Discussed MJ Berry
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Put in some cw figures of some hyp theoretical energy equivalents
main figure/pair KW
~10 x 10^6 cals/hr

THE POTENTIAL FOR GEOTHERMAL EXPLOITATION OF SEDIMENTARY BASINS OF WESTERN CANADA

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INTRODUCTION

The purpose of this report is to promote in Canada the use of geothermal energy from deep sedimentary basins as an alternative to conventional methods of space heating.

Geothermal energy resource are not restricted to the volcanic and seismic belts of the earth, but may be available wherever sedimentary sequences reach a depth of at least 1500 m (4900 ft.) and coincide with geothermal gradients that are at least equal to the world average of about 25 mK/m (14°F/Kft.). The useful energy is held in the form of hot water that fills the porous rocks in the lower parts of the basins.

The most significant example of current usage is the heating of large apartment complexes in the suburbs of Paris, France. Water at about 60°C (140°F) is being taken from a reservoir at a depth of about 1500 m (4900 ft.). At Creil 1700 apartments are being supplied, and at Villeneuve la Garenne the completed complex will contain 4000 apartments. Full details of the reservoirs may be found in 'Potentiel Géothermique du Bassin Parisien' compiled by Housse and Maget and published by the Bureau de Recherches Géologigues et Minières, hereafter referred to as the *BRGM report* The particular significance of the Paris Basin is that there is nothing geologically unusual about it. It is not particularly big, and it does not have a high geothermal gradient.

Earlier developments in other parts of the world were described at the U.N. Symposium on the Development and Utilization of Geothermal Resources, Pisa, 1970. Heat from the Hungarian Basin was then being used for space heating in Szeged, where 1200 apartments were being supplied (Boldizsar). The Hungarian Basin is known to have a high geothermal gradient. Large resources of heat in the Gulf of Mexico Basin were described by Jones, where there are large zones of geopressured formations, which have unusually high thermal gradients and water content. Makerenko et al claimed that water in the temperature range 40°C - 100°C (104°F - 212°F) is to be found beneath 20% of the territory of the USSR. These resources are being exploited in many areas (Tikhonov and Dvorov, Makerenko et al), and probably include large volumes of water in sedimentary basins.

In Canada the first look at hot water in sedimentary basins as an energy source has been taken by the Geothermal Service by means of a contract to Sproule Associates Ltd. of Calgary. The investigators examined the existing information and produced a report that gave a summary of the possible water reservoirs in selected areas. This report will hereafter be referred to as the *Sproule Report*.

Review of Data

The geothermal potential of a sedimentary unit depends on its temperature, porosity, permeability, thickness and lateral extent. Within sedimentary areas, and particularly around oil and gas fields and exploration targets, detailed information is maintained by the oil companies concerned and in Provincial files, but the useful working knowledge and experience resides with the experienced geologists of the oil companies and consulting companies. It is difficult to extract the information that one requires from the mass of available records without the benefit of years of experience. In formations devoid of hydrocarbons knowledge is less complete. Studies of the composition, origin and movement of formation water have also been made in both Federal and Provincial Government establishments, e.g. van Everdingen (1968) and Hitchon and Friedman (1969).

The measurement of temperature in drilled wells is usually less thorough than for other properties and conditions. Most temperature readings have been obtained by including a maximum reading thermometer in the logging tool. Accounts of the development and difficulties of this method may be found in early reports of the British Association for the Advancement of Science (Everett, 1868) and the technique has long since been abandoned for accurate scientific measurement. However, for results to an accuracy of 1°C (2°F) the methods are quite adequate provided care is taken in obtaining and recording the results. Unfortunately the required care is not usually applied, and measurements are made at a time when the well is most disturbed by the process of drilling. A good account of the shortcomings of the data is to be found in the Sproule report (pp. 5-8).

In an attempt to gather the available temperature data together the 'Geothermal Survey of North America' was set up at the University of Oklahoma, sponsored by the American Association of Petroleum Geologists. Temperature data were extracted from company and State records and place on a computer-based file. Canadian data were extracted from the records and added to the file by a Canadian coordinator. Using this data base, temperature gradients have been calculated and contoured maps of gradient have been produced for all areas that have sufficient data, including western Canada. The gradient maps show many small anomalies that depend on only one well, and these anomalies are probably spurious. The gradients also show a tendency to increase with decreasing thickness of sedimentary column, and this also is probably spurious. This is probably due, at least in part, to the practice of taking the mean annual air temperature to represent the surface of the ground, whereas the true mean ground temperature is lower than the mean annual air temperature by up to 5°C. In shallow sedimentary sections the variation in average thermal conductivity may play some part in creating anomalies, but large lateral variations are not probable in thick sections except where thick shale sequences in young delta areas predominate. Lateral water movement within permeable formations could cause irregular gradients, but one is forced to the conclusion that many of the anomalies are the result of inadequacies of the temperature data, the neglect of the thermal conductivity and the unsatisfactory method of assessing surface temperature.

Anglin and Beck (1965) reached the same conclusions on the quality of the data in a study that was completed before the Geothermal Survey of North America was begun. Data from about 70 wells were accepted as reliable and lines of equal gradient and geotherms at sea-level were produced, as shown in Fig. 1. The area covered was southern Alberta, and the results showed temperature gradients increasing to the east and north, in the direction of decreasing thickness of sedimentary formations.

'he Sproule Report

The work done by Sproule Associates Ltd. was intended as a first look at the possibilities of using hot water from sedimentary basins in Canada, and it was based entirely on existing data. The original intention was to choose several areas of anomalously high temperature gradient for detailed examination. It was found that the areas of apparent high gradient usually coincided with areas of shallow drilling and consequently with low bottom hole temperatures. As a result of this, the areas of detailed study were selected on the basis of high bottom-hole temperature rather than on the basis of high temperature gradient. The study consisted of the selection of a number of wells, usually five or six, from each area and a review of the data on porosity, salinity and temperature of the deep reservoir formations. Wells were chosen to produce profiles of 50 to 250 km (30 to 150 miles) in length, and information for each profile was displayed on large composite diagrams.

The areas studied are indicated in Fig. 2, with the maximum bottom-hole temperature indicated beside each profile. All temperatures quoted are based on the existing data and are subject to its general limitations, and they have been rounded downwards to the nearest 5°C (9°F). Since measured temperatures are usually below equilbrium rock temperatures because of cooling by circulation of drilling mud, these figures are probably minimum estimates of the temperature of the deepest reservoir formations. Other permeable formations are mentioned in the descriptions of the profiles, and temperature will ɔe proportional to the depth. Fig. 2 also shows the boundaries of the region of sedimentary rocks, drawn to include the severely folded and faulted zone of the Rocky Mountains and Mackenzie Mountains. The sedimentary area is divided into areas where the majority of bottom-hole temperature readings are above 80°C (175°F) and below 80°C, regardless of depth. This dividing line runs through Alberta from north to south, the higher temperature being to the west of the line. There are insufficient data in the Northwest Territories to define the northward continuation. There is a further small area of southern Saskatchewan where temperatures over 80°C are found. This area are on the north flank of the Williston Basin, so that high temperature is related to great depth, but the area is in line with the high heat flow belt to the south associated with the Rio Grande Rift (e.g. Blackwell, 1971).

The highest temperatures recorded in the report are in the Pointed Mountain area, at the southern end of the Yukon-N.W.T. boundary. Bottom-hole temperatures are as high as 179°C (354°F) at a depth of 4419 m (14,498 ft.) and reservoir temperatures are about 170°C (338°F) at depths of 3397-4304 m (11,146-14,122 ft.). Unfortunately, the population density of the area is very low, the nearest settlement being Fort Liard. High temperatures are found in a continuous belt to the east of the Rocky Mountains, as far south as 50°N. There is a tendency towards lower temperature with lower latitude, but even in the Calgary area at about 51°N the temperatures are still about 120°C (248°F) at a depth of 3975 m (13040 ft.)

The Sproule report includes comments on the salinity of reservoir waters. In many of the areas covered by the profiles the total content of dissolved solids is high, and salinities in excess of

200,000 ppm are common. This may be compared with 35,000 ppm for average sea-water.

Table 1 summarizes the data from the fourteen sections and three single wells included in the report. The ranges of total depths and bottom-hole temperatures given apply only to the wells used in the survey. In most areas there are many more wells that are not included in the profile, and any formations mentioned usually extend for large distances (hundreds of kilometers) around the selected profiles. Although the profiles were selected on the basis of high bottom-hole temperature, the choice was still somewhat arbitrary and regional representation was intended. The particular profiles selected should not be taken as an indication of unfavourable interposed areas.

<u>Exploitation in France</u>

Hot water from sedimentary formations in the Paris Basin is now being used to heat apartment buildings in the suburbs of Paris, France. This exploitation was the subject of a NATO/CCMS meeting in Paris on 9-10 June 1976, and is the subject of a separate report (Jessop, 1976).

The Paris Basin is smaller than the western plains of Canada, being about 500 km (300 miles) across and having the deepest reservoirs at a depth of about 2000 m (9200 ft.). Temperatures as high as 110°C (230°F) are found in the deepest reservoirs. The main water-bearing reservoir rocks were found in the Purbeck limestone of the upper Jurassic, the Lusitanian limestone also of the upper Jurassic, the Dogger series of the middle Jurassic, the Lias series of the lower Jurassic, and Rhaetian sandstone, Keuper sandstone, Muschelkalk limestone and Bunter sandstone of the Triassic. Generally the basin rests on a basement of

Prepermian rocks and is bounded by massifs of Hercynian age, but some Devonian limestone is to be found in the north of France.

The basic data for the evaluation of the aquifer formations were provided by the records of oil exploration companies. Some local studies were also carried out by BRGM. Data from about one thousand wells were used in a computer-based study of the lithology and hydrogeology of the Basin. It was not practical to carry out a detailed study of all aquifers, and selection criteria were adopted based on temperatures greater than 50^{o}C (112^{o}F), adequate thickness and wide lateral continuity. The data assembled included the basic geological sections obtained during drilling and various geophysical measurements, including self potential, resistivity, gamma-ray, neutron and sonic logs. Some porosity and permeability data were also obtained from tests on drill cores, and data from formation and production testing were also used. Complete analysis of aquifer potential was hampered by the fact that the original data collection was directed towards a different purpose.

The available temperature data were used to produce a map of temperature gradient. It was found that the gradient varied with depth according to conductivity variations, and that anomalies due to poor data had to be neglected. The resulting map is shown in Fig. 3. Observed gradients are in the range 33 to 40 mK/m (18 to 22^{o}F/Kft.), and are similar to gradients in the western Canadian plains.

Total dissolved solids are quoted as being up to 26,000 ppm in the Dogger series and up to 10,000 ppm in the Lusitanian formation. These figures are considerably lower than most figures in the Sproule report. The presence of hydrogen sulphide in the Dogger series was also noted.

A set of coloured diagrams, separate from the bound text, forms part of the BRGM report. These include cross-sections and maps showing extent, depth, thickness, temperature, hydrochemistry and transmissivity for each reservoir unit of the Lusitanian, Dogger, Lias and Trias. Synthesis maps of transmissivity and temperature are also included. Notes on the extent and properties of the reservoir are also included in the text.

The BRGM report does not mention any data that were actively obtained for geothermal purposes. All the analyses are based on data resulting from oil and gas exploration. Such data are bound to exhibit some shortcomings when used for a purpose that was not originally intended, but the successful exploitation of the hot water has demonstrated that the data were adequate.

State of Progress in Canada

It seems probable that sufficient data concerning the sedimentary basins of western Canada already exist from which to develop plans for the exploitation of hot water. There are many thousands of wells, the data from which are stored in the files of exploration companies and provincial governments. Some observation wells, maintained for repeated testing, might also be used to obtain detailed formation temperatures, provided they are not in areas of gas or oil production. The Sproule report has already started along the path followed by French workers. The readily available temperature data have been examined, and the general areas most promising from the point of view of temperature have been indicated. Problems with the quality of the data have been commented on by both French and Canadian users. Brief comments on depth, thickness and permeability of the reservoirs and chemical composition of the water have been included, but no detailed account of these factors has been prepared. .

From the point of view of markets, the Paris Basin is a thickly populated area, containing one of the world's major cities and many other cities and towns. In contrast, the Canadian plains are thinly populated, containing Edmonton (442,000), Calgary (433,000) and Regina (147,000) within the areas of reasonable probability of geothermal development. Other major municipalities are listed in Table 2. At Villeneuve la Garenne a complex of 4000 apartments is to be served by the geothermal development. Assuming an average occupancy of only two persons, this gives a total population of 8000, which is greater than most communities on the Canadian plains. On the hand, because of the difference in climate, the energy that serves 4000 apartments in France will supply fewer units in Alberta, perhaps only 1000 or 1500. This situation will be helped by the fact that the temperature of the water is higher in Canada than in France, although this is counteracted to some extent by greater depth of the reservoirs.

Future Requirements

French workers have made a detailed study of the whole central part of the Paris Basin, neglecting only the areas where sedimentary rocks are too thin to accomodate high temperatures. This amounts to an area roughly 300 km across in all direction. This distance is two to three times greater than the length of the profiles in the Sproule report.

The next step in the Canadian programme should be the detailed study of a few areas. Each area should be about 100 km in extent, depending on the shape and extent of promising reservoirs. The results of this study should show the distribution of thickness and depth of the reservoirs, the porosity and permeability, the fluid pressure and the need for pumps, the temperature and energy content of the water, the hydrochemical character of the water, the probable corrosion and precipitation problems, and the relation between rate of production and life of the reservoirs.

Beyond this point the problem becomes one of engineering. Once the quantity and nature of the hot water supply is defined, it will be necessary to determine the most effective and economic way of using it within the context of the local market.

The selection of the first areas to be studied in detail should be based on the existing information and the location of possible consumers. Fig. 2 shows that the most promising areas are in northern British Columbia, western Alberta and southern Saskatchewan. Looking ahead to the economic investigations, it is appropriate to choose areas of different community character. A city area, an area of several small communities, and an isolated northern community present a wide range of applications. In the area of small communities the use of hot water for greenhouse development should be considered as a further possibility.

The best choice for the city area is Calgary, but either Edmonton or Regina are possibilities.

The choices for an area of numerous small communities include the Red Deer area, the Lethbridge area, both in Alberta, and the Weyburn area of southern Saskatchewan. The first two are close to Calgary, and will probably have many geological similarities, whereas the Weyburn area is in a different geological environment, being on the north flank of the Williston Basin. For this reason the Weyburn area is preferable.

The choices for a northern community include Grande Prairie, Alberta, Dawson Creek, Fort St. John and Fort Nelson, British Columbia. Other communities on the Mackenzie River, such as Fort Simpson, might be considered, but they are small and the geological data are very sparse. Of these four places, Fort Nelson is the most remote but it is small. The other three are close enough that it may be possible to include them all in the study area. In any case, Fort St. John and Dawson Creek are only about 65 km (40 miles) apart and the study area should be chosen to include both towns.

Once this technical study is completed, attention must be shifted to the engineering and economic aspects of the use of the resource. A demonstration project may be appropriate. It has been argued by some coordinators of programmes within Task IV - Exploit Renewable Resources that demonstration is a legitimate part of the activities funded by the Energy Panel. Engineering and economics studies and demonstration projects would probably be more appropriate at the Municipal or Provincial level than at the Federal level, since large apartment communities are the suitable users of the resource.

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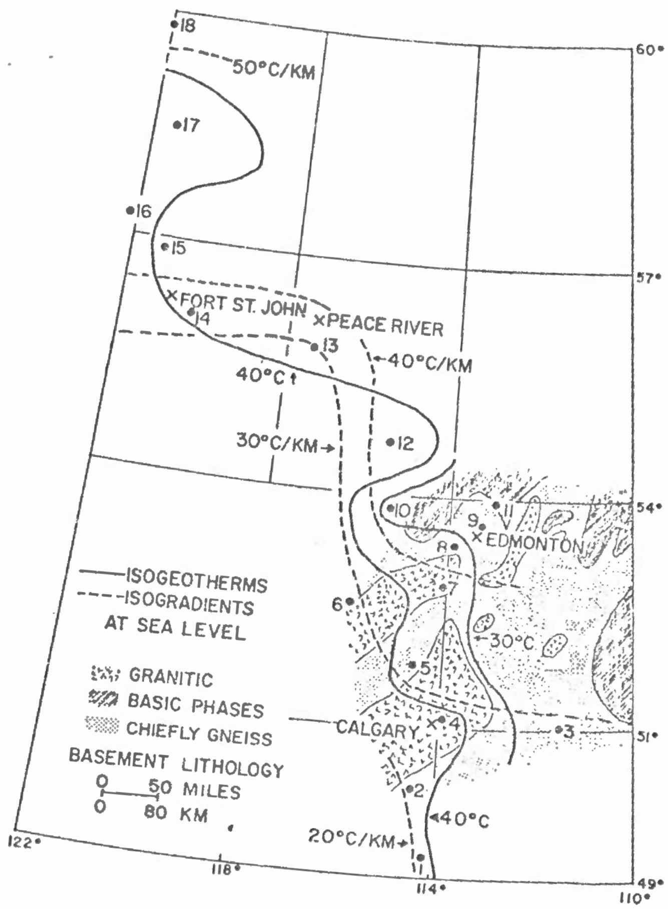


Fig. 1 Sea-level geotherms and thermal gradients in Alberta.
From: Anglin and Beck (1965)

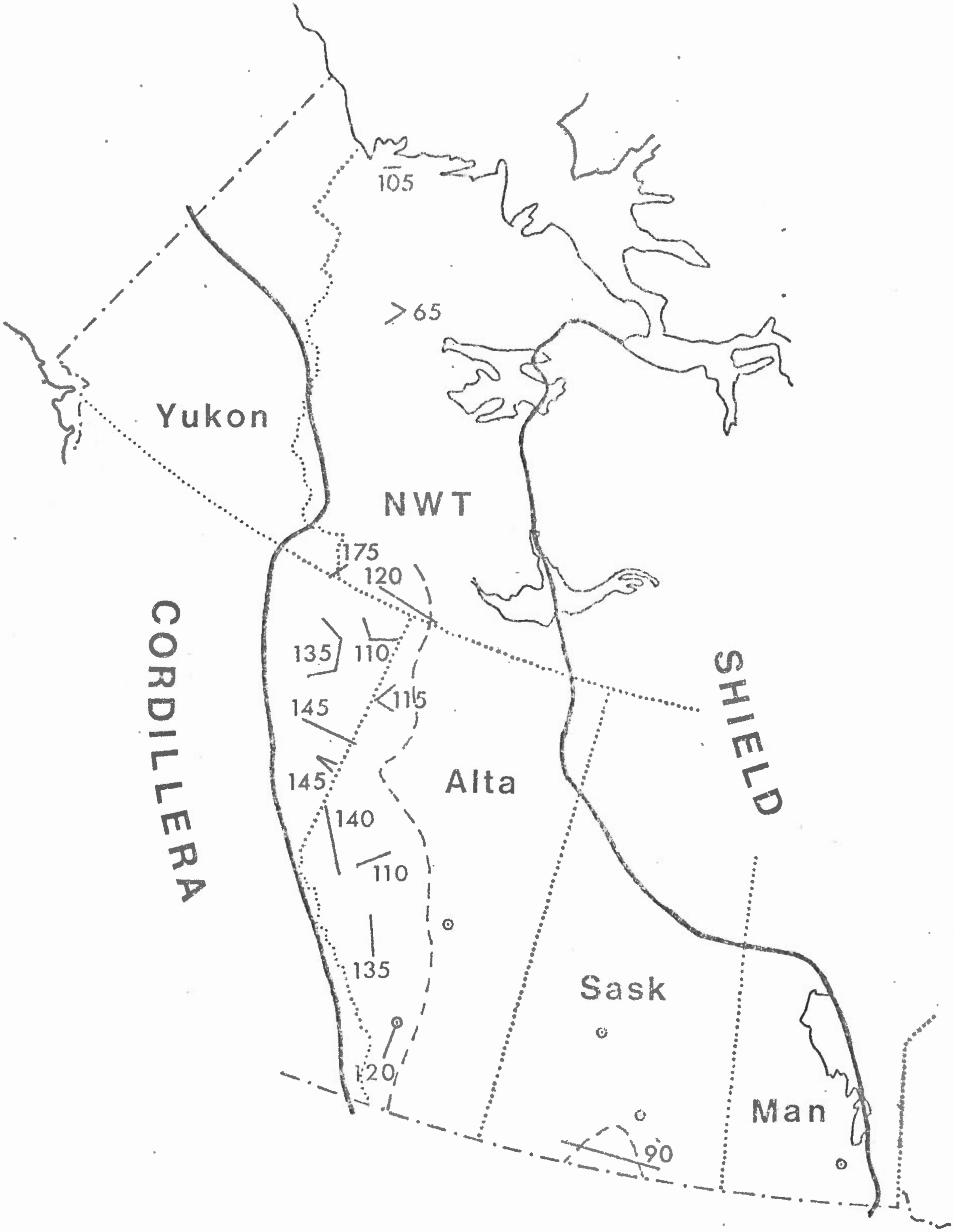
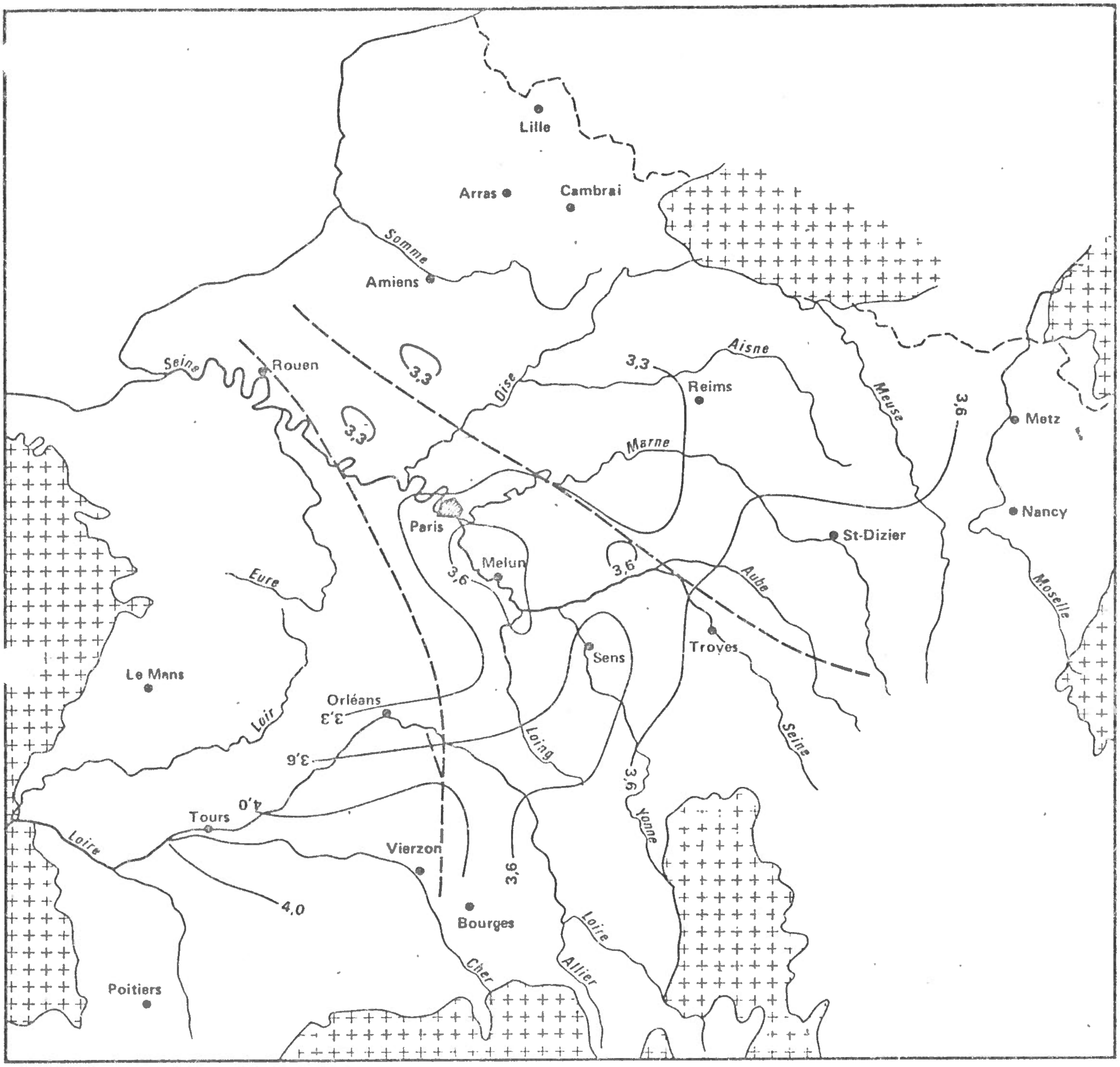


Fig. 2 Temperature in the lowest sedimentary formations. Data condensed from the Sproule report. Dashed line divides areas having bottom hole temperatures above and below 80°C (176°F).



——— — — Direction des grandes fractures citées précédemment (chapitre 2.1)

——3,3—— Courbe d'égale valeur du gradient géothermique (en °C/100 m)

Massifs anciens

Fig. 3 Geothermal gradient in the Paris Basin.
From: BRGM report.

TABLE 1

SUMMARY OF DATA IN SPROULE REPORT

Section	Wells	Total depth m & (ft)	B.H. Temp. °C & (°F)	Porosity	Dissolved Solids ppm	Towns or Cities
A	5	2644 - 3178 (8675 - 10426)	59 - 89 (139 - 198)	Several Fmtns.	15,000	Weyburn
B	6	2670 - 3975 (8760 - 13040)	79 - 122 (175 - 251)	Turner V	60,000	Calgary High River
C	7	4263 - 4843 (13986 - 15890)	113 - 138 (235 - 280)	Nisku Leduc	200,000	Harlech
D	6	4289 - 5480 (14070 - 17980	121 - 142 (250 - 288)	Leduc/Beaverhill	150,000	Grande Prairie
E	6	3108 - 4115 (10200 - 13500)	79 - 112 (174 - 234)	Cathedral Gilwood/Stephen	200,000	
F	6	3545 - 4022 (11630 - 13196)	107 - 148 (224 - 299)	Poor		Fort. St. John Dawson Creek
G	5	3184 - 3876 (10447 - 12715)	106 - 148 (222 - 298)	Poor		Fort St. John
H	9	2083 - 2932 (6835 - 9619)	92 - 116 (198 - 240)	Chinchaga Keg River Muskeg	18,000	
I	6	2450 - 3463 (8039 - 11361)	104 - 138 (220 - 280)	Cambrian Slave Point Elk Point		Fort Nelson

Section	Wells	Total depth	B.H. Temp.	Porosity	Dissolved Solids	Towns or Cities
J	7	2035 - 2661 (6675 - 8730)	103 - 113 (218 - 235)	Keg River Slave Point Elk Point		
K	4	4369 - 4528 (14335 - 14856)	168 - 179 (335 - 354)	Nahanni Reff	200,000	
L	7	1900 - 2484 (6234 - 8150)	69 - 122 (156 - 252)	Slave Point Keg River	150,000	
M	3	1724 - 1951 (5606 - 6400)	33 - 69 (92 - 156)	Ronning		Fort Good Hope
N	3	3205 - 3734 (10515 - 12250)	78 - 109 (172 - 228)	Devonian (?)		
Single Wells						
Tununuk	K-10	3757 (12326)	102 (?) (215) (?)			
Mayogiak	J-17	3681 (12077)	102 (216)			
Ellice	0-14	2898 (9507)	69 (157)			

TABLE 2

Municipalities in excess of 10,000 inhabitants within area of probable geothermal potential.

Alberta		
Edmonton	442	
Calgary	433	
Lethbridge	44	
Red Deer	28	
Medicine Hat	27	
St. Albert	18	(near Edmonton)
Grande Prairie	15	
British Columbia		
Dawson Creek	12	
Saskatchewan		
Regina	147	
Moose Jaw	32	
Swift Current	16	

Figures are in units of 1000 persons and are taken from the 1971 census.