POTASH SALTS IN THE WILLISTON BASIN, U.S.A.

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Abstract

The potash deposits of North Dakota and Montana are extensions of the rich deposits now being mined in Saskatchewan. These deposits underlie 28,500 km² (11,000 sq miles) in northwestern North Dakota and 7,800 km² (3,000 sq miles) in northeastern Montana. The Middle Devonian potash deposits occur in beds within the Prairie Formation, an evaporitic sequence composed primarily of halite. The Prairie Formation evaporites were deposited within the Devonian Elk Point Basin, which extended from northwestern Alberta to the northwestern North Dakota–northeastern Montana area. On the U.S. side of the border, the Prairie Formation salt reaches a maximum thickness of 168 m (550 ft) in Burke County, North Dakota, whereas in Saskatchewan it exceeds 213 m (700 ft). North Dakota's potash ranges from 1,707 m (5,600 ft) deep near its eastern limit in northwestern Bottineau County to over 3,660 m (12,000 ft) in eastern McKenzie County. In Montana, the deposits range from 2,530 m (8,300 ft) in Daniels County to 3,500 m (11,500 ft) in Richland County. Three potash zones can be identified in Saskatchewan and North Dakota; two, in Montana. In North Dakota, the two major beds, the Esterhazy and Belle Plaine, reach a combined gross thickness of 25 m (83 ft) and a net thickness of 17 m (55 ft). In Montana they reach a combined thickness of 19 m (61 ft) gross and 13 m (43 ft) net.

Introduction

THE potash deposits of North Dakota and Montana are extensions of rich deposits now being mined in Saskatchewan. The potash deposits underlie 11,000 sq miles (28,500 km²) in northwestern North Dakota and 3,000 sq miles (7,800 km²) in northeastern Montana. They are of Middle Devonian age and occur in beds within the Prairie Formation (Fig. 1), an evaporitic sequence composed primarily of halite, but also potash and anhydrite. The formation conformably overlies the Winnipegosis Formation and is conformably overlain by the Dawson Bay Formation. Both formations are of Devonian age and are composed primarily of carbonates.

The evaporites of the Prairie Formation were deposited in the Devonian Elk Point Basin, a large trough which extended southeastward from the Northwest Territories and northwestern Alberta to its southern terminus in northwestern North Dakota and northeastern Montana (Fig. 2).

Geologic History of the Potash Units

During deposition of the Winnipegosis Formation, reefs, which restricted inflow of waters from the open sea, formed in Alberta in the northern part of the Devonian Elk Point Basin. Circulation within the basin was further restricted by reefs that formed on structural highs in the northwestern part of the basin and along the basin margins (Saskatchewan Dept. Min. Resources, 1973). These restrictions, coupled with arid conditions, caused concentration of brines within the Elk Point Basin, resulting first in deposition of gypsum, then of halite, and finally of potassium salts. Periodic influxes of fresh sea water into the basin caused deposition of alternating beds of halite and potash. Potash deposition was restricted to the southern part of the Elk Point Basin, an area that covers parts of Saskatchewan, North Dakota, Montana, and a small part of Manitoba adjacent to the Saskatchewan border.

Initial evaporite deposition of the Prairie Formation in North Dakota and Montana is represented by a basal anhydrite (Fig. 3). Deposition of anhydrite on the U. S. side of the international boundary appears to have been restricted to North Dakota and extends 60 to 65 miles (96 to 104 km) east of the present salt limits of the Prairie. The anhydrite may indicate the original extent of the salt. Solution is known to have occurred along the eastern salt margins in western Bottineau, eastern Renville, and northeastern Ward Counties, North Dakota, but whether salt extended as far east as the anhydrite is unknown. The eastern edge of the basal anhydrite is farther east than the eastern edge of the overlying Prairie salt, which may indicate a westward tilt of the Williston Basin in early Prairie time with a resulting westward shift in deposition. Westward tilting of the basin is also indicated in Saskatchewan (Holter, 1969).

Following deposition of salt of the Prairie Formation, the Dawson Bay carbonates were conformably deposited. A reddish argillaceous bed known as the "second red" that occurs at the base of the section

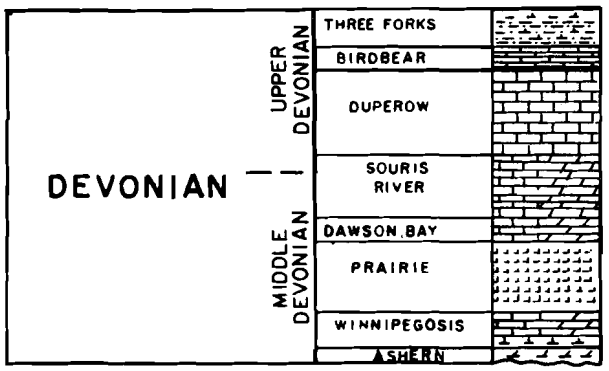

FIG. 1. Stratigraphic section of the Devonian system, Williston Basin, U. S. A.

probably kept waters of the Dawson Bay Sea from coming in contact with the salt.

Geology of the Deposits

The present limits of the Prairie salt in the United States are from western Bottineau County in north-central North Dakota to Daniels County in eastern Montana and as far south as northern Dunn County in west-central North Dakota (Fig. 4). Evidence of solution is indicated along both the eastern and western margins as well as in three other areas in eastern Montana. Thickness of the salt ranges from a feather-edge along the margins to over 500 ft (150 m) in Burke County, North Dakota. In Montana, the thickest section is in east-central Sheridan County where the salt has a thickness of slightly more than 300 ft (90 m).

On the U. S. side of the international boundary, as in Saskatchewan on the Canadian side, three potash beds are present (Fig. 5). The Esterhazy and Belle Plaine Members, the lower beds, are present in both North Dakota and Montana and continue across the international boundary. The upper bed, termed the "Patience Lake Member" in Saskatchewan and the "Mountrail Member" in the U. S., is discontinuous and cannot be traced across the boundary; however, the two members are probably correlative. The Mountrail Member is not known to occur in Montana.

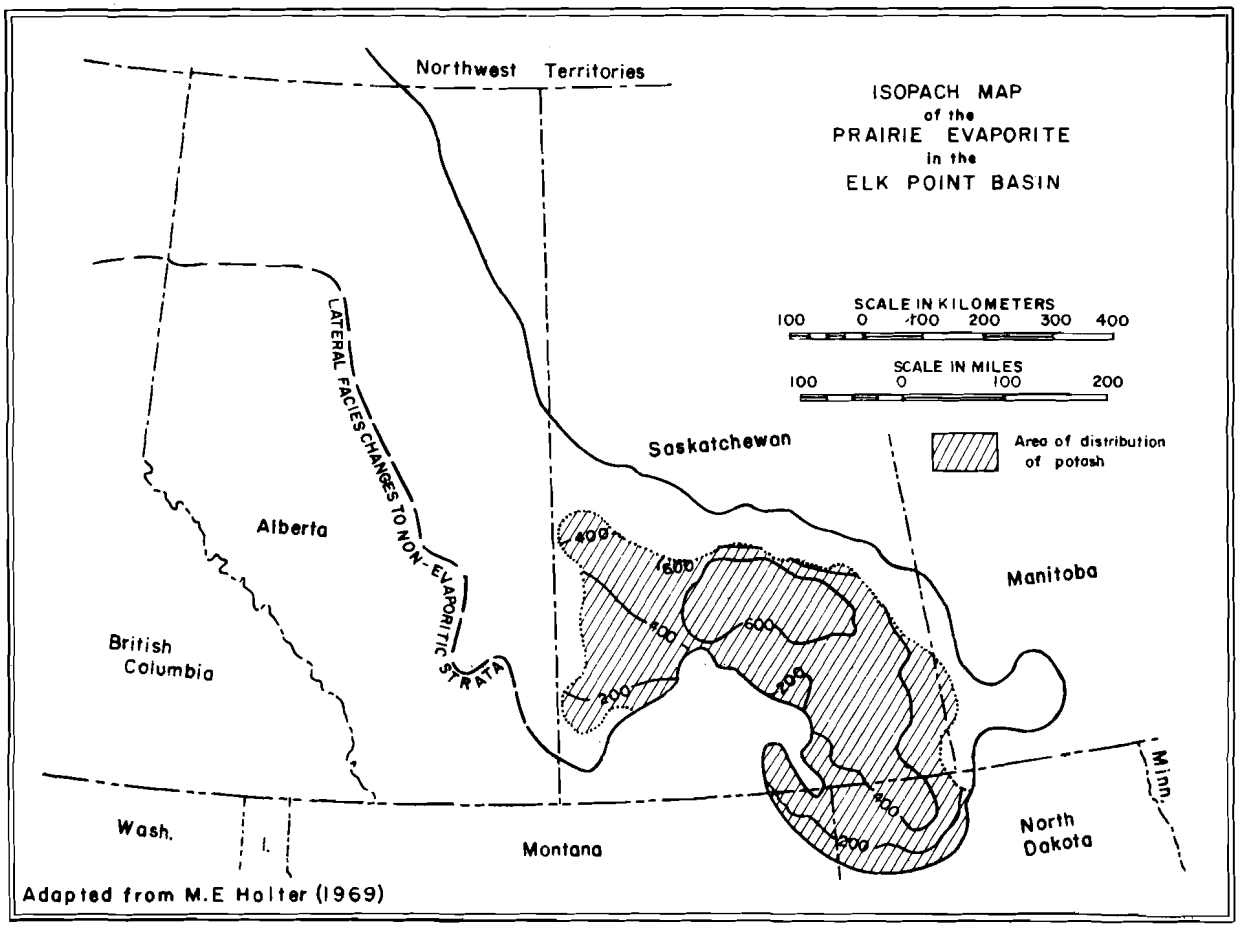

FIG. 2. Devonian Elk Point Basin.

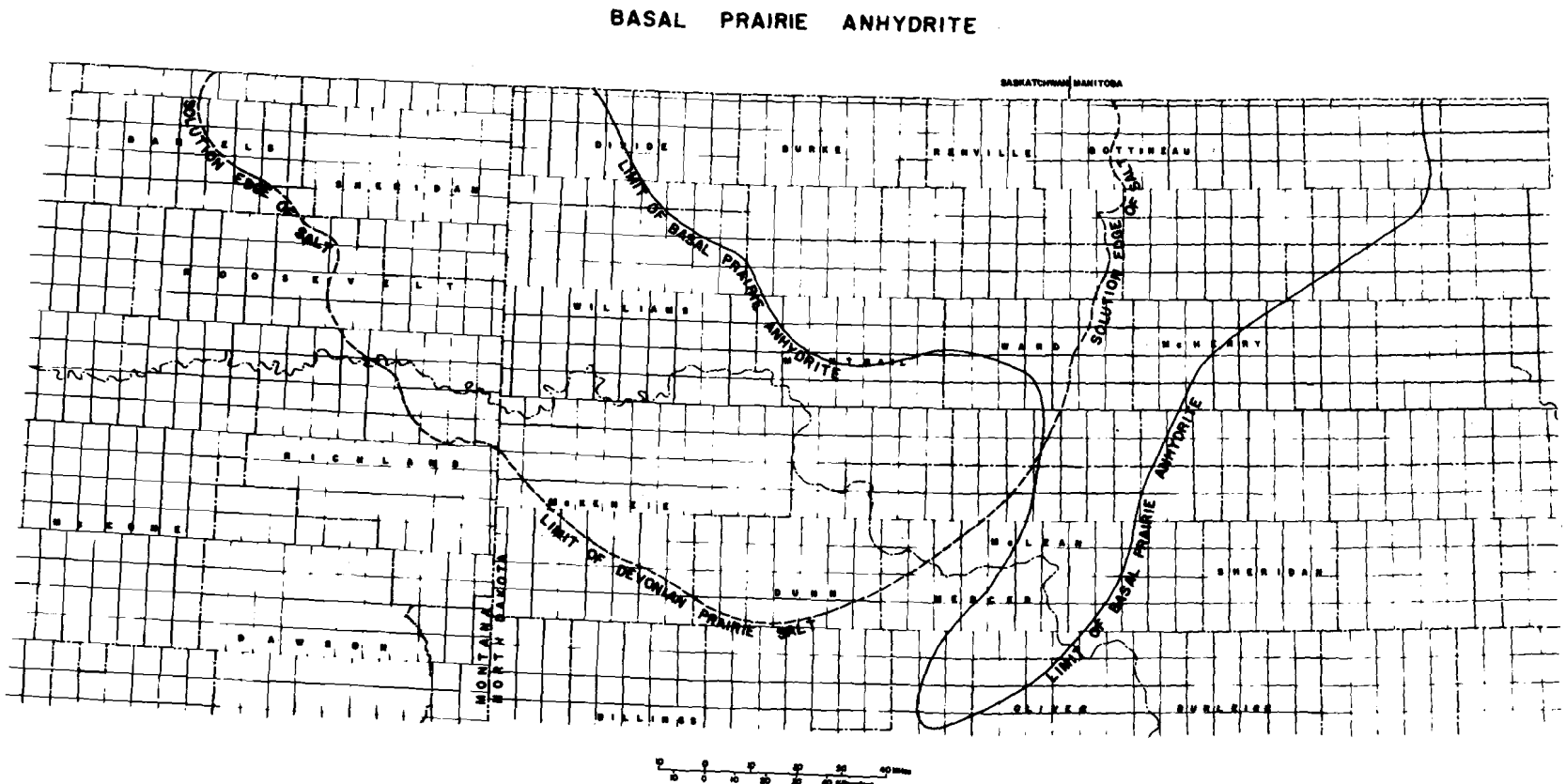

FIG. 3. Extent of the basal Prairie anhydrite and Prairie salt in northwestern North Dakota and northeastern Montana.

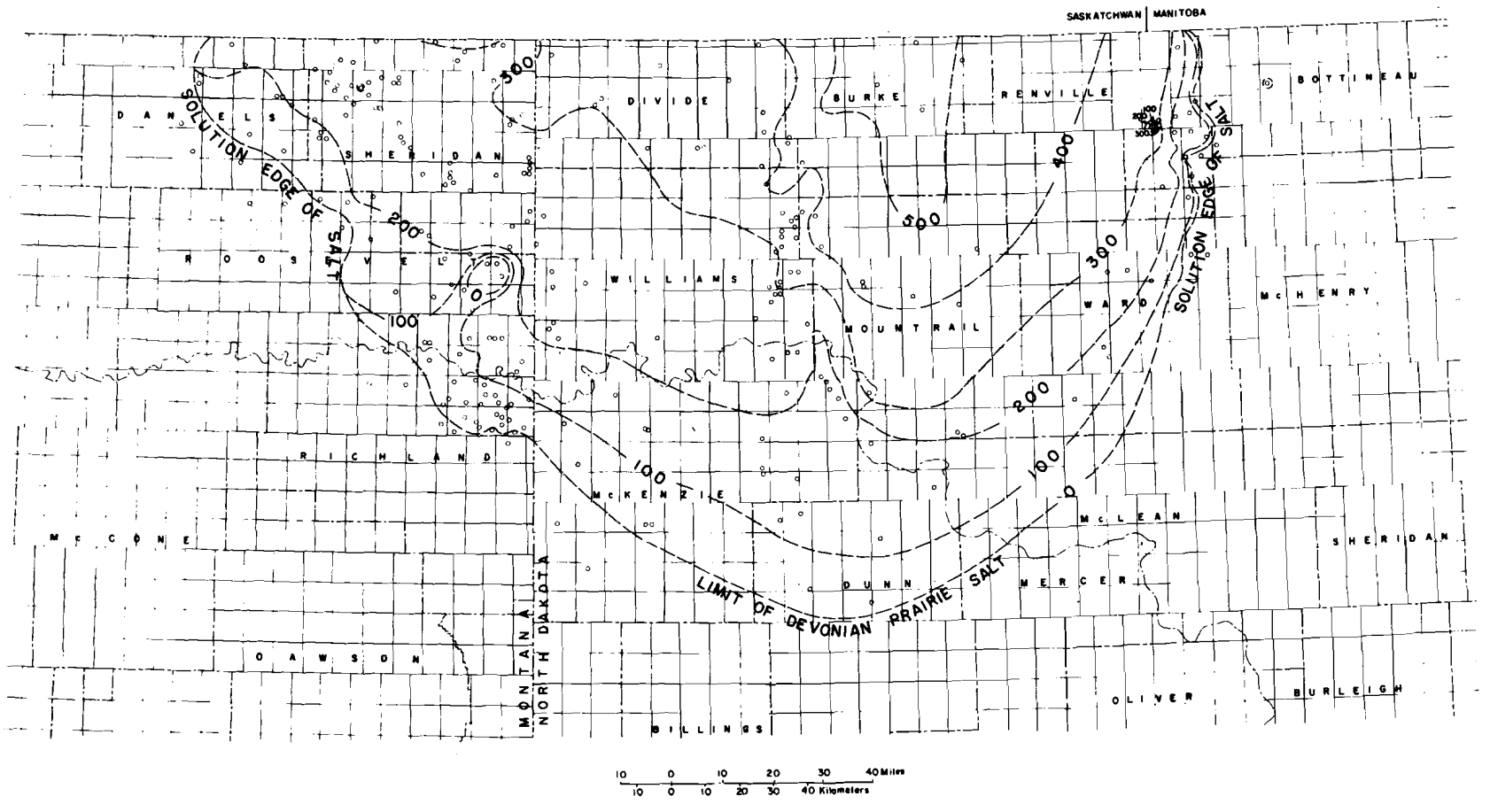

FIG. 4. Prairie salt isopach in northwestern North Dakota and northeastern Montana.

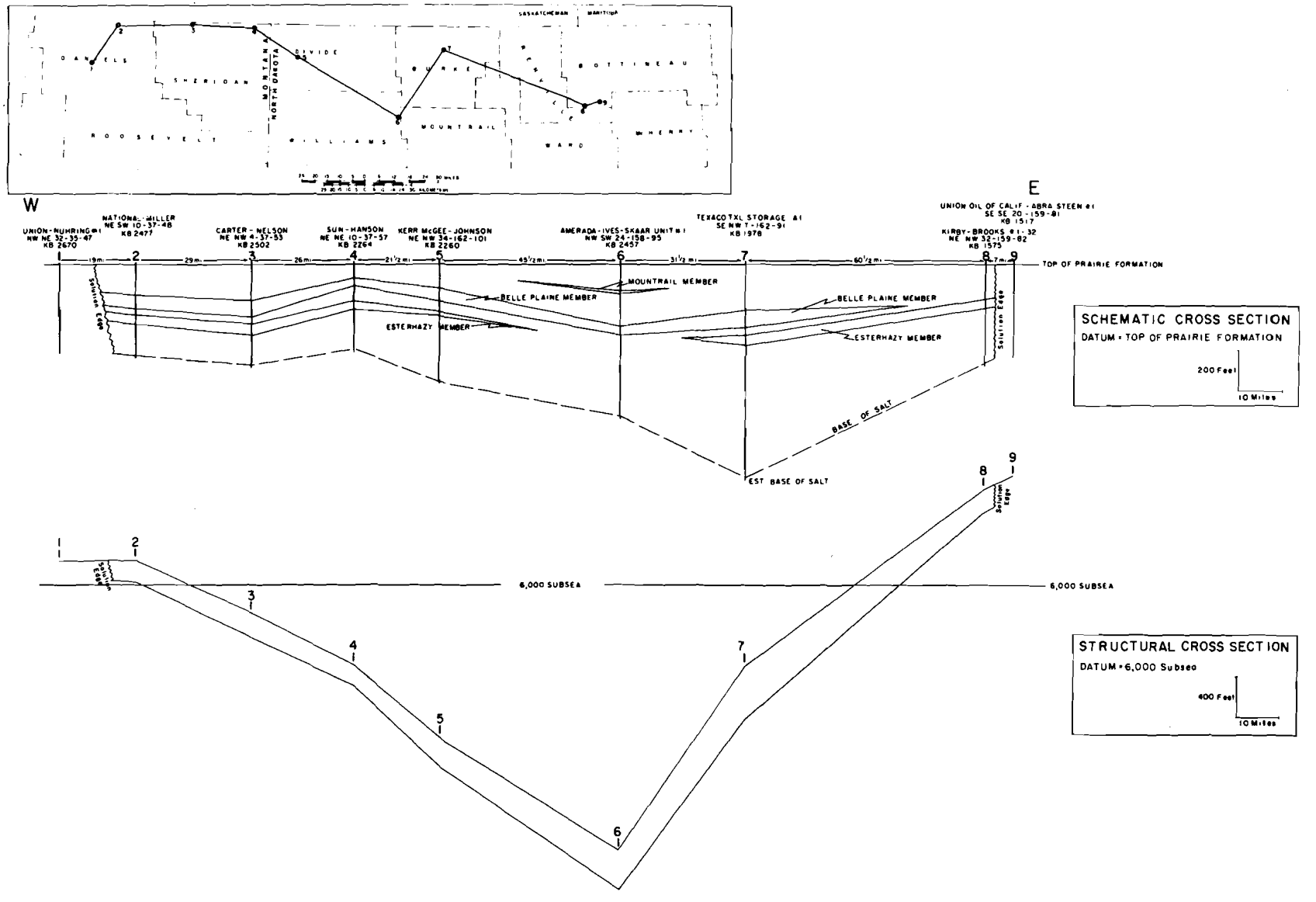

FIG. 5. Schematic and structural cross sections of the Prairie Formation, northwestern North Dakota and northeastern Montana.

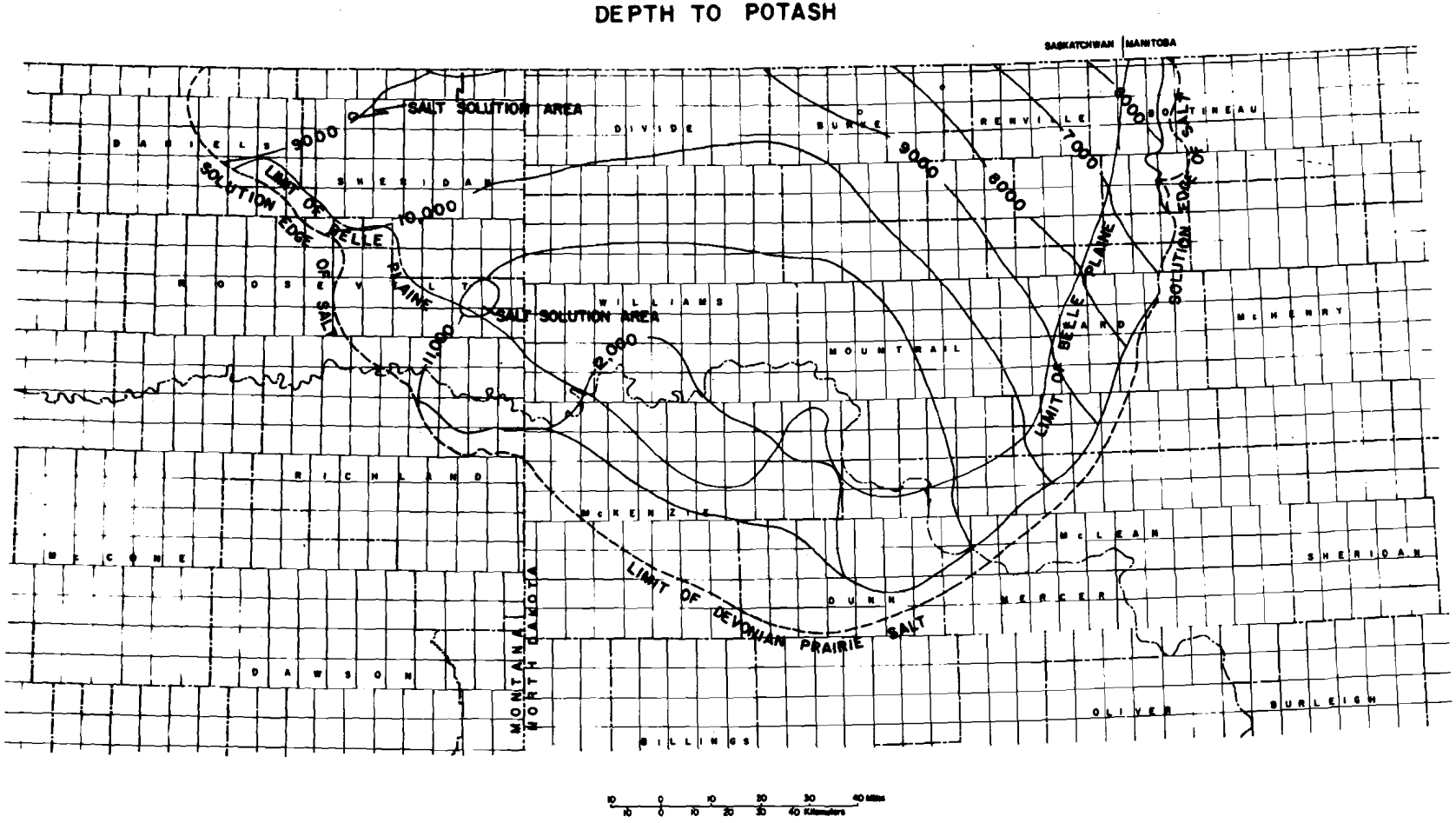

FIG. 6. Depth to potash in northwestern North Dakota and northeastern Montana.

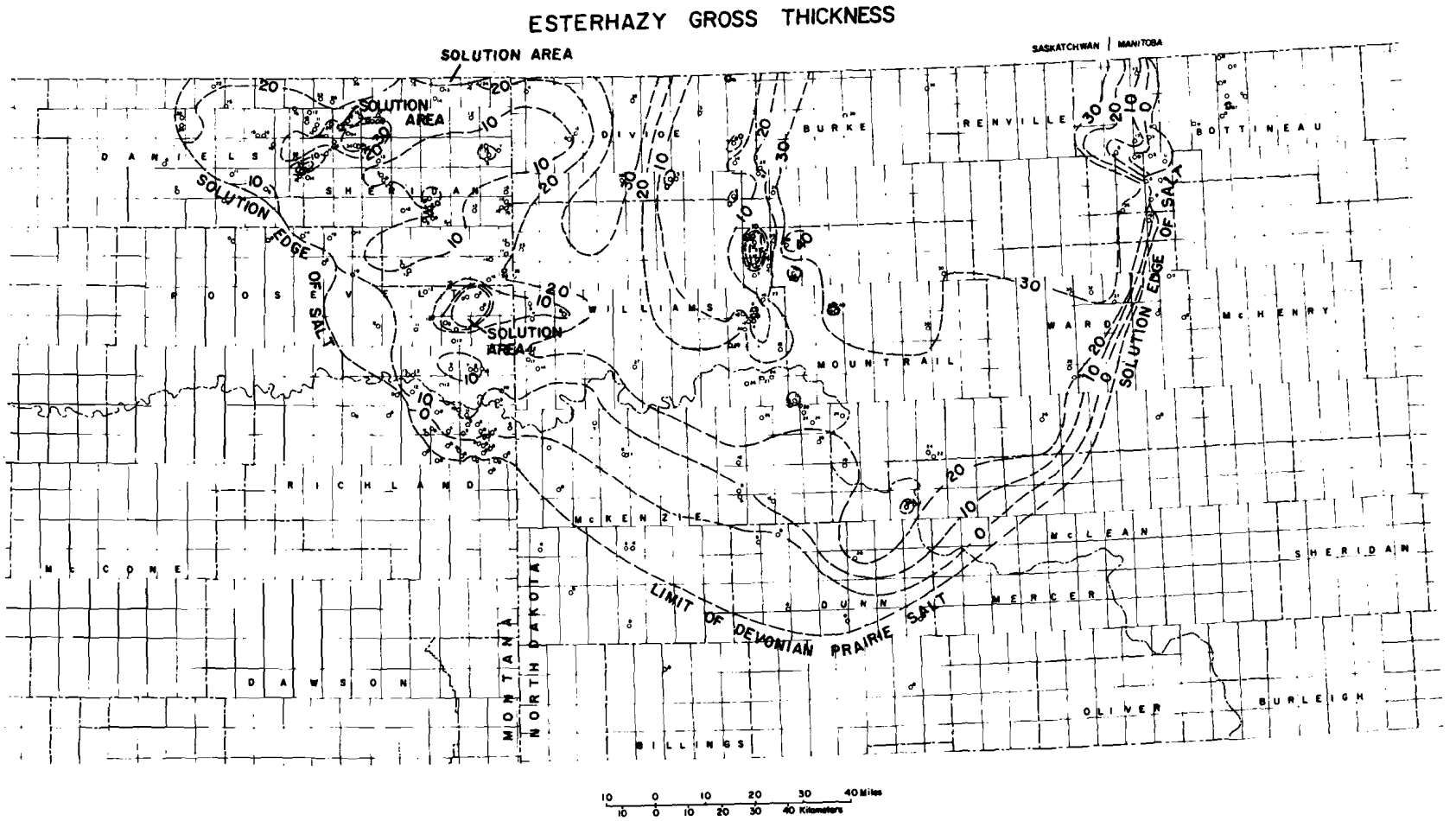

FIG. 7. Gross thickness of the Esterhazy Member of the Prairie Formation in northwestern North Dakota and northeastern Montana.

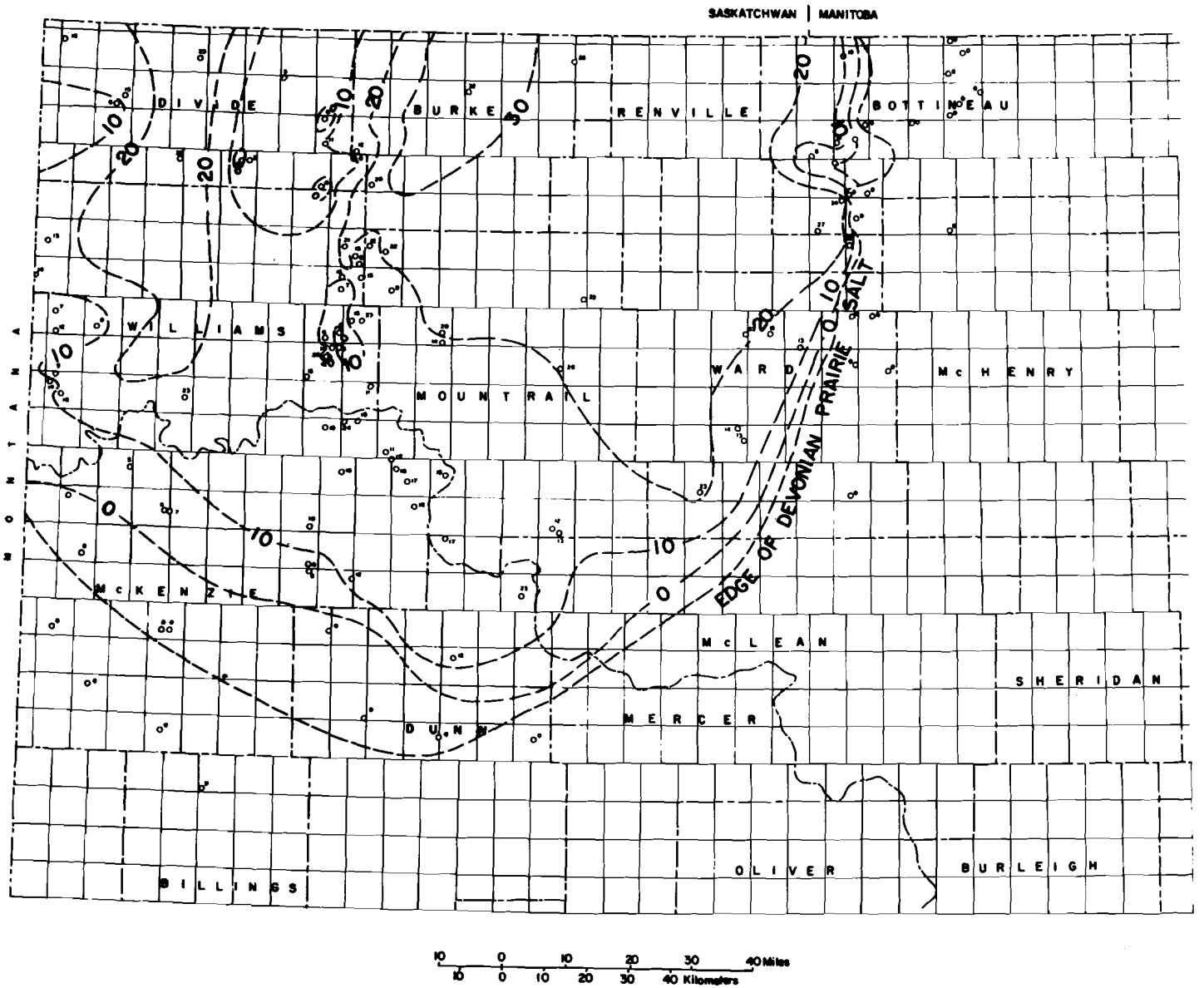

FIG. 8. Net thickness of the Esterhazy Member of the Prairie Formation in northwestern North Dakota.

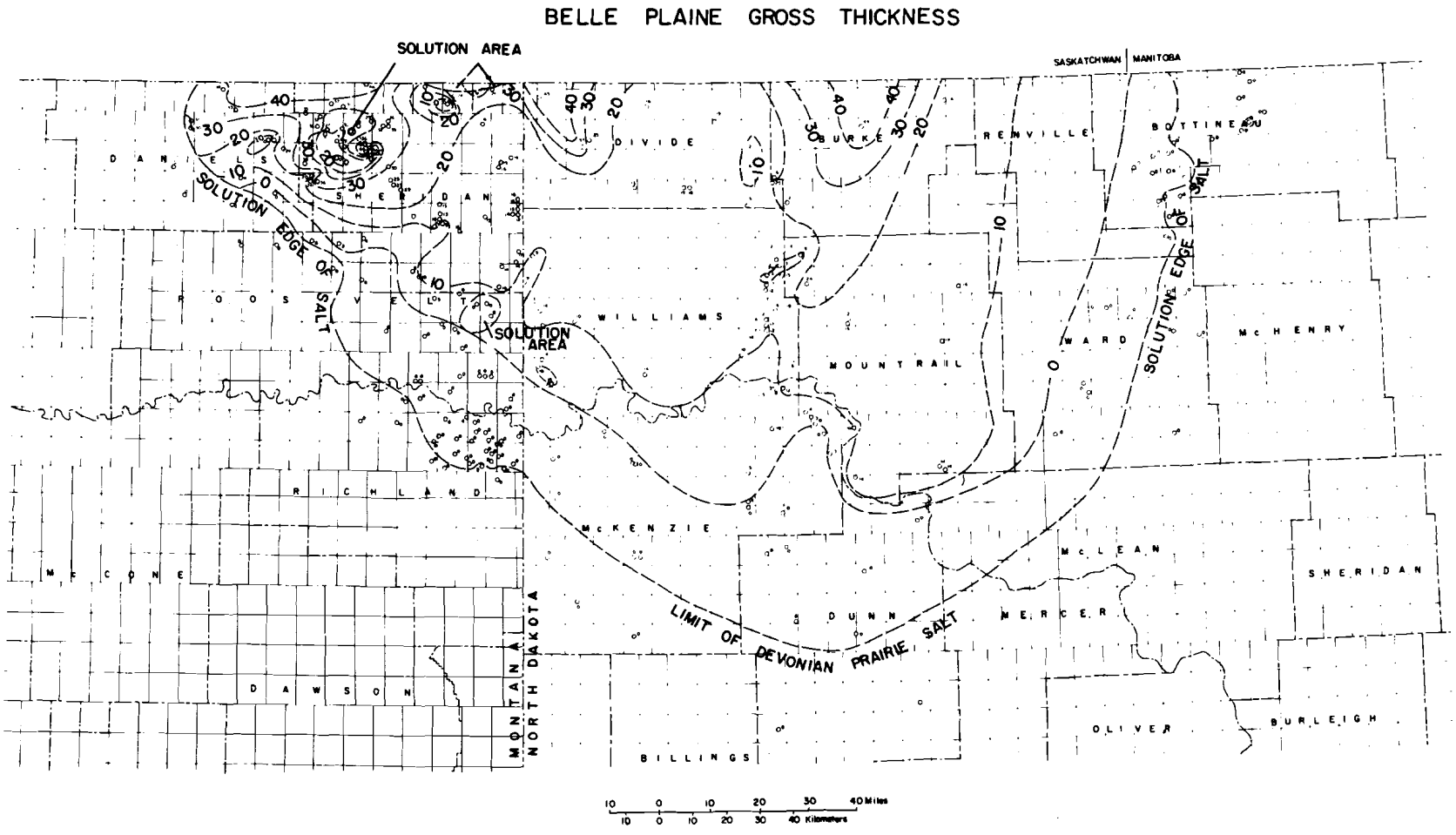

FIG. 9. Gross thickness of the Belle Plaine Member of the Prairie Formation in northwestern North Dakota and northeastern Montana.

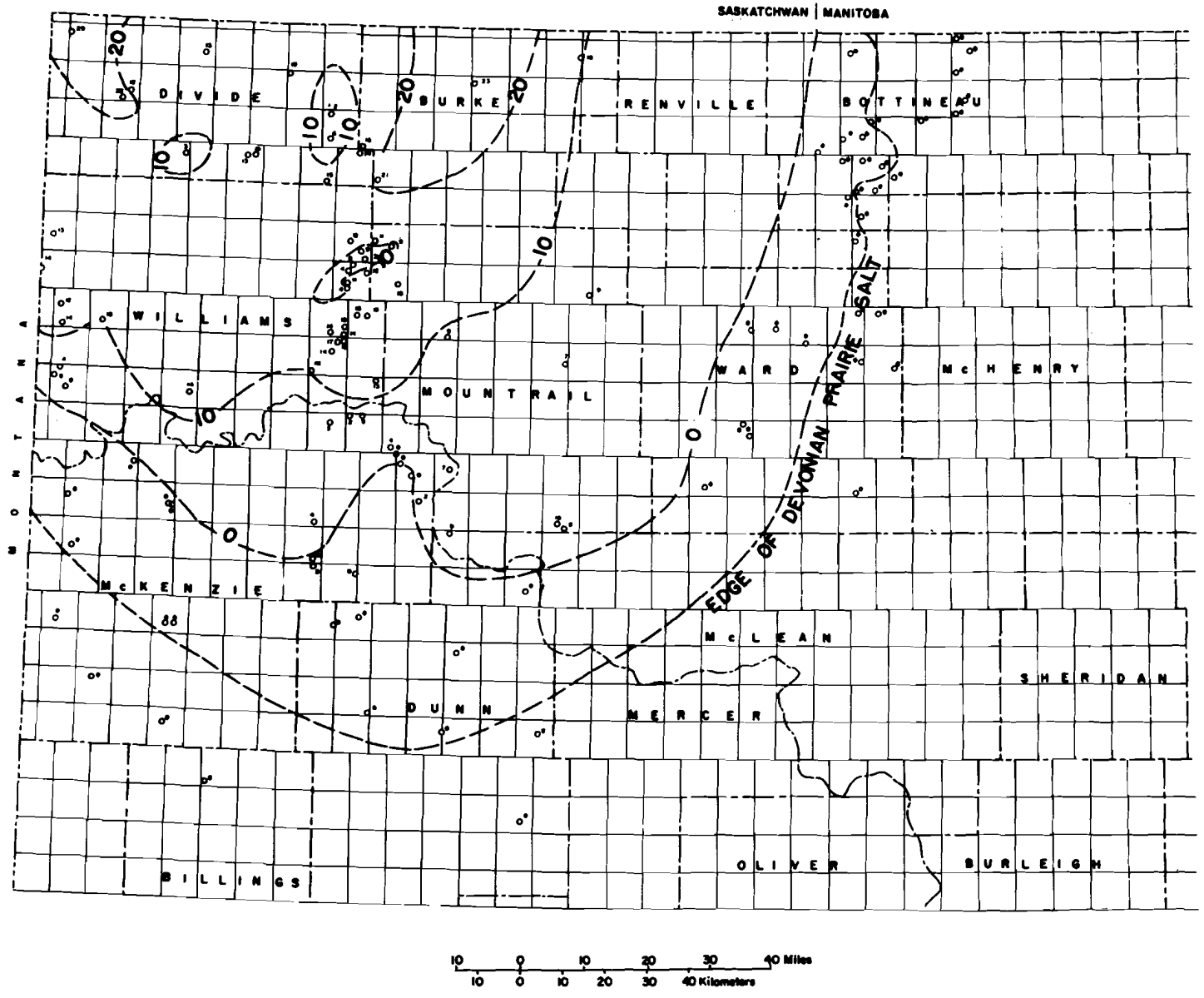

FIG. 10. Net thickness of the Belle Plaine Member of the Prairie Formation in northwestern North Dakota.

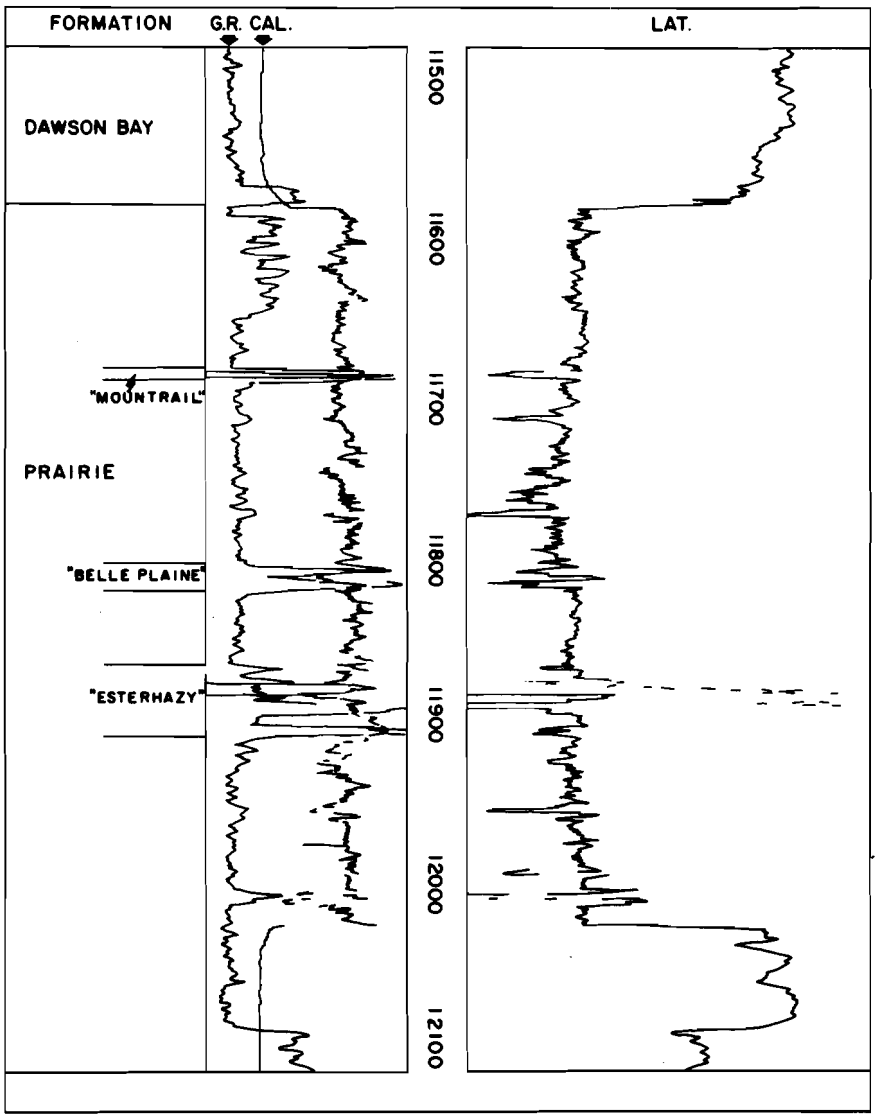

FIG. 11. Log section of the Shell Oil Company–Texel No. 21–35 well, Mountrail County, showing the Prairie Formation.

The two major beds, the Esterhazy and Belle Plaine Members, reach a combined gross thickness of 83 ft (25 m) and a net thickness of 55 ft (17 m) in North Dakota. In Montana they reach a combined thickness of 61 ft (18.5 m) gross and 43 ft (13 m) net.

This study is based on apparent potash-bed thicknesses from gamma ray logs. The thicknesses were determined by selecting characteristic points on the well logs; however, actual minable thicknesses may be less because of the gradational contacts of halite and sylvite.

The potash deposits of North Dakota and Montana occur at depths exceeding 3,500 ft (1,065 m), which precludes the possibility of conventional shaft-mining and makes solution-mining the only viable method

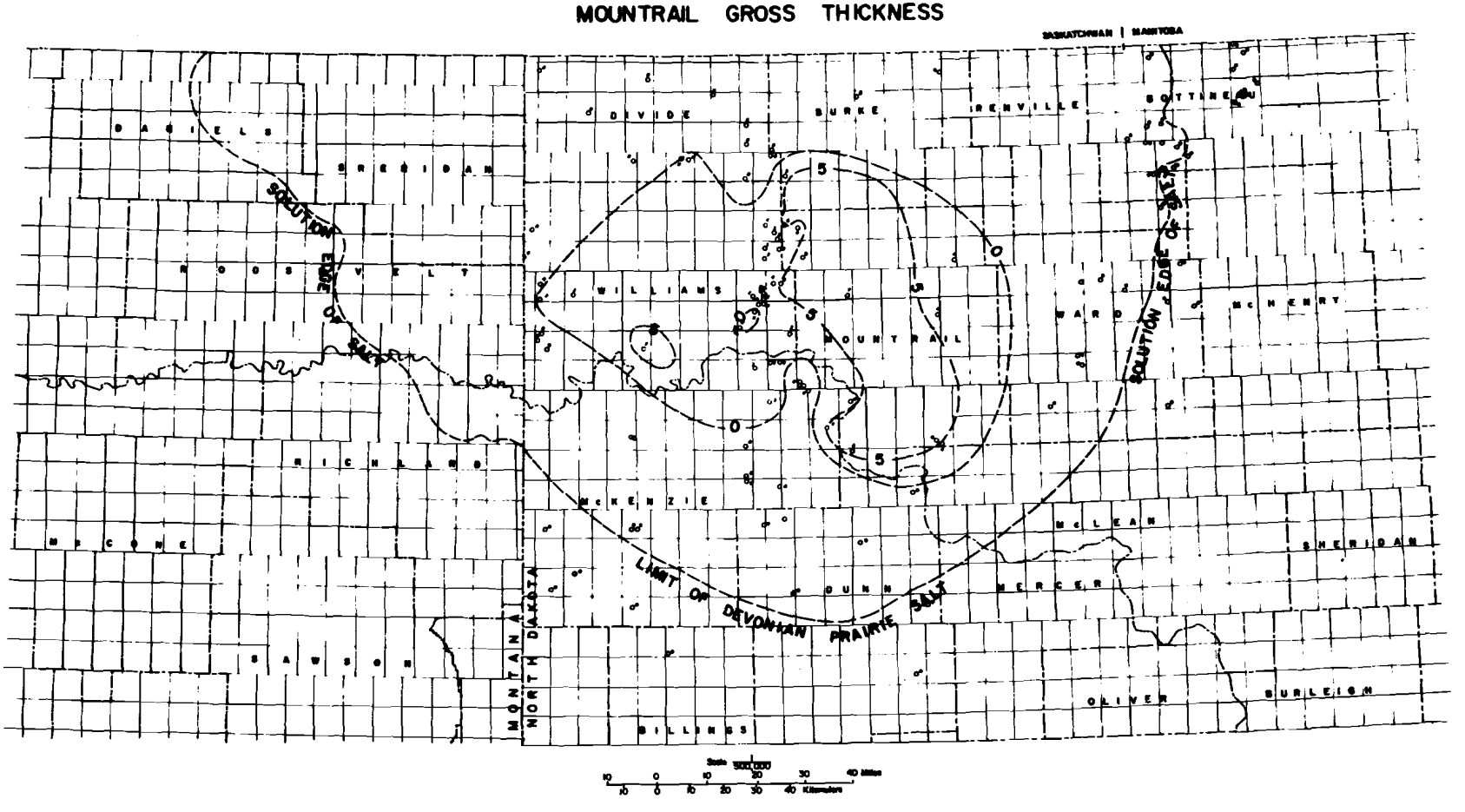

FIG. 12. Gross thickness of the Mountrail Member of the Prairie Formation in the study area.

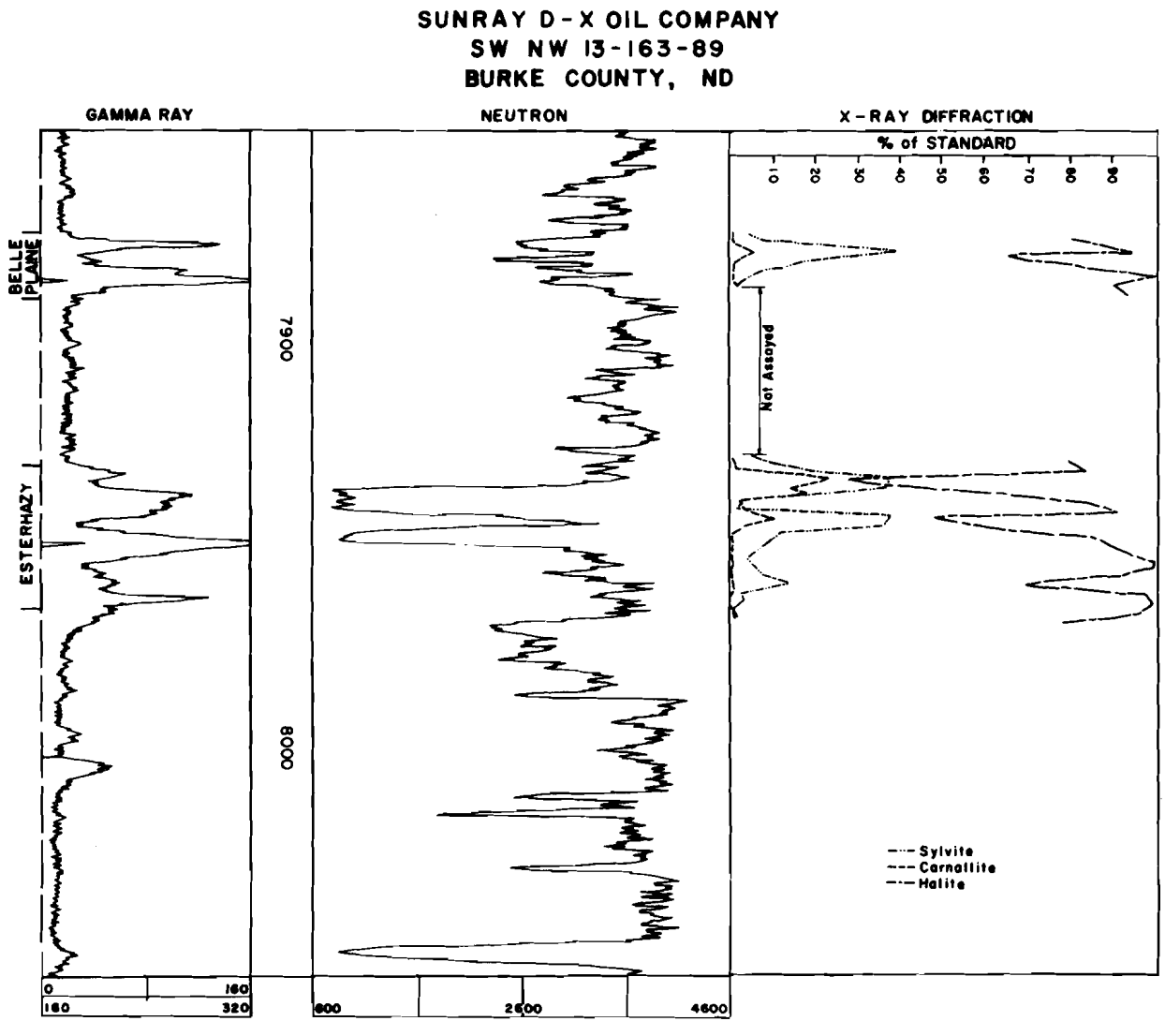

FIG. 13. Log section of the Prairie Formation in the Sunray D-X well in northeastern Burke County, North Dakota, with X-ray analysis.

(Fig. 6). In North Dakota depths range from 5,600 ft (1,700 m) near the eastern limit in northwestern Bottineau County to over 12,000 ft (3,650 m) in southern McKenzie and northern Dunn Counties. Depths in Montana range from 8,300 ft (2,530 m) near the western limit in Daniels County to 11,500 ft (3,500 m) in Richland County (Fig. 6).

Esterhazy Member

The Esterhazy Member is the most extensive potash bed in the U. S. portion of the Williston Basin (Fig. 7); extending westward from western Bottineau County, North Dakota, to Daniels County, Montana, and south from the international boundary to northeastern Dunn County, North Dakota. This member is also the lowest stratigraphically and the shallowest. The Esterhazy Member occurs at a depth of 5,632 ft (1,717 m) in northwestern Bottineau County, which is the shallowest known occurrence of potash in the U. S. portion of the basin.

In North Dakota, the Esterhazy Member has a maximum known gross thickness of 44 ft (13 m) at a depth of 11,800 ft (3,600 m) in west-central Mountrail County. In eastern and central Burke County,

North Dakota, gross thicknesses of 38 to 39 ft (12 m) are developed at depths of 7,900 ft (2,400 m) to 7,000 ft (2,130 m). In Montana, gross thicknesses of 31 ft (9.4 m) to 34 ft (10 m) are developed in west-central Sheridan County at a depth of about 9,000 ft (2,750 m). Three areas without potash occur in eastern Divide County, North Dakota, and another in southeastern Williams County. These areas occur where the potash is generally less than 10 ft (3 m) thick. The possible explanations are: (1) the Nesson anticline may have influenced deposition; (2) the area may have been higher than surrounding areas during deposition of the potash; and (3) fresher water may have entered the area and dissolved the potash soon after deposition.

In North Dakota the maximum net thickness known is 32 ft (10 m) in north-central Burke County (Fig. 8). The net thickness equals the gross thickness of the potash member minus the thickness of the interfingering halite beds. Other areas in North Dakota with substantial net thicknesses are: central Divide County, 29 ft (9 m); northeastern Burke County, 28 ft (8.5 m); and southwestern Bottineau County, 27 ft (8 m). In Montana the maximum net thickness is 22 ft (7 m) in northwestern Sheridan County.

Belle Plaine Member

The Esterhazy and Belle Plaine Members are separated by an interval of halite that ranges from

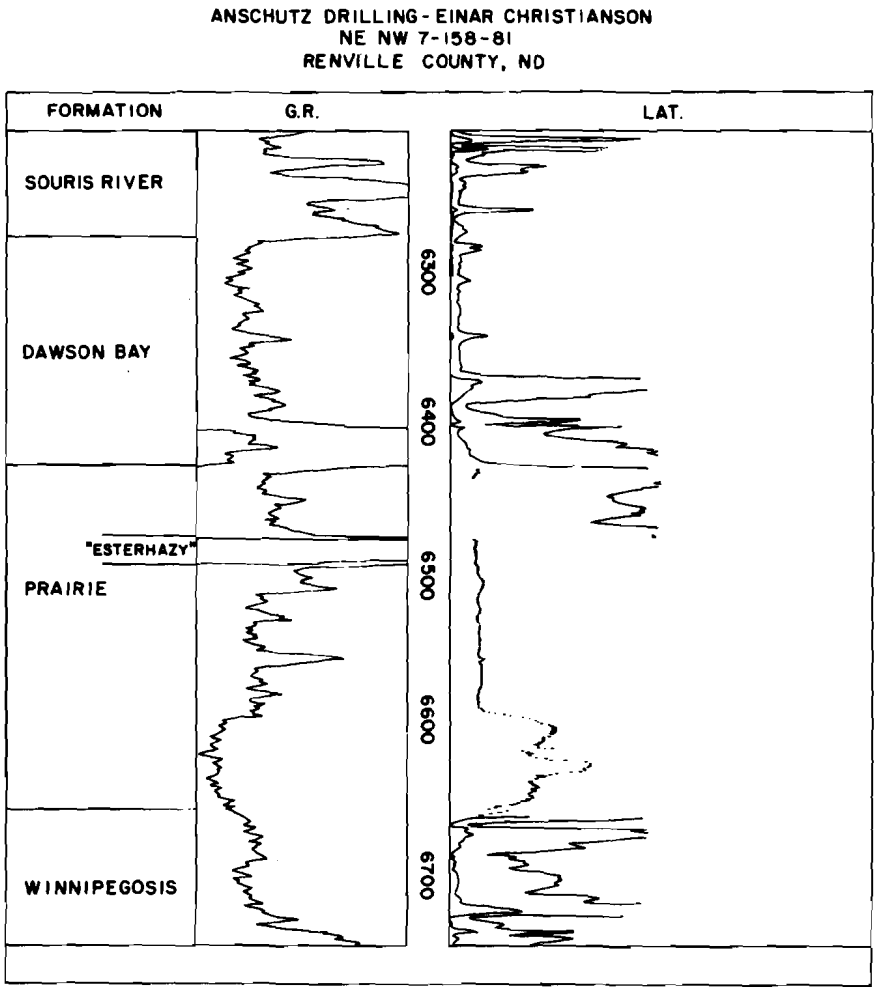

FIG. 14. Log section of the Prairie Formation in the Anschutz Drilling-Einer Christianson well in Renville County, North Dakota.

less than 15 ft (4.5 m) to more than 50 ft (15 m) thick. The Belle Plaine Member, which is not as extensive as the Esterhazy Member, extends from western Bottineau County, North Dakota, west to central Daniels County, Montana, and south from the international boundary to northeastern Dunn and east-central McKenzie Counties, North Dakota (Fig. 9). The greatest known gross thickness in the U. S. portion of the Williston Basin is in west-central Sheridan County, Montana; here the member attains a thickness of 46 ft (14 m) at a depth of slightly more than 9,000 ft (2,750 m). In North Dakota, the greatest known thicknesses are in northwestern Divide County where the gross thickness reaches 45 ft (14 m) and in central Burke County where it reaches 44 ft (13 m). Net thicknesses in North Dakota reach maximums of 29 ft (8.8 m) in Divide County and 23 ft (7 m) in central Burke County (Fig. 10). In Montana they are as much as 38 ft (12 m) in northeastern Daniels County and 30 ft (9 m) in northwest Sheridan County.

Mountrail Member

The Belle Plaine Member is overlain by another potash member that has not been named; it is here informally named the Mountrail Member. Between the Belle Plaine and Mountrail Members is an interbed of halite that ranges in thickness from 40 ft

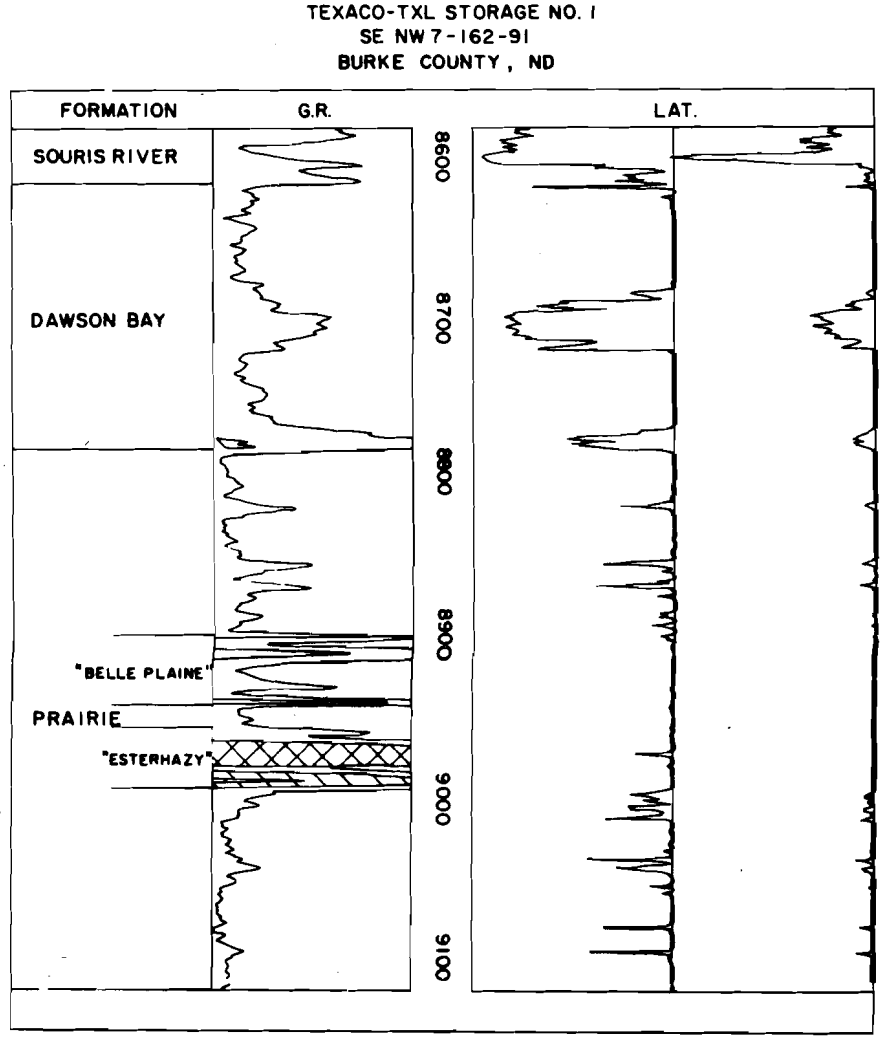

FIG. 15. Log section of the Prairie Formation in the Texaco-TXL Storage No. 1 well in Burke County, North Dakota.

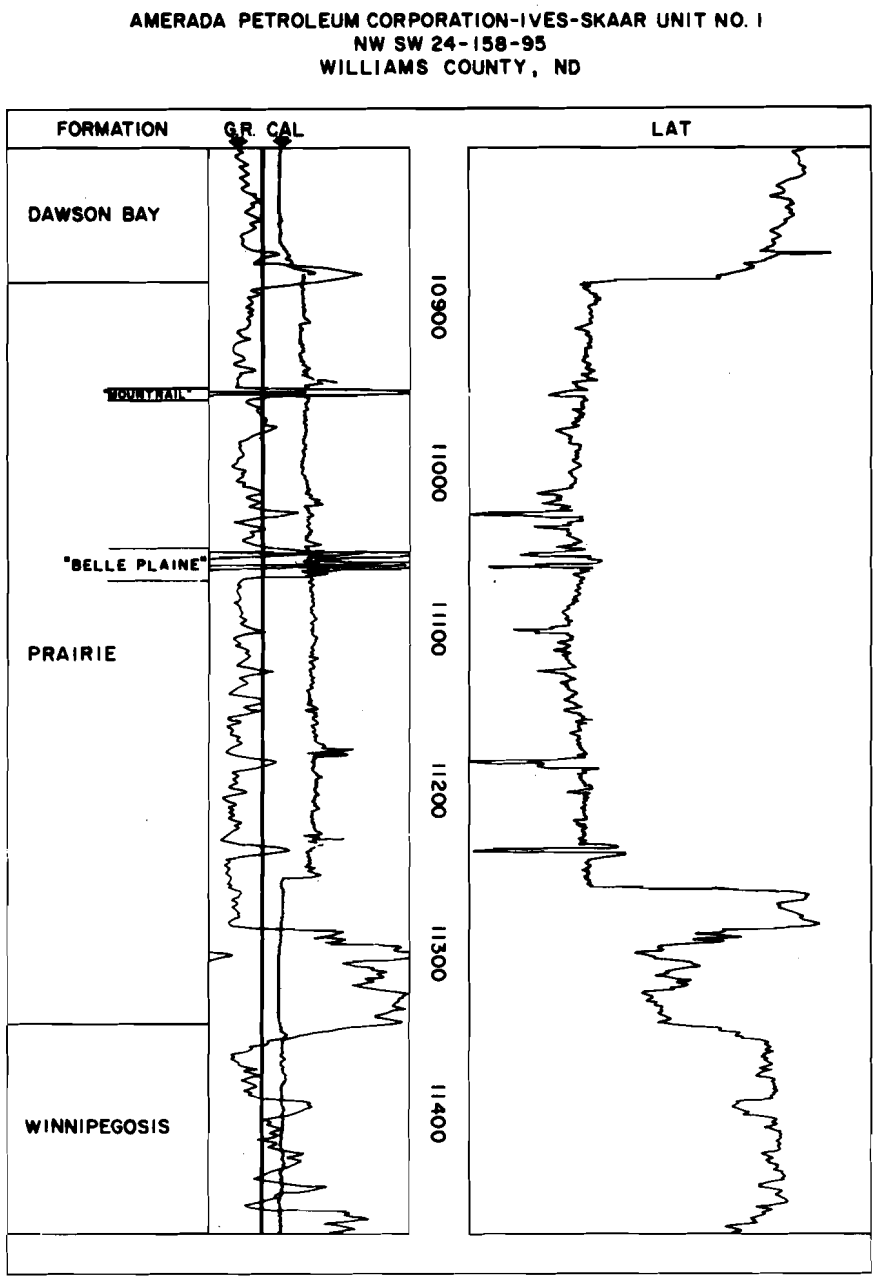

FIG. 16. Log section of the Prairie Formation in the Amerada Ives-Skaar Unit No. 1 well in Williams County, North Dakota.

(12 m) to 130 ft (40 m). The Mountrail Member is established for the potash bed between depths of 11,680 ft (3,560 m) and 11,687 ft (3,562 m) in the Shell-Texel No. 21–35 well located in the NE¼NW¼ of sec. 35, T 156 N, R 93 W, Mountrail County, North Dakota (Fig. 11).

The Mountrail Member is thinner and covers a smaller area than the Esterhazy or Belle Plaine Members. The Mountrail Member attains a maximum thickness of 8 ft (2.4 m) in south-central Mountrail County (Fig. 12). The member occurs near the top of the Prairie salt section; however, it probably has

TABLE I. Structural Cross-Section Data

CROSS SECTION NUMBERS AND DISTANCE BETWEEN WELLS

9 ← 7mi → 8 ← 60 1/2mi → 7 ← 31 1/2mi → 6 ← 45 1/2mi → 5 ← 21 1/2mi → 4 ← 26mi → 3 ← 29mi → 2 ← 19mi → 1

W-E STRUCTURAL CROSS SECTION DATA

WELL NAMES AND LOCATION	PRAIRIE SALT		POTASH MEMBERS		NOTES
	TOP OF SALT	BOTTOM OF SALT	THICKNESS AND TOP OF BELLE PLAINE	THICKNESS AND TOP OF ESTERHAZY	
Union-Nuhring #1 NWNE 32-35-47 KB 2670	NOT		PRESENT		Base of 2nd Red Bed at -5782
National Miller NWSE 10-37-48 KB 2477	-5759'	-5981'	38' at -5831'	22' at -5831'	
Carter Nelson NENW 4-37-50 KB 2502	-6273'	-6525'	46' at -6365'	28' at -6420'	
Sun-Hansen NENE 10-37-57 KB 2264	-6788'	-6997'	26' at -6814'	24' at -6874'	
Kerr McGee-Johnson NENW 34-162-101 KB 2260	-7522'	-7823'	37' at -7580'	6' at -7642'	
Amerada-Ives-Skaar #1 NWSW 24-158-95 KB 2457	-8624'	-9006'	11' at -8785'	NOT PRESENT	Mountrail Member 3' at 8690'
Texaco TXL Storage #1 SENW 7-162-91 KB 1978	-6804'	-7339'	44' at -6920'	39' at -6978'	Well TD in salt
Kirby-Brooks #1-32 NENW 32-159-82 KB 1575	-5041'	-5283'	NOT PRESENT	28' at -5123'	
Union-Steen #1 SESE 20-159-81 KB 1517	NOT		PRESENT		Base of 2nd Red Bed at 6418'

no economic value because of vertical separation from the Belle Plaine and Esterhazy Members and because it is so thin.

Mineralogy of the Potash Deposits

The sparse mineralogical data about the Prairie Formation, on the U. S. side of the basin, indicate that it is similar to the Prairie in Saskatchewan and includes halite, sylvite, and carnallite, as well as the insolubles anhydrite, clay, and dolomite (Fig. 13).

Carnallite in Saskatchewan is restricted largely to the northern and eastern margins of each of the three potash members (Holter, 1969). In apparent contrast, though based primarily on neutron logs, carnallite in the U. S. portion of the basin seems to be largely, but not entirely, restricted to the Easterhazy

Member. The mineral occurs where the member is thick and buried deeply. On its eastern margin in North Dakota and in Montana the Esterhazy Member appears to be relatively free of carnallite.

Favorable Areas for Potash Development

In North Dakota the most favorable areas for potash development appear to be: central Burke County, where the depth to potash is 8,300 ft (2,650 m) to 9,000 ft (2,745 m); western Divide County, where the depth is from about 8,900 ft (2,715 m) to 9,200 ft (2,800 m); and western Bottineau, eastern Renville, and central Ward Counties, where the depth is 6,000 ft (1,830 m) to 7,500 ft (2,285 m). Figures 14 through 17 illustrate selected log sections in these areas of the Prairie Formation.

In Montana, the northeast portion of Daniels County and the northwest portion of Sheridan County appear to be the most favorable areas for potash development. In northeast Daniels County depths range from 8,300 ft (2,530 m) to 8,900 ft (2,715 m) and in northwest Sheridan County depths range from 8,600 ft (2,620 m) to 9,000 ft (2,745 m).

Potash Resources

The total potash resources in the U.S. portion of the Williston Basin are estimated to be approximately 60 billion tons; North Dakota has an estimated 50

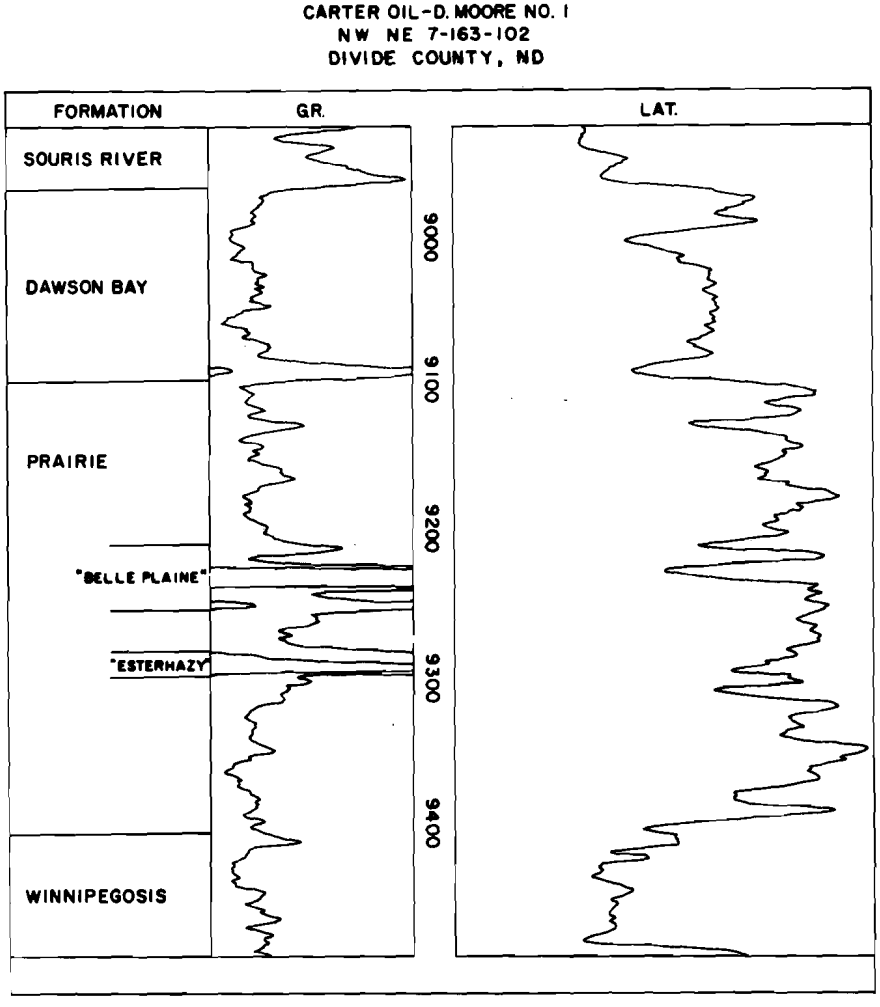

FIG. 17. Log section of the Prairie Formation in the Carter-D. Moore No. 1 well in Divide County, North Dakota.

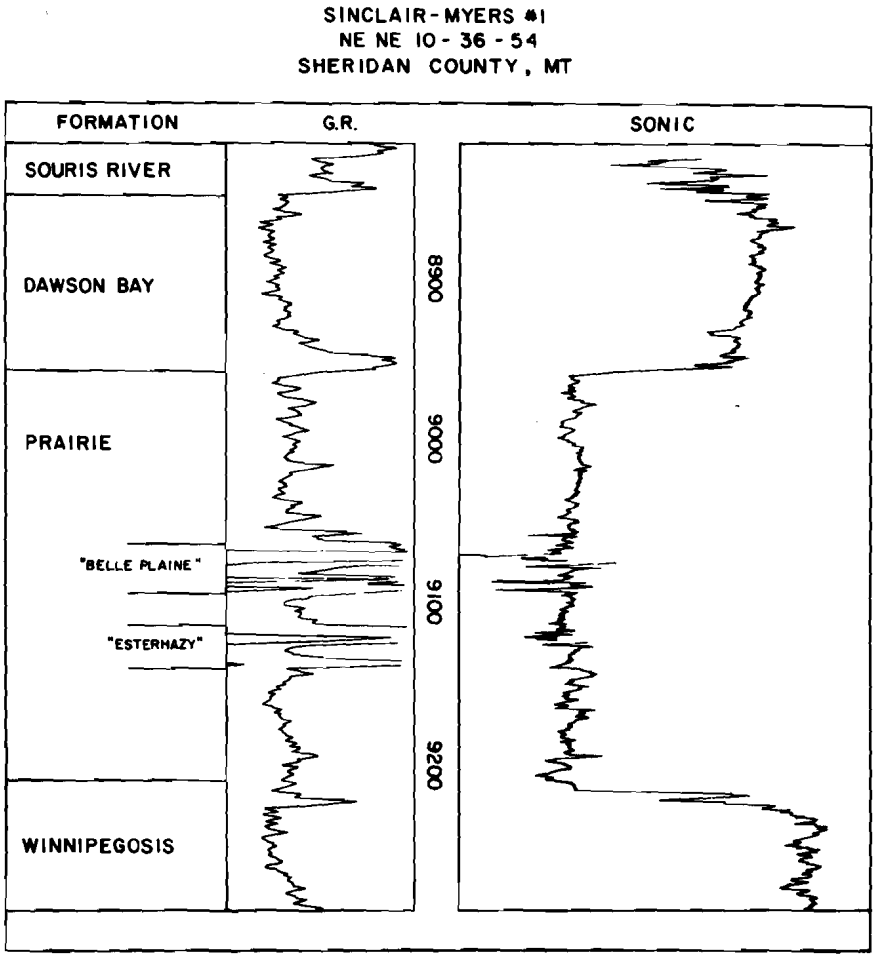

FIG. 18. Log section of the Prairie Formation in the Sinclair Myers No. 1 well in Sheridan County, Montana.

billion tons and Montana, 10 billion tons. We do not have an estimate of recoverable resources.

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