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A GRAVEL AND SAND AQUIFER IN THE BASSANO-GEM REGION, ALBERTA

by

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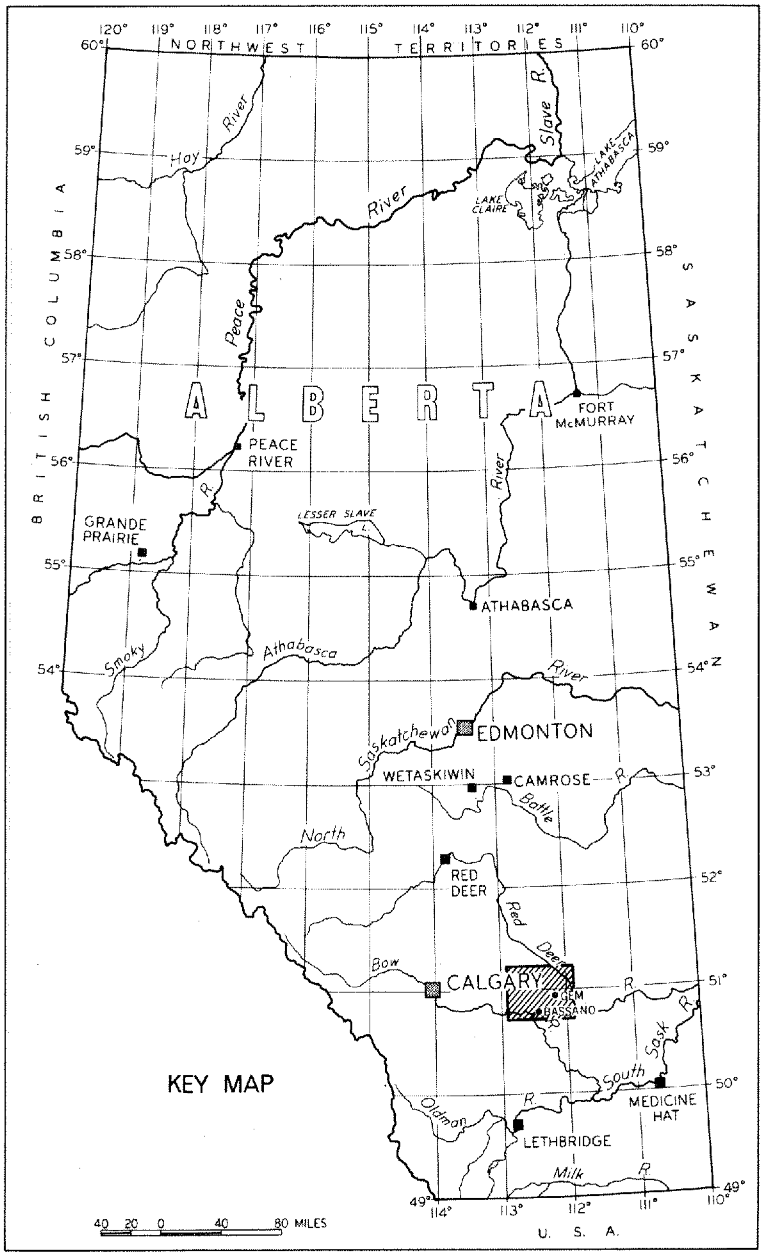

Figure 1. Location of Bassano-Gem region.

A GRAVEL AND SAND AQUIFER IN THE BASSANO-GEM REGION, ALBERTA

Abstract

Underlying the study area is a northeast-trending preglacial river valley whose extensive northern flank is covered by sand and gravel. The floor of the valley is also gravel covered but the abbreviated southern bank is not. The gravel and sand appear to be extensive and continuous and, where saturated, to constitute a potential aquifer of some importance. Estimated safe yields for wells finished in this gravel and sand range from less than 10 to approximately 80 imperial gallons per minute on a 20-year basis; however, only limited testing has been carried out. The water appears to be chemically suitable judging from the few chemical analyses available.

INTRODUCTION

Location and Topography

The area discussed in this report lies approximately 30 miles southeast of the city of Drumheller and 70 miles due east of the city of Calgary (Fig. 1). It is contained within the rectangular area defined by meridians 111°50' and 113° west longitude and parallels 50°40' and 51°15' north latitude. Its boundaries were chosen to encompass an extensive sheet of gravel and sand, the northern edge of which coincides with the south flank of the Wintering Hills, which attain a height of approximately 3,400 feet above sea level within the study area. The eastern boundary is the Red Deer River valley, incised to depths of 100 to 600 feet. The southern and western boundaries of the deposit lack topographic expression. Except for the Bow River valley (Tp. 21, R. 19) and Crawling Valley (Tp. 25, R. 17), which are incised to depths of about 100 feet, the gross topography of the study area is a general southeastward slope, with a total elevation decrease of about 700 feet.

Purpose and Scope

This report provides a general description and preliminary evaluation of an extensive preglacial gravel and sand deposit in the southern part of Alberta. To provide the physical framework for the evaluation of its potential as an aquifer, maps of preglacial gravel and sand thickness and extent, overburden thickness, surficial deposits and bedrock topography are included. Discussion is largely limited to the physical characteristics of the gravel and sand bed and its geologic setting, but data concerning chemical quality of the contained water, as well as results of a constant-rate pump test, a step-drawdown test, and three bail tests, are also presented. These aquifer tests were conducted by Research Council personnel. Analyses of drillers' bail-test data, available for two additional sites, are presented as well. It is hoped that the data in this report will allow efficient planning of exploration programs to develop groundwater supplies in the study area and will encourage local small-scale groundwater users to consider the buried gravels as a groundwater source.

Previous Investigations

The bedrock formations of the study area were mapped and described by Stewart (1943) and Allan and Sanderson (1945) and the surficial geology by Stalker (1965) and Craig (1957). Known and suspected locations of preglacial river courses in central and southern Alberta were first mapped by Stalker (1961). A similar but more detailed map was subsequently produced by Farvolden (1963). In neither case were contours of the bedrock surface provided, but these have recently become available for the Gleichen (Geiger, 1968) and Drumheller (Carlson, in preparation) map-areas. These maps provide coverage of most of the study area.

Compilation and Accuracy

Most of the data used in compiling this report were derived from shot-hole logs obtained from co-operating oil companies. This information was supplemented by logs of test holes drilled under Research Council supervision, including those of Campbell and Almadi (1964) and Campbell (1967).

The bedrock topography map (Fig. 2) is based on maps by Geiger (1968) and Carlson (in preparation), with minor modifications made to accommodate recent test-hole data. The contours are of necessity generalized because of difficulties in interpreting conflicting data reported by drillers generally unskilled in geology. Figure 2 also shows thickness and extent of preglacial gravels and sands. As in the case of the bedrock contours, difficulties in interpretation were encountered, so that thickness intervals selected for mapping of the gravels and sands were large and the boundaries between mapped areas have been generalized. The interpretation procedure assumed that gravels and sands lying on bedrock (or near the predicted bedrock elevation for holes not penetrating to bedrock) were preglacial and that those found within the drift were glacial. An exception was made in the case of gravel deposits lying on bedrock in Crawling Valley, which are reported to be glacial by Craig (1957) and Stalker (1965). The drift thickness map was constructed by plotting and contouring thicknesses of glacial materials reported to overlie bedrock or preglacial sands and gravels. Some generalization was again involved in the contouring and therefore small discrepancies exist between calculated drift plus gravel thicknesses as given by figures 2 and 4 and as determined from the difference between surface and bedrock elevations shown in figure 2.

Acknowledgments

The writers gratefully acknowledge the co-operation of the following organizations who provided data used in compiling this report: Alberta Coal Ltd.; Canadian Pacific Oil and Gas Co. Ltd.; Canadian Superior Oil Ltd.; Hudson's Bay Oil and Gas Co. Ltd.; Imperial Oil Ltd.; Mobil Oil Canada Ltd.; and Pan American Petroleum Corp. Well-log and bail-test information provided by Doering Drilling was particularly helpful.

The cost of test drilling to extend and improve the available control was shared equally by the federal and provincial governments under the terms of the federal Agricultural and Rural Development Act (ARDA). This financial support is sincerely appreciated. The authors also wish to acknowledge the loan by the Alberta Department of Agriculture, Water Resources Division, of a rotary drill, complete with technical personnel, from April 18 to June 1, 1967. Information gained during this time was of great value.

This paper was read critically by D. H. Lennox and the authors wish to express their gratitude for his many helpful suggestions. Also, the results of two test holes drilled for a thesis study by N. E. Jensen were made available to the authors.

GEOLOGY

The gravel and sand bed which is the subject of this report lies primarily on a gentle bedrock slope forming the north flank of a preglacial river valley. The gravels and sands are considered to be Saskatchewan Gravels and Sands (Westgate and Bayrock, 1964; Stalker, 1968). They are underlain by Cretaceous bedrock strata and overlain by Pleistocene materials, including till and lacustrine deposits.

Cretaceous Strata

The bedrock units underlying the study area are the Bearpaw and Edmonton Formations, both of late Cretaceous age. The Bearpaw Formation, present in the southern portion of the area, is composed of marine shale (Stewart, 1943). The Edmonton Formation underlies the major portion of the area and consists of nonmarine bentonitic shales with lenticular sandstone layers and coal zones (Ower, 1958). Both formations are poorly consolidated and have a general dip of a few feet per mile to the west, northwest, or north (Stewart, 1943).

Preglacial Topography and Drainage

Erosion during Tertiary and early Pleistocene time originally shaped the bedrock surface of Alberta (Farvolden, 1963). It is believed that subsequent glacial modification in the study area was a minor factor and that the bedrock topography map (Fig. 2) is a reasonable facsimile of the preglacial land surface. No attempt has been made to correct the map for glacial or postglacial erosion.

The bedrock topography map (Fig. 2) shows a wide, assymmetrically shaped, preglacial valley with an extensive, gently sloping, northern flank and an abbreviated southern one. This is the Calgary Valley (Geiger, 1968) which originates in the mountains to the west, passes eastward near the city of Calgary, and in which flows the Bow River as far east as the western part of the study area. From this point the Calgary Valley trends eastward through the study area towards the Saskatchewan border. Within this area it is joined by two known minor tributaries — the Makepeace and Deadhorse Valleys (Geiger, 1968). These valleys descend from the northwest and are farily well defined until they reach the broad north slope of the Calgary Valley.

Gravel and Sand Deposits

The extensive deposit of gravel and sand immediately overlying bedrock in the study area is believed to belong to the preglacial Saskatchewan Gravels and Sands (Westgate and Bayrock, 1964; Stalker, 1968). Pebbles taken from the buried gravels and sands encountered in the observation well near test hole 66-7 (Lsd. 16, Sec. 36, Tp. 23, R. 17, W. 4th Mer.) consisted of 60 per cent quartzite, 32 per cent limestone and dolomite, and 8 per cent chert and other rock types (L.A. Bayrock, pers. comm.). This compares closely to the composition of Saskatchewan Gravels and Sands from the Calgary Valley in the city of Calgary (Meyboom, 1961) (50 per cent quartzite, 44 per cent dark limestone and dolomite, and 5 per cent chert). No rock types indicative of Precambrian Shield lithologies are present.

The preglacial gravel and sand deposits in the study area (Fig. 2) consist primarily of coarse materials, and in the great majority of drillers' logs are referred to simply as "gravel." Research Council test hole evidence, however, indicates that these deposits do contain appreciable amounts of finer materials and are therefore more properly described as gravel and sand. A sample from test hole 66-7 was about 17 per cent sand-size or finer material. (This test hole was eventually used as the pumped well for an aquifer test, and during well development the driller reported that much "clay" was taken from the hole. Similarly, during bail testing of test hole 67-11, about 5 miles to the southeast, considerable sand was produced.)

The gravels and sands cover the northern slope and most of the bottom of the Calgary Valley in the area of interest. Available data indicate that the south slope of the Calgary Valley has little or no sand and gravel cover, except in township 21, ranges 19 and 20 (Fig. 2). This conclusion is supported by test drilling results for profile AA' (Fig. 3). Gravel was absent from test hole 67-1 located on the south bank but present in 67-2 located a short distance away but near the bottom of the valley.

The inferred northern boundary of the gravel and sand deposits trends generally toward the northeast (Fig. 2), except in the Deadhorse and Makepeace Valleys, where the gravel and sand was possibly removed by fluvial action, resulting in the indentations observed in the boundary. As indicated on the map, the gravels in the Calgary Valley persist to the west beyond the boundary of the study area. To the east, across the Red Deer River valley, gravels similar to those discussed in this report are also known to exist (Carlson, in preparation). Thus, although the gravel sheet in the map-area now apparently pinches out or becomes discontinuous near the Red Deer River valley, it apparently was deposited as part of a continuous body extending to the east of the river and later dissected by a stream following roughly the same course as the present Red Deer River.

Though the gravel and sand bed is, according to available information, continuous in the study area, it is not of uniform thickness (Fig. 2). The thicker gravel and sand deposits are concentrated in the western portion and along the northern border. Those parts of the deposit greater than 40 feet in thickness generally form linear bodies oriented subparallel to the axis of the Calgary Valley and are not found east of range 18. Gravel and sand greater than 20 feet in thickness comprise the major part of the deposit in an area extending from the west boundary to a line which trends generally northwest from section 20, township 21, range 16. East of this line there are individual linear bodies of gravel and sand in this thickness range, the two largest of which are located in the northern portion of the deposit, parallel to its northern edge. Concentration of the thicker gravel deposits in the western portion of the area could be a natural consequence of the stream flowing in the Calgary Valley adjusting to a reduced gradient. This would be in keeping with Geiger's observation (1968) that a large area of relatively featureless bedrock topography begins in the present study area and extends eastward.

The positions of the gravels within the broadening Calgary Valley indicate that they are the result of a gradual change in valley direction during preglacial time. Apparently the stream originally flowed in a northeasterly direction from about township 21, range 21, but by the time of glaciation it followed a path extending due east from this location. Campbell and Almadi (1964, p. 57) postulate a similar rotation of the direction taken by the preglacial Calgary Valley (which they call the preglacial Bow River Valley). They suggest that the valley was initially directed toward the north-northeast from over Cluny Hill (Tp. 22, R. 21) and that by the commencement of glacial time it trended eastward from a point about 4 miles south of Cluny Hill. With a gradual change in valley direction of this sort, the stream would, as it altered its course, then leave a gentle, gravel-covered, bedrock slope on the north flank and cut a steeper gravel-free slope on the south side. Present data are not adequate to determine if terraces exist on either of these slopes.

Saturation of the Gravel and Sand

The elevation of the gravel deposits relative to modern drainage has a bearing on their usefulness as aquifers. Buried gravel deposits below the level of local streams are almost certainly saturated, and available drawdown in these cases can be substantial. Those situated above river level may be unsaturated or have a very limited available drawdown, particularly where the gravel outcrops on a present-day valley.

According to the shot-hole drillers' reports, the gravels do not extend eastward to the banks of the Red Deer River valley but pinch out or become discontinuous a short distance from it, except in the vicinity of township 22, ranges 14 and 15. Thus, even though Calgary Valley encounters the Red Deer River valley some 100 to 150 feet above river level in township 22, range 14, and the gradient of the preglacial valley is toward the modern valley, rapid drainage of the gravels in this direction appears unlikely. In fact, two flowing shot holes, apparently producing water from the gravels (Fig. 4), have been reported only 4 miles from the river bank in township 23, range 15. Five more, also apparently producing water from the gravels, are reported in townships 21 and 22, range 16. These are some 10 to 12 miles from the Red Deer River bank, but only 1 to 5 miles from the closest edge of the gravel body.

The Bow River is presently located some 80 to 100 feet above the gravels on the floor of Calgary Valley in township 21, range 19, as is shown on profile AA' (Fig. 3), and the gravels should be saturated in this area. The springs along the west bank of Crawling Valley probably drain water from the gravels (profile BB', Fig. 3). The degree of drainage is, however, not known but water wells completed in the gravel and sand are reported from north of Crawling Valley (Fig. 4). The locations of water wells reported finished in the gravel and sand are shown in figure 4 along with the depth to water reported in these wells. Approximate contours on the piezometric surface of this aquifer are also shown.

Glacial Deposits

Most of the area is covered by either ground moraine or hummocky moraine. The final retreat of Pleistocene ice was towards the northeast (Craig, 1957). As retreat proceeded, a number of glacial lakes formed, the former presence of which is marked by areas covered by lacustrine deposits. Several spillways were formed, the most prominent of which is today known as Crawling Valley. The meltwater in Crawling Valley apparently drained into a glacial lake, forming a delta (Stalker, 1965). The delta deposits, along with the more widespread inwash deposits immediately to the west, make up an extensive continuous deposit of near-surface permeable materials. Stalker indicates that both delta deposits and inwash deposits are composed of sand and gravel. Drillers operating in and near the delta and inwash areas (E 1/2, Tp. 21, R. 18 and NW 1/4, Tp. 21, R. 17), however, generally describe the near-surface materials encountered as "sand", although there is an occasional reference to "sand and gravel." Since they commonly refer to the preglacial Saskatchewan Gravels and Sands as "gravel", it has been assumed that sands reported overlying the basal gravel represent glacial material whereas the basal gravel is assumed to be preglacial. Interpreted on this basis the glacial sand is about 100 feet thick in the region of sections 13, 24, and 25, township 21, range 18, and sections 18 and 19, range 17.

The drift isopach map (Fig. 4) shows total thickness of drift over buried gravel and sand or over bedrock where gravel is absent. Reported drift thicknesses vary markedly in some areas and contours in these areas are probably somewhat generalized. The thickest drift

Table 1. Water Quality

Test hole No.	Concentrations in parts per million								
	Total solids	Ignition loss	Hard-ness	Sulfate (SO_4)	Chloride (Cl)	Alkali-nity	Nitrate (N)	Iron (Fe)	Fluoride (F)
66-7	1,212	218	330	289	16	585	Nil	0.1	†
67-3	878	228	485	302	6	345	Nil	0.2	0.42
67-4	1,340	222	534	547	10	524	Nil	10.0	†
67-11	1,580	254	531	636	18	558	Nil	47.5	†
Suggested upper limit*	1,600-2,000			400-800	435		10	0.3	

*Suggested by the Alberta Department of Health

†Not included in analysis

deposits are located on the northern flank of Calgary Valley in an irregular band trending northeast from township 21, range 19, where reported thicknesses are generally 100 feet or more. Over the bottom of the bedrock valley, eastward as far as the town of Bassano, drift thickness also exceeds 100 feet. Eastward from Bassano the drift cover thins to about 50 feet in township 21, range 16. Drift cover is absent or very thin over the gravel in parts of township 22, range 21 and townships 23 and 24, range 15.

TEST DRILLING AND PUMP TEST RESULTS

The test drilling program was begun after the preliminary versions of the maps contained in this report had been constructed and was primarily directed toward testing the accuracy of these maps. In the fall of 1966 six test holes — one of which was pump-tested — and one observation well were drilled, all with a rotary rig. Since position and thickness of the gravels was the chief concern of the drilling program, lithologic logs are based on the examination of normally circulated drill cuttings. Electric logs were run in all test holes and test hole elevations were established using 1:50 000 scale maps with a 25-foot contour interval. In the spring of 1967 further rotary drilling was carried out following much the same procedure as the previous fall. During the 1967 program, however, an effort was made to obtain water samples from the gravels. Three bail tests — two in one test hole — were attempted but no pump tests were conducted. Test hole locations for 1966 and 1967 are shown on figure 2.

Water Quality

Only one water sample was taken during the course of the 1966 test drilling program; it was taken from test hole 66-7 during the pump-testing period. Water samples were taken in 1967 from test holes 67-3, 67-4, 67-5, and 67-11 with a bailer. The sample from 67-5 contained so much suspended clay that it could not be filtered and consequently no analysis was possible. The 67-3 water sample was analyzed after filtering. Samples from 67-4 and 67-11 were from cased holes and, although cloudy, they were not filtered. The very high iron values shown for these two locations are likely due to clay particles suspended in the water. In a properly finished well the determined iron content probably would be lower. The chemical analyses, which are routine analyses from the Alberta Provincial Analyst, are reproduced in table 1.

Aquifer Tests

The amount of water a well will yield depends on the hydrologic properties of the aquifer and adjacent geologic strata, on the areal extent of the aquifer and its degree of hydraulic connection with recharging surface water on the available hydraulic head, and on the construction and development of the well. Hydrologic properties and effects of limited areal extent and availability of surface-water recharge may be evaluated from the results of a constant-rate bailing or pumping test (Ferris *et al*., 1962; Walton, 1962) whereas evaluation of well-construction and well-development effects depends on the results of a step-drawdown test (Rorabaugh, 1953; Lennox, 1966).

Permeable beds immediately underlying till in Alberta have been commonly observed to behave as leaky-artesian aquifers (Vanden Berg and Lennox, 1968; Bukhari *et al*., 1968). It was anticipated, therefore, that the Bassano-Gem gravel and sand sheet might behave in a similar fashion and standard analytical methods were applied to the bail- and pump-test results with this hypothesis in mind. These methods included: (1) the modified nonequilibrium method for the analysis of pumped-well drawdown and residual-drawdown data, (2) the type-curve method for the analysis of observation-well drawdown data, and (3) the Hantush inflection-point method for the analysis of observation-well drawdown data. All three methods are described by DeWiest (1965) and none of the theoretical development of formulas will be given here. The calculations presented with the drawdown and recovery plots (Figs. 7 to 10) can be related quite readily to the standard formulas as given by DeWiest.

Pump Test

Test hole 66-7 (Lsd. 16, Sec. 36, Tp. 23, R. 17, W. 4th Mer.) was pumped continuously at a constant rate of 83 imperial gallons per minute (igpm) for a 24-hour period beginning October 17, 1966. Test hole 66-7a, located 110 feet southeast of 66-7, was the observation well. Lithology, electric logs, and well-completion information are shown on figure 5 and the results of a mechanical analysis of a sample from 66-7a on figure 6. The electric logs shown on figure 5 are typical for test holes penetrating the preglacial gravels and sands in this area; hence, electric logs for other test holes are not reproduced in this report. The well screen in the gravel-packed, pumped well was a 20-foot length of 8-gauge louvre screen; in the case of the observation well it was a 10-foot lenght of 20-slot stainless steel sand screen. The pumped well was equipped with a turbine pump.

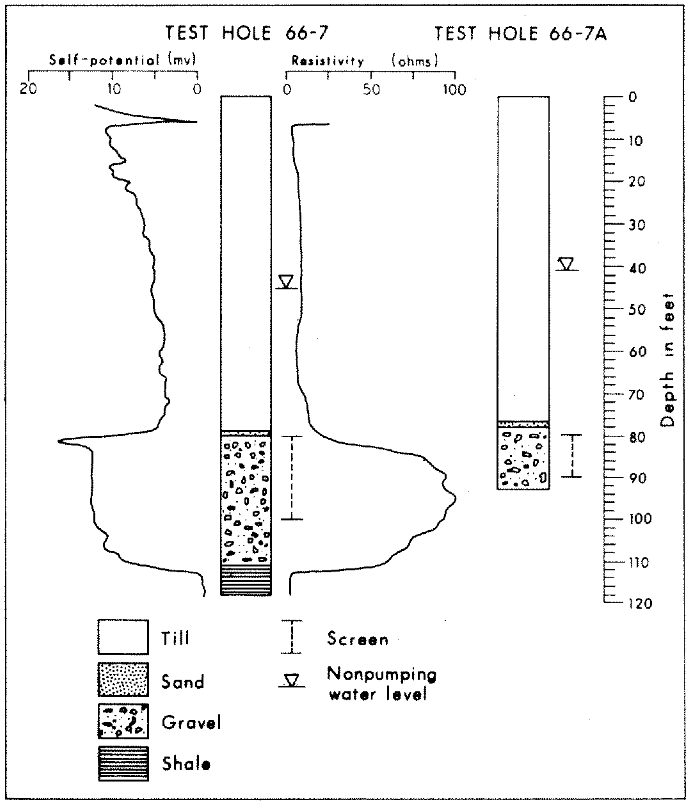

Figure 5. Lithology and well completion of pump test well 66-7 and observation well 66-7a.

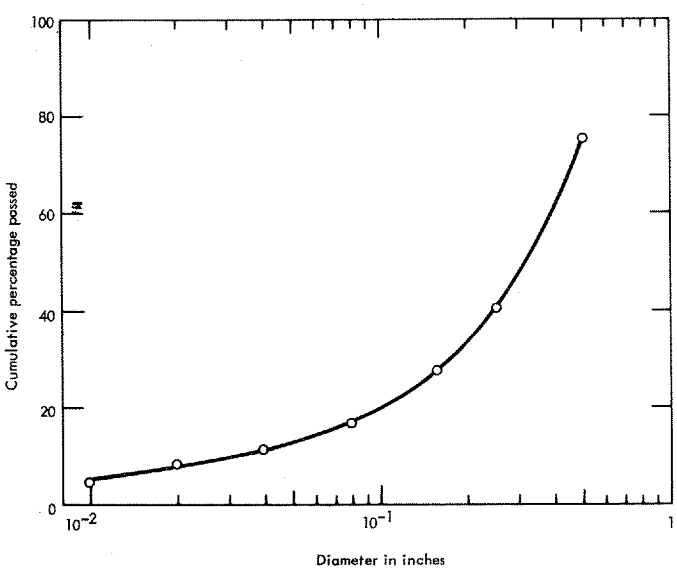

Figure 6. Mechanical analysis of gravel and sand sample from observation well 66-7a.

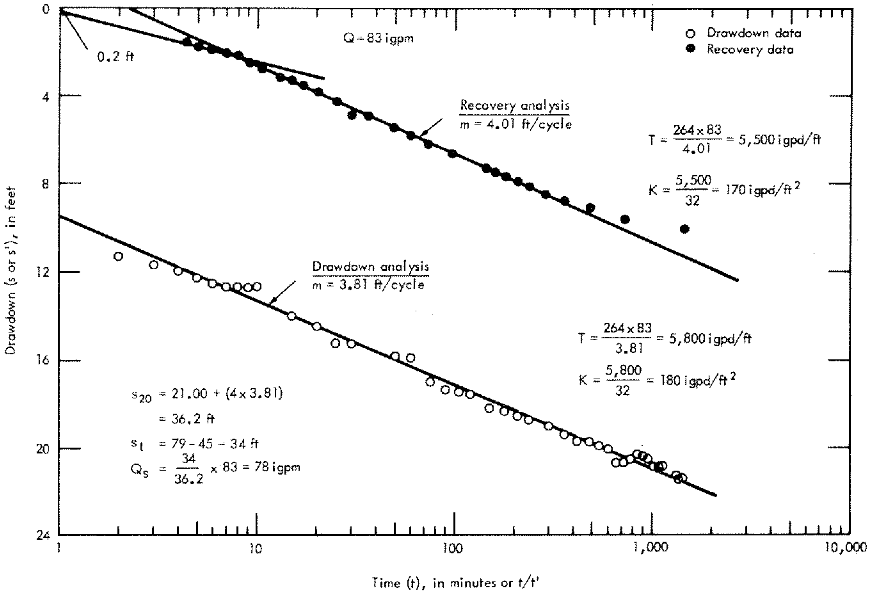

Figure 7. Drawdown and recovery plots, test hole 66-7.

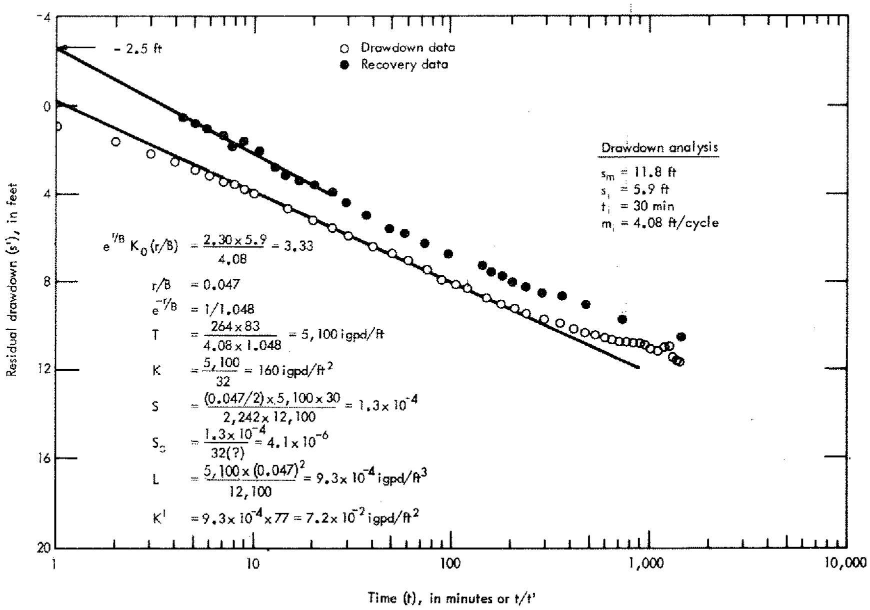

Figure 8. Drawdown and recovery plots, test hole 66-7a.

Drawdown and recovery observations for the two wells, together with the calculations of the aquifer and leaky-bed characteristics, are shown on figures 7 to 9. The calculations are summarized in table 2.

A step-drawdown test was conducted on October 15, 1966. The drawdown plot has not been reproduced here since there are some unexplained inconsistencies in the results, but an attempt to analyze the data by standard methods (Rorabaugh, 1953; Lennox, 1966) suggested that flow in the immediate vicinity of the well bore was probably of the laminar Darcy type for all pumping rates up to the maximum used in the test, which was 100 igpm. It was therefore assumed that this was actually the case and the 20-year safe-yield estimate of 78 igpm (Fig. 7, Table 2) derived from the extrapolation of the observed drawdown trend to 10^7 minutes is based on this assumption. Strictly speaking, this safe-yield estimate applies to test hole 66-7 only but similarly constructed or developed wells at or near the same location should have similar potential yields. It should also be noted that the 78 igpm figure applies for an isolated single well; development of a well field in the area of this test site could lead to an average yield per well of less than 78 igpm because of mutual interference effects.

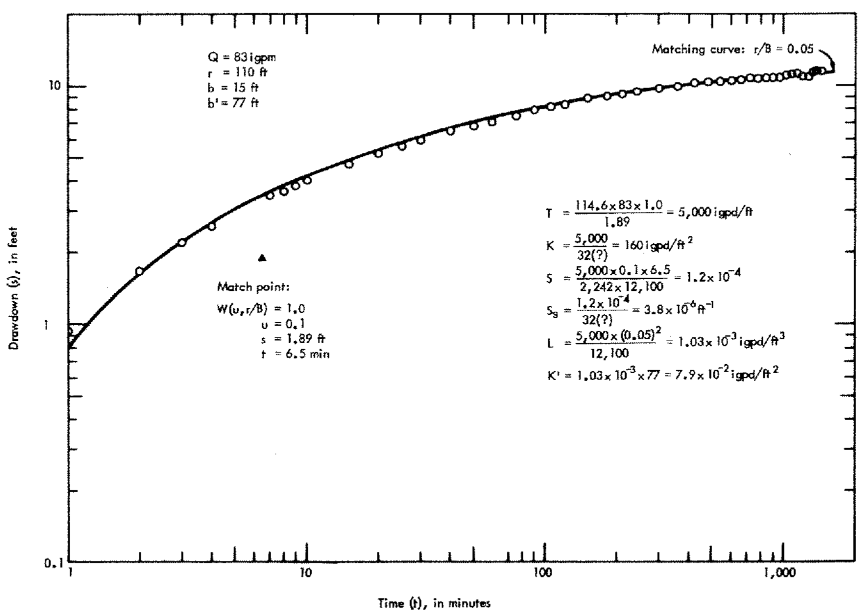

Figure 9. Type curve analysis of drawdown data, test hole 66-7a.

Table 2. Aquifer Test Results

	Test hole 66-7	Test hole 66-7a	Test hole 67-4	Test hole 67-11	Fuller well	Cee-Bar feed lot well
Location (Lsd or 1/4 Sec., Tp., R.)	16-36-23-17	110 ft SE 66-7	NE-24-21-19	14-9-23-16	NE-16-21-17	SE-17-21-17
Date of test	17/10/66	17/10/66	24/5/67	31/5/67	10/8/67	18/4/68
Function	Pumped	Observation	Bailed	Bailed	Bailed	Bailed
Nonpumping water level (ft below surface)	44.90	40.88	73.17	14.58	13.30	21.80
Aquifer interval (ft)	79-111	77-92+	137-157	84-99	53-70	94-99
Slotted casing (C) or screen (S) interval (ft)	80-100(S)	80-91(S)	142-152(C)	82-92(C)	70*	99*
Transmissivity (igpd/ft)	5,600	5,000	67	220	1,500	1,400
Horizontal hydraulic conductivity (igpd/ft^2)	180	160	3	15	90	280
Storage coefficient	.....	1.2×10^{-4}	.....	.....	.....	.....
Specific storage (ft^{-1})	.....	3.8×10^{-6}	.....	.....	.....	.....
Leakage coefficient (igpd/ft^3)	.....	9.8×10^{-4}	.....	.....	.....	.....
Vertical hydraulic conductivity (igpd/ft^2)	.....	7.5×10^{-2}	.....	.....	.....	.....
Estimated 20-year single-well safe yield (igpm)	78	.....	<10(?)	<10(?)	<31	<37

*Unslotted casing driven to depth indicated

Bail Tests

Three bail tests were conducted during the test drilling program of 1967. One was for test hole 67-4 (NE corner, Sec. 24, Tp. 21, R. 19, W. 4th Mer.) and two for test hole 67-11 (Lsd. 14, Sec. 9, Tp. 23, R. 16, W. 4th Mer.). Both wells were cased with the producing section consisting of 10 feet of slotted casing. Aquifer-depth and slotted-casing intervals are given in table 2.

Water-level measurements were taken only during the recovery period, after bailing had been completed, and as a result no reliable safe-yield estimates could be made. Some very approximate calculations suggest, however, that the 20-year single-well safe yields for each of these test holes is probably less than 10 igpm. Screened-well completions could presumably result in higher yields, but the relatively low values calculated for transmissivity and hydraulic conductivity at these sites suggest that yields must be lower than that estimated for the vicinity of test hole 66-7.

The residual-drawdown plots of the recovery data are shown on figure 10 for all three 1967 bail tests, and the data are listed in appendix B. Table 2 gives calculated transmissivities and hydraulic conductivities. In the case of test hole 67-11, the figures shown are averages for the two tests.

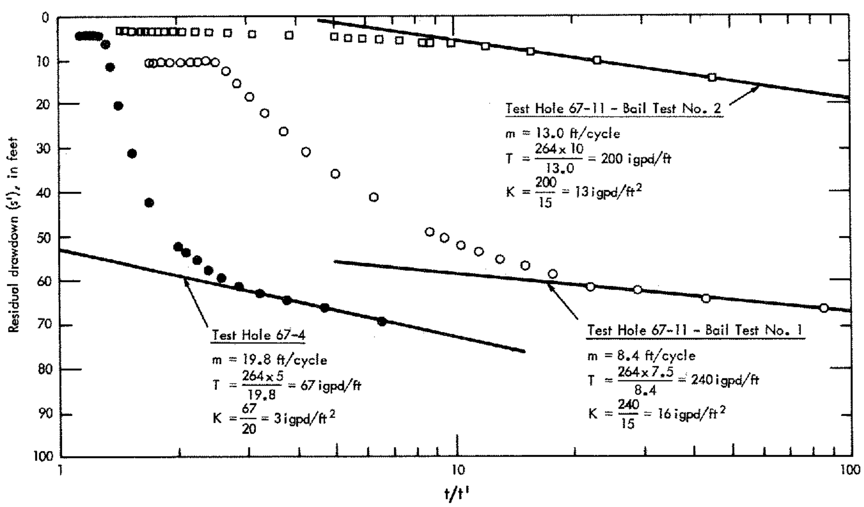

Figure 10. Bail-test recovery plots.

The behavior of test hole 67-11 during recovery differed markedly for the two tests (Fig. 10). The difference is believed to reflect some development of the well and suggests there may be some opportunity for improving yields by proper well-construction and development procedures.

Short bail tests were conducted by Doering Drilling of Torrington, Alberta on two wells located in the northeast quarter of section 16 and the southeast quarter of section 17, township 21, range 17, west of the 4th meridian. Well logs are listed in appendix B. Both holes drew water from permeable deposits — presumably the Saskatchewan Gravels and Sands — lying at depths from 53 to 99 feet below surface. Estimated 20-year safe yields were 31 and 37 igpm (Table 2), respectively. Both estimates are somewhat open to question and probably represent overestimates rather than underestimates. It is felt, however, that more precise determinations would probably not reduce the safe-yield estimates below 20 igpm.

CONCLUSIONS

The preglacial gravels and sands underlying the Bassano-Gem region are extensive and continuous. Although the available drawdown in wells finished in the gravels and sands apparently decreases from southeast to northwest (upslope on the northern flank of the preglacial river valley), these deposits are saturated throughout the area except for one area on the northern boundary. The pump-test and bail-test results suggest safe yields of from less than 10 to about 80 igpm on a 20-year basis. The bail tests are, however, considered to be of questionable reliability. The water is classed as hard but is nevertheless suitable for human consumption or stock-watering at the locations tested.

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APPENDIX A. NOTATION

B = $\sqrt{Kbb'/K'}$ = leakage factor;

b = aquifer thickness;

b' = thickness of leaky bed;

e = base of the natural logarithm;

K = horizontal hydraulic conductivity of aquifer;

K' = vertical hydraulic conductivity of leaky bed;

$K_o(x)$ = modified Bessel function of second kind and zero order;

L = K'/b' = leakage coefficient or leakance;

m = slope of a semilogarithmic drawdown plot expressed as drawdown per log cycle;

m_i = slope at the inflection point for the drawdown curve for an infinite leaky artesian aquifer;

Q = pumping rate;

Q_s = estimated 20-year safe yield;

r = distance from the pumped well;

S = bS_s = storage coefficient;

S_s = specific storage coefficient;

s = drawdown;

s_i = drawdown at the inflection point for the drawdown curve for an infinite leaky artesian aquifer;

s_m = maximum stabilized drawdown for an infinite leaky artesian aquifer;

s_t = total available drawdown;

s_{20} = estimated drawdown at the end of 20 years of continuous pumping at rate Q;

s' = residual drawdown;

T = transmissivity;

t = time after pumping or bailing started;

t_i = time for which there is an inflection point on the drawdown curve for an infinite leaky artesian aquifer;

t' = time after pumping or bailing stopped;

$$u = \frac{r^2 S}{4Tt}$$

$W(u,r/B)$ = well function for leaky artesian aquifers.

APPENDIX B. LITHOLOGIC LOGS

Test-Hole Logs

Test hole No. 66-1
Location: NE corner, Sec. 36, Tp. 25, R. 19, W. 4th Mer.

Depth (feet)	Description
0-11	Brown till, some gravel
11-12	Hard, weathered, fine sandstone
12-20	Soft brown sandstone
20-40	Silty brown shale

Test hole No. 66-2
Location: NE corner, Sec. 20, Tp. 25, R. 18, W. 4th Mer.

Depth (feet)	Description
0-20	Brown till and boulders
20-25	Brown shale
25-40	Silty grey shale

Test hole No. 66-3
Location: NE corner, Sec. 10, Tp. 25, R. 18, W. 4th Mer.

Depth (feet)	Description
0- 1	Brown till
1- 2	Gravel
2-42	Till
42-45	Till, some gravel
45-60	Gravel

Test hole No. 66-4
Location: NE corner, Sec. 36, Tp. 24, R. 18, W. 4th Mer.

Depth (feet)	Description
0- 47	Brown till
47-100	Grey till
100-101	Fine gravel
101-131	Till
131-132	Gravel
132-141	Till
141-143	Gravel and till
143-191	Grey till
191-207	Gravel
207-210	Hard bentonitic shale

Test hole No. 66-5
Location: Lsd. 1, Sec. 29, Tp. 24, R. 17, W. 4th Mer.

Depth (feet)	Description
0- 1	Brown till
1- 4	Coarse gravel
4-26	Clay and gravel
26-42	Gravel and boulders, some sand, caving badly
42-50	Brown silty clay or shale
50-60	Grey silty shale

Test hole No. 66-6
Location: NE corner, Sec. 36, Tp. 23, R. 17, W. 4th Mer.

Depth (feet)	Description
0- 18	Brown till
18- 25	Brown till with gravel

25- 79	Grey till
79- 80	Sand
80-111	Gravel
111-120	Brown shale

Test hole No. 67-1
Location: 0.5 mi west of SW corner, Sec. 26, Tp. 20, R. 18, W. 4th Mer.

Depth (feet)	Description
0- 5	Brown till
5- 15	Dark grey silty clay
15- 28	Sandy brown clay
28- 52	Grey clay, sandy to silty
52- 56	Grey siltstone (?)
56- 82	Silty grey clay
82-108	Dark grey shale

Test hole No. 67-2
Location: NE corner, Sec. 33, Tp. 20, R. 18, W. 4th Mer.

Depth (feet)	Description
0- 5	Brown silty clay
5- 20	Brown till
20- 25	Very fine uniform gravel
25- 30	Silty brown clay
30- 38	Gravel and sandy clay
38- 65	Grey till
65- 95	Grey silty clay, quite hard
95-107	Till
107-122	Gravel
122-140	Dark blue sandy hard clay
140-152	Gravel
152-170	Black shale

Test hole No. 67-3
Location: 0.5 mi west of NE corner, Sec. 8, Tp. 21, R. 18, W. 4th Mer.

Depth (feet)	Description
0- 7	Fine brown sand
7- 20	Brown silt
20- 30	Fine brown sand

30- 70	Sandy grey clay
70-108	Grey till
108-115	Gravel
115-120	Gravel with sand and brown clay
120-122	Gravel
122-140	Black shale

Test hole No. 67-4
Location: NE corner, Sec. 24, Tp. 21, R. 19, W. 4th Mer.

Depth (feet)	Description
0- 5	Dark brown silty clay
5- 11	Brown sand
11- 35	Brown till
35- 43	Sandy brown till
43-137	Grey till
137-157	Gravel
157	Black shale

Test hole No. 67-5
Location: 0.45 mi south of NE corner, Sec. 3, Tp. 22, R. 19, W. 4th Mer.

Depth (feet)	Description
0- 2	Clay
2- 7	Fine gravel
7- 15	Grey silty clay
15- 45	Silty till
45-145	Grey till
145-175	Silty clay
175-207	Fine gravel and sand
207	Shale

Test hole No. 67-6
Location: 0.6 mi west of NE corner, Sec. 29, Tp. 22, R. 19, W. 4th Mer.

Depth (feet)	Description
0- 20	Silty brown clay, some coal
20- 35	Brown till
35- 45	Grey till
45- 60	Sandy silty clay
60- 70	Till

70-160	Silty clay
160-167	Silty sandy clay
167-209	Gravel
209	Shale

Test hole No. 67-7
Location: SW corner, Sec. 5, Tp. 23, R. 19, W. 4th Mer.

Depth (feet)	Description
0- 10	Sandy brown till
10- 20	Silty brown till
20- 40	Brown till
40-145	Grey till
145-163	Brown clay, silty to sandy with gravel lenses
163-179	Gravel
179	Black shale and sandstone

Test hole No. 67-8
Location: 0.5 mi east of NE corner, Sec. 12, Tp. 23, R. 20, W. 4th Mer.

Depth (feet)	Description
0- 7	Silty brown clay
7-20	Brown till
20-50	Sandy brown till
50-60	Brown till
60-70	Grey till
70-71	Thin gravel layer (?)
71-85	Shale

Test hole No. 67-11
Location: 0.5 mi west and 0.2 mi south of NE corner, Sec. 9, Tp. 23, R. 16, W. 4th Mer.

Depth (feet)	Description
0- 60	Silty brown clay
60- 84	Grey till
84- 99	Gravel
99-120	Bedrock

Water Well Logs

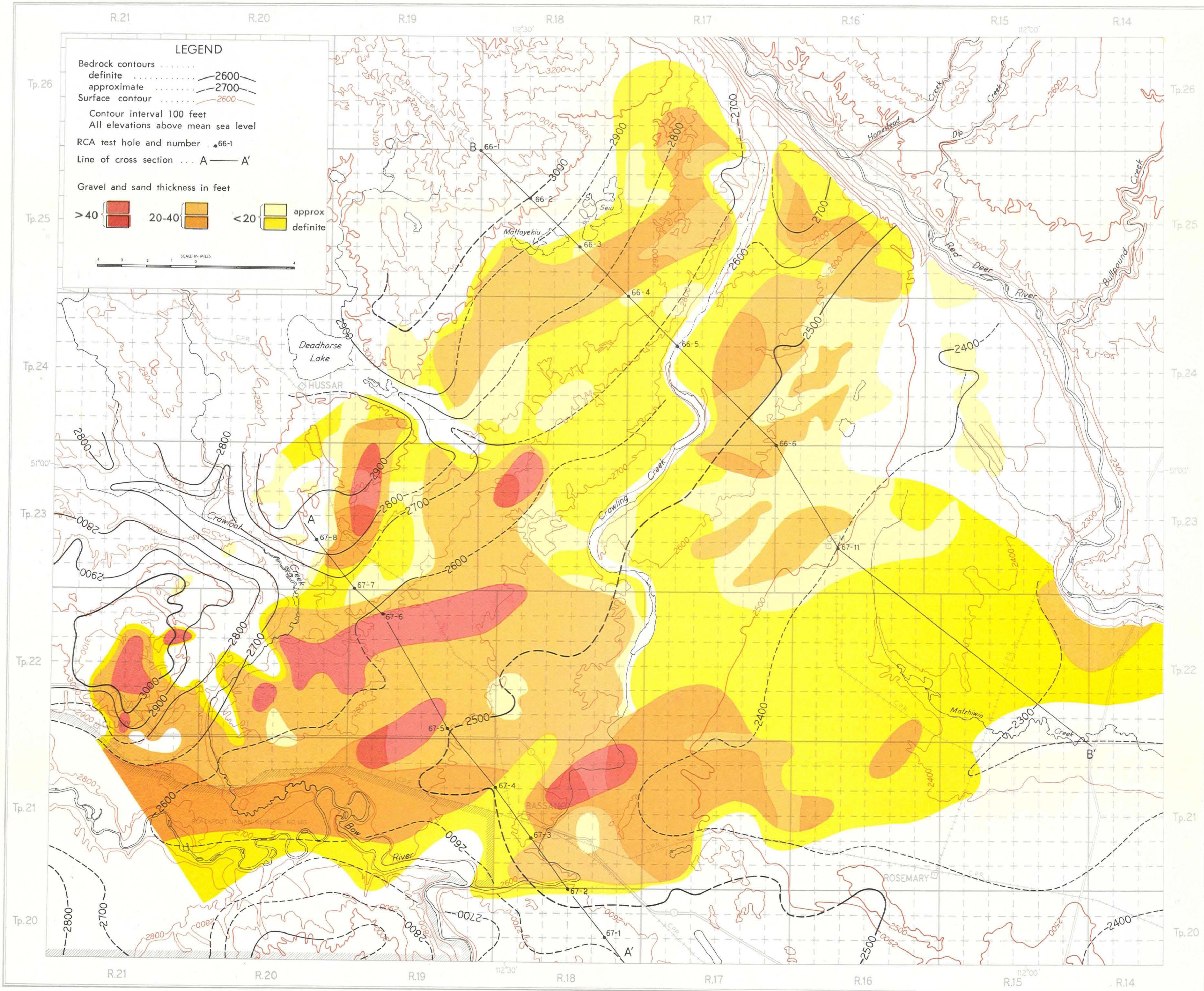
Owner: Harvey Fuller
Location: NE 1/4, Sec. 16, Tp. 21, R. 17, W. 4th Mer.
Driller: Doering Drilling, Torrington, Alberta

Depth (feet)	Description
0-16	Till
16-53	Sandy clay
53-67	Sand
67-70	Pea gravel

Owner: Cee-Bar Feed Lot
Location: SE 1/4, Sec. 17, Tp. 21, R. 17, W. 4th Mer.
Driller: Doering Drilling, Torrington, Alberta.

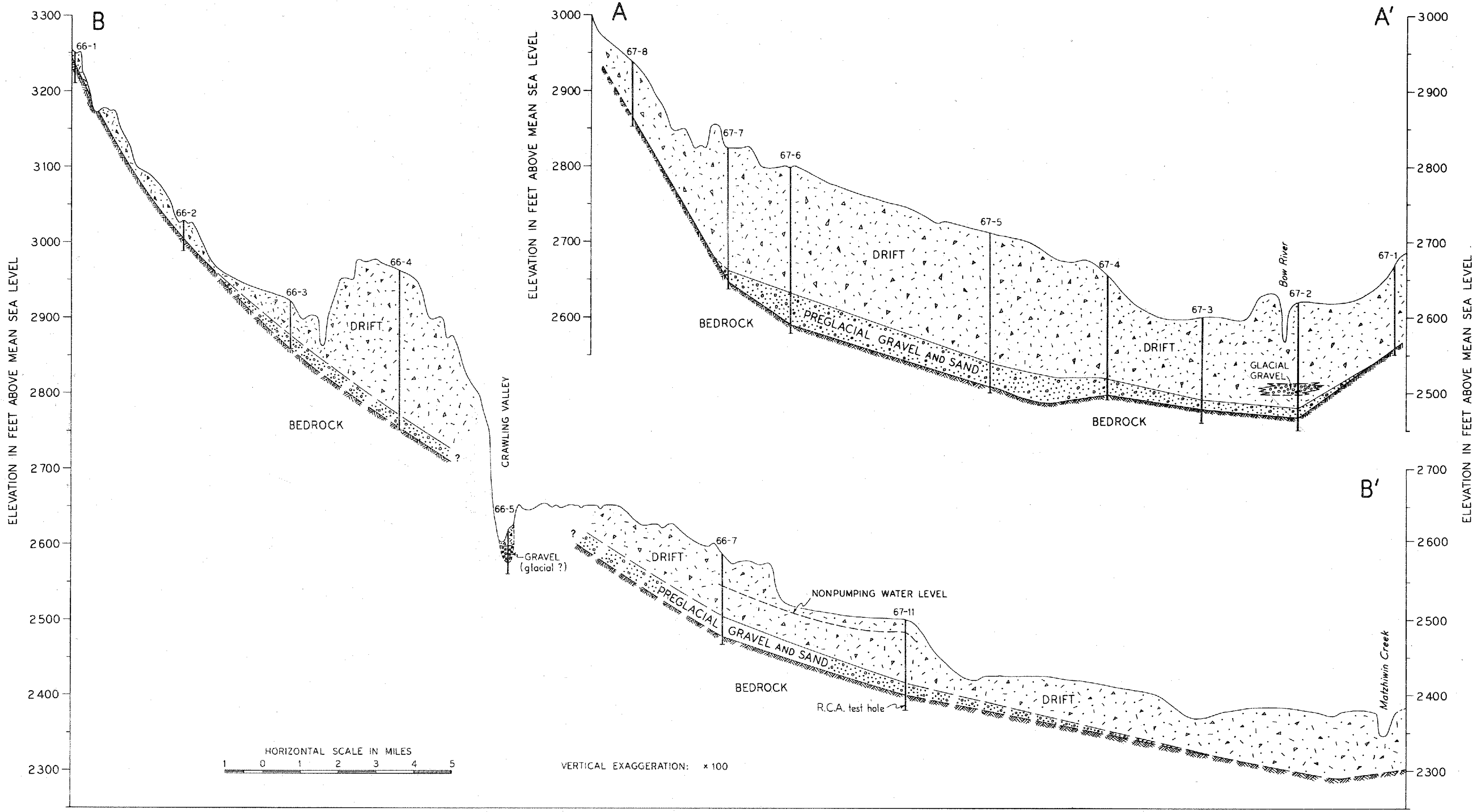
Depth (feet)	Description
0-38	Silty sand
38-62	Sandy clay, sand layers
62-94	Clay, sand layers
94-99	Coarse sand

Figure 2. Bedrock topography and distribution of preglacial sands and gravels in the Bassano-Gem region



Note:
To accompany Research Council of Alberta Report 69-4, by V. A. Carlson et al.

Figure 3. Cross sections AA' and BB' (ref. Fig. 2)



Note:
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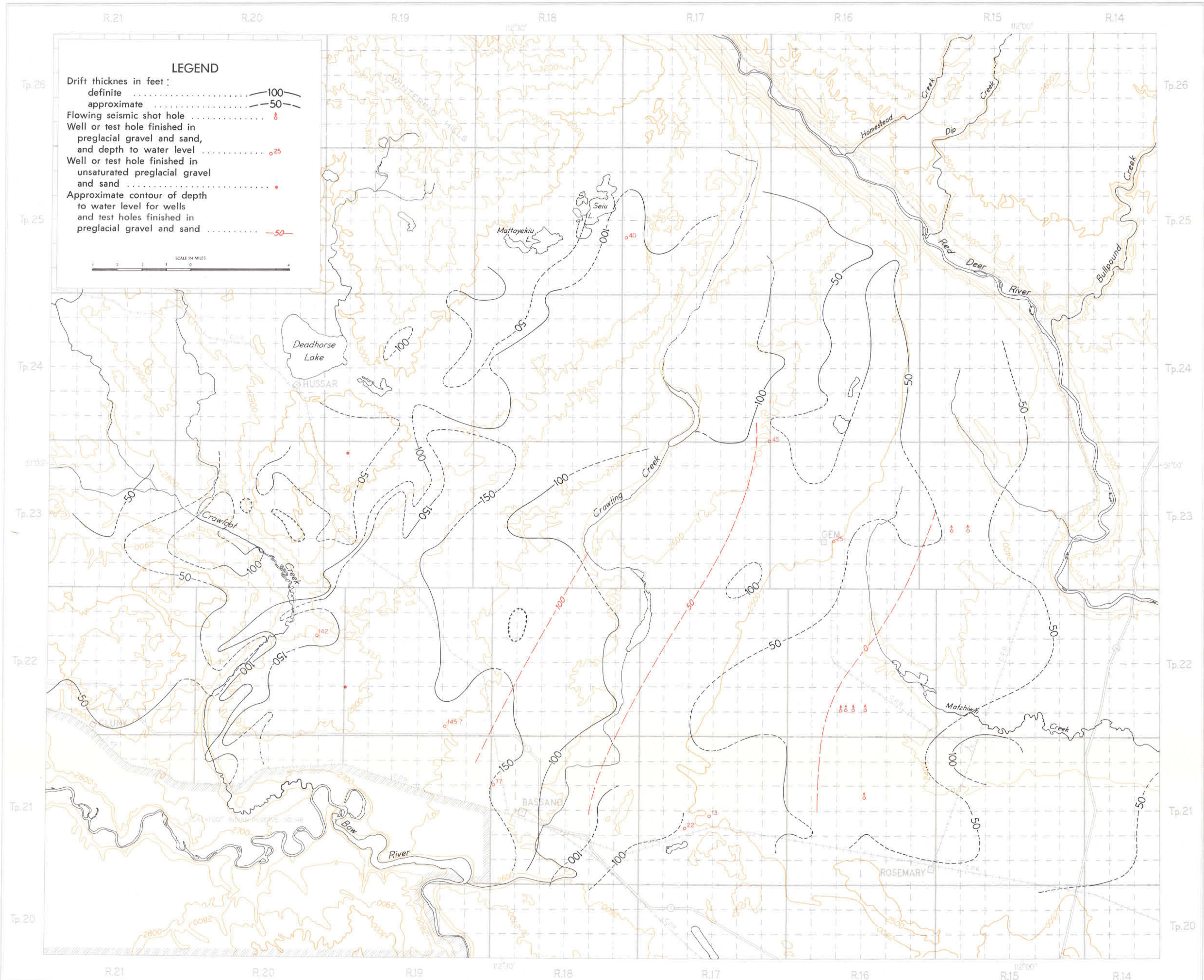
Figure 4. Drift thickness in the Bassano-Gem region



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