from Mowitch Creek, Spray River shales overlie siliceous and cherty limestones, quartzites and limestones of Permo-Pennsylvanian and Mississippian age. In the vicinity of Devona east of the Snake Indian River, easterly dipping, dark-grey shales are overlain by quartzite which he tentatively calls Rocky Mountain (Permo-Pennsylvanian). In the same general locality, Allan records the following sequence, in descending order:

4. Red and buff beds with poor gypsum
3. Cavernous cherty rocks
2. Thin sandstones
1. Cherty quartzite

Bed 1 Allan again considered as possibly being the Rocky Mountain formation; he also notes that the evaporitic part of the section is essentially similar to that on the east side of Cinquefoil Mountain.

Interpreting these data in the light of present knowledge it is suggested that a normal Sulphur Mountain sequence is present, overlain by a sequence which has quartzite as its lowest and uppermost members (it is perhaps the same quartzite; or the one may be Whitehorse, the other Halfway); this in turn is overlain by the evaporitic sequence.

E. W. Best (1958) has cast doubt upon the post-Whitehorse stratigraphic position for the Mowitch Creek gypsum suggested by McLearn (1953). Best recognizes two facies in the Whitehorse member between the North Saskatchewan and Athabasca Rivers: a dolomite-sandstone facies and an evaporitic facies. The latter—which consists of red, yellow, and green shales, and colored argillaceous and brecciated dolomites—is restricted to the more westerly areas and is always developed at the base of the Whitehorse. Moreover, Best suggests a transgression towards the northwest, and a possibility that both the Sulphur Mountain and Whitehorse members become younger towards the west. These views cannot be entirely accepted: to substantiate the claim that the evaporitic sequence lies at the base of the Whitehorse, it is necessary to show a section with Anisian fauna overlying the evaporitic strata, a situation which Best has not reported. Indeed, direct evidence to the contrary is provided by the section on Llama Mountain (Irish, 1954) where an Anisian fauna has been found in essentially sandy strata; the latter are overlain by some 700 feet of cavernous, vuggy, grey and yellow limestones and dolomites which presumably represent an evaporitic sequence (Fig. 7). It is generally accepted that all transgressive phases of the Triassic are towards the east (Hunt and Radcliffe, 1959; Warren and Stelck, 1958); comparison of the contours for the base of the Nordegg (Fig. 8) with isopachs for total Triassic (Fig. 4) similarly belie a westward transgression (see also Fig. 6, 7). Moreover, the prevalence of sandy facies towards the east suggests an eastern shoreline (Fig. 6, 7; Hunt and Ratcliffe, 1959). To accept Best's hypothesis involves postulating either two entirely separate periods of evaporitic conditions, one in the Lower Triassic in the south, the other in the Upper Triassic in the north; or that the evaporitic strata are diachronous from Lower Triassic to Upper Triassic having an onlap relationship south to north. There is no evidence for either of these alternatives.

Best has also thrown doubt upon the identification of *Monotis* cf. *M. subcircularis* at Vine Creek (Parajas, 1931). There is some justification for this: at the east end of Cinquefoil Mountain Jurassic strata rest directly upon the gypsum series; if Norian beds exist at Vine Creek and if a late Triassic age be permitted for the gypsum series, it is necessary to assume that within a distance of about three miles there is a sufficient expansion of the Triassic sequence to accommodate the remainder of the Charlie Lake equivalent, the Baldonnel equivalent, and at least part of the Pardonet equivalent. This is not impossible, for the actual thickness may not be more than 100 feet and, as is clearly shown in figure 8, the pre-Jurassic topography had sufficient relief in places to accommodate differences of this magnitude within short distances.

The correlations of McLearn (1953), Hunt and Ratcliffe (1959) and the writer are combined in figure 5. McLearn's placing of the Mowitch Creek deposit in the upper Middle Triassic (Ladinian) corresponds with Allan's (1943) correlation with the Schooler Creek group. It is believed that there is sufficient evidence to correlate tentatively the evaporitic sequences in the Rocky Mountains with the Upper Triassic Charlie Lake formation (Karnian) of the Peace River area. A thorough examination of the strata at Vine Creek, near Devona, and on Cinquefoil Mountain, would probably contribute much to the classification of the Trias north of Jasper.

It is logical to assume that the Fetherstonhaugh Creek deposit is of essentially the same age as that at Mowitch Creek, that is, late Triassic. The gypsum unit at Fetherstonhaugh Creek overlies at least 1,300 feet of typical Lower and Middle Triassic strata; it lies only 21 miles west of the Llama Mountain section where evaporitic-type rocks overlie Middle Triassic strata (see Fig. 7 for correlation), although it should be noted that there are two major thrusts between these localities.

No other gypsum deposits were located within the field-area, although many sections exhibit evaporitic-type sediments. In addition to the Llama Mountain section, the upper part of the Triassic strata (which exceeds 2,000 feet in thickness) at a small creek tributary to Kvass Creek in Sec. 26, Tp. 54, R. 9, W. 6th Mer. is characterized by cavernous and vuggy limestones and dolomites. Along the east bank of the Sulphur River in Tps. 53, 54, R. 7 contorted and cavernous yellow silty dolomites, and rotten pink dolomites are present in the Triassic succession, whilst at the head of the Sulphur River, underlying overthrust Cambrian quartzites, there are white, grey, buff, and yellow limestones, cavernous limestones, and crossbedded sandstones which overlie Sulphur Mountain-type siltstones and shales. At the head of the (North) Berland River the uppermost Triassic exposed consist of pink, yellow, and brown crumbly siltstones and dolomites. Northeast of Mowitch Creek in the Moon Creek area, Irish (1947) records the highest strata as Whitehorse (Anisian): the absence of higher strata may be due to non-deposition or to post-Triassic erosion, or a combination of both. In the N.F.A. Muskeg No. 1 well (Lsd. 15, Sec. 13, Tp. 57,

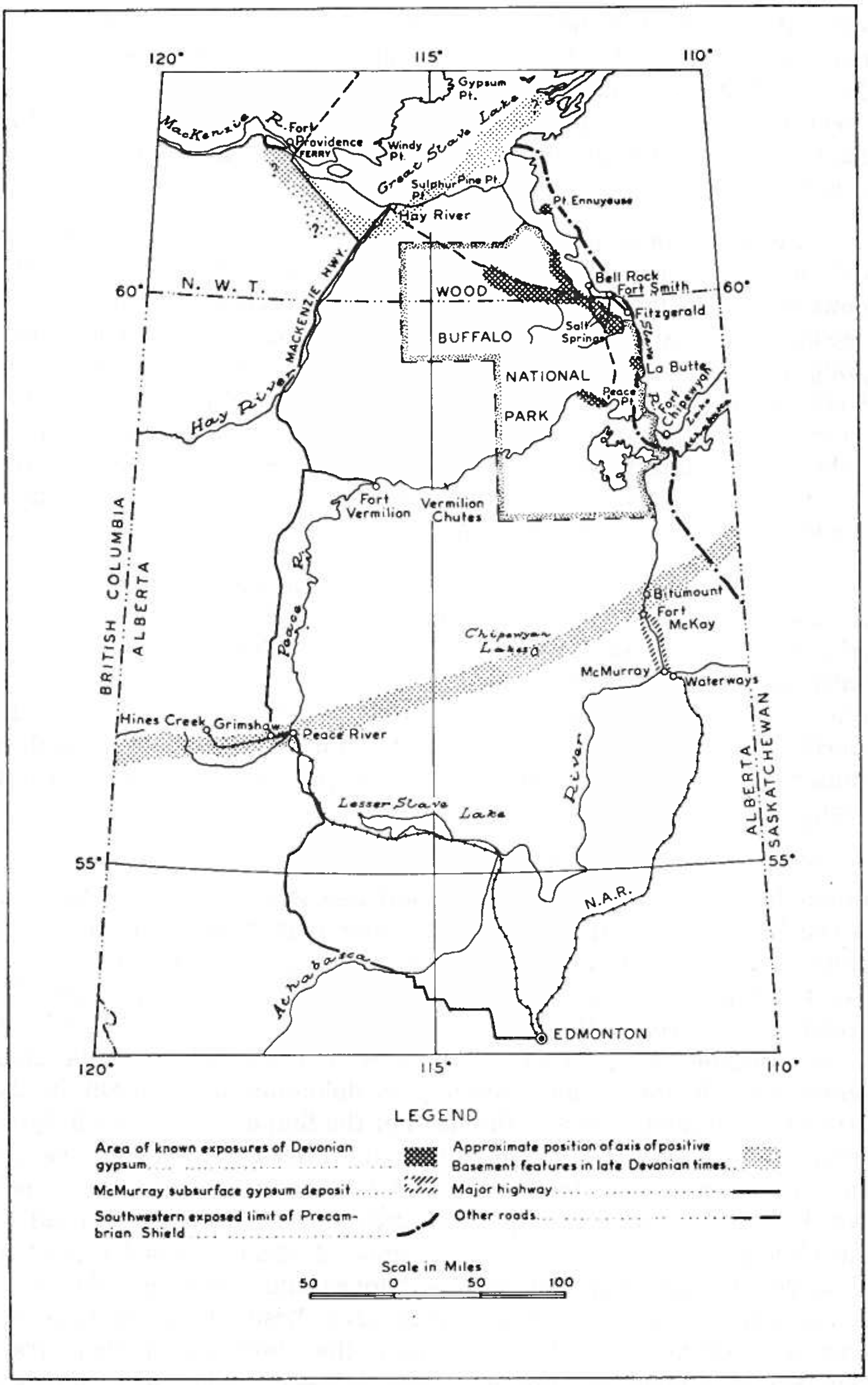


FIGURE 9. Location of gypsum deposits of Middle Devonian age in northern Alberta

R. 6, W. 6th Mer.) there is a trace of anhydrite about 1,100 feet above the base of the Triassic (Fig. 7).

Colored beds are generally interpreted as evidence of shoreline deposition under arid or semiarid conditions. On this basis, the Snake Indian River area, Mowitch Creek, head of the Berland River, and Sulphur River areas represent a shoreline or near-shoreline margin of the evaporite deposits. The evidence of wind-blown gypsum at Mowitch Creek overlain by red beds suggests a migration (westwards, see p. 22) of the evaporitic basin. The Fetherstonhaugh Creek deposit, from the purity and thickness of the gypsum, and the apparent absence of red beds, seems to have been farther removed from shoreline conditions; this deposit may be younger than that at Mowitch Creek because of the westward migration of the evaporitic basin. In fact, the Fetherstonhaugh Creek deposit may bear an offlap relationship to the Mowitch Creek deposit.

Other Triassic gypsum deposits should be sought southwest of a line trending northwest through Mowitch Creek, for this clearly represents the approximate location of the shoreline of the evaporitic basin. In particular, the westernmost Triassic beds east of the equivalent of the Pyramid Mountain fault (Fig. 3) are likely to prove most fruitful. It should be noted that Allan (1933) reported (secondhand) that gypsum occurs south and west of the Snake Indian River at the north end of the De Smet Range (Fig. 2).

MIDDLE DEVONIAN GYPSUM AND ANHYDRITE DEPOSITS IN ALBERTA

Introduction

Surface exposures of gypsum in northern Alberta were first described in detail by Camsell (1917), and the most important of these—the very large deposit exposed along the Peace River in the vicinity of Peace Point—was thoroughly investigated by Cameron (1930), who published many sections and analyses. In 1921 Allan published a detailed log of the Alberta Government Salt Well No. 1, drilled in the vicinity of McMurray, which showed gypsum beds. These surface and subsurface deposits have been discussed frequently in the intervening years (Allan, 1929, 1943; Cameron, 1922, 1930) and great debate has centred on their respective ages and correlations.

In this section the subsurface deposits of the McMurray area, and the surface deposits at Peace Point, and along the Little Buffalo, Salt and Slave Rivers are described and correlated with the Elk Point evaporitic strata of central Alberta. Some additional field data obtained by M. A. Carrigy and L. B. Halferdahl is incorporated in the section on the Peace Point deposit.

McMurray

Location and Access

The area discussed as a potential source of gypsum is bounded by latitudes 56°30′ and 58°00′ north, and longitudes 110°30′ and 112°00′ west (Fig. 9). A single-line railway from Edmonton has its terminal at Waterways, three miles southeast of McMurray; the freight depot lies between these two settlements on the Clearwater River, and access northwards from here is afforded by barge along the Athabasca River. The railway is operative throughout the year, but the shipping season extends only from about April 25 to October 20.

Stratigraphy and Structure

Gypsum in the McMurray area occurs within an evaporitic sequence of Middle Devonian age (Carrigy, 1959). These strata unconformably overlie the Precambrian Basement, and are paraconformably overlain by rocks of Late Devonian age (Beaverhill Lake formation and the Woodbend group); the latter are overlain unconformably by Lower Cretaceous strata. Erosion along the valleys of the Clearwater and Athabasca Rivers has exposed the Devonian rocks; Cretaceous rocks have also been eroded from a wide area farther north, but a thin mantle of glacial drift covers most of the area and there are few outcrops.

The stratigraphy of this area has been described by Carrigy (1959), and a table of the Middle Devonian formations is given in descending order:

Formation	*Lithology*
Slave Point equivalent	limestone and dolomite
Dawson Bay equivalent	reddish siltstone with interbeds of dolomite and anhydrite
Prairie evaporite	halite, anhydrite, gypsum, and dolomite
Methy (including Elm Point equivalent)	buff dolomite, reefal, argillaceous; evaporitic and fossiliferous limestones
Ashern equivalent	green dolomitic claystone, and beds of anhydrite
Meadow Lake equivalent	red claystone, siltstones, and sandstones; arkose at base

Carrigy (1959) denoted the Elk Point group as including Prairie evaporite, Methy, and Ashern equivalent formations, though he included the Dawson Bay in the Elk Point group in his graphical correlations. For descriptive purposes in this section, the Dawson Bay formation equivalent is included in the Elk Point group (see p. 38; also appendix B). The Dawson Bay is in many places inseparable from the Prairie evaporite, and together these two formations constitute the major evaporitic sequence in this area.

The Devonian strata are inclined gently towards the southwest. The beds above the evaporites are, in places, more disturbed than those below, a circumstance which has been ascribed to solution of the evaporites (Carrigy, 1959). Other domes and depressions have been variously explained as being due to volume changes accompanying hydration of anhydrite, or to local thickening of the salt (Carrigy, 1959). A northwest-trending fault having a downthrow to the southwest of 200 feet has been postulated by Carrigy (1959) to explain an otherwise anomalous outcrop of Beaverhill Lake (Calumet member) limestone along the Athabasca River in Sec. 30, Tp. 97, R. 10, W. 4th Mer.

Description of the Gypsum

The chief characteristic of the gypsum beds is their apparent lack of uniformity, and the difficulty in correlating any one bed between drill holes. This situation is due in part to the variable amount of anhydrite present, and to the presence, in the west and south, of halite beds. Thus 130 feet of gypsum are recorded in the Athabasca Oils Limited No. 1 well between Fort MacKay and Bitumount; about 90 feet of dominantly anhydrite with minor gypsum in the Bear Vampire No. 2 well; 210 feet of anhydrite and gypsum, anhydrite, and including some 30 feet of dolomite and anhydrite in Bear Rodeo No. 2 well; 270 feet of anhydrite interbedded with halite, shale, dolomite and limestone in Bear Rodeo No. 1; 180 feet of gypsum, with lesser amounts of anhydrite, with 30 feet of dolomite and shale in the Alberta Government Salt Well No. 2; and 150 feet of anhydrite, some gypsum, with 20 feet of shale in Bear Westmount No. 1 well. This northwest to southeast section is shown in greater detail in figure 10.

A west to east section from Bear Biltmore No. 1 well, through Bear Vampire No. 1 well and Alberta Government Salt Well No. 2 to Bear Westmount No. 2 well is shown in figure 11. Two main features are apparent in this section: firstly, the evaporitic sequence thickens rapidly in a westerly direction and is probably absent in the east in Weymarn No. 1 well; secondly, the salt beds are underlain and overlain by gypsum or anhydrite, and halite apparently passes eastward into anhydrite or gypsum.

Figure 12 shows a section between Alberta Government Salt Well No. 1, Industrial Minerals Nos. 4, 3, and 1 wells, and Alberta Government Salt Well No. 2. In this section it is clear that there is considerable variation in the character of the gypsum beds within very short distances; thus, compare the sections between Industrial Minerals No. 4, and Industrial Minerals No. 1 which lies only 447 feet to the southeast; and the section in Industrial Minerals No. 3 which lies 560 feet southwest of No. 1 and 580 feet south of No. 4.

There are, unfortunately, few chemical analyses available for the gypsum at McMurray. Analyses for Alberta Government Salt Well No. 1 were published by Allan (1921) and are reproduced as table 8 here. Analyses for strata of Bear Westmount No. 2 and Bear Vampire No. 2 wells are presented in tables 7 and 9. Chip samples from the cores of these latter two wells were taken at intervals of one to three inches, and combined as a single sample over intervals varying from 5 to 30 feet. Paucity of data limits any general conclusions, beyond the fact that the purity of the calcium sulfate deteriorates eastwards and improves northwards from Alberta Government Salt Well No. 1.

Effect of Depth of Burial on Gypsum-Anhydrite Inversion

It is not the concern of this report to discuss whether the calcium sulfate was deposited as gypsum or anhydrite; subsequent to deposition the evaporites were almost certainly buried beneath a sufficient thickness of younger strata to convert any gypsum present to anhydrite. Therefore, any gypsum now present has resulted from hydration of anhydrite during comparatively recent geologic time. Inasmuch as any development of this gypsum deposit must be by mining methods, it is of interest to determine at what depth gypsum is the stable form.

On the basis of temperature, pressure, and salinity data published by MacDonald (1953) and using a temperature gradient determined by Beach (1952), a graph has been constructed showing the relationship of the gypsum-anhydrite inversion point to depth of burial and degree of saturation of groundwater with sodium chloride (Fig. 13). Thus, in the presence of saturated sodium chloride, gypsum is stable only to a depth of 700 feet, whereas in the presence of pure water it may exist to a depth of about 2,900 feet. Obviously, under natural conditions, some gypsum may be expected below these two transition depths, and some anhydrite above them. At McMurray gypsum does not occur in significant amounts below 700 feet, although it is present in thin bands and lenses to a recorded depth of 1,915 feet (in Bear Vampire No. 1 Well); anhydrite is recorded in most well logs.

Chemical analyses for the evaporites in Bear Vampire No. 2 well (table 7) show marked transition from gypsum to anhydrite at a depth of 545 to 555 feet; in Alberta Government Salt Well No. 1, where the shallowest calcium sulfate bed is at a depth of 534 feet, the calcium sulfate is present almost entirely as anhydrite (table 8). In Bear Westmount No. 2 well, where the deepest bed analyzed lies at a depth of

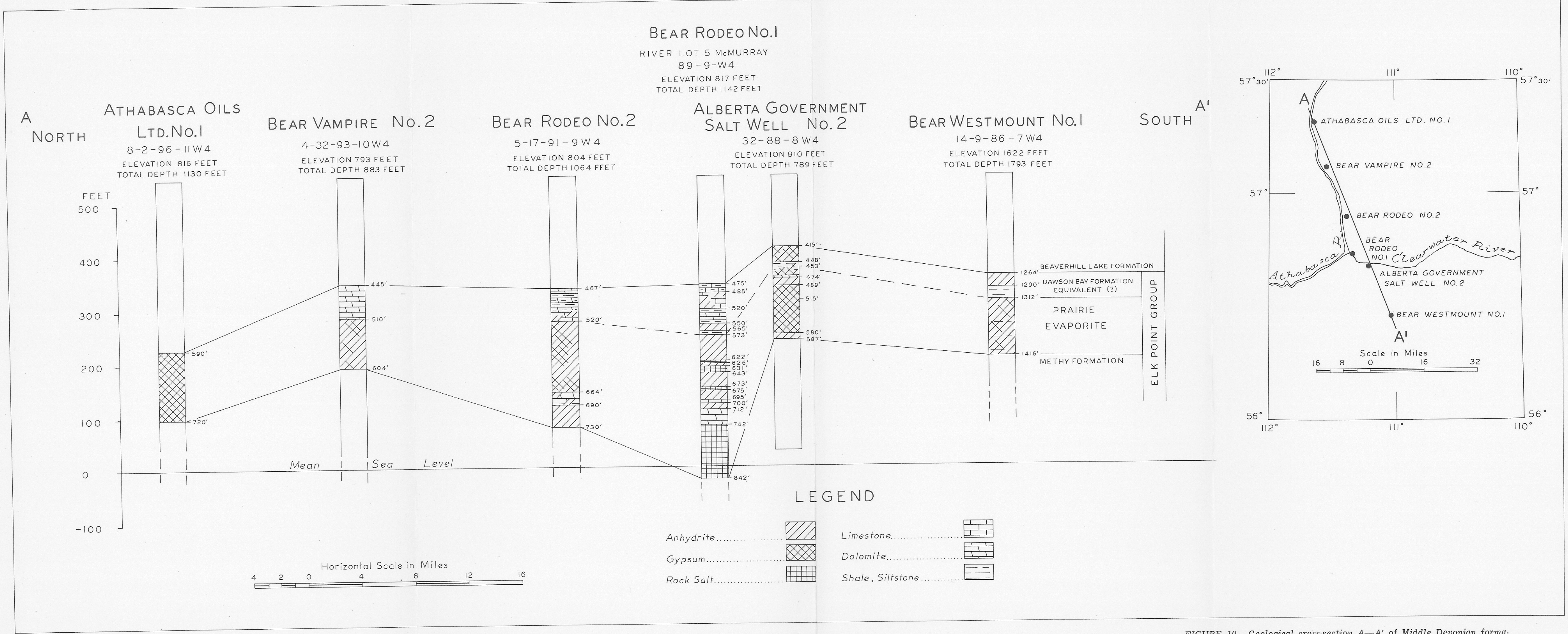


FIGURE 10. *Geological cross-section A—A' of Middle Devonian formations (after Carrigy, 1959)*

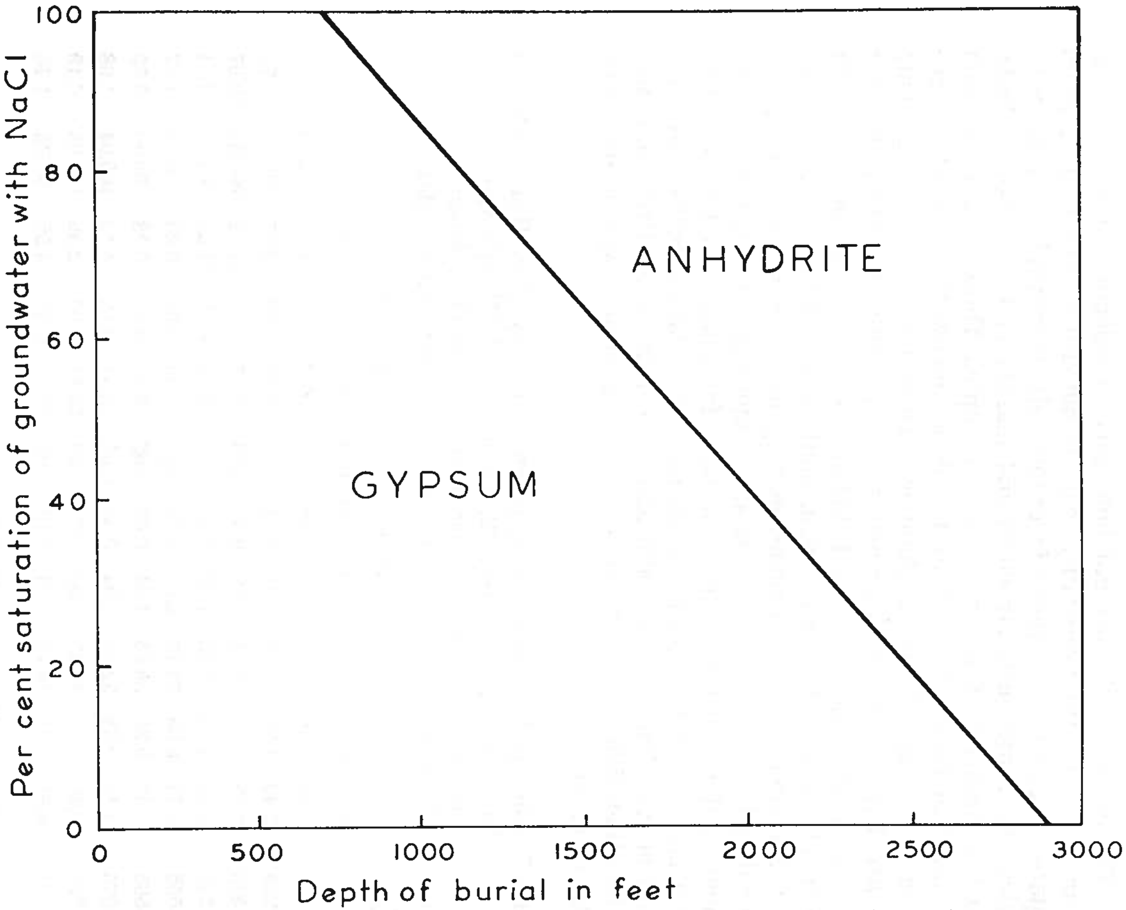


FIGURE 13. Gypsum-anhydrite stability relationships (after MacDonald, 1953; Beach, 1952); temperature gradient is assumed to be 20°F. per 1000 feet; pressure gradient is assumed to be 71.4 bars per 1000 feet; it is further assumed that rock pressure is acting on solid phases, and hydrostatic pressure on aqueous phases.

527 feet, calcium sulfate is present predominantly in the form of gypsum to a depth of 477 feet, below which anhydrite becomes increasingly important (table 9).

The nearer to the present land surface calcium sulfate minerals occur, the better the probability that the mineral is present as gypsum —quite apart from the more favorable mining conditions. Figure 14 depicts the conjectured structure and margin of the evaporitic beds, also the contours of the present topography. These data have been combined in figure 15 to show the depth below the present surface at which the top of the Elk Point evaporites may be expected: along the Athabasca River the evaporites are generally less than 600 feet (in places less than 500 feet) below the valley bottom, except in the vicinity of the Bitumount basin, south of the fault. Eastwards along the Clearwater River the evaporites may be less than 400 feet below the valley bottom, although it must be remembered that they become thinner in this direction. If the postulated fault has indeed reality, then there are wide areas to the northeast where the evaporites are at a depth of less than 400 feet, and along the Athabasca River they may be less than 200 feet from the surface. The subject will be discussed further (p. 43).

Table 7. Chemical analyses of gypsum and anhydrite, Bear Vampire No. 2 Well Lsd. 4, Sec. 32, Tp. 93, R. 10, W. 4th Mer.

Analyzed by H. Wagenbauer, Research Council of Alberta

Theoretical composition of gypsum: CaO, 32.57%; SO_3, 46.50%; H_2O, 20.93%

Depth, feet	Composition, per cent weight										
	SiO_2	R_2O_3 (1)	CaO	MgO	Na_2O	K_2O	SO_3	H_2O^- (2)	L.O.I. (3)	Total	H_2O^+ (4)
510-520	1.06	0.53	32.00	0.93	0.02	0.02	42.96	0.90	21.85	99.44	19.44
520-525	2.42	1.88	32.04	1.81	0.06	0.03	40.36	0.09	23.27	99.96	17.71
525-535	2.05	1.02	31.45	1.18	0.06	0.06	42.67	0.11	21.91	100.51	18.67
535-545	2.89	1.45	31.39	1.22	0.07	0.03	40.98	0.12	21.59	99.74	18.14
545-555	1.14	0.69	37.13	0.61	0.04	0.02	50.00	0.09	9.40	99.11	7.67
555-565	1.45	0.36	38.85	4.54	0.06	0.02	28.41	0.08	25.78	99.66	5.73
567-575	1.14	0.23	32.33	2.04	0.06	0.02	52.94	0.16	4.12	100.04	1.08
575-585	0.46	0.11	40.45	1.09	0.06	0.02	55.44	0.06	2.36	100.05	0.19
585-595	0.91	0.24	39.16	1.69	0.10	0.04	52.70	0.09	4.85	99.78	1.48

(1)—R_2O_3 = Al_2O_3, Fe_2O_3, TiO_2, P_2O_5
(2)—H_2O^- determined at 43° C
(3)—L.O.I. = loss on ignition
(4)—H_2O^+ determined at 200°C

Abbreviated log for section analyzed (after Carrigy, 1959)

Depth in feet	Description
510 - 604	Anhydrite, with some gypsum

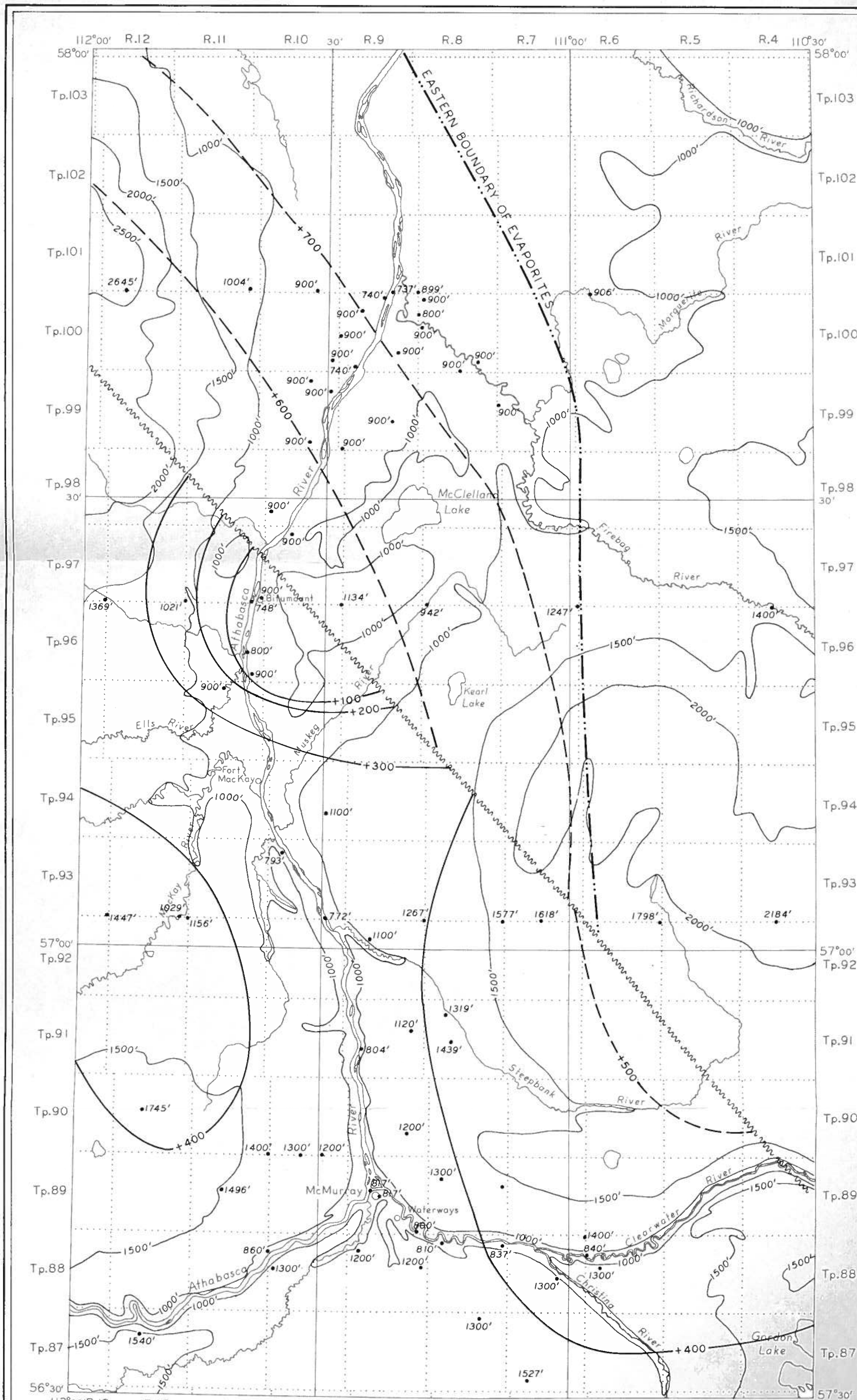
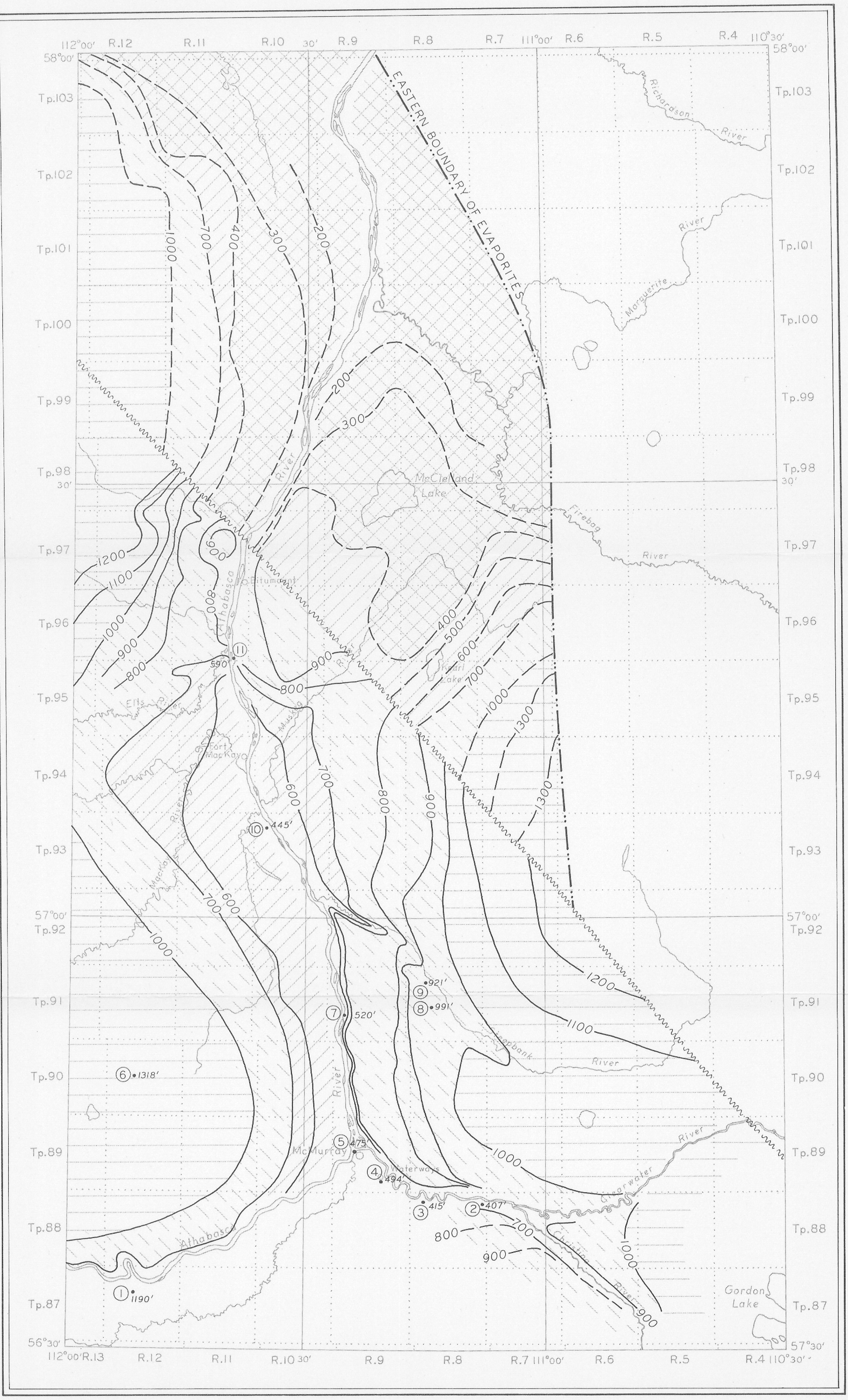


FIGURE 14. *Structure contours on upper surface of Elk Point evaporites (from Carrigy, 1959)*



Key to well names:

1. Bear Vampire No.1
2. Bear Westmount No.2
3. Alberta Government Salt Well No.2
4. Industrial Minerals Ltd. Salt Well No.1
5. Bear Rodeo No.1
6. Amerada Mink Lake S.T.H. No.4
7. Bear Rodeo No.2
8. Baysel Steepbank 13-16
9. Baysel Steepbank 15-29
10. Bear Vampire No.2
11. Athabasca Oils Ltd. No.1

LEGEND

*Isopachyte showing thickness from surface to top of Elk Point evaporites .... ——700——

Isopachyte, assumed .... — —600— —

*Isopachytes have not been drawn along the major river valleys

Evaporites more than 1000 feet below surface ....

Evaporites 700-1000 feet below surface ....

Evaporites 400-700 feet below surface ....

Evaporites less than 400 feet below surface ....

Fault, assumed ....

Depth of top of Elk Point evaporites in selected wells .... 590′•

Scale in Miles

5 0 5 10 15 20

FIGURE 15. Isopachs of total thickness of rock strata and superficial material above the Elk Point evaporites

Table 8. Chemical analyses of gypsum and anhydrite, Alberta Government Salt Well No. 1, Lot 8, McMurray townsite, Tp. 89, R. 9, W. 4th Mer. (Allan, 1921)

Theoretical composition of gypsum: CaO, 32.57%; SO_3, 46.50%; H_2O, 20.93%

Depth, feet	Composition, per cent weight					
	Siliceous residue	Al_2O_3+ Fe_2O_3	CaO	MgO	SO_3	L.O.I.(1)
534	3.01(2)		32.81	5.14	58.11	2.72
546	38.53(3)	11.20	17.36	6.66	0.63	25.62
564	2.02		33.88	0.98	48.62	14.01
662	4.22		37.42	1.25	54.05	0.72
664.5	5.62	5.98	34.58	0.00	49.07	4.01
665	5.20		35.27	0.24	49.16	9.02
666	1.02	4.02	29.46	0.00	41.88	2.78
670-673	7.72		33.00	0.09	47.09	7.30
671	4.72		35.84	0.46	52.46	1.24
676	2.01		35.56	6.66	50.67	4.52
681	4.02		37.04	0.12	54.62	3.01
684			40.78	0.37	58.34	0.42
685.5	1.38		40.00	0.09	57.44	1.07

(1)—Loss on ignition
(2)—Includes 1.99% NaCl
(3)—34.20% SiO_2, 4.33% alkali

Abbreviated log for section analyzed (after Carrigy, 1959)

Depth in feet	Description
534 - 537	Anhydrite
537 - 571	Dolomite, gypsum, anhydrite, some salt
571 - 586	Anhydrite, small amount of dolomite
586 - 590	Dolomite, some anhydrite
590 - 625	Anhydrite, some dolomite and salty dolomite
625 - 648	Anhydrite, dolomite, salt
648 - 662	Rock salt
662 - 663	Anhydrite, dolomite and salt
663 - 666	Anhydrite and dolomite
666 - 675	Anhydrite, salt, dolomite
675 - 680	Anhydrite, dolomitic
680 - 685	Anhydrite, dolomitic, some salt

Table 9. Chemical analyses of gypsum and anhydrite, Bear Westmount No. 2 Well, Lsd. 9, Sec. 36, Tp. 88, R. 8, W. 4th Mer.

Analyzed by H. Wagenbauer, Research Council of Alberta

Theoretical composition of gypsum: CaO, 32.57%; SO_3, 46.50%; H_2O, 20.93%

Depth, feet	Composition, per cent weight										
	SiO_2	R_2O_3(1)	CaO	MgO	Na_2O	K_2O	SO_3	H_2O^-(2)	L.O.I.(3)	Total	H_2O^+(4)
418 - 426	11.52	2.22	28.27	5.72	0.11	0.14	29.30	0.24	21.33	98.85	9.09
449 - 462	12.26	2.30	27.29	4.99	0.10	0.12	28.14	0.20	23.51	99.01	12.47
468 - 477	10.17	1.51	27.90	2.98	0.10	0.08	34.91	0.16	21.51	99.32	15.53
477 - 494	7.44	1.23	31.45	1.86	0.13	0.09	41.78	0.14	15.37	99.55	11.43
494 - 527	6.67	1.40	32.23	1.88	0.10	0.08	45.53	0.24	10.49	99.49	7.51

(1)—R_2O_3=Al_2O_3, TiO_2, P_2O_5
(2)—H_2O^- determined at 43° C.
(3)—L.O.I.=loss on ignition
(4)—H_2O^+ determined at 200°C.

Abbreviated log for section analyzed (after Carrigy, 1959)

Depth in feet	Description
418 - 426	Gypsum, bands of silty claystone
426 - 449	Dolomite, siltstone, claystone
449 - 462	Gypsum, dolomite stringers, some green shale at the top
462 - 468	Dolomite, argillaceous
468 - 477	Gypsum, many shale bands
477 - 494	Gypsum and anhydrite, shaly
494 - 527	Anhydrite, partly altered to gypsum, shaly impurities and dolomitic bands

Peace Point

Location and Access

Gypsum beds outcrop along the Peace River between latitudes 59° 0′ and 59° 12′ north, and between longitudes 112° 15′ and 112° 45′ west; this area lies entirely in Wood Buffalo National Park in townships 116 and 117, ranges 14, 15, and 16, west of the Fourth Meridian. Intermittent exposures occur along the river from about 8 miles west of Peace Point to about 6 miles east of Peace Point, that is, a total distance of about 14 miles (Fig. 16). The country away from the river valley is low-lying and swampy and bedrock is obscured by drift cover.

Peace Point is connected by road to Fort Smith in the Northwest Territories; the latter settlement is joined by a winter road to Hay River, which lies on the Mackenzie Highway. Current and projected road construction will join Peace Point to Fort Vermilion, thus providing a southern link with the Mackenzie Highway. Access by water is afforded from the northern terminus of the Northern Alberta Railways at McMurray via the Athabasca River, Lake Athabasca, and Peace River.

Stratigraphy and Structure

The lowest exposed beds are gypsum, which are overlain by thinly bedded, argillaceous, or slightly dolomitic limestone about 10 feet thick; this is overlain by blue shale and thinly bedded limestone (Warren, 1957). There are 3 to 50 feet of till overlying all strata. Halferdahl (1960) states that the shale is green at the bottom and red at the top. The 10 feet of limestone are correlated with the Slave Point formation, whilst the overlying beds contain a Waterways (Beaverhill Lake) fauna (Warren, 1957). The gypsum beds are therefore late Middle Devonian in age. The maximum thickness of gypsum measured by Cameron (1930) was 55 feet (Section C, Fig. 17), whilst the maximum thickness of overlying carbonates measured was 18 feet (Section F, Fig. 16); Halferdahl (1960) estimated as much as 80 feet of gypsum towards the western part of the deposit. Halferdahl states that at the western end of the deposit and east of Peace Point the gypsum beds are flat-lying with gentle dips; in these exposures the bedding of the overlying limestone

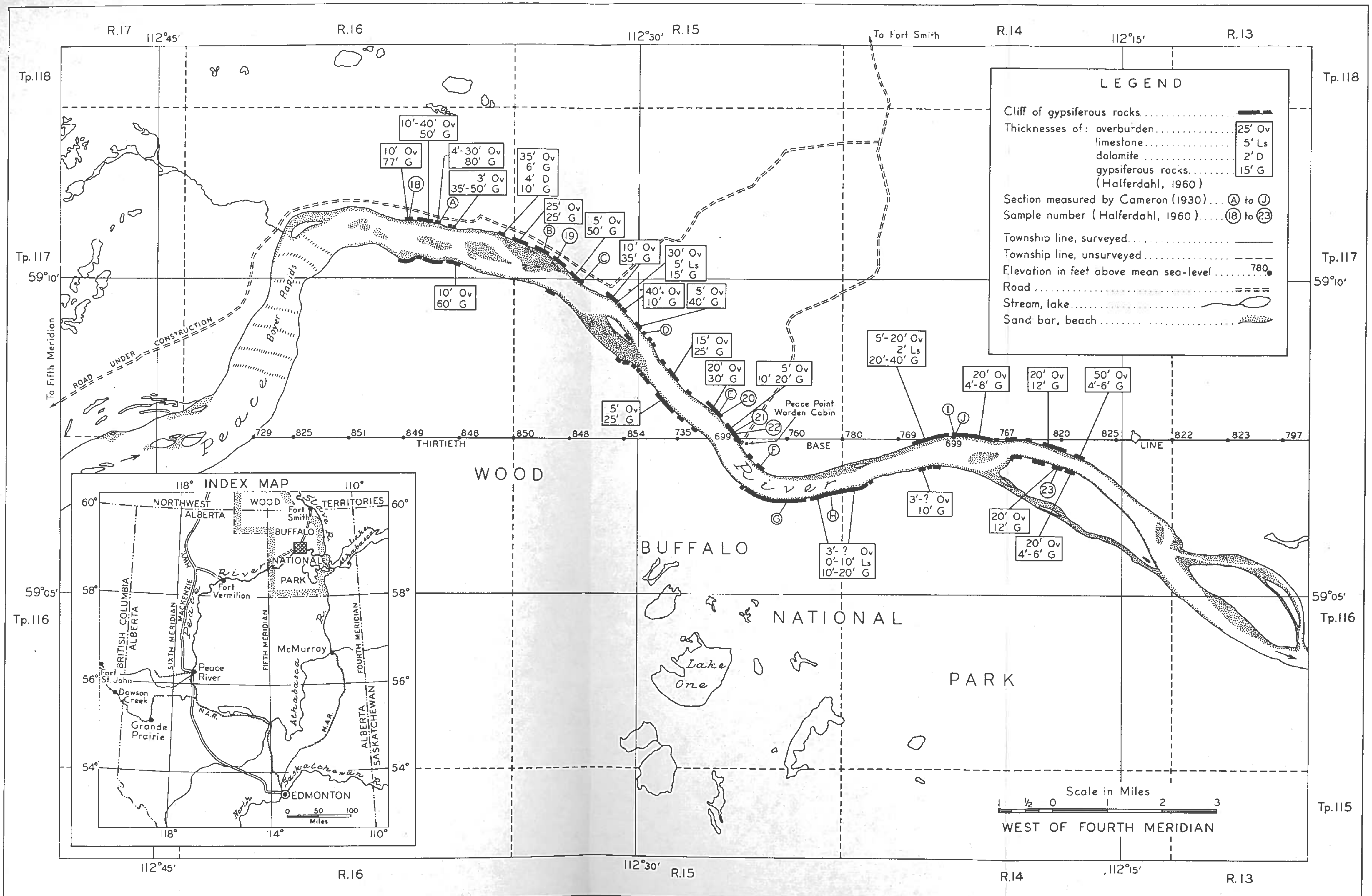


FIGURE 16. Locations of Middle Devonian gypsum exposures along the Peace River near Peace Point; chemical analyses for lettered sections in table 10; chemical analyses for numbered sections in table 11 (after Halferdahl, 1960)

is conformable with that of the gypsum and shows no brecciation. For a distance of five miles west of Peace Point, Halferdahl (1960) reports that the bedding is undulatory, and at one point the beds form a sharp anticline. Between these exposures of gypsum is a limestone breccia (reported as a dolomite-breccia by Camsell, 1917, and Cameron, 1930) up to 60 feet thick. Where exposed, the contact between the breccia and gypsum is generally vertical, the breccia consists of finely laminated, fine-grained limestone, with blocks of coarse-grained limestone and some shale.

The brecciation of the carbonates and undulatory nature of the gypsum are ascribed by Camsell (1917) to expansion resulting from hydration of anhydrite to gypsum. It is believed more probable that the cause is solution of the gypsum and perhaps of an underlying salt bed (see p. 43) resulting in collapse of overlying beds. The small-scale folds and contortions of the gypsum described later may well be due to hydration of anhydrite.

No outcrops have been recorded away from the valley of the Peace River; the low-lying, swampy, drift-covered nature of the country precludes any extensive outcrop. Sink holes, however, testify to an extension of the gypsum to the north and south (p. 43).

Description of the Gypsum

Camsell (1917) reported that the thickness of gypsum exposed varies from a few feet to a maximum thickness of 50 feet on the south side of the river at Little Rapids; Halferdahl (1960) reports a maximum of 80 feet in the west and a minimum of 4 feet in the east. Cameron (1930) describes the gypsum as normally white and massive, in places earthy and thinly bedded, with narrow bands of dolomitic limestone; selenite is rare, but thin beds of satin spar are common; anhydrite is present as rounded nodules or thin beds. Cameron (1930) stated that a characteristic of the deposit is the variation over a few hundred yards from a dense, hard, whitish-grey, thinly bedded gypsum to a coarse, soft, massive, saccharoidal type. The general characteristics of the gypsum beds are illustrated in figure 16 which has been drawn on the basis of measured sections published by Cameron (1930). Halferdahl (1960) confirms these earlier observations, and presents some detailed comments: the individual beds of gypsum vary from a fraction of an inch up to two feet; the beds are commonly separated by beds or laminae of dolomite generally less than one-tenth of an inch thick, but in places up to one inch thick; selenite is rare, and where present the cleavage planes are parallel to the bedding; satin spar, believed to be due to recrystallization of massive gypsum, is present in beds up to 2 to 3 inches thick, the fibres being at right angles to the

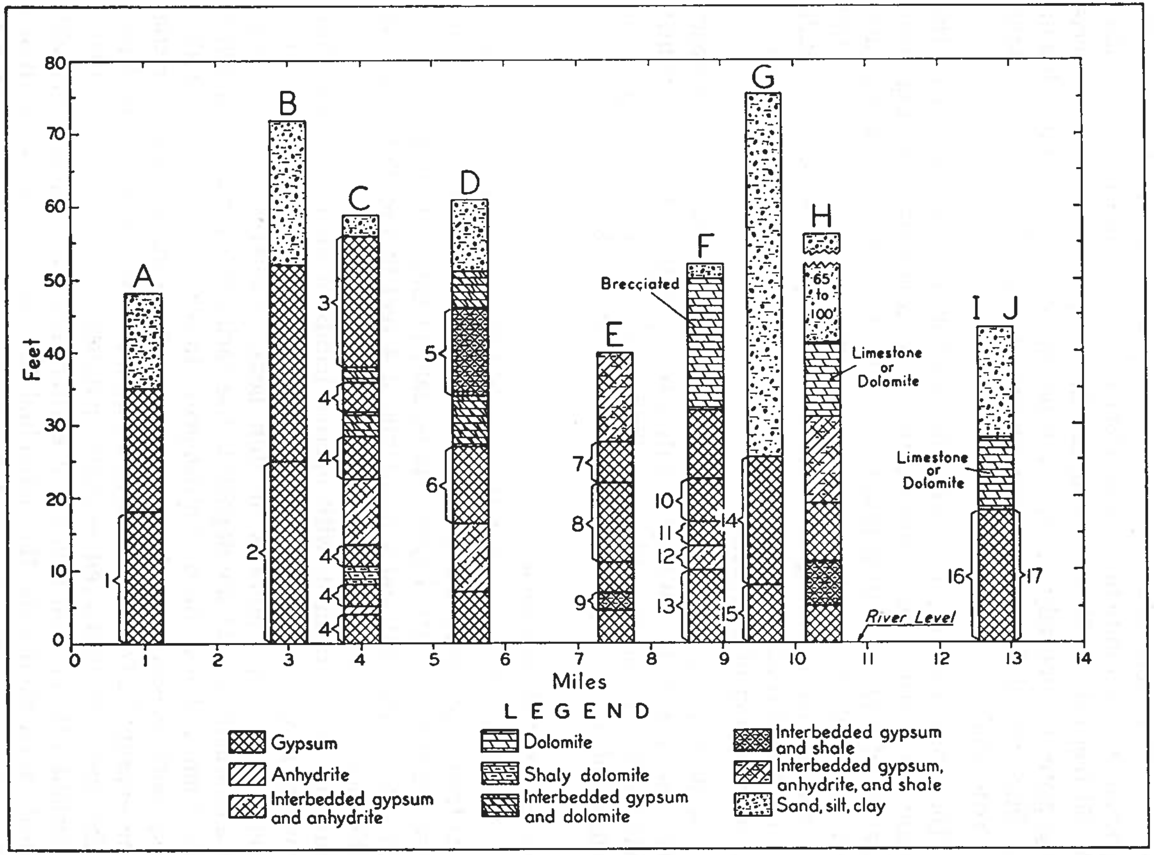


FIGURE 17. Geological sections of Middle Devonian gypsum unit near Peace Point

bedding plane; anhydrite, which commonly passes into gypsum over a short distance, is present as thin beds up to a few inches thick, separated by gypsum or dolomite.

Microscopic examination (Halferdahl, 1960) shows the gypsum to be composed of sutured crystals up to 0.1 mm. in size, and blocky grains up to 1.5 mm. in size. The latter are commonly bounded by small crystals of gypsum about 0.02 mm. diameter, and are mottled when viewed under polarized light. Anhydrite is seen to be composed of blocky crystals 0.1 mm. to 0.5 mm. in size, traversed by veins of sutured gypsum. All anhydrite grains are bounded by layers of gypsum, and recrystallization of anhydrite to gypsum is clearly seen in many sections. Dolomite is present as discontinuous stringers or laminae outlining intricate folds in gypsum. The dolomite grains are generally up to 0.01 mm. in size; there are some grains of carbonate up to 0.1 mm. in size surrounded by gypsum.

The purity of the gypsum over a wide area is evidenced by chemical analyses of channel samples collected by Cameron (1930) shown in table 10. This is confirmed by analyses of random grab samples collected by Halferdahl (table 11).

Table 10. Chemical analyses of chip samples of gypsum from Peace Point

(after Cameron, 1930)

Theoretical composition of gypsum: CaO, 32.57%; SO_3, 46.50%; H_2O, 20.93%

		Composition, per cent weight						
Sample No.	Section[1]	SiO_2	Fe_2O_3 Al_2O_3	CaO	MgO	SO_3	L.O.I.[2]	Total
1	A	2.54	0.92	31.58	2.02	42.10	20.74	99.70
2	B	1.10	0.74	32.56	0.30	45.30	19.95	99.95
3	C	1.76	0.96	32.19	4.54	34.83	25.59	99.87
4	C	0.82	----	32.63	----	45.60	21.00	100.05
5	D	1.42	----	31.82	0.20	45.00	21.37	99.81
6	D	4.18	1.10	31.39	0.30	43.10	19.98	100.05
7	E	1.34	----	31.64	0.25	45.20	21.43	99.86
8	E	2.04	----	31.80	0.33	44.32	21.34	99.83
9	E	1.46	----	32.80	0.31	44.70	21.74	100.01
10	F	0.58	----	32.11	0.20	46.00	20.50	99.39
11	F	1.48	----	32.00	0.20	45.00	21.37	100.05
12	F	6.28	----	30.97	0.76	41.09	20.80	99.90
13	F	1.04	----	32.18	0.22	46.02	20.54	100.00
14	G	0.64	----	32.18	0.22	45.91	21.02	99.97
15	G	1.42	----	32.50	0.10	45.68	20.24	99.94
16	I	0.88	----	32.35	0.30	45.60	20.57	99.70
17	J	5.02	0.60	31.24	0.40	42.50	20.15	99.91

(1)—Refers to sections in figure 17
(2)—L.O.I.=loss on ignition

Table 11. Chemical analyses of grab samples of gypsum from Peace Point collected by Halferdahl (1960)

Analyzed by H. Wagenbauer, Research Council of Alberta

Theoretical composition of gypsum: CaO, 32.57%; SO_3, 46.50%; H_2O, 20.93%

Sample	Composition, per cent weight										
No.(1)	SiO_2	R_2O_3(2)	CaO	MgO	Na_2O	K_2O	SO_3	H_2O^-(3)	L.O.I.(4)	Total	H_2O^+(5)
18	0.42	0.07	32.70	0.65	0.02	n.d.	45.32	0.07	21.56	100.81	20.05
19	n.d.(6)	0.55	32.69	0.77	0.02	n.d.	44.44	0.10	21.38	99.95	19.98
20	0.11	0.28	32.65	0.20	n.d.	n.d.	45.81	0.14	21.63	100.82	20.64
21	0.47	0.38	34.72	0.76	0.01	n.d.	39.58	0.08	23.85	99.85	17.76
22	0.23	0.08	32.48	0.22	0.01	n.d.	45.93	0.06	20.95	99.96	20.65
23	0.20	0.09	32.76	1.69	0.02	n.d.	44.61	0.07	21.46	100.90	20.12

(1)—Refers to sections in figure 16

(2)—R_2O_3=Al_2O_3 TiO_2, P_2O_5

(3)—H_2O^- determined at 43°C.

(4)—L.O.I.=loss on ignition

(5)—H_2O^+ determined at 200°C.

(6)—n.d.=not detected

Little Buffalo, Salt, and Slave Rivers

Location and Access

A little-known area of gypsum deposits in northern Alberta lies between the Slave River on the east, and about longitude 113° on the west; the deposits extend northwards into the Northwest Territories, and southwards towards Peace Point. The specific outcrops described below lie along the Slave, Salt, and Little Buffalo Rivers (Fig. 9). The nearest settlements are Fitzgerald, in Alberta, and Fort Smith, Northwest Territories. Fitzgerald is accessible by barge from McMurray via the Athabasca River, Lake Athabasca, and the Slave River. Rapids along the Slave River between Fitzgerald and Fort Smith necessitate a 16-mile portage; a winter road connects these settlements with the Town of Hay River (N.W.T.) which is joined to Grimshaw (Alberta) by the Mackenzie Highway.

Stratigraphy, Structure, and Description of the Deposits

An eastward-facing escarpment extends from near the salt springs 8 miles southwest of Fitzgerald in a northwesterly direction for at least 40 miles across the Little Buffalo River, and south and southeasterly towards La Butte. Gypsum outcrops along the base of the escarpment and is overlain by dolomite and limestone. Camsell (1917) recorded 50 feet of thinly bedded, impure gypsum with some narrow bands of anhydrite or dolomite four miles south of the salt springs on the Salt River. Eight miles southwest of Fitzgerald where the Salt River flows along the base of the escarpment, 20 feet of thinly bedded gypsum are overlain by 10 feet of dolomitic limestone. The southernmost exposure of this gypsum occurs on the west bank of the Slave River a few miles north of La Butte; here, 20 feet of fractured and broken limestone are underlain by 10 feet of thinly bedded, impure, white to bluish gypsum, with narrow bands of selenite and satin spar. Below the falls on Little Buffalo River (in Northwest Territories) massive gypsum, in places thinly bedded with dark impure streaks lies conformably beneath dolomites and limestones (Douglas, 1959). At Bell Rock on the Slave River massive, white gypsum with thin, greenish-grey shale is overlain by limestones and shales, and separated by a vertically dipping northeasterly trending fault from limestones and dolomitic limestones (Douglas, 1959). Other exposures of this gypsum in the Northwest Territories are recorded by Douglas (1959) along the escarpment west of the Little Buffalo River, and at Point Ennuyeuse on the Slave River. Cameron (1922) believed that these beds were of Silurian age, but Douglas (1959) suggests them to be Middle Devonian. Camsell (1917) records the presence of *Martinia* cf. *M. meristoides* and *M.* cf. *M. sublineata* above the gypsum at Point Ennuyeuse and *M sublineata* at La

Butte, which suggests that the carbonate unit should be correlated with Pine Point formation.

At the falls on Little Buffalo River Douglas (1959) records a second (upper) series of gypsum beds, consisting of massive, white, crystalline and banded gypsum with some laminated limestone. The basal beds (overlying the lower gypsum strata) are brown and dark-grey dolomite, vuggy dolomite, and thinly bedded argillaceous and fossiliferous limestone. These strata lie close to the surface over a wide area south of Great Slave Lake in the Northwest Territories, and are exposed in sink holes, wave-cut cliffs, and along the road from Fort Smith to Hay River (Douglas, 1959). This series of gypsum beds has not been specifically recorded in Northern Alberta, but since Douglas equates the gypsum with the Pine Point-Presqu'ile formations of Great Slave Lake (equivalent to the Methy-Prairie evaporite formations of McMurray) it is believed that this gypsum should be correlated with the Muskeg formation. The lower gypsum bed is probably the off-shore facies equivalent of the Ashern-Meadow Lake equivalents of McMurray, and is therefore correlated with the Chinchaga formation of northwestern Alberta. Stratigraphic correlations are discussed more fully in the following paragraphs.

Age, Correlations and Possible Extensions of Devonian Gypsum Deposits

Introduction

Three areas where gypsum of Middle Devonian or earlier age lies on or near the surface have been described: namely, McMurray, Peace Point, and the Slave, Salt and Little Buffalo Rivers. The oldest firmly dated formation is the Methy and its equivalents which are Middle Devonian (Crickmay, 1954). Underlying beds have variously been ascribed to the Ordovician (Walker, 1957), Lower Devonian (Van Hees, 1956), and Middle Devonian (Buller, 1958). For the purposes of discussion of the development of the evaporitic basins, the entire evaporitic sequence is considered to be Middle Devonian; strata below the Methy formation and its equivalents being considered as lower Elk Point, and younger beds being considered as upper Elk Point.

Correlations between these areas, and with other Devonian strata, are uncertain because of the almost complete absence of fossils; correlation on the basis of lithology may be misleading. It has been intimated (p. 4) that the normal order of precipitation from an evaporating body of sea water is firstly carbonates (as calcite or dolomite), followed by calcium sulfate (as gypsum or anhydrite), halite, and in the most advanced cases potassium salts and complex salts. Thus, a vertical bottom to top sequence may be limestones or dolomites, gypsum or anhydrite, and halite. Continued evaporation would lead to the uppermost beds being potassium salts whilst, on the other hand, dilution of the sea water would lead to the halite being succeeded upwards by gypsum or anhydrite, and limestone or dolomite. In addition to this vertical layering, a horizontal zoning is also likely, the least soluble components being precipitated at the margins of the basin, the most soluble in the centre (Wells, 1951). Thus, the lateral equivalents of carbonates would be gypsum or anhydrite, succeeded in turn by halite. In the case of continuing evaporation with resulting shrinking of the sea and an offlap relationship of successive beds, it is conceivable that gypsum or anhydrite could come to lie over earlier-deposited halite, or limestone over earlier-deposited gypsum. Within the limitations imposed by the aforementioned characteristics of evaporitic sediments, the development of Devonian evaporitic basins will be discussed with the purpose of correlating known gypsum deposits and outlining areas where other deposits may be found.

Summary of Historical Geology

The early Middle Devonian sea advanced from northwest of Alberta, becoming steadily more saline in a southeasterly direction. There may have been a partial restriction along the south shore of Great Slave Lake due to a positive area in the Precambrian Basement associated with the fault along the east arm of the lake (Douglas, 1959; Fig. 9); major restrictions were caused by the Peace River land mass on the west, and the Precambrian Shield on the east (Fig. 9). The exact position of the eastern shoreline north of McMurray is not known, but it seems likely that although McMurray itself was a positive area, an embayment extended some distance to the east along Lake Athabaska, as evidenced by the topography of the Basement (Green, 1958), and the presence of massive gypsum below the Methy equivalent along the Slave River. The lithology of the strata in this northern basin — the Chinchaga formation — is carbonates and anhydrite towards the northwest, passing into anhydrite and salt towards the southeast (Fig. 18). The quantity of salt within the known area of the northern basin is small, but probably increases eastward between Fort Vermilion and the Shield shelf area, and this formation is probably the source of the salt springs along the Salt and Slave Rivers. Although proof is not yet available, the configuration of isopachs for the Elk Point group (Fig. 19) suggests that waters flowed southwards from the northern basin through a narrow channel over the Chipewyan Lakes sill (Green, 1958) into the lower Elk Point basin of central Alberta. The central Alberta basin extended a short distance into Saskatchewan where the Meadow Lake beds (Van Hees, 1956) were deposited. By virtue of

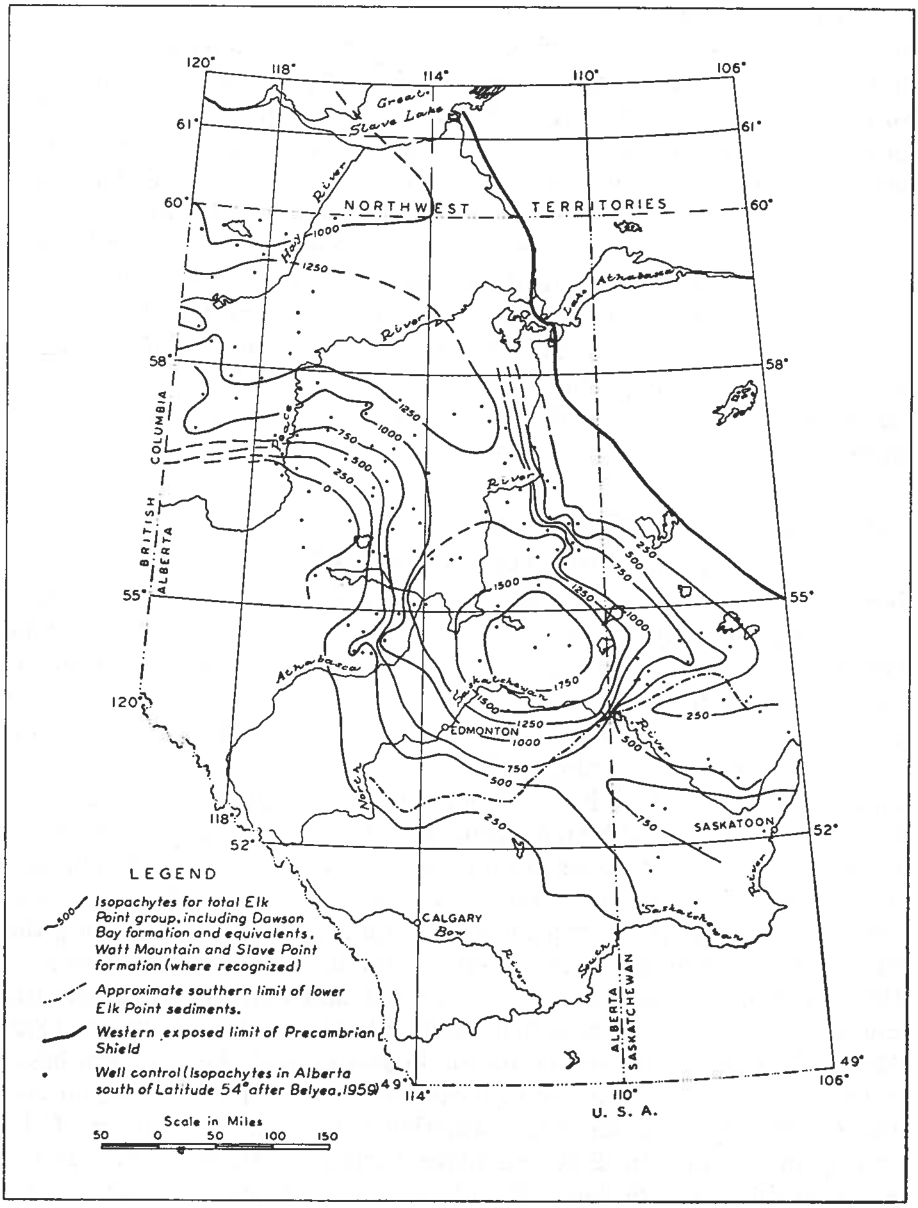


FIGURE 19. Isopachs of the Elk Point group in Alberta and adjacent areas of the Northwest Territories and Saskatchewan

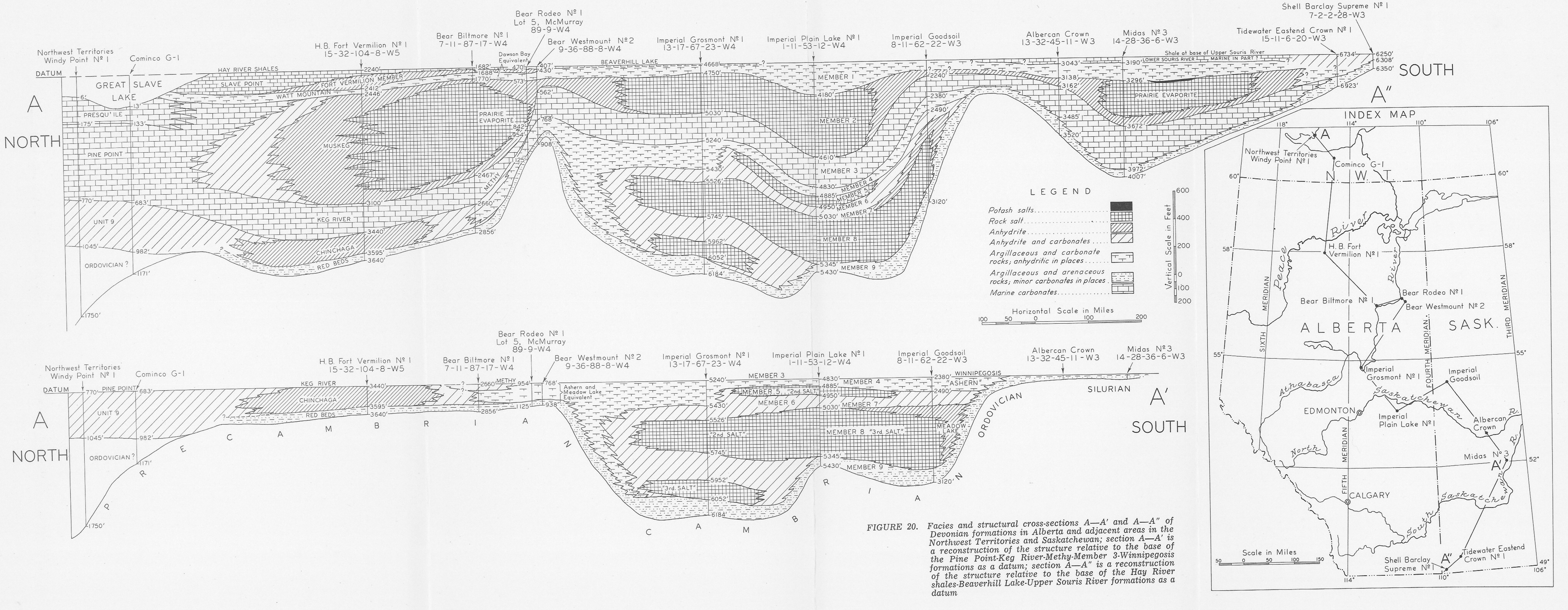


FIGURE 20. *Facies and structural cross-sections A—A′ and A—A″ of Devonian formations in Alberta and adjacent areas in the Northwest Territories and Saskatchewan; section A—A′ is a reconstruction of the structure relative to the base of the Pine Point-Keg River-Methy-Member 3-Winnipegosis formations as a datum; section A—A″ is a reconstruction of the structure relative to the base of the Hay River shales-Beaverhill Lake-Upper Souris River formations as a datum*

the almost complete restriction, except for over the aforementioned Chipewyan Lakes sill, thick salt beds accumulated — the second, third, and fourth salt beds in Alberta, and the Meadow Lake salt beds (Buller, 1958) in Saskatchewan. These thick deposits were apparently accommodated in a pre-existing topographic basin. North of the Peace River arch (Fig. 9) there was a stable shelf area sloping gently northwards (Fig. 20), whilst south of the position of the Peace River arch was a basin bounded on the north by a steep scarp (Fig. 20).

The marine incursion that deposited the carbonates at the base of the upper Elk Point evaporites transgressed over wide areas. The Peace River ridge appeared to cease to be an important restrictive barrier except in the extreme west, and the sea made its first major advance into Saskatchewan through a somewhat restricted channel centered about latitude 52° 40′, with an embayment at about latitude 50° 30'. These marine beds are represented probably by at least the lower part of the Pine Point formation (Law, 1955; Douglas, 1959; Belyea, 1959; see also Fig. 18,20) in the Northwest Territories by the Keg River formation of northwestern Alberta (Law, 1955; Douglas, 1959), by the Methy formation at McMurray (Carrigy, 1959), by member 3 of the Elk Point basin (Belyea, 1959), and by the Winnipegosis formation in Saskatchewan (Walker, 1957). All these formations are marine carbonates, essentially dolomites with varying amounts of dolomitic argillaceous beds and limestones south of latitude 59° and essentially limestones north of latitude 59°. Northwards beyond Great Slave Lake the limestones pass into shales and limestones. The transgressive nature of these beds has been demonstrated in many areas and may be inferred in others. For example, Law (1955) states that the Keg River formation overlaps the Chinchaga formation on the north flank of the Peace River ridge, whilst Walker (1957) has recorded facies change in southwestern Saskatchewan from carbonates to interbedded anhydrite and dolomite, and finally red shales. Towards the southern margin in Alberta a similar relationship holds, and Belyea (1959) has reported an interfingering of marine and freshwater deposits.

Restriction of circulation caused marine conditions to give way to a very widespread evaporitic environment. In the Great Slave Lake region carbonates were still deposited — the upper Pine Point limestones, followed by the Presqu'ile dolomite. The latter has been interpreted as a barrier reef migrating northwards over the fore-reef deposits of the Pine Point (Law, 1955). Behind this reef an elongate evaporitic basin developed, extending into southeastern Saskatchewan. In northwestern Alberta the evaporites are represented by the Muskeg formation, consisting of anhydrite and dolomite in the northwest, passing southwards into salt and anhydrite (Fig. 18,20). The salinity of the seawater increased southeastwards, and west of McMurray almost the entire succession is composed of salt (Bear Biltmore No. 1 well, Fig. 10, 18) which towards the Shield passes into salt and gypsum (Bear Westmount No. 2, Fig. 10, 18). This salt unit continues as the first salt of central Alberta, and thence through a restricted channel as the Prairie evaporite of Saskatchewan. In the centre of the elongate basin the concentration of the seawater became sufficiently high to permit deposition of potassium salts in the upper part of the succession, a circumstance aided by the restriction along the Alberta-Saskatchewan boundary. Towards the northeast (Shield) margin and the southwest margin of the basin, halite passed into anhydrite and dolomite. Thus, the upper Elk Point evaporitic basin is interpreted as a classical evaporitic basin, with anhydrite and dolomite around the margins and halite towards the centre, with the final deposits being potash salts. Such a sequence indicates a steady increase in salinity, and it is possible that the evaporitic basin was slowly shrinking in size during this period.

The final event in the Middle Devonian evaporitic basin was the deposition of what may be classed as "transition beds" of terrigenous clastics, dolomites, anhydrite, and marine limestones, with a greater or lesser hiatus between the top of the Middle Devonian and the widespread Upper Devonian marine transgression (Beaverhill Lake). In northwestern Alberta, Law (1955) takes the top of the Elk Point at the top of a clastic unit, the Watt Mountain formation. This unit consists of green shale, dolomitic siltstone, anhydrite and dolomite, which towards the Peace River land mass becomes sandy. This is equated with the lithologically similar member 1. (Crickmay, 1954) in central Alberta and with the Dawson Bay plus First Red Bed in Saskatchewan (the Dawson Bay formation is excluded from the Elk Point group in Saskatchewan). Overlying the clastic unit in northwestern Alberta and the Northwest Territories is the Slave Point limestone. Anhydrite—the Fort Vermilion member—is developed at the base (Fig. 18) towards the southeast, and it thickens in this direction, although the formation as a whole thins towards the east. Carrigy (1959) recognizes a thin equivalent of the limestone at McMurray, but it is considered entirely possible that the anhydrite at the top of his Dawson Bay equivalent in some wells is the equivalent of the Fort Vermilion member; the upper part, at least, of the thick gypsum at Peace Point also should probably be correlated with the Fort Vermilion member. Recognition of the presence of the Slave Point formation farther south in Alberta is problematical, although Law (1955) states that the lower 40 feet of the Beaverhill Lake group in central Alberta represents the Slave Point. This formation is there interpreted as the main precursor of the Late Devonian marine transgression; marine conditions, represented by the limestone, gradually extended south and east during

Middle Devonian time, possibly not reaching parts of east and central Alberta, and Saskatchewan until late Devonian time. The correlations presented in figure 20 suggest that the upper Elk Point deposition, in contrast to the lower Elk Point, was characterized by considerable and contemporaneous subsidence. Thus, there was general subsidence, relative to the Shield shelf on the east and the remnants of the Peace River land mass on the west, in both northern and central Alberta. Subsidence was probably somewhat greater in northern Alberta, and both areas exhibit a basin-type structure relative to the datum of the base of Upper Devonian strata. Similar subsidence occurred in Saskatchewan, although a distinct positive area remained along the Alberta-Saskatchewan border (this is evident from comparison of isopachs in Fig. 19 and section A—A′ in Fig. 20).

Correlation of Middle Devonian Gypsum Deposits and Their Possible Extensions

Gypsum encountered in wells in the vicinity of McMurray is entirely of upper Elk Point age. This gypsum lies near or at the surface between here and the Northwest Territories, where it is exposed in sink holes along the Fort Smith-Hay River road. Between McMurray and the Northwest Territories the gypsum beds may be underlain by salt.

The gypsum at Peace Point is overlain by 10 feet of limestone which Warren (1957) states "occupies the stratigraphic position of the Slave Point". The gypsum is, therefore, entirely Slave Point (that is, Fort Vermilion member; compare 120 feet of anhydrite in subsurface near Fort Vermilion, Fig. 18) underlain by Watt Mountain equivalent and Muskeg equivalent; or, the upper part of the gypsum may be Slave Point and the lower part Muskeg, separated by an as yet unrecognized Watt Mountain equivalent. Whatever the precise relationship at Peace Point, post-Methy gypsum is probably within an economic depth of the surface north of the Peace River into the Northwest Territories, and south of the Peace River towards McMurray. Post-Devonian movements along the Lake Athabasca zone of disturbance (Godfrey, 1958) may have complicated the structure south of Peace Point.

East of a line trending approximately north through Lake Claire, erosion has removed upper Elk Point evaporites. Lower Elk Point gypsum outcrops along the Little Buffalo, Salt, and Slave Rivers, and is presumably continuous with the Chinchaga evaporites encountered in wells in northwestern Alberta. A number of exposures along the Slave River show sandy red beds underlying carbonates and overlying Precambrian rocks; nowhere have evaporites been recorded resting directly on Shield rocks in this area. This, and the fact the massive gypsum outcrops within a short distance of the Shield, indicate that lower Elk Point (at least) sedimentation extended farther east than the present limits, and lend some strong support to the suggestion by Godfry (1958) that there has been post-Devonian movement along the north-trending Rutherford fault, with a downthrow to the west. The fault that displaces lower Elk Point strata at Bell Rock (Douglas, 1959) may be an expression of the Rutherford fault system; existing exposed sediments found overlying Precambrian rocks are presumably on the upthrow side of the fault. Liberty (1960) has suggested that Paleozoic sedimentation generally extended much farther onto the Shield than popularly supposed, as shown by accumulating evidence of Paleozoic outliers; Webb (1954) similarly considers that Paleozoic sedimentation extended much farther east than the present outcrop limits. Though little information is available concerning lower Elk Point gypsum, it may be expected to outcrop between the base of the Methy dolomite equivalent (which forms the escarpment along the Salt River, (see p. 37) and the Rutherford fault, that is, approximately as far east as the Slave River.

UPPER DEVONIAN GYPSUM DEPOSITS IN ALBERTA

Head Creek, Highwood Range

An occurrence of gypsum in the Highwood Range of southwestern Alberta, found and staked by Messrs. V. Hume and S. Mason of Turner Valley, was reported to the Resarch Council of Alberta by the Alberta Department of Mines and Minerals during the summer of 1960. This deposit was investigated briefly by the writer during September, 1960.

Location and Access

The gypsum beds outcrop at the headwaters of Head Creek in the southeastern quarter of Sec. 31, Tp. 17, R. 5, W. 5th Mer. (about 50° 28′ N. and 114° 40′ W.) on a ridge about 8,000 to 8,200 feet above sea level.

Access may be obtained by the Highwood River road west from Longview (Longview is about 15 miles west of High River) as far as Flat Creek, and thence by a truck-trail along Flat Creek to Head Creek. The distance by road from Head Creek to Canadian Pacific Railway at Longview is 30 to 35 miles; the gypsum deposit lies about 4 miles west of the confluence of Head and Flat Creeks. The location and access is shown on figure 21.

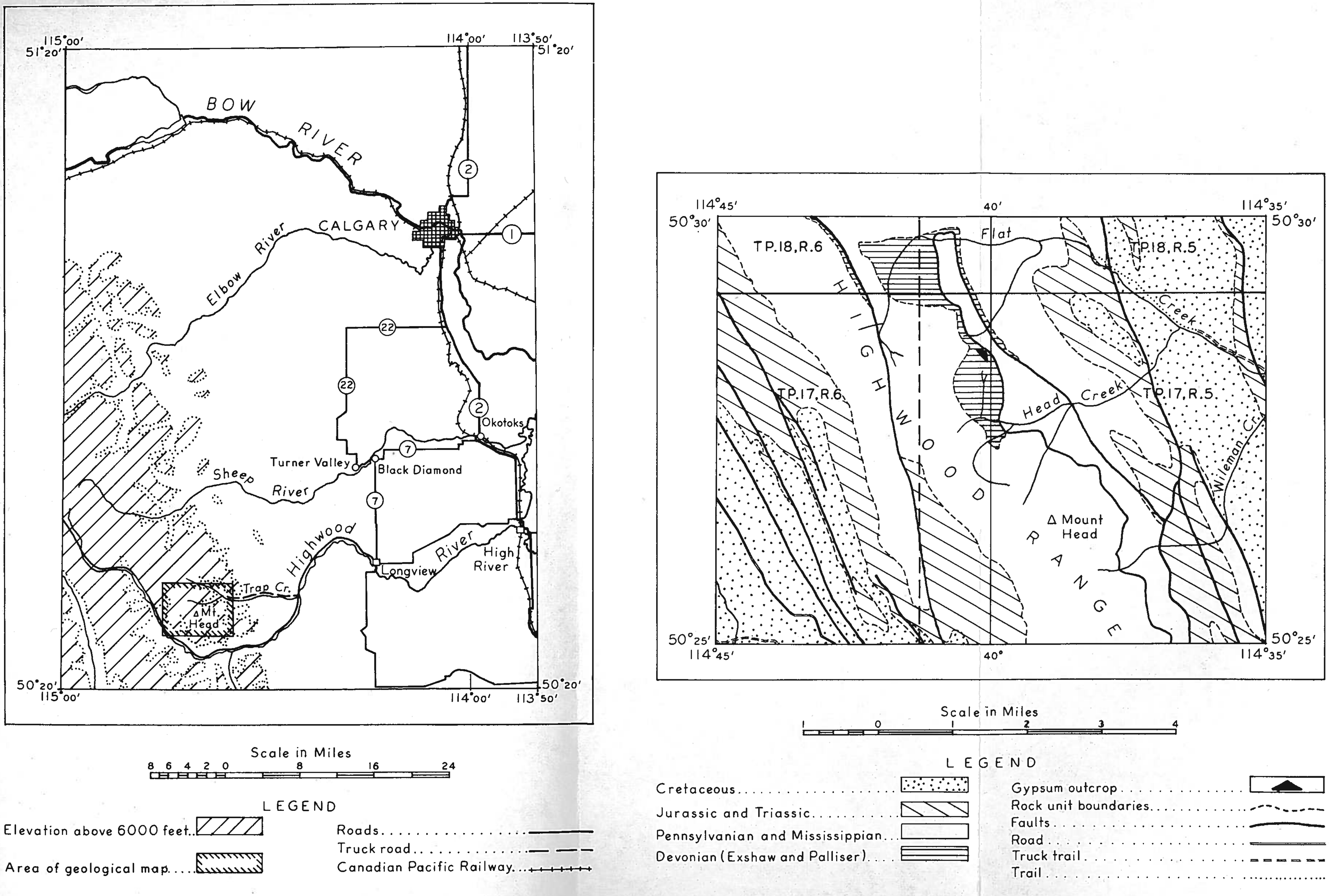


FIGURE 21. Location and geology of the Upper Devonian gypsum deposit at Head Creek (geology from Douglas, 1958)

Description, Stratigraphy, and Structure of the Gypsum Beds

The gypsum beds occur in the Palliser formation of the Upper Devonian at an estimated 20 to 40 feet beneath the Exshaw formation. The beds overlying the gypsum consist of rubbly weathering dolomitic breccias, and limestones. The underlying beds are massive-bedded cliff-forming, limestones and dolomites. The gypsum unit consists of about 16 feet of laminated and massive gypsum, with interbedded lenses and beds of dolomite, shale, and limestone. The lithology of the gypsum unit is shown in table 12.

Table 12. Description of gypsum beds at Head Creek

Thickness feet	Thickness inches	Lithology	Bed designation and Analysis No. (see table 13)		
		Dolomitic breccia, limestone			
1	2	Massive gypsum	A	2	1 (beds A–F)
2	1	Laminated gypsum, dolomite and shale	B		
1	7	Massive gypsum	C	3	
2	8	Laminated gypsum and shale, gypsum and dolomitic shale	D		
7	8	Gypsum, laminated gypsum and shale	E		
1	8	Massive and laminated gypsum, minor shale partings	F	4	
		Massive limestone and dolomite			
16	10	Total, gypsum unit			

The gypsum beds strike northwest and dip at about 35° towards the southwest. The gypsum forms a scree-covered dip-slope to the southwest, is terminated by a steep cliff on the southeast and northeast, and probably continues beneath younger strata in a scarp toward the northwest. The accessible strike-length of exposed gypsum is about 200 feet.

Chemical analyses (table 13) indicate that the gypsum unit comprises 65 to 70 per cent gypsum, whilst individual beds have a high degree of purity, for example bed F (table 13). The quality and quantity of available gypsum at Head Creek does not indicate that economic development is likely; exploration of the Palliser rocks north of Head Creek may modify this opinion, although evidence at Head Creek suggests that the gypsum becomes more shaly towards the northwest.

Table 13. Chemical analyses of gypsum from Head Creek

Analyzed by Technical Service Laboratories, Toronto

Theoretical composition of gypsum: CaO, 32.57%; SO_3, 46.50%; H_2O, 20.93%

Sample No.	Bed[1]	Composition, per cent weight										
		Sample type	SiO_2	R_2O_3[2]	CaO	MgO	Na_2O	K_2O	SO_3	H_2O^-[3]	L.O.I[4]	Total	H_2O^+[5]
1	A to F	Chip samples	4.16	0.46	31.50	5.32	0.04	0.18	32.04	nil	26.85	100.55	13.34
2	A	Channel	0.65	0.16	32.62	2.19	<0.01	<0.01	42.27	0.03	22.40	100.34	17.85
3	C	Channel	1.90	0.14	32.00	2.26	<0.01	<0.01	40.45	nil	23.06	99.83	17.05
4	F	Channel	0.02	0.04	32.90	0.06	<0.01	<0.01	46.12	0.04	20.69	99.89	19.81

(1)—Refers to beds in table 12

(2)—$R_2O_3 = Fe_2O_3 + Al_2O_3$

(3)—H_2O^- determined at 43°C.

(4)—L.O.I. = loss on ignition

(5)—H_2O^+ determined at 200°C.

ECONOMIC DEVELOPMENT OF GYPSUM DEPOSITS IN ALBERTA

There are three main considerations which control the development of gypsum deposits in Alberta. These are (a) federal legislation relating to development of natural resources within National Parks and provincial legislation relating to development of natural resources within Provincial Parks, (b) markets for the gypsum products, and (c) location, accessibility and transportation facilities. These factors will be discussed separately.

Development in National and Provincial Parks

Two of the gypsum deposits described in this report, Mowitch Creek and Peace Point, lie within National Parks, and their development is forbidden by law. This situation is deplored as a general rule and is particularly unrealistic as regards Alberta. The Province of Alberta accounts for only 6 per cent of the total area of Canada and supports only 6.5 per cent of the Canadian population, yet 80.3 per cent of Canadian National Parks area lies within the Province. This means that 10 per cent of Alberta is closed to development of natural resources. This circumstance was protested by Allan who wrote in 1933:

> This is a regrettable situation that applies not only to Jasper Park but to the very large areas throughout Canada that are included in park reservations and in which, therefore, the development of mineral resources is not permitted. It is hoped that the day will soon come when these areas in Canada that are reserved chiefly for pleasure purposes will be made available for prospecting and for the development of economic minerals. (Allan, 1933, p. 17.)

Allan wrote this nearly 30 years ago, and yet there is still no change in the situation. The original concept of National Parks is not decried, indeed it is applauded; it is believed, however, that their purpose of preserving areas of natural beauty can be achieved without penalizing the people they are meant to serve. A number of alternative changes in legislation are possible which would allow the development of natural resources whilst maintaining the other benefits derived from park areas. As it is considered that the characters of Jasper National Park and Wood Buffalo National Park are quite different, they will be discussed separately.

Jasper National Park

Jasper Park, together with Banff and Waterton Parks, is an international tourist attraction, and the areas around the towns and main highways must remain inviolate. If this is adopted as a guiding principle, there are three possible changes in legislation:

(a) All land falling outside a defined zone of normal travel would be freed for prospecting. Mowitch Creek would obviously be outside the forbidden zone.

(b) The Mowitch Creek gypsum deposit lies along the northeast boundary of the Park. Moving the boundary about half a mile to the southwest in this area would place the deposit outside the Park.

(c) A thorough and complete geological mapping and prospecting of Park areas would be undertaken by government agencies. The natural resources of the park areas will cease to be an unknown factor, and it should be possible to define that part which shall be made available for development, and possibly change the Park boundaries to maintain the same total protected area.

Method (b) is the least satisfactory solution; it would set a precedent for whittling the size of Parks and, furthermore, after such a change a better gypsum deposit might be found farther to the southwest. This method, moreover, would not alleviate the general situation, but merely free one specific deposit. Method (c) is obviously the most satisfactory which would have the additional advantage of expanding geological knowledge. Whichever method is adopted, stringent regulations concerning the building of access roads to, and disposal of waste material from, any development project would be a necessity. With these safeguards development of mineral resources, far from detracting from the present attractions of National Parks, would greatly enhance them by opening up areas to tourist travel which are now inaccessible except by pack-train.

Wood Buffalo National Park

By no stretch of the imagination can Wood Buffalo Park be considered a tourist attraction. It is simply a game reserve, and since it is reported that the wood buffalo is now almost extinct through interbreeding with the plains buffalo, even this function seems to have partly failed. As recorded in a recent Research Council report (Govett and Bryne, 1958), all that is required in this case is "revised Federal legislation giving adequate protection to the indigenous fauna". The writer is personally acquainted with large game reserves in other continents where mining development proceeds with no resulting harm to the prolific natural fauna. Indeed it is possible in the case of Wood Buffalo Park that wild life might benefit: development will obviously increase accessibility which would permit freer visits by naturalists and game wardens. Inasmuch as lumbering and trapping operations are already permitted, it is a small step to allow prospecting.

It is recommended that Wood Buffalo National Park be designated as a game or wildlife reserve, with complete freedom for the development of natural resources.

Wilderness Provincial Park

The Fetherstonhaugh gypsum deposit lies within the boundaries of Wilderness Provincial Park. Article 7 of the Act establishing the Park (Alberta Government, 1959) states: "Nothing in this act affects the administration and control of mines and minerals within the area of the Park". This is interpreted by the writer as implying that there will be no restriction upon development of natural resources resulting from their geographical location within this Provincial Park .

Markets and Utilization

The writer is not competent to assess accurately the market for gypsum produced in Alberta (this is far better judged by interested commercial parties), though it is thought probable that the market will be confined to this province.

The major use of gypsum in Alberta will probably continue to be for the manufacture of plaster and related products for the building industry. Agricultural practice in some localities may profit by a wider use of gypsum, provided a cheap source is available. Anhydrite plasters and aggregates should find an application if the subsurface gypsum deposits at McMurray are developed. There is no immediate prospect for the utilization of gypsum and anhydrite in the chemical industry because of the very large supplies of sulfur available as a by-product of the natural gas industry. There is probably a small market for gypsum for many of the minor uses outlined earlier in this report.

Location, Transportation Facilities, Quality, and Reserves of Gypsum

None of the gypsum deposits in Alberta is particularly well situated with regard to transportation, except the McMurray deposit which requires mining.

From the point of view of quality, quantity (a minimum of one billion tons available), and ease of development, the Peace Point deposit is undoubtedly the most suitable. The nearly flat-lying gypsum beds are amenable to opencast quarrying, and the Peace River is navigable by barge downstream from Peace Point. The deposit lies at a distance of about 300 miles by river from McMurray, and a further 300 miles by rail to Edmonton; Cameron (1930) considered that the gypsum could compete on the Edmonton market with gypsum imported from Manitoba. Transportation from Peace Point by barge is limited by the length of the shipping season, about 5 to 6 months.*

Cameron (1930) believed that gypsum could be mined at McMurray and placed on the Edmonton market more cheaply than Manitoba gypsum. Even with present knowledge, it is obvious that mining operations need not be deeper than 500 feet; however, as intimated earlier, there is good reason to expect gypsum much nearer the surface between Fort MacKay and Lake Claire. The reserves along the Shield shelf area are expected to be virtually limitless. A modest, shallow-drilling program along the west side of the Athabasca River in this area could rapidly delimit areas suitable for development. The nearer to the surface the gypsum can be developed, the less anhydrite may be expected.

The Triassic gypsum deposits in the Rocky Mountains are, compared with the Northern Alberta Devonian deposits, very small. Nevertheless, they are much nearer to markets, though they require construction of new transportation facilities.

The beds of pure gypsum at Mowitch Creek are thin and steeply dipping and, on the basis of present knowledge, the deposit is of doubtful economic importance. More thorough investigation of this deposit and the surrounding area may revise this estimate. Transportation of gypsum from this deposit would necessitate construction of an access road. The most suitable route would be from rail at Devona up the Snake Indian River Valley, a distance of 35 miles; an alternative access route is along Rock Creek to Rock Lake or through the Eagles Nest Pass and down the Wildhay River to Rock Lake, a distance of about 18 miles. Rock Lake is about 35 miles by road from rail at Entrance.

The quality of the gypsum at Fetherstonhaugh Creek compares favourably with that at Peace Point though reserves are considerably less; the quality and quantity are superior to those of the known deposit at Mowitch Creek, and beds have a much lower dip. The distance of this deposit from existing transportation facilities in Alberta is prohibitive to development; the situation may be improved if a rail line is constructed to carry coking coal westwards from the Smoky River and Sheep Creek deposits (Pearson, 1960). On the other hand, the distance between Fetherstonhaugh Creek and Loos in British Columbia is

* It may be noted that the proposed eastern (McMurray) route for a railway to Pine Point in the Northwest Territories passed through the Peace Point area; inasmuch as it appears that the alternative western (Grimshaw) route has won Government approval, any development of the Peace Point gypsum deposit will depend upon the transportation facilities outlined.

only about 40 miles. Loos lies on the Canadian National Railways line from Prince Rupert to Edmonton.

The Upper Devonian gypsum deposit at Head Creek in the Highwood Range is, within the limits of present knowledge, of academic interest only. However, if further prospecting within this area should reveal commercial reserves, proximity to road and rail communication with Calgary should ensure rapid development.

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APPENDIX A: DISCUSSION OF THE POSSIBILITIES OF ECONOMIC DEPOSITS OF POTASSIUM SALTS IN DEVONIAN EVAPORITIC SEQUENCES IN ALBERTA

Towards the top of the Prairie evaporite formation in Saskatchewan there are up to 200 feet of potassium salts, overlying halite with minor anhydrite. This area lay farthest from normal marine conditions at the time of deposition and, furthermore, was partly isolated from the main Alberta evaporitic basin by a northeast-trending positive area. By comparison, the Prairie evaporite equivalents in Alberta were deposited in a comparatively open basin: the Peace River ridge had ceased to be a serious restriction, and normal marine waters flowed into Alberta from the north and northwest, influx being restricted by the reefal deposits. Thus, the Saskatchewan potassium deposits would seem to be the ultimate facies deposit of a normal evaporitic basin: carbonates in the extreme north, passing south and southeast through carbonates and anhydrite, anhydrite and halite, halite (central Alberta), and finally potash. On this basis it is unlikely that the first salt of Alberta contains potassium salts in any major quantity. There is one circumstance under which this conclusion may not be valid. If towards the end of deposition of the Prairie evaporites the Saskatchewan basin became completely isolated and precipitation from nearly stagnant waters continued in Alberta, it is possible that potassium salts were deposited in the centre of the halite facies, that is, southeast of Calling Lake. The area north of McMurray was too close to marine influences during this period to be considered as a possible area of potash salts. Analyses of spring and well-head waters shown in table 14 testify to this conclusion.

The lower Elk Point evaporites offer distinct possibilities for potash salts in central Alberta. This evaporitic basin extended but a short distance into Saskatchewan, and was bordered by restrictive land barriers on all sides except for a narrow channel over the Chipewyan Lakes sill.

Inasmuch as evaporitic conditions obtained throughout northern Alberta (and far into the Northwest Territories) during this time, the central Alberta basin was far removed from marine conditions and had an analogous relative facies position to the upper Elk Point evaporitic basin of Saskatchewan. The most likely area for any potassium salts is in the vicinity of south, and east, of Calling Lake. These deposits unfortunately lie at great depths, being of the order of 3,000 to 4,000 feet below the surface. There are possibly halite deposits west of the Athabasca and Slave Rivers, but potassium salts are unlikely in this area.

Table 14.
Chemical analyses of well and spring water in northern Alberta and Northwest Territories.

Sodium: Potassium ratio in sea water is 278

Spring, or well	Composition, p.p.m. Na	K	Ca	Mg	Cl	SO_4	HCO_3	Ratio Na/K
1	21,184	496	1,821	571	39,792	4,688	530	43
2	23,937	868	1,574	496	38,461	4,702	......	28
3	84,076	192	3,354	1,021	127,960	2,956	36	438
4	76,268	336	1,347	585	118,636	4,920	372	227
5	22,988	296	1,638	385	36,188	4,144	469	78
6	4,783	36	947	122	7,399	2,759	......	133
7	100,700	400	1,200	200	156,400	3,100	......	253
8	100,800	400	1,200	200	156,600	3,100	......	250
9	101,500	500	1,200	200	157,700	3,100	......	201
10	200	trace	480	130	213	1,500	370	......
11	4,760	12	289	189	8,340	100	......	398

1. Largest spring at La Saline (Allan, 1920)
2. Spring, La Saline (Allan, 1920)
3. Overflow from casing-head of Fort MacKay Oil and Asphalt Company, La Saline (Allan, 1920)
4. Overflow from casing-head of "Salt of the Earth" well, west bank Athabasca River, 1 mile north of Fort MacKay (Allan, 1920)
5. Overflow from casing-head of Athabasca Oils No. 1 well (Allan, 1920)
6. Spring, west bank of Athabasca River, 2 miles north of the mouth of Red Clay Creek (Allan, 1920)
7. Snake Mountain springs, about 2 miles east of 8 (Camsell, 1917)
8. Mission springs, about 6 miles south of forks of the Salt River (Camsell, 1917)
9. Hudson's Bay Springs, forks of Salt River (Camsell, 1917)
10. Sulphur Point spring, south shore of Great Slave Lake (Camsell, 1917)
11. Bore-hole 26 ft. at Vermilion Chutes, Peace River (Camsell, 1917)

APPENDIX B: PRE-UPPER DEVONIAN STRATIGRAPHY OF ALBERTA AND ADJACENT AREAS

Certain conclusions and correlations were made earlier in this report without detailed explanatory stratigraphic data. These deficiencies are here remedied, with some additional conclusions which are believed to be pertinent to the nomenclature and correlations of the pre-Upper Devonian strata of Western Canada.

Age of the Evaporitic Deposits

Over most of Saskatchewan the Ashern Formation is the lowest series of beds that are associated with Devonian strata; this formation transgresses strata ranging in age from late Ordovician to late Middle Silurian (Niagaran). In the Meadow Lake area of Saskatchewan a series of evaporites and red beds (Meadow Lake formation) underlies so-called Ashern, and transgresses from the Deadwood formation (Cambro-Ordovician) over the Winnipeg formation (late Ordovician?), Red River formation (late Ordovician) and onto Middle

Silurian strata. In central and north-central Alberta a thick evaporite sequence rests upon Precambrian, Cambrian, and Ordovician rocks. The Chinchaga evaporites rest upon the Precambrian Basement in northwestern Alberta, although it is possible that the lower part, at least, of the red beds beneath the Chinchaga may be Ordovician in age, correlative with the Ordovician at Great Slave Lake. In the Great Slave Lake region evaporites overlie late Ordovician (Douglas, 1959; Lord, 1942; Hume, 1926). In the Mackenzie Basin the evaporite-carbonate sequence (Bear Rock formation) transgresses Middle Silurian (Niagaran Mount Kindle formation) to Lower (?) Silurian (Franklin Mountain formation) beds.

Thus, the latest definitely dated sub-Devonian-unconformity beds over this great area of Western Canada are of Middle Silurian age. The pre-Middle Devonian rocks above this unconformity thus cannot be older than Middle Silurian. During the interval between the end of Middle Silurian time and the deposition of the pre-Middle Devonian strata, uplift, warping and considerable erosion took place. The pre-Middle Devonian strata are structurally allied to the Middle Devonian succession and, therefore, it is highly probable that they are not late Silurian in age. These pre-Middle Devonian beds are therefore either Early or Middle Devonian in age. Beds of definite Early Devonian age have been recorded only from the Arctic Archipelago (Martin, 1959); in the lower part of the Hare Indian shale formation in the Northwest Territories (Warren and Stelck, 1950, 1956) have recorded the fauna of the *Radiastraea arachne* zone, which is the lowest Middle Devonian zone of Nevada. They state further that the fauna occurring below this in the Bear Rock formation has Lower Devonian affinities; Buller (1958) reports the presence of ostracods having a possible Middle Silurian-Lower Devonian range in the Meadow Lake beds of Saskatchewan, although he favors a Middle Devonian age for this formation. It is thus possible that the beds beneath the Methy formation and its equivalents are Lower Devonian in age. It should be noted that the lowest Middle Devonian zone (*R. arachne*) has not been recorded in the Elk point group; the Methy-Winnipegosan units belong to the *Stringocephalus burtini* zone, and the underlying Elm Point formation (included in the Methy of McMurray district) represents only the upper part of the *Ambocoelia meristoides* zone. The remainder of the *A. meristoides* zone and the *R. arachne* zone may be represented by an hiatus in the Elk Point evaporitic basins, or represented by the member 4—"Ashern" strata. Since the *A. meristoides* zone is present in the upper part of the Pine Point limestone (Warren and Stelck, 1950) it is possible that the complete succession of Middle Devonian zones is present within this formation. Although no fauna has been cited from the Keg River formation of the subsurface of northwestern Alberta, for reasons given below it is possible that all zones are present here also. It should, however, be noted that Crickmay (1954) states Middle Devonian plant spores have been recorded in many wells in Alberta and Saskatchewan at the base of his member 6, that is, below the second salt.

Ashern Formation Nomenclature

The basal beds of the Middle-Lower (?) Devonian rocks are almost invariably red beds; moreover, where adequate data are available it has been demonstrated that the shoreward facies of any particular facies is also red beds (Belyea, 1959; Walker, 1957). The Ashern formation—a series of red and grey shales, dolomitic marls, and mudstones — forms the basal beds of the Devonian over much of Saskatchewan, ranging in age from pre-Winnipegosan to post-Dawson Bay. Van Hees correlates this basal unit with similar sediments lying between the Winnipegosis and Meadow Lake in Saskatchewan, and with member 4 (underlying member 3) in central Alberta. It is noteworthy that there is no lithologic equivalent of member 4 at this horizon in the northern Alberta basin: the Keg River formation rests directly upon carbonates or anhydrite of the Chinchaga formation. It is suggested that inasmuch as the Keg River-Methy-Winnipegosan marine incursion is transgressive from the northwest, that whilst the lower zones of the Keg River were being deposited, lagoonal conditions existed south of the Chipewyan sill (also on the Shield shelf at McMurray) and that the member 4 and "Ashern" beds of the Meadow Lake area represent a silting-up of the evaporitic basin preceding the marine breakthrough in these areas during late *A. meristoides* time. In this case, the member 4 beds should be correlated with the lower Keg River carbonates and not with the upper Chinchaga as depicted in figure 20. This uncertainty in correlation is indicated in section A—A′, figure 20 (see also "Elk Point nomenclature" below). Thus, correlation of the Ashern of Saskatchewan where no Meadow Lake beds are present, with the beds overlying the Meadow Lake formation and member 4 of central Alberta, is misleading. The term Ashern should be therefore confined to the basal red beds of the Elk Point strata.

Middle-Upper Devonian Boundary

The Middle Devonian-Upper Devonian boundary in Western Canada is generally unconformable, or at least disconformable (Warren and Stelck, 1949). This stratigraphic break lies either below or above the *Cyrtina panda* zone, thus the *Caryorhynchus castanea* zone is probably Upper Devonian whilst the *Stringocephalus burtini* zone is certainly upper Middle Devonian (Givetian stage of Europe).

In the Northwest Territories the Fort Creek shales (bearing the

C. castanea fauna at its base) rests unconformably upon three different Middle Devonian formations: the Beavertail limestone (*C. panda* zone?), the Ramparts limestone (*S. burtini* and *R. laevis* zones) and Hare Indian shales (*A. meristoides* and *R. arachne* zones). In the vicinity of Great Slave Lake there seems to have been little erosion between Middle and Late Devonian time; for Upper Devonian Hay River shales rest upon the Slave Point formation which Warren (1957) equates with the Beavertail formation.

Correlations and interpretations in central Alberta and through Saskatchewan and Manitoba are tenuous and uncertain. In the McMurray area and central Alberta, member 1 and its equivalent, the Dawson Bay formation equivalent (Carrigy, 1959) is overlain by the Beaverhill Lake formation (Belyea, 1952).

The basal bed of the Beaverhill Lake formation in Bear Biltmore No. 1 consists of 8 feet of highly fossiliferous, light-brown limestone, which Belyea (1952) correlates with similar beds 60 feet thick in Socony Utikuma No. 1 well (Lsd. 12, Sec. 11, Tp. 78, R. 8, W. 5th Mer.), 25 feet thick in Imperial Dapp No. 1 well (Lsd. 5, Sec. 29, Tp. 62, R. 1, W. 5th Mer.), and about 6 feet thick in Anglo-Canadian Beaverhill Lake No. 2 well (Lsd. 11, Sec. 11, Tp. 50, R. 17, W. 4th Mer.). Overlying this unit Belyea (1952) reports widely distributed chocolate-brown shales and shaly limestones, generally 15 to 20 feet thick, but only one foot thick in Bear Biltmore No. 1 well. This lower limestone unit is readily distinguished on electric logs: it seems to be about 30 feet thick in T.G.T. Futurity Hondo No. 1 well (Lsd. 4, Sec. 15, Tp. 70, R. 2, W. 5th Mer.), 12 feet in Union Hondo No. 4 - 15 (Lsd. 4, Sec. 15, Tp. 70, R. 26, W. 4th Mer.) and 12 feet in Imperial Willingdon No. 1 well (Lsd. 14, Sec. 14, Tp. 55, R. 15, W. 4th Mer.). Eastwards in Saskatchewan Van Hees (1956) equated Member 1 with the First Red Bed plus the underlying Dawson Bay formation (Walker, 1957). The First Red Bed together with the overlying Davidson evaporite (or carbonate facies) is termed the Lower Souris River by Walker (1957). The top of this formation is taken at the base of a widely distributed grey shale unit at the base of the Upper Souris River, which is reported to rest unconformably upon Lower Souris River formation. In Manitoba the Point Wilkins formation (*Spirifer allani* zone) lies uncomformably upon the Dawson Bay (*Stringocephalus burtini* zone) (Warren and Stelck, 1956).

In northwestern Alberta Law (1955) has demonstrated that the Fort Vermilion anhydrite is a facies of the Slave Point carbonates.

At least the lower 5 feet of the basal Beaverhill Lake limestone in Bear Biltmore No. 1 well has been shown to be correlative with the Slave Point (Crickmay, 1957); it would seem logical to correlate the upper anhydritic beds of Carrigy's (1959) Dawson Bay with the Fort

Vermilion member of the Slave Point, for example: 26 feet of anhydrite at the top of the Dawson Bay in Bear Westmount No. 1, 30 feet of anhydrite in Bear Vampire No. 1 and 33 feet of anhydrite, gypsum and shale in Alberta Government Salt Well No. 2. This correlation for Bear Biltmore No. 1, Bear Rodeo No. 1, and Bear Westmount No. 2 is shown in figure 20.

If Warren's (1957) correlation of the Slave Point formation with the Beavertail formation is correct, then it follows that the late Middle Devonian unconformity (probably, but not certainly, marking the division between Middle and Upper Devonian) must be post-Slave Point. The fact that Slave Point limestone is overlain by shales containing a lower Beaverhill Lake fauna at Peace Point, and the indentification of a Slave Point fauna in the basal Beaverhill Lake limestone in Bear Biltmore No. 1 suggests that this lower limestone unit in central Alberta may be correlated with the Slave Point. Accepting this as a working hypothesis, the late Middle Devonian stratigraphy of Alberta and adjacent areas is interpreted thus: marine conditions, which became permanently established in the Great Slave area in Pine Point time onward, reached north-central Alberta in late Slave Point time and are represented by the basal limestone unit of the Beaverhill Lake formation in central Alberta; in parts of Saskatchewan evaporitic conditions obtained throughout Slave Point time (Davidson evaporite). Prior to the deposition of Upper Devonian sediments, warping and erosion occurred. This period of emergence was quite prolonged in parts of the Northwest Territories (Warren and Stelck, 1949) and Manitoba (Warren and Stelck, 1956), whilst probably of short duration in the Great Slave Lake area (Warren and Stelck, 1949). In Saskatchewan the break in sedimentation is evidenced by the unconformable relationship between the Upper and Lower Souris River formations (Walker, 1957); it is suggested that the wide variation in the thickness of the basal limestone unit of the Beaverhill Lake formation is a result of this unconformity in central and north-central Alberta.

Elk Point Nomenclature

Van Hees (1956) proposed that the Elk Point formation should be divided into an upper and a lower member: the upper member between the top of the First Red Bed and the base of the Ashern; the lower member below the Ashern. It is believed that the present state of knowledge warrants a revision of the Elk Point nomenclature, and although no formal proposals are made, the following remarks are considered pertinent to such a revision.

Upper Boundary of Upper Elk Point

By the same reasoning as Van Hees (1956, p. 37) proposed that the First Red Bed and the Dawson Bay formation should be included in the Elk Point group, beds above the First Red Bed and below the Middle-Upper Devonian unconformity should be placed in the Elk Point also. Thus, although they may be predominantly marine in Alberta (however, note the Fort Vermilion anhydrite at the base of the Slave Point in northern Alberta), in areas remote from marine influences as in Saskatchewan, evaporitic conditions prevailed.

Lower Boundary of Upper Elk Point

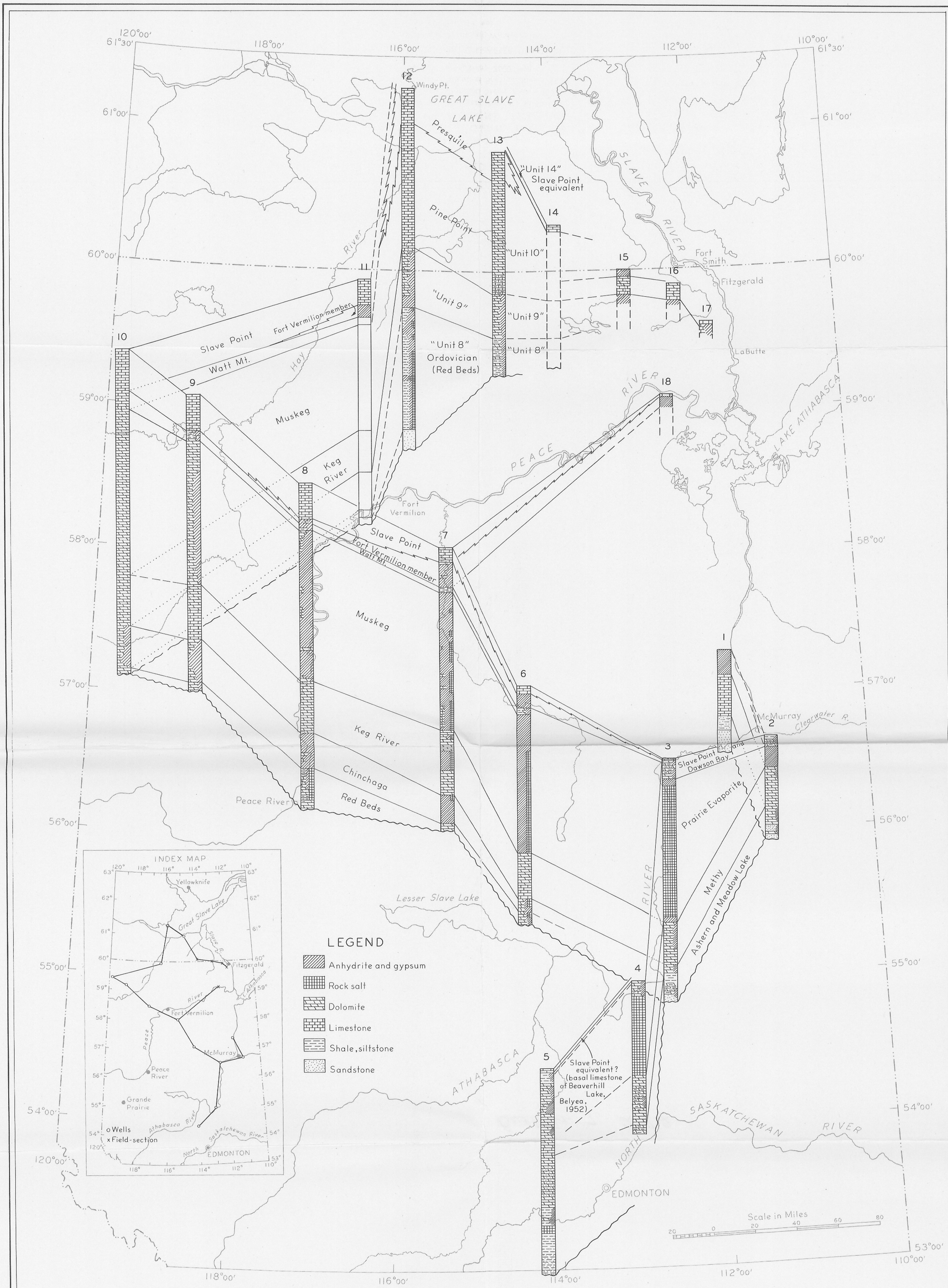
The usefulness of placing the boundary at the base of a red-bed sequence (member 4) is questionable except perhaps in Saskatchewan outside the area of Meadow Lake deposition. This is particularly so when correlating into northern Alberta where lithologically similar beds are absent. Greater practical advantages would result from placing it at the base of the carbonate unit (Methy-Winnipegosis and equivalents) as this forms a very widespread, readily recognizable, lithologic unit. If this terminology were adopted, then all questionably dated early Devonian evaporitic sequences in Western Canada could be referred to a single sub-group, lower Elk Point: the Bear Rock formation below the Hare Indian Shales formation of the Mackenzie Basin; Unit 9 evaporites (Douglas, 1959) below the Pine Point limestones; the Chinchaga evaporites and underlying red beds (although the lower strata of these red beds may be Ordovician in age; see p. 58) below the Keg River carbonates in northwestern Alberta; Crickmay's (1954) evaporitic members 4, 5, 6, 7, 8, and 9 below member 3 in central Alberta; Meadow Lake and Ashern formations below the Winnipegosan carbonates in Saskatchewan.

FIGURE 3

GEOLOGICAL MAP SHOWING PART OF WILDERNESS PROVINCIAL PARK AND ADJACENT AREAS

WEST OF SIXTH MERIDIAN

Scale in Miles



SOURCES OF INFORMATION, NAMES OF WELLS AND FIELD SECTIONS, AND DEPTH FROM SURFACE AT TOP SECTION

WELLS AND FORMATIONS AFTER CARRIGY, 1959:

1 Athabasca Oils No. 1; 590 feet
2 Bear Westmount No. 2; 407 feet
3 Bear Biltmore No. 1; 1670 feet

WELLS AND FORMATIONS AFTER BELYEA, 1952:

4 Bear Maxgeorge No. 1; 3645 feet to base at Beaverhill Lake
5 Imperial Dapp No. 1; 5945 feet

WELLS AND FORMATION AFTER LAW, 1955:

6 Imperial House Creek No. 1; 3300 feet
7 H.B. Fort Vermilion No. 1; 2240 feet
8 Imperial Crossroads No. 1; 3300 feet
9 California Standard Steen River; 4270 feet
10 California Standard Shekilie River; 5500 feet
11 Imperial Yates River; 2600 feet

WELLS AND FORMATIONS AFTER DOUGLAS, 1959:

12 Northwest Territories Windy Point No. 1; 6 feet
13 Cominco G-1; 13 feet

SURFACE EXPOSURES; MAINLY AFTER DOUGLAS, 1959 AND CAMSELL, 1917:

14 Needles Lake
15 Little Buffalo River falls
16 Salt River escarpment
17 Salt River escarpment
18 Peace Point

FIGURE 18. Fence diagram showing stratigraphical correlations of Middle Devonian rock units in northern Alberta and adjacent areas in the Northwest Territories