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# A Thermal Analysis into the Region of Regina, Saskatchewan, Canada for Geothermal Energy Prospecting

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**Abstract:** This paper focuses on the thermal analysis of the wells within the proximity of those used by previous geothermal demonstration project carried out at the University of Regina in 1977. In addition, wells around Moose Jaw within the deep clastic and carbonate rock units (between 2 km and 3 km); with focus on the Deadwood and Winnipeg formations were also investigated. The bottom-hole temperatures (BHT) of the target wells were extracted from the well database (IHS AccuMap and GeoScount) and corrected using the Harrison correction method. The thermal gradient for each well was obtained using the corrected BHT values, through which the subsurface temperature for each well (at depths 2.5 km and 3.0 km) was calculated using the Lachenbruch model. The paper presents findings of a conservative subsurface temperature range of approximately $\mathbf{50}\,℃ - \mathbf{90}\,℃$ consistent at depths 2.5 km and 3.0 km. This range is certainly inadequate for electricity generation from the resource, though direct use applications can be pursued. A potential heat mining field is highlighted within the findings east of Regina as a potential area of interest for direct use applications (heating and cooling of buildings).

**Keywords:** Subsurface Temperatures, Regina, Geothermal Energy.

## 1. INTRODUCTION

Geothermal energy plays a key role in realizing targets in energy security, economic development and mitigating climate change. Through harnessing the stored thermal energy trapped within rocks, this resource can be utilized in generating electricity and in direct applications. However, before the energy can be extracted from depths within the Earth, exploratory methods are crucial in locating and prospecting the potential of a geothermal system. Heat mining from the earth can theoretically supply the world at the present level of energy demand for many millennia [13].

### 1.1. Regina and City of Moose Jaw Geothermal Projects

The University of Regina embarked on a geothermal demonstration project for fluid extraction from the sedimentary aquifers in 1977. The Geothermal Energy Program funded a feasibility study to illustrate the prospects for geothermal fluids on the University campus [19]. The WCSB accounts for two-thirds of southern Saskatchewan, whereas Precambrian crystalline rocks covered by nearly flat-lying Phanerozoic sedimentary rocks are found towards the eastern margin [18]. The Phanerozoic strata found in Regina can be classified into three groups of geological subdivisions: a Basal Clastic Unit of sandstone and shale; a carbonate-evaporite Unit of dolostone, limestone, salt and anhydrite; and an Upper Clastic Unit composed predominantly of shale and sandstone, [18].

The main findings showed the prime targets were the Winnipeg Formation (depth 2,042 m and thickness 34 m) and the Deadwood Formation (depth 2,088 m and thickness137 m), with predicted temperatures of 71 ℃ and 74 ℃, respectively [8]. Other reservoirs at shallower depths, comprised of the Interlake Formation (depth 1,825 m and temperature 64 ℃) and the Winnipegosis Formation (depth 1,726 m and temperature 63 ℃), whilst others carried temperatures below 50 ℃. The Regina well was completed in the summer of 1979 with “open hole” in both the Winnipeg and Deadwood Formations below the casing shoe at 2,034 m depth [17]. These findings are summarized in Table 1 as seen below.

**Table 1: Main temperatures findings of formations at depth for the Regina well [17]**

| Formation | Temperature (℃) | Depth (m) |
|---|---|---|
| Deadwood | 74 | 2088 |
| Interlake | 64 | 1825 |
| Winnipeg | 71 | 2042 |
| Winnipegosis | 63 | 1726 |

 

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1.2 Western Canada Sedimentary Basin

The Western Canada Sedimentary Basin (WCSB) is the best characterized and detailed sedimentary basin within Canada, consisting of significant volumes of fluid in porous rocks. The target area investigated for this paper is highlighted within the green rectangle of Figure 1. This area falls outside the Williston basin which is part of the WCSB. The target wells are localized around the areas of Moose Jaw and Regina, $50'$N of this latitudinal line. Well data from fourteen target wells are used in the investigation. Key sedimentary units (major lithology) within the vicinity of Regina are: the Upper Clastic, Carbonate-Evaporite, and the Basal Clastic each having thicknesses of $1000$ m, $1000$ m, and $200$ m respectively [18].

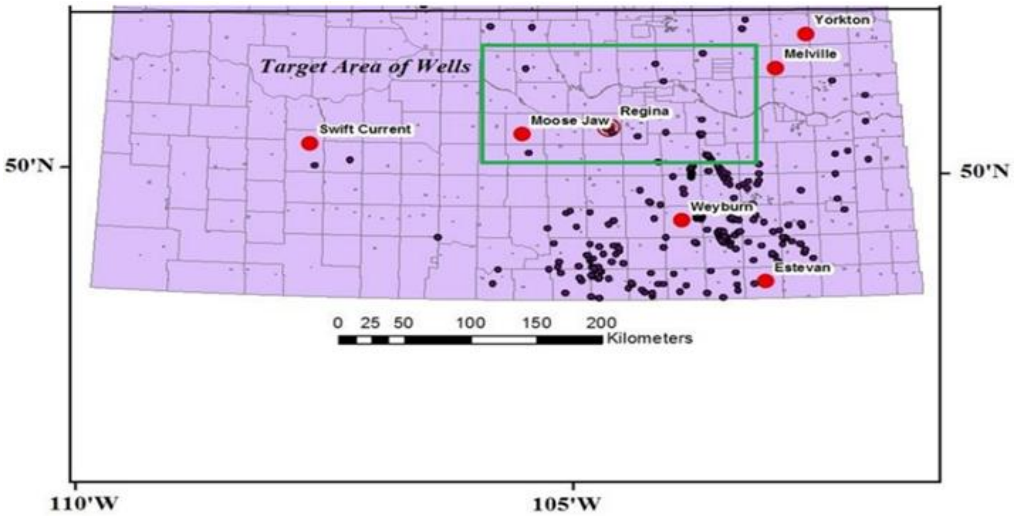


Fig. 1 Distribution of well locations localized around Regina

Canada does not possess electricity generation through geothermal energy. Though regions across Canada have been investigated as illustrated within the Executive Summary, Research Needs of the Geological Survey of Canada Open File 6914 [8], there still is a greater need to thoroughly investigate specific areas through computer modelling to fill data gaps. In many areas across Canada where information exists, the data are insufficient to characterize geothermal resource [8]. The paper serves to thoroughly investigate wells within the vicinity of Moose Jaw and Regina. It provides in-depth findings for the thermal gradient, surface heat flow and subsurface temperature (at depths 2.5 km and 3 km) furthermore; the paper highlights a potential area of interest for geothermal direct use exploitation.

## 2. THERMAL ANALYSIS

2.1 Harrison Correction Method for Thermal Equilibrium

The IHS AccuMap and GeoScount provide the required well core data for the regions of Moose Jaw and Regina. Oil and gas data have been incorporated into conventional heat flow data to fill large spatial gaps. Datasets of bottom-hole temperatures (BHTs) and geological formations are made possible through drilling of oil and gas wells [16]. BHT data are usually of low quality as mentioned by Blackwell [3, 4] and Shope [14]. The true formation temperature values are not represented by the geophysical logs. This is because of recording the data shortly after cessation of drilling operation. The Harrison Correction Method (HCM) is made possible typically through data constraints with publicly available oil and gas well information. Through such an empirical correction factor is used, as demonstrated by Harrison [9], Blackwell [3], Frone and Blackwell [4], and Shope [14].

The Harrison correction can be described as a second order polynomial function of depth. Through this method the generated $\Delta T$ value in ℃ is a correction factor that is summed to the BHT from the geological well data to yield an estimated equilibrium temperature.

It is stated by the following:

$$\Delta T(℃) = -16.51 + 0.01827z - 2.345 \times 10^{-6} z^2 \qquad (1)$$

Through this approach the BHT values are corrected and tabulated as seen in the following table. Each BHT value carries its associated True Vertical Depth (TVD) value and Well Identification Number.

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**Table 2: Calculated thermal equilibrium values for the well data**

| Well Identification Number | TVD ($m$) | BHT (℃) | HCM Factor (℃) | Corrected BHTs (℃) |
|---|---|---|---|---|
| 101/01-17-027-28W2/00 | 1775.5 | 42.0 | 8.5 | 50.5 |
| 101/14-10-027-25W2/00 | 1815.1 | 50.0 | 8.9 | 58.9 |
| 131/03-08-017-19W2/02 | 1859.6 | 52.0 | 9.4 | 61.4 |
| 131/11-29-016-17W2/00 | 2113.0 | 75.0 | 11.6 | 86.6 |
| 121/16-04-017-15W2/00 | 2152.5 | 68.0 | 12.0 | 80.0 |
| 101/02-11-015-26W2/00 | 2225.6 | 56.0 | 12.5 | 68.5 |
| 101/14-11-014-16W2/00 | 2326.0 | 68.0 | 13.3 | 81.3 |
| 101/08-20-011-17W2/00 | 2359.2 | 54.0 | 13.5 | 67.5 |
| 111/10-13-010-17W2/00 | 2361.0 | 71.0 | 13.6 | 84.6 |
| 121/06-36-012-15W2/02 | 2481.5 | 70.0 | 14.4 | 84.4 |
| 101/06-32-008-16W2/00 | 2519.5 | 65.0 | 14.6 | 79.6 |
| 141/03-11-010-16W2/00 | 2584.0 | 62.0 | 15.0 | 77.0 |
| 101/03-14-008-20W2/00 | 2601.8 | 71.0 | 15.2 | 86.2 |
| 101/02-04-022-15W2/00 | 2606.0 | 63.0 | 15.2 | 78.2 |

The Harrison correction method is applied to the trend line of the BHT values, from which these values are calculated and tabulated as seen in Table 2. It can be noted through the application of the HCM it increases the $R^2$ value (accounts for a greater correlation between the temperature and depth values) as seen in Fig 2, when comparing the trend lines for the uncorrected BHT values ($R^2 = 0.397$) and the corrected of thermal equilibrium values ($R^2 = 0.551$).

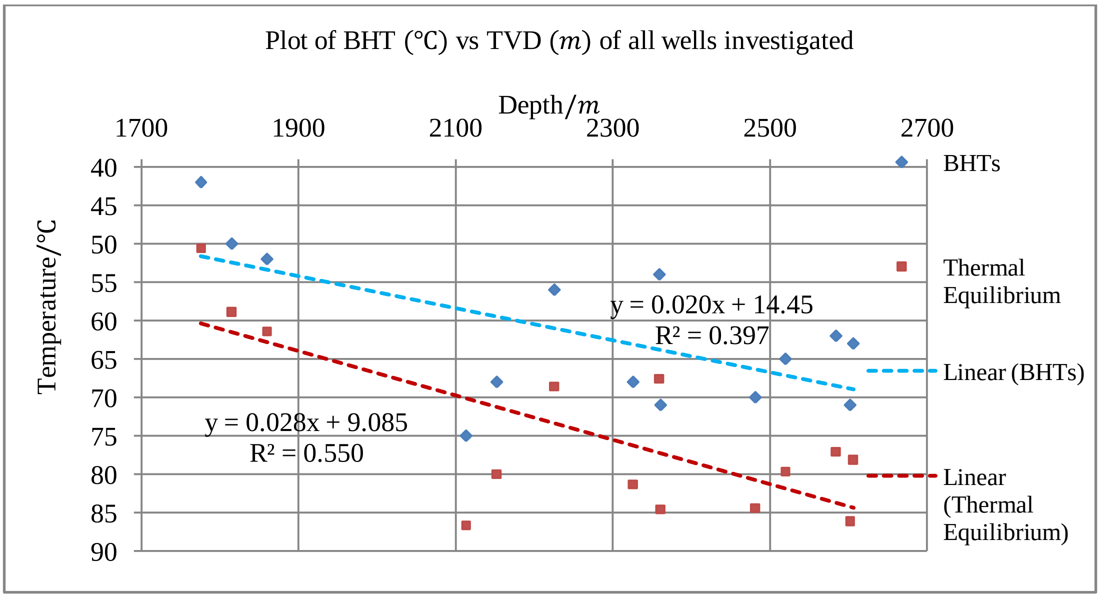


Fig. 2 Corrected BHT values for wells localized around Moose Jaw and Regina

2.2 Well by well Thermal Gradient and Heat Flow Calculations

Through the use of the corrected bottom-hole values, the thermal gradient values were calculated utilizing equation (2)

$$\left(\frac{dT}{dz}\right) = \frac{T_{BHT} - T_s}{z} \qquad (2)$$

where $dT/dz$ is the thermal gradient, $T_{BHT}$ is the corrected BHT values, $T_s$ is the average annual surface temperature, and $z$ is the true vertical depth. All temperature values are calculated in degree Celsius (℃), and the TVD in meters ($m$). The average thermal equilibrium gradient for the investigated region is determined to be 28.8 ℃$/km$. For the regions of Moose Jaw and Regina an average annual surface temperature, $T_s$ of 2 ℃ is used in the calculation of the thermal equilibrium gradients [2]. The well numbers in Figure 3 below correlates to the order of the well identification numbers as seen on Table 3. Hence well number 1 correlates to 101/01-17-027-28W2/00, well number 2 correlates to 101/14-10-027-25W2/00 and so on.

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**Table 3. Calculated thermal equilibrium gradient values for the wells**

| Well Identification Number | Corrected BHTs (℃) | Thermal Gradient ($℃/km$) |
|---|---|---|
| 101/01-17-027-28W2/00 | 50.5 | 23.4 |
| 101/14-10-027-25W2/00 | 58.9 | 26.9 |
| 131/03-08-017-19W2/02 | 61.4 | 28.1 |
| 131/11-29-016-17W2/00 | 86.6 | 36.7 |
| 121/16-04-017-15W2/00 | 80.0 | 33.0 |
| 101/02-11-015-26W2/00 | 68.5 | 26.3 |
| 101/14-11-014-16W2/00 | 81.3 | 31.1 |
| 101/08-20-011-17W2/00 | 67.5 | 24.8 |
| 111/10-13-010-17W2/00 | 84.6 | 32.0 |
| 121/06-36-012-15W2/02 | 84.4 | 30.4 |
| 101/06-32-008-16W2/00 | 79.6 | 28.0 |
| 141/03-11-010-16W2/00 | 77.0 | 26.3 |
| 101/03-14-008-20W2/00 | 86.2 | 29.6 |
| 101/02-04-022-15W2/00 | 78.2 | 26.5 |

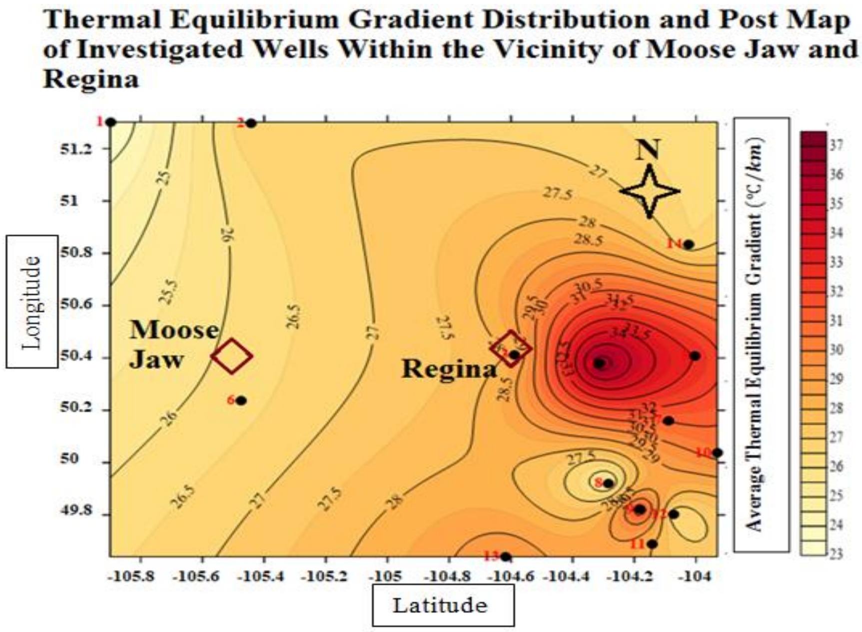


Fig. 3 Map of Thermal Gradient Distribution of all 14 Wells Investigated

The surface heat flow is then calculated from the corrected thermal gradient values. A 1D vertical conduction of heat through the rock column can be assumed; hence the resulting heat flow can be expressed as:

$$Q_s = k\left(\frac{dT}{dz}\right) \quad (3)$$

where the corrected thermal gradient is in $℃/km$, the thermal conductivity $k$ is in $W/mK$, and the calculated heat flow $Q_s$, is in $mW/m^2$. For the 1D case to be accurate the following conditions must hold to prevent the nullification of the assumption of steady-state heat flow: the depth of the well is small compared to the distance of significant structural alterations in geology, and excluding current volcanism within the area [16]. The thermal conductivity of the dominant lithology found in each well number was compiled across multiple sources of literature to generate Table 4. These formations comprised of, Black Island, Deadwood, Icebox, Precambrian, Winnipeg and Yeoman. For instances, where heterogeneous formations having multiple distinguishable lithologies were encountered, an average value for each was determined to describe the overall thermal conductivity. Among these were cases of igneous rock and gneiss, and sandstone and shale. Multiple sources of literature were used to fill this data gap in which the thermal conductivity values ranged between 2.90 $W/mK$ $-$ 6.85 $W/mK$ [1, 11, 12].

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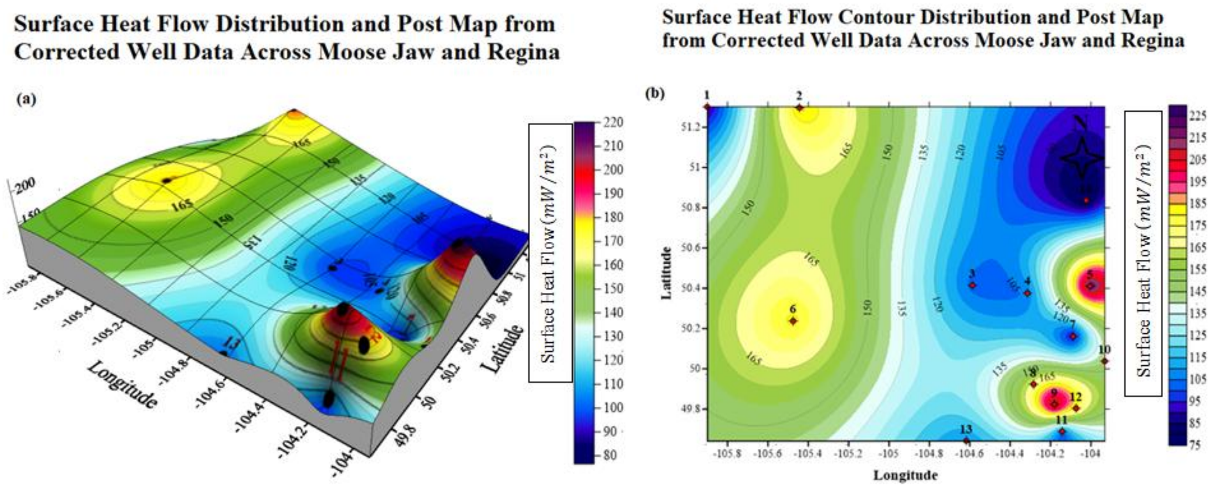


Fig. 4 Surface Heat Flow Maps with Well Number Distribution: (a) 3D Surface Contour, (b) 2D Contour

The surface heat flow findings are represented in both parts (a) and (b) of Figure 4. The 3D surface contour distribution map in part (a) clearly highlights two major peaks that are distinctive of maximum areas of surface heat flow. Through Figure 4 (b) these two areas relate to well numbers 5 and 9. It can be observed that high values of thermal gradient do not directly relate to high surface heat flow values as such with well number 4. Well number 4 has the highest corrected BHT value, and thermal gradient value (Figure 3) at 86.6 ℃ and 36.7 ℃/$km$ respectively. However, this translated only into a value of 106 $mW/m^2$. Hence, it is clearly seen that the surface heat flow is much more dependent on the thermal conductivity values. Those wells that reached into the Precambrian formation carried a higher thermal conductivity values than others. It should be noted that localized on well number 3; Regina is located, whereas just north of well number 6, Moose Jaw can be found.

2.3Subsurface Heat Calculations

Based on Table 1, it is observed that the TVD ranges from 1775.5 $m$ to 2606.0 $m$. Therefore, for depths exceeding 2606.0 $m$ were no measured temperature data is available the heat flow maps can be utilized for these calculations. Through the 'Lachenbruch model' which describes the exponential decrease of crustal heat generation with depth, the calculations to determine the variation of temperature with depth are made possible. The basement heat flow $Q_0$ ($W/m^2$) is statistically correlated to the heat generation of the basement, $A_0$ ($W/m^3$) in the form:

$$Q_0 = Q_r + DA_0 \quad (4)$$

where $Q_r$ is the reduced heat flow ($W/m^2$) and $D$ is measured in units of depth, furthermore both $Q_r$ and $D$ are constants characteristic of large geological provinces. The key parameters used to calculate temperature with depth relations for the geological Craton region are [8]: $D = 9.6\ km, Q_r = 33\ mW/m^2,$ and $A_0 = 2.7\ \mu W/m^3$. The basement heat flow value will be the same for all wells under investigated, as this value was found to be 58.92 $mW/m^2$. Given that the basin fill of 2 $km$ is overlying the basement at depth of 3 $km$, the temperature $T_{2\ km}$ at the top of the basement needs to be found first. Therefore for the first 2 $km$, that is at $X = 0 - 2\ km$:

$$T_{2\ km} = \frac{Q_0 X}{k} - A_0 \frac{X^2}{k} \quad (5)$$

For $X > 2\ km$, the temperature ($T$) vs. depth ($m$) equation can be written as:

$$T(z) = T_{2\ km} + Q_r \frac{z}{k} + \frac{A_o D^2 \left[1 - exp\left(-\frac{z}{D}\right)\right]}{k} \quad (6)$$

Equations (5) and (6) are explicitly utilized in the calculation of the subsurface temperature $T(z)$, for each well data entry from Table 2. Figure 5 parts (a) and (b) were generated for depths of 2.5 $km$ and 3.0 $km$ respectively. It can be observed that the consistency of subsurface temperatures for wells 4, 7 and 14 are among the highest at both depths of 2.5 $km$ and 3.0 $km$. The thermal conductivity values of the formations at depth play a crucial role, influencing the overall value of the subsurface temperature. In addition, the approach undertaken to investigate the overall heat flow estimation for a column as mentioned by Blackwell [3], also dictates the equations used in the calculation of the subsurface temperatures.

Well 3, exhibited the highest corrected bottom-hole temperature and thermal gradient values of 86.6 ℃ and 36.7 ℃/$km$ respectively. However, from Figure 5 (a) and (b) it clearly shifts the focus away from well 3 unto wells 4, 7 and 14.


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Hence the lithology of the formations within these three outlined wells are much more conducive for temperatures at depths of $2.5\ km$ and $3.0\ km$. It can be surmised that areas east and north-north east of Regina holds the greatest potential of thermal resources.

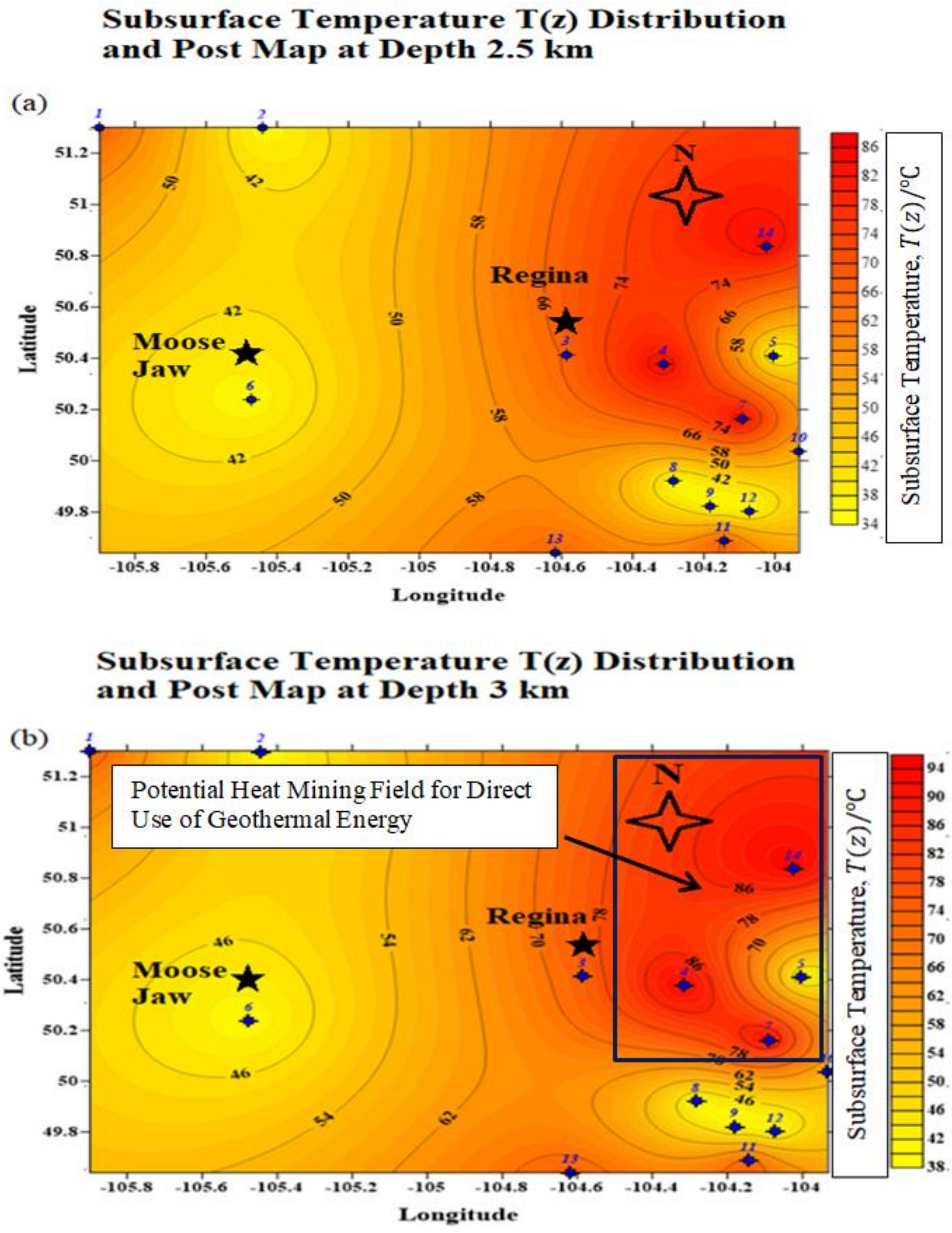


Figure 5. Subsurface Temperatures $T(z)$: (a) Depth $2.5\ km$, (b) Depth $3.0\ km$

The main findings of the well drilled at the University of Regina, found temperatures of 71 ℃ and 74 ℃, for the Winnipeg Formation (depth 2,042 m and thickness $34\ m$) and the Deadwood Formation (depth $2{,}088\ m$ and thickness $137\ m$) respectively. Those findings were localized to one specific target well, whereas these sparse data points for the study were obtained from abandoned oil and gas wells through AccuMap and Geoscout. These findings are outside the prime focus of geothermal energy exploitation within Canada for resources displaying temperatures between 80 ℃ − 150 ℃. Such resources can be utilized for binary type geothermal power plant for electricity generation. However, from the findings presented in the paper a conservative temperature range of approximately 50 ℃ − 90 ℃ is determined. This range is certainly inadequate for electricity generation from the resource, though direct use applications can be pursued.


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However, it has potential for direct application purpose which requires temperatures above 50°C [10, 6]. It could be used for heating and cooling of buildings like the type considered by Alberta government in Leduc or the Temple Gardens Mineral Spa in Moose Jaw, Saskatchewan which has created about 200 jobs [5]. Based on these findings the Regina project can be revisited. In addition, the location of well 4 is closer to Regina when compared to wells 7 and 14. Therefore, it can be considered an area of greater interest in regards to site selection for direct use exploitation of the thermal resource.

## 3. CONCLUSION

The study shows that there is a potential heat mining field for direct application for geothermal energy east of Regina $(50.2°\ N - 51.2°\ N, 104°\ W - 104.4° W)$. While it does not offer a conclusive answer on the feasibility of direct use application, it does offer direction for future prospect based on thermal analysis. There is potential for direct application based on the subsurface temperature findings $(50\ ℃ -\ 90\ ℃)$ at both the 2.5 km and 3.0 km depths across the areas investigated. Future studies should consider the sustainability of a geothermal doublet system using these wells for direct purpose by incorporating hydraulic properties and fluid content.

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