GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

PAPER 65-23

INTERBASINAL GROUNDWATER FLOW, OAK RIVER, MANITOBA

(Report and 4 figures)

A. Lissey and J. E. Wyder

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Illustrations

ABSTRACT

A successful combination of geophysical and geohydrological techniques has been used to demonstrate the fact that groundwater can flow between the Salt Lake and Oak River drainage basins in Manitoba.

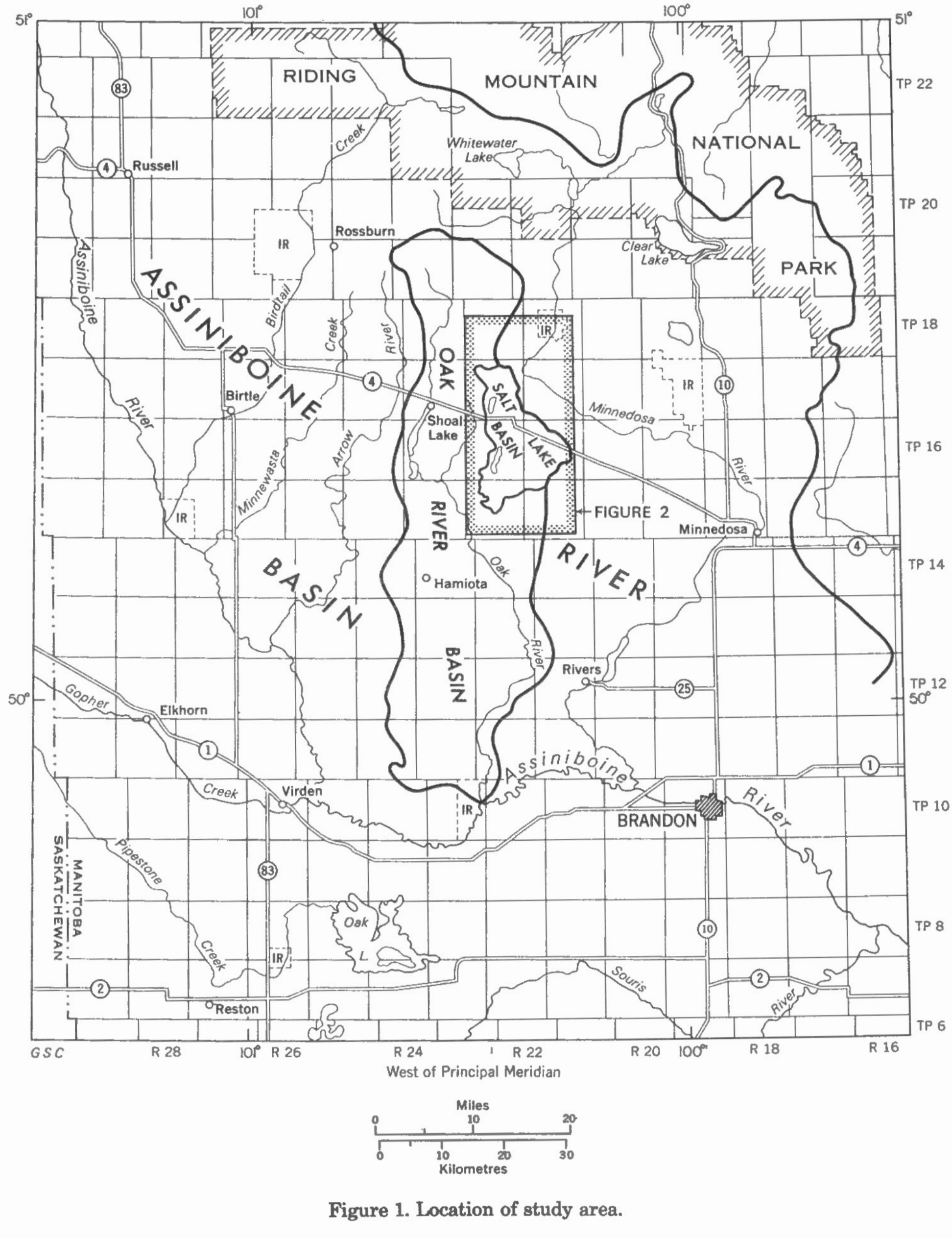

Figure 1. Location of study area.

INTRODUCTION

Preliminary work was done in 1964 to determine whether groundwater can flow between drainage basins and whether surface electrical resistivity techniques could be used to delineate bedrock channels and gravel deposits in areas where both ground and surface waters are saline. This work comprises part of a continuing study of the Oak River drainage basin, Manitoba.

The area studied for this investigation lies between township 15 and township 18, ranges 21 and 22, west of the prime meridian in west-central Manitoba (Fig. 1). It comprises the Salt Lake drainage basin and adjoining parts of the Oak and Minnedosa River drainage basins. These three basins constitute part of the Assiniboine River basin.

The regional slope of the Assiniboine basin's northeast flank is 16 feet per mile to the southwest across the study area. The Salt Lake basin has a general flank slope of 25 feet per mile near Strathclair. This decreases to about 18 feet per mile at the south end of Salt Lake. The Oak River basin has similar flank slopes. The local relief within the study area ranges from 10 to 25 feet (Klassen, 1963).

Both the Oak River and Salt Lake basins are of the fluctuating drainage area type (Stichling and Blackwell, 1957). During very wet years the Salt Lake basin drains into Oak River via minor meltwater channels located in township 15, range 22. During normal years it becomes a closed drainage basin with its intermittent streams ceasing to flow by mid-summer. The suspected gross drainage area of the Salt Lake basin is shown in Figure 2.

The mean annual temperature is about 35°F. Prevailing winds are from the northwest and the mean annual precipitation is about 18 inches (Thomas, 1953).

GEOLOGY

Permeability, an important factor of groundwater flow, is largely dependent on rock type. The rocks occurring in the Oak River drainage basin area are gravel, shale, till, and clay, in order of decreasing permeability.

A fractured, hard, siliceous, grey shale, underlying the entire area and termed the Odanah shale, is 191 feet thick in a piezometer hole drilled in lsd. 1, sec. 5, tp. 17, rge. 22, w.p.m. A soft, greenish grey clay containing bentonite stringers and bands of clay ironstone concretions underlies the shale and is between 50 and 70 feet thick (Davies et al., 1962). These basal Millwood beds and the overlying Odanah shale comprise the Riding Mountain Formation (Tovell, 1951). This formation is of Late Cretaceous age and forms the bedrock in the area.

In general the bedrock surface corresponds to the present topography of the area except for a buried meltwater channel, which corresponds to the trend of Salt Lake and North Salt Lake. This channel has been cut about 100 feet into shale and is about 2,000 feet wide below the lakes.

A dark grey, moderately stony, clayey till containing abundant shale pebbles comprises the surficial material of the area. This till, which weathers to a dark greyish brown, unconformably overlies the bedrock except in the Salt Lake channel. It is about 55 feet thick within the channel near Strathclair, thins to between 10 and 25 feet on either side of the channel, and thickens eastward to between 60 and 80 feet near Glossop. Drill-holes also indicate a thickening toward the north and west.

A coarse, shaly sand, and gravel, laterally confined to the Salt Lake channel, underlies the upper till and rests unconformably on Odanah shale. In places it is underlain by remnants of an earlier sandy till. Toward the south it interfingers with a very shaly phase of the upper till, which appears to contain ice-thrust blocks of shale up to 15 feet thick. In many holes, between 2 and 4 feet of fractured shale were encountered directly above the gravel. Although the origin of this shale is not certain it is believed to represent stream deposition of material eroded from the neighbouring highlands.

Of these rock types, the most important hydrogeological unit is the highly permeable gravel. Its extent could not be determined by a simple drilling program because it is confined to the narrow Salt Lake channel whose buried position is in no way indicated at the surface except at the lakes. Although closely spaced drilling in 1963 detected its presence in the northeast corner of sec. 20, tp. 15, rge. 22, w.p.m., a geophysical survey was requested to trace the channel's position both north and south of the lakes. It was felt that prudent use of geophysical techniques would be a more economical alternative to pattern drilling.

GEOPHYSICS

Electrical Properties

The decision to use surface resistivity techniques in an area known to be saturated with saline groundwater was based on investigations made by Sarma and Rao (1962). Their results demonstrated that although the resistivity of a substance is determined largely by the nature of the saturating fluid, rock properties such as grain size and mineralogical composition can also significantly affect rock resistivity. Considering Sarma's and Rao's results, as well as experience gained in similar but non-saline areas in Manitoba (Wyder, 1964), the authors suspected that in the survey area the resistivity of the gravel deposits would be greater than that of the siliceous Odanah shale, which would have an associated resistivity greater than that of the overlying till. It was also suspected that the Millwood clays would have a resistivity significantly lower than that of any of the other rock types present in the survey area. These assumptions were made with the knowledge that the resistivity of the groundwater in the gravel deposits and the surface water in the lakes was less than 3.3 ohm-feet.

Geological Control

In general, resistivity surveys are of little use unless definite geologic control is established by either drill-holes or some other technique.

In the area under discussion the necessary geophysical control was obtained by conducting expanding Wenner configuration surveys (Curves 11, 12, 15, 16, Appendix A) at or near the sites of 4 drill-holes (C-3, C-4, C-1, C-2, Appendix B) from which stratigraphic information had been obtained. The results of the surveys conducted at the control sites indicated that surface resistivity techniques could satisfactorily detect the bedrock channel.

Equipment

Direct-current surface resistivity equipment mounted in a one-ton panel truck was used to conduct the resistivity survey. The power supply for the equipment consisted of three parallel banks of five 45-volt radio B batteries. The voltmeter used to measure the potential difference between the potential electrodes had an input impedance of 10^{14} ohms. The truck carried 6,000 feet of current cable and 4,000 feet of potential cable. The cable was mounted on power-operated reels. Using this equipment the 4-man resistivity crew completed 41 depth profiles in 5 working days.

Type Curves

The two families of field curves obtained in the survey area are shown in Figure 3. Field curves 4 and 6 are typical of those curves obtained in areas where 30 to 60 feet of clay till, possibly containing local lenses of sand, gravel, and silt, overlies the Odanah shale. Two notable variations in the family of field curves represented by curves 4 and 6 are exemplified by field curve 12 and 16 (Appendix A). The former shows an approximately linear decrease of resistivity with increasing a-span, while the latter shows an exponential-like decrease of resistivity with increasing a-span. Field curve 12 was obtained where oxidized and unoxidized clay till overlie the Odanah shale. Field curve 16 was obtained where sandy till overlies fractured Odanah shale.

The family of field curves represented by curve 5 (Fig. 3) is indicative of the buried bedrock channel. The initial increase of resistivity with a-span probably reflects the increased thickness of the upper till within the channel. The peak in this curve corresponding to an a-span of 80 feet is thought to reflect the presence of high resistivity material occurring within the channel. This material may be either transported Odanah shale, sand and gravel, or possibly both. As is shown by field curves 11 and 15 (Appendix A) a secondary peak is very noticeable in areas where the channel contains significant thicknesses of sand and gravel. The maximum value of the field curve possibly reflects the point beyond which, with increasing a-span, the effect of the more resistive Odanah shale is masked by the influence of the much less resistive Millwood clays. Tests conducted at the control sites indicated that a-spans in excess of 200 feet were not needed for the purpose of locating the bedrock channel.

In order to trace the channel it was decided to do vertical profiling using an expanding Wenner configuration with twelve a-spans between 5 and 200 feet at each station. The station intervals chosen were 500 feet in the southern part of the area and 1,000 feet in the northern part of the area. These decisions were based on the following considerations:

1. The major purpose of the resistivity surveys was to locate the buried channel quickly and with a minimum of ambiguity.

2. The area in which the channel was expected to occur was established by the extrapolation of known geology.

3. The characteristic field curves indicative of both the presence and absence of the bedrock channel had been obtained.

4. Sufficient time was not available to conduct a number of horizontal profiles across the known location of the channel.

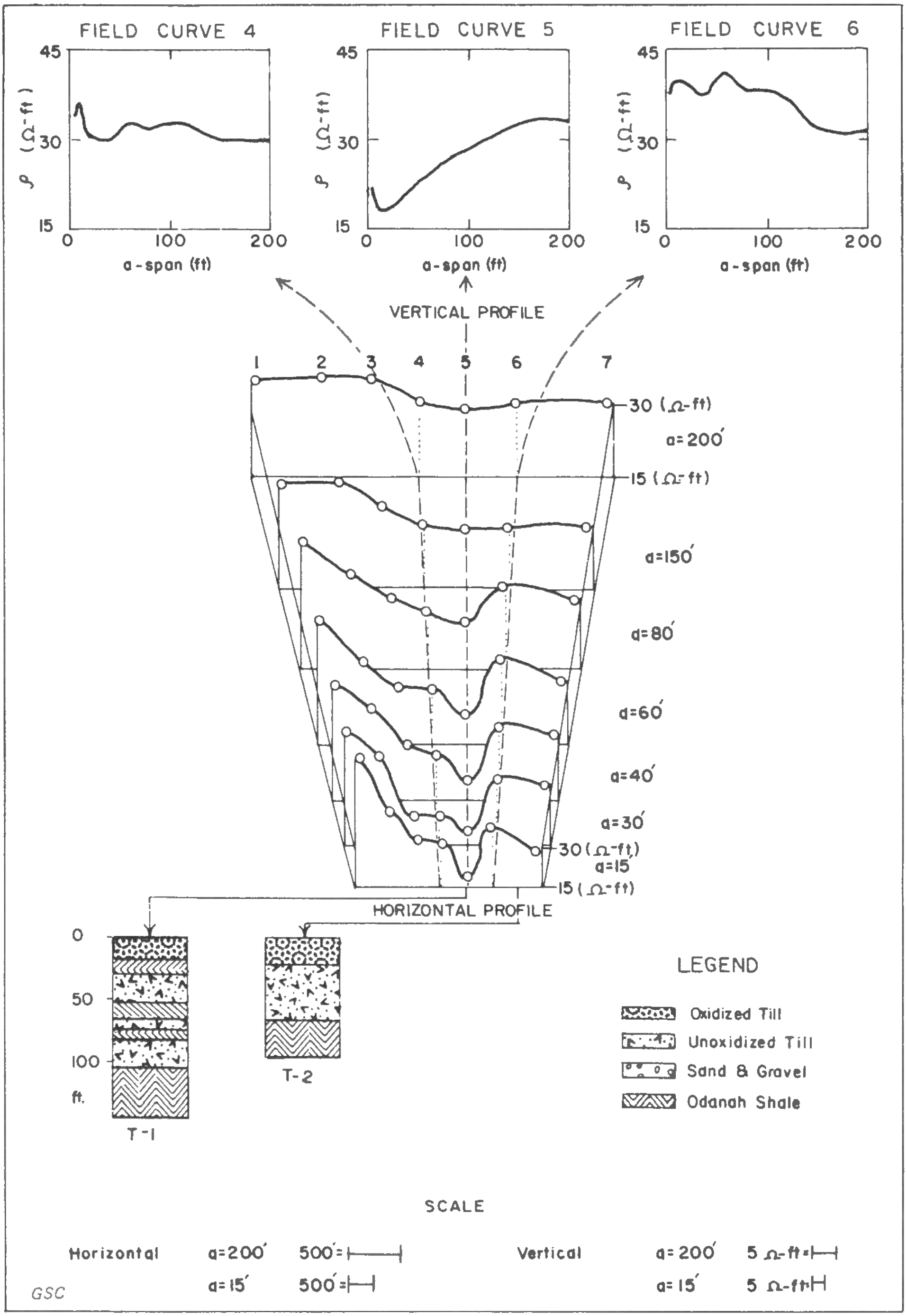

Figure 3. Resistivity and drilling results along line A.

5. It was conceivable that for a given a-span, resistivity values obtained over the gravel-filled channel could be very similar to those obtained over areas where the channel did not exist. This is exemplified by the 40-foot a-span for field curves 15 and 16.

6. The use of vertical profiles would be more definitive in analyzing anomalous resistivity results than would horizontal profiles.

Results

The field data are tabulated in Appendix A. The positions of the resistivity stations (a field curve has been assigned the same number as its corresponding station) are plotted on Figure 2.

Lines A and B

Line A was located so as to lie across the suspected position of the bedrock channel. The results of the survey along line A are presented in Figure 3. The vertical profile values were used to plot horizontal profile traverses for 7 different a-spans. The resistivity low in the horizontal profiles disappears with increasing a-span. This effect would be expected if the channel contained little or no material more resistive than the Odanah shale. The shapes of field curves 4, 5, and 6 suggest that the channel lies under station 5 and is probably less than 1,000 feet wide. Sites for drill-holes T-1 and T-2 were picked on the basis of the resistivity results. The stratigraphic sections obtained from these holes verified the existence of a non-gravel bearing bedrock channel at the site of drill-hole T-1 and a bedrock high at the site of drill-hole T-2.

The site of station 9 was selected by interpolating known geology. The results obtained at stations 8 and 10 show that the bedrock channel does occur under or very near station 9. For a-spans greater than 80 feet the horizontal profiles become convex upwards rather than remaining concave upwards as was the case for line A. This suggested the presence, in the channel, of material more resistive than the Odanah shale. The drilling of test hole T-3 at the site of station 9 verified the presence of sand and gravel, thereby eliminating the need for further resistivity work south of North Salt Lake (Fig. 2).

Lines C and D

Field curve 23 is typical of many of the field curves obtained at stations along lines C and D (Fig. 2). This curve appears similar to field curves used south of North Salt Lake, which indicated the presence of a buried channel. However, the curve is initially much steeper and reaches a maximum at much lower a-spans than the curves used as channel indicators. Curves similar to field curve 23 are interpreted as representing a thin (less than 30 feet) layer of till essentially free of sand and gravel, overlying fractured Odanah shale. Assuming that the qualitative interpretation of the family of curves represented by field curve 23 is correct, the suspected position of the bedrock channel north of North Salt Lake has been plotted on Figure 2. Further work at one mile intervals may show the extrapolated position of the channel to be somewhat in error.

There has been no attempt to present quantitative results based on the resistivity data: The reasons for this are:

1. Only the location of the channel was desired.

2. There is not sufficient drilling control to establish empirical relations between field curve characteristics and depths to bedrock.

3. It is ludicrous to analyze field data by theoretical methods based on the layered-earth concepts when it is known that the geological model does not approach this hypothetical situation.

HYDROLOGY

After determining the extent and relationship of all hydrogeological units in the area, six piezometers were installed to measure head conditions within the buried channel across the divide between the Salt Lake and Oak River drainage basins. The piezometers were installed in nests of two. The deep piezometer in each nest was completed at the top of the Odanah shale. The shallow piezometer in each nest was completed within the sand and gravel at an elevation of 1,770 feet above sea-level (Fig. 4):

Each piezometer was completed in a rotary-drilled 5 5/8 inch diameter hole, cased with 2 inch standard black pipe, and grouted with 15.5 lb /gal neat cement for 30 feet. Each was completed with a slotted screen one foot long and a metal-petal basket placed one foot above the top of the screen. The basket retained the grout plug. All piezometers were developed by first flushing out drilling mud prior to cementing, then alternately jet cleaning the screen and swabbing after the cement had set. All were capped and ventilated.

Head readings were obtained on October 1, 1964 by the wetted-tape method, two weeks after completion of the last piezometer. Readings were again taken on April 30, 1965. The results are shown in the following table of piezometer readings.

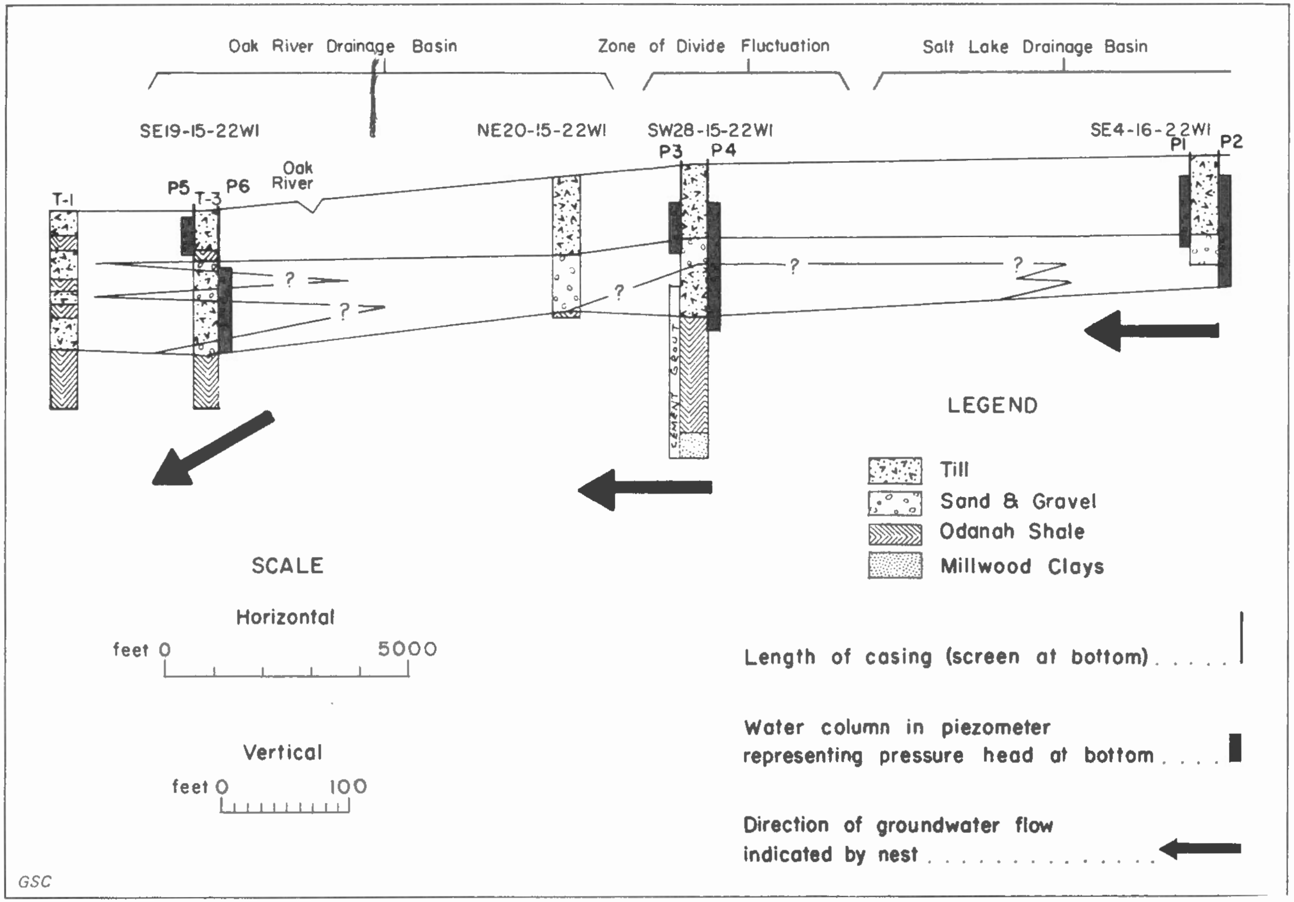

Figure 4. Cross-section along line A-A'.

	Piezometer Number	Nest Number	Elevation of Water Level
October 1, 1964	1	1	1827.34
October 1, 1964	2		1826.23
October 1, 1964	3	2	1807.47
October 1, 1964	4		1808.03
October 1, 1964	5	3	1796.16
October 1, 1964	6		1753.61
April 30, 1965	1	1	1826.74
April 30, 1965	2		1825.24
April 30, 1965	3	2	1806.68
April 30, 1965	4		1808.39
April 30, 1965	5	3	frozen
April 30, 1965	6		1758.20

These readings indicate that groundwater flows laterally from the Salt Lake basin, across the fluctuating drainage divide, and into the Oak River basin via the highly permeable gravel confined to the Salt Lake buried channel (Fig. 4).

CONCLUSIONS

Groundwater can flow across the divides between a series of asymmetric drainage basins that form one flank of a larger basin. The factors thought to contribute to the shallow occurrence of interbasinal flow are: (1) high regional slope of the large basin; (2) low general slopes in the smaller basins; (3) low local relief; and (4) a buried zone of higher permeability at a shallow depth. Except for a high regional slope, all the conditions favourable for shallow interbasinal flow are found between the Salt Lake and Oak River drainage basins.

Surface resistivity techniques can be used successfully to locate buried bedrock channels in the saline environment of the Oak River drainage basin. The success of the surveys conducted in such an environment indicates the importance of factors other than fluid resistivity in determining the resistivity of a saturated rock.

A cooperative exploration program combining surface geophysical techniques with rapid rotary test drilling is a practical and economical means of delineating subsurface geology. Such a program is especially applicable when tracing narrowly confined occurrences like the Salt Lake channel, which can be missed even by dense pattern drilling.

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APPENDIX A

SURFACE RESISTIVITY DATA

Location West of Principal Meridian	3200' W of NE 18-15-22	2500' W of NE 18-15-22	2000' W of NE 18-15-22	1500' W of NE 18-15-22	1000' W of NE 18-15-22	500' W of NE 18-15-22	500' E of NE 18-15-22	500' N of NE 18-15-22	1500' N of NE 18-15-22	2500' N of NE 18-15-22	¼ Mile W of NE 20-15-22	¼ Mile W of NE 21-15-22	2500' W of NW 8-15-22
Station	1	2	3	4	5	6	7	8	9	10	11	12	13
°Drill-Hole					T-1	T-2	T-2		T-3		C-3	C-4	
a-span													
† 5	*151	56	41	34	22	38	31	54	24	46	34	57	14
10	107	54	37	36	18	40	29	53	26	40	27	56	17
15	70	46	33	33	18	40	30	53	27	37	26	56	20
20	55	45	34	31	18	39	34	48	28	38	25	53	23
30	57	45	31	30	19	38	35	45	30	37	27	53	26
40	55	43	33	30	21	38	36	42	32	38	31	55	27
60	55	39	33	33	24	42	33	39	36	38	38	49	28
80	50	40	34	32	27	38	33	37	38	42	40	48	28
100	49	40	35	33	28	38	31	36	39	40	44	45	29
125	43	41	34	32	30	36	32	34	38	40	46	42	29
150	40	41	36	30	32	32	31	32	38	41	45	39	28
200	35	36	35	30	33	32	29	32	38	36	39	37	26
250					30				35		39	33	
300					30				33		38	31	
350					39				33		37	29	
400					28				31		33	28	
500											29	25	
600											26	25	

† a-spans given in feet   * resistivities given in ohm-feet   ° see appendix B

SURFACE RESISTIVITY DATA

Location West of Principal Meridian	1500' W of NW 18-15-22	NE 33-16-22	½ Mile W of NE 35-16-22	2500' W of NE 21-17-22	2000' W of NE 21-17-22	1000' W of NE 21-17-22	500' W of NE 21-17-22	NE 21-17-22	1000' E of NE 21-17-22	1000' E of NE 29-17-22	2000' E of NE 29-17-22	9500' W of NE 2-18-22	8500' W of NE 2-18-22	7500' W of NE 2-18-22
Station	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Drill-Hole		C-1	C-2											
a-span														
5	49	30	67	25	26	40	29	25	46	31	56	22	53	30
10	54	36	68	28	25	37	35	28	41	38	49	17	56	37
15	58	38	68	29	27	36	41	29	40	40	44	17	47	40
20	55	40	60	30	28	39	40	30	38	42	43	19	45	38
30	56	43	56	32	34	40	43	32	40	43	41	22	47	38
40	58	46	47	33	35	40	45	32	39	43	40	25	48	38
60	55	47	41	35	39	41	47	37	42	42	41	30	48	40
80	48	50	38	34	40	41	48	43	40	40	42	33	48	46
100	44	51	37	34	39	40	47	44	39	38	42	36	46	48
125	39	51	37	34	37	39	45	43	36	36	39	38	49	49
150	36	51	36	34	36	39	42	42	34	37	38	39	47	49
200	35	47	35	31	33	37	38	36	31	35	35	38	45	45
250		43												
300		38												
350		35												
400		33												
500		30												
600		28												

† a-spans given in feet * resistivities given in ohm-feet ° see appendix B

SURFACE RESISTIVITY DATA

Location West of Principal Meridian	6500' W of NE 2-18-22	5500' W of NE 2-18-22	4500' W of NE 2-18-22	3500' W of NE 2-18-22	2500' W of NE 2-18-22	1500' W of NE 2-18-22	500' W of NE 2-18-22	500' E of NE 2-18-22	1000' E of NE 2-18-22	1500' E of NE 2-18-22	2000' E of NE 2-18-22	2500' E of NE 2-18-22	3500' E of NE 2-18-22	4500' E of NE 2-18-22
Station	28	29	30	31	32	33	34	35	36	37	38	39	40	41
Drill-Hole														
a-span														
5	47	25	14	50	45	56	60	31	25	26	21	32	27	20
10	51	29	19	51	38	48	57	35	29	29	26	34	28	22
15	50	28	22	49	38	43	55	36	32	30	30	36	30	27
20	48	31	25	46	39	43	52	36	34	33	32	37	34	32
30	49	32	30	45	42	45	51	38	36	36	32	39	36	34
40	46	34	33	43	43	45	48	38	37	37	33	41	38	35
60	45	38	36	41	41	43	47	38	40	39	35	41	42	38
80	46	40	36	39	39	41	46	38	40	41	37	42	44	40
100	43	40	36	38	39	39	47	39	40	42	38	43	46	42
125	42	38	35	38	38	38	45	40	41	43	39	42	45	44
150	41	37	34	38	38	38	42	40	40	44	41	43	45	44
200	38	35	33	36	38	36	38	38	40	44	42	43	43	44
250									40	42	42	42	40	44
300									38	40	40	40	36	42
350									37	38	38	40	36	39
400									34	35	36	37		
500												35		
600												32		

† a-spans given in feet

* resistivities given in ohm-feet

APPENDIX B

Logs of Drilled Holes

Resistivity Control Holes

Hole No. C1
N.E. corner sec. 33, tp. 16, rge. 22, w.p.m.
completion: piezometer

0-15	oxidized clayey till
15-57	unoxidized clayey till
57-85	coarse, shaly sand and gravel
85-120	fractured, siliceous Odanah shale

Hole No. C2
N.W. corner sec. 35, tp. 16, rge. 22, w.p.m.
completion: abandoned Man. gov't. test hole

0-18	oxidized clayey till
18-35	unoxidized clayey till
35-60	fractured, siliceous Odanah shale

Hole No. C3
N.E. corner sec. 20, tp. 15, rge. 22, w.p.m.
completion: abandoned test hole

0-20	oxidized clayey till
20-26	unoxidized clayey till
26-42	coarse, shaly sand and gravel
42-62	unoxidized clayey till
62-96	coarse shaly sand and gravel
96-100	fractured, siliceous Odanah shale

Hole No. C4
N.E. corner sec. 21, tp. 15, rge. 22, w.p.m.
completion:

0-17	oxidized clayey till
17-53	unoxidized clayey till
53-60	fractured, siliceous Odanah shale

Test Holes Based on Resistivity Results

Hole No. T1
1,000 feet west of N.E. corner sec. 18, tp. 15, rge. 22, w.p.m.
completion: abandoned test hole

0-18	oxidized clayey till
18-30	fractured, siliceous shale
30-53	unoxidized, shaly, clayey till
53-66	fractured, siliceous shale
66-73	unoxidized clayey till
73-83	fractured shale
83-106	unoxidized, slightly sandy till
106-145	fractured, siliceous Odanah shale

Hole No. T2
S.E. corner sec. 19, tp. 15, rge. 22, w.p.m.
completion: abandoned test hole

0-20	oxidized clayey till
20-66	unoxidized clayey till
66-75	fractured, siliceous Odanah shale

Hole No. T3
1,500 feet north of S.E. corner sec. 19, tp. 15, rge. 22, w.p.m.
completion: abandoned test hole

0-18	oxidized clayey till
18-26	unoxidized clayey till
26-44	fractured siliceous shale w/gravel
44-62	unoxidized clayey till
62-72	med. gnd. sand
72-110	unoxidized clayey till
110-117	very coarse gravel
117-155	fractured siliceous Odanah shale

Piezometer Holes

Nest No. 1
S.W. 3-16-22 w.p.m.
Piezometer No. 1 completed @ 75 feet
Piezometer No. 2 completed @ 105 feet

Hole P1

0-19	oxidized clayey till
19-63	unoxidized clayey till
63-86	med. gnd. gravel

Hole P2 (600 feet east of P1)

0-18	oxidized clayey till
18-30	unoxidized clayey till
30-38	coarse gravel
38-96	unoxidized clayey till
96-106	coarse gravel
106-120	fractured siliceous Odanah shale

Nest No. 2
S.W. 28-15-22 w.p.m.
Piezometer No. 3 completed @ 63 feet
Piezometer No. 4 completed @ 123 feet

Hole P3

0-22	oxidized clayey till
22-52	unoxidized clayey till
52-56	fractured siliceous shale
56-81	coarse sand and gravel
81-120	unoxidized sandy till
120-212	fractured siliceous Odanah shale
212-230	greasy Millwood clays

note: hole plugged back with cement from 90 to F.T.D.

Hole P4 (15 feet north of P3)

Log as in P3

Nest No. 3
S.E. 19-15-22 w.p.m.
Piezometer No. 5 completed @ 35 feet
Piezometer No. 6 completed @ 113 feet

Hole P5 (10 feet south of T3)

Log as in T3

Hole P6 (10 feet north of T3)

Log as in T3