REPORT NO. 158

GEOLOGICAL INVESTIGATIONS

in the

PASQUIA HILLS AREA

BY

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1974

DEPARTMENT OF MINERAL RESOURCES

SASKATCHEWAN GEOLOGICAL SURVEY

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PROVINCE OF SASKATCHEWAN

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INTRODUCTION

LOCATION AND ACCESS

The area discussed in this report includes Townships 44-53 and extends westwards from the Saskatchewan-Manitoba border to Range 11, W2, an area of approximately 4,700 square miles.

Highways bound the periphery of the area but the central portion, occupied by the Pasquia Hills, is difficult to traverse. Only one road crosses the hills, the so-called Fir River road, which extends northwards from Veillardville to join Highway 163 just south of the Red Earth Indian Reserve. At the time of the survey (1967), this road was not navigable by 4-wheel vehicles because of numerous "wash outs" and steep grades.

Access to the northern flank of the hills, which was extremely difficult at the time of the field work, has improved considerably with the extension of Highway 163 to the east to join the Otosquen road at Mile 54.4.[1]

Particularly in the western part of the hills, limited access is provided by logging trails but these are generally impassable by 4-wheel vehicles. Suzuki trail bikes (80 c.c.) were used in the present survey and proved invaluable; they are recommended as a cheap, reliable means of transportation for anyone contemplating field work in this type of terrain.

FIELD WORK AND ACKNOWLEDGEMENTS

Field work was carried out during the summer of 1967 and was designed to investigate the surface economic geology of the area, particularly the oil shale and silica sand deposits. At the same time, the area was prospected for other deposits and an attempt was made to produce a geological map.

As outcrop is almost exclusively restricted to cut-banks of rivers and streams almost all of the waterways were traversed and all outcrops were plotted on air photographs on a scale of approximately 3,000 feet to one inch. Data were then transferred to a contoured base map on a scale of 1:250,000. It should be noted that all streams were not traversed for their entire length. It was generally found that if Cretaceous detritus was not evident in the first mile of traverse along a stream bed then the chances of discovering outcrop up-stream were virtually nil.

The writer was assisted in the field by D. V. McLain. Local officers of the Department of Natural Resources were helpful, in particular Mr. Bill Crothers, Conservation Officer at Carrot River who gave much valuable assistance in connection with the field work in the western part of the hills. The writer is grateful to Mr. John Hudson of the Saskatchewan Research Council for carrying out X-ray work on the manganese nodules.

PHYSIOGRAPHY

The dominant physical feature of the area is the Pasquia Hills, a northeast-trending escarpment that rises steeply from the Carrot River on its north side and from the Manitoba plain to the east, to elevations of 2,600 feet and greater, above sea-level. The summit level of the eastern part of the hills is approximately 1,600 - 1,700 feet above the adjacent lowlands.

The abrupt scarp face of the hills, a continuation of the Manitoba escarpment and part of the first prairie steppe, is directly related to the presence of relatively resistant Cretaceous shales that overlie more easily eroded psammitic and calcareous rocks of Cretaceous and earlier ages. These strata dip gently to the southwest and, in consequence, an escarpment was formed. It is likely that in preglacial times the escarpment was more pronounced in relation to the lowland to the east but glacial deposits, in particular those of Lake Agassiz, have filled in the lowlands and buried the lower Cretaceous and earlier formations.

The deposition of a mantle of glacial deposits presumably rejuvenated the erosion cycle and most of the streams and rivers are in a youthful stage. Steep V-shaped valleys are particularly common on the north flank of the hills and, in this area, they are referred to by the local inhabitants as "canyons".

Most of the glacial deposits covering the hills are transported tills or boulder clay that range from a few feet to several tens of feet in thickness. Sandy tills are common on the north flank of the hills in the vicinity of the Carrot River, presumably resulting from glacial smearing of the underlying Blairmore sands. Hummocky till is evident in a few places on the summit of the hills and may represent deposition from stagnant ice at the end of the glacial period. Transverse ridges, generally trending northwesterly, are fairly common on both the northwest and southeast flanks of the hills.

Evidence of the latest stages of glaciation is provided by strand lines, which represent beach levels of glacial Lake Agassiz. They are particularly common on the northwest flank of the hills between the Cracking River (Tp 50, R7, W2) and Mountain Creek (Tp 53, R2, W2) and on the southeast flank between Hudson Bay and the northeast edge of the hills. Most of the beach deposits occur at elevations between 950 feet and 1,300 feet above sea-level and indicate that the part of the hills above the 1,300-foot-contour was an island during the final stages of glaciation, whilst most of the surrounding lowland was covered by melt waters.

PREVIOUS WORK

The earliest recorded geological work was by William McInnes who traversed part of the area during his survey of the basins of the Nelson and Churchill Rivers (McInnes, 1913).

The southeast part of the area (Tp 44-46 and from the Provincial Boundary to R7, W2) was included in Wickenden's study of the Mesozoic stratigraphy of the Eastern Plains (Wickenden, 1945).

The only other geological work in the area has been in connection with broader surveys of which the Pasquia Hills has formed only a part (Ells 1923, McLearn and Wickenden 1936, Johnston 1946).

The Saskatchewan Department of Mineral Resources previously carried out an investigation of the Red Deer silica sand (Babey, 1955).

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[1]Mileages on the Otosquen road are measured northwards from Hudson Bay.

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STRATIGRAPHY

GENERAL

Much of the area is covered by glacial deposits and outcrop is restricted to the lower slopes of the hills where a few of the streams have cut through surficial material to bedrock. Excellent cliff exposures are found on the Waskwei, Man, and Cracking Rivers and on Mountain Creek. In the southern part of the area, scattered exposures occur along the Red Deer River and some of its tributaries.

Apart from an outcrop of poorly consolidated sands on the Man River, which may be Tertiary, all of the exposed bedrock is believed to be Cretaceous. The general succession established from the geological mapping is shown in Table 1.

Table 1 – Table of Formations

Formation	*Unit No.*	*Thickness*	*Lithology*
Tertiary (?) sands		30′ +	Unconsolidated sands with calcareous sandstone concretions.
Riding Mountain	4	450′ +	Soft, greenish-grey shales and clays interbedded with siliceous shales and clay ironstone bands near to the base.
Vermilion River: Boyne Member	3	200 - 300′	Calcareous speckled shale
Vermilion River: Morden Member			Impersistent, black non-calcareous shales. May be interbedded with speckled shales.
Favel			Calcareous speckled shale.
Lower Colorado	2	150′ +	Dark grey to black, non-calcareous shale.
Blairmore	1	150′ +	Poorly consolidated sands, silts, clays, lignites. Some calcareous sandstone lenses.

The base of the Riding Mountain Formation is well exposed at several localities around the escarpment and is drawn on the accompanying geological map with reasonable accuracy. Similarly the top of the Blairmore was defined in the field with confidence. The middle part of the stratigraphic section, comprising the Lower Colorado, Favel, and Vermilion River poses problems, however. Firstly, outcrops are scattered and boundaries cannot be defined accurately and, secondly, a complete stratigraphic section is not exposed in any of the streams making correlation from stream section to stream section somewhat tenuous.

The problem is further compounded by the lithological similarities of (1) the Boyne Member and the Favel Formation, both calcareous shales, the First and Second "Specks" of the sub-surface, respectively, and (2) the Morden Member and the Lower Colorado shales, both of which are dark brown to black non-calcareous shales. Thus if only one calcareous, or one non-calcareous shale is exposed in a particular stream section, the stratigraphic position of the units is in doubt. For example on the Waskwei, Bainbridge, and Man Rivers, a black non-calcareous shale (occurring at elevations between 1020 - 1080 feet) is overlain by a thick (250 - 300 feet) sequence of speckled calcareous shales with minor interbedded non-calcareous shale which, in turn, is overlain by the Riding Mountain Formation.

This might be interpreted as a thick Boyne Member overlying the Morden Member but this interpretation would assume a thickening of the Boyne from about 40 feet at the north end of the Porcupine Hills to almost 300 feet at Bainbridge River. It would also place the base of the Vermilion River Formation at Bainbridge River about 250 feet lower than on the north slope of the Porcupine Hills, east of Hudson Bay, which is not likely in view of the west to southwesterly regional dip of the beds.

In view of this, an alternative interpretation that the Morden Member is either missing or is only intermittently developed north of Hudson Bay, is favoured, thereby implying that the thick sequence of speckled shales represents both the Favel Formation and Boyne Member of the Vermilion River Formation. On this basis, the base of the Vermilion River Formation and Favel are at roughly the same elevations at both Hudson Bay and the north end of the Pasquia Hills, which is in better accord with the known regional structure. Disappearance of the Morden Member and the merging of the Favel Formation and Boyne Member in central Saskatchewan was confirmed by studies of foraminifers (Park, 1965).

As the Morden is only intermittently developed, and because the Favel and Boyne are not divisible on the basis of lithology, the two units of speckled shales were mapped as a single unit in the current study.

In this report, the stratigraphic terminology of the stratigraphic correlation chart (1963) of the Saskatchewan Department of Mineral Resources is followed. Some of the problems arising out of the stratigraphic nomenclature used by various workers is discussed by Wickenden (1945, pp. 2-3).

BLAIRMORE FORMATION

The Blairmore is exposed in cut-banks of the Red Deer River north of Armit. The most westerly exposures, and the stratigraphically highest, are in the NE1/4-13-46-31-W1 and consist of iron-stained clays and indurated medium-grained sandstones. Down stream at several places in sections 19, 20, 21, and 22 of Tp. 46, R30, W1 are cut-banks of unconsolidated and partly consolidated sands commonly cross bedded and containing thin lignites (Plate 1). Within this succession of sands there is a bed of well sorted silica sand of possible commercial importance that is discussed further in the chapter on "Economic Geology".

The only other exposure of Blairmore found in the area was on the north bank of the Carrot River in NW1/4-6-52-7-W2. At that locality, near to the water's edge, 4 feet of cross-bedded, partly consolidated iron-stained sandstone overlies 16 inches of unconsolidated, well sorted sand containing carbonaceous fragments.

LOWER COLORADO SHALES

Lower Colorado Shales are exposed on the Red Deer River southeast of Erwood, on Waskwei River east of the Otosquen road, and on the Bainbridge and Man Rivers.

On the north side of the Red Deer River in Sec 33-44-2-W2 there are several cut banks exposing finely bedded, dark grey shales (Plate 2) overlain by a black, plastic mudstone. The shales are iron-stained and have abundant selenite crystals

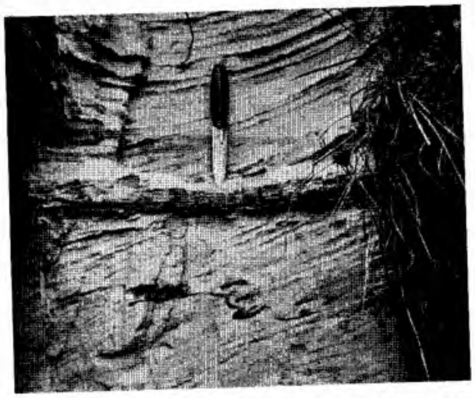

Plate 1. — Cross bedded sands with thin lignite; "Downstream" deposit, SW1/4-22-46-30-W1.

Plate 3. — Thin limestone overlying Lower Colorado shale; Bainbridge River.

Plate 2. — Black, finely bedded Lower Colorado shale; Red Deer River, Sec 33-44-2-W2.

Plate 4. — Interbedded speckled calcareous shale and non-calcareous shale; Man River, Sec 33-50-5-W2.

along bedding planes. Further upstream in 30-44-2-W2 and 24-44-3-W2 similar outcrops occur. The maximum thickness of shale exposed in a single outcrop is about 25 feet.

On Waskwei River, about 3,000 feet east of the Otosquen road, there are two cut banks each with a few feet of black, plastic mudstone. The mudstone is very slightly calcareous and is probably at or near to the contact with the overlying speckled shales.

At Bainbridge River, about 800 feet upstream from the road, a cut bank exposes 10 - 15 feet of black, finely bedded shale with pale yellow limonite stain and abundant selenite along bedding planes. The shale is black when fresh and medium grey when dry and weathered. On weathering, the shale breaks into small chips generally less than one inch in diameter. About 2,000 feet further upstream similar black shales are exposed overlain by a 6 inch massive limestone bed that is presumed to mark the contact between the Lower Colorado Shales and the overlying Favel Formation (Plate 3).

A long cut bank of Lower Colorado Shales, as much as 15 feet thick, occurs about 1,000 feet upstream from Highway 163 on the Man River. The shale is black and plastic when wet and dries to a medium-grey colour. The shales are stained with pale yellow limonite and contain abundant selenite.

FAVEL AND VERMILION RIVER FORMATIONS
(Speckled shale unit)

As mentioned earlier in the report, the Favel and Vermilion River Formations are indistinguishable in the field and have been mapped as a single unit of speckled shales.

In places such as on the Waskwei River, the sequence between the underlying Lower Colorado shales and the overlying Riding Mountain Formation consists almost wholly of speckled, calcareous shales with thin interbedded limestones. At Bainbridge River, Mountain Creek, and Man River, the succession consists of speckled shales in the lower part with interbedded black, non-calcareous shales and shaly mudstones in the upper part (Plates 4 and 5). Further west on the

Plate 5. — Non-calcareous shale within the speckled shale sequence; Mountain Creeck, Sec 14-53-R2-W2.

Plate 7. — Flaggy speckled shales; Mountain Creek, Sec 14-53-2-W2.

Plate 6. — Black non-calcareous shale; Cracking River, Sec 32-49-7-W2.

Plate 8. — Speckled shales, NE1/4-27-48-11-W2.

Cracking River, no speckled shales are exposed. Instead a thick sequence (at least 130 feet) of dark brown to black, non-calcareous shales are developed in what is assumed to be near the middle of the speckled shale unit (Plate 6). It is therefore probably the Morden Member of the Vermilion River Formation or its equivalent.

These non-calcareous shales within the speckled shale map-unit somewhat resemble the Lower Colorado shales but generally they have a higher clay content and are more plastic when wet.

The speckled shales over most of the area consist of flaggy, well jointed cliff-forming calcareous shales (Plates 7 and 8), that are dark to medium grey when fresh and which weather characteristically to a light grey with white calcareous "specks". Interbedded with the flaggy shales are thin bedded fissile speckled shales and thin beds of impure limestone. Pale cream bentonite beds ranging from a few inches to 20 inches in thickness occur throughout the speckled shale unit but are more common in the upper part particularly at the contacts of calcareous and non-calcareous beds.

The speckled shales are generally fossiliferous. Inoceramus is the most common fossil recognizable megascopically.

RIDING MOUNTAIN FORMATION

The best exposure of the Riding Mountain Formation is on the Bainbridge River about 1.7 miles upstream from the Otosquen road. At that locality the basal beds of the formation are exposed in an impressive cliff section (Plate 15). The cliff, about 100 feet high, consists essentially of dark grey, siliceous shales interbedded with thinner, greenish, clayey shale beds. Clay ironstone layers are common in the section.

Shales of similar lithology are exposed on Whitepoplar Creek, Man River, and in an un-named canyon in the northeast corner of Tp. 52, R3, W2.

TERTIARY (?) SANDS

There are two excellent exposures of sands and silts of doubtful age and origin on the Man River. The first exposure is on the east bank of the river about 4,500 feet upstream from Highway 163, and consists of 40 feet of tan and pale yellow clays and unconsolidated, bedded, fine sands and silts that contain concordant ledge-like lenses of lithified calcareous sandstone with included organic and plant (?) remains. A second exposure, a further 3,000 feet upstream, has a similar succession capped by 15 - 20 feet of boulder clay (Plate 9).

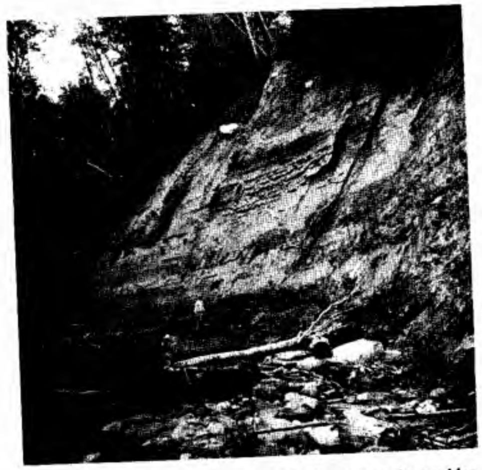

Plate 9. — Silts and clays with lenses of calcareous sandstone; Man River, NW1/4 Sec 6-51-5-W2.

STRUCTURAL GEOLOGY

Because of hill-side creepage, landsliding, and the scattered nature of the outcrops, the structural geology cannot be resolved accurately by field mapping. In most places, strata appear to be horizontal or near-horizontal except for the basal beds of the Riding Mountain Formation, which invariably dip from 40° to vertical (Plate 10). This is due to large-scale slumping, perhaps modified by glacial thrusting, particularly on the north flank of the hills.

The base of the Riding Mountain Formation is at an elevation of 1,400 feet above sea-level on the east flank of the hills but drops to about 1,300 feet at the Man River indicating a regional westerly or southwesterly gradient of about 5 feet to one mile. This is comparable to the gradient established from well data in the southeastern part of the area (Wickenden, 1945, p. 52).

Plate 10. — Back-tilted, slumped block of Riding Mountain Formation; Whitepoplar Creek, NE1/4-17-52-1-W2.

ECONOMIC GEOLOGY

OIL SHALES

The occurrence of oil shales in the Pasquia Hills was first reported by McInnes (1913). A sample collected by him assayed 7.0 gals. of crude oil and 22.5 lbs. of ammonium sulphate per ton. Later, Ells (1923) sampled the oil shales at several localities and recorded assay results ranging from 3.1 to 12.8 gals. of crude oil and 1.7 to 8.7 lbs. ammonium sulphate per ton. Ells noted that at all sample locations, trenches were dug and material was selected from 4 to 8 feet below the surface and consisted of apparently unaltered shale.

In 1964, Sun Oil Company carried out a program of surface sampling but obtained erratic assay results. They concluded that this was a result of leaching of the surface samples and that a thorough evaluation of the grade of the shales could only be ascertained by drilling. Accordingly in 1965 drilling was carried out and results of holes lying outside of the current disposition areas (at September 1972) are listed in Table 2.

Table 2 – Test hole data for the oil shales

			Assay Results		
No.	*Location*	*T.D.*	*Interval*	*Width*	*Gals/ton*
1	20-50- 5-W2	219	66-218	152	8.56
2	8-49- 7-W2	223	83-193	110	11.30
4	4-44- 2-W2	117	27-57	30	7.58
10	8-53- 1-W2	260	142-250	108	9.10
11	15-52- 1-W2	161	–	–	nil
12	9-44- 2-W2	89	13-52	39	8.00
22	20-45- 4-W2	269	111-260	149	6.70
27	15-48-11-W2	186	83-175	92	8.60
28	21-47-11-W2	314	202-314	112	7.29
30A	7-49- 7-W2	140	36-140*	104	9.87
31	23-49- 7-W2	172	54-170	116	10.51
32	32-49- 6-W2	150	23.5-130	106.5	8.75
33	19-50- 5-W2	145	19-145*	126	8.28
33B	19-50- 5-W2	115	17-115*	98	8.23
34	32-50- 5-W2	105	38-105*	67	8.79
35	14-50- 6-W2	115	49-115	75	7.71
36	2-50- 7-W2	120	14-90	76	10.78
37A	30-49- 7-W2	60	15-60*	45	11.73
38	4-49- 8-W2	180	38-150	112	10.18
39	27-48- 9-W2	150	51-150	99	9.26
40	18-48- 9-W2	180	55-165	110	9.04
40A	18-48- 9-W2	185	100-165	65	9.61
41	4-48-10-W2	210	86-195	109	9.50

*In petroliferous shale at end of hole.

As can be seen in Figure 1, most of the test holes were collared near to the top of the speckled shale unit. Exceptions are Hole No. 11, which was collared near the base of the unit and, as a result, did not intersect petroliferous shales, and Holes Nos. 4 and 12, located near to the base of the formation; these holes only intersected 30 and 39 feet of petroliferous shales respectively. Most holes cut a complete section of the oil shale. For example Hole No. 22 was collared just below the base of the Riding Mountain Formation and, after 111 feet of barren shale, intersected 149 feet of petroliferous shale, thus cutting almost the entire thickness of the speckled shale map-unit at that locality.

As indicated by the drill results, the top of the petroliferous horizon ranges from just below the base of the Riding Mountain Formation (eg. Hole No. 1) to over 100 feet below the horizon (Hole No. 10). In general, however, the top of the petroliferous horizon is within a few tens of feet of the base of the Riding Mountain Formation. The maximum recorded thickness of the petroliferous horizon is about 150 feet and the average thickness is probably close to 100 feet.

The total tonnage of oil shales in the Pasquia Hills is immense but only the part amenable to strip mining is of initial economic interest. The area most amenable to strip mining is on the north flank of the escarpment, from Range 5-9 inclusive. East of Range 5 the slope of the scarp is steep and the outcrop area is resultingly narrow, and west of Range 9 most of the land is actively farmed and would not be readily available for mining. Within Ranges 5-9 the oil shales form an outcrop area ranging from 1 to 12 miles wide for a strike length of 35 miles and a total area of about 150 square miles.

Assuming an average grade of 8 gallons per ton across an average thickness of 100 feet, the area favourable for strip mining has indicated reserves of 2.6 billion (2.6×10^9) barrels of oil in place.

PETROLEUM AND NATURAL GAS

Several oil and gas test holes have been put down in the Pasquia Hills area (Map 158A) and oil and gas shows have been recorded from two holes near Hudson Bay. An early paper by McLearn and Wickenden (1936) discussed oil and gas possibilities around Hudson Bay and a recent review by Simpson (1970) discusses the economic potential of a broader area of east-central Saskatchewan, of which the Pasquia Hills forms a part.

Of perhaps historic rather than geologic interest, the remains of a cable-tool rig (Plate 11) were found near the Man River (Sec 5-51-5-W2). This was presumably an oil test-hole and judging from the timber growth in the original clearing around the drill site, the exploration was probably carried out in the early 1930's.

Plate II. — Remains of a cable tool rig, Man River.

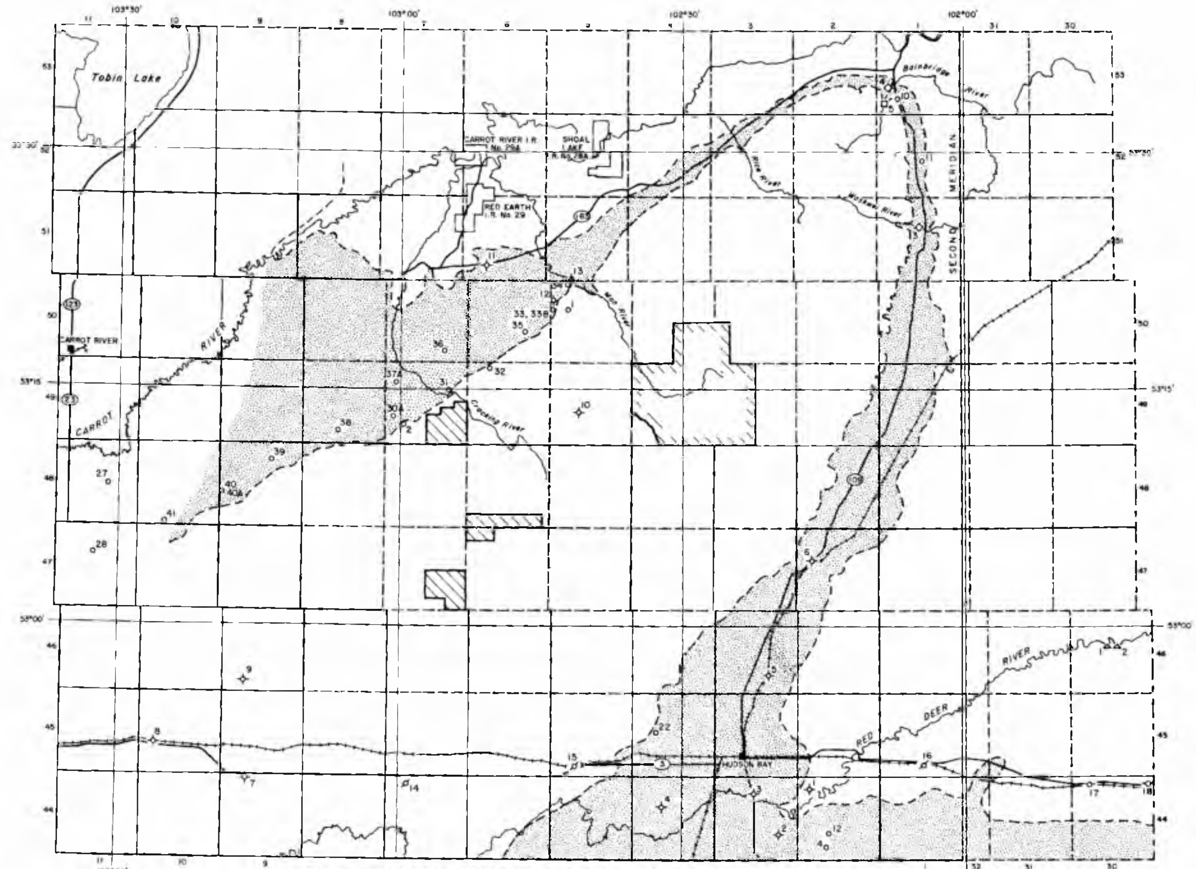

Figure 1 MINERAL DEPOSITS AND DRILL-HOLE LOCATIONS, PASQUIA HILLS

MILES 5 0 5 10 15 20

KILOMETRES 5 0 5 10 15 20 25 30

LEGEND FOR FIGURE 1

Speckled shales — Oil shale permits (Sun Oil) — Wildcat Hill Wilderness Area

Oil-gas test holes recorded in DMR files 2

1. Trail Blazer No. 1	Lsd 1-31-44-2-W2
2. Hudson Bay Junction No. 6	Lsd 15-11-44-3-W2
3. Stampede Lashburn Brady No. 1	Lsd 16-28-44-3-W2
4. Hudson Bay Junction No. 3	Sec 21-44-4-W2
5. Hudson Bay Junction No. 2	Lsd 8-10-46-3-W2
6. Hudson Bay Junction No. 1	Lsd 12-20-47-2-W2
7. Husky Mistatim No. 1	Sec 32-44-9-W2
8. Husky Mistatim No. 2	Sec 17/18-45-10-W2
9. Cal. Std. Bannock 15-5	Lsd 15-5-46-9-W2
10. Fleetwood 5-16	Lsd 5-16-49-5-W2
11. Cal. Std. Pasquia Hills 2-8	Lsd 2-8-51-6-W2

[1] According to Simpson (1970) a well termed "Hudson Bay Junction No. 1" was drilled in Lsd 3-16-45-3-W2.

Oil-gas test not recorded in DMR files 12

12. Man River Core hole	Sec 30-50-5-W2
13. Cable tool hole	SE1/4 Sec 5-51-5-W2

S.R.C. Test Hole for groundwater studies 15

14. S.R.C. 53-68	Lsd 14-32-44-7-W2
15. S.R.C. Greenbush 63D/15	Lsd 9-5-45-5-W2
16. S.R.C. Smoking Tent 63D/16	Lsd 13-3-45-1-W2

S.R.C. Test hold for silica sand 17

17. DMR Armit 63C/13	Lsd 6-32-44-30-W1
18. Auger hole 63C/13	Lsd 7-36-44-30-W1

Test holes for oil shale (Sun Oil) 4
(same numbers as used for the company)

Mineral deposit (silica sand; cement rock; manganese) 1, 3, 5

1. Red Deer River "upstream deposit"
2. Red Deer River "downstream deposit"
3. Waskwei River cement rock deposit
4. Bainbridge River cement rock deposit
5. Bainbridge River manganese deposit

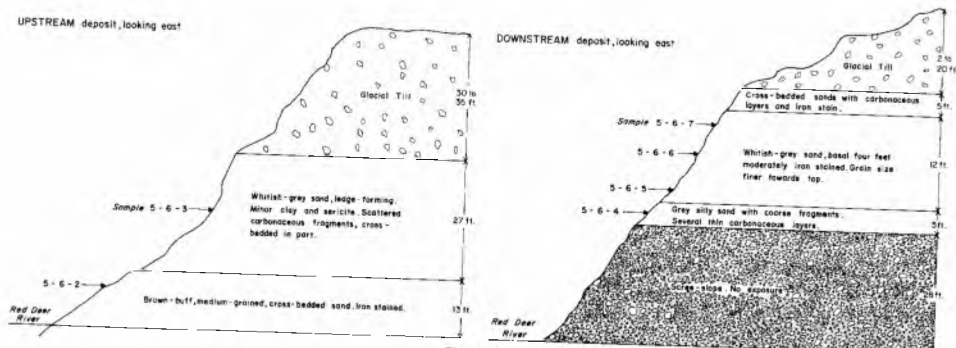

Figure 2
Cross sections and sample locations, Red Deer River silica sand deposits

SILICA SAND

Silica sand deposits along the Red Deer River have been known for many years and have been investigated several times. Wickenden (1945) described the outcrops along the Red Deer River between Hudson Bay and the Saskatchewan-Manitoba boundary and included some sections of the silica sands. In 1955 the Saskatchewan Department of Mineral Resources carried out an investigation of the "upstream" and "downstream" deposits (localities 1 and 2 respectively in Figure 1) involving auger drilling and sampling followed by mechanical and chemical testing. Results of this program are outlined by Babey (1955), whose investigation indicated that the two deposits were outcrops of the same sand horizon and that the sand itself was of glass sand quality.

Grain Size	*B-7-5-6-2*	*B-7-5-6-3*	*B-7-5-6-4*	*B-7-5-6-5*	*B-7-5-6-6*	*B-7-5-6-7*	*Armit Test Hole 110'*	*Armit Test Hole 120'*
< 3 > 2 mm	0.1	tr.	1.5	0.4	tr.	0.1		
< 2 > 1 mm	12.7	0.1	13.8	23.4	10.8	2.6	0.4	0.1
< 1 > ½ mm	46.4	0.4	34.2	39.4	57.3	23.8	5.0	3.6
< ½ mm > 60 mesh	17.1	13.8	31.7	26.3	22.1	55.1	21.6	25.7
< 60 > 100 mesh	16.4	58.6	11.4	7.0	6.0	13.5	56.0	58.0
< 100 > 200 mesh	6.7	25.9	5.1	2.4	3.3	3.8	13.7	10.2
< 200 mesh	0.6	1.2	2.3	1.1	0.5	1.1	3.3	2.4
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Each field sample of about 3 lbs. was split into two parts and a sieve analysis was performed on each. The above results are the averages of the 2 analyses for each sample.

Table 3 – Sieve Analyses of Red Deer River silica sand samples.

Table 4 – Stratigraphic Section and Chemical Analyses of the Waskwei River exposure.

Unit No.	*Thickness*	*Lithology*
6	10 - 17'	Glacial overburden. Clay with abundant boulders.
5	14' 3"	Thin bedded, grey, speckled calcareous shale with thin bentonite at base.
4	6' 6"	Flaggy impure limestone with abundant fish scales and thin bentonite at base.
3	2' 9"	Massive limestone with thin impersistent shale layers. Bentonite layer at base.
2	5' 2"	Flaggy calcareous shale with abundant Inoceramus and selenite. Thin bentonite layers.
1	10' 0"	Thin bedded, grey, speckled shale.

Field Number	Unit	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Ignition loss
18-6-2	1	20.32	4.50	(R_2O_3)	35.54	0.30	38.04
3-4-4	2	18.15	2.48	1.17	36.50	0.63	39.8
3-4-3	3	6.60	1.12	2.28	46.79	0.78	42.0
3-4-2	4	3.40	0.51	2.49	50.64	1.05	42.0
3-4-5	Channel Units 2, 3 and 4	10.45	1.50	3.35	42.41	0.75	40.4
3-4-6	5	23.05	4.43	9.12	28.00	1.16	34.8
3-4-7	5	19.55	4.30	7.45	31.90	1.56	35.2
3-4-8	5	23.55	3.78	13.12	24.60	0.54	34.1

Note: Sample 18-6-2 analyzed by Technical Services Laboratories; other analyses by Saskatchewan Research Council.

Plate 12. — "Upstream" silica sand deposit, Red Deer River.

The investigation carried out by the writer consisted of measuring the sections of the "upstream" and "downstream" deposits (Figure 2) and carrying out sieve analyses on selected samples (Table 3, and Figure 3).

As one of the main drawbacks to economic development of the deposits, either for glass manufacture or other uses, appears to have been the remote location, two drill holes were put down at two localities near to the railroad (Figure 1) in an endeavour to find out: (a) whether the silica sand horizon extended laterally to the south and southwest; and (b) the depth of the deposit near to the railroad.

One of the drill holes (D.M.R. Armit 63 c/13) was put down near Armit settlement and intersected a quartz sand from 75 to 136 feet with a very clean white sand from 100 to 130 feet. This is lithologically similar to the sand exposed in the Red Deer River and it shows a remarkable grain size similarity to the main sand horizon of the "upstream" deposit (Figure 3).

An auger hole was put down at the DNR Armit River campsite. According to the regional dip estimated from the first drill hole, the quartz sand should have been intersected at a vertical depth of 40 - 45 feet but no equivalent to the silica sand was found in the hole which was drilled to a total depth of 85 feet. It is therefore assumed that the Red Deer silica sand deposit extends from its outcrop on the Red Deer River to the south as far as Armit settlement, but further east towards the Manitoba border at Armit River it changes laterally to a less pure sand.

CEMENT ROCK

Two excellent cliff exposures of speckled shales, one on the Waskwei River (Plate 13) and the other on the Bainbridge River (Plate 14) were sampled in an attempt to determine their suitability for use in cement manufacture.

The Waskwei River exposure lies about 1,500 feet upstream from the Otosquen road and can be easily reached by a trail leading from the Department of Natural Resources picnic site on the south bank of the river. The stratigraphic section and analytical data are shown in Table 4.

Plate 13. — Speckled shales, Waskwei River.

Plate 14. — Speckled shales, Bainbridge River.

Plate 15. — Manganese-bearing horizon; Bainbridge River.

Figure 3

Particle-size distribution, Red Deer River silica sand deposits

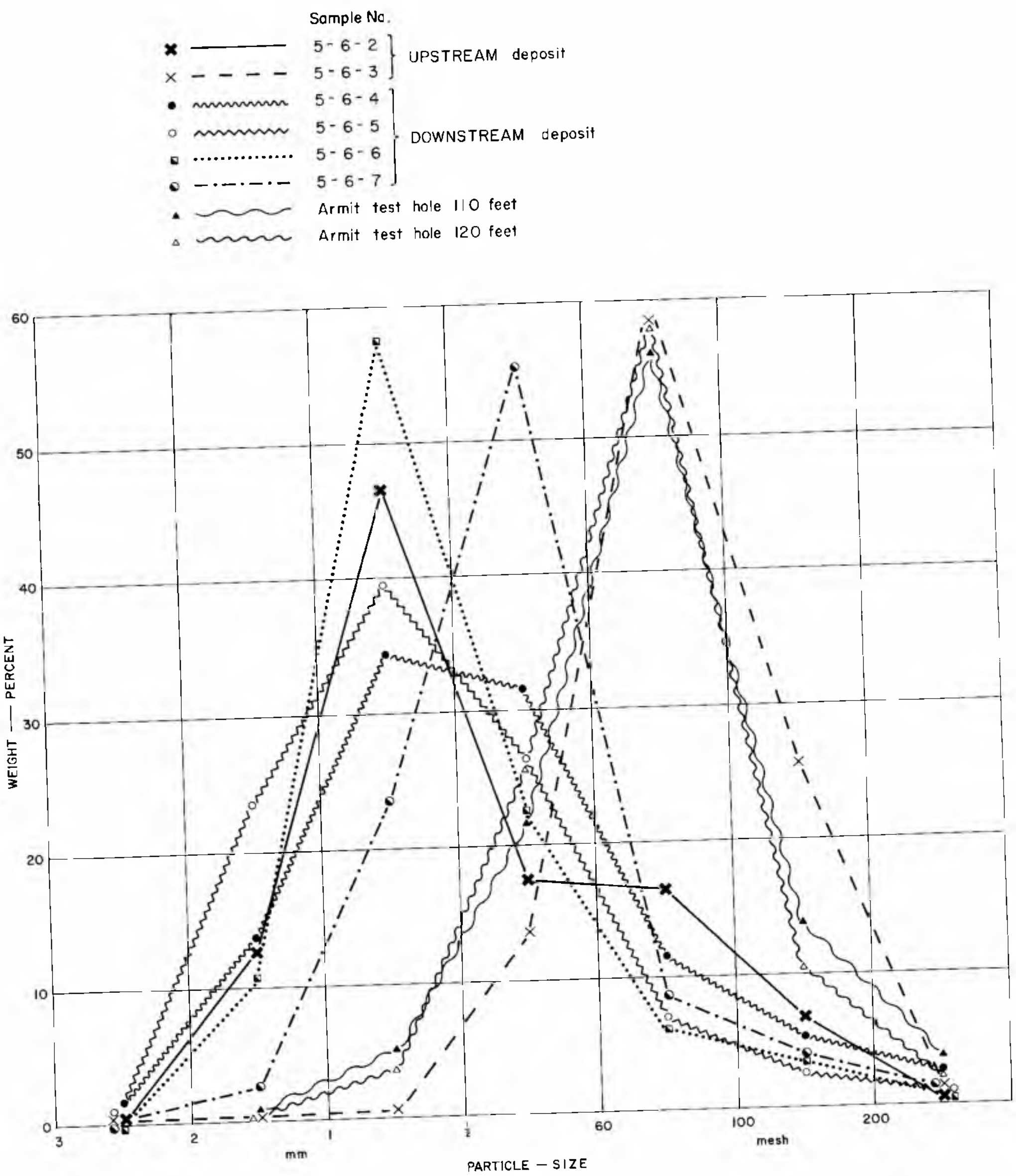

Table 5 – Stratigraphic Section and Chemical Analyses of the Bainbridge River Exposure.

Unit No.	*Thickness*	*Lithology*
7	11′	Boulder clay.
6	22′ 0″	Thin bedded dark grey to black shale slightly calcareous and heavily iron stained in part. Thin bentonite at base.
5	1′ 0″	Thin bedded calcareous shale.
4	2′ 4″	Flaggy, dense, hard, recrystallized limestone.
3	12′ 6″	Thin bedded speckled calcareous shale with abundant fish scales and Inoceramus. Flaggy near top. Bentonite at base.
2	5′ 6″	Thin bedded speckled shale. Bentonite at base.
1	16′ 6″	Very thin bedded calcareous shale with fish scales.

Field Number	Unit	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Ignition loss
24-6-4	1	8.58	4.12 (R_2O_3)		43.32	0.72	42.36
3-4-9	1	28.85	3.67	18.63	14.46	3.58	31.6
3-4-14	1	19.05	2.59	6.51	34.80	0.49	36.1
3-4-10	2	19.60	2.99	6.06	30.85	0.94	38.3
3-4-15	2	16.20	3.36	5.29	32.20	2.41	40.0
24-6-5	3	3.94	1.18 (R_2O_3)		49.95	0.65	43.65
3-4-11	3	11.65	1.24	4.41	39.20	0.78	42.2
3-4-16	3	28.05	3.50	7.15	28.45	0.69	32.4
3-4-12	4	2.04	0.68	2.37	51.03	0.77	43.3
3-4-17	4	3.65	0.83	1.17	51.57	0.69	41.6
24-6-6	6	43.14	14.87 (R_2O_3)		11.59	0.79	29.30
3-4-13	6	42.55	6.03	18.06	3.61	0.34	28.7
3-4-18	6	42.70	4.65	17.34	8.42	0.57	26.7

Note: Samples 24-6-4, 24-6-5, and 24-6-6 analyzed by Technical Services Laboratories; other analyses by Saskatchewan Research Council.

The Bainbridge exposure is about 4,500 feet from the Otosquen road. The stratigraphy and analytical results are given in Table 5.

The analyses show that at least part of the speckled shales approach cement rock in chemical composition and that the Waskwei section appears to be the most favourable. Table 6 compares the weighted average chemical composition of the Waskwei section with typical cement rock and with the Sturgeon Lake marl, hitherto the only other investigated source of raw material for cement manufacture in the province.

MANGANESE

Geology

The basal few hundred feet of the Riding Mountain Formation contain nodular concretions rich in iron and manganese. The nodules are resistant to erosion and are abundant in stream beds thereby providing a ready guide to prospecting for their outcrops. The manganiferous horizon is exposed on the Waskwei, Whitepoplar, and Bainbridge Rivers and in several of the canyons on the north slope of the hills as far west as the Man River.

Table 6 · Comparative chemical data for the Waskwei speckled shale, Lehigh Valley limestone, and Sturgeon Lake marl.

	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO
A	17.32	2.48	5.67	35.37	0.76
B	19.82	ND	5.40	38.9	2.72
C	26.09	2.31	3.48	30.78	2.11

A: Speckled shales, Waskwei River section.
B: Typical cement rock; Lehigh Valley limestone. From W. M. Myers, Cement Materials, Ind. Mins. and Rocks, 2nd. Ed.
C: Sturgeon Lake marl, average chemical composition.

The best exposure found during the course of field mapping is a near-vertical cliff section on the Bainbridge River (Plate 15) about 1.7 miles upstream from the Otosquen road. At that locality the following section was measured:

Thickness	*Lithology*
6 - 25′	Boulder clay.
50′ (estimated)	Flaggy dark shale with lenses and layers and scattered clay ironstone nodules..
2′ 0″	Flaggy iron stained dark shale.
4′ 8″	Fissile dark shale with a few scattered ironstone concretions.
3′ 0″	Flaggy iron stained dark shale.
3′ 0′	Grey shale with four thin persistent concretionary layers.
5′ 6″	Grey fissile shale; no nodules.
0 - 23′	Scree slope.

Manganese-bearing nodules occur scattered or, more commonly, in layers along bedding planes. Layers as long as 20 to 30 feet are common and layers are never greater than one nodule thick.

At the Bainbridge section, the volumetric ratio of nodule to shale was estimated visually to be about 1 to 40. Assuming a specific gravity of 3.4 for the nodules, 1 ton of nodules could be recovered from 400 - 450 cu. ft. of shale. This should be considered a maximum, rather than average, concentration of nodules as at all other exposures of the manganiferous horizon the proportion of nodules to shale appears to be less than at the Bainbridge River section.

Individual nodules are sub-rounded, egg-shaped, or disc-shaped and lie with their longest dimension parallel to the bedding planes. Most of the nodules are 1 to 4 inches thick but a few are as much as 6 inches thick. Diameters are generally between 2 and 6 inches although a few nodules as much as 20 inches in diameter were observed (Plate 16). The colour of the nodules ranges from light grey to greenish grey and most of them are covered by a thin (5 mm or less) black or light brown skin. A few nodules have an inner brown skin covered by an outer black crust and occasionally this sequence may be reversed.

Chemistry and Mineralogy

In hand specimens the nodules are extremely fine grained

Plate 16. — Manganese nodules.

and homogeneous. In thin section they consist of a granular mosaic of greyish brown to light brown, slightly pleochroic carbonate. Judging from optical criteria, only one carbonate is present in the groundmass. Individual grains range from 0.02 to 0.07 mm in diameter and average about 0.05 mm.

Irregularly-shaped areas and ramifying veinlets within the nodules are more heavily iron stained to a mid or dark brown colour, and are almost massive in texture; only with difficulty can a vague granular texture and polarization colours of carbonate be discerned. Within these darker patches a few vague rounded and egg-shaped forms ranging in diameter from 0.3 to 0.7 mm may be ooliths not destroyed by recrystallization. A few composite grains (1 mm or less in diameter) of clear carbonate, probably calcite, are scattered through the nodules as are thin veinlets of clear calcite. Also included are a few small dull black grains (probably organic) and scattered grains of quartz.

An opaque black skin (1 mm or less) coats the nodules and also lines fractures within the nodules. Clear carbonate occupies the centre of some of the fracture fillings and also forms thin veinlets cutting the opaque mineral. In polished section the opaque mineral is medium grey, massive, isotropic to very weakly anisotropic, and is tentatively identified on optical criteria as bixbyite - $(Mn\ Fe)_2O_3$.

Six representative samples of the nodules were assayed for iron and manganese and gave the following results:

Field No.	*Location*	*Total Iron %*	*Manganese %*
21-6-7	Bainbridge River	18.92	22.45
4-4-1	Bainbridge River	18.72	12.66
4-4-3	Bainbridge River	21.95	12.54
4-4-4	Bainbridge River	20.19	17.58
4-4-5	Bainbridge River	17.54	17.14
30-8-1	Un-named canyon 15 miles S.W. of Bainbridge exposure	21.07	17.44

Note: Analyses by Technical Service Laboratories.

Semi-quantitative spectrographic analysis of two of the above samples (21-6-7 and 30-8-1) showed in addition to manganese and the rock-forming elements aluminum, calcium, iron, magnesium, silicon, and sodium, the presence of minor or trace amounts of the following elements; barium, chromium, cobalt, copper, gold, lead, molybdenum, nickel, silver, titanium, vanadium, zinc, and zirconium.

One sample of bedrock shale from the Bainbridge River locality assayed 1.32 per cent manganese and 4.02 per cent iron and a semi-quantitative spectrographic analysis disclosed minor or trace amounts of barium, boron, chromium, copper, lead, nickel, silver, strontium, titanium, vanadium, yttrium, and zirconium, in addition to the common rock-forming elements.

X-ray diffraction examination of unoxidized portions of samples 4-4-1, 4-4-3, 4-4-4, and 4-4-5 and the oxidized crust of sample 4-4-4 was carried out by Mr. J. H. Hudson of the Saskatchewan Research Council. He found that the unoxidized samples consisted essentially of a mixture of $FeCO_3$ and $MnCO_3$, probably a solid solution, as any given peak is of d-spacing intermediate between the two members. Other minerals identified were quartz and opal. The oxidized crust proved to be essentially amorphous with minor amounts of quartz, calcite, rhodochrosite, and an unidentified oxide of manganese.

In view of the petrographic and spectrographic evidence, the nodules consist essentially of mix crystals of rhodochrosite and siderite and as Mn ≥ Fe, the term "manganosiderite" is applicable (Deer, Howie, and Zussman, 1962, p.265).

A mineralogical study of four representative samples from the Bainbridge River locality was carried out by S. Kaiman of the Mines Branch, Department of Energy, Mines and Resources, Ottawa (Extraction Metallurgy Division, Internal Report EMT 69-14, November 1969).

Results of this investigation confirmed that the nodules consist essentially of a compound of iron and manganese carbonate in which the metal ions substitute for each other. The black coating was found to be amorphous. Chemical analysis of two of the specimens yielded the following results:

Specimen No.	*Mn %*	*Fe %*	*Ca %*	*CO_2 (evol) %*
2	14.9	19.5	5.83	30.4
3	17.3	18.9	3.56	30.4

From these data it was calculated that the combined divalent oxides total 52.5 per cent and 51.6 per cent respectively. Thus assuming that all of the Mn, Fe, and Ca occurs as carbonate this would account for 82 per cent of both samples.

The specific gravity of the nodules was determined on three samples of 15 - 20 grams each and gave values ranging from 3.4 to 3.5.

Genesis

Sedimentary deposits of manganese are widespread in the geological column, from Precambrian to Recent, and these include nodules found on present-day ocean floors and lake beds. Considerable controversy rages as to the origin of manganese deposits; opinion being sharply divided between two schools of thought, one advocating a volcanic origin, and the other a non-volcanic origin.

The Pasquia Hills deposit consists of single layers of manganosiderite nodules along bedding planes separated by several feet, or several tens of feet, of nodule-free shale. There is no reason to invoke an epigenetic origin for the nodules so the most likely explanation is that they formed during sedimentation when physico-chemical conditions were favourable for precipitation of manganese and iron. $MnCO_3$ is a primary precipitate in moderately low Eh and pH conditions and as the stability fields of iron and manganese partly overlap, the association siderite-rhodochrosite as a primary precipitate is not uncommon. Only low concentrations of manganese and other elements occur in surface waters and although the nodule-free shales are anomalously rich in manganese (a representative sample assayed 1.32 per cent Mn), indicating the presence of abnormal amounts of the metal during sedimentation, it is difficult to explain the concentration of manganosiderite layers without resorting to explanations involving massive, periodic influxes of the metals relative to terrigenous material into the sedimentary basin.

The role of diagenesis in forming manganese deposits has been pointed out by several workers. Strakhov (1966) suggested that in lacustrine and certain marine environments, iron and manganese precipitate and settle to the lake or sea bottom together with clastic material. When the iron and manganese compounds reach a certain depth of burial, where reducing conditions exist, they are taken into solution and migrate upwards through the overlying sediment and are reoxidized and re-deposited at the sediment-water interface. This process appears to offer a more plausible explanation for the concentration of manganosiderite in discrete layers, than any other theory involving spasmodic and massive influx of the metals into the depositional basin.

The foregoing hypothesis must be regarded as speculative in view of the fragmentary chemical data available and much more information is required on the geochemistry of the whole of the manganese-bearing sequence at the base of the Riding Mountain Formation. Such a study might well prove to be other than of purely academic interest because if, on a regional basis, manganese-bearing nodules are found to occur only where the bedrock shales themselves are anomalously rich in manganese, a useful prospecting guide will have been provided.

Economic Considerations

(i) *Reserves*. The manganiferous horizon is exposed at various localities on the east flank of the hills north of the Waskwei River and on the north slope of the hills as far west as the Man River. Assuming continuity of the deposit between these localities, the horizon may have an areal extent of 150 square miles. Over much of this area, however, the manganese-bearing shales are covered by a considerable thickness of later sediments and glacial deposits. Only the part of the deposit at, or near to, the surface that can be mined by stripping will be of any economic significance in the foreseeable future. If the manganiferous horizon is 30 feet thick and continuous around the scarp edge of the hills between Waskwei and Man Rivers, a maximum potential tonnage can be calculated for the portion of the deposit mineable at a stripping ratio of 0.5 (waste) to 1 (ore) or better. Dimensions used in the calculation are, as follows:

	*Length**	*Thickness*	*Scarp Slope*	*Horizontal mining width*
Block A (Waskwei R.) to Bainbridge R.)	9 miles	30 feet	170 ft. per mile	1000 ft.
Block B (Bainbridge R. to Man R.)	25 miles	30 feet	260 ft. per mile	700 ft.

*Straight line distance; actual strike length will be greater because of sinuosity of the scarp edge.

Using these figures and assuming an average cover of ten feet of glacial overburden and an average concentration of 1 ton of nodules per 400 cu. ft. of shale, a maximum potential tonnage of 5 to 6 million tons of nodules is inferred.

As it is possible that the manganiferous horizon is not continuous and the average concentration of nodules is lower, the actual tonnage might be less and can be only estimated with confidence after a thorough drilling and sampling programme has been carried out.

(ii) *Beneficiation*. In view of the suspected high tonnage potential of the Pasquia Hills deposit, an investigation into the utilization of the nodules for ferromanganese production was carried out at the Metals Reduction and Energy Centre of the Federal Mines Branch. The main findings of this study (Campbell and Sirianni, 1971) were, as follows:

(a) For the production of standard high-carbon ferromanganese by conventional methods it is necessary to have an ore with a Mn:Fe ratio of at least 4 : 1. The Pasquia Hills nodules have a ratio of only 0.7 : 1.

(b) As the manganese mineral is evenly distributed throughout the nodules, there seems to be little chance of upgrading the material by ore-dressing techniques.

(c) Experiments involving roasting followed by magnetic separation were attempted but failed to improve the Mn:Fe ratio.

(d) Direct smelting will not increase the Mn:Fe ratio but work carried out at the Mines Branch several years ago on similar material showed that it is technically feasible to produce ferromanganese (about 75 per cent Mn) by the Udy Process. Briefly this process involves calcination of the nodules to convert carbonates to oxides followed by a two- or three-stage smelting process. In the first stage, the ore is smelted with a carbonaceous reductant to produce metallic iron. Manganese remains in the slag that has a Mn : Fe ratio of 4 : 1 or greater. The slag is then resmelted with a carbonaceous reductant to produce high-carbon ferromanganese. Alternatively some of the slag from the first stage can be resmelted with a carbonaceous reductant to form silicomanganese and the silicomanganese is utilized as a reductant for the remainder of the slag from the first stage to produce medium-carbon ferromanganese.

(iii) *Similar Deposits*. A vast deposit of manganese nodules occurs near Chamberlain, South Dakota, and is similar geologically and mineralogically to the Pasquia deposit. The nodules, consisting of manganese and iron carbonates occur in the Sully Member of the Pierre Formation that outcrops along the sides of the Missouri Valley and its tributaries for a lineal distance of 523 miles. Drill-indicated reserves that can be recovered by surface mining at a stripping ratio of 0.5 : 1 or better are 77.7 million tons of nodules grading 15.51 per cent Mn and 9.13 per cent Fe (Pesonen, Tullis, and Zinner, 1945 p. 85).

Any investigation into the economic potential of the Pasquia Hills deposit should take into account the vast amount of information available on the geology, mining, concentration, and beneficiation of the Missouri Valley nodules. Much of this information has been published by the United States Bureau of Mines as a result of their investigation of the deposit during the Second World War. A few of the more important papers are listed in the references to this report.

URANIUM

Since the printing of this report commenced, considerable interest has been shown in the uranium potential of the western flank of the Pasquia Hills. Although it was possible to add a brief account of the uranium situation in the text of the report, printing had advanced to the stage where additions could not be made to the geological map.

The current interest in uranium was sparked by the results of a Federal-Saskatchewan reconnaissance airborne radiometric survey, which was carried out in 1973 in the northern part of the province, along east-west flight lines spaced 50 km. apart. The results are on Open File 169 of the Geological Survey of Canada, released on November 8, 1973. Copies of the open-file material are available from the Publications Office, Department of Mineral Resources, Regina.

Flight line no. 1 of the airborne survey crossed the Pasquia Hills at approximately 53°15'N and disclosed a three-mile-wide uranium anomaly across sections 21, 22, and 23 of Township 49, Range 7, W2. At the time of the field work carried out for this report (1967), the nearest recorded bedrock to the anomaly was approximately five miles to the northeast, where several cut-banks on the Cracking River expose black, non-calcareous shales of the Vermilion River Formation. These shales are at about the same topographic elevation as the anomalous area.

Since 1967, much of the forest cover in this part of the Pasquia Hills has been cleared for agricultural purposes and as the till cover is generally thin, further exposures of the bedrock may be present nearer to the anomaly than the Cracking River outcrops.

The anomaly has a peak of about 220 counts in the uranium channel at a 2.5 second count rate. According to information supplied in the legend of the Open-File maps, this is equivalent to a ground concentration of approximately 8 ppm uranium.

Ten samples collected from various localities on the Man and Cracking Rivers during the 1967 field season, were analyzed for uranium by R. Mode of the Regina Campus Geochemical Laboratory in 1974. Results are tabulated below:

Sample No.	*Location*	*Description*	*U. (ppm)*
8-6-1	Cracking River	Non-calcareous shale of the Vermilion River Formation	0.57
9-6-1	Cracking River	"	0.71
9-6-2	Cracking River	"	5.00
28-7 1	Cracking River	"	9.28
16-8-1	Man River	Non-calcareous shale, Lower Colorado	1.33
16-8-3	Man River	Poorly consolidated sand (Tertiary?)	0.44
16-8-5	Man River	Calcareous speckled shale of the Vermilion River Formation	0.39
17-8-2	Man River	"	1.81
18-8-1	Man River	"	3.15
18-8-2	Man River	Non-calcareous shale of the Vermilion River Formation	0.73

The highest values (5.00 and 9.28 ppm) represent samples of the non-calcareous Vermilion River Formation from outcrops on the Cracking River about five miles northeast of the anomalous area.

Although these concentrations of uranium in the bedrock are high enough to explain the airborne anomaly, it is possible that the samples are leached as they were collected from the surface. In view of this, any thorough evaluation of the uranium potential of the area must involve test-pitting and drilling.