GEOLOGICAL SURVEY OF CANADA

OPEN FILE 5690

Review of National Geothermal Energy Program Phase 1 – Geothermal Potential of Sedimentary Basins

Alan M. Jessop

2008

Natural Resources Canada Ressources naturelles Canada

Canada

GEOLOGICAL SURVEY OF CANADA

OPEN FILE 5690

Review of National Geothermal Energy Program Phase 1 – Geothermal potential of sedimentary basins

Alan M. Jessop

2008

Available from
Geological Survey of Canada
601 Booth Street
Ottawa, Ontario K1A 0E8

Jessop, Alan M.
2008: Review of National Energy Program
Phase 1- Geothermal potential of sedimentary basins;
Geological Survey of Canada, Open File 5690, 155 p.

Open files are products that have not gone through the GSC formal publication process.

CONTENTS

REVIEW OF NATIONAL GEOTHERMAL ENERGY PROGRAM

PHASE 1 - GEOTHERMAL POTENTIAL SEDIMENTARY BASINS

CHAPTER 1 - NATURE AND USE OF GEOTHERMAL ENERGY

INTRODUCTION 1
TYPES OF GEOTHERMAL RESOURCE 2
Dry-steam resources 2
Hot-water resources 3
Warm-water resources 3
Low-temperature resources 4
Water in abandoned mines 4
Hot dry rock 5
INTERNATIONAL UTILISATION 5
PHYSICAL QUANTITIES USED IN THIS REPORT 6
UNITS 8

CHAPTER 2 - THE GEOTHERMAL ENERGY PROGRAMME 10

INTRODUCTION 10
THE GEOTHERMAL ENERGY PROGRAMME 11
Objectives 11
Scientific base 12
Responsibilities and resources 13
MAJOR PROJECTS 13
Meager Mountain 13
Regina 14
ENGINEERING AND ECONOMIC STUDIES 14
GROWTH OF OUTSIDE INTEREST 15
THE GEOTHERMAL COMMUNITY 15
Provincial governments and agencies 15
The industrial community 16
The university Community 16
Municipalities 17
The public 17
Technical groups and symposia 17
The international community 18
ASSESSMENT OF THE RESOURCE 19
Estimation of the resource base 22

CHAPTER 3 - GEOTHERMAL RESOURCES IN SEDIMENTARY BASINS 23

I INTRODUCTION 23
REVIEW OF CONTRACTED STUDIES 24
Reports from Sproule Associates 24
Reports from the University of Regina 27
Reports to the University of Regina 30
Reports from the University of Alberta 31
Reports for other sources 33
REVIEW OF INTERNAL STUDIES 34
EARTH SCIENCE ADVANCES 34
Temperature, gradients and thermal properties 34
Porosity, permeability and hydraulic potential 35
Chemical content of geothermal waters 36
Water flow and the thermal field 36
THE REGINA PROJECT 36
The feasibility study 37
Drilling the well 38
Research based on the well 38
THE MOOSE JAW PROJECT 40
ASSESSMENT OF RESOURCES 40
Definitions 41
Methods 42
Accessible resource base 43
The useful resource base 45
Estimation of local resources 45
CONCLUSIONS 46

CHAPTER 4 - GEOTHERMAL RESOURCES OF THE ATLANTIC MARGIN 48

INTRODUCTION 48
REVIEW OF CONTRACTED STUDIES 48
REVIEW OF INTERNAL STUDIES 50
EARTH SCIENCE 51
Temperature and gradient 52
Hot dry rock potential 52
ASSESSMENT OF RESOURCE 55
Pictou Basin 56
LEGAL DEFINITION OF GEOTHERMAL RESOURCES 56

CHAPTER 5 - SHALLOW AND LOW-TEMPERATURE RESOURCES 57

INTRODUCTION 57
MECHANISM OF APPLICATION 57
REVIEW OF CONTRACTED STUDIES 57
REPORTS FROM OTHER SOURCES 60
REVIEW OF REPORTS FROM INTERNAL SOURCES 60
EARTH SCIENCE 60
THE SPRINGHILL PROJECT 65
OTHER LOCATIONS 66
Carleton University, Ottawa 66
Okotoks, Alberta 66
Oshawa. Ontario 66
Timmins, Ontario 66
PROFESSIONAL AND INDUSTRIAL ORGANISATIONS 67
FUTURE DIRECTIONS 67

CHAPTER 6 - ENGINEERING AND ECONOMICS 69

INTRODUCTION 69
REVIEW OF CONTRACTED STUDIES 69
COMMUNITY AND INDUSTRIAL ENQUIRIES 73
Hinton, Alberta 73
Bowden, Alberta 73
Charlottetown, Prince Edward Island 73
Edson, Alberta 73
Moose Jaw, Saskatchewan 73
Summerland, British Columbia 74
Springhill, Nova Scotia 74
Mayo, Yukon Territory 74
Kindersley, Saskatchewan 74
Hot Springs Cove, British Columbia 74
Mt. Cayley, British Columbia 74
Potash mines in Saskatchewan 74
CONCLUSIONS 74

CHAPTER 7 - FUTURE RESEARCH AND DEVELOPMENT

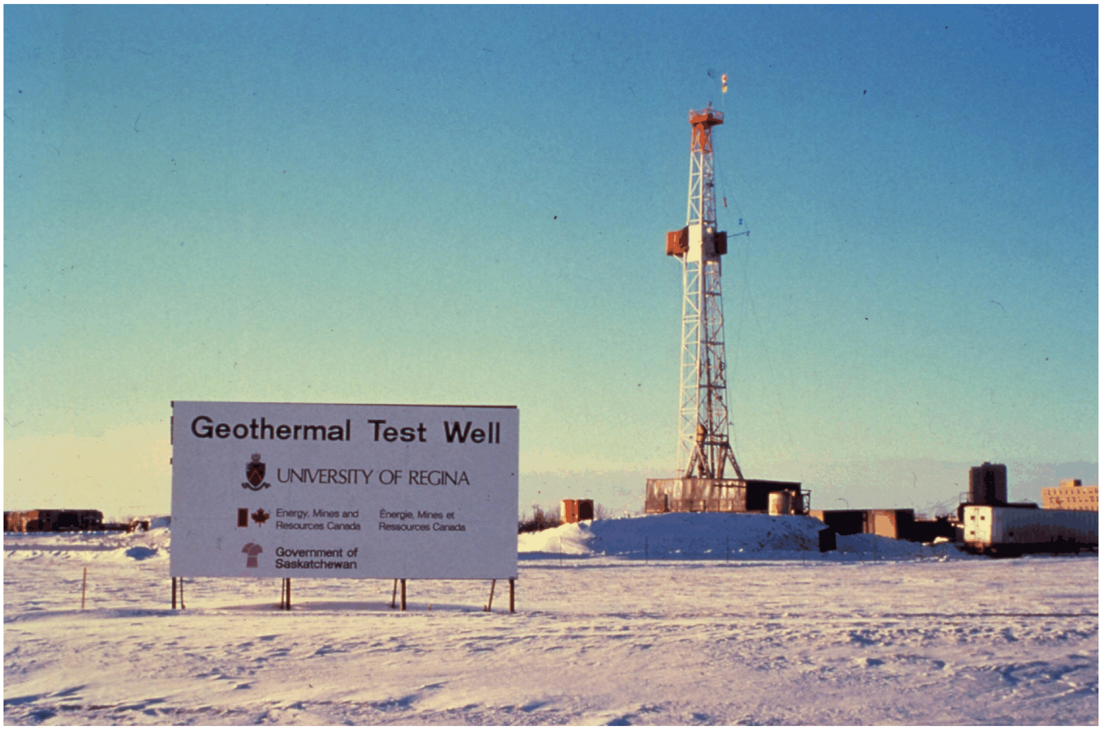
INTRODUCTION	77
THE WESTERN CANADA SEDIMENTARY BASIN	77
THE ATLANTIC REGION	78
ABANDONED MINES	78
THE ST. LAWRENCE LOWLANDS	78
SOUTHWESTERN ONTARIO	79
THE CANADIAN SHIELD	79
THE MACKENZIE CORRIDOR AND DELTA	79
THE ARCTIC ISLANDS	79
IMMEDIATE PRIORITIES	79
Specific priorities	80
General needs	80

REFERENCES	82
References in the text	82
Canadian geothermal energy bibliography	90
Canadian geothermics bibliography	107
APPENDICES	140
1 - Expenditures of the program	140
2 - Federal participants	143
3 - Industrial participants	145
4 - University participants	146

FOREWORD

The purpose of this report is to set down a record of the work done, the contracts let, and the knowledge gained during the Geothermal Energy Program of 1976 to 1986. Small projects, both before and after the Program, are also included. It is hoped that this will provide a base on which to build further research into geothermal energy in Canada and that will stimulate the use of geothermal energy as hydrocarbon resources decline, as environmental concerns grow, and as economic conditions change.

This report contains details of the work in the Western Canadian Sedimentary Basin, in the Atlantic Provinces, and in all other parts of Canada east of the Rocky Mountains. It is anticipated that the corresponding report for the Cordillera and volcanic belts of British Columbia and the Yukon will appear in 2008.



Drilling the Geothermal Well

University of Regina

January 1979

CHAPTER ONE

NATURE AND USE OF GEOTHERMAL RESOURCES

INTRODUCTION

Geothermal energy comes from the solid earth in the form of heat. The Earth's heat is a combination of the original heat resulting from formation and layering of the earth and of the heat generated since the formation by the decay of radioactive isotopes. Both of these depend on the finite amount of energy associated with the formation and original content of the earth, and so this is not, in principle, a renewable energy resource. However, the total heat of the earth is so great that it may be regarded, for human practical and economic purposes, as inexhaustible.

On a scale limited by human development and technology or by the individual geothermal system the heat is drawn from a limited volume of the Earth's crust, and so it is finite. In systems associated with recent volcanic plutons or batholiths the heat may be renewed by natural hydrothermal circulation, but ultimately the resource is finite. In other systems, notably in sedimentary aquifers, the heat is drawn down much faster than it can be renewed, and so any individual production system must be regarded as having a finite life span.

Heat energy is in all material on the earth, since the only matter without heat is at a temperature of absolute zero. The temperature of the earth's surface is controlled by the level of radiation from the sun, the filtering and insulating effects of the atmosphere, the local vegetation cover and the annual cycle of seasons. The annual average temperature of the surface of the earth normally lies between -15 ^{O}C, in regions near the poles, and 30 ^{O}C, in equatorial regions. Apart from perturbations of up to 4 ^{O} C near the surface, due to rapid surface warming in the last 100 to 200 years, temperature in the solid earth increases with depth.

Heat energy needs a carrier. In geothermal exploitation the carrier is normally the water in the ground that has collected and concentrated the heat in reservoirs. The only exception to this is in the use of hot dry rock, where water must be introduced artificially. It is convenient to take the freezing point of water as a base temperature for energy content. Below that temperature water can be neither produced nor reinjected. Since temperature of the solid earth rises with increasing depth, geothermal energy is present below the entire surface of the continents. However, the mechanisms and economics of extraction mean that most of the earth's energy is not useful. Only in special circumstances is geothermal energy capable of being exploited. Conditions for utility are governed by the geological setting, the physical nature, the available technology of extraction, and the economic need for the resource. Of these, the first two are constant for any particular reservoir, the available technology improves with time, but economic conditions fluctuate. This report of research and development of geothermal energy thus focuses on the first three conditions. Exploitation depends on the level of knowledge of these three conditions and the economic conditions of the time.

Temperature of the oceans depends on currents, and is often lower at great depth than at the surface. The temperature range of ocean water is approximately -5 ^{O}C to 20 ^{O}C . Useful energy may be extracted from ocean water, using the vertical temperature differences, but that subject is not within the scope of this report

TYPES OF GEOTHERMAL RESOURCE

The physical nature of the resource and the technology of extraction impose a system of classification of geothermal resources. The physical nature provides a division into steam, water, and hot dry rock resources, and the technology of extraction divides the water resources by temperature, according to the suitability for electrical generation, direct heat use, or conversion by heat pumps. Geological setting, including the geomorphological character of the surface, may affect the ease and economic feasibility of development. Human factors, such as population density, effect the potential uses and economic situation. However, in order to describe the nature of geothermal resources the most suitable classification is by physical nature, and this system will be followed in this chapter. Further description of each type of resource may be found in Jessop (1990).

Dry-steam resources

Dry steam reservoirs, often referred to as "vapour-dominated reservoirs", consist of steam trapped in porous rocks, and trapped by impermeable cap-rocks. The steam usually overlies a hot water reservoir, with which it is in dynamic equilibrium. The temperature and pressure of dry-steam reservoirs is controlled by an enthalpy maximum of saturated steam. Either higher or lower pressure results in slight superheating, so that the reservoir is stable. At any lower temperature an increase in pressure would cause condensation. Maximum enthalpy occurs at a temperature of about 235ºC and a pressure of about 3 MPa, and all dry-steam reservoirs have this temperature and pressure unless they contain significant quantities of contaminant gas. Since a hydrostatic pressure of 3 MPa implies a hydraulic depth of only about 300 m, these reservoirs are usually found within the upper 1000 m. Production wells are thus relative short, but the difficulties and hazards of drilling are great. A well drilled into a dry-steam reservoir produces a flow of steam with some gas, but with very little contaminating dissolved solid. Any grains of solid material carried in the fluid stream are removed by filters and the steam is then fed directly to turbines for the generation of electrical power. The best known examples of exploited dry-steam systems are at Larderello, Italy, and the Geysers, California, U.S.A. The total installed capacity at the Geysers field is now 1421 MW, and the annual production is 7784 GWh, 62.5% of full production (Lund et al., 2005). In Italy the dry-steam fields at Larderello and neighbouring Travale-Radicondoli have a total installed capacity of 702.5 MW and produce 4715 Gwh, 76.6% of full production (Cappetti,G. And Ceppatelli,L,. 2005)

Dry-steam reservoirs are generally the cleanest and most efficiently converted of geothermal resources. Unfortunately, they are comparatively rare. They are found only in zones of active volcanism or recent tectonic disturbance. They depend on the convenient proximity of a confined aquifer to a hydrothermal circulating system and a high temperature heat source.

No dry steam reservoirs have yet been found in Canada, but their presence cannot be ruled out. Any centre of recent silicic volcanism may have one or more associated intrusive bodies capable of supporting hydrothermal systems leading to dry-steam reservoirs. Only the south side of Mount Meager has been explored: this has been shown to have sufficiently high temperatures, but the presence of dry steam has not yet been demonstrated. Other volcanic centres have not been explored.

Hot-water resources

Hot water resources, often referred to as "fluid-dominated reservoirs", are much more common than dry-steam reservoirs. The water in the reservoir is at a high temperature, and pressure drop in a well will permit the water to evaporate partially to a mixture of saturated steam and water. In theory, any reservoir at temperature above $100\,^{O}C$ will produce steam, but in practice a reservoir must be above about $180\,^{O}C$ for the steam to be useful for direct use in turbines. This technological limitation imposes a lower limit on the definition of “hot-water resources", by association with electrical power generation through steam turbines. There is no upper limit, but most reservoirs are in the range $180\,^{O}C$ to $300\,^{O}C$. Temperatures as high as $340\,^{O}C$ have been recorded at Cerro Prieto, Mexico, (Banwell and Valle, 1970). In Mexico the currently installed capacity, in five locations, is 953 MW, which provides an average annual production of 6282 Gwh, 75.2% of full production (Gutierrez-Negrin and Quijano-Leon, 2005). Hot-water reservoirs may be found at any depth that is great enough or beneath any cap-rock impervious enough to provide the confining pressure required to prevent boiling. Temperature and pressure may be substantially higher than in a dry-steam reservoir, since the stability is not controlled by specific enthalpy on the boiling curve.

A hot-water reservoir has been demonstrated at Mt. Meager, British Columbia, although the production capabilities of the reservoir have not been adequately determined. Other reservoirs probably exist at other locations within the Mt. Meager centre and at other volcanic centres in Canada.

Warm-water resources

Warm-water reservoirs differ from hot-water reservoirs only in temperature and economic utility. This category is usually taken to include temperatures from about $50\,^{O}C$ to about $180\,^{O}C$. These boundaries are set by considerations of use and have no physical significance. The upper limit is set by the limit of direct steam supply to turbines for electrical generation. The lower limit is set by the temperature at which the use of heat pumps is needed for economic utilisation.

Warm-water reservoirs are to be found in volcanic areas, but the greatest are probably in the large sedimentary basins. Aquifers are found in porous sedimentary formations, of thickness of tens of metres and lateral extent of hundreds of kilometres, to depths of several kilometres. In areas of normal geothermal gradient of 20 to 30 mK/m, these aquifers may contain water at temperatures up to $150\,^{O}C$ or more.

Warm-water reservoirs of volcanic origin are used in Iceland for heating of homes and public buildings. Reservoirs in sedimentary basins have been used in and around Paris, France for heating apartment buildings. Recent developments in Australia, Austria and Germany have included the generation of electricity, using a secondary fluid of low boiling point and water at temperatures of 98 ^{O}C to 105 ^{O}C. So far these installations are on a small scale, with installed capacity up to 500 kW (Bertani, 2005)

Very large warm-water reservoirs have been shown to exist in Canada, particularly beneath the Prairies. As will be described the later, the resource has been proved at Regina, Saskatchewan, and usable resources probably exist beneath other urban centres. In the deeper parts of the Western Canada Sedimentary Basin there is ample water of temperatures similar to or greater than the water now being used to generate electrical power as described above, which could be valuable in remote communities.

Low-temperature resources

The lower limit of useful temperature of a reservoir is set only by economic utility. There is no clear dividing line between systems that are generally accepted as geothermal and systems using heat pumps to extract from water in surficial unconsolidated material. Shallow ground-water is commonly available, and may be present to depths of several hundred metres in deep valleys or areas of sedimentary accumulation.

The City of Whitehorse and the Village of Mayo are using low-grade geothermal energy in the form of warm groundwater to keep prevent their municipal water supplies from freezing in winter, providing an extreme low-temperature example of water used because its temperature. Many small systems have been installed by individuals to heat private homes, and there are several commercial source of such systems. There were an estimated 30,000 such installations in private homes in the year 2000, and numbers are increasing by about 3000 per year (Ghomshei et al, 2005) On a larger scale, Carleton University in Ottawa has been using, since 1990, groundwater from limestone aquifers at a temperature of about 9 ^{O}C for direct cooling of air in the summer and preheating of intake air in the winter. The energy potential of low-temperature geothermal resources in Canada is very large. Development depends mainly on local economic factors and on local initiatives.

Water in abandoned mines

Water in flooded mines is a special case of low-temperature resources. The aquifer has been formed by human activity, and it consists of networks of interconnected tunnels and caverns, which readily fill with water. In these circumstances it is possible for water to circulate and mix, producing temperatures in the upper levels higher than would not normally be found at those depths.

This type of resource has been used very successfully in Springhill, Nova Scotia, one of the first developments of this kind anywhere in the world. Water at about 18 ^{O}C is pumped from the mine workings and used with heat pumps to heat industrial buildings. The flooded mine workings are extensive, and the temperature of the water confirms that there is circulation within the mine. Further, some applications return more heat to the mines in summer than they extract in winter, so that the heat reservoir may last for hundreds of years (Jessop et al., 1995).

Hot dry rock

Hot dry rock is solid rock at an unusually high temperature, but without a geothermal reservoir. Since heat requires a carrier in order to bring it to the surface, an artificial circulating system for water must be created. The source of the heat may be either a magmatic intrusive that is sufficiently young to retain some of its initial heat, or a rock that contains sufficient radioactive potassium and trace-elements to generate its own heat. A magmatic intrusive must be younger than about ten million years, depending on its dimensions, and may still have associated hydrothermal systems beyond its boundaries. A radioactive rock must be of substantial size and depth in order to produce the high geothermal gradient needed for hot-dry rock exploitation. The levels of radioactivity required are three orders of magnitude lower than those of rocks considered to be of ore grade and the heat-producing isotopes are not generally mobile. Hot dry rock experiments pose no threat to health from this cause.

Hot-dry rock exists extensively in volcanic areas, and is the heat source for many of the hot- and warm-water reservoirs that are known. Unfortunately hot-dry rock is difficult to detect with the available surface survey tools, and is often too deep for economic exploitation. The techniques of utilisation are still being developed. Extensive experiments have been conducted at Los Alamos, New Mexico, U.S.A., in a young magmatic intrusive, and in the Carnmenellis Granite of Cornwall, England, in an old rock of high radioactive heat generation. The present European Union Hot Dry Rock Project is located at Soultz-sous-Forets, in the Rhine Graben about 50 km north of Strasbourg. It has been in operation since about 1993. The first deep well reached a depth of 5000 m in 1999, and the temperature at the bottom was found to be 200^{O}C. Two more deep wells have since been drilled. Experiments in hydrofracturing and brine injection and extensive surveys of induced microseismicity have been carried out (Baria et al., 2005)

Except for information from a drilling experiment in the Coryell Syenite of southern British Columbia, and from routine heat-flow measurement, the hot dry rock potential of the Canadian crust is unknown. Hot dry rock exists below Mt. Meager and probably below other volcanic centres such as Mt. Cayley and Mt. Edziza. Substantial bodies of intrusive rock in the interior of British Columbia are sufficiently radioactive to produce high geothermal gradients and a hot dry rock potential better than that of the Carnmenellis Granite in England.

INTERNATIONAL UTILISATION

The "Energy Crisis" of 1973 to 1980 prompted a wide interest in the potential of geothermal energy, which has been sustained in countries having little or no domestic fossil fuels. There are now 24 countries with electrical generation from geothermal sources. The total installed electrical capacity reported in 2005 was 8912 MW, with an annual output of 56,798 Gwh, 72.7% of full production. The leading countries in installed capacity are USA (2544 MW), Philippines (1931 MW), Mexico (953 MW), Indonesia (797 MW) and Italy (790 MW). All 24 countries, with the exceptions of Australia, Austria and Germany, which have very small installations, are

Table 1 Methods of direct use

Means of use	Installed Capacity MW	Annual energy TJ	Capacity Factor
G-C heat pumps	15723	86673	0.17
Space heating	4158	52868	0.40
Greenhouse	1348	19607	0.46
Aquaculture	616	10969	0.56
Crop drying	157	2013	0.41
Industrial process	489	11068	0.72
Snow melting	282	1596	0.18
Space cooling	56	288	0.16
Bathing, swimming	0.35	7.0	0.63
Other	86	1045	0.39

parts of the volcanic zones of the Circum-Pacific Belt, the Mediterranean-Himalaya Belt, the African Rift, or the Mid-Atlantic Ridge (Bertani, 2005).

The Proceedings of the International Geothermal Congress of 2005 show that there is a great deal of world-wide interest in the exploitation of geothermal resources. Seventy eight countries submitted "Country Updates", including Canada. Direct use of geothermal heat, as reported at the end of 2004 amounts to 27,825 MWt, which is almost twice the quantity reported in 2000, and growing at about 12.9% annually. The total annual energy use is 261,418 TJ (72,622 GWh), calculated from the reports of 72 countries. The countries with the largest installed capacity were USA, Sweden, China, Iceland, and Turkey. Sweden is not in any of the world's volcanic belts, but derives its position in this list from its use of ground-coupled heat pumps. Details of energy usage by means is given in Table 1.

The direct use of geothermal energy replaces the use of other sources of heat. Since the total reported energy usage is 261,418 TJ/yr, and assuming that a barrel of oil contains 6.06 GJ and is used to provide replacement electricity, the saving of oil is 123 million barrels or 18.4 million tonnes. If the oil were used to produce heat by direct burning these savings would be reduced by about half.

Carbon savings would depend on the fuel displaced. If the whole energy displaced were in the form of electricity, the carbon savings would be 14.0, 59.3, or 69.2 million tonnes, depending on whether the primary fuel were natural gas, oil or coal. If the fuels were burned directly the carbon savings would be about half these figures. The true savings are probably somewhere between the two extremes (Lund et al., 2005)

PHYSICAL QUANTITIES USED IN THIS REPORT

Several scientific quantities will be referred to in this report.

Terrestrial Heat Flow is the amount of heat conducted to the surface of the earth from below. It is a property of the heat generation in the crust and tectonic structure and age of the location. It is expressed in mW/m^2 (milliWatts per square metre). It is used as a geophysical indicator of the nature of the crust of the earth. The world average is 65 mW/m^2 and normal observed values are in the range 20 to 100 mW/m^2, but anomalous circumstances produce values well outside this range.

Temperature difference is expressed in K (Kelvin). This quantity has the same magnitude as a degree Celsius, but without the implication of a point on fixed scale of temperature. Temperature is expressed in ^{O}C (degrees on the Celsius scale)

Geothermal gradient is the rate of increase of temperature with depth. It is expressed in mK/m (milliKelvin per metre, the same as degrees Celsius per kilometre. Observed values range from 10 mK/m to over 100 mK/m. At any one location the geothermal gradient can vary with depth, being inversely proportional to thermal conductivity of the rocks so that heat flow remains uniform.

Heat generation is the amount of heat being generated continuously in the rocks by radioactive decay. It is expressed in $\mu W/m^3$ (microWatts per cubic metre). Normal values range from undetectably low to the order of 10 $\mu W/m^3$.

Thermal conductivity is the conducting property of rock through which heat is flowing. It is a property of the rock and depends on the conductivities of the component minerals in the rock. It is expressed in W/mK (Watts per metre Kelvin) and typical values range from 0.3 W/mK for coal, and 0.6 W/mK for water, 1.5 to 4.0 W/mK for most rocks, and 40 to 400 W/mK for metals.

Thermal diffusivity is a further property of materials, being the conductivity divided by the volumetric heat capacity. This property controls transient thermal changes in solid materials. It is expressed in m^2/s (square metres per second). Most rocks have a diffusivity of the order of 10^{-6} m^2/s, and since the prefix in a unit expression modifies the first unit quantity to the first power, this is usually expressed as 1 mm^2/s.

Porosity is the open space between the grains of a granular material or in cracks and fissures within a solid. It is usually expresses in % (per cent). In rocks the space is usually filled by water. In crystalline rocks porosity is usually less than 1 %, but in sandstone or limestone porosity may be as high as 25 %.

Permeability is the ability of a solid to allow the flow of water through it. It is usually expressed in terms of the "Darcy" and one Darcy is the permeability through which a fluid of viscosity of 1 centipoise will flow at the rate of 1 ml/s through an area of 1 cm^2 under a pressure gradient of 1 atmosphere/cm. This depends on the properties of the fluid and of the earth's atmosphere, and so is a non-standard unit. It has the dimensions of an area and has the value of 9.8697×10^{-13} m^2. The nearest practical SI unit is 1.0×10^{-12} m^2.

Volumetric Flow Rate is also known as *absolute discharge* and is the volume of fluid passing unit area in unit time. It has the dimensions of a velocity. The linear particle velocity of the fluid may be derived by dividing by the porosity.

UNITS

All units in this report will be expressed in the Systeme Internationale des Pieds et Mesures (SI). Data introduced from old work using other systems have been converted to SI, but the original data are given in brackets. Scientific publications from before about 1970 are usually expressed in an older metric system, based on grams and centimetres rather than the kilograms and metres of SI. Imperial and US systems, based on feet, pounds and degrees Fahrenheit, are occasionally still used by engineers.

Table 2
Unit conversion

Energy - expressed in Joules (J)

1 Joule	=	0.2338 Cal
1 Cal	=	4.187 J
1 kWh (kiloWatt.hour)	=	3.6 MJ
1 MWy (MegaWatt year)	=	31.56 TJ
1 BTU (British thermal unit)	=	1055 J
1 barrel of oil equivalent	=	5.7 GJ (approx)
1 tonne of oil equivalent	=	42 GJ
1 m^3 of natural gas	=	38 MJ

Power - expressed in Watts (W)

1 W	=	1 J/s
1 W (Watt)	=	3.412 BTU/Hr
1 kW (kiloWatt)	=	1.341 horse-power

Heat flow - expressed in Watt per square metre (W/m^2)

1 W/m^2	=	0.2388×10^{-5} cal/cm^2sec
1 cal/cm^2 sec	=	41.87 kW/m^2

Geothermal gradient - expressed in Kelvin/metre (K/m)

1 mK/m	=	1 ^{O}C/km
1 mK/m	=	0.5486×10^{-3} ^{O}F/ft

Thermal conductivity - expressed in Watts/metre.Kelvin (W/mK)

1 W/mK	=	2.39×10^{3} cal/cm sec ^{O}C

The main difference between the two metric systems is in the unit of energy. SI uses the Joule (J), whereas the older cgs system uses the Calorie. The Joule is directly derived from the fundamental units, whereas the Calorie depends on the properties of water and is subject to the inaccuracies of measurement. The Watt (W) is the power of one Joule per second. In terms of human energy use these are small units. To avoid the use of large numbers, larger composite units are often used, but because of the non-decimal time system, some of these are not simple multiples of powers of ten. The conversions given in Table 2, with other important conversions. In this report energy is expressed in Joules. When circumstances prompt the use of a different unit (e.g. kWh) this will be expressed in brackets after the main expression.

Prefixes to quantities are used in SI to avoid repetition of powers of ten. The most common prefixes occur in steps of three, and they are shown in Table 3:

Table 3
Prefixes to SI units

k	kilo	3	m	milli	-3
M	Mega	6	µ	micro	-6
G	Giga	9	n	nano	-9
T	Tera	12	p	pico	-12
P	Peta	15			
E	Exa	18			

NB There should be no confusion between m for "milli" and m for "metre". Prefixes denoting scale come only at the beginning of a unit expression. Thus, in the unit expression for diffusivity the first "m" denotes "milli" and the second "m" denotes "metre"

CHAPTER TWO

THE GEOTHERMAL ENERGY PROGRAM

INTRODUCTION

Geothermal energy research by the Government of Canada was initiated as part of a major new approach to the problems of future energy supply, prompted in October1973 by the sudden rise in the price of oil and the subsequent popular perception that the supply of oil was approaching a serious decline. In the winter of 1974 the Geological Survey of Canada (GSC) and the Earth Physics Branch (EPB), both branches within the Department of Energy, Mines and Resources (EMR) began a small-scale investigation into the potential for geothermal energy in Canada.

Although the price of oil began to rise in 1973, the formal Task structure of the Office of Energy Research and Development did not come into operation until 1976. The Geothermal Energy Program was one Program within the Task of Renewable Energy. Much of the control of the Renewable Energy Task was in the Division of Energy of the National Research Council (NRC), but the Geothermal Program was operated entirely outside NRC, until a small engineering component was added in 1981.

The price of oil remained high until 1985, but the public fears of future declining supply had disappeared by about 1980. Most of the Renewable Energy Task was eliminated in November 1984, when the energy Division of Energy of NRC was eliminated. The remaining part of the Geothermal Energy Program, located in EMR was reduced. The Program was eliminated entirely on 31 March 1986, when the EPB was combined with GSC, under the name Geological Survey of Canada..

During the years since 1986 popular concern with global environmental problems has grown substantially. The combustion of oil, gas and coal has been recognised as a producer of gaseous oxides, resulting in acid rain in areas down-wind from industrialised countries. The emission of these gases, in company with methane, has also been recognised as most probably responsible for "global warming", a long-term change in climate that will eventually result in some melting of polar ice-caps and subsequent rise in sea level. In early 2007 this reached the point where the Government of Canada was forced to acknowledge public concerns. The Intergovernmental Panel on Climate Change (IPCC) states: “Carbon dioxide is the most important anthropogenic greenhouse gas .... The global atmospheric concentration of carbon dioxide has increased from a pre-industrial value of about 280 ppm to 379 ppm in 2005. The atmospheric concentration of carbon dioxide in 2005 exceeds by far the natural range over the last 650,000 years (180 to 300 ppm) as determined from ice cores. The annual carbon dioxide concentration growth-rate was larger during the last 10 years (1995-2005 average: 1.9 ppm per year) than it has been since the beginning of continuous direct atmosphere measurements” (IPCC Report, 2007)

The role of carbon dioxide and other gasses as conservers of earth heat has long been known. It was first described by Arrhenius in 1896. In early 2007 the association of the increase of carbon dioxide in the atmosphere and the observed warming of the climate is inescapable, but it is impossible to be certain of the cause and effect relationship. The IPCC report states: "Most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations." In the IPCC report the term "very likely" implies at least a 95% probability of occurrence.

A substantial part of our present energy supply is obtained by burning fossil fuel, in power stations, aircraft, surface transport and domestic heating, the exhausts of which are vented directly into the atmosphere. Geothermal energy has the advantage that its use does not depend on the release of chemical energy by combustion, and so it can claim to be environmentally benign in this respect. There are other potential environmental factors, which will be mentioned below, but they have generally been successfully counteracted.

THE GEOTHERMAL ENERGY PROGRAM

During the ten years of the Geothermal Energy Program a series of unpublished internal reports was written by the participant in the program, and even before the formal Program began there had been a written discussion of the Canadian geothermal potential and the scientific expertise available to the Program. A copy of most of these reports has survived with the author of the current report, and they have provided much of the data planning, costs, and operational sequence that has been included in this report. They contain little or no technical material, and since they are not accessible to readers, they are not referenced further. Useless details required by central planners, like forecasts of expenditures for 25 years, are not repeated here.

Objectives

Research into geothermal energy in Canada from 1974 to 1986 can be divided roughly into four phases, with considerable overlap.

Phase one consisted of the examination of the accumulated geological knowledge and was directed towards two main questions. Where are the Canadian resources? How large are they? During the first phase, which lasted from about 1974 to 1977, objectives became focussed towards two specific sites and four geological regions.

The examination of these sites and regions constituted the second phase. What is the geothermal potential for electrical generation at the Meager Creek site? What is the geothermal potential at Regina, and how can it be integrated into the energy supply of the University campus? What parts of the Tertiary and Holocene volcanic areas of Canada offer geothermal resources? What parts of the western mountains, not of recent volcanic origin, offer geothermal resources, and of what type? What is the potential for low-temperature geothermal energy from Canadian sedimentary basins? What is the geothermal potential of the Atlantic Region, where costs of conventional energy are higher than the national average?

The question of shallow (<100 m) resources and the use of ground-coupled heat pumps was not raised and was not included in the mandate of the Geothermal Energy Program.

About 1980 the Program entered a third phase, in which the emphasis changed from the application of earth sciences to the assessment the resources and to the application of engineering to assess the technology and economics of utilisation. The questions asked in this third phase were: What is the available technology, to be learned from other countries, for development in Canada? What are the economic facts governing the use of geothermal energy in Canada? What are the institutional, legal, and fiscal factors governing the use of geothermal energy in Canada?

From about 1983 the fourth phase of the Program produced a series of requests for advice and assistance, mainly from municipalities concerned with the cost of energy supply for public buildings within their jurisdiction, or with novel ways of reducing costs. These purely local questions developed into studies of feasibility, drawing on the developed experience in earth sciences, engineering and economics, each one directed at a specific location. By March 1986 the Geothermal Energy Program had established that there was a demand from the public for advice and assistance in the examination of geothermal resources, but at this point the Program was cancelled.

Fortunately, most of the local projects in progress had reached a stage where they could proceed without further assistance from the Program, or they were formally part of some other Program that could be continued. These projects are described in a later section of this chapter. From 1986 to 1994 a small Program was funded by CANMET, with the technical assistance of the GSC. Scientists within both CANMET and the GSC continued to answer questions from the public and to provide what assistance they could, within the limitations of their resources, to municipalities actively pursuing geothermal projects. Priority was given to projects that were already in progress and where previous efforts would have been wasted by the abrupt termination of the Program. After 1986, as active participants moved into other lines of work or reached the age of retirement, the remnant experience and expertise within EMR declined.

Scientific base.

The Geothermal Energy Program EMR formally began on 1st April 1976, when the first funds generated by the Panel on Energy Research and Development (PERD) became available. Scientific Programs on which the Geothermal Energy Program was based had been in existence for many years. Volcanology had long been a part of the activities of the GSC , mainly in the Vancouver office. Volcanic centres of the four major volcanic belts of the Canadian Cordillera had been mapped and an inventory of hot springs had been maintained for many years. A geothermal research group had been set up in 1962 at the Dominion Observatory, Ottawa, later renamed Earth Physics Branch. Heat flow and heat generation had been measured and interpreted in many areas of Canada: the thermal regime of the crust was known in a broad regional manner, and equipment was available for detailed surveys of specific localities.

Scientific staff of EPB and GSC had worked together on projects of scientific geothermics since 1965, and they began to cooperate on projects related to geothermal resources in early 1974. They were having informal meetings, both among themselves and with consulting companies by the summer of 1975. As the start of the formal Geothermal Energy Program was put back from April 1974, to 1975, and finally to 1976, small projects were undertaken as regular funds were diverted.

Thus, when the Geothermal Energy Program of EMR began in 1976, energy studies had already begun in sedimentary basins and volcanic terrains, and a strong scientific base was in place on which to build. Without these scientific programs there would have been no readily available scientific management for the new Geothermal Energy Program. This is an excellent example of how long term scientific studies within the government laboratories have provided an operational base at a time of national need.

Responsibilities and resources

The Geothermal Energy Program, with funding from the PERD ran for exactly ten years, from 1st April 1976 to 31st March 1986. Contract funds and supporting operational funds were supplied by PERD, through the Office of Energy Research and Development (OERD) and the Renewable Energy Division of the National Research Council. Scientific personnel and supporting geoscience were provided by the two scientific Branches, with a later contribution from the National Research Council. Details of the resources supplied by the various agencies are to be found in Appendix 1. British Columbia Hydro and Power Authority (BCH) eventually invested a much greater amount in the drilling of three deep holes in the Meager Creek Valley, this being believed to have reached the order of M$25.

In June 1978 a new source of funds appeared in a system of Federal-Provincial Agreements. This caused a rapid re-evaluation of the field season of 1978 by both BCH and EMR and resulted in parallel contracts by the two agents to the same consultant. Neither agency was happy with this means of contracting, but it was the only mechanism available to deal with the administrative changes so close to the field season. The amount spent on geothermal research within this system is not known to the present author and is not included in the figures of Appendix 1.

MAJOR PROJECTS

During the course of the Geothermal Energy Program two major projects developed, one in the volcanic terrain of the Cordillera and one in the sedimentary terrain of the Western Canada Sedimentary Basin. These became the two foci of much of the research.

Meager Mountain

The first considerations were focussed on the western mountains, where hot springs and recent volcanism were well known. At the same time BCH began to consider geothermal steam as one of their options for future power developments and employed Nevin, Sadlier-Brown, Goodbrand Ltd. (NSBG) as geological consultants. Based on hot-spring water chemistry and geothermo-metry, compiled by the GSC, both EMR and BCH chose the Mt. Meager Volcanic Complex as the first target of examination. Thus was started a project of cooperation, at times formal and at other times informal, that was to last for most of the life of the EMR Program. A full description will be found in Volume Two of this report.

Regina

The second area of interest to EMR scientists was the geothermal potential of sedimentary aquifers. It was known that such resources were in use in Hungary and France. In 1975 a contract was let for a study of the data set known as the Geothermal Survey of North America (Conolly, 1972) and analysis in terms of its use as an indication of the potential for geothermal development in Canada. This first contract was let to Sproule Associates Ltd., of Calgary. The principal investigator was H.A.Gorrell, who took a keen interest in the topic from that time until his death in 1985, providing an extremely valuable industrial perspective to the course of the research.

Early in 1977 the University of Regina approached EMR with the question of a geothermal demonstration project of geothermal water from sedimentary aquifers at the University. A feasibility study, funded by the Geothermal Energy Program, showed that the prospects for geothermal water were good, and a well was drilled in the winter of 1979 to a depth of 2214 m. Tests showed that the geothermal potential was excellent, the potential flow rates being higher than predicted, but the temperature being slightly lower than expected. The water was saline, roughly four times as saline as sea water, and a reinjection well would have been required.

Unfortunately, the large sports building that was intended to be the load for the well was not built, and the remainder of the campus uses a steam heating system, and so the well has never been used for its intended purpose. However, it has been used as a research facility, for temperature logging, hydrofracture testing, water level monitoring and corrosion testing. It has thus been of great value to the Geothermal Energy Program, in a manner that was not originally intended. A full account of the Regina project and of the data obtained from the well will be found in Chapter 3.

ENGINEERING AND ECONOMIC STUDIES

In the year 1981/82 an engineering component was added to the Geothermal Energy Research and Development Program, in order to provide information on the technology and economics of use of the resources being investigated by the earth scientists. This responsibility was assigned to the National Research Council, and an account of the work done appears in Chapter 6. Early contracted studies were very general in nature, but after the first two years the emphasis shifted to specific feasibility studies associated with the growing demand from potential users, as described in the next section. In 1984 a comprehensive report on the "Regulatory and Commercial aspects of Geothermal Energy Development" was produced under contract, which examined the current state of Canadian law regarding geothermal development, provincial assistance programs, taxation, incentives, and institutional factors.

GROWTH OF OUTSIDE INTEREST

Starting in 1983, participants in the Geothermal Energy Program received a growing number of enquiries from outside agencies interested in the use of geothermal resources at specific locations. In addition to the projects at Meager Creek and Regina, which received substantial assistance from the Program, there were several that involved a municipality and commercial consultant, notably Springhill, Nova Scotia, Moose Jaw, Saskatchewan, and Summerland, British Columbia. Details of these enquiries are given in Chapter 6 and in volume two of this report.

THE GEOTHERMAL COMMUNITY

One of the tasks perceived by the managers of the Geothermal Energy Program was to build up a core of expertise in government and industry, to carry on the exploration for and development of geothermal resources after the end of government involvement. Of the core group of five scientists and engineers that steered the Geothermal Energy Program from 1976 to 1986, four are now retired (2007) and none remains in a scientific role. All university participants whose location is still known have retired. Consultants who developed a strong interest and expertise in geothermal resource exploration and development have necessarily moved on to other things and we can reasonably assume that the experience is almost totally dissipated.

In the later years of the Program "Conservation and Renewable Energy Officers" (CREOs) were set up by EMR in the provincial capitals. The duty of these officers was to facilitate joint projects of demonstration of energy conservation or renewable energy, including geothermal energy, in response to provincial or industrial initiatives. This system has since been terminated. Names and addresses of the principal federal participants are given in Appendix 2. Names of the CREOs are not recorded and cannot be presented here.

Provincial governments and agencies

Provincial governments have not generally been involved in research into geothermal resources. However, some of them took an interest in federal activities. Significant interest was shown by British Columbia, Alberta and New Brunswick. Only British Columbia and Nova Scotia have enacted any legislation that specifically deals with the exploration and development of geothermal resources. In British Columbia structures are in place that allow for the leasing of land for exploration and the permitting of drilling. In Nova Scotia legislation has been developed to regulate the development of low-temperature resources in abandoned mines. In British Columbia most of the direct exploration has been carried out by BCH, as recounted above, but the lease taken out by O'Brien Resources Ltd. for exploration in the Mount Cayley area was the first provincially regulated geothermal activity in Canada. By 1986 activity had ceased, and attempts were being made to find a profitable use for the three deep wells drilled by BCH at Meager Creek. Legislation has been enacted permitting the generation of power by private companies for export to the US. This encouraged a new look at the potential for electrical power from geothermal resources in the Meager Mountain area.

In Alberta collection of temperature data from files of the Oil and Gas Conservation Board, by the Physics Department of the University of Alberta, has been sponsored by the Alberta Department of Energy and Natural Resources. Unfortunately, publication of this data-base was not a condition of the funding, and the task has been recommenced by the Alberta Research Council under its hydrogeology program. Data collection has been extended by federal operations in neighbouring provinces and the data have been analysed of the data in terms of temperature field and implied hydrodynamic patterns.

In New Brunswick provincial geophysicists have compiled data on surface heat generation as an indicator of radiogenic potential of intrusive rocks, and have taken a strong interest in the geothermal potential of the Fredericton Graben.

All of these activities are described in more detail in the appropriate Chapters of this report.

The industrial community.

The ultimate requirement for the successful development of any energy resource is a strong industrial community. Thus the succession of contracts was aimed not only at the specific tasks contracted, but also at the development of a geothermal community in industry so that there would be a technological base to take advantage of commercial geothermal opportunities. Companies that performed surveys or studies for the federal government or other agencies are given in Appendix 3, with an indication of their particular interests.

The university community

Some contracted studies have been more suited to the academic research style than to industrial consultants. By this means a basic scientific component of research was maintained and enhanced.

The greatest university participation has been by the University of Regina, where a major feasibility study was contracted out, a demonstration project was designed, and a deep water-production well was drilled on the campus. The University work proved the resource beneath the campus.

The University of Alberta maintained an earth-science approach and carried out a series of thermal analyses of parts of the Western Canada Sedimentary Basin. These gave new insights into the detailed thermal nature of the Western Canada Sedimentary Basin and the possible transfer of heat by water flow as well as by conduction.

The University of Toronto performed stress measurements in the rocks surrounding the well at Regina, which added to their knowledge of the stresses throughout Canada and would have provided important information if exploitation of hot dry rock had ever become a reasonably economic prospect.

These programs will be described in detail in Chapter 3. A list of the principal university participants, with their research specialties, is given in Appendix 2. Most of these participants have since retired.

Municipalities

Several municipalities have taken an interest in the development of geothermal resources for space-heating or other uses. These have been described briefly above, and further details appear in the appropriate Chapters of this report. Direct approach to the Geothermal Energy Program has been made by many, including the Town of Edson, Alberta, the City of Moose Jaw, Saskatchewan, the Town of Springhill, Nova Scotia, and the Town of Summerland, British Columbia. Approach through the Remote Community Demonstration Program has been made on behalf of Hot Springs Cove.

The public

Over the life of the Geothermal Energy Program numerous talks were given to high schools, university groups, energy-related courses, church groups, clubs, and civic meetings associated with the municipalities listed above. The "Shell Merit" course for school teachers on energy requested a presentation every year from 1981 to 1985. All the federal participants have been involved. British Columbia Hydro and Power Authority made a film entitled "The Earth's Furnace" to describe geothermal resources and their exploration Program at Mt. Meager. Although the development work has been stopped, the film remained a valuable educational tool for some time. It was generally found that the public had very little knowledge of geothermal resources. Where there was any knowledge it was generally considered that such resources were to be found in very limited parts of the world, and not in Canada. With balanced information popular enthusiasm for solar energy, which was successfully generated at the time of the "energy crisis", could have been extended to the other, less familiar, unconventional sources of energy. This task was beyond the capacity of the participants in the Geothermal Energy Program and was neglected by those with the resources to perform it. In early 2007 the public interest in global warming and the energy-related causes is again high, and public awareness of alternate energy sources should be stimulated.

Technical groups and symposia

During the period of the Geothermal Energy Program the subject of geothermal energy attracted considerable interest from technical groups and some special groups were set up to provide opportunities for dissemination of results. The Canadian Geothermal Energy Association (CGEA) was started in Vancouver at the end of 1976, by the efforts of NSBG and the federal and provincial geothermal scientists. A technical session was arranged in conjunction with the Canadian institute of Mining and Metallurgy in Vancouver in April 1978, and for some years the Association continued to hold a technical session with its annual general meeting in April, in British Columbia. CGEA has held sessions on sedimentary aspects at prairie locations. The Association has remained small and has never exceeded about 60 people, but it is still in existence in 2007.

An informal group known as the Sedimentary Panel on Geothermal Energy (SPONGE) met in a prairie location from 1979 to 1986, to discuss geothermal matters related to sedimentary basins. The meetings were organised by the federal Coordinator, and most of them were held at the Institute of Sedimentary and Petroleum Geology, Calgary.

The University of Regina has held two conferences, in 1982 and 1984, on all aspects of energy under the name Energex. Because of the strong interest of the University in geothermal research, these included sessions on geothermal topics.

A Geothermal Energy Review Meeting (GERM) was held at the Earth Physics Branch, Ottawa, in March 1982. Review papers were presented by all federal participants and current projects were reported by numerous contractors and others.

A one-day meeting on Electrical Power from Geothermal Sources was organised by the British Columbia Ministry of Mines and Petroleum Resources in November 1983.   The meeting was held at the Pacific Geoscience Centre, near Victoria, and was chaired by R.Durie, Assistant Deputy Minister, and David Anderson, Executive Director of the U.S. Geothermal Resources Council provided a paper and an outsiders assessment of the situation as revealed.

<u>The international community</u>

The Committee on Challenges to Modern Society of the North Atlantic treaty Organisation (NATO-CCMS) sponsored a series of informational meetings from 1973 to 1980. The aim of the meetings was the free flow of information and the enhancement of international knowledge of research and development of relevance to the member countries. The initial meeting, was held at the Lawrence Livermore Laboratory in California on 1 to 5 October 1973, and included visits to the Geysers geothermal power plant, California, the research sites in Imperial Valley, California, and the Cerro Prieto power plant in northern Mexico. Four Canadian delegates attended. Meetings were later held at sites of geothermal development, including Los Alamos, U.S.A.; Pisa, Italy; Wairakei, New Zealand; Reykjavik, Iceland; Paris, France; and the Azores, Portugal.

In addition Canadian scientists have made visits to the hot dry rock research site in Cornwall, England, to sites of sedimentary exploitation in and around Paris, France, at the time of a promotional meeting in 1983, to Los Alamos to observe progress on the Hot-Dry Rock Program, and to Larderello and Pisa, Italy, for observation and for lecturing to the International Course on Geothermal Energy.

On 9 and 10 June 1976 a meeting was held in Paris on the subject of the uses of hot water from sedimentary basins.   This meeting was an excellent introduction to the current exploitation and the geothermal potential of sedimentary basins. The system in place made use of pairs of wells, one to produce and one to reinject, with the spacing of the wells in the producing formation designed to give a lifetime of 30 years before the production stream began to suffer from the cooled reinjection stream. Further details of these systems are to be found in Chapter 3.

Several reports were produced by the managers of the group. Non-electrical uses were examined in detail (Howard, 1975a, 1975b).   The final report of the group was entitled "Creating an International Geothermal Energy Community" (Howard, 1978), a task that was successfully achieved. An International Geothermal Energy Association was set up in 1989, with the aim of fostering an international community and of holding international meetings at five-year intervals. The last was at Antalya, Turkey, in 2005. The Canadian Geothermal Energy Association is now affiliated with the international organisation. Despite the availability of cheaper oil after 1984, many countries, notably those without major hydrocarbon resources continued to invest in geothermal energy.

The Geothermal Resources Council of the U.S.A. holds annual technical meetings, some of which of which have been attended by Canadian scientists and engineers. Individual contacts have been maintained with the geothermal community in many countries, by attendance at meetings, by visits and by informal exchange of papers and reports.

ASSESSMENT OF THE RESOURCE

Methods and definitions for the assessment of geothermal resources have been proposed by Muffler and Cataldi (1978), to follow the conventional terms for hydrocarbon or other mineral resources. The conventional definitions may be applied directly to geothermal resources, but the character of the resource introduces some peculiarities in the separation into the various categories. Differences generally result from the fact that most mineral resources are material, either solid, liquid, or gas, whereas the geothermal resources is heat - energy itself. For the purpose of definition these differences may be summarised as follows: 1 - the heat requires a carrier and cannot be recovered independently. The carrier is usually water, which normally is naturally associated with the heat. However, the fluid may be introduced artificially, including reinjection of spent fluid, and it need not necessarily be water. 2 - The resource of heat may be renewable, but not necessarily in an economic time-span. Thus the usable resource may be larger than the static resource estimated from present conditions, but with a time-factor that is not included in the conventional resource terminology. 3 - The size of the resource depends on the use to which it is to be put. Thus, water at 60 ^{o}C is a useful resource for space-heating, but is not useful for the generation of electrical power. This is in contrast with the conventional situation where one useful commodity is uniform in its application.

The divisions so defined are illustrated in Fig.1, in a manner described by McKelvey (1972). The "geothermal resource base" is the total thermal energy in the earth's crust beneath a specified area, measured from local mean annual surface temperature. The limit of the resource base at the base of the crust is somewhat arbitrary, since the heat in the whole earth is equally inaccessible for the foreseeable future. The resource base is divided into "accessible resource base" and "inaccessible resource base", the division being defined by the reasonable limit of accessibility by drilling, which has been arbitrarily set at 7 km. Drilling technology has been advanced in the U.S.S.R. and in Germany, but the cost of such drilling as far as 7 km is still extremely high, and there is no reason at present to change the definition. As with all minerals, and for various physical and economic reasons a fraction of the accessible resource base will always be left in the ground, and it may thus be divided into "useful" and "residual". The criteria for usefulness depend on a subjective prediction of purpose, recovery technology and economics at some future time. "Geothermal resource" may now be identified with the useful accessible geothermal resource base.

Geothermal resources, particularly those of moderate or low temperature have the additional criterion of geographical location, because of the economic impossibility of transportation over

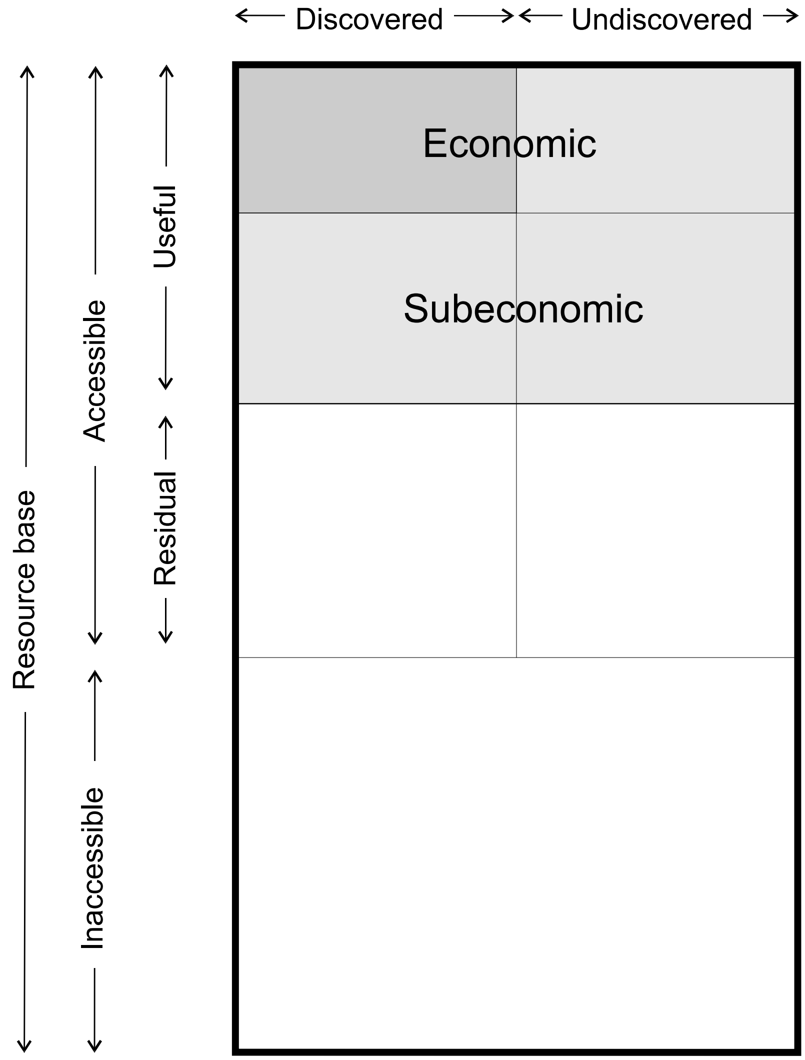


Fig 1 McKelvey diagram, showing the subdivision of geothermal resources into various categories.

long distances. All parts of the accessible resource base may be divided further into discovered and undiscovered parts. This is shown by a vertical line on Fig.1. The discovered part of the geothermal resource is further divided into economic and subeconomic portions, the criteria depending on conditions at the present time. We may now define "geothermal reserve" as that part of the geothermal resource that is known and economically and legally usable at the present time.

The distinction between discovered and undiscovered resources is somewhat indistinct in geothermal resources in sedimentary basins. Sedimentary aquifers are generally known to extend over long distances, temperature is a continuous field and reasonably known in the Western

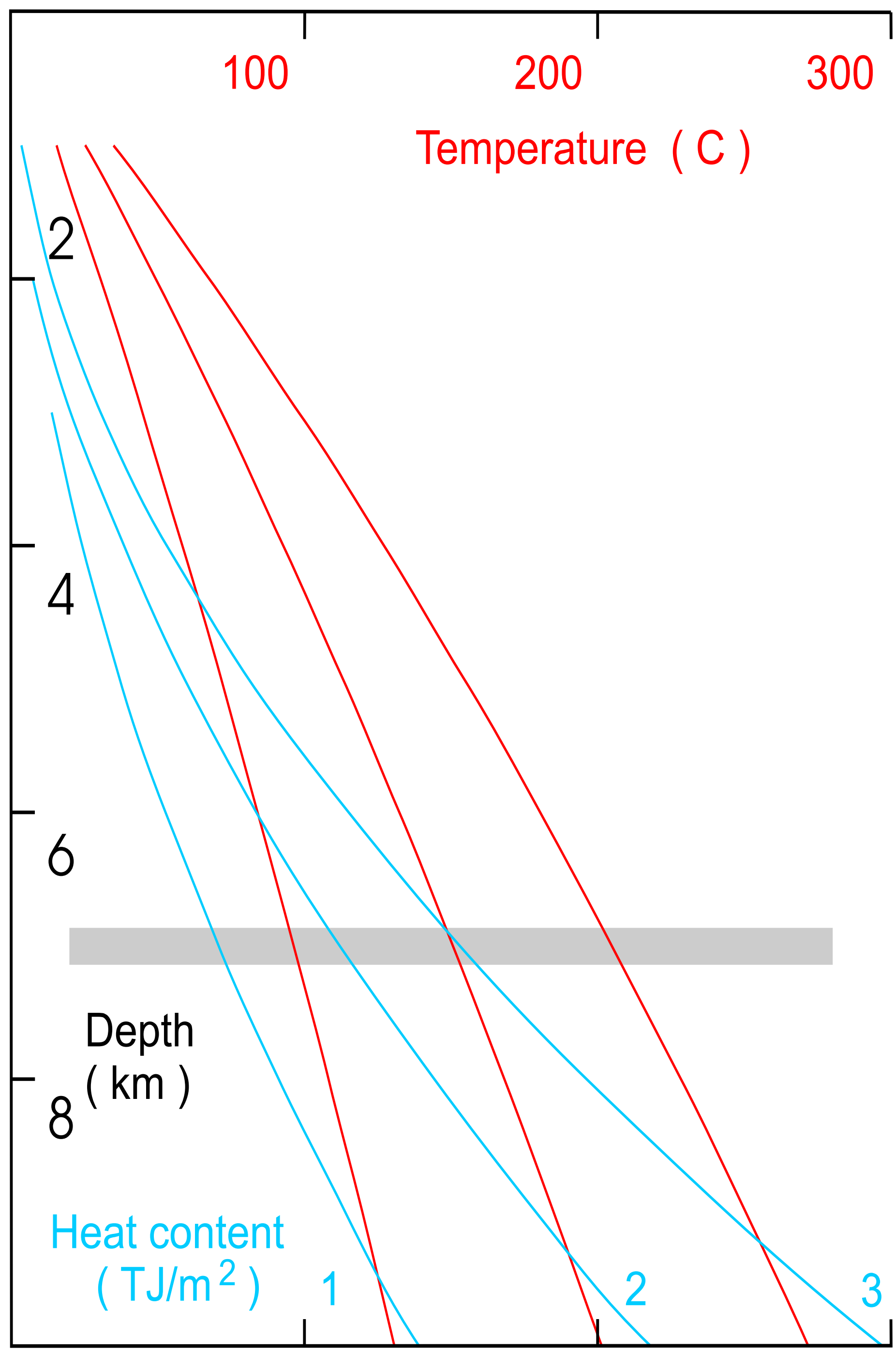


Fig.2 Temperature and heat content of the crust of the earth to a depth of 10 km, based on terrestrial heat flow of 40, 65, and 90 mW/m^2, thermal conductivity of 2.5 W/mK, heat generation of 4 $\mu W/m^3$, density of 2500 kg/m^3 and specific heat of 800 J/kgK. Red lines show temperature. Blue lines show the heat content of the crust down to that depth. The grey horizontal line shows the depth of 7 km, used as a cut-off point for the geothermal resource.

Canada Basin, and it may be reasonably assumed that porosity and permeability is generally continuous and that the resident fluid is water. However, the properties of an aquifer at any specific location cannot be defined with certainty without examination of well records from that location, or, better, the drilling of a test-well.

Estimation of the resource base

It is difficult to calculate with any degree of certainty the total heat in the earth, since the temperature, the physical properties of materials under ambient conditions of temperature and pressure, and the nature of the material itself are known only by interconnected models and conjecture. However, assumptions can be made on the basis of low, average and high heat flow in areas that are not severely disturbed by volcanic activity or water flow. The average heat flow over the land surface of the earth is about 65 mW/m^2. For calculation we will take low, average and high values as 40, 65 and 90 mW/m^2. Assuming thermal conductivity of 2.5 W/mK, heat generation of 4 $\mu W/m^3$, Density of 2500 kg/m^3 and specific heat of 800 J/kgK, the average heat flow implies a total heat content, above surface temperature, in the rocks to a depth of 7 km, of about 1.1 TJ/m^2. Fig 2 shows temperature and heat content for areas of low, average and high heat flow.

In a world of total land area of 150×10^6 km^2 this amounts to about 160×10^{24}J. Since the land area of Canada is about 10×10^6, the resource base below Canadian territory is about 11×10^{24} J. These quantities are very large and well beyond the scale of human energy usage. They are also meaningless in terms of exploitation. The difference between a "resource base" as defined above and the "useful resource" is extremely large and varied in location and time.

Geothermal resources are found in different geological settings, at different temperatures, and in different market options. The uses to which they may be put are so diverse that the assessment of useful reserves and resources can have meaning only if done in the context of the local conditions For this reason it is left to the chapters dealing with the different regions.

CHAPTER THREE

GEOTHERMAL RESOURCES IN SEDIMENTARY BASINS

INTRODUCTION

Geothermal sources in sedimentary basins are of moderate to low temperature. Water is produced through a well that strongly resembles an oil well. Since the water is usually saline, heat is removed through either a simple plate-type heat exchanger or by means of heat pumps. Used water is normally reinjected to the producing aquifer through a second well

Investigation of the geothermal resources of Canadian sedimentary basins has been substantially modelled on the French experience in the Paris Basin. Geothermal exploitation of the Paris Basin began at Villeneuve la Garenne in 1976**.** The normal configuration of wells, widely used in France, consists of pairs, or "doublets" of wells, one to produce and one to reinject the cooled water. The wells of each pair were drilled within a few metres of each other, but angled so that the separation at the aquifer was of the order of 1 km. This system was designed to provide pressure maintenance in the reservoir and to permit the disposal of potentially harmful brines after use. However, it imposes a finite lifetime on the production of hot water, since the cooled water eventually completes the circuit.

In France there was a keen interest in geothermal development from 1973 to about 1990, followed by a period of decline. There has been "a boost in activity since 1998, following the Kyoto Agreement, and the decision taken in France to resume an active policy for energy management and the development of renewable energies." At the end of December 2004 there were 51 deep geothermal production plants in operation in France, mainly in the Paris and Aquitaine Basins. Water temperatures ranged from 25 ^{0}C to 85 ^{0}C, and the total energy utilisation was 4727 TJ/yr (Laplaige et al., 2005)

Geothermal reservoirs in sediments are mostly associated with flat-lying or gently dipping aquifers of basins or platforms, they extend over long distances, often of hundreds of kilometres, and they take the shape of the layered host-rocks. In disturbed zones, such as the Rocky Mountains, aquifers may be steeply inclined or truncated by faults. Most aquifers are found in sandstone or carbonate formations, and the porosity may be as high as 25%. Most sedimentary rocks are porous to some extent, with the exception of evaporites such as salt, but only when porosity exceeds about 10% can they be thought of as reservoirs. The ability of a well to produce water over a long period of time depends on permeability of the rock as well as porosity, and both properties must be adequate to provide a good geothermal reservoir.

Temperatures in sedimentary aquifers in the Western Canada Sedimentary Basin (WCSB) range from below zero to 150 ^{O}C and possibly higher in very deep or very hot basins. Higher temperatures will give a larger supply of heat, since the amount of heat to be extracted from the water depends directly on the reduction of temperature that can be achieved, but higher temperature demands deeper and more expensive drilling. Since heat pumps may be used to raise temperature of any water, freezing of the water determines the lower limit of the temperature of the source. The definition of a useful resource at any location depends on the intended use and the costs involved compared with competing energy sources. The design engineer must balance the energy requirements with the costs of drilling, heat pumps and maintenance for each individual project.

Exploration for geothermal water in sedimentary basins usually benefits from the large amount of previous work by the hydrocarbon industry, in fact it is unlikely that geothermal exploration could be economically worthwhile alone, despite the enormous size of the resource. Thus a relatively undeveloped source of energy has benefited from the expenditures in search of a well established energy source.

Since water is present to some extent in all sediments, with the exception of halite and other evaporites, there is a very good chance that geothermal heat may be recoverable from some part of the section at any point in a sedimentary terrain. However, the amount of water, its temperature, chemical character, pressure and potential production rate may vary considerably from place to place, even in the same aquifer. Thus the economic geothermal potential must be individually evaluated at any proposed location.

REVIEW OF CONTRACTED STUDIES

Most of the contracted studies were performed by Sproule Associates and their allied engineering companies, by the University of Regina and their subcontractors, or by the University of Alberta and associated consultants. In general, Sproule Associates provided the link with the expertise of the hydrocarbon industry in drilling technology and knowledge of aquifer characteristics. The University of Regina embarked on a demonstration project, which unfortunately could not be completed, and some new ideas on aquifer analysis and potential applications of geothermal energy. The University of Alberta provided mapping and interpretation of the observed thermal patterns throughout the Western Canada Sedimentary Basin.

Reports from Sproule Associates

> *Sproule Associates Ltd., 1976. Study of geothermal resources in western Canada sedimentary basins from existing data, phase one.*

Research into geothermal resources of Canadian sedimentary basins began in 1975, when the Earth Physics Branch let a small contract to Sproule Associates Ltd., of Calgary, to look at the possibilities of geothermal energy from the WCSB. The study covered basins from the Williston Basin in Saskatchewan to the Mackenzie Delta in the Northwest Territories. The contractor was asked to indicate in broad terms the areas where geothermal resources were most likely to be found.

At that time a large file of temperature data from wells throughout North America had been compiled under the name "Geothermal Survey of North America". The Canadian data had been added by compilation from provincial data files by a Canadian member of the organising group (Conolly,1972). The contractor was asked to examine this data file, combine it with a knowledge of the aquifers, derived from experience as a consultant in reservoir engineering for the oil industry, and thus interpret in terms of geothermal potential.

It was found that, as a general rule, the temperature gradient is inversely related to the depth of sediments. In the deeper parts of the basin, close to the Rocky Mountains, the gradient is low, and in some of the shallower parts of the basin, towards the edge of the exposed Precambrian shield, the apparent gradient is significantly higher. However, the depth variation is stronger than the gradient variation, so that, in general, the temperature at the base of the sediments is higher in the deeper parts of the basin.

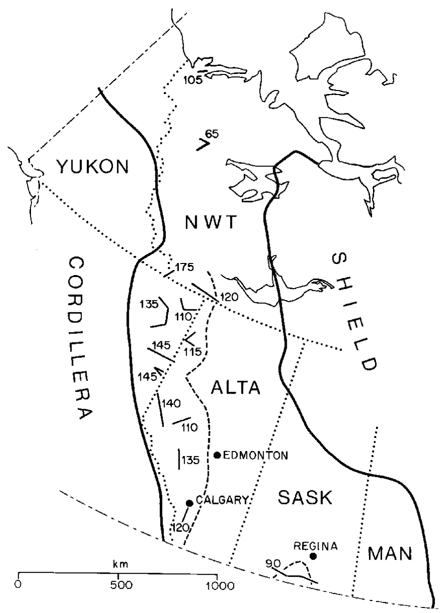


Fig.3 Temperature at the base of the sedimentary column in the Western Canada Sedimentary Basin, derived from the work of Sproule Assoc. (1976). Each profile of wells is shown with the maximum log-heading temperature. The dashed line divides areas having log-heading temperatures above and below 80 ^{0}C.

The results are summarised in Fig.3, which shows the approximate temperature at the base of the sedimentary formations. This map clearly shows that there are wide areas where good temperature is available, but it does not show the qualities of the reservoir rocks, the probable production rates, or the potential markets for the energy. The most promising areas are in southern Saskatchewan, western Alberta, northeastern British Columbia, and the southwestern corner of the Northwest Territories.

Sproule Associates Ltd., 1977. Study of geothermal resources in western Canada sedimentary basins from existing data, phase two.

A second contracted study by Sproule Associates Ltd. concentrated on three areas: rural southern Saskatchewan, Calgary, and Fort Nelson. The report began by stating that temperatures in the first report referred to the deepest formations, usually the Cambrian, whereas the best aquifers were probably at lesser depth. It also pointed out that there was very little data on porosity and permeability of water-bearing formations, since the oil industry had no interest in those.

In the Weyburn area is in the Williston Basin, the centre and deepest parts of which are in the USA. Three formations were identified as potential sources. The Winnipeg Formation has maximum depth in Canada of about 3200 m, temperature in the deepest parts of about 95 ^{0}C, good porosity and very high salinity. The Winnipegosis Formation has maximum depth of about 2750 m, with temperature about 80 ^{0}C, good porosity in limestone rock, and high salinity. The Interlake Formation has a depth of about 2300 m, with temperature of about 55 ^{0}C. Porosity in the Interlake Formation tends to be local rather than regional. Apart from the towns of Weyburn and Estevan the area is rural, so potential users would be mainly agricultural.

In the Calgary area the best geothermal prospects are in the Elkton Member of the Turner Valley Formation and the Crossfield Member of the Wabamun Group. Strata incline towards the west. In the City of Calgary the Crossfield Member is at a depth of about 2900 m, the temperatures are about 74 ^{0}C. Water tends to contain fairly high quantities of bicarbonate and sulphate and hydrogen sulphide may be present in any wells in this area. Porosity and permeability are not well known and may vary considerably within the area. The Elkton Member is at a depth of about 2500 m, has temperature of about 65 ^{0}C. The major dissolved solid is sodium chloride and hydrogen sulphide is present. The City of Calgary now (2007) has a population in excess of one million and provides a large market for space heating.

In the Fort Nelson area the available data comes from the Clarke Lake gas field., which is about 10 to 15 km distant from the town. The only stratigraphic unit for which there is any significant data is the Slave Point Reef, from which the gas is produced. Temperatures are about 110 ^{0}C, at a depth of about 2000 m. The main dissolved solid is sodium chloride and the salinity is similar to that of sea water. Apart from the town of Fort Nelson, there is little or no market for thermal energy.

It was concluded that southern Saskatchewan offered the best prospects from a geological point of view, but all three areas had possibilities. This report gave a good indication of the extent to which data generated by the hydrocarbon industry can be used for geothermal assessment.

Sproule Associates Ltd., 1978. Report on the acquisition of data on the lithological character of the sedimentary rocks, Western Canada.

This report provided lithological data on a selected set of 225 wells uniformly distributed over the Western Canada Sedimentary Basin from 49^{O}N to 63^{O}N. The data took the form of estimates of the content of each stratigraphic unit in terms of rock type. From these data it was possible to derive estimates of the thermal conductivity of each unit. These data have been used extensively in numerous studies of the thermal state of the basin. Since the report contained proprietary data it was not published.

Sproule Associates Ltd., 1983. Report on study of the feasibility of geothermal reservoir mapping in deep sedimentary basins using existing data.

A fourth contract to Sproule Associates Ltd. continued in the progression of analyses in areas of decreasing size. This study first looked at the grid of 225 wells chosen for the previous contract and summarised the relevant information available for each site. This kind of survey can provide a very limited knowledge of the resource, because any individual well record contains only partial data. To examine an area in sufficient detail requires the examination of as many wells as possible. The second part of the study examined the area around Innisfail and Red Deer, since it combined the presence of potential markets on the surface with a well-known reef reservoir below. This was considered to be a large area for a geothermal study, because of the large number of wells. Any specific geothermal target area would be smaller and the wells in the area would be more closely scrutinised. The study area contains several units that may provide a geothermal resource, but they need to be examined on a more localised basis. For example, the Leduc Reef is capable of supplying large quantities of saline water at temperatures of 70 ^{O}C to 80 ^{O}C, but only in a part of the study area.

Gorrell,H.A., 1984. Applications of existing data to low temperature geothermal exploration.

This conference paper summarised the experience gained in using industrial data from the hydrocarbon industry to derive information on geothermal resources. It was concluded that there is a very large amount of information available and most of it is in the public domain. However, information on the stratigraphic units that have the best geothermal potential is not complete, since the industry has been looking for oil and gas and not water.

Reports from the University of Regina

Vigrass,L.W., Kent,D.M. and Leibel,R.J., 1978. Low-grade geothermal project, geological feasibility study, Regina - Moose Jaw area, Saskatchewan.

Starting in 1977, The University of Regina performed a geological feasibility study of the concept of geothermal resources in the Regina - Moose Jaw area. The report showed that prospects for a usable supply of hot water from aquifers below Regina were excellent.

The report showed that there were excellent aquifer formations below the study area, each of which could give a good supply of hot water. The best target was a combination of the Winnipeg

Formation (depth 2042 m and thickness 34 m) and the Deadwood Formation (depth 2088 m and thickness 137 m). Temperatures were predicted to be 71 ^{O}C in the Winnipeg Formation and 74 ^{O}C in the Deadwood Formation. Combined flow was estimated at a maximum of 400 m^3/hr. It was predicted that the water would be found to have a high sodium chloride content, probably about four to five times the salinity of sea water, and a low content of hydrogen sulphide.

There were several good reservoirs at shallower depths, including the Interlake Formation (depth 1825 m and temperature 64 ^{O}C), the Winnipegosis Formation (depth1726 m and temperature 63 ^{O}C) and others with temperatures less than 50 ^{O}C.

The report concluded that "Geological and engineering conditions for low-grade geothermal energy are favourable at the University of Regina and, pending the results of other studies, a geothermal research-test-demonstration facility is warranted."

Supplementary reports included a seismic profile, a seismic data compilation, and an engineering study.

Vigrass,L.W., 1979. Final well report, U of Regina 3-8-17-19 (W.2nd.Mer.) Saskatchewan.

A well was drilled on the campus of the University of Regina between 28 December 1978 and 7 February 1979. The aquifers in the deeper part of the well were capable of supplying the needs of the sports building that was planned to make use of the heat from the well. Strata depths matched predictions very closely. Temperatures at the bottom of the well were still highly disturbed by drilling, but log-heading data suggested a bottom-hole temperature of about 70 ^{O}C. Salinity was observed to amount to 10 to 12% dissolved solids by weight, and dissolved hydrogen sulphide was present.

It was estimated that water could be produced at 100 m^3/hr at about 65 ^{O}C, with a draw-down to 131 m below the surface after seven years. Power requirements for pumping were predicted at 66 kW, about 1.9% of the 3.5 MW of heat available assuming a baseline temperature of 35 ^{O}C.

Because of the high salinity and the potential for surface pollution, the used water would have to be returned to the formations from which it came. This would mean the drilling of a reinjection well to put the water into the formation at a distance sufficiently great to avoid recycling within the lifespan of the system.

Vigrass,L.W., 1980. Completion and pump test, U. of Regina 3-8-17-19, phase 1b - geothermal project.

During the summer of 1979 the Regina well was completed with "open hole" in the Winnipeg and Deadwood Formations, below the casing shoe at 2034 m depth. Two six-hour pumping tests were carried out at 100 m^3/hr. Water temperature was about 60 ^{O}C. Draw-down was calculated to reach 222 m below ground level after 2,500 days.

Vigrass,L.W., 1980. Geothermal Feasibility Project at Regina. Phase 2: disposal well and pipeline.

This is a proposal rather than a report. It outlines the technical and financial requirements for the continuation of the Geothermal Demonstration Project. Since the Province os Saskatchewan withdrew the promise of funding for a large new sports building, the recommendations were never implemented.

Postlethwaite,J., Vigrass,L.W., Gummadi,V., Neufeld,R. And Kybett,B.D., 1980. Water chemistry testing on western Canada geothermal waters.

Dissolved solids in the water from the Regina well were found to be 101,000 ppm, mainly sodium chloride, but with potassium, calcium, magnesium, bicarbonate and sulphate present in small amounts. Dissolved gases were hydrogen sulphide (19 to 24 ppm), carbon dioxide (52 ppm), nitrogen (35 ppm) and oxygen (0.9 to 1.2 ppm). The hydrogen sulphide and oxygen were identified as potential contributors to corrosion problems.

Vigrass,L.W., 1983. University of Regina Geothermal Project, Phase 2a, work preliminary to drilling of disposal well and building of pipeline.

The optimum location of a disposal well was found to be 1000 m north-east of the first well, based on considerations of aquifer pressure changes, return of water to the production well, and costs of piping disposal water on the surface to the top of the injection well. Retrofit of two buildings on the campus and initial fitting of a new building for use the geothermal water was recommended.. The recommended geothermal demonstration at the University would probably not be economic, depending on the future rise of energy costs. This report also included a sub-report on mathematical modelling of the two-well production and reinjection system.

Vigrass,L.W. and Jessop,A.M. 1984. Regina geothermal experiment - geological and hydrological aspects.

This conference paper summarised the stratigraphic sequence penetrated by the well at Regina and the observed hydrological properties of the potential producing formations. It concluded that the Basal Clastic Unit, the Winnipeg and Deadwood Formations, is capable of geothermal water production for a long period of time with reasonable drawdown.

Hutchence,K., Vigrass,L.W., Law,A.G. and Weston.J.H. 1984. Modelling of the Regina geothermal aquifer.

This conference paper reviewed the modelling of the aquifer at Regina during production of water at the existing well and reinjection at a second well at a distance of 1 km. It was shown that, on the assumption of laterally uniform strata and continuous water production and reinjection in the Basal Clastic Unit of 100 m^3/hr the initial water breakthrough would occur at 18.3 years. Since the cooled water would be reheated by the solid rock, which contains about 3.2 times as much heat as the water, the temperature decline at the production well would not be significant until after about 45 years.

Ruse,D.C. and Vigrass,L.W., 1985. Deepening of the University of Regina 3-8-17-19 well.

In March 1985 an attempt was made to deepen the well at Regina. The purposes of this were to clear the hole for accurate temperature logging through the whole of the productive aquifer formations and into the Precambrian basement rocks and to obtain samples of basement rock for isotope analysis. Drilling difficulties, mainly because of lost circulation in the aquifer formations prevented deepening beyond 11 m, and no core of the Precambrian basement could be obtained.. This achieved the first objective but not the second.

Garven,G. And Vigrass,L.W. 1985. Modelling of deep groundwater flow in Saskatchewan.

Mathematical analysis of the known characteristics of aquifer formations in Saskatchewan showed that possible flow rates are quite capable of perturbing the normal conductive heat transfer, and hence temperature fields, in the sedimentary strata.

Vigrass,L.W., Viraraghan,T. and Curtis,F.A., 1984. University of Regina, Preliminary study use of geothermal energy in wastewater treatment.

Low grade heat, if available at low cost, could be used to improve the performance of wastewater treatment plants. The use of geothermal heat is technically possible but economically unattractive.

Hutchence,K. 1985. Subsurface modelling for geothermal production and energy storage.

Thermal energy can be stored in aquifers in sedimentary basins with efficiencies of 80 to 90%. Extra input during the initial input phase can have a lasting effect on the efficiency of the system.

<u>Reports to the University of Regina</u>

Bens,A.R., McCartan,J.J. and Vigrass,L.W. 1982. Use of geothermal energy at the University of Regina - results of an engineering and economic study.

Given that the sports building that had originally been associated with the geothermal demonstration project was no longer to be built, an engineering and economic study of the use of the geothermal resource within the existing buildings of the campus had been performed. Retrofit operations considered were direct air heating and other means of space heating, swimming pool heating, provision of domestic hot water.

It was concluded that ”The recommended option has considerable technical merit, and also considerable economic merit if energy costs continue to escalate at a rate well above the inflation rate." and "If energy costs do not escalate at a rate well above the inflation rate, then the economic case is not compelling."

> *Bens,A.R., and McCartan,J.J. 1982. Use of geothermal energy combined with conventional energy sources at the main campus University of Regina.*

This report is the basis of the previous published paper. It has not been possible to obtain access to this report, but it is probably kept in the archives of the University of Regina.

Reports from University of Alberta

In 1978 the University of Alberta began to take a new look at the question of data collection from oil and gas well files. The oil and gas industry has drilled thousands of wells in the prairie provinces, and well-organised provincial conservation engineers have maintained files of data from all of them. Well files often contain bottom-hole temperature data, but their quality is not always good. The data file assembled by the University of Alberta began by covering the Province of Alberta, taking a maximum of twelve data per township (10 km x 10 km) where wells were closely spaced. The file was later extended to include Saskatchewan, Manitoba, British Columbia and the Territories north of 60º. In its final form it was considerably larger than the Canadian part of the Geothermal Survey of North America, but it did not include all available data and it has never been published or available to other users.

Provincial well files contain data on lithology and it is thus possible to derive a net-rock analysis of each formation, or an estimate of the fraction of sandstone, shale limestone, etc. This has been done on a commercial basis by Canadian Stratigraphic Ltd. Provided one can assign conductivity values to these rocks, an estimate of conductive resistance can be obtained, for combination with temperature data to give heat flow. The results have revealed strong lateral and vertical contrasts of heat flow, which has been interpreted in terms of large-scale water migration in the aquifer formations (Majorowicz et al.,1984, 1985, 1986). Description of the thermal state of the WCSB is based almost entirely on this compilation and the subsequent interpretation.

Many contracts with the University of Alberta resulted in papers published in scientific journals as well as the contract report. These papers are included in the bibliographies, and they are indicated below, in square brackets, wherever there is a direct connection.. There are two main categories of report; those that dealt with the temperature and geothermal gradient distribution within the Western Canada Sedimentary Basin, and those that focussed on specific areas worthy of more attention.

> *Lambert,K. 1980. Report of geothermal gradient study of two areas of Alberta.*

A preliminary report of temperature gradient anomalies in Alberta, at Hinton and over the Steen River structure in the far north of the province.

> *Jones,F.W., Rahman,M., Lam,H.L. and Sworder,J.E., 1983. A preparatory study for application of geothermal energy in the Hinton/Edson area of Alberta.*

Based on previous studies of geothermal gradients in Alberta, the Hinton/Edson area was selected as a potential target for geothermal development, because of a higher than normal gradient. Contacts with he petroleum industry were attempted but met with a lack of interest. Possible aquifer formations, production wells and surface applications were studied. Other areas that show favourable opportunities include the Bowden Correctional Centre.

Jones,F.W. and Majorowicz,J.A., 1985. A study of the geothermal environment of the Western Canadian Sedimentary Basin [Jones,F.W., Majorowicz,J.A., Linville,A. And Osadetz,K.G., 1986. Bull.Can.Petrol.Geol., 34, 226-239]

This report outlines the distribution of geothermal gradient both above and below the Paleozoic erosional surface. There is a definite co-relation between areas of high geothermal gradient and the presence of oil and gas pools in Cenozoic strata

Jones,F.W., Majorowicz,J.A., Ertman,M.E., Linville,A. And Nguyen,C.D., 1986. Detailed study of the geothermal environment of the area included in map sheet NN-12 - Edmonton

An analysis of industrial log-heading temperature data to produce a map of geothermal gradient.

Jones,F.W. and Majorowicz,J.A., 1986. Study of existing temperature data from Canadian sedimentary basins, Phase 5, and Majorowicz,J.A., Jones,F.W., and Jessop,A.M. 1988. Preliminary geothermics of the sedimentary basins in the Yukon and Northwest Territories (60ºN - 70ºN) - estimates from bottom-hole temperature data.

A review of the existing temperature data in the Territories, analysing in terms of anomalies in temperature and geothermal gradients. It was thought possible that hydrodynamic forced convection could be responsible , at least in part, for the anomalies in the southern part of the study area, but this cause was probably not valid in the northern part.

Majorowicz,J.A., Jones,F.W. and Jessop,A.M., 1987. Low enthalpy geothermal energy potential of the Western Canadian Basin - heat flow and hydrological considerations.

A review of the aquifer formations showing the best potential for geothermal development in regions of the Western Canada Sedimentary Basin. Generally the reservoirs mentioned had temperature in excess of 60 ^{O}C, and some were as high as 130 ^{O}C.

Jones,F.W., 1987. A study of the geothermal environment of the Lesser Slave Lake map sheet NN-11 area.

An analysis of industrial log-heading temperaturedata to produce a map of geothermal gradient in the 1:1,000,000 map sheet NN-11.

Jones,F.W., 1988. A study of the geothermal environment of the Peace River map sheet NO-11 area.

An analysis of industrial log-heading temperature data to produce a map of geothermal gradient in the 1:1,000,000 map sheet NO-11.

<u>Reports form other sources</u>

Northern Geothermal Consultants, 1994. Study of the relationship of the thermal and hydrogeological regimes of the Western Canada Sedimentary Basin: Study of the anomalous regime in the northern Cordilleran Foreland Basin, and Majorowicz,J.A., 1996. Anomalous heat flow regime in the western margin of the North American Craton.

An examination of some large areas of elevated geothermal gradient in western Canada, including a large northeastern British Columbia and the southern Northwest Territories between the Cordillera and Great Slave Lake and an elongated zone to the east of the Rocky Mountains in the Hinton - Edson area and extending towards Calgary.

Acres International Ltd, 1985. Moose Jaw Geothermal Study.

This report reviewed the aquifer formations below the City of Moose Jaw that are capable of providing a source of water and the potential for retrofitting existing buildings to make use of the energy resource. Four possible schemes of geothermal exploitation were presented. Each scheme associated the total demand of the proposed users with the volume and temperature of the geothermal water, and hence with pumping requirements and depth of drilling. It was concluded that the smaller schemes, associating retrofit of a few close buildings with the renewed Natatorium, offered the best prospects for economic use of a geothermal resource. Larger schemes, involving retrofit of more buildings over a wider area were judged to be best left until some operational experience had been gained.

Loveseth,G.E. 1988. Location, indentification and inventory of aquifers with the greatest geothermal potential in the sedimentary rocks of Alberta.

This report was the result of a contract let by the Renewable Energy Branch of Energy Mines and Resources after the end of the Geothermal Energy Program. This report suggested that temperatures derived from drill-stem tests are much more reliable than temperatures from log headings, commonly known as “bottom-hole temperatures”. This claim depended on the relatively new technology of making such measurements, which involved a temperature recorder that tracked the temperature changes as the fluid entered the well. It was also suggested that there should be a program of taking reliable temperature measurements in wells that have been shut in for some time, to allow temperature to stabilise. This would avoid the two problems of poorly calibrated industrial equipment and drilling disturbance. The report was accompanied by a collection of maps showing current information of depth, temperature, water salinity and capacity of the main aquifer formations in Alberta.

Loveseth,G.E. 1989. The geothermal resources of Saskatchewan and S.W. Manitoba.

This report was a sequel to the previous report and provided maps of the same aquifer characteristics for Saskatchewan and Manitoba.

REVIEW OF INTERNAL STUDIES

Jessop,A.M. 1976. Geothermal energy from sedimentary basins. Geothermal Series of the Earth Physics Branch, No. 8.

This report reviewed the Geothermal systems of the Paris Basin, their design, spacing, energy output and economics, and went on to describe the currently known opportunities in the WCSB.

Jessop,A.M. and Vigrass,L.W. 1984. The Regina geothermal experiment - thermal aspects.

This conference paper presented the measured temperatures from log-headings, drill-stem tests and accurate measurements in the well. It was shown that the industrial data from an extended area and the industrial well log tended to exceed the accurate measurements by up to 15 ^{O}C. The best estimate of production temperature from The Basal Clastic Unit was 60 ± 0.5 ^{O}C.

Jessop,A.M. and Vigrass,L.W., 1989. Geothermal measurements in a deep well at Regina, Saskatchewan.

This paper presented all the thermal data and interpretations derived from the well at Regina, including the interpretation of water flow in the open part of the well through the porous formations, changes in thermal gradient through strata of differing conductivity, and the best estimate of the terrestrial heat flow from the Precambrian basement.

EARTH SCIENCE ADVANCES

Research into geothermal resources of sedimentary basins requires the accumulation of a knowledge of the present thermal regime of the basins and an understanding of the tectonic and hydrodynamic forces that control that regime. For this reason, a series of contracted studies was sponsored by the Geothermal Energy Programme, the work being done mainly in the Universities of Alberta and Regina.

<u>Temperature, gradients, and thermal properties</u>

Temperature in sedimentary basins is surprisingly difficult to determine. Although well-logging provides large numbers of data, they are of doubtful quality at best. Temperatures on the headings of geophysical logs are usually recorded by maximum-reading glass thermometers, which are intended to reach their maximum temperature while near the bottom of the well before the upward logging run. For this reason they are often referred to as "bottom-hole temperatures", abbreviated to BHT. Bottom-hole temperatures are taken at the time of maximum disturbance of the well, they are often omitted, and they are subject to significant and unpredictable instrumental and human error. For a comparison of bottom-hole temperatures with more accurate data see Jessop (1990b). Despite their inaccuracies, large numbers of bottom-hole temperatures may, by statistical treatment, give a general picture of temperature distribution and the major regional anomalies. However, there is a tendency for BHT to be systematically high in wells of shallow (<500 m) depth

The University of Alberta used their file of BHT to show variations in temperature gradient and heat flow, both laterally and vertically, and very large anomalies have been found. The data file was not generally open to other users, including the Geological Survey, it was highly selective of wells, and it has been mostly superceded by the Geological Survey and the Alberta Research Council.

Drill-stem test reports often include a record of temperature. Most of these have been obtained by means of a maximum-reading glass thermometer enclosed in the valve assembly. Human error has been known to include the effects of cleaning the equipment with a hot-water hose before removing the maximum-reading thermometer. The large thermal mass and long thermal time-constant of the valve assembly make single maximum readings unreliable. Modern equipment includes a recorder that produces a temperature reading at intervals, typically of thirty seconds or one minute. This provides a means of judging the approach of the temperature recorder to the temperature of the formation water.

Temperature logs are intended to show anomalies, such as zones of setting cement, they are run at times of maximum disturbance, and calibration of the thermometer system is often neglected. They are not intended as a measurement of equilibrium rock temperature and their scientific value is extremely low.

Porosity, permeability and hydraulic potential

The porosity of a reservoir determines the amount of water available, and the permeability governs the rate at which it can approach the well through the rock matrix, both of which are determined from measurement on cores and from analysis of the rates of flow during drill-stem tests. These properties combine to control pressure draw-down when the well is pumped and a lifetime for any production well.

Hydraulic potential is determined from "shut-in" pressures recorded during drill-stem tests. The pressure of the water in the aquifer determines the pumping requirements of the project. A high pressure means that the down-hole pump may be of lower power and thus less expensive, and in the extreme, artesian flow may provide the flow needed. However, high aquifer pressure requires a more powerful reinjection pump, but since a surface pump can be used for reinjection, this is much less expensive in both capital and maintenance costs.

Drill-stem tests run by the hydrocarbon industry are usually in the upper parts of porous sections where the hydrocarbons accumulate. Thus it is rare to have data on a complete porous section. Geothermal analysis requires a knowledge of the porosity and hydraulic properties integrated over each porous unit. Hydraulic potential may differ in adjacent porous zones separated by relatively thin impervious layers. Thus, although data generated by the hydrocarbon industry is essential for revealing the broad outline of geothermal potential, it does not provide complete information at any specific site.

Chemical content of geothermal waters

Water in deep aquifers often has a high content of dissolved solids. Sodium chloride is the most common solute, but calcium, potassium, sulphate and bicarbonate ions are often present, with minor amounts of others. Dissolved gases usually consist of nitrogen and carbon dioxide, sometimes with significant hydrogen sulphide, and minor amounts of helium and others. The potential harm on the heating system from these chemicals must be carefully evaluated.

Data are obtainable from provincial records, where chemical analyses are stored with other well data. Collections of water-chemistry data, in computer-compatible format, are available from some commercial sources, for example International Petrodata Ltd.

Water flow and the thermal field

One of the main conclusions of the studies performed at the University of Alberta was that the temperature field, and hence heat flow distribution, is strongly influenced by regional water migration. It was hypothesised that basin-wide water flow, driven by the high elevation of the southwestern margin of the basin towards the much lower northeastern part is sweeping heat steeply downward in the southwest, and gently upward towards the northeast. This results in reduced temperature gradients at shallow depth and enhanced temperature gradients at greater depth in the southwest and the reverse in the northeast. This basin-wide pattern is distorted by other flow systems in all parts of the basin.

This hypothesis has been disputed on hydrological grounds on the basis of the inability of the aquifers to carry sufficient water flow. It is also possible that observed heat flow patterns have been distorted by inadequate knowledge of thermal conductivity of clastic rocks. It has also been observed that industrial temperature data tend to give high temperature gradients in shallow parts of basins, and it is not clear to what extent these relatively shallow data are biassed upwards. However, the published temperature fields are as accurate as possible, given that the data come mainly from industrial BHT. The zones of high temperature gradient described in some of the reports are real.

THE REGINA PROJECT

Co-operation between the Earth Physics Branch and the University of Regina began with a meeting between Dr. L.I.Barber, President Dr. C.W.Blachford, Dean, Faculty of Graduate studies, and Dr.L.Vigrass, Director of Energy Research, all of the University of Regina, and Mr.A.D.Hunt, ADM, Energy Policy, Dr.K.Whitham, Director-General, Earth Physics Branch, and the present author, all of Energy Mines and Resources, on 21 February 1977.

The University had independently arrived at the idea of using geothermal energy to provide the energy input to a geothermal demonstration project on the campus of the University of Regina. It was agreed that the author would provide all possible technical help and advice to Dr Vigrass with the aim of drawing up a plan for a demonstration project.

The demonstration plan that emerged called for the provision of space heating and domestic hot water to a large sports and recreation facility on the campus, and at the same time to establish a demonstration of the use of geothermal energy in Canada. On 14 July 1978 Dr Barber was advised that Treasury Board gave approval for a contribution of $655,000 for the drilling of the first geothermal well at Regina in the year 1978/79. As drill rigs were fully occupied at that time, the drilling did not start until late December 1978.

Unfortunately, the sports facility, which the University confidently expected to be able to build, has not yet been built, and so the production well has never been used for its main purpose. However, this delay has permitted a programme of research into the thermal, chemical and hydrological character of the sediments, which would have been impossible without the use of this well.

<u>The feasibility study</u>

During 1977-1978 a contracted study was performed by the University, (Vigrass et al., 1978) to determine the geothermal potential in an area of roughly 100 km x 130 km that included the cities of Regina and Moose Jaw. The City of Moose Jaw was known to have used warm water from an unsuccessful gas well for its "Natatorium" for many years until the well deteriorated beyond recovery.

The authors of the study compiled information from wells in the area in order to derive forecasts of the characteristics of a potential geothermal production well on the campus of the University. The main objectives were predictions of the fluid flow rates from the most favourable aquifers, the chemical character of the water, and the temperatures within the aquifers.

It was concluded that the Winnipeg Formation, at a depth of about 2040 m offered the best prospects for a geothermal source, with a temperature of 71 ^{O}C and a static hydraulic head of about 45 m below surface. The second target formation was thought to be the Deadwood Formation, at a depth of about 2090 m, and having a temperature of about 74 ^{O}C. Water in both formations was predicted to have salinities up to 150,000 ppm, being mainly sodium chloride, but corrosion was not predicted to be a serious problem because the content of oxygen and hydrogen sulphide was predicted to be low and the waters were predicted to be slightly alkaline or neutral. These two formations constitute the Basal Clastic Unit, and the Deadwood Formation rests on the Precambrian basement. They are thus the hottest aquifers to be found in the sediments at Regina. Other aquifers, higher in the column, offered less potential as geothermal resources.

Drilling the well

In the winter of 1978-79 a well was drilled to a depth of 2215 m on the campus of the University to prove the resource and to serve as the production well for the demonstration project. An account of the drilling and some of the immediate findings may be found in the Final Well Report (Vigrass, 1979).

The well was cased with 178 mm casing to a depth of 2033 m, and the well was left open below that point, through the aquifers of the Winnipeg and Deadwood Formations. Results of drill-stem tests indicated that the well could produce water at a rate of 100 m^3/hr, with draw-down to 131 m below ground level after seven years. This indicated a power requirement for pumping of 66 kW, about 2% of the 3.5 MW of heat energy available by cooling the water to 35°C.

All forecasts were exceeded except temperature, which turned out to be about 14 K lower than expected. This erroneous forecast was based mainly on a preference of temperature from drill-stem tests over bottom-hole temperatures, whereas the opposite preference is justified by post-drilling measurement. The Bureau de Recherches Geologiques et Minieres in France have indicated that they also tended to overestimate temperature in their early projects (personal communication).

Research based on the well

Since completion, the well has not been used as a geothermal production well but it has been an invaluable research facility. The Universities of Regina, Saskatchewan and Toronto, with contractors and EMR personnel have carried out a variety of studies using the well, and it has been used as a training facility by the drilling industry.

Hydrofracturing experiments showed that the maximum horizontal stress undergoes an abrupt change in both magnitude and direction across the Deadwood Formation, the lowest part of the sedimentary column, indicating a decoupling of the stress fields in the Precambrian basement and in the sediments (McLennan et al., 1987).

Chemical analyses of the gas from the well show that 95% of it is nitrogen, with some carbon dioxide and less than 1% of others, including oxygen and hydrogen sulphide. The samples were taken during pump tests of the entire open section of the well, and so the results represent the combined content of several aquifers in two formations. Total dissolved solids was found to be 101,000 ppm, over 90% of which was sodium chloride (Postlethwaite et al., 1980b).

Thermal data from the well are shown in Fig.4. Temperature gradients are higher in the Upper Clastic Unit, of Mesozoic age, than in the Carbonate-Evaporite Unit of Upper Paleozoic age, corresponding to contrasts in thermal conductivity in the opposite sense. However, the uniform heat flow in the Carbonate-Evaporite Unit, of 51 mW/m^2, is not maintained in the Upper Clastic Unit, where it increases with decreasing depth to a value of about 70 mW/m^2. This may be attributed errors in conductivity measurement, resulting from the need to make all conductivity measurements on drill cuttings, rather than on solid cores, but alternatively it could be caused by

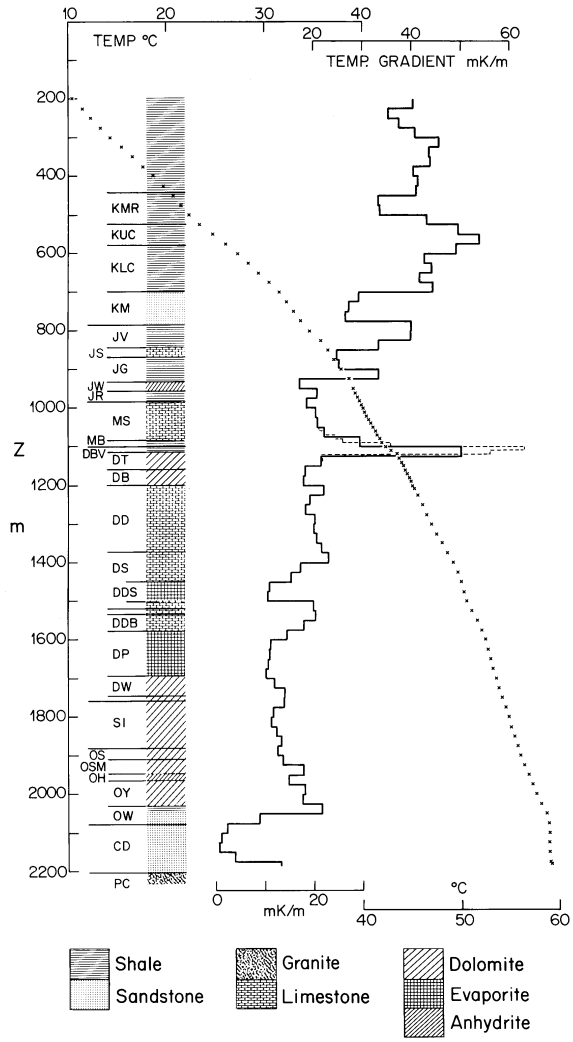


Fig.4 Temperature, temperature gradient and stratigraphic section in the well at the University of Regina. The very low temperature gradient in the Winnipeg Formation (OW) and the Deadwood Formation (CD) are caused by circulating water in the open hole.

an upward component of water flow. The data do not permit the separation of these two potential causes (Jessop and Vigrass, 1989).

In addition to these, other studies have been directed towards corrosion of metals in the water (Postlethwaite et al., 1980a), alternative uses of the energy (Bens et al., 1982a), and production rates from and flow regime within the producing reservoir (Vigrass, 1980a).

Although it has so far not been used, the Geothermal Energy Program demonstrated the existence of a significant energy source below the City of Regina. This energy is a proven reserve and is available whenever the costs of use and the need to reduce carbon emissions make it attractive.

THE MOOSE JAW PROJECT

From 1933 to 1957 the "Natatorium" was fed with warm saline water from a deep well, originally drilled for gas exploration. The Natatorium was an attraction to the local population and an attraction to tourists. The water was described as "rich in sodium chloride, sodium sulphate and magnesium sulphate, comparable with the waters of Carlsbad and the more notable German curative springs" (Moose Jaw Times Herald, 10 June 1933). The same report also stated "visitors from all over the dominion and many points south of the border have been loud in their praises of the hot mineral water with which the pool is supplied" (ibid). Eventually the old wooden casing of the well collapsed and the supply of warm water was cut off. After 1957 the geothermal water was replaced by surface water, heated with natural gas, and chlorinated for health reasons.

After the drilling of the well at the university of Regina the City of Moose Jaw expressed interest in restoring the water source for the Natatorium. Energy Mines and Resources contracted a study of the feasibility of restoring the water supply and of other possible uses for the water or the heat. It was found that the initial cost of drilling the two wells required, one to produce and one to reinject the water, was a major part of the total cost, and that a large deep well could provide an energy supply for a wide range of existing buildings in the centre of the city.

Geological conditions had already been examined in preparation for the drilling at Regina, and the options for producing aquifers were similar to those at Regina, at similar depths. Seventeen potential users were identified, including municipal and commercial buildings, mostly within an area of four by five city blocks.

The report produced four schemes, each of which matched aquifer potential with potential users and the distribution system. Details appear in Chapter 6.

In the autumn of 1989 two wells were drilled to the Birdbear Formation. One of them had a temperature of 53.1 ^{O}C at 1352 m depth. A temperature log of one of the wells is shown in Fig.5. Pressure in the wells was such that an open well would produce a fountain about 20 m high. This means that reinjection requires high pump pressures.

In December 1989 the City of Moose Jaw published a "Proposal Call for development of a hotel, recreation, leisure and convention facility using geothermal water as the key attraction". ventually the Temple Gardens Mineral Spa was built, and the water feeds a pool on the top floor of a hotel. Guests of the hotel and local people may use the facilities. Times and admission prices are published on the internet at http://www.templegardens.sk.ca/.

ASSESSMENT OF RESOURCES

In order to obtain an estimate of the total energy contained in the formation waters of sedimentary

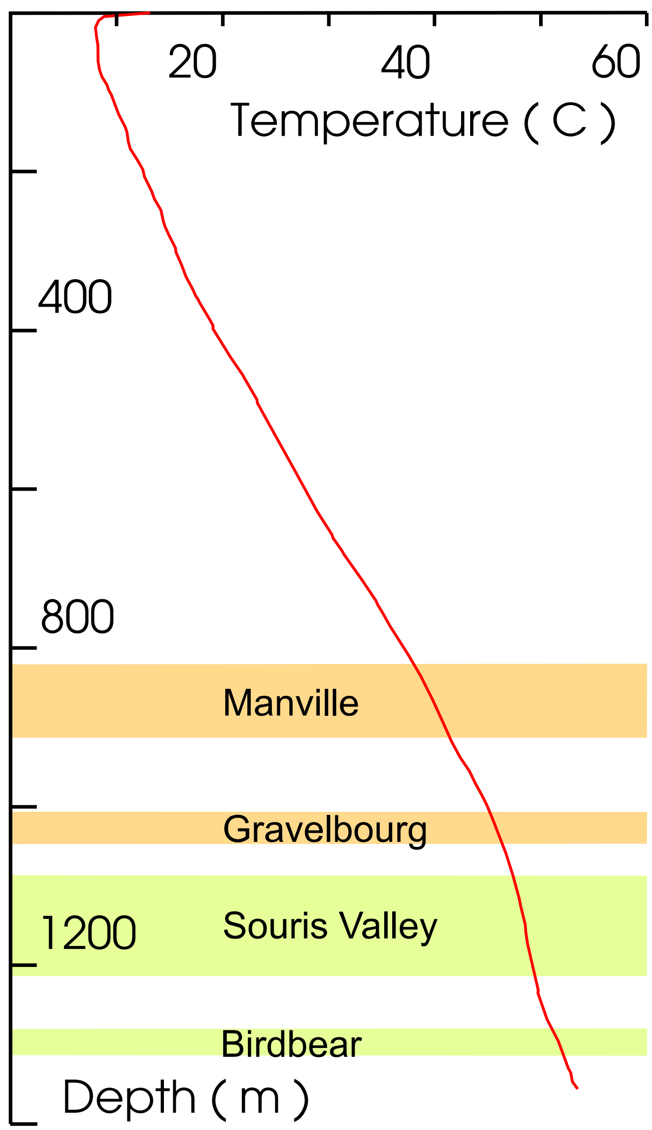


Fig.5 Temperatures in the well at Moose Jaw, with aquifer formations. Orange colour shows sandstone aquifers and green shows limestone.

basins it is necessary to adopt some definitions of resources and the limits of economic exploitation. For present purposes these are as follows.

Definitions

Classification of resources is based on the system described by Muffler and Cataldi (1976), which is illustrated and described in Chapter 2. For the purpose of assessing the useful resource of geothermal aquifers two temperatures, characteristic of the heat extraction system must be defined, as follows.

The "threshold temperature" is the temperature below which it is not practical to produce water. This may about 60 °C if a heat exchanger system is in use, and may be as low as 10 °C if heat pumps are used. Since temperature normally increases with increasing depth, a low threshold temperature means that it is possible to use shallow aquifers, with a great saving in costs of drilling.

The "return temperature" is the temperature at which the water is rejected from the extraction system and returned to the ground. This is the effective base for calculations of heat, and a decrease in return temperature provides an increase in heat supply. This may be 30 °C for a heat-exchanger system. If heat pumps are used the only fixed limit is the freezing point of the fluid, but each system has its own limiting useful temperature.

<u>Methods</u>

In the WCSB, between the latitudes of 49 °N and 60 °N, and between the Rocky Mountains and the exposed Precambrian Shield, the area of sedimentary cover is 1.26 x 10^6 km^2 (486,785 sq.miles), the average depth is 1778 m (5834 ft), and the volume of sediments is 2.24 x 10^{15} m^3 (537,895 cubic miles), (Hitchon, 1968). The total pore volume has been estimated to be 265 x 10^{12} m^3 (63,000 cubic miles) (Hitchon and Friedman, 1969), which implies an average porosity of 11.8%. Assuming a density of 1.0 Mg/m^3, this means that the rocks contain 265 x 10^{15} kg of water. The data of Sproule Associates Ltd (1976) report, as shown in Fig.6, provide an average geothermal gradient of 33 mK/m.

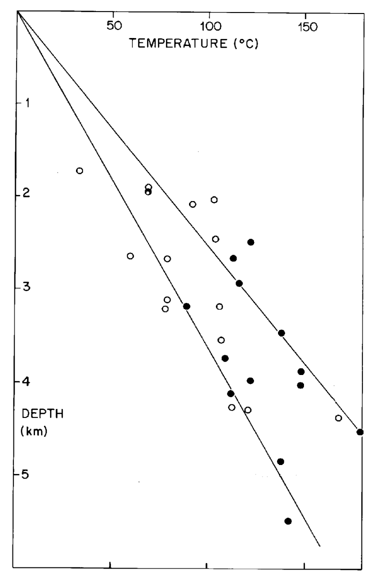


Fig.6. Temperatures plotted against depth in the Western Canada Sedimentary Basin, the data from Sproule Assoc. (1976). Solid circles show the highest temperature of each profile and open circles show the lowest. The two lines include 50% of the data and exclude 25% on each side, and the gradients are 27.6 mK/m and 39.6 mK/m

The generalised isopach map of Sproule Associates Ltd. (1978) has been used to derive a distribution of the depth of the basin. Surface areas have been measured between successive isopachs of 304.8 m (1000 ft) and the total area is found to be 1.27 x 10^6 ± 2%, not including the "disturbed belt" of the Rocky Mountain Foothills. A simple volume calculation for each interval yields a total volume of 2.16 x 10^{15} m^3 ± 5%. This figure is about 4% lower than the estimate of Hitchon (1968), but this difference is within the limits of accuracy of the present work. A depth distribution of the sedimentary wedge is shown in Fig.

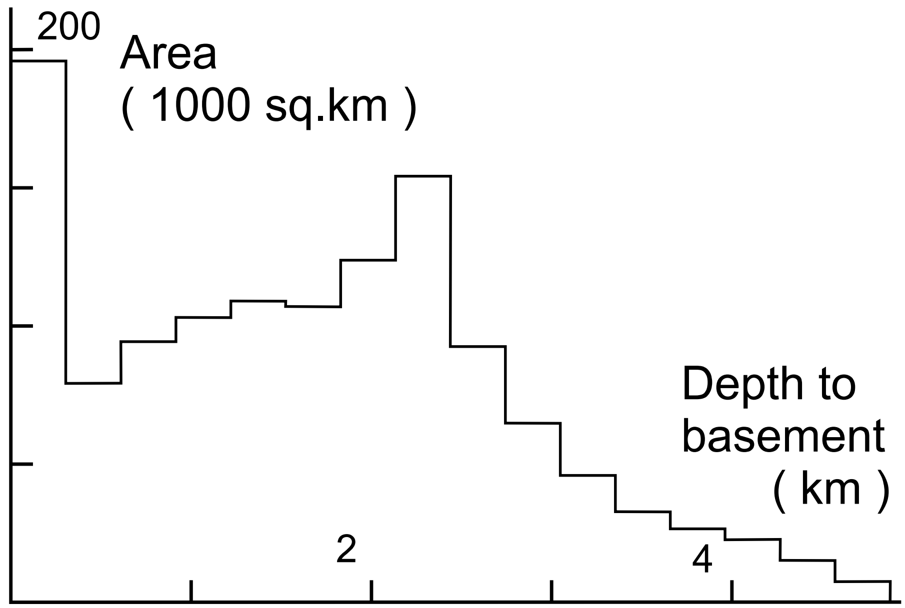


Fig.7 Histogram of depth to the base of sediments in the Western Canada Sedimentary Basin, in depth intervals of 305 m (1000 ft). The Basin has the form of a foreland basin, formed by crustal compression from the south-west and filled by clastic sediments from the same direction, superimposed on an older platform structure.

It is assumed that the specific heat is 4200 J/kgK, and that the mean surface temperature is 4 ^{O}C. We may now calculate the total useful heat in the water of the basin, for any values of the threshold and return temperatures, and the results are shown in Fig.8. The heavy line shows the limiting energy when the threshold and return temperatures are equal. For practical and economic reasons this level of utilisation is unlikely to be achieved, and curves are shown for return temperatures that are 20 K, 40K and 60K lower than the threshold temperature and for constant threshold temperatures. Given that depths are averaged over each zone, surface temperature is averaged over the whole area, estimates of rock and pore volumes, specific heat and density are all subject to error, the resulting energy estimates are probably subject to a possible error of 20%.

The values in Fig.8 are the energy in the water only. The heat in the rock is not included. Given the above assumptions, the heat in the solid rock is 3.7 times as great as the heat in the water. As pointed out by Hutchence et al. (1984) the heat in the rock is drawn upon during circulation by the conventional well doublet method, so that at least part of the heat in the solid rock is part of the accessible resource base at any location.

Accessible resource base

Reasonable threshold and return temperatures in geothermal systems that do not employ heat

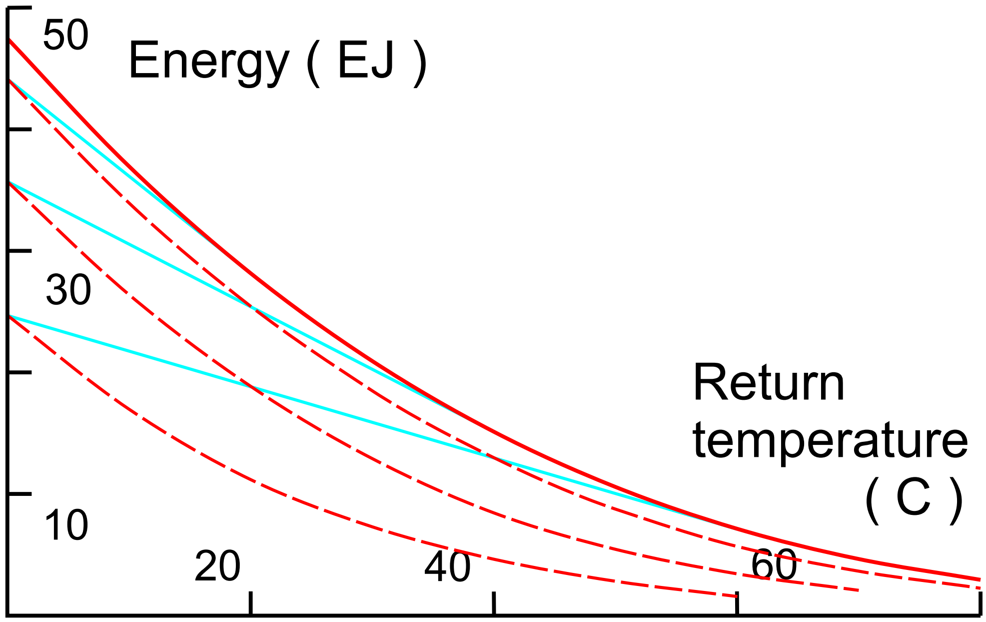


Fig.8. The amount of heat in geothermal water beneath the prairies as a function of the threshold and return temperatures. Return temperature is plotted on horizontal axis. The continuous red line shows the limiting energy when the threshold and return temperatures are equal, i.e. the total energy above the return temperature. The dashed red lines shows the available energy for a threshold temperatures that are 20 K, 40K and 60K higher than the return temperature. Blue lines show the energy above constant threshold temperatures of 20 ^{0}C, 40 ^{0}C and 60 ^{0}C as a function of return temperature.

pumps are 60 ^{O}C, and 30 ^{O}C respectively, and for systems that include heat pumps these are reduced to 40 ^{O}C and 10 ^{O}C. It may be seen from Fig 8. that the total heat in the basin that meets or exceeds these criteria is 16 x 10^{21} J and 31 x 10^{21} J respectively. Canadian oil reserves on 31 December 2004 were 16.5 barrels (BP 2006), which is equivalent to 94 x 10^{18} J. Canadian gas reserves at the same time were 1.59 x 10^{12} m^3 (BP, 2006), which is equivalent to 60 x 10^{18} J.

The these figures are very large, but they represent that part of the accessible resource base in the water in the porous sediments. Only a small fraction of the accessible resource base may be regarded as a proven economic reserve. The presence of the energy does not imply that it is economically and technically feasible to exploit more than a small portion of it.

By the definition of Muffler and Cataldi (1976), the accessible resource base includes all heat to a depth of 7 km, regardless of the material holding the heat. Since the maximum depth of sediments in the Western Canada Sedimentary Basin is about 5 km, all heat in the water residing in the pores of these sediments and all heat in the solid fabric of the sedimentary rock is included in the accessible resource base, as so defined, but the heat in the solid rock is not included in the above calculations. There is also a portion of the Precambrian basement between the lowermost sediments and the limit at 7 km that holds part of the accessible resource base as hot dry rock. By adding these three components, the total accessible resource base of the Western Canada Sedimentary Basin, to a depth of 7 km, is found to be 1.8×10^{24} J. Without major developments in drilling and the technology of extraction the heat in the Precambrian basement will never be part of the truly accessible resource base.

The useful resource base

The above calculation illustrates the effects of the nature of the geothermal resource on its potential for exploitation. The water in the sediments may be produced by existing technology, although not necessarily at an attractive price. The heat in the solid rock will be partially produced during the life span of the production system. The heat in the dry rock of the basement may be recovered only by deep drilling, the creation of a circulatory loop and the injection of water from the surface, a technology that is still in the course of development. This is unlikely to become an economic process. This may be compared with the effect of differing grades of ore in a mine.

Estimation of local resources

The above estimate of the geothermal resource depends on assumptions of uniform geothermal gradient, porosity, and thermal properties of the water and the rock. It takes no account of variations of these factors, and so it must be refined for use on the local scale. The magnitude of the accessible resource base at any single location depends on the nature of the strata below that place, particularly the nature of the aquifer formations. The distinction between residual and useful resources depends on the depth to the aquifer, the reservoir pressure, the thickness and permeability of the host rocks. The distinction between economic and sub-economic depends on the local demand for energy, the technology to be used, and the cost of development of the geothermal resource compared to costs of other sources.

The best geological conditions are found in reef systems or in extensive thick sandstone units. The most probable locations for energy demand are in or near large centres of population, where the need for space heating is the highest. The next most probable areas are those where low-grade heat is useful for industrial processes, including agriculture or horticulture. In other areas there is no immediate use for geothermal heat at present. The first of these categories may be defined by proximity to towns and cities, but the second is very difficult to define, since there are so many unpredictable uses for the energy.

The first step in the estimation of local resources is a review of the data from hydrocarbon wells in the area, preferably over an area of 50 km around the site. From this data the potential aquifer formations are identified, the thickness, porosity, permeability and temperature of these aquifers are estimated. The best fit between the possible sources and the needs of the surface installation is identified. The data from the hydrocarbon wells will probably not provide all the data needed, as pointed out by Gorrell (1984).

Of the major cities of the Western Canada Basin, geothermal resources are best known at Regina. Information has been assembled in the course of a feasibility study for heating at the University of Regina (Vigrass et al.,1978), and as the result of the drilling of an exploratory well on the campus of the University (Vigrass, 1979). The temperature at the base of the sediments is about 60 ^{O}C. The best source of geothermal water is the Basal Clastic Unit, at depths from 2045 m to 2208 m, but there are other aquifers at shallower depths and of less favourable temperature and water supply.

The net sand aquifer in the Basal Clastic Unit has a thickness of 113 m, divided between the Winnipeg and Deadwood Formations. Average porosities are 15.7% and 14.7% respectively, giving an integrated porosity x thickness of 15.6 m. Salinity of the water is about 12%, mainly sodium chloride, giving a density of 1.09 Mg/m^3 and a specific heat of 3600 J/kgK. From these data the heat content of the water of these formations, per unit area is 61 x 10^6 J/m^2. Since the Basal Clastic unit is reasonably uniform in character and the area of the City of Regina is approximately 130 km^2, this amounts to a geothermal resource below the City of 19 x 10^{15} J. This quantity may be regarded as a useful, discovered resource.

Table 4
Summary of Resource Estimates

Resource base:	
Total heat in continental crust to 7 km	160 x 10^{24} J
Heat in crust below Canada	11 x 10^{24} J
Accessible resource base:	
Heat in water of WCSB	
With heat pumps	31 x 10^{21} J
Without heat pumps	16 x 10^{21} J
Useful, discovered resource	
Heat below the City of Regina	
In water	19 x 10^{15} J
In host rock	60 x 10^{15} J
Energy in hydrocarbon reserves at 31 Dec 2004	
Oil	94 x 10^{18} J
Gas	60 x 10^{18} J

CONCLUSIONS

Resource estimates derived in this chapter are summarised in Table 4. There is a very large resource of heat in the Western Canada Sedimentary Basin and other smaller resources in other basins. Most of this resource is too remote from potential users to be of interest, but some of it is beneath cities where it could easily be exploited for domestic or industrial space heating. The technology is simple: it has been demonstrated in France and in other countries. Expertise and industrial capability could easily be developed in Canada.

The resource has been conclusively proved at Regina, but has not been used there. One well has been drilled that could have produced hot water, and a second well could be drilled. The first well is 28 years old, and its maintenance is unknown. It may be suffering from corrosion, so one may not conclude that it is in the same condition as it was in 1979.

Geothermal development in sedimentary basins requires the drilling of two deep wells at the beginning of the project, and thus suffers from a capital cost at the beginning that must be financed by income generated. Hydrocarbon wells work the same way, but the numbers of wells involved, the continuous process of exploration and development has developed to the point where this is no longer an obstacle to economic development.

This report is not intended to look into present economic conditions. However, the use of deep geothermal water in the heating of large residential or industrial buildings in the urban centres of the Prairie Provinces should be examined in terms of current economic conditions and current environmental considerations.

CHAPTER FOUR

GEOTHERMAL RESOURCES OF THE ATLANTIC MARGIN

INTRODUCTION

Geothermal resources of the Atlantic Margin were completely unknown at the beginning of the Geothermal Energy Program. The Atlantic Margin contains no evidence of Tertiary Volcanism, and so no high-temperature resources could be expected. There are sedimentary basins with the potential for low- or medium-temperature resources, and there are granitic bodies that could have a potential for hot dry rock.

This part of the program was managed by M.J.Drury, beginning from the time that he was recruited in 1979. The Provinces of Nova Scotia, Prince Edward Island, New Brunswick and Newfoundland, and the eastern part of Quebec were included in the general area of investigation. Most of the Province of Quebec is underlain by the Precambrian Shield, and the only part of interest was the St.Lawrence Valley and the Gaspe Peninsula.

The Springhill project was the most successful application of geothermal energy in the Atlantic region. However, because of its nature as a use of low-temperature water and heat pumps, all information on this project is included in Chapter 5 - Shallow and low-temperature resources.

REVIEW OF CONTRACTED STUDIES

John A.Leslie and Assoc.Ltd., 1981, Investigation of geothermal energy resources - Nova Scotia and Prince Edward Island.

John A.Leslie and Assoc.Ltd., 1982, Investigation of geothermal energy resources, Atlantic Provinces.

John A.Leslie and Assoc.Ltd., 1983, Investigation of geothermal energy resources - Atlantic Provinces.

John A.Leslie and Assoc.Ltd., 1984, Investigation of geothermal energy resources: Atlantic Canada.

John A.Leslie and Assoc.Ltd., 1985, 1984 investigations of geothermal energy resoucres, Atlantic provinces.

These reports all contain measured temperature data collected by the contractor throughout the Atlantic provinces. At the beginning of the Geothermal Energy Program there was a shortage of data on which to base any assessment of geothermal potential. It was anticipated that the most likely areas of geothermal potential would be warm water in the sedimentary basins or hot dry rock in the granitic batholiths. The search for data took several years and was concentrated on such areas, but the contractor made temperature measurements wherever he could find suitable boreholes. These reports contain relevant data of temperature, thermal properties of rock, porosity, permeability, water chemistry, radioactive heat generation, and ages of batholiths. Results showed that geothermal gradient was generally low, from 12 to 20 mK/m.

The last report includes an account of the drilling of an exploratory diamond drill hole in the Wedgeport Granite. Temperature and lithological logs and heat generation data are included. Temperature gradient was found to be about 18 mK/m. The last report also included mention of a geothermal gradient of 22 mK/m at West Gore, Nova Scotia.

John A.Leslie and Assoc.Ltd., 1983, Geothermal gradients in granite batholiths of New Brunswick.

This report recounts the drilling of two diamond drill holes in two batholiths, in search of good temperature gradients. The St.George and Pokiok Batholiths both gave indication of encouraging heat generation, which suggested that heat flow and temperature gradient should be high. The holes were drilled in the winter of 1982-83, and temperature measurements were made both during and after drilling. Results showed geothermal gradients of 18 mK/m, well below expectations, suggesting that any high heat generation is in small , localised, segments of the intrusive body and not representative of the batholith as a whole.

John A.Leslie and Assoc.Ltd., 1984, Geothermal investigation: Prince Edward Island drilling.

An account of the drilling to 484 m and logging of a diamond drill hole on the campus of the University of Prince Edward Island. There was an interest in the possibility of geothermal heating, but the measured geothermal gradient of 14 mK/m was discouraging. Temperature and lithological logs and other data were included in the report.

John A.Leslie and Assoc.Ltd., 1985, Geothermal investigation, Prince Edward Island drilling, MacDougall, Prince County, hole number EPB 345.

An account of the drilling to 495 m and logging of a diamond drill hole at MacDougall, Prince Edward Island. A nearby oil exploration well had suggested a geothermal gradient of about 25 mK/m, but the measured geothermal gradient of 16 mK/m was discouraging. Temperature and lithological logs and other data were included in the report.

Nolan, Davis & Associates Ltd, 1984, Groundwater flow patterns in Carboniferous sediments of Atlantic Canada.

This report describes the work done to relate hydrological flow to geothermal gradient patterns within the Carboniferous sediments of the Stellarton - New Glasgow area of Nova Scotia. It was concluded that there are two distinctly different groundwaters. The deeper water is a NaCl water of meteoric origin. Carbon dates are not reliable because of contamination from coal. This water has probably not been exposed to temperatures greater than 50 ^{o}C. Shallow groundwater (<100 m) are also of meteoric origin. Hydrological flow patterns cannot be defined with any confidence. The extent to which fractures contribute to the flow patterns is substantially unknown but is probably significant.

Acres Consulting Services Ltd., 1984, Survey of geothermal energy in the Maritime Provinces.

This study addressed the engineering and economic aspects of geothermal use in the Maritime Provinces. It examined the potential application of shallow resources, with the inclusion of a heat pump, and of deep resources with or without the help of heat pumps. It was concluded that there was a clear economic potential for direct-use geothermal energy development. The most favourable systems involved the use of heat pumps. The cost of retrofitting, rather than installation in new buildings, was considered to be a handicap, but even that might be economically justifiable. However, one of the primary constraints to development was the ability to find sufficient load for a single doublet of wells.

REVIEW OF INTERNAL STUDIES

Drury,M.J., 1983, Temperature gradients and heat production in two granitic batholiths of New Brunswick.

No copy of this internal report had survived, but the data are preserved and presented elsewhere.

Drury,M.J., 1984, Assessment of the geothermal resources of Atlantic Canada.

This paper was a review of the geothermal energy research directed at the Atlantic region. It was concluded that only the Fredericton, Stellarton, or Deer Lake sedimentary areas showed any promise as geothermal potential. It was also concluded that the temperatures observed in boreholes drilled into radiogenic batholiths were not encouraging. However, the best prospect is probably in places where sedimentary rocks overlie radiogenic plutonic rocks, such as in the Fredericton Graben. In such circumstances the water in the sedimentary aquifers might be warmer than usual because of radiogenic heat from the batholith. If useful geothermal potential is to be found in the Atlantic region it will be in small areas.

Drury,M.J., Jessop,A.M. and Lewis,T.J., 1987. The thermal nature of the Appalachian crust. Tectonophysics, 133, 1-14.

This paper described the current information about the crust of the Maritime Provinces, based on the available heat flow and heat generation measurements. Data from Wedgeport, drilled in the Wedgeport pluton to examine the hot dry rock potential showed a heat flow slightly below the world average, despite an encouraging level of radioactive heat production in the near-surface rocks. Heat flow in the St. George Batholith was higher, but the radiogenic heat production suggested that the thickness of batholith rocks must be small. Heat flow in the Pokiok Batholith was similar, but the heat generation was lower, so that there was no reason to suppose that the intrusive rocks were thin. The Wedgeport and St. George Batholiths do not fit the general relation of heat flow to heat generation for the Maritime Provinces as defined by Wright et al (1980). Heat flow in Prince Edward Island and other parts of the Magdalen basin were generally low, implying low temperature gradients and poor potential for use of water from sedimentary aquifers.

Thomas,M.D. and Willis,C., 1989. Gravity modelling of the St. George Batholith and adjacent terrain within the Appalachian Orogen, southern New Brunswick.

This paper reported a detailed gravity survey across the St. George Batholith, designed to examine the shallow depth of radiogenic rocks postulated on the basis of thermal data. It was found that the gravity data implied a much deeper batholith. The four gravity profiles showed that the St.George Batholith has a thickness ranging from 4.3 to 7.0 km. At the Welsford borehole site it was found to be about 6.5 km thick, compared with the 1.4 to 3.3 km deduced from th relation of heat flow to heat generation. The discrepancy was thought to be due to the concentration of radiogenic elements in the upper layers by hydrothermal systems while the intrusive still retained its initial heat. The depletion of the heat generating isotopes in the lower parts of the batholith severely reduces its capacity as a source of hot dry rock.

EARTH SCIENCE

The Atlantic region has an eventful tectonic history, and has a much more complex geological and tectonic structure than other parts of Canada covered by this report.. The region suffered major upheavals when the European plate collided with the North American plate, starting in Early Ordovician time, and concluding with the Taconic Orogeny in Middle Ordovician time. The Acadian Orogeny took place in Middle Devonian time, probably related to the accretion of the Avalon terrain, the eastern part of Newfoundland, and accompanied by the intrusion of large granitic batholiths. The Magdalen Basin was formed in Late Devonian and Carboniferous time. Rifting began in Late Triassic time, followed by the opening of the Atlantic Ocean in Jurassic time. Volcanic activity produced mafic volcanic rocks on the south-east shore of the Bay of Fundy. Since then the Atlantic Ocean has steadily widened and the sediments of a passive margin have accumulated on the east coast from Nova Scotia to Labrador. Parts of the old European plate were left behind in North America, and parts of the old North American plate remained with Europe. The complex geological terrain is a legacy of these changes.

Granitic batholiths of Devonian age have long lost any residual heat or associated hydrothermal systems, and any geothermal potential that they still have is related to heat generation by radioactive trace elements and potassium.

While geothermal gradient is the best indicator of geothermal energy potential, the thermal nature of the crust is best indicated by heat flow. Heat flow is controlled by the radioactive heat generation of the whole crust as well as the tectonic history of the area. Measured terrestrial heat flow and geothermal gradients generally reflect the long time since tectonic events caused crustal heating.

Heat flow measurements are usually corrected for the effects of Pleistocene glaciation, which usually adds 15% to 20% to the observed value. Since the heat flow is intended to represent a property of the crust as a whole, it is necessary to make this correction to remove the effect of purely surface disturbances. On the other hand, temperature gradient, as needed in the search for geothermal resources, is not a property of the whole crust but of the upper few hundred metres. Thus the observed value, rather than the corrected value, is shown in the following diagrams. In any case, geothermal gradient varies with depth, depending inversely on the thermal conductivity of the rocks.

Temperature and gradient

Several wells and boreholes in the Atlantic Provinces had been used for temperature measurement, by both the Earth Physics Branch and by Dalhousie University (Hyndman et al., 1979; Wright et al. 1980). Contracts to John Leslie and Associates Ltd. Provided a more comprehensive collection of temperature data.

Temperature gradients in the Maritime Provinces are shown in Fig. 9. Temperature gradients are mostly in the range 10 to 18 mK/m, values that are not encouraging for geothermal resource development. The lower values, shown in red, occur mainly in the sediments of the Cumberland Basin and older sedimentary rocks. Values in plutonic rocks, mainly of Middle Paleozoic age, show slightly higher temperature gradients, but they are still not high enough for geothermal development.

Temperature gradients in Newfoundland are shown in Fig.10. Here the highest known gradient occurs in the Precambrian rocks of the southern part of the island. Known gradients in other parts do not exceed 15 mK/m. Gradients in many parts of Newfoundland are unknown, particularly in the small areas of Carboniferous sediments.

Hot dry rock potential

Granitic intrusive bodies often have elevated heat generation because of high levels of radioactive isotopes, uranium, thorium and potassium. Heat generation levels can often be as much as 4 mW/m^3. If there is sufficient thickness, about 10 km of such rock, the heat flow is augmented by 40 mW/m^2, which, added to a normal crustal heat flow of 50 mW/m^2, gives a heat flow of 90 mW/m^2. Given a thermal conductivity of 2.5 W/mK, this can produce a geothermal gradient of about 35 mK/m. A 2500 m well will thus encounter temperatures of about 100 ^{O}C. These values had been found in intrusive rocks of southwest England, and had been the subject of studies financed by the European Union.

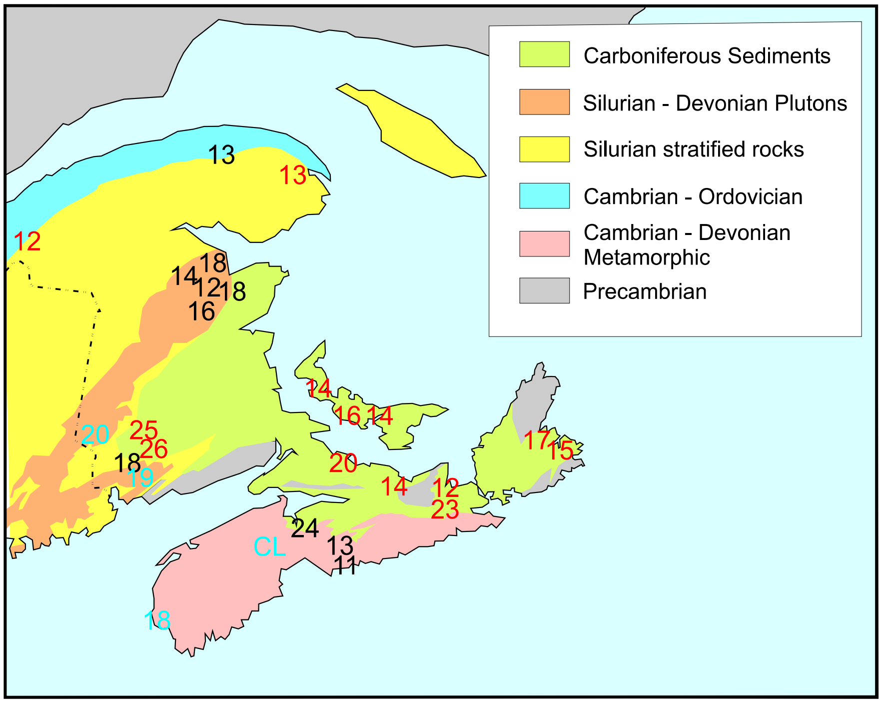


Fig. 9. Geothermal gradients in the Maritime Provinces, plotted on a simplified map of bedrock geology. Gradients in sedimentary rocks are shown in red, those in batholiths are shown in blue, and others are shown in black. The Card Lake site is a lake measurement and so has no relevant geothermal gradient. It is shown by the initials CL.

Investigations into the potential for hot dry rock in three batholiths in New Brunswick and Nova Scotia were based on the relation between heat flow and heat generation derived for Newfoundland and the Maritime Provinces by Wright et al. (1980). In several areas of the world, known as "heat-flow provinces" a linear relation between heat flow and heat generation is observed. This implies either a uniform heat generation for each observation site for a uniform depth below the surface, underneath which is a uniform crust, or an exponentially decreasing heat generation with a uniform exponential decrement. The linear relation is expressed by

$$Q = Q_0 + bA_0$$

where Q is heat flow at any depth, Q_0 is heat flow at the surface, b is the thickness of the radiogenic layer and A_0 is the heat generation at the surface. This equation is satisfied by a heat generation related to each heat flow with a constant thickness, or an exponential decrease of heat generation given by

$$A(z) = A_0 \exp(-z / b)$$

Further detail of this empirical relationship may be found in Jessop (1990a).

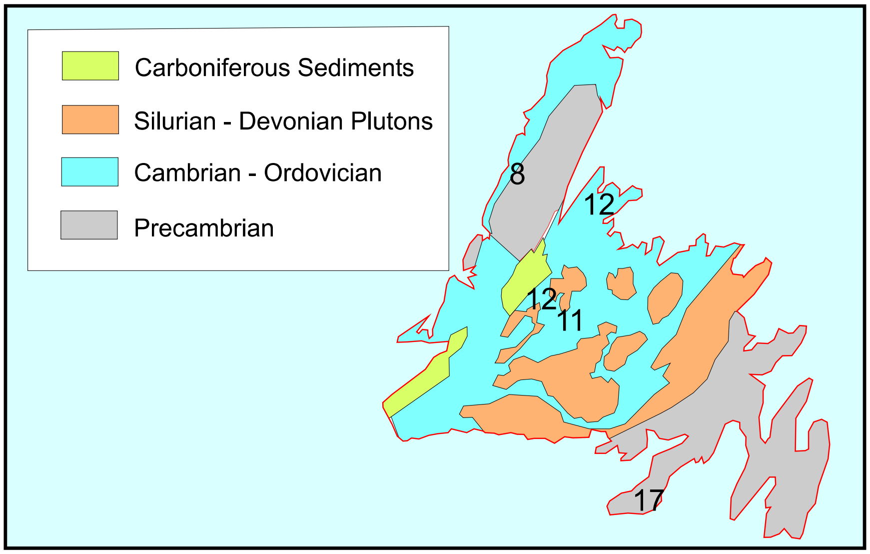


Fig. 10. Geothermal gradients in Newfoundland, plotted on a simplified map of bedrock geology. Gradients in sedimentary rocks are shown in red, while others are shown in black

Fig 11 shows the observed relation for Atlantic Canada, with some others. The points for the sites in granitic batholiths are shown in red. The Pokiok and Card Lake points are in agreement with the general linear relationship. The Wedgeport and St.George sites are to the right of or below the line, implying that the observed heat generation is too high and does not represent as much of the crust as the slope of the line indicates. The interpretation by Thomas and Willis, that radiogenic elements have been concentrated near the surface gives a reasonable explanation, implying that the potential for hot dry rock cannot be determined by measurements of radiogenic heat production alone, but must be accompanied by drilling and the measurement of thermal gradient and heat flow. This interpretation also implies that the potential for exploitable hot dry rock at the St. George and Wedgeport Batholiths is poor.

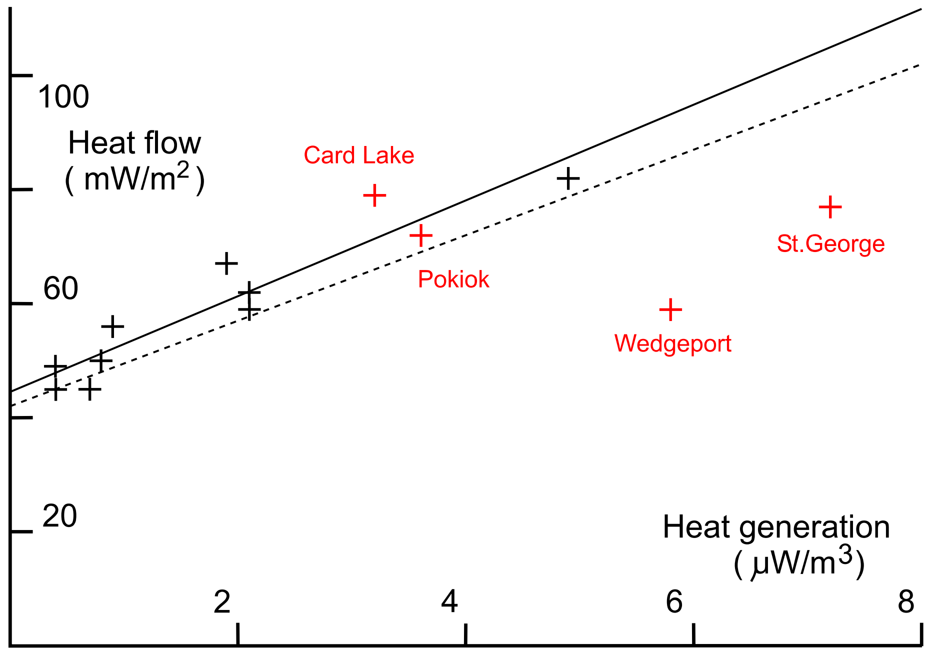


Fig. 11. Plots of heat flow against heat generation for Atlantic Canada. The best linear relation is shown by a solid line The dashed line shows the similar line for New England. The points for sites within granitic batholiths are shown in red with the site names attached.

ASSESSMENT OF RESOURCE

No attempt has been made to do detailed estimates of the geothermal resources of Atlantic Canada. The example of the Western Canada Sedimentary Basin in Chapter 3 could be applied to the sedimentary basins, but it would first be necessary to collect data from hydrocarbon exploration and other sources. Because geothermal gradients are generally low, at least in the onshore parts of the basins, the deep geothermal resources may not be economically attractive. Places where the geothermal gradients are higher than most, as in the Fredericton Graben, may have thin sediments that do not extend to depths sufficient to hold water of sufficient temperature.

The hot dry rock resources that have been investigated also turned out to be rather disappointing, but few of the possible sites were investigated. Two sites of the three investigated show poor prospects for hot dry rock at a reasonable depth, but a sample of three sites is insufficient to provide a definite conclusion.

The potential for geothermal energy use in the Atlantic region probably depends on local anomalies in geology and temperature. Temperature gradients so far known are not encouraging, but the area is geologically diverse. Discovery of useful thermal anomalies may be difficult and may depend more on chance than on systematic investigation. Places to examine are the smaller sedimentary basins, such as the Pictou Basin and small basins in Newfoundland and Cape Breton. Exploration of batholiths for high temperature gradients and hot dry rock have not been encouraging.

As recounted in Chap. 5, the most successful exploitation in the area has been the site of the abandoned coal mines at Springhill, and old mines in other areas could be profitably explored.

Pictou Basin

A study of the application potential in the Pictou Basin was proposed by Novacorp International Consulting Ltd. In 1985. This study was approved for a cost-sharing between the Geothermal Energy Programme, the Renewable Energy Division of DEMR and the "unsolicited proposal" fund of Dept Supply and Services. Before the contract could be let the Geothermal Energy Program was terminated and a blanket freeze on new spending was announced, and the work proposed work was never started. Thus a potentially useful study was lost.

LEGAL DEFINITION OF GEOTHERMAL RESOURCES

As a result of the development of geothermal resources from the mines at Springhill, the Govt of Nova Scotia passed an amendment to the Mineral Resources Act to include geothermal resources.

Geothermal resources are defined as: "a substance, including steam, water and water vapour, that is found anywhere below the surface of the earth and that derives an added value from the natural heat of the earth present in, resulting from or created by the earth". The act also provided for the designation of "geothermal resource areas" (Govt of Nova Scotia, 1992).

CHAPTER FIVE

SHALLOW AND LOW-TEMPERATURE RESOURCES

INTRODUCTION

The question of the use of low-temperature and shallow aquifers, combined with heat pumps, was not generally within the scope of the Geothermal Energy Program of 1976 to 1986. However, when requests came from municipalities participants of the program undertook to be of assistance. The projects that came to fruition were at Carleton University, Ottawa, and Springhill, Nova Scotia.

MECHANISM OF APPLICATION

Shallow and low-temperature resources are usually used in association with heat pumps. Heat pumps are devices that will take heat from a cooler to a hotter fluid. The primary fluid is water from the ground, usually at temperatures from 5 ^{O}C to 20 ^{O}C. This water may be brought to the surface for direct access to the heat pump, or a down-hole heat exchanger may be used so that a secondary fluid reaches the heat pumps.

Since the action of a heat pump is in opposition to the laws of thermodynamics, an external energy source must be provided. The power source is usually electricity, derived from the national grid. The performance of a heat pump is defined by the energy converted to usable temperature as a fraction of the energy input, known as the "Coefficient of Performance" or COP. The value of this is usually about three.

Application systems have a wide variety of formats, depending on the nature of the geothermal source, the land area available, and the nature of the load. Applications vary in size from the individual family house, of which there are about 36,000 installations in Canada, to industrial buildings at Springhill, to large apartment buildings in Paris, France.

REVIEW OF CONTRACTED STUDIES

Since the Geothermal Energy Program was not aimed at shallow resources, there were few contracted studies. Most studies were aimed at developments at Springhill.

John M. Booth Engineering Ltd. 1985. Outline report on the minewater *geothermal heat source*

The Town of Springhill, assisted by John Booth Engineering Ltd, perceived that water from flooded mines and heat pumps had been used successfully in some locations in Pennsylvania, USA. They proposed to both Provincial and Federal governments that this system should be examined in the context of the Town of Springhill. The Geothermal Energy Program funded the first feasibility study, after which other agencies were willing to take part.

Springhill had been a major coal-mining centre until rock bursts forced the closing of the mines in 1958. The mine workings went to a depth of 1323 m and were the deepest in the world. By 1984 they were flooded. Water in the mines was circulating by convection and had a temperature of 18 ^{O}C to 20 ^{O}C, much higher than the normal ground temperature of about 6 ^{O}C to 8 ^{O}C. The industrial buildings of the town were almost all over mine workings. It was proposed that boreholes into the mine workings could bring up the warm water, which could be run through heat pumps and returned to the mines by a second borehole. It was shown that there were at least 25 buildings that could benefit from geothermal heating. Energy costs would be about 40% of the costs of oil heating. Capital pay-back times would be from four to six years for heating systems and better than two years for systems delivering both heating and cooling. The report concluded that the concept of geothermal heating was technically feasible and identified twenty four facilities that could benefit by retrofit.

Jacques Whitford & Associates Ltd. 1987. Town of Springhill geothermal demonstration project: report on the test drilling and pumping test results.

Three test wells were drilled in July 1987, at sites near the Can Am Container plant and the community rink. Temperature measurements were taken and water samples were taken for chemical analysis. One well was reamed to 203 mm and equipped with a 25 HP pump for flow testing. Thorough reports of pumping test results, chemical content and corrosion or scaling potential. The report concluded that the flooded mine workings are a suitable source of water for use with heat pumps and that water produced from the workings has a temperature of at least 18^{O}C. Conclusions on the potential scaling and pumping rates were also included.

Katherine Arkay Consulting. 1992. Geothermal energy from abandoned mines: a methodology for an inventory, and inventory data for abandoned mines in Quebec and Nova Scotia.

Because of the success of the pioneer work of the Town of Springhill in the use of mine water and heat pumps for heating industrial buildings, an investigation into the sources of information about abandoned mines was conducted. There are many abandoned mines in all provinces of Canada, and the Provinces of Quebec and Nova Scotia were used as the model for a system of search and data record. The report includes the design of a data form, which includes the questions of location and size of the mine, possible temperature of the water, proximity to potential users. Information on the mines is to be found in provincial records. Data were included of about 160 old mines in Quebec and 400 mines in Nova Scotia.

Vaughan Engineering Associates Ltd. Undated, probably 1992. Feasibility study to establish a community heating system un the Town of Springhill, N.S. using warm mine water.

This report was sponsored by the Canadian Centre for Mineral and Energy Technology (CANMET), probably in 1991 to 1992, although the report is not dated. The report examined the potential for district distribution of mine water to large numbers of buildings within the town. It concludes that the costs of retrofit of many small buildings, accompanied by extensive distribution systems, were much less attractive than the same process in large industrial buildings. Thus, the development of geothermal heating in the Springhill Industrial Park was the best use of the resource. The most cost-effective system at the time of writing was the continuation of the policy of localised wells for individual buildings.

Katherine Arkay Consulting. 1993. First Springhill geothermal energy conference, Springhill, Nova Scotia, 28-29 October 1992.

In October 1992 the Town of Springhill hosted a conference to display and discuss the successes of the geothermal applications to that date. There were ten formal presentations and four group sessions, followed by reports and discussion. There were 91 participants.

The conference dealt with:

- the nature of low-temperature geothermal resources;
- an inventory of abandoned mines;
- technology for assessment and recovery;
- district heating systems;
- aquifer management systems;
- economics and ownership of the resource.

The conference concluded that cost-effective recovery and use of the energy had been proved to be feasible, that the Springhill experience was of potential benefit to other communities, and that there legislative issues that needed to be addressed.

It was decided that there should be another conference the following year to examine advances in the identified needs, but the Town changed the management of the Geothermal Committee and no further conferences have been held.

Office of Energy Research and Development, Natural Resources Canada. Renewable Energy in Canada Status Report 2002.

This report devoted little space to geothermal energy, but it estimated that there were 30,000 residential ground-coupled heat pump systems in Canada.

REPORTS FROM OTHER SOURCES

Morofsky,E. Aquifer thermal energy storage at the Scarborough Government of Canada building.

This conference paper described the plans to use a ground-coupled heat pump system at a new Government of Canada building in Scarborough Ontario. This being a new building there was no question of retrofitting. A comprehensive program of monitoring the system and the thermal effects on the aquifer.

REVIEW OF REPORTS FROM INTERNAL SOURCES

Jessop,A.M., MacDonald,J.K. and Spence,H. 1995. Clean energy from abandoned mines at Springhill, Nova Scotia.

This published paper described the geological setting of the Springhill coal mines. It included estimates of the volume of coal removed and the volume and temperature of water that is now in the flooded workings. Records of temperature of the water from the mine, both before and after the heat pumps were analysed for heat extraction. It was found that the Ropak Can-Am plant puts more heat into the mines during the summer air-conditioning season than it takes out during winter heating, mainly because the plastics moulding process itself produces a great deal of heat. Other industrial buildings, office buildings, and multiple residential buildings would be expected to take out more heat in the winter than they would put back in the summer. It was calculated that operating the heat pumps by means of electricity generated in coal-fired power stations reduces the carbon dioxide emissions by about 50% from the level that would be produced by local heating by fuel oil.

EARTH SCIENCE

Ground temperature is controlled by latitude, elevation, climate, and geological conditions. The land area of Canada covers a wide range of latitude, from about 42 ^{O}N to 82 ^{O}N, and a wide range of elevation, from sea-level to over 5000 m. Climate varies widely from temperate rain-forest to semi-desert, and geological conditions from exposed Precambrian rock to deep deposits of Pleistocene glacial material. Most applications may be expected to be in lower elevations, or at least in elevated plains.

Temperatures immediately below the ground surface vary from winter to summer. Fig.12 shows a record of temperature measured at the depth of one metre on a patch of open ground in north-west Calgary. The curve is roughly sinusoidal, except that the minimum is truncated by freezing of water in the soil. The minimum temperature recorded was -0.1 ^{O}C, and the temperature remained at that point for about two months. Because of capillary effects, -0.1 ^{O}C probably represents the ambient freezing point, so that the ground at that depth was probably never

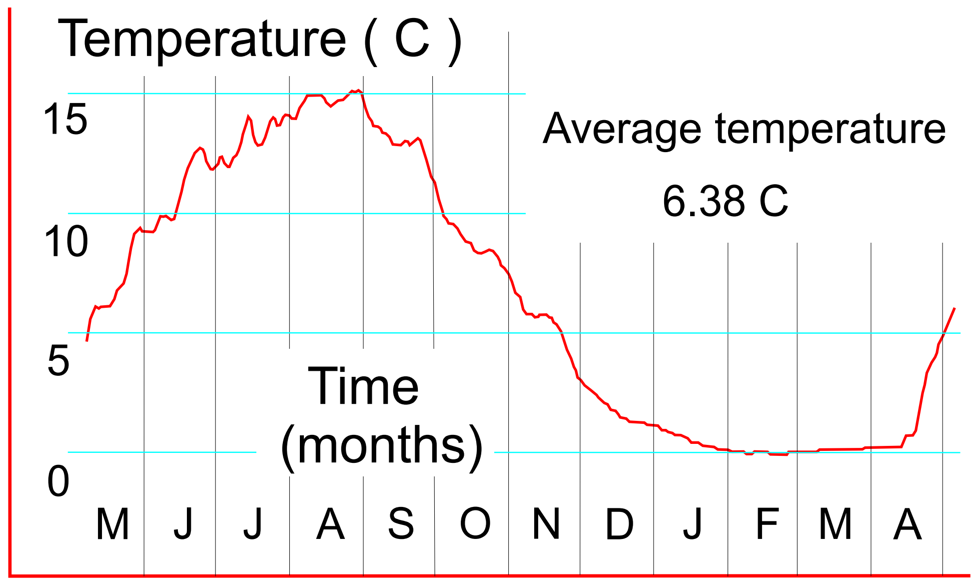


Fig 12 Record of temperature over a period of one year at a depth of 1.1 m below grass-covered open land within the City of Calgary. The temperature minimum is truncated by latent heat of freezing. The record shows the delay caused by the diffusion process: the temperature does not reach the freezing point until the end of January and the highest temperature occurs at the end of August.

completely frozen. The rise from that point was rapid, after all moisture was thawed. Where there is no water present the temperature distribution with depth looks approximately as shown in Fig. 13. These are theoretical curve, with the extreme seasonal temperature range set at 20 ^{o}C, and assuming a dry soil of thermal diffusivity 0.5 mm^2/s. The seasonal changes are attenuated and the times of maximum and minimum are delayed with increasing depth. At a depth of 7 m the maximum temperature occurs in the winter, but at that depth the annual variation is reduced from 20 ^{o}C at the surface to 0.86 ^{o}C, or to 4.3 % of the surface value. Below a depth of 10 m the seasonal variation is very small. Water in the soil will distort the curves if the temperature drops below the freezing point.

There is a further disturbance from long-term climate changes. Temperature changes resulting from the Pleistocene glaciations are of no importance, but the climatic warming of the last two centuries has a significant influence. Fig.14 shows two temperature profiles from a borehole at Hearst, Ontario. The data were obtained in1970 and 1985. The lower part of the temperature log indicates that most of the subsurface is at temperatures that are in equilibrium with a surface temperature of 2.5 ^{o}C, whereas the upper sequence of data are in equilibrium with a temperature of 5.5 ^{o}C. Since warming has been so rapid, the subsurface temperatures have not had time to adjust to an equilibrium geothermal gradient. The1970 data and others were used in one of the first attempts to derive climate records from subsurface temperature profiles (Cermak, 1971), who

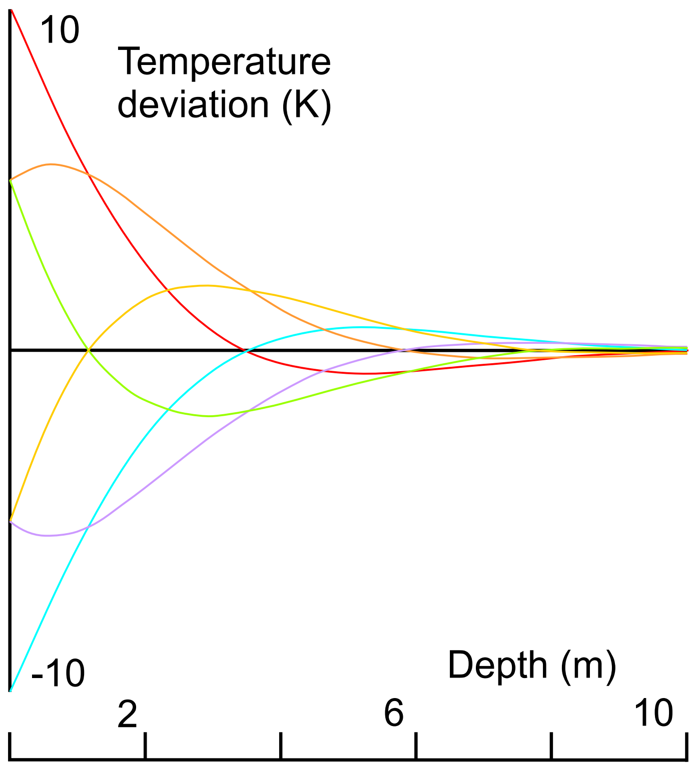


Fig 13 Theoretical temperature profiles in a dry soil with a seasonal temperature range of 20 K. The red curve represents the temperature profile in July, orange in September, yellow in November, blue in January, purple in March, and green in May.

showed that inversion of such observed temperature profiles yields history of the surface temperature, including the recent warming and, in profiles of about 600 m in depth, the warm period of medieval times and the "Little Ice Age" of the 17th to 19th centuries. The temperature minimum progresses downward, and is at a depth of about 80 m in this curve. The data indicate that the surface temperature has decreased slightly between 1970 and 1985, but seasonal effects may be disguising the effect. The 1985 curve shows how the minimum temperature zone is being warmed from both above and below, so that the temperature is increasing. This kind of temperature inversion is found in most parts of Canada and other parts of the world.

Table 5 shows some surface temperatures from selected places within Canada. Two temperatures are given for each locality, the first being the temperature with which the straight part of the temperature log appears to be in equilibrium, and the second being the observed seasonal average of temperatures close to the surface at the time of measurement. The year of measurement is also shown. Where the second temperature is missing the data are insufficiently close to the surface to show the current temperature.

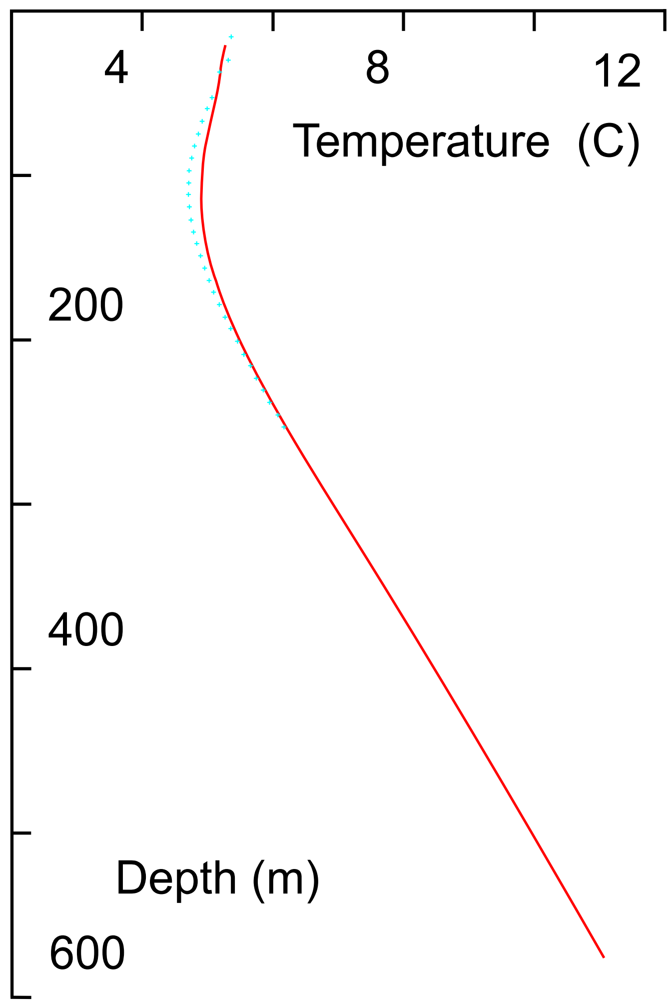


Fig 14 Two temperature logs from a 600 m borehole near Hearst, Ontario. Blue points represent data from 1970, and the red line from 1985. The temperature inversion is attributed to surface warming since about 1850. Some unknown disturbance in the upper 40 m obscures the purely conductive response to surface temperature change, but the "filling in" of the minimum, by conduction from both above and below, is clear.

Climatic warming of the industrial era has warmed the surface of the earth by up to 4 K, depending on location, resulting in an inverted geothermal gradient in the first 50 m to100 m. This means that temperatures of rock or water in the ground does not increase with depth at shallow depth, but is often found to decrease at first. Thus climatic warming has improved the temperature of the shallow resource and improved the prospects of finding enough heat in the

Table 5

Surface temperature from selected locations

Site	Lat.	Long.	Temp 1	Temp 2	Date	Comments
Reindeer D-27, NWT.	69-06	134-37	-8		1978	MacKenzie Delta
Red Mountain, YT.	61-00	133-45	1	2	1981	
Dease Lake B.C.	58-39	130-00	2			
Summerland B.C.	49-36	119-36	10	10	1992	In town
High River, Alberta	50-39	113-52	4	6		
Calgary, Alberta	51-05	114-07		6	1999	Directly measured
Instow, Sask.	49-45	108-20	6			
Moose Jaw, Sask.	50-23	105-30	6			In town
Regina, Sask	50-28	104-43	2	5		Water disturbance
Bent Horn F-72A, NWT.	76-22	103-58	-16		1981	Arctic Islands
Winnipeg, Man.	49-49	97-08	6	8		In town
Hearst, Ont.	49-41	83-32	2	5	1985	
Kapuskasing, Ont.	49-25	82-23	3	5	1970	
Cochrane, Ont	49-07	80-56	2	6	1970	
Nielsen Is, NWT.	55-24	77-41	0	1	1964	
Franktown, Ont	45-00	76-04	6	9	1962	
Ottawa, Ont.	45-24	75-43	7	10		In town
St.Jerome, Que.	45-49	74-01	6	7		
Roberval, Que.	48-32	72-15	6	7		
St.George Bath NB.	45-27	66-26	6	9		
Pokiok Bath, NB.	45-43	67-19	6	6		
Wedgeport, NS.	43-45	66-00	8	10		
Brunswick Mine, NB.	47-29	65-53	5			Mine site
McDougall, PEI.	46-30	63-57	6	7		
Oldham, NS.	44-55	63-29	7	7		
Wallace, NS.	45-47	63-27	6	8		
Kelly Cross, PEI.	46-16	63-27	6	7		
Antigonish, NS.	45-39	61-52	6			

ground for successful exploitation.

Although the normal geothermal gradient cannot cause convective overturn in a diamond drill hole of 5 cm to 10 cm in diameter, it is sometimes capable of causing overturn in water in a hole of the size normally drilled by the hydrocarbon industry. Such convective movement has been occasionally observed. Thus a vertical hole the size of a mine shaft is almost certainly able to sustain convective overturn in water. The connected workings of the mines can also probably sustain convection, provided ventilation doors and seals have been opened or have decayed sufficiently. Thus the temperature of water in a mine is able to reach a value roughly intermediate between surface temperature and the temperature at the deepest point reached. For example, at Springhill, the surface temperature is about 7 ^{O}C. The geothermal gradient has not been measured, but is probably is between 14 mK/m and 20 mK/m. The temperature at the lowest point in the mine, at a depth of 1350 m, is thus between 26 ^{O}C and 34 ^{O}C. The mean temperature between surface and extreme depth is thus between 16.5 ^{O}C and 20.5 ^{O}C. The temperatures reported by observers at Springhill fall within this range.

THE SPRINGHILL PROJECT

A delegation from the Town of Springhill visited the Earth Physics Branch in the August 1985, with questions about the feasibility of using water from abandoned coal mines at a temperature of about 20 ^{O}C, for the purpose of heating industrial buildings. The Town had already approached the Govt of Nova Scotia for support for their research, but with no result. Scientists of the Geothermal Energy Program saw the idea as having a good chance of success and worthy of support, and agreed that they would fund a small contract for a feasibility study of the local situation, including availability of the source water, the location of potential users, and the economic advantages to be gained.

Results of the study showed that the Industrial Park was fortunately located over the mine workings as they dip to the west from pit-heads on the east side of the town. Provided the surface and underground maps could be reconciled, it would be easy to drill into water-filled cavities or tunnels. There were already buildings in place that could be retrofitted, and there were good prospects of new building to take advantage of the low-cost heating and cooling. An expert surveyor in the Provincial Department of mines, by the name of Chris Kavanaugh, provided the necessary alignment of the surface surveys with the mine surveys.

As reported above, one successful application, at the Ropak Can-Am building, was economically and environmentally successful in 1990. Other companies had or were planning similar installations, and the Town of Springhill was actively seeking new industries to take advantage of the low cost of heating and cooling available in their industrial park.

In 1992 the Province of Nova Scotia published the following:

“Order in Council 92-906

The Governor in Council on the report and recommendation of the Minister of Natural Resources dated the 19th day of August, 1992, pursuant to clauses (a) and (b) of subsection (1) of Section 8A of Chapter 18 of the Acts of Nova Scotia 1990, the Mineral Resources Act, is pleased to

(a) designate as a geothermal resource area that area of Springhill, in the County of

Cumberland, more particularly described in Schedules"A" and "B" attached to and forming part of the report and recommendation, and which area shall be referred to as the Springhill Geothermal Resource Area;

(b) determine that the designation of the Springhill Geothermal Resource Area shall be effective on, from and after the 3rd day of September, 1992; “.

OTHER LOCATIONS

It is estimated that there are over 36,000 domestic ground-coupled heat-pump systems in Canada, which is one of the leading countries in this kind of energy use. Countries that exceed the Canadian number are the USA, with 600,00, Sweden, with 200,000, and Germany, with 40,000. The world-wide total is about 900,000. (Curtis et al., 2005)

Carleton University, Ottawa.

Since 1990 Carleton University, in Ottawa, has been using groundwater to cool buildings in the summer and to pre-heat building air in the winter. The groundwater comes from faults and fractures in the local limestone at a temperature of about 9 ^{O}C. Wells yield from less than a few litres/sec to over 100 litres/sec, depending on the proximity to fractures.

Okotoks, Alberta

The Town of Okotoks, near Calgary, Alberta, has built a solar heating system for a subdivision of 52 houses, using seasonal underground storage. The principle is well known in Europe but this is the first in North American. The system uses 2300 m^2 of solar panels, which on a sunny summer day will generate 1.5 MW of thermal power. In the summer much of this energy is stored in a borehole field under the neighbouring park. There are 144 boreholes of depth of 37 m, within an area 70 m across. The system is designed so that the underground storage temperature reaches 80 ^{O}C by the end of the summer. This combination of solar and geothermal systems is expected to provide up to 90% of the space heating needs of the 52 houses.

Oshawa, Ontario

The University of Ontario Institute of Technology, at Oshawa, Ontario, planned the eight buildings of its new campus to be heated and cooled entirely by a ground-coupled heat pump system. The system will use 384 boreholes of depth 213 m, and approximately 160 km of plastic pipe in the ground. (Options, 2004)

Timmins, Ontario

The City of Timmins has investigated the use of water from a former gold mine. The temperature in the shaft is reported to be about 12 ^{O}C to 13 ^{O}C

PROFESSIONAL AND INDUSTRIAL ORGANISATIONS

The Canadian Association for Renewable Energies provides information on a variety of renewable sources. Its publications contain a selection of news items on all renewable sources. Within the web page on 25 January 2007 was the following notice.

"Renewable Energy Association Ceases Operation 2006-11-28 (Canadian association for renewable energies). A national association that promotes a leading renewable energy technology will cease its operations, effective immediately. The Earth Energy Society of Canada (formerly Canadian Earth Energy Association) was incorporated in 1989 to promote geothermal heat pumps, and administered a $20 million utility program during the 1990s as the industry installed 38,000 systems across the country. Geothermal currently provides the thermal equivalent of 600 million kWh a year and displaces the emission of 250,000 tonne of GHG. EESC has been forced to stop its promotional activities as a result of a law suit that alleges improper use of domains with 'geo-exchange' in the name. The claim in federal court says EESC, the Canadian Association for Renewable Energies and Bill Eggertson (personally) violated the term 'geoexchange,' a U.S. trademark. "We offered to transfer ownership of the domains to the plaintiff for free, if they had dropped the case before lawyers got involved," says Eggertson. "They refused, and the legal fees have drained the reserves." Geothermal heat pumps will remain represented in the Green Heat Global partnership through GeoCanada.org / EcoHeat.org, and c.a.r.e. will track the millions of dollars in federal spending for geothermal that is no longer directed to the domestic industry."

As of the same date, the web page of the Earth Energy Society of Canada was still available. It provided a long list of contractors and information on CSA standards for such installations.

There are many web sites belonging to contractors who will install ground-coupled heat pump systems in residential buildings. Associations or societies of these contractors provide a more useful starting point

Canadian Association for Renewable Energies	www.renewbles.ca/
Earth Energy Society of Canada	www.earthenergy.ca/

FUTURE DIRECTIONS

This is one type of geothermal resource that has had a history of successful application since 1976, although it was not generally within the range of interest of the Geothermal Energy Program.

The residential market for ground-coupled heat pump systems is in a healthy state. The number of installations exceeds 36,000 across the country, mainly in British Columbia and Ontario. CSA standards have been established. This technology is probably best used with new buildings, where the heat-exchange pipes can be laid in the ground before the house is constructed. However, given the present trend towards larger houses and smaller lots, the ability to install the necessary underground systems may be reduced.

Multiple housing units are excellent candidates for this type of heating system. The example of Okotoks, Alberta, is an excellent model to be followed almost anywhere in the country.

Reservoirs in abandoned mines deserve more attention than they have been receiving. The example of Springhill, Nova Scotia, stands out as an attempt by the town to revive and replace its industrial base. There must be many other old mining towns that could benefit from this example, and an active program of education could bring benefits.

CHAPTER SIX

ENGINEERING AND ECONOMICS

INTRODUCTION

Early work of the Geothermal Energy Program addressed the question of the existence of geothermal resources and was necessarily based on earth science. As the existence of resources was demonstrated and the nature of the resources became clear, the question of the means and costs of using the resource came to the fore. Eventually the National Research Council added an engineer, Dr. Brian Larkin to the program to build on the work already done by the geologists and geophysicists.

REVIEW OF CONTRACTED STUDIES

SNC group. 1982. Survey of geothermal heat extraction technology. Rept. to Nat.Res.Council Ottawa, 192pp.

This report began with a review of some existing geothermal technology and earth science. It then reviewed Canadian conditions, borrowing mainly from publications of scientists of the Geothermal Energy Program. This was followed by a review of utilisation systems of several foreign installations and of the various uses to which process heat could be put. The report comprises a good introduction to all aspects of geothermal energy use, as they existed in 1982, but it contained nothing new and most of the material can be found elsewhere.

Acres Consulting Services Ltd. Low temperature geothermal energy applications

This study examined many potential applications of geothermal energy, including space heating, both domestic and agricultural, mine air heating, aquaculture, feedwater heating, and desalination. The term "low temperature" in this report means between 60 ^{O}C and 100 ^{O}C . It was concluded that the size of an individual doublet system, as used in France and proposed at Regina, limits the application to large-scale applications, such as large commercial office and government administration buildings. The cost of geothermal heat would be more attractive if the prevailing cost of natural gas in Saskatchewan and Alberta were not so low.

All economic conclusions of this report were based on conditions in 1983, which came at a time of falling energy prices and a low level of environmental concern.

Acres International Ltd. 1985. Moose Jaw Geothermal Study.

For almost thirty years the City of Moose Jaw operated the "Natatorium", a warm pool of mineralised water from an unsuccessful gas well. The wooden casing of the well collapsed in 1957 and the flow of brine ceased. After the success of the Regina well in proving a source of hot water, the City of Moose Jaw expressed an interest in restoring the Natatorium and in investigating the further benefits that might come from a renewed geothermal system. The feasibility study was funded by the Geothermal Energy Program.

For economic operation the following requirements had been identified: heating applications with high load demands, the ability to retrofit to accept lower than normal supply temperatures, and the ability to use sufficient of the resource throughout the year. Geothermal systems require a high capital cost in exploration, drilling and testing, but low operating costs. Thus the economic viability depends heavily on the costs of investment.

Available data on geological and thermal conditions were reviewed, including information derived from the Regina well, and on which to base predictions of temperature for each of the main reservoir formations. The water from the old well came from the Manville and Gravelbourg formations at rates of 6.8 and 14.2 m^2 /hour, flowing under artesian pressure without the need for pumping. Total dissolved solids were about 10,000 ppm, about one third the salinity of sea water. Parameters were predicted for all the major reservoir formations that would be encountered by a well to the base of sediments at Moose Jaw. The deep reservoirs, in the Winnipeg and Deadwood formations, the source at Regina, would be hotter, at about 60 ^{O}C, but would have a substantially higher dissolved solid content, at about 180,000 ppm, or five times the salinity of sea water.

In addition to the Natatorium, sixteen buildings were considered for geothermal application. The potential for retrofit of heating systems, and costs were estimated for each building. Four report considered fou schemes for exploitation of geothermal heat. Scheme one included the Natatorium, an attached health spa, and the adjacent YMCA and YWCA buildings, with water at temperature up to 44 ^{O}C. Heating schemes two to four included increasingly larger distribution systems, each growing outward from the Natatorium complex, and using water from increasingly deeper formations at higher temperature. It was assumed that the City would be the sponsor, owner and operator of any central heat system that might be installed, and all financial analysis was based on this assumption.

The report concluded that the combining geothermal heating with Natatorium restoration and the development of the spa was practical and economically attractive for some of the schemes. It was recommended that the City should pursue the question of sources of financial assistance for such an energy demonstration project. Unfortunately, the federal government lost interest in all alternative energy options shortly after the report was written, and the City abandoned any plans to implement the systems suggested. Two wells were drilled, and one was logged for temperature by GSC staff. The results are shown in Fig 6-1. After some delay the source was bought and incorporated into a commercial hotel and spa.

Acres Consulting Services Ltd and Nevin Sadlier-Brown Goodbrand Ltd. 1984. Regulatory and commercial aspects of geothermal energy development.

At the time this report was written it was recognised that geothermal development in Canada was at an early stage of "limited exploration, resource testing and the examination of potential applications", and that "a multitude of regulatory, jurisdictional and commercial issues need to be identified and resolved". This report identified five basic types of geothermal resource, but did not mention shallow resources exploited by ground-coupled heat pumps. This type of resource was implicitly excluded from consideration.

The first offering of geothermal rights under the British Columbia Resources Act was made in June 1983. The rights consisted of a permit to explore and develop Crown geothermal resources near Mt. Cayley, a Quaternary volcano. The legislation under which this offering was made was intended to regulate exploration in the volcanic belts of the Cordillera, but it presumably applies also to the part of the Western Canada Sedimentary Basin that lies in north-eastern British Columbia. If so, this was, and still remains the only provincial or territorial legislation to govern geothermal operations outside the Cordillera and Nova Scotia. The well at Regina was drilled under existing regulations for oil and gas and for water resources.

The report reviews legislation in other countries. In the USA regulatory and commercial aspects have been addressed by the federal Congress and states known to have resources. The report comments: "Often the conclusion reached, and the direction given by these differing bodies, have been significantly different. Often, as well, the legislation has left as many questions unanswered as answered, or created as many new problems as it resolved. In some cases, the legislation has, in fact, proven to be more of an obstacle to development than an aid." These statements are followed by 103 pages of review of US legislation, environmental regulation, financial incentives and tax regulations. This is followed by 29 pages of information on legislative, financial and commercial aspects of the development of water from the Paris Basin. By the end of 1983 80 geothermal operations had been approved and 27 systems were in operation. In accordance with French convention, the economic benefit of these systems was given as the annual saving of 75,000 tonnes of oil, where one tonne equivalent of oil is 41.8×10^{9} J (11,600 kWh), for a total energy equivalent of 3.13×10^{15} J. Assuming that oil is 85% carbon, this saving of oil amounts to an annual saving of 2.4×10^{6} tonnes of carbon dioxide emissions, not accounting for the generation of electrical power needed to drive pumps. Short reviews of developments in the European Union, the United Kingdom, New Zealand, Iceland and Japan followed.

In Canada, natural resources, which include geothermal resources, fall under provincial jurisdiction. At the time of this report only British Columbia had any legislation that directly referred to geothermal resources, but Nova Scotia has since introduced legislation. In the absence of specific legislation, geothermal resources may be regulated under a variety of other legislation, including those related to oil and gas, land ownership, pollution control, pipelines, utilities, industrial safety, corporate tax, royalties, and others. Most geothermal use was then, and still is, governed by a collection of laws that ere not designed to govern geothermal resources and may be unsuitable for the purpose. Some provincial governments considered that the time to develop regulations was after the beginning of geothermal development, rather than in anticipation, an attitude that may be an obstacle to geothermal innovations.

The report includes six pages of details concerning the British Columbia Geothermal Act, followed by a brief statement for each other province or territory. Other provinces have no legislation, but the report summarises the situation in some of them. In Saskatchewan, where the Regina Geothermal Well was located, the drilling required a licence from the Dept. Of energy and Mines, because it penetrated strata that were potentially oil and gas bearing. There was no competition for the oil and gas rights because the area was regarded as having little hydrocarbon potential. The regulatory agencies were generally helpful on this particular occasion, but this may not always be so. There was perceived to be a potential for conflict between the Departments of Energy and Mines and of Environment. A further source of conflict could arise from the requirement that reinjection wells must not affect hydrocarbon rights within a radius of 1.6 km.

Geothermal development was perceived to be at the stage of exploration, innovation, and demonstration projects. The technological infrastructure was not present in Canadian industry. Financial assistance from governments was essential to early projects, followed by favourable treatment by tax laws. Apart from the assistance provided by the Federal Government under the Geothermal Energy Program and the Conservation and Renewable Energy Development and Demonstration Program (CREDA), and some provincial programs aimed at subsidising demonst5ation projects, there was little encouragement to industry to become interested in geothermal development. In British Columbia CREDA provided $750,000. The Geothermal Energy Program provided funds and expertise over a period of ten years. The bulk of the funds for the project were provided by the British Columbia Hydro and Power Authority.

In Saskatchewan, about 97% of the funds for the introductory research and drilling of the well at Regina was provided by the federal Geothermal Energy Program. CREDA provided funds for a feasibility study of the reinjection well, but the project was taken no further when hydrocarbon prices fell. In other provinces and territories costs of geological research and feasibility studies were generally borne by the Geothermal Energy Program.

It was concluded that the use of geothermal energy would have to be demonstrated before it could be considered as a viable alternative energy resource. Government funds were available at the time, but federal funds were all closed down in or before1986. Demonstration projects were required before progress could be made to the commercial development phase. Government support for such projects would increase interest. The motives for government support have changed since 1986, depending on the price of oil and gas, the perceived supply situation, and concerns over exhaust emissions. The conditions under which this report was written are not necessarily valid in 2007.

John M. Booth Engineering Ltd. 1985. Outline report on the minewater geothermal heat source

This study has been reported in the previous chapter

COMMUNITY AND INDUSTRY ENQUIRIES

Starting in 1983, participants in the Geothermal Energy Programme received a growing number of enquiries from outside agencies interested in the use of geothermal resources at specific locations. In addition to the projects at Meager Creek and Regina, which received substantial assistance from the Programme, there were several that involved a municipality and commercial consultant. Geographical distribution of the sources of these enquiries is shown in Fig.3. Details of specific projects follow.

Hinton, Alberta

A plan by developers for a resort on the Yellowhead Highway outside the Jasper National Park included a possible geothermal pool and heating plant. The site was in the foothills of the Rocky Mountains, only about 10 km from Miette hot springs. The complexities of predicting reservoir capacities and drilling in the highly faulted and tilted rocks of the foothills made the project very risky, and no geothermal development has taken place.

Bowden, Alberta

The possibility of geothermal heating of the Bowden jail was discussed in 1983. One of the earth science contracts was amended to include the site in its study area. Geological predictions were favourable, but the lead-time was too short for inclusion of geothermal heating in changes then planned.

Charlottetown, Prince Edward Island

In 1983 Noval Technologies Ltd proposed to the University of Prince Edward Island that the new veterinary college should be heated by a geothermal system. EMR scientists were doubtful of estimates of geothermal gradient of 25 mK/m, which they considered to be high. A shallow test well was drilled, and the gradient was shown to be only about 14 mK/m.

Edson, Alberta

In 1984 the Town of Edson and their consultants, Underwood McLellan Ltd. of Edmonton, asked for advice on their geothermal plans. A feasibility study was funded by the federal government, which described the geological conditions beneath the Town and some of the development options. Economic prospects were not attractive unless the cost of drilling geothermal wells could be substantially reduced by cooperation with the gas industry, whereby the industry would make available unsuccessful gas wells. This question was not resolved.

Moose Jaw, Saskatchewan

In 1984 the City of Moose Jaw requested advice on the restoration of the geothermal supply to the Natatorium, an indoor swimming pool that had been supplied by an unsuccessful gas well from its opening to about 1954. A feasibility study, funded by the federal government, showed a range of geothermal possibilities, with the most attractive being the drilling of a new well to tap the same artesian sources as before, with the addition of a spa facility. Detailed examination by the City of its plans for swimming facilities and of the tourist potential of a spa followed the completion of the feasibility study. A pair of wells for geothermal water was drilled by the City in 1989, in preparation for a spa. One of the wells was logged by GSC personnel in 1991 and results are described in Chap.3.

Summerland, British Columbia

Greenhouse operators in Summerland asked advice on the heating of greenhouses by low-temperature geothermal water from the sediments below. Since the temperature needed for heating or for hydroponic feeding is in the range 25 ^{O}C to 40 ^{O}C, an examination of the geothermal potential of the Town seemed appropriate. Consultants for the Town made a proposal to the federal government, but it was too late to be accepted before the Programme was cancelled in 1986. A small-diameter (150 mm) exploratory well was drilled in 1990, but funds were insufficient to reach the basal conglomerate, where the best aquifer was predicted. This well was deepened in 1992 to a depth of 940 m. Temperatures at that point were about 41 ^{O}C, but the expected aquifer formation was not reached and the available water supply was inadequate for development. Further drilling might encounter sufficient water, but the cost of drilling a production well would probably render the project uneconomic. Details will appear in the second part of this report.

Springhill, Nova Scotia

In 1985 the Town of Springhill asked advice on the heating potential, using heat pumps, of the water in the abandoned coal mines, which had been found to be at about 20 ^{O}C near the top of the old shaft. A feasibility study was funded by the federal government for completion in July 1986. The first operating system was installed in 1989, in an industrial park on the edge of the Town. New drilling in 1990 was designed to permit the installation of a second system in the middle of the Town. This constitutes a valuable new idea for the extraction of heat from shallow ground-water, since the supply is large and only shallow drilling is needed. A two-day conference was held in Springhill in October 1992, which was attended by representatives from other municipalities with abandoned mines and government representatives of federal, provincial and municipal levels. By 1994 there were eight users of the geothermal resource within the industrial park of Summerland and the long term potential of the energy supply is very attractive (Jessop et al, 1994). Details are to be found in Chap.4.

Mayo, Yukon Territory.

The Town of Mayo has been using water from a well in the gravels of the river valley as a source for heat pumps. Through the Remote Communities Demonstration Programme (RCDP) application was made to extend the system. Some questions regarding the reliability of the supply had been raised. Survey work within the Geothermal Energy Programme was cut off by the cancellation of the Programme, but the project was continued under the RCDP.

Kindersley, Saskatchewan

In 1983 Page Petroleum Ltd. drilled a water well to the basal clastic rocks in the Kindersley oilfield, to supply warm saline water for improving the recovery of oil from a higher formation. Temperature logging of the well was carried out by federal personnel in January 1984. It proved to be impractical to keep the water hot while it was on the surface, and a heat exchanger was installed in 1986. The heat was successfully used for preparation of the oil for input to the pipeline. This was the first industrial application of geothermal heat on the prairies. Its present (2007) condition is unknown.

Hot Springs Cove, British Columbia

Application was made to the RCDP by the Indian Band at Hot Springs Cove for help in developing the hot water of the springs for heating or other purposes. Several small springs are known, some of which are on the sea-floor. Surveys indicated that the natural springs are not well placed and that flow rates are low. Drilling to intersect the fractures carrying the water has a low probability of success and the potential increase of flow is limited.

Mt. Cayley, British Columbia

Mount Cayley is a recent volcanic centre in southwestern British Columbia, and with Mounts Meager and Garibaldi is the northern end of the Cascade Volcanic Range. Mount Cayley is known to have associated hot springs, and by drilling and surface surveys in the period 1980 to 1986, it was shown to have a geothermal anomaly and resistivity anomalies similar to those of Mount Meager. Details will appear in the second part of this report. Under legislation of the Provincial of British Columbia, O'Brien Resources Ltd. took out leases for exploration over the area immediately around the central peak,

Potash mines in Saskatchewan

Ventilation air in potash mines must be heated in winter to avoid structural problems caused by contraction of steel in the shafts. Preliminary study of the potential for heating by geothermal water instead of natural gas showed that there are technical advantages in the use of geothermal water, but that fiscal restraints make the conversion completely uneconomic.

CONCLUSIONS

The Geothermal Energy Program necessarily began with a strong earth science bias. As it became evident that there are considerable geothermal resources within Canada, the addition of an engineering and economic component was added.

Several municipalities showed interest, and scientists and engineers within the Program gave what help they could, but there was no apparent interest in the energy industry, particularly the hydrocarbon industry, which was best placed to look beyond the conventional energy sources.

The economic potential of geothermal energy, particularly of space heating could have been attractive in certain locations, but, by 1986, the cost of hydrocarbon energy had fallen below the peaks of 1975 to 1980 and there was no environmental concern about the long-term effects of continued combustion and free venting of exhaust gas.

The work of the Program was attracting attention and interest and was beginning to show results in applications when the Program was suddenly cancelled. Thus the accumulated knowledge of the resource was never put to its intended purpose.

CHAPTER SEVEN

FUTURE RESEARCH AND DEVELOPMENT

INTRODUCTION

The sudden cancellation of the Geothermal Energy Program cut off funding for all studies of Geothermal Energy. Economic conditions had changed and alternative energy sources no longer attracted the same interest that they had during the so-called "Energy Crisis" of 1973 to 1982. The possibility that this situation might change once more in the opposite direction was of no concern. The twenty years since the cancellation of the program has given ample time to ponder the future requirements for successful geothermal exploitation. It has also allowed time for another cycle of public concern over security of energy supply and environmental degradation to appear. Unfortunately the twenty years has also allowed ample time for participants to reach the age of retirement or to move into other lines of work

THE WESTERN CANADA SEDIMENTARY BASIN

In the Western Canada Sedimentary Basin the resource has been proved. There is ample evidence that there is a great deal of warm or hot water in the sedimentary aquifers. However, only at Regina and Moose Jaw have the necessary detailed feasibility study and confirming drilling been done.

At almost any point that lies over the deeper parts of the basin the chances of finding a good geothermal aquifer are very good, but each location must be examined individually. There are ample data of temperature, geological formations, porosity and permeability produced by the hydrocarbon industry, but, as Gorrell (1984) warned, these are not aimed at water-bearing strata and may not a give a complete picture of the geothermal resource at all locations. The economic conditions of each location must be included in the study. Fig.3 in Chap.3 shows the areas that might be reasonable expected to yield resources, including such large, medium and remote centres of population as Lethbridge, Calgary, Red Deer, Edmonton, Hinton, Edson, Rocky Mountain House, Grande Prairie, Dawson Creek and Fort Nelson.

The need here is not more basic science, but the willingness to consider geothermal heat as an alternate source and the local analysis of the potential applications. These are engineering and economic studies. The initial impetus must come from the communities themselves or from the hydrocarbon companies that are willing to consider alternative energy sources.

THE ATLANTIC REGION

The most likely source of geothermal energy in the Atlantic Region is in the sedimentary basins. These are not as well explored as the Western Canada Sedimentary Basin, except in some offshore areas, and so the earth science data are not as easily or cheaply compiled. However, the coal industry has produced some data in Nova Scotia. Unfortunately, geothermal gradients tend to be low, less than 20 mK/m, and so the prospects are not generally encouraging. Intrusive rocks are generally too old and lacking in adequate radiogenic isotopes to offer good prospects for hot dry rock. Warm water in abandoned mines is probably the best option in the Atlantic Region.

The impetus for investigation must come from municipalities, potential users or energy providers.

ABANDONED MINES

Towns situated above abandoned mines present a special case in all parts of the country. The example of Springhill, Nova Scotia, is one that could be profitably followed in many places where the closure of mines has removed the main economic base of the community.

Preferably the mines will be deep and extensive, in order to provide the opportunity for water circulation and mixing that occurs at Springhill, but this is not essential. Any mine may be regarded as a shallow aquifer that is unlikely to run out of water. The temperature of the water at Springhill is , at 18 ^{O}C to 20 ^{O}C, very attractive, but most shallow aquifers used for ground-coupled heat pumps are in the range 5 ^{O}C to 8 ^{O}C, and so almost any mine in temperate latitudes offers opportunities.

The study of existing abandoned mines (Katherine Arkay,1992) covers only Nova Scotia and Quebec, but that study was limited by the size of the size of the task rather than by any geographical or geological constraint. In addition to the coal mining areas of Nova Scotia, there are many possible old mines in other provinces, notably the Quebec-Ontario mining belt, including Rouyn, Noranda, Timmins and the Sudbury area. British Columbia, which will be dealt with in the second volume of this report, must be included in these comments.

THE ST. LAWRENCE LOWLANDS

There has been some exploration and drilling hor hydrocarbons in the St. Lawrence Lowland, stretching from Montreal to the Gaspe Peninsula. The depth of sedimentary rocks is limited, the geothermal gradients are generally below average, and so aquifers of high temperature cannot be expected. However, this area has not been explored and the energy potential of any location is worth examination.

SOUTH-WESTERN ONTARIO

The same comments may be made concerning the geothermal potential of the sedimentary rocks of south-western Ontario, from Toronto to Windsor. The data may be better and the sediments may be deeper than in the St. Lawrence Lowlands, particularly in and around the oilfields of the Sarnia area. This area has not been explored and the energy potential is worth examination.

THE CANADIAN SHIELD

The rocks of the Canadian Shield are probably the most unlikely to yield geothermal resources of any in Canada. Generally these Precambrian rocks are not porous or permeable, except in fractures. Studies related to the question of nuclear waste disposal have shown that water moves only in fractures and that the drilling of a slim hole to examine this water movement creates a significant change to the water circulation system and prevents any effective understanding of the natural system. Furthermore, the terrestrial heat flow from the old crust beneath the shield is low, resulting in low geothermal gradients. The combination of low porosity and low geothermal gradient means that the prospect for geothermal development is very low.

In old mines, which may be of great depth, there will be major volumes of water, which may serve as aquifers for input to heat pumps. Since geothermal gradients are typically in the range of 10 mK/m to 15 mK/m, and surface temperatures are in the range 2 ^{O}C to 6 ^{O}C, underground temperatures are likely to be lower than average. However, any old mine probably presents an opportunity for geothermal development provided that the potential users are well placed above the mine workings.

THE MACKENZIE CORRIDOR AND DELTA

This area has not been examined, but parts of it have high heat flow, in excess of 90 mW/m^2, and geothermal gradient. Surface temperatures tend to be at 0 ^{O}C or below, but there may be useful geothermal resources with applications to remote communities.

THE ARCTIC ISLANDS

In the Arctic Islands heat flow, to the extent that it is known, tends to be lower than average. Further, surface temperatures are very low, down to -15 ^{O}C. This combination makes it unlikely that useful geothermal resources are present.

IMMEDIATE PRIORITIES

The Geothermal energy Program of 1976 to 1986 provided a good knowledge of the basic earth science on which to base site-specific studies and demonstration projects. The technology of geothermal development is generally available and demonstrated in other countries. The present need in Canada is the demonstration of the resource and its use in technologically sound and economic installations. Apart from systems involving ground-coupled heat pumps and shallow low-temperature aquifers, the immediate need is industrial and municipal involvement in active utilisation. To do this a new geothermal community must be built up, using the experience of the past as presented in this report.

Specific priorities

As a sample of situations that could be profitably examined promptly as possible demonstration projects, the following are perhaps the most likely to give good results.

1 Reopen the project at the University of Regina. Reopen the well, check it for corrosion problems, examine the proposal for the reinjection well, complete the well doublet, and use the energy for space heating of a large campus building.

2. Examine the possibility of using water at 100 ^{O}C, as input to binary-cycle power generation plants. This could be valuable in remote communities that depend on diesel fuel transported at high expense. In particular, the hot water produced from the gas wells in the Clarke Lake gas field could generate power to supply the needs of the gas field installations and the nearby town of Fort Nelson.

3. Examine towns in the mining belt of Ontario-Quebec for the possible use of water from abandoned mines, as has been done successfully at Springhill, Nova Scotia. The towns of Kirkland Lake, Timmins, Rouyn, Noranda, Malartic, Sudbury and others should be examined.

4. Cooperate with the hydrocarbon industry to use unsuccessful wells as water producing wells in communities such as Hinton and Edson, where temperature gradients are known to be more favourable than elsewhere.

General needs

The Geothermal Energy Program of 1976 to 1986 concentrated on earth science to show that there are geothermal resources in Canada. Once this was conclusively demonstrated the Program began to move towards technology of applications and applications at specific localities. The earth science effort was generally successful. It provided an overview of most of the more promising parts of Canada, but it was not practical or necessary to cover every area in detail. Further earth science is needed to be able to use the general knowledge to permit analysis of smaller areas or specific locations. Meanwhile, further examination of the thermal state of the crust needs to be continued.

The engineering component that followed achieved a similar state. It showed that technology was available and that geothermal energy was technologically feasible, if not always economically feasible, in many parts of Canada.

The present needs in Canada are as follows.

1 The willingness of industry, particularly the hydrocarbon industry to look at alternative sources of energy. The enormous accumulated experience of the hydrocarbon industry in drilling and geological exploration should permit them to initiate small moves in the direction of alternate sources.

2 Encouragement of municipalities to promote geothermal or other alternative energy sources, or combinations of these. The best examples so far are Springhill Nova Scotia, and Okotoks, Alberta, where the municipal governments took an active part in searching out the technology and promoting its use.

3 A centre of expertise and knowledge within the Federal Government to promote the exploration for and utilisation of geothermal resources. This centre needs to accommodate earth science, environmental science, technological and economic capabilities. The location of this centre is open to debate, but should probably be a cooperative venture between Natural Resources Canada and Environment Canada.

4 A continued examination of the thermal nature of the crust within Canada. This could be housed within the Geological Survey of Canada, but could be done in a university environment. Government groups are more amenable to changes of direction as national needs arise, as the geothermal group and the volcanological group were at the beginning of the Geothermal Energy Program in 1976. Good in-house measurement capabilities are essential, so that Canadian researchers have control and complete participation in the work.

5 Willingness on the part of provincial governments to put in place legislation to regulate and encourage geothermal development. It is not sufficient to wait until geothermal development is an accomplished fact, as industrial developers deserve to know in advance what rules they will be working under.

REFERENCES

Three lists of references are presented. The first is a list of all references cited in the text. The second is a bibliography of all known documents related to geothermal energy produced by Canadians or describing Canadian locations or conditions. The third is a similar bibliography of scientific geothermics.

Items in the first list may be repeated in either the second or third list. The second and third lists may be incomplete because the author does not know of all publications. They are also subject to the author's judgement as to whether any item belongs in the list, and a judgement as to which list it should be in. There are no clear boundaries by which these judgements may be made. Some items may be in both lists because they are relevant to both scientific geothermics and geothermal energy.

REFERENCES IN THE TEXT

Acres Consulting Services Ltd., 1984, Survey of geothermal energy in the Maritime Provinces. Earth Phys.Br., Open File 84-13, 139pp

Regulatory and commercial aspects of geothermal energy development. 1984. Acres Consulting Services Ltd and Nevin Sadlier-Brown Goodbrand Ltd.

Acres International Ltd, 1985. Moose Jaw Geothermal Study. Earth Phys.Br., Open File 85-7, 225pp

Arrhenius,S. 1896. On the Influence of Carbonic Acid in the Air Upon the Temperature of the Ground. Philosophical Magazine, 41, 237-276.

Banwell,C.J. and Valle,R.G., 1970. Geothermal exploration in Mexico. Geothermics Spec.Issue 2, Vol.2,27-40.

Baria,R., Michelet,S., Baumgartner,J., Dyer,B., Nicholls,J., Hettkamp,T., Teza,D., Soma,N., Asanuma,H., Garnish,J. And Megel,T. 2005. Creation and mapping of 5000 m deep HDR/HFR reservoir to produce electricity. Proc. World Geothermal Congress 2005.

Bens,A.R., and McCartan,J.J. 1982a. Use of geothermal energy combined with conventional energy sources at the main campus University of Regina. Rept.to Univ.Regina, 137pp+diags.

Bens,A.R., McCartan,J.J. and Vigrass,L.W., 1982. Use of geothermal energy at the University oif Regina - results of an engineering economic study. Proc. ENERGEX 82, Univ.Regina, Ed. Curtis,F.A., 1123-1128.

Bertani,R. 2005. World geothermal generation 2001-2005: state of the art. Proc. World Geothermal Congress 2005.

BP 2006. Quantifying Energy, BP Statistical Review of World Energy, June 2006.

Cappetti,G. And Ceppatelli,L,. 2005. Geothermal power generation in Italy 2000-2004 update report. Proc. World Geothermal Congress 2005.

Cermak,V. 1971. Underground temperature and inferred climatic temperature of the past millenium. Palaeography, Palaeoclimatology, Palaeoecology. 10, 1-19

Conolly,E.T. 1972. Geothermal Survey of North America progress report and associated data-gathering problems. Trans. Can. Well Logging Soc. Fourth Evaluation symp. 37pp.

Curtis,R., Lund,J., Sanner,B., Rybach,L. And Hellstrom,G., 2005. Ground source heat pumps - geothermal energy for anyone, anywhere: current worldwide activity. Proc. World Geothermal Congress 2005.

Drury,M.J., 1983, Temperature gradients and heat production in two granitic batholiths of New Brunswick. Earth Phys.Br., Internal Rept., 83-9, 11pp.

Drury,M.J., 1984, Assessment of the geothermal resources of Atlantic Canada. In - Energy Developments: New Forms, Renewables, Conservation, Ed.Curtis,F.A.,Proc.Energex Conf.,285-290.

Drury,M.J., Jessop,A.M. and Lewis,T.J., 1987. The thermal nature of the Appalachian crust. Tectonophysics, 133, 1-14.

Garven,G. And Vigrass,L.W. 1985. Modelling of deep groundwater flow in Saskatchewan. Earth Phys.Br., Open File 85-17, 36pp+24maps

Ghomshei,M.M., MacLeod,K., Sadlier-Brown,T.L., Meech,J.A. and Dakin,R.A. 2005. Canadian geothermal energy poised for takeoff. Proc. World Geothermal Congress 2005.

Gorrell,H.A., 1984. Applications of existing data to low temperature geothermal exploration. Proc ENERGEX ‘84, ed. Curtis,F.A., Univ Regina.

Govt of Nova Scotia, 1992. Mineral Resources Act. An act to amend chapter 18 of the acts of 1990, of the Mineral Resources Act. Assented to 30 June 1992.

Gutierrez-Negrin,L.C.A. and Quijano-Leon,J.L. Update of Geothermics in Mexico. Proc. World Geothermal Congress 2005.

Hitchon,B., 1968. Rock volume and pore volume data for plains region of Western Canada

Sedimentary Basin between latitudes 49° and 60°N. Bull.Am.Ass.Petrol.Geol, 52, 2318-2323.

Hitchon,B., 1984. Geothermal gradients, hydrodynamics, and hydrocarbon occurrences, Alberta, Canada. Bull.Am.Assoc.Petrol.Geol., 68, 713-743.

Hitchon,B. and Friedman,I., 1969. Geochemistry and origin of formation waters in the Western Canada Sedimentar Basin - 1. stable isotopes of hydrogen and oxygen. Geochim.Cosmochim.Acta, 33, 1321-1349.

Howard,J.H. 1975a. Present status and future prospects for nonelectrical uses of geothermal resources. Lawrence Livermore Lab., Univ. California, UCRL-51926, NATO-CCMS Rept 40, 116pp + append.

Howard,J.H. 1975b. Principal conclusions of the Committee on the Challenges of Modern Society non-electrical applications project. Proc. U.N. Symp. Geothermal Resources., San Francisco, 2127-2139.

Howard,J.H. 1978. Creating an International Geothermal Energy Community.

Hutchence,K., Vigrass,L.W., Law,A.G. and Weston.J.H. 1984. Modelling of the Regina geothermal aquifer. In - Energy Developments: New Forms, Renewables, Conservation, Ed.Curtis,F.A.,Proc.Energex Conf.,309-313

Hutchence,K. And Vigrass,L.W. 1985. Subsurface modelling for geothermal production and energy storage. Earth Phys.Br., Open File 85-16, 57pp

IPCC Report. 2007. Intergovernmental Panel on Climate Change. Climate Change 2007: the Physical Science Basis. Summary for policy makers. IPCC Secretariat, Geneva, Switzerland. Website http://www.ipcc.ch

Jaques, Whitford & Associates Ltd., 1987, Town of Springhill geothermal demonstration project: report on the test drilling and pumping test results. Rept to Town of Springhill Geothermal Committee, 33pp+ append.

Jessop,A.M. 1976. Geothermal energy from sedimentary basins. Geothermal Series of the Earth Physics Branch, No. 8.

Jessop,A.M. and Vigrass,L.W. 1984. The Regina geothermal experiment - thermal aspects. In - Energy Developments: New Forms, Renewables, Conservation, Ed.Curtis,F.A., Proc.Energex Conf., 315-318

Jessop,A.M. and Vigrass,L.W., 1989. Geothermal measurements in a deep well at Regina, Saskatchewan. J.Volcan.Geothermal Res.,37,151-166.

Jessop,A.M., 1990a. Thermal geophysics. Elsevier Sci.Publ., 306pp.

Jessop,A.M., 1990b. Comparison of industrial and high-resolution thermal data in a sedimentary basin. Pageoph, 133, 251-267.

Jessop,A.M., MacDonald,J.K. and Spence,H. 1995. Clean energy from abandoned mines at Springhill, Nova Scotia. Energy Sources, 17, 93-106.

John A.Leslie and Assoc.Ltd., 1981, Investigation of geothermal energy resources - Nova Scotia and Prince Edward Island. Earth Phys.Br., Open File 81-9, 120pp.

John A.Leslie and Assoc.Ltd., 1982, Investigation of geothermal energy resources, Atlantic Provinces. Earth Phys.Br., Open File 82-8, 127pp+map.

John A.Leslie and Assoc.Ltd., 1983, Geothermal gradients in granite batholiths of New Brunswick. Earth Phys.Br., Open File 83-19, 90pp.

John A.Leslie and Assoc.Ltd., 1983, Investigation of geothermal energy resources - Atlantic Provinces. Earth Phys.Br., Open File 83-20, 37pp.

John A.Leslie and Assoc.Ltd., 1984, Geothermal investigation: Prince Edward Island drilling. Earth Phys.Br., Open File 84-3, 60pp.

John A.Leslie and Assoc.Ltd., 1984, Investigation of geothermal energy resources: Atlantic Canada. Earth Phys.Br., Open File 84-5, 44pp and 1 map.

John A.Leslie and Assoc.Ltd., 1985, 1984 investigations of geothermal energy resoucres, Atlantic provinces. Earth Phys.Br., Open File 85-8, 69pp.

John A.Leslie and Assoc.Ltd., 1985, Geothermal investigation, Prince Edward Island drilling, MacDougall, Prince County, hole number EPB 345. Earth Phys.Br., Open File 85-10, 78pp.

John M. Booth Engineering Ltd. 1985. Outline report on the minewater geothermal heat source. Unpublished report to Earth Physics Branch

Jones,F.W., Rahman,M., Lam,H.L. and Sworder,J.E., 1983. A preparatory study for application of geothermal energy in the Hinton/Edson area of Alberta. Rept. to Min.Energy & Natural Resources, Alberta, 177pp + append.

Jones,F.W. and Majorowicz,J.A., 1985. A study of the geothermal environment of the Western Canadian Sedimentary Basin. Unpublished report to Earth Physics Branch. See Jones, Majorowicz, Linville and Osadetz, 1986.

Jones,F.W., Majorowicz,J.A., Ertman,M.E., Linville,A. And Nguyen,C.D., 1986. Detailed study of the geothermal environment of the area included in map sheet NN-12 - Edmonton

Jones,F.W. and Majorowicz,J.A., 1986. Study of existing temperature data from Canadian sedimentary basins, Phase 5. Unpublished report to Earth Physics Branch. See Majorowicz, Jones and Jessop, 1988.

Jones,F.W., Majorowicz,J.A., Linville,A. And Osadetz,K.G., 1986. Bull.Can.Petrol.Geol., 34, 226-239.

Jones,F.W., 1987. A study of the geothermal environment of the Lesser Slave Lake map sheet NN-11 area. Unpublished report to Geol.Surv.Can.

Jones,F.W., 1988. A study of the geothermal environment of the Peace River map sheet NO-11 area. Unpublished report to Geol.Surv.Can.

Katherine Arkay Consulting. 1992. Geothermal energy from abandoned mines: a methodology for an inventory, and inventory data for abandoned mines in Quebec and Nova Scotia. Geol.Surv.Can., Open File 3825.

Katherine Arkay Consulting, 1993, First Springhill Geothermal Energy Conference, Springhill, Nova Scotia,Geol.Surv.Can., Open File 2773, 60 pp + append.

Lambert,K. 1980. Report of geothermal gradient study of two areas of Alberta. Unpublished report to Earth Physics Branch.

Laplaige,P., Lemale,J., Decottegnie,S., Desplan,A., Goyeneche,O. And Delobelle,G. 2005. Geothermal resources in France. Proc. World Geothermal Congress 2005

Loveseth,G.E. 1988. Location, indentification and inventory of aquifers with the greatest geothermal potential in the sedimentary rocks of Alberta. Geol.Surv.Can., Open File 2423, 28 pp.

Loveseth,G.E. 1989. The geothermal resources of Saskatchewan and S.W. Manitoba. Geol.Surv.Can., Open File 2422, 19 pp.

Lund,J.W., Bloomquist,R.G., Boyd,T.L. and Renner,J. 2005. The United States of America country update. Proc. World Geothermal Congress 2005.

Lund,J.W., Freeston,D.H. and Boyd,T.L. 2005. World-wide direct uses of geothermal energy 2005. Proc. World Geothermal Congress 2005.

Majorowicz,J.A., Jones,F.W., Lam,H.L. and Jessop,A.M., 1984. The variability of heat flow both regional and with depth in southern Alberta, Canada: effect of groundwater flow? Tectonophysics, 106, 1-29.

Majorowicz,J.A., Jones,F.W., Lam,H.L. and Jessop,A.M., 1985. Terrestrial heat flow and geothermal gradients in relation to hydrodynamics in the Alberta Basin, Canada. J.Geodyn., 4, 265-283

Majorowicz,J.A., Jones,F.W. and Jessop,A.M., 1986. Geothermics of the Williston Basin in Canada in relation to hydrodynamics and hydrocarbon occurrences. Geophysics, 51, 767-779.

Majorowicz,J.A., Jones,F.W. and Jessop,A.M., 1987. Low enthalpy geothermal energy potential of the Western Canadian Basin - heat flow and hydrological considerations. Unpublished report to the Geological Survey of Canada..

Majorowicz,J.A., Jones,F.W., and Jessop,A.M. 1988. Preliminary geothermics of the sedimentary basins in the Yukon and Northwest Territories (60ºN - 70ºN) - estimates from bottom-hole temperature data. Bull.Can.Petrol.Geol., 36, 39-51.

McLellan,J.D., Hasegawa,H.H., Roegiers,J.G. and Jessop,A.M., 1987. Hydraulic fracturing experiment at the University of Regina campus. Can.Geotech.J. ,23, 548-555.

McKelvey,V.E.,1972. Mineral resource estimates and public policy. American Scientist, 60, 32-40.

Minty,D.H., 1990. Ground water / heat-pump / medium temperature hot water project: Carleton University. Report to Carleton University, 13pp.

Morofsky,E. 1982. Aquifer thermal energy storage at the Scarborough Government of Canada building. In - A forum on Energy Self-reliance: Conservation, Production and Consumption. Ed.Curtis,F.A., Proc. Energex Conf., 1119-1122

Muffler,P, and Cataldi,R.,1978. Methods for regional assessment of geothermal resources. Geothermics, 7, 53-89.

National Energy Board, 1984. Canadian energy supply and demand 1983-2005. National Energy Board, NE23-15/1984, 107pp + append.

Nolan, Davis & Associates Ltd, 1984, Groundwater flow patterns in Carboniferous sediments of Atlantic Canada., Earth Phys.Br., Open File 84-29, 101pp and 1 map.

Northern Geothermal Consultants, 1994. Study of the relationship of the thermal and hydrogeological regimes of the Western Canada Sedimentary Basin: Study of the anomalous regime in the northern Cordilleran Foreland Basin. [Majorowicz,J.A., 1996. Anomalous heat flow regime in the western margin of the North American Craton, Canada. J.Geodynamics, 21, 123-140.]

Office of Energy Research and Development, Natural Resources Canada. Renewable Energy in Canada Status Report 2002.

Options, 2004. Can. Assoc. Renewable Energies.

Paola,G.M. and Stefansson,V., 1988. Rapporteurs' report. Proc.United Nation workshop on

Geothermal Energy, Reykjavik, Pisa, and Rome, (1986).

Postlethwaite,J., Gummadi,V., Scoular,J.R. and Vigrass,L.W., 1980a. Corrosion testing on western Canada geothermal waters. University of Regina, Rept to Public Works Canada, 8pp.

Postlethwaite,J.,Vigrass,L.W., Gummadi,V. Neufeld,R. and Kybett,B.D. 1980b. Water chemistry testing on western Canada geothermal waters. University of Regina, Rept to Public Works Canada,12pp + append.

Ruse,D.C. and Vigrass,L.W., 1985. Deepening of the University of Regina 3-8-17-19 well.

SNC group. 1982. Survey of geothermal heat extraction technology. Rept. to Nat.Res.Council Ottawa, 192pp.

Sproule Associates Ltd., 1976. Study of geothermal resources in western Canada sedimentary basins from existing data, phase one. Earth Physics Branch, Open File 77-13, 110pp + diagrams.

Sproule Associates Ltd., 1977. Study of geothermal resources in western Canada sedimentary basins from existing data, phase two. Earth Physics Branch, Open File 77-14, 127pp + diagrams

Sproule Associates Ltd., 1978. Report on the acquisition of data on the lithological character of the sedimentary rocks, Western Canada. Unpublished report to Earth Physics Branch.

Sproule Associates Ltd., 1983. Report on study of the feasibility of geothermal reservoir mapping in deep sedimentary basins using existing data. Earth Physics Branch, Open File 83-27, 80pp + maps.

Thomas,M.D. and Willis,C., 1989, Gravity modelling of the Saint George Batholith and adjacent terrain within the Appalachian Orogen, southern New Brunswick., Can.J.Earth Sci., 26, 561-576.

Vaughan Engineering Associates Ltd. Undated, probably 1992. Feasibility study to establish a community heating system un the Town of Springhill, N.S. using warm mine water. Unpublished report to CANMET.

Vigrass,L.W., Kent,D.M. and Leibel,R.J., 1978. Low-grade geothermal project, geological feasibility study, Regina - Moose Jaw area, Saskatchewan. Earth Physics Branch Open File 78-4, 79pp + append.

Vigrass,L.W., 1979. Final well report, U or R Regina 3-8-17-19 (W.2nd.Mer.) Saskatchewan. Earth Physics Branch Open File 79-9, 36pp+diagrams.

Vigrass,L.W., 1980a. Completion and pump test, U. of Regina 3-8-17-19, phase 1b - geothermal project. Earth Physics Branch Open File 80-6,90pp.

Vigrass,L.W., 1980b. Geothermal Feasibility Project at Regina. Phase 2: disposal well and pipeline. Unpublished technical proposal to Earth Physics Branch

Vigrass,L.W., 1983. University of Regina Geothermal Project, Phase 2a, work preliminary to drilling of disposal well and building of pipeline. Unpublished report to Earth Physics Branch.

Vigrass,L.W. and Jessop,A.M. 1984. Regina geothermal experiment - geological and hydrological aspects. In - Energy Developments: New Forms, Renewables, Conservation, Ed.Curtis,F.A., Proc.Energex Conf., 303-308

Vigrass,L.W., Viraraghan,T. and Curtis,F.A., 1984. University of Regina, Preliminary study use of geothermal energy in wastewater treatment. Unpublished report to National Research Council.

Wallace,R.H. and Schwartz,K.L., 1987. Geothermal energy. Geotimes, February, 28-29.

Wright,J.A., Jessop,A.M., Judge,A.S. and Lewis,T.J. 1980. Geothermal measurements in Newfoundland.. Can.J.Earth Sci., 17, 1370-1376"

CANADIAN GEOTHERMAL ENERGY BIBLIOGRAPHY

Abdel-aal,O.Y. and Hall,J.M. 1978. Opaque mineral alteration states correlated with temperature in an active geothermal system. Nature, 272, 239-240

Acres Consulting Services .Ltd. and Nevin, Sadlier-Brown, Goodbrand,Ltd 1984. Regulatory and commercial aspects of geothermal energy development. Earth Phys.Br., Open File 84-12, 377pp

Acres Consulting Services Ltd. 1983. Low temperature geothermal energy applications. Rept.to Nat.Res.Coun., 159pp,

Acres Consulting Services Ltd. 1984. Study of mine air heating with geothermal energy. Earth Phys.Br., Open File 84-14, 66pp

Acres Consulting Services Ltd. 1984. Survey of geothermal energy in the Maritime Provinces. Earth Phys.Br., Open File 84-13, 139pp

Acres International Ltd. 1985. Geothermal mine air heating. Earth Phys.Br., Open File 85-24,106pp

Acres International Ltd. 1985. Moose Jaw geothermal study. Earth Phys.Br., Open File 85-7, 225pp

Allen,D.M., Ghomshei,M.M., Sadlier-Brown,.T.L., & two others. 2000. The current status of geothermal exploration and development in Canada. Proc.World Geothermal Congress, 2000.

Anonymous 1981. The role of water in geothermal energy resources. In - Canada Water Year Book 1979-1980, Water Research Edition, Environment Canada, 104-105

Apex Airborne Surveys Ltd. 1982. Report on a helicopter E.M. and magnetometer survey in the Meager Creek area, British Columbia. Rept.to Nevin,Sadlier-Brown,Goodbrand,Ltd., 6pp+append.

B.C.Hydro,Power Authority 1982. Meager Creek mapping program - 1981. B.C.Hydro,Power Auth. Rept.SE8209, 23pp+append.

B.C.Hydro,Power Authority 1983. Meager Creek geothermal project summary report for 1982-83. B.C.Hydro,Power Auth., 36pp

Bawden,W.F. and Roegiers,J.C. 1980. Discussion and interpretation of the mathematics governing radial flow in a single horizontal rock fracture. Earth Phys.Br., Open File 80-5, 134pp

Bawden,W.F., Roegiers,J.-C. and Schlumberger,D. 1985. Gas escape from underground mined storage facilities - a multiphase flow phenomenon. Preprint

Beck,A.E. 1971. Prospects for geothermal power. Comments Earth Sci.Geophys.,1,139-149

Bens,A.R. and McCartan,J.J. 1982. Use of geothermal energy combined with conventional energy sources at the main campus University of Regina. Rept.to Univ.Regina, 137pp+diags.

Bens,A.R., McCartan,J.J. and Vigrass,L.W. 1982. Use of geothermal energy at the University of Regina - results of an engineering economic study. Proc. ENERGEX 82, Univ.Regina, Ed. Curtis,F.A.1123-1128

Bentkowski,W.H. and Lewis,T.J. 1983. Preliminary results of shallow drilling in the Garibaldi Volcanic Belt British Columbia,1982. Earth Phys.Br., Open File 83-23, 39pp

Bentkowski,W.H. and Lewis,T.J. 1984. Preliminary results from shallow drilling in the Alert Bay Volcanic Belt. Earth Phys.Br., Open File 84-2, 17pp

Bentkowski,W.H. and Lewis,T.J. 1985. Preliminary results from shallow drilling in the Anahim Volcanic Belt, B.C. Earth Phys.Br., Open File 85-9, 19pp

Chorney,R.J. and Sherwood,R.L. 1981. Geothermal electric energy and its impacts on the environment. Dept.Environment,Env.Protn.Serv.,Pacif,Yukon Reg., Prog.Rept.81-05, 37pp

Clark,I.D. 1980. Isotope hydrogeology and geothermometry of the Mount Meager geothermal area. Thesis,M.Sc., University of Waterloo

Clark,I.D., Fritz,P. and Michel,F.A. 1980. Isotope hydrogeology and geothermometry of the Mount Meager geothermal area. Rept.to Geol.Surv.Can., 131pp

Clark,I.D., Fritz,P. and Souther,J.G. 1989. Geochemistry and isotope hydrogeology of the Mount Edziza - Mess Creek geothermal area. Can.J.Earth Sci., 26, 1160-1171

Clark,I.D., Fritz,P., Michel,F.A. and Souther,J.G. 1982. Isotope hydrogeology amd geothermometry of the Mount Meager geothermal area. Can.J.Earth Sci., 19, 1454-1473

Combs,J. 1979. Review of the proposed 1979 exploration program for the Meager Creek geothermal project. Rept.to B.C.Hydro and Power Auth.,14pp

Cousins,R.J. and Larkin,B.S. 1984. Low temperature geothermal energy in Canada. In - Energy Developments: New Forms, Renewables, Conservation, Ed.Curtis,F.A.,Proc.Energex Conf.,267-272

Crandall,J.T. and Sadlier-Brown,T.L. 1978. Data on geothermal areas - cordilleran Yukon, Northwest Territories, and adjacent British Columbia, Canada. Earth Phys.Br., Open File 78-1, 23pp+append+diagr.

D.R.Piteau and Assoc. 1985. Summerland Basin hydrogeological study. Earth Phys.Br., Open File 85-29, 82pp

Davis,E.E. and Lewis,T.J. 1984. Heat flow in a back-arc environment: Intermontane and Omineca Crystalline Belts, southern Canadian cordillera. Can.J.Earth Sci., 21, 715-726

Deep Grid Analysis Ltd. 1975. Deep resistivity surveys and supplementary geophysics at Meager Creek selected area, Pemberton, B.C. Rept.to Nevin Sadlier-Brown Goodbrand,Ltd., 15pp+append

Dragert,H., Law,L.K. and Sule,P.O. 1980. Magnetotelluric soundings across the Pemberton Volcanic Belt, British Columbia. Can.J.Earth Sci., 17, 161-167

Drury,M.J. 1983. Temperature gradients and heat production in two granitic batholiths of New Brunswick. Earth Phys.Br., Internal Rept. 83-9, 11pp

Drury,M.J. 1984. Assessment of the geothermal resources of Atlantic Canada. In - Energy Developments: New Forms, Renewables, Conservation, Ed.Curtis,F.A.,Proc.Energex Conf.,285-290

Elworthy,R.T. 1925. Hot springs in western Canada; their radioactive and chemical properties. Min.Br.Invest.Miner.Resour.Min.Indust., 1-33

Epstein,N., Watkinson,A.P. and Yu,W. 1986. A study of the fouling characteristics of prairie geothermal waters. Dept.Chem.Engng., Univ.Brit.Columbia, Rept.to Nat.Res.Council, OST-83-00414,11pp+tables+append

Everdingen,R.O.van. 1972. Thermal and mineral springs in the southern Rocky Mountains of Canada. Environment Canada, 151pp.

Fairbank Engineering LTd. 1992. Geothermal feasibility study for the use of hot water near Riondel. B.C. Geol.Surv.Can., Open File 2502, 108 pp

Fairbank,B.D. and twelve others 1992. Geothermal resources of British Columbia. Geol.Surv.Can., Open File 2526.

Fairbank,B.D., Openshaw,R.E., Souther,J.G. and Stauder,J.J. 1981. Meager Creek geothermal project - an exploration case history. In - Geothermal Potential of the Cascade Mountain Range, Exploration and Development, Spec.Rept.10,Geothermal Resources Coun.,15-19

Fairbank,B.D., Reader,J.F. and Sadlier-Brown,T.L. 1980. Report on 1979 drilling and exploration program Meager Creek geothermal area upper Lillooet River, British Columbia. Rept.to B.C.Hydro and Power Authority,.57pp+append.

Fairbank,B.D., Shore,G.A., Werner,L.J. and Nevin,A.E. 1979. Report on 1978 field work Meager Creek geothermal area upper Lillooet River, British Columbia. Earth Phys.Br., Open File 79-10, 82pp+append.

Fritz,P., Clark,I.D., Michel,F.A. and Souther,J.G. 1980. Isotope hydrology and geothermometry of the Mount Meager geothermal area. Trans.Geothermal Resour.Coun., 4, 161-164.

Garven,G. and Vigrass,L.W. 1985. Modelling of deep groundwater flow in Saskatchewan. Earth Phys.Br., Open File 85-17, 36pp+24maps

Geoprobe Ltd. 1978. Report on the Maxi-probe EMR-16 test survey around Meager Creek area (B.C.). Rept.to Geol.Surv.Can., 12pp+append.

Ghomshei,M.M., Croft,S.A.S. and Stauder,J.J. 1986. Geochemical evidence of chemical equilibria in the south Meager Creek geothermal system, British Columbia, Canada. Geothermics, 15, 49-61

Ghomshei,M.M., MacLeod,K., Sadlier-Brown,T.L., Meech,J.A. and Dakin,R.A. 2005. Canadian geothermal energy poised for takeoff. Proc. World Geothermal Congress 2005.

Glass,I.I. 1976. Utilization of geothermal energy. Univ.Toronto, Inst.Aerospace Studies, Review 40, 21pp

Glass,I.I. 1977. Prospects for geothermal energy applications and utilization in Canada. Energy, 2, 407-428

Gorrell,H.A. 1978. Hot water under the plains. Geos, Energy Mines and Resources, Ottawa, Spring, 12-14

Gorrell,H.A. 1979. Geothermal studies in the plains region of western Canada. Bull.Can Inst.Min.Metall., 72, Oct., 66-69

Gorrell,H.A. 1984. Application of existing data to low temperature geothermal exploration. In - Energy Developments: New Forms, Renewables, Conservation, Ed.Curtis,F.A., Proc.Energex Conf.,291-295

Grant,M.B. and Michel,F.A. 1985. Study of the hydrogeology of the White Lake Basin, British Columbia. Earth Phys.Br., Open File 85-28, 63pp

Haines,P.J. and Jessop,A.M. 1975. Geothermal potential and geothermal exploration in the Caribbean Islands. Canadian International Development Agency,30pp

Hammerstrom,L.T. and Brown,T.H. 1977. Geochemistry of thermal waters in the Mount Meager Hotsprings area, British Columbia. Geol.Surv.Can., Paper 77-1a, 283-285

Hammerstrom,L.T. and Brown,T.H. 1977. The geochemistry of thermal waters from the Mount

Meager Hotsprings area, B.C. Geol.Surv.Can., Open File 532, 32pp+append.

Hutchence,K. and Vigrass,L.W. 1985. Subsurface modelling for geothermal production and energy storage. Earth Phys.Br., Open File 85-16, 57pp

Hutchence,K., Law,A.G., Vigrass,L.W. and Weston,J.H. 1984. Geothermal aquifer modelling: a low temperature production/disposal system. Proc.Fourth Int.Conf.Math.Modelling In Science and Technology, Zurich, Switzerland, Pergamon Press, 634-639

Hutchence,K., Law,A.G., Weston,J.H. and Vigrass,L.W. 1984. Predicting thermal breakthrough for a liquid phase geothermal system. Appl.Math.Notes, 9, 13-19

Hutchence,K., Vigrass,L.W., Law,A.G. and Weston,J.H. 1984. Modelling of the Regina geothermal aquifer. In - Energy Developments: New Forms, Renewables, Conservation, Ed.Curtis,F.A.,Proc.Energex Conf.,309-313

Hutchence,K., Weston,J.H., Law,A.G. and Vigrass,L.W. 1986. Modeling of a liquid phase geothermal doublet system at Regina, Saskatchewan, Canada. Wat.Resour.Res., 22, 10, 1469-1479

Ingham,M.R., Bingham,D.K. and Gough,D.I. 1983. A magnetovariational study of a geothermal anomaly. Geophys.J.R.Astr.Soc., 72, 597-618

Jaques, Whitford & Associates Ltd. 1987. Town of Springhill geothermal demonstration project: report on the test drilling and pumping test results. Rept to Town of Springhill Geothermal Committee, 33pp+ append.

Jessop,A.M. 1975. Energy R and D Program statement - Task 5 - Exploit renewable energy resources - Program 4 - Geothermal energy. Earth Phys.Br., Geothermal Ser.4, 6pp

Jessop,A.M. 1975. Geothermal energy. Geos, Energy Mines and Resources, Ottawa, Spring, 2-4

Jessop,A.M. 1976. Geothermal energy from sedimentary basins. Earth Phys.Br., Geothermal Ser.8, 10pp

Jessop,A.M. 1977. The role of non-conventional energy resources - geothermal. In - The Canadian Energy Situation in 1990 and Beyond, Proc.Can.Natnl. Energy Forum

Jessop,A.M. 1978. Geothermal energy from sedimentary formations of western Canada. In - Geothermal Energy, a Novelty Becomes a Resource, Trans.Geothermal Resour. Coun., 2, 331-334

Jessop,A.M. 1982. Using the heat of the earth. Land, Environment Canada, 3, 2, 10-12

Jessop,A.M. 1984. Geothermal energy in Canada - a review of the resources. In - Energy Developments: New Forms, Renewables, Conservation, Ed.Curtis,F.A.,Proc.Energex

Conf., 263-266

Jessop,A.M. 1985. Geothermal energy in Canada. Trans.Geothermal Resour.Coun., 9, 37-42.

Jessop,A.M. 1988. Geothermal regimes and geothermal resources of sedimentary basins. In - hydrogeology of sedimentary basins: application to exploration and exploitation, Third Can/Am.Conf.Hydrogeol.Natl.Water Well Assoc. (US), 127-139

Jessop,A.M. 1998. Geothermal energy in Canada. Geoscience Canada, 25, 1, 1998.

Jessop,A.M. and Church,B.N. 1991. Geothermal drilling in the Summerland Basin, British Columbia, 1990. Geol.Surv.Can., Open File 2348, 19 pp.

Jessop,A.M. and Vigrass,L.W. 1984. The Regina geothermal experiment - thermal aspects. In - Energy Developments: New Forms, Renewables, Conservation, Ed.Curtis,F.A., Proc. Energex Conf., 315-318

Jessop,A.M. and Vigrass,L.W. 1989. Geothermal measurments in a deep well at Regina, Saskatchewan. J.Volcan.Geothermal Res., 37, 151-166

Jessop,A.M., Ghomshei,M.M. and Drury,M.J. 1991. Geothermal energy in Canada. Geothermics, 20, 369-385.

Jessop,A.M., MacDonald,J.K. and Spence,H. 1995. Clean energy from abandoned mines at Springhill, Nova Scotia. Energy Sources, 17, 93-106

Jessop,A.M., and nine others. 2005. The Canadian geothermal data compilation. Geol.Surv.Can., Open File 4887, one CD.

John A.Leslie and Assoc.Ltd. 1981. Investigation of geothermal energy resources - Nova Scotia and Prince Edward Island. Earth Phys.Br., Open File 81-9, 120pp

John A.Leslie and Assoc.Ltd. 1982. Investigation of geothermal energy resources, Atlantic Provinces. Earth Phys.Br., Open File 82-8, 127pp+map

John A.Leslie and Assoc.Ltd. 1983. Geothermal gradients in granite batholiths of New Brunswick. Earth Phys.Br., Open File 83-19, 90pp

John A.Leslie and Assoc.Ltd. 1983. Investigation of geothermal energy resources - Atlantic Provinces. Earth Phys.Br., Open File 83-20, 37pp

John A.Leslie and Assoc.Ltd. 1984. Geothermal investigation: Prince Edward Island drilling. Earth Phys.Br., Open File 84-3, 60pp

John A.Leslie and Assoc.Ltd. 1984. Investigation of geothermal energy resources: Atlantic Canada. Earth Phys.Br., Open File 84-5, 44pp and 1 map

John A.Leslie and Assoc.Ltd. 1985 1984 investigations of geothermal energy resoucres, Atlantic provinces. Earth Phys.Br., Open File 85-8, 69pp

John A.Leslie and Assoc.Ltd. 1985. Geothermal investigation, Prince Edward Island drilling, MacDougall, Prince County, hole number EPB 345. Earth Phys.Br., Open File 85-10, 78pp

John M. Booth Engineering Ltd 1985. Outline report on the minewater geothermal heat source. Unpublished report to Earth Physics Branch

Johnstone,M.C. 1982. Study of the feasibility of using Middle Devonian formation water from the Clarke Lake Gas Field, N.E. British Columbia, as a geothermal energy resource. Unpublished Memorandum to Petr.Resources Branch, BC Min.Energy, Mines Petr. Resources.

Jones,F.W. and Majorowicz,J.A. 1985. Study of existing temperature data from Canadian sedimentary basins - phase 4. Earth Phys.Br., Open File 85-6, 79pp

Jones,F.W., Kushigbor,C., Lam,H.L., Mahorowicz, J.A., et al 1984. Estimates of terrestrial thermal gradients and heat flow variations with depth in the Hinton-Edson area of the AlbertaBasin derived from petroleum bottom-hole temperature data. Geophys. Prospecting, 32, 1111-1130

Jones,F.W., Lam,H.L. and Majorowicz,J.A. 1985. Temperature distributions at the Paleozoic and Precambrian surfaces and their implications for geothermal energy recovery in Alberta. Can.J.Earth Sci., 22, 1774-1780

Jones,F.W., Lam,H.L. and Yuen,D. 1982. A study of existing temperature data from Canadian sedimentary basins. Earth Phys.Br., Open File 82-22, 107pp

Jones,F.W., Majorowicz,J.A. and Lam,H.L. 1983. A study of existing temperature data from Canadian sedimentary basins, phase 2. Rept.to Earth Phys.Br.

Jones,F.W., Majorowicz,J.A. and Lam,H.L. 1984. A study of existing temperature data from Canadian sedimentary basins, phase 3. Rept.to Earth Phys.Br., 161pp

Jones,F.W., Rahman,M., Lam,H.L. and Sworder,J.E. 1983. A preparatory study for application of geothermal energy in the Hinton/Edson area of Alberta. Rept. to Min.Energy & Natural Resources, Alberta, 177pp + append.

Jones,F.W., Rahman,M., Majorowicz,J.A. and Lam,H.L. 1983. A study of thermal properties of sedimentary rocks of western Canada. Earth Phys.Br., Open File 83-7, 1079pp

K.R.T.A.Ltd. 1982. Geothermal project Meager Creek well completion report MC-1. Rept.to B.C. Hydro,Power Auth., 56pp

K.R.T.A.Ltd. 1982. Geothermal project Meager Creek well completion report MC-2. Rept.to B.C.Hydro and Power Auth., 63pp

K.R.T.A.Ltd. 1982. Review of geochemical data from the Meager Creek geothermal area. Rept.to B.C.Hydro and Power Auth., 32pp

K.R.T.A.Ltd. 1983. Geothermal project Meager Creek well completion report MC-3. Rept.to B.C.Hydro and Power Auth., 70pp

K.R.T.A.Ltd. 1983. Geothermal project Meager Creek, summary report for 1981-82. Rept.to B.C.Hydro and Power Auth., 14pp+append.

K.R.T.A.Ltd. 1983. Report on Meager Creek geothermal project 1981-1982. Rept.to B.C.Hydro and Power Auth., 214pp+append.

Kamp,G.van der. 1984. Evaluating the influence of groundwater flow systems on geothermal conditions. In - Energy Developments: New Forms, Renewables, Conservation, Ed.Curtis,F.A.,Proc.Energex Conf.,297-301

Katherine Arkay Consulting 1992. Geothermal energy from abandoned mines: a methodology for an inventory, and inventory data for abandoned mines in Quebec and Nova Scotia. Geol.Surv.Can., Open File 3825

Katherine Arkay Consulting 1993. First Springhill Geothermal Energy Conference, Springhill, Nova Scotia, summary report. Geol.Surv.Can., Open File 2773, 60pp + append.

Lam,H.L. and Jones,F.W. 1984. An assessment of the low-grade geothermal potential in a foothills area of west-central Alberta. In - Energy Developments: New Forms, Renewables, Conservation, Ed.Curtis,F.A.,Proc.Energex Conf.,273-278

Lam,H.L. and Jones.F.W. 1985. Geothermal energy potential in the Hinton-Edson area of west-central Alberta. Can.J.Earth Sci., 22, 369-383

Lam,H.L., Jones,F.W. and Lambert,C. 1982. Geothermal gradients in the Hinton area of west-central Alberta. Can.J.Earth Sci., 19, 755-766

Lambert,C. 1980. Report on geothermal gradient study of two areas of Alberta. Inst. Earth, Planet Phys.,Univ.Alberta, 21pp+figs.

Lefebvre,T.H.(chairman). 1981. Geothermal energy. In - Energy Alternatives, Report of Special Committee on Alternative Energy and Oil Substitution to the Parliament of Canada, 171-177

Legg,J.F. 1988. The record and status of geothermal energy R&D in Canada from the perspective of the Government of Canada. Energy, Mines and Resources, Office of Energy Research and Development,3399 + appendices

Leroux,J. 1980. Geothermal potential of the Coryell Intrusions, Granby River area, British Columbia. Geol.Surv.Can., Paper 80-1b, 213-215

Lewis,J.F. 1978. Preliminary field report of drilling near Mt. Meager and Mt.Cayley volcanic centres - 1977. Earth Phys.Br., Open File 78-2, 12pp+append+diagr.

Lewis,J.F. and Jessop,A.M. 1981. Heat flow in the Garibaldi Volcanic Belt, a possible Canadian geothermal resource area. Can.J.Earth Sci., 18, 366-375

Lewis,T.J. 1982. Geothermal gradients on the west side of Okanagan Lake, B.C. Earth Phys.Br., Open File 82-06, 59 pp.

Lewis,T.J. 1984. Geothermal energy from Penticton Tertiary Outlier, British Columbia. Can.J.Earth Sci., 21, 181-188

Lewis,T.J. and Souther,J.G. 1978. Meager mountain, B.C. - a possible geothermal energy resource. Earth Phys.Br., Geothermal Ser.9, 17pp

Lewis,T.J. and Werner,L. 1982. Geothermal gradients on the west side of Okanagan Lake, B.C. Earth Phys.Br., Open File 82-6, 58pp

Lewis,T.J., Allen,V.S., Taylor,A.E. and Jessop,A.M. 1979. Temperature observations during drilling of two 400 m wells in the Coryell intrusives north of Grand Forks, British Columbia. Earth Phys.Br., Open File 79-2,16pp+diagr.

Lewis,T.J., Judge,A.S. and Souther,J.G. 1978. Possible geothermal resources in the Coast Plutonic Complex of southern British Columbia, Canada. Pure Appl. Geophys., 117, 172-179

Loveseth,G.E. 1989. The geothermal resources of Saskatchewn and S.W. Manitoba. Geol.Surv.Can., Open File 2422, 19 pp.

Loveseth,G.E. and Pfeffer,B.J. 1988. Location, indentification and inventory of aquifers with the greatest geothermal potential in the sedimentary rocks of Alberta. Geol.Surv.Can., Open File 2423, 28 pp.

Majorowicz,J.A., Jones,F.W. and Jessop,A.M. 1986. Geothermics of the Williston Basin in Canada in relation to hydrodynamics and hydrocarbon occurrences. Geophysics, 51, 3, 767-779

Majorowicz,J.A., Jones,F.W. and Lam,H.L. 1984. A comment on "a magnetovariational study of a geotheral anomaly" by M.R.Ingham, D.K.Bingham and D.I,Gough. Geophys. J.R. Astr. Soc., 76, 667-672

Majorowicz,J.A., Jones,F.W., Lam,H.L. and Jessop,A.M. 1984. Heat flow and geothermal gradient studies in the Alberta Basin, an essential part of geothermal potential evaluation.

In - Energy Developments: New Forms, Renewables, Conservation, Ed.Curtis,F.A., Proc.Energex Conf.,279-284

Majorowicz,J.A., Jones,F.W., Lam,H.L. and Jessop,A.M. 1984. The variability of heat flow both regional and with depth in southern Alberta, Canada - effect of groundwater flow. Tectonophysics, 106, 1-29

Majorowicz,J.A., Jones,F.W., Lam,H.L. and Jessop,A.M. 1985. Heat flow and geothermal gradient studies in the Alberta Basin, an essential part of geothermal potential evaluation. Proc.Energex Conf., 279-284

Majorowicz,J.A., Jones,F.W., Lam,H.L. and Jessop,A.M. 1985. Regional variations of heat flow differences with depth in Alberta, Canada. Geophys.J.R.Astr.Soc., 81, 479-487

Majorowicz,J.A., Jones,F.W., Lam,H.L. and Jessop,A.M. 1985. Terrestrial heat flow and geothermal gradients in relation to hydrodynamics in the Alberta Basin, Canada. J.Geodyn., 4, 265-283

Majorowicz,J.A., Jones,F.W., Lam,L. and Linville,A. 1985. Topography and the subsurface temperature regime in the western Canadian sedimentary basin: implications for low-enthalpy geothermal energy recovery. Geothermics, 14, 175-187

Mark,D.G. 1978. Seismic refraction study in the Meager Mountain geothermal region, Lillooet River Valley, B.C. Earth Phys.Br., Open File 78-3(part), 11pp+diagr.

Mark,D.G. 1978. Seismic refraction study in the Meager mountain geothermal region, Job Creek area, upper Lillooet River Valley, B.C. Earth Phys.Br., Open File 78-3(part), 11pp+diagr.

McDonald,J., Pollock,D. and McDermot,B. 1978. Hotsprings of western Canada - a complete guide. Labrador Tea Co., 161pp.

McLellan,J.D., Hasegawa,H.H., Roegiers,J.G. and Jessop,A.M., 1987. Hydraulic fracturing experiment at the University of Regina campus. Can.Geotech.J. ,23, 548-555.

Michel,F. and Fritz,P. 1979. Isotope hydrology of the Meager Creek thermal waters. Rept. to Geol.Surv.Can.,10pp+append.

Michel,F. and Fritz,P. 1980. Isotope hydrology of the Meager Creek geothermal waters. Rept.to Geol.Surv. Can.,24pp

Michel,F.A. and Fritz,P. 1985. An initial study of the hydrology of White Lake Basin, B.C. Earth Phys.Br., Open File 85-27, 37pp

Moore,J.N., Adams,M.C. and Stauder,J.J. 1983. Geochemistry of the Meager Creek geothermal field, British Columbia, Canada. Trans.Geothermal Resour.Coun., 7, 315-319

Morofsky.E. 1982. Aquifer thermal energy storage at the Scarborough Government of Canada building. In - A forum on Energy Self-reliance: Conservation, Production and Consumption. Ed.Curtis,F.A., Proc. Energex Conf., 1119-1122

Nevin,A.E. and Sadlier-Brown,T.L. 1972. Electricity from geothermal steam and possible utilization in British Columbia. Western Miner, April, 88-93

Nevin,A.E. and Stauder,J. 1975. Canada - early stages of geothermal investigation in British Columbia. Proc.U.N.Symp.Geothermal Res., San Francisco, 1161-1165

Nevin,A.E., Crandall,J.T., Souther,J.G. and Stauder,J. 1978. Meager Creek geothermal system, British Columbia, part 1 - Exploration and research programme. In - Geothermal Energy, a Novelty Becomes a Resource, Trans.Geothermal Resour.Coun.,2,491-494

Nevin,Sadlier-Brown,Goodbrand Ltd. 1977. Report on 1976 geothermal investigation at Meager Creek - north and northeast flanks of the volcanic complex. Rept.to B.C.Hydro and Power Authority,.0pp+append.

Nevin,Sadlier-Brown,Goodbrand Ltd. 1978. Progress report for 1977 Meager Creek geothermal project investigations for 1977-1978. Rept.to B.C.Hydro and Power Authority,. 15pp+append.

Nevin,Sadlier-Brown,Goodbrand Ltd. 1978. Report on 1977 geothermal investigation at Meager Creek principally on the northeast flank of the volcanic complex. Rept.to B.C.Hydro and Power Authority,.22pp+append

Nevin,Sadlier-Brown,Goodbrand,Ltd. 1974. Investigation of geothermal resources in southwestern British Columbia. Rept.to B.C.Hydro and Power Authority,. 40pp+diagr+append.

Nevin,Sadlier-Brown,Goodbrand,Ltd. 1975. Detailed geothermal investigation at Meager Creek. Rept.to B.C.Hydro and Power Authority,.18pp+diagr+append.

Nevin,Sadlier-Brown,Goodbrand,Ltd. 1975. Interim report on Meager Creek selected area geothermal investigations phase 2. Rept.to B.C.Hydro and Power Auth.,17pp+append.

Nevin,Sadlier-Brown,Goodbrand,Ltd. 1975. Preliminary investigation of the geothermal resources of western Vancouver Island. Rept.to B.C.Hydro and Power Authority, 10pp+diagr+append.

Nevin,Sadlier-Brown,Goodbrand,Ltd. 1977 1976 geothermal investigation at Meager Creek. Rept.to B.C.Hydro and Power Authority,.18pp+diagr+append.

Nevin,Sadlier-Brown,Goodbrand,Ltd. 1980. Report on 1979 drilling and exploration program Meager Creek geothermal area upper Lillooet River, British Columbia. Rept.to B.C. Hydro and Power Auth.,.57pp+append.

Nevin,Sadlier-Brown,Goodbrand,Ltd. 1981. Geothermal energy resources in British Columbia. Rept.to Min.Energy,Mines,Petr.Resources, 142pp+append.

Nevin,Sadlier-Brown,Goodbrand,Ltd. 1981. Meager Creek geothermal area MC-1 geological summary, July 1981 - October 1981. Rept.to B.C.Hydro and Power Auth.,10pp+append.

Nevin,Sadlier-Brown,Goodbrand,Ltd. 1981. Meager Creek geothermal area slim hole drilling summary, volume 1: south reservoir area. Rept. to B.C.Hydro,Power Auth.

Nevin,Sadlier-Brown,Goodbrand,Ltd. 1981. Meager Creek geothermal area slim hole drilling summary, volume 2: Lillooet River valley. Rept.to B.C.Hydro and Power Auth.

Nevin,Sadlier-Brown,Goodbrand,Ltd. 1981. Report on 1980 drilling and exploration program Meager Creek geothermal area, upper Lillooet River, British Columbia. Rept. to B.C. Hydro,Power Auth.,.123pp+append.

Nevin,Sadlier-Brown,Goodbrand,Ltd. 1982. Interpretation of an airborne electromagnetic survey over the Meager Creek geothermal area. Rept. to Geol.Surv.Canada, 30pp

Nevin,Sadlier-Brown,Goodbrand,Ltd. 1982. Report on 1981 drilling and exploration program Meager Creek geothermal area upper Lillooet River, British Columbia. Rept.to B.C. Hydro and Power Auth., 93pp+append.

Nevin,Sadlier-Brown,Goodbrand,Ltd. 1982. Report on geothermal reconnaissance exploration of selected areas in southwestern British Columbia. Rept.to B.C.Hydro and Power Auth., 102pp+append.

Nevin,Sadlier-Brown,Goodbrand,Ltd. 1983. Report on 1982 geological mapping program, north reservoir area, Meager Creek, B.C. Rept.to B.C.Hydro and Power Auth.,14pp+append.

Nevin,Sadlier-Brown,Goodbrand,Ltd. 1983. Report on 1982 temperature gradient drilling on Shovelnose Creek at Mount Cayley, southwestern British Columbia. Rept.to Geol. Surv. Can., 12pp+append.

Nevin,Sadlier-Brown,Goodbrand,Ltd. 1983. Report on a reconnaissance hydrogeochemistry survey of the south- western drainage of Mount Cayley, British Columbia. Rept.to Geol.Surv.Can., 17pp+append.

Nevin,Sadlier-Brown,Goodbrand,Ltd. 1984. Report on preliminary evaluations of three potential geothermal sites in southern British Columbia. Rept. to Geol.Surv.Canada, 11pp + append.

Noel,G.A. 1978. Cenozoic rocks in the western Canadian cordillera of British Columbia. Geol.Surv.Can., Open File 659, 39pp

Nolan, Davis & Associates Ltd 1984. Groundwater flow patterns in Carboniferous sediments of

Atlantic Canada. Earth Phys.Br., Open File 84-29, 101pp and 1 map

Openshaw,R.E., Britton,J.M., Fairbank,B.D. and Reader,J.F. 1982. Report on 1981 drilling and exploration program, Meager Creek geothermal area upper Lillooet River, British Columbia. Rept.to B.C.Hydro and Power Auth., 93pp+append.

Pham van Ngoc. 1976. Magneto-telluric reconnaissance survey in the Lillooet Valley, British Columbia. Earth Phys.Br., Open File 77-20, 22pp+diagr.

Pham van Ngoc. 1978. Magneto-telluric prospecting in the Mount Meager geothermal region (British Columbia). Earth Phys.Br., Open File 78-6e(engl.), 78-6f(fre.), 31pp+diagr.

Pham van gnoc 1980. Etude magneto - tellurique de la region du Mont Meager et de la Vallee de Squamish, Colombie Britannique. magneto-telluric survey of the Mount Meager region of the Squamish Valley (British Columbia). Earth Phys.Br., Open File 80-8(French) 80-8-E(English), 77pp

Phoenix Geophysics Ltd. 1982. Magnetotelluric survey data North Thompson Valley area British Columbia. Rept.to Geol.Surv.Can., 3pp+append.

Phoenix geophysics Ltd. 1984. Magnetotelluric survey data, Mount Cayley area, British Columbia. Geol.Surv.Can., Open File 1018

Piteau and Assoc. 1984. Summerland Basin hydrogeological study. Earth Phys.Br., Open File 84- , 49pp+append.

Piteau and Assoc. 1988. Geochemistry and isotope hydrogeology of the Mount Edziza and Mess Creek geothermal waters. Geol.Surv.Can., Open File 1732, 47pp.

Postlethwaite,J., Gummadi,V., Scoular,J.R. and Vigrass,L.W. 1980. Corrosion testing on western Canada geothermal waters. Univ.Regina,Rept.to Public Works Can., 8pp

Postlethwaite,J., Vigrass,L.W., Gummadi,V. Neufeld,R. and Kybett,B.D. 1980. Water chemistry testing on western Canada geothermal waters. Univ.Regina,Rept.to Public Works Can., 12pp+append

Rahman,M., Jones,F.W., Lam,H.L. and Hutchence,K. 1984. Temperature front progression associated with a geothermal well doublet: a numerical study. Geothermics, 13, 319-331

Read,P.B. 1977. Meager Creek Volcanic Complex, southwestern British Columbia. Geol.Surv.Can., Paper 77-1a, 277-281

Reader,J.F. and Croft,S.A.S. 1984 1982 temperature gradient drilling on Shovelnose Creek at Mount Cayley, southwestern British Columbia. Geol.Surv.Can., Open File 1017

Reader,J.F. and Fairbank,B.D. 1983. Heat flow in the vicinity of the Meager Volcanic Complex, southwestern British Columbia. Trans.Geothermal Resour.Coun., 7, 535-539

Reid, Crowther and Partners Ltd. 1979. Environmental reconnaissance report Meager Creek geothermal area. Rept.to B.C.Hydro and Power Authority,.131pp+append.

Reid, Crowther and Partners Ltd. 1980. Geothermal energy utilisation in N.E. British Columbia: a direct heat application, Phase 1. Unpublished report to BC Min.Energy, Mines Petr. Resources, Energy Conservation and Technology.Div.

Reid, Crowther and Partners,Ltd. 1980. Meager mountain geothermal project status of environmental studies baseline data collection program. Rept.to B.C.Hydro and Power Authority,.77pp+append.

Roegiers,J.C. and McLennan,J.D. 1978. Numerical modelling of pressurized fractures. Rept.to Los Alamos Sci.Lab. 225pp

Roegiers,J.C. and McLennan,J.D. 1980. Stress determination at great depth of the geothermal well on the University of Regina campus. Earth Phys.Br., Open File 80-7, 110pp

Roegiers,J.C. and Wiles,T.D. 1981. Hydraulic fracturing of rock masses. Earth Phys.Br., Open File 81-10, 31pp

Roegiers,J.C., Curran,J.H. and Bawden,W.F. 1979. Numerical modelling of flow in fractured rock masses - discontinuous versus continuum approaches. Earth Phys.Br., Open File 79-8, 119pp

SNC group 1982. Survey of geothermal heat extraction technology. Rept. to Nat.Res.Council Ottawa, 192pp

Scintrex Ltd. 1981. Report on magnetometric resistivity (MMR) survey Meager Mountain geothermal resource British Columbia. Rept.to Geol.Surv. Can.,9pp+figs

Shore,G.A. 1978. Meager Creek geothermal system, British Columbia, part 3 - Resistivity methods and results. In - Geothermal Energy, a Novelty Becomes a Resource, Trans.Geothermal Resour.Coun.,2,593-596

Shore,G.A. 1981. Report on a resistivity survey in the vicinity of Mt. Cayley, august 1980. Geol.Surv.Can., Open File 792

Shore,G.A. 1983. Application and interpretation of multiple pole-pole resistivity survey, Mt. Cayley, B.C. Trans.Geothermal Resour.Coun., 7, 545-550

Shore,G.A. 1983. Electrical resistivity results from the Anahim Volcanic Belt, B.C. Trans.Geothermal Resour.Coun., 7, 551-554

Shore,G.A. 1984. Report on E-Scan multiple pole resistivity survey at Mt. Cayley, British

Columbia. Geol.Surv.Can., Open File 1019, 12pp+append

Shore,G.A. and Ryder,A.J.D. 1986. Mapping the Makushin Reservoir with 3-D E-scan resistivity. Trans.Geothermal Resour.Coun.,10,229-236

Shore,G.A. and Schlax,M.G. 1982. Report on coordination and review of resistivity survey results from the Meager Creek geothermal area, 1974 to present. Rept.to B.C.Hydro and Power Auth., 68pp+append.

Souther,J.G. 1975. Geothermal potential of western Canada. Proc.U.N.Symp.Geothermal Res., San Francisco, 259-267

Souther,J.G. 1976. Geothermal power, the Canadian potential. Geoscience Canada, 3, 14-20

Souther,J.G. 1979. Canadian Geothermal Research Program. Am.Inst/Petrol.Geol., 391-400,

Souther,J.G. 1980. Geothermal reconnaissance in the central Garibaldi Belt, British Columbia. Geol.Surv.Can., Paper 80-1a, 1-11

Souther,J.G. 1981. Projected geothermal energy development in Canada. Proc.Epri Natl.Mtg., 7.51-7.56,Approx

Souther,J.G. 1991. Geothermal Energy. In - Energy and groundwater resources of the Canadadian Cordillera, Geology of the Cordilleran Orogan in Canada, Ed Gabrielse,H. and Yorath,C.J. Geol.Surv.Can., Geology of Canada, No.4, 787-792.

Souther,J.G. and Dellechaie,F. 1984. Geothermal exploration at Mt. Cayley - a Quaternary volcano in southwestern British Columbia. Trans.Geothermal Resour.Coun., 8, 463-468

Souther,J.G. and Halstead,E.C. 1969. Mineral and thermal waters of Canada. 23rd.Int.Geol.Cong., Prague, 225-256

Souther,J.G. and Halstead,E.C. 1973. Mineral and thermal waters of Canada. Geol.Surv.Can., Paper 73-18, 32pp

Sproule Associates Ltd. 1976. Report on study of geothermal resources in western Canadian sedimentary basins from existing data, phase one. Earth Phys.Br., Open File 77-13, 110pp+diagr.

Sproule Associates Ltd. 1977. Report on study of geothermal resources in western Canadian sedimentary basins from existing data, phase two. Earth Phys.Br., Open File 77-14, 127pp+diagr.

Sproule Associates Ltd. 1983. Report on study of the feasibility of geothermal reservoir mapping in deep sedimentary basins using existing data. Earth Phys.Br., Open File 83-27, 80pp+maps

Sproule Associates Ltd. and Angus-Butler-Engng,1980,Ltd. 1981. Report on preliminary assessment of the potential applications of geothermal energy. Earth Phys.Br., Open File 81-7, 86pp

Stauder,J.J. 1980. Meager Creek geothermal prospect,British Columbia 1979 progress report. Proc EPRI Natl.Mtg., 4.36-4.43, Approx

Thomas,M.D. and Willis,C. 1989. Gravity modelling of the Saint George Batholith and adjacent terrain within the Appalachian Orogen, southern New Brunswick. Can.J.Earth Sci., 26, 561-576

UMA Engineering Ltd. 1985. Feasibility study in the use of geothermal energy to heat large facilities. Earth Phys.Br., Open File 85-25, 165pp

Univ.Utah,Res.Inst. 1983. Multielement geochemistry of the Meager Creek geothermal system. Rept.to Nevin,Sadlier-Brown,Goodbrand,Ltd., 25pp+append.,Approx

Vandenberghe,D.G. and Vigrass,L.W. 1979. Low-grade geothermal energy - feasibility and demonstration at Regina, Canada. Proc.Intern.Conf.Alt.Energy Sources, Miami

Vaughan Engineering Associates Ltd. 1992. Feasibility study to establish a community heating system in the Town of Springhill, N.S. using warm mine water. Unpublished report to CANMET

Vigrass,L.W. 1979. Final well report, U of R Regina 3-8-17-19 (W.2nd.Mer.) Saskatchewan. Earth Phys.Br., Open File 79-9, 36pp+diagr.

Vigrass,L.W. 1979. Utilization of low-grade geothermal energy. Proc.Conf.Energy Commun.Planning,Prairies

Vigrass,L.W. 1980. Completion and pump test, U. of Regina 3-8-17-19, phase 1b - geothermal project. Earth Phys.Br., Open File 80-6, 90pp

Vigrass,L.W. 1982. Geothermal energy from the Williston sedimentary Basin at Regina Canada. Proc.Int.Conf.Geothermal Energy, Florence, Italy, 113-122

Vigrass,L.W. 1983. University of Regina Geothermal Project phase IIa: Work preliminary to drilling of disposal well and building of pipeline. Unpublished report to Earth Physics Branch.

Vigrass,L.W. and Jessop,A.M. 1984. Regina geothermal experiment - geological and hydrological aspects. In - Energy Developments: New Forms, Renewables, Conservation, Ed.Curtis,F.A.,Proc.Energex Conf.,303-308

Vigrass,L.W., Bens,A.R., McCartan,J.J. and Hutchence,K. 1983. Final report of phase 2a geothermal project. Rept. to Govt of Saskatchewan

Vigrass,L.W., Kent,D.M. and Leibel,R.J. 1978. Low-grade geothermal project, geological feasibility study, Regina - Moose Jaw area, Saskatchewan. Earth Phys.Br., Open File 78-4, 79pp+append+diagr+sub.Repts.

Vigrass,L.W., Kent,D.M. and Leibel,R.J. 1979. Low-grade geothermal potential of the Regina - Moose Jaw area, Saskatchewan. Bull.Can Inst.Min.Metall., 72, Oct., 70-76

Vigrass,L.W., Viraghaven,T. and Curtis,F.A. 1984. Preliminary study - use of geothermal energy in wastewater treatment. Rept. to Natl.Res.Council

Vigrass,L.W., Viraraghan,T. and Curtis,F.A. 1984. University of Regina preliminary study use of geothermal energy in wastewater treatment. Rept.to Nat.Res.Council, 45pp+append.

Vtn Consolidated,Inc. 1980 1979 slope stability study - Meager mountain geothermal area. Rept. to B.C.Hydro and Power Authority,.37pp+append.

Ward,S.H. 1981. Report on analysis of dipole-dipole resistivity data, Meager Creek, British Columbia. Rept.to Premier Geophysics, 0pp

Water management services Ltd. 1984. Study of groundwater flow patterns in Carboniferous sediments of Atlantic Canada Fredericton Subbasin. Earth Phys.Br., Open File 84-11, 60pp+maps

Werner,L.J. 1981. Report on preliminary magnetometer survey Mt.Cayley area southern B.C. Rept.to Geol.Surv. Can.,17pp+figs.

Wiles,T.D. and Roegiers,J.C. 1981. Some applications of the boundary integral technique in stress analysis. Earth Phys.Br., Open File 81-8, 73pp.

CANADIAN GEOTHERMICS BIBLIOGRPAHY

Adams,J. 1993. A suite of type temperature-depth profiles in permafrost for areas of Holocene shoreline regression and ,arine transgression, Arctic Canada. Geol.Surv.Can. Open File 2656

Allis,R.G. 1975. Geothermal measurements in five small lakes of northwestern Ontario, Canada. Thesis, M.Sc., University of Toronto.

Allis,R.G. 1979. A heat production model for stable continental crust. Tectonophysics, 57, 151-165

Allis,R.G. and Garland,G.D. 1976. Geothermal measurements in five small lakes of northwest Ontario. Can.J.Earth Sci., 13, 987-992

Allis,R.G. and Garland,G.D. 1979. Heat flow measurements under some lakes in the Superior Province of the Canadian Shield. Can.J.Earth Sci., 16, 1951-1964

Allis,R.G. and Garland,G.D. 1980. Heat flow measurements under some lakes in the Superior Province of the Canadian Shield - reply. Can.J.Earth Sci., 17,-1108-1110

Anderssen,R.S. and Saull,V.A. 1973. Surface temperature history determinations from borehole measurements. Math.Geol., 5, 269-283

Anglin,F.M. 1964. Subsurface temperature in Western Canada. Thesis, M.Sc., Univ.Western Ontario

Anglin,F.M. and Beck,A.E. 1964. The use of terrestrial heat flow data in interpreting regional geology. Proc.Third Ann.Conf.Ont.Pet.Inst., 14pp

Anglin,F.M. and Beck,A.E. 1965. Regional heat flow patterns in western Canada. Can.J.Earth Sci., 2, 176-182

Arctic geotechnical group. 1982. Acquisition of geothermal data in offshore wells - phase 1. Earth Physics Br., Open File 82-14, 142pp

Ashwal,L.D., Morgan,P., Kelley,S.A. and Percival,J.A. 1987. Heat production in an Archaean crustal profile and impklications for heat flow and mobilisation of heat-producing elements. Earth,Planet.Sci.Lett., 85, 439-450

Bachu,S. 1985. Influence of lithology and fluid flow on the temperature distribution in a sedimentary basin: a case study from the Cold Lake area, Alberta, Canada. Tectonophysics, 120, 257-284

Bachu,S. 1987. Convective versus conductive heat flow in the central Alberta part of the

Western Canada Sedimentary Basin. Rev.Bras.Geofis., 5, 127-190

Bachu,S. 1988. Analysis of heat transfer processes and geothermal pattern in the Alberta Basin, Canada. J.Geophys.Res.,93, 7767-7781

Bachu,S. 1993. Basement heat flow in the Western Canada Sedimentary Basin. Tectonophysics, 222, 119-133

Bachu,S. and Burwash,R.A. 1991. Regional-scale analysis of the geothermal regime in the Western Canada Sedimentary Basin. Geothermics, 20, 387-407

Beach,R.D.W., Jones,F.W. and Majorowicz,J.A. 1987. Heat flow and heat generation estimates for the Churchill basement of the Western Canadian Basin in Alberta, Canada. Geothermics, 16, 1-16

Beck,A.E. 1962. Terrestrial flow of heat near Flin Flon, Manitoba. Nature, 195, 368-369

Beck,A.E. 1963. Lightweight borehole temperature measuring equipment for resistance thermometers. J.Sci.Inst., 41, 452-454

Beck,A.E. 1964. Flusso di calore terrestre ed energia geotermica. La Scuola in Azione San Donato Milanese, Ente Nazionale Idrocarburi, E.N.I., 165-189

Beck,A.E. 1965. Techniques of measuring heat flow on land. In - Terrestrial Heat Flow, Ed.Lee, Am.Geophys.Un.Monograph 8, 24-57

Beck,A.E. 1966. Problems in measuring temperature and terrestrial heat flow in deep boreholes. In - Drilling for scientific purposes, Ed.Findlay & Smith, Geol.Survey Can. Paper 66-13, 77-84

Beck,A.E. 1967. Heat flow studies. Geol.Surv.Can., Paper 67-41, 133-146

Beck,A.E. 1970. Non-equivalence of oceanic and continental heat flows and other geothermal problems. Comments Earth Sci.Geophys., 1, 29-34

Beck,A.E. 1971. Prospects for geothermal power. Comments Earth Sci.Geophys., 1, 139-149

Beck,A.E. 1976. An improved method of computing the thermal conductivity of fluid-filled sedimentary rocks. Geophysics, 41, 133-144

Beck,A.E. 1976. The use of thermal resistivity logs in stratigraphic correlation. Geophysics, 41, 300-309

Beck,A.E. 1977. A potential systematic error when measuring the thermal conductivity of porous rocks saturated with a low-conductivity fluid. Tectonophysics, 41, 9-16

Beck,A.E. 1977. Climatically perturbed temperature gradients and their effect on regional and continental heat-flow means. Tectonophysics, 41, 17-39

Beck,A.E. 1980. Heat flow measurements under some lakes in the Superior Province of the Canadian Shield - discussion. Can.J.Earth Sci., 17,-1108-1110

Beck,A.E. 1982. Precision logging of temperature gradients and the extraction of past climate. Tectonophysics, 83, 1-11

Beck,A.E. 1987. The maturaion of geothermics as a discipline and some unresolved problems. Rev.Bras.Geofis., 5, 73-90

Beck,A.E. 1988. Thermal properties: methods for determining thermal conductivity and thermal diffusivity. In - Handbook of terrestrial heat-flow density determination, Ed.Haenel,R., Rybach,L., Stegena,L., Kluwer Acas Publ., 87-124

Beck,A.E. 1992. Inferring past climatic change from subsurface temperature profiles: problems and methods. Palaeogeog.Palaeoclim.Palaeoecol., 98, 73-80

Beck,A.E. and Balling,N. 1988. Determination of virgin rock temperatures. In - Handbook of terrestrial heat-flow density determination, Ed.Haenel,R., Rybach,L., Stegena,L., Kluwer Acas Publ., 59-85

Beck,A.E. and Beck,J.M. 1958. On the measurement of the thermal conductivities of rocks by observations on a divided bar apparatus. Trans.Am.Geophys.Un., 39, 1111-1123

Beck,A.E. and Judge,A.S. 1969. Analysis of heat flow data-detailed observations in a single borehole. Geophys.J.R.Astr.Soc., 18, 145-158

Beck,A.E. and Logis,Z. 1963. Terrestrial flow of heat in the Brent Crater. Nature, 201, 383

Beck,A.E. and Mustonen,E. 1972. Preliminary heat flow data from Ghana. Nature,Phys.Sci., 235, 172-174

Beck,A.E. and Neophytou,J.P. 1968. Heat flow and underground water flow in the Coronation Mine area. In - Symposium on the Geology of Coronation Mine, Saskatchewan, Ed.Byers, Geol.Surv.Can.Paper 68-5, 229-239

Beck,A.E. and Sass,J.H. 1966. A preliminary value of heat flow in the Muskox Intrusion near Coppermine, N.W.T., Canada. Earth,Planet.Sci.Lett., 1, 123-129

Beck,A.E. and Shen,P.Y. 1985. Temperature distribution in flowing liquid wells. Geophysics, 50, 1113-1118

Beck,A.E. and Shen,P.Y. 1989. On a more rigorous approach to geothermic problems. Tectonophysics, 164, 83-92

Beck,A.E., Anglin,F.M., and Sass,J.H. 1971. Analysis of heat flow data - in situ thermal conductivity measurements. Can.J.Earth Sci., 8, 1-19

Beck,A.E., Hamza,V.M. and Chang,C.C. 1976. Analysis of heat flow data - correlation of thermal resistivity and shock metamorphic grade and its use as evidence for an impact origin of the Brent Crater. Can.J.Earth Sci.,13, 929-2936

Beck,A.E., Shen,P.Y., Beltrami,H., and others. 1992. A comparison of five different analyses in the interpretation of five borehole temperature data sets. Palaeogeog. Palaeoclim. Palaeoecol., 98, 101-112

Beck,A.E., Wang,K. and Shen,P.Y. 1985. Sub-bottom temperature perturbations due to temperature variations at the boundary of inhomogeneous lake or ocean sediments.. Tectonophysics, 121, 11-24

Beck,J.M. and Beck,A.E. 1965. Computing thermal conductivities of rocks from chips and conventional specimens. J.Geophys.Res., 70, 5227-5239

Becker,K., Langseth,M.G. and Hyndman,R.D. 1984. Temperature measurements in Hole 395a, Leg 78b. Init.Rept.Deep Sea Drilling Proj., 78. 689-698

Beltrami,H. 2001. Surface heat flux histories from geothermal data: inferences from inversion. Geophys.Res.Lett., 28, 655-658.

Beltrami,H. and Bourlon,E. 2004. Ground warming patterns in the northern hemisphere during the last five centuries. Earth,Planet.Sci.Lett., 227, 169-179

Beltrami,H. and Mareschal,J.C. 1992. Ground temperature histories for central and eastern Canada from geothermal measurements: little ice age signature. Geophys.Res.Lett., 19, 689-692

Beltrami,H. and Taylor,A.E. 1995. Records of climatic change in the Canadian Arctic: towards calibrating oxygen isotope data with geothermal data. Glob.,Planet.Change, 11, 127-138

Beltrami,H., Jessop,A.M. and Mareschal,J.C. 1992. Ground temperature histories in eastern and central Canada: evidence from geothermal measurements. Palaeogeog. Palaeoclim. Palaeoecol., 98, 167-184

Beltrami,H., Wang,J. and Bras,R.L. 2000. Energy balance at the Earth's surface: heat flux history in eastern Canada. Geophys.Res.Lett., 27, 3385-3388

Ben Dhia,H., Jones,F.W., Meddeb,N., and two others. 1992. Shallow geothermal studies in Tunisia: comparison with deep subsurface information. Geothermics, 21, 503-517

Bentkowski,W.H. and Lewis,T.J. 1983. Preliminary results of shallow drilling in the Garibaldi Volcanic Belt, British Columbia, 1982. Earth Physics Br., Open File 83-23, 38 pp

Bentkowski,W.H. and Lewis,T.J. 1984. Preliminary rsults from shallow drilling in the Alert Bay Volcanic Belt, 1982. Earth Physics Br., Open File 84-2, 16 pp

Bentkowski,W.H. and Lewis,T.J. 1985. Preliminary results from shalow drilling in the Anahim Volcanic Belt, B.C. Earth Physics Br., Open File 85-9 19 pp

Bentkowski,W.H. and Lewis,T.J. 1986. Heat flux in the Raft Batholith, central British Columbia. Geol.Surv.Can., Open File 1337, 24pp

Bentkowski,W.H. and Lewis,T.J. 1988. Thermal measurements in the Fraser Valley, British Columbia. Geol.Surv.Can., Open File 1743, 19pp

Bentkowski,W.H. and Lewis,T.J. 1989. Thermal measurements in Cordilleran boreholes of opportunity 1984-1987. Geol.Surv.Can., Open File 2048, 31pp

Bentkowski,W.H. and Lewis,T.J. 1994. Heat flow determinations in the Cordillera 1988-1992. Geol.Surv.Canada, Open File 2981, 34pp

Bodri,B. and Jessop,A.M. 1989. Geothermal model of the continental margins of eastern Canada. Tectonophysics, 164, 139-150

Bristow,Q. and Conaway,J.G. 1984. Temperature gradient measurements in boreholes using low noise high resolution digital techniques. Current Research, B, Geol.Surv.Can. Paper 84-1B, 101-108

Burgess,M.M. 1984. Summary of heat flow studies in the Sohm Abyssal Plain: C.S.S.Hudson cruise 80-016. Atomic Energy Can.Ltd., Tr-242

Burgess,M.M. 1986. A discussion of non-linear temperature profiles at six closely-spaced heat flow sites, southern Sohm Abyssal Plain, northwest Atlantic Ocean. Deep-sea Res., 33, 1213-1224

Burgess,M.M. and Judge,A.S. 1981. Heat flow studies in the Sohm Abyssal Plain and their relevance to nuclear waste disposal investigations. Earth Physics Br., Open File 81-15, 21pp and Appendices

Burgess,M.M. and Riseborough,D.W. 1989. Measurements frequency requirements for permafrost ground temperature monitoring: analysis of Norman Wells pipeline data, Northwest Territories and Alberta. Geol.Surv.Can., Paper 89-1D, 69-75

Burgess,M.M., Judge,A.S. and Taylor,A.E. 1982. Yukon ground temperature data collection - 1966-August 1981. Earth Physics Br., Open File 82-1, 138pp

Burgess.M.M. and Naufal,J.A. 1990. Norman Wells pipeline monitoring sites, ground temperature data file. Geol.Surv.Can., Open File 2155, 201pp

Burwash,R.A. 1979. Uranium and thorium in the Precambrian basement of western Canada. Can.J.Earth Sci., 16, 472-483

Butler,R.B. 1961. Terrestrial heat flow in the St. Lawrence Lowland of Quebec. Thesis, Ph.D., MGill Univ. 55pp

Caritat,P.de. 1993. Heat: a Fortran computer program for calculating 1-D conductive and advective heat transport in geological formations. Comput.Geosci., 19, 673-689

Cermak,V. 1971. Underground temperature and inferred climatic temperature of the past millenium. Palaeography, Palaeoclimatology, Palaeoecology. 10, 1-19

Cermak,V. and Jessop,A.M. 1971. Heat flow, heat generation, and crustal temperature in the Kapuskasing area of the Canadian Shield. Tectonophysics, 11, 287-303

Cermak,V. and Jessop,A.M. 1972. Heat flow and heat production in the Canadian Shield. Geothermics, 1, 70-72

Chen,Y. and Beck,A.E. 1991. Application of the boundary element method to a terrestrial heat flow problem. Geophys.J.Int., 107, 25-35

Conaway,J.G. 1976. Continuous logging of borehole temperature gradients. Thesis, Ph.D., Univ.Western Ontario

Conaway,J.G. 1977. Deconvolution of temperature gradient logs. Geophysics, 42, 823-837

Conaway,J.G. and Beck,A.E. 1977. Fine-scale correlation between temperature gradient logs and lithology. Geophysics, 42, 1401-1410

Conaway,J.G. and Beck,A.E>. 1977. Continuous logging of temperature gradients. Tectonophysics, 41, 1-7

Connolly,E.T. 1972. Geothermal Survey of North America progress report and associated data-gathering problems. Trans.Can.Well Logging Soc. Fourth Formn.Evaln.Symp.,37pp

Cook,F.A. 1983. The effect of lateral deformation on heat flow - heat production relations. Can.J.Earth Sci., 20, 1621-1630

Correia,A. and Jones,F.W. 1995. On the importance of measuring thermal conductivities for heat flow density estimates: an example from the Jeanne d'Arc Basin, offshore eastern Canada. Tectonophysics, 257, 71-80.

Correia,A., Jones,F.W. and Frocker,A. 1990. Terrestrial heat-flow density estimates for the Jeanne D'Arc Basin, offshore eastern Canada. Geophysics, 55, 1625-1633

Corriea,A. and Jones,F.W. 1991. The thermal regime of the Jeanne d'Arc Basin, offshore eastern Canada. Tectonophysics, 194, 357-361

Crain,I.K. 1969. A simple method of calculating climatic corrections to heat flow measurements. Can.J.Earth Sci., 6, 499-502

Crain,I.K. 1967. The influence of post-Wisconsin climatic change. Thesis, M.Sc., McGill Univ

Crain,I.K. 1968. The glacial effect and the significance of continental terrestrial heat flow measurements. Earth,Planet.Sci.Lett, 4, 69-72

Dallimore,S.R., Edwardson,K.A., Hunter,J.A. and two more. 1995. Composite geotechnical logs for two deep boreholes in the Fraser River Delta, British Columbia. Geol.Surv.Canada, Open File 3018.

Davis,E.E. and Lewis,T.J. 1984. Heat flow in a back-arc environment: Intermontane and Omineca Crystalline Belts, southern Canadian cordillera. Can.J.Earth Sci., 21, 715-726

Davis,E.E. and Villinger,H. 1992. Tectonics and thermal structure of the Middle Valley sedimented rift, northern Juan de Fuca Ridge.. Proc.Ocean Drill.Prog.Init.Rept., 139, 9-41

Davis,E.E., Chapman,D.S. Wang,K. and seven others. 1999. Regional heat flow variations across the sedimented Juan de Fuca Ridge eatern flank: constraints on lithospheric cooling and lateral hydrothermal heat transport. J.Geophys.Res., 104, 17675-17688.

Davis,E.E., Chapman,D.S., Forster,C.B. and Vilinger,H. 1989. Heat-flow variations correlated with buried basement topography on the Juan de Fuca Ridge flank. Nature, 342, 533-537

Davis,E.E., Chapman,D.S., Mottl,M.J., and others. 1992. FlankFlux: an experiment to study the nature of hydrothermal circulation in young ocean crust. Can.J.Earth Sci., 29, 925-952

Davis,E.E., Lister,C.R.B. and Sclater,J.G. 1984. Towards determining the thermal state of old ocean lithosphere: heat-flow measurements from the Blake-Bahama Outer Ridge, north-western Atlantic. Geophys.J.R.Astr.Soc., 78, 507-545

Davis,E.E., Lister,C.R.B., Wade,U.S. and Hyndman,R.D. 1980. Detailed heat flow measurements over the Juan de Fuca Ridge system. J.Geophys.Res., 85, 299-310

Doig,R. 1961. A further study of terrestrial heat flow in the St. Lawrence Lowlands of Quebec. Thesis,M.Sc.,Mcgill University, 73pp

Doig,R. and Saull,V.A. 1961. A new borehole thermometer. J.Geophys.Res., 66, 4263-4264

Drury,M.J. 1984. Assessment of the geothermal resources of Atlantic Canada. Proc. Intl. Symp. Energex 84, Regina, 285-290

Drury,M.J. 1984. On a possible source of error in extracting equilibrium formation temperature from borehole BHT data. Geothermics, 13, 175-180

Drury,M.J. 1984. Borehole temperature logging for the detection of water flow. Geoexploration, 22, 231-243

Drury,M.J. 1984. Perturbations to temperature gradients by water flow in crystalline rock formations. Tectonophysics, 103, 19-32

Drury,M.J. 1985. Heat flow and heat generation in the Churchill Province of the Canadian Shield, and their palaeotectonic significance. Tectonophysics, 115, 25-44

Drury,M.J. 1985. The Iceland Research Drilling Project crustal section: physical properties of some basalts from the Reydarfjordur borehole, Iceland. Can.J.Earth Sci., 22, 1588-1593

Drury,M.J. 1986. Heat flow in greenstone belts. Proc. Workshop on Tectonic evolution of greenstone belts, Houston, LPI Tech.Rept 86-10, 92-94

Drury,M.J. 1986. Thermal conductivity, thermal diffusivity, density and porosity of crystalline rocks. Earth Physics Br., Open File 86-5, 52pp

Drury,M.J. 1987. Thermal diffusivity of some crystalline rocks. Geothermics, 16, 105-115

Drury,M.J. 1987. Heat flow and heat generation in the Churchill Province of the Canadian Shield, and their paleotectonic significance: reply. Tectonophysics, 132, 347-349

Drury,M.J. 1987. Heat flow provinces reconsidered. Phys.Earth Planet.Inter., 49, 78-96

Drury,M.J. 1987. The thermal nature of the Canadian Appalachian crust. Tectonophysics, 133, 1-14

Drury,M.J. 1988. Tectonothermics of the North American Great Plains basement. Tectonophysics, 148, 299-307

Drury,M.J. 1988. A simple needle-probe method for measuring thermal diffusivity of unconsolidated materials. Geothermics, 17, 757-763

Drury,M.J. 1989. The heat flow - heat generation relationship: implications for the nature of the continental crust. Tectonophysics, 164, 93-106

Drury,M.J. 1989. Fluid flow in crystalline crust: detecting fractures by temperature logs. In - Hydrological regimes and their subsurface effects. Ed. Beck,A.E., Garven,G, Stegena,L. Am.Geophys.Un., Geophys.Momogr. 47, 129-135

Drury,M.J. 1991. Heat flow in the Canadian Shield and its relation to other geophysical parameters. In - Terrestrial heat flow and the lithosphere Structure, Ed. Cermak,V. and

Rybach,L., Springer Verlag, 317-337

Drury,M.J. 1992. Tectonothermics of modern and ancient continental margins. In - Characterisation and comparison of ancient and mesozoic continental margins, Proc 8th Intl.Conf.Basement Tectonics, Ed.Bartholemew, Hyndman, Monk, Mason, Intl.Base. Tect.Assoc.Publ. 8, 27-36

Drury,M.J. and Jessop,A.M. 1982. The effect of a fluid-filled fracture on the temperature profile in a borehole. Geothermics, 11, 145-152

Drury,M.J. and Jessop,A.M. 1983. The estimation of rock thermal conductivity from mineral content - an assessment of techniques. Zbl.Geol.Palaont., 1, 35-48

Drury,M.J. and Lewis,T.J. 1979. Thermal studies in the Lac du Bonnet Batholith at Pinawa, Manitoba. Atomic Enrgy Can.Ltd, Tech.Rec. TR-12

Drury,M.J. and Lewis,T.J. 1983. Water movement within Lac du Bonnet Batholith as revealed by detailed thermal studies of three closely spaced boreholes. Tectonophysics, 95, 337-351

Drury,M.J. and Taylor,A.E. 1988. Some new measurements of heat flow in the Superior Province of the Canadian Shield. Can.J.Earth Sci., 24, 1486-1489

Drury,M.J., Allen,V.S. and Jessop,A.M. 1982. The measurement of thermal diffusivity of rock cores. Tectonophysics, 103, 321-333

Drury,M.J., Jessop,A.M. and Lewis, T.J. 1983. Geothermal logging for the detection of groundwater flow. Proc.Int.Conf.on Groundwater and Man, Sydney, 79-87

Drury,M.J., Jessop,A.M. and Lewis,T.J. 1984. The detection of groundwater flow by precise temperature measurements in boreholes. Geothermics, 13, 163-174

Drury,M.J., Jessop,A.M. and Lewis,T.J. 1987. The thermal nature of the Appalachians of eastern Canada. Tectonophysics, 133,1-14

Durham,W.B., Mirkovich,V.V. and Heard,H.C. 1987. Thermal diffusivity of igneous rocks at elevated pressure and temperature. J.Geophys.Res., 92, 11615-11634

Ferguson,G. and Beltrami,H. 2006. Transient lateral heat flow due to land-use changes. Earth,Planet.Sci.Lett., 242, 217-222.

Ferguson,G. and Woodbury,A.D. 2004. Subsurface heat flow in an urban environment. J.Geophys.Res. 109, B02402, doi:10,1029/2003JB002715.

Forster,C. and Smith,L. 1989. The influence of groundwater flow on thermal regimes in mountainous terrain: a model study. J.Geophys.Res., 94, 9439-9451

Fou,J.T.K. 1969. Thermal conductivity and heat flow at St. Jerome, Quebec. Thesis, M.Sc., McGill University, 79pp

Fountain,D.M., Furlong,K.P. and Salisbury,M.H. 1987. A heat production model of a shield area and its implications for heat flow - heat production relationship. Geophys.Res.Lett., 14, 283-286

Fountain,D.M., Salisbury,M.H. and Furlong,K.P. 1987. Heat production and thermal conductivity of rocks from the Pikwitonei Sachigo continental cross section, central Manitoba: implications for the thermal structure of the Archean crust. Can.J.Earth Sci., 24, 1583-1594

Furlong,K.P. and Chapman,D.S. 1987. Crustal heterogeneities and the thermal structure of the continental crust. Geophys.Res.Lett., 14, 314-317

Garland,G.D. and Lennox,D.H. 1962. Heat flow in western Canada. Geophys.J.R.Astr.Soc., 6, 245-262

Geo-engineering (M.S.T.) Ltd. 1990. Report of geothermal modelling, offshore temperature profiles at Angasak and Amauligak, Beaufort Shelf. Geol.Surv.Can., Open File 2226, 56pp

Geo-engineering (M.S.T.) Ltd. 1990. Modelling of offshore temperature profiles, final results for Amauligak and Angasak, Beaufort Shelf. Geol.Surv.Can., Open File 2227, 14pp

Geotech Ltd. 1984. Subsurface temperature data from wells north of sixty, Yukon - Northwest Territories. Earth Physics Br., Open File 84-28, 557 pp and 5 maps

Gosselin,C. and Mareschal,J.C. 2003. Variations in ground surface temperature histories in the Thompson Belt, Manitoba, Canada: environment and climate changes. Glob.Planet.Change, 39, 271-284

Gosselin,C. and Mareschal,J.C. 2003. Variations in ground surface temperature histories in the Thompson Belt, Manitoba, Canada: environmental and climate changes. Glob.,Planet.,Change, 39, 271-284

Gough,D.I. and Porath,H. 1970. Long-lived thermal structure under the southern Rocky Mountains. Nature, 226, 837-839

Gray,J.T. 1983. Extraction and compilation of available temperature and snow-fall in the Ungava Peninsula as input to geothermal modelling of quaternary palaeoclimates. Earth Physics Br., Open File 83-12, 38pp

Gretener,P.E. 1982. Geothermics: using temperature in hydrocarbon exploration. Am.Assn.Petr.Geol., Education Course Note Ser.17, 170pp

Guillou,L., Mareschal,J.C., Jaupart,C., and three others. 1994. Heat flow, gravity and structure of the Abitibi Belt, Superior Province, Canada: implications for mantle heat flow. Earth,Planet.Sci.Lett., 122, 103-123

Guillou-Frottier,L., Jaupart,C., Marescal,J.C. and four othe. 1996. High heat flow in the trans-Hudaon Orogen, central Canadian Shield. Geophys.Res.Lett., 23, 3027-3030.

Guillou-Frottier,L., Mareschal,J.C. and Musset,J. 1998. Ground surface temperature history in central Canada inferred from 10 selected borehole temperature profiles. J.Geophys.Res., 103, 7385-7397.

Guillou-Frottier,L., Mareschal,J.C., Jaupart,C. and three ot. 1995. Heat flow variations in the Grenville Province, Canada. Earth,Planet.Sci.Lett., 136, 447-460

Hackbarth,D.A. 1978. Groundwater temperatures in the Athabaska oil sands area, Alberta. Can.J.EArth Sci.,15, 1689-1700

Hamdani,Y. and Mareschal,J.C. 1993. Paleo heat flow of eastern Canada's passive margins. Tectoinophysics, 225, 107-121

Hamdani,Y., Mareschal,J.C. and Arkani-Hamed,J. 1994. Phase change and thermal subsidence of the Williston Basin. Geophys.J.Int., 116, 585-597

Hamza,V.M. 1973. Vertical distribution of radioactive heat production in the Grenville. Thesis, Ph.D., Univ.Western Ontario

Hamza,V.M. and Beck,A.E. 1972. Terrestrial heat flow, the neutrino problem, and a possible energy source in the core. Nature, 240, 343-344

Hamza,V.M. and Beck,A.E. 1975. Analysis of heat flow data - vertical variations of heat flow and heat producing elements in sediments. Can.J.Earth Sci., 12, 996-1005

Hart,S.R., Steinhart,J.S. and Smith,T.J. 1993. Terrestrial heat flow in Lake Superior. Can.J.Earth Sci., 31, 698-708

Hitchon,B. 1984. Geothermal gradients, hydrodynamics, and hydrocarbon occurrences, Alberta, Canada. Bull.Am.Ass.Petrol.Geol., 68, 713-743

Hobson,G.D., Beck,A.E. and Findlay,D.C. 1966. Notes on geophysical logs and borehole temperature measurement from the Muskox drilling project. In - Drilling for scientific purposes, Ed.Findlay & Smith, Geol.Survey Can. Paper 66-13, 108-122

Hyndman,R.D. 1976. Heat flow measurements in the inlets of southwestern British Columbia. J.Geophys.Res., 81, 337-349

Hyndman,R.D. and Drury,M.J. 1976. The physical properties of oceanic basement rocks from deep drilling on the mid-Atlantic Ridge. J.Geophys.Res., 81, 4042-4052

Hyndman,R.D. and Jessop,A.M. 1971. The Mid-Atlantic Rifdge near 45 degrees north, XV Thermal conductivity of dredge and drill core samples. Can.J.Earth Sci.,8, 391-393

Hyndman,R.D. and Lewis,T.J. 1995. Review: the thermal regime along the southern Canadian Cordillera lithoprobe corridor. Can.J.Earth Sci., 32, 1611-1617

Hyndman,R.D. and Lewis,T.J. 1999. Geophysical consequences of the Cordillera - Craton thermal transition in southwestern Canada. Tectonophysics, 306, 397-422

Hyndman,R.D. and Lewis,T.J. 1999. Geophysical consequences of the Cordillera-Craton thermal transition in southwestern Canada. Tectonophysics, 306, 397-422

Hyndman,R.D. and Rankin,D.S. 1972. The Mid-Atlantic Ridge near 45N. XVIII. Heat flow measurements. Can.J.Earth.Sci.,8,664-670

Hyndman,R.D., Christensen,N.I. and Drury,M.J. 1979. Seismic velocities, densities, electrical resistivities, porosities and thermal conductivities of core samples from boreholes into the islands of Bermuda and the Azores. In - Deep Drilling Results in the Atlantic Ocean, Ed.Talwani, Harrison & Hayes, Am.Geophys.Un. Maurice Ewing Ser. 2, 94-112

Hyndman,R.D., Christensen,N.I. and Drury,M.J. 1984. The physical properties of basalt core samples from deep sea drilling project Leg 78b Hole 395a. Init.Rept.Deep Sea Drilling Proj., 78, 801-810

Hyndman,R.D., Davis,E.E. and Wright,J.A. 1979. The measurement of marine geothermal heat flow by a multipenetration probe with digital acoustic telemetry and insitu thermal conductivity. Mar.Geophys.Res., 4, 181-205

Hyndman,R.D., Fluck,P., Mazzotti,S. and three others. 2005. Current tectonics of the northern Canadian Cordillera. Can.J.Earth Sci., 42, 1117-1136

Hyndman,R.D., Foucher,J.P., Yamano,M. and Fisher,A. 1992. Deep sea bottom-simulating reflectors: calibration of the base of the hydrate stability field as used for heat flow estimates. Earth,Planet.Sci.Lett., 109, 289-301

Hyndman,R.D., Jessop,A.M., Judge,A.S. and Rankin,D.S. 1979. Heat flow in the Maritime Provinces of Canada. Can.J.Earth Sci., 16, 1154-1165

Hyndman,R.D., Langseth,M.G. and Von Herzen,R.P. 1984. A review of the deep sea drilling project geothermal measurements through leg 71. Init.Rept.Deep Sea Drilling Proj., 78, 813-823

Hyndman,R.D., Lewis,T.J., Wright,J.A., and three others. 1982. Queen Charlotte Fault Zone - heat flow measurements. Can.J.Earth Sci., 19, 1657-1669

Hyndman,R.D., Muecke,G.K. and Aumento,F. 1974. Deep drill 1972. Heat flow and heat production in Bermuda. Can.J.Earth Sci.,11,809-818

Hyndman,R.D., Rogers,G.C., Bone,M.N., and seven others. 1978. Geophysical measurements in the region of the Explorer Ridge off western Canada. Can.J.Earth Sci., 15, 1508-1525

Issler,D.R. and Beaumont,C. 1986. Estimates of terrestrial heat flow in offshore eastern Canada: discussion. Can.J.Earth Sci.,, 23, 2083-2085

Issler,D.R., Beaumont,C., Willett,S.D., and others. 1990. Preliminary evidence from apatite fission-track data concerning the thermal history of the Peace River Arch region, Western Canada Sedimentary Basin. Bull.Can.Petr.Geol., 38, 250-269

Jessop,A.M. 1964. Geothermal research in Canada. Can.Min.Met.Bull. 67

Jessop,A.M. 1964. A lead-compensated thermistor probe. J.Sci Inst., 41, 503-504

Jessop,A.M. 1968. Three measurements of heat flow in eastern Canada. Can.J.Eartth Sci., 5, 61-68

Jessop,A.M. 1970. The effect of environment on divided bar measurements. Tectonophysics, 10, 39-49

Jessop,A.M. 1971. The distribution of glacial perturbation of heat flow in Canada. Can.J.Earth Sci., 8, 162-166

Jessop,A.M. 1972. Heat flow and permafrost. Bull.Can.Inst.Min.Met., 65, 45-48

Jessop,A.M. 1973. Terrestrial heat flow and permafrost. Nat.Res.Coun.technical Memorandum 108, 57-59

Jessop,A.M. 1976. Geothermal energy from sedimentary basins. Earth Physics Br., Geothermal Series 8, 10pp

Jessop,A.M. 1976. Geothermal studies in Canada. In - Geophysics of the Americas, Ed.Tanner & Dence, Publ.Earth Phys.Br., 46, 3, 70-73

Jessop,A.M. 1983. The essential ingredients of a continental heat flow determination. Zbl.Geol.Palaont., 1, 70-79

Jessop,A.M. 1987. Estimation of lateral water flow in an aquifer by thermal logging. Geothermics, 16, 117-126

Jessop,A.M. 1989. Hydrological distortion of heat flow in sedimentary basins. Tectonophysics, 164, 211-218

Jessop,A.M. 1990. Thermal geophysics. Elsevier Publishing Co., 305pp

Jessop,A.M. 1990. Comparison of industrial and high-resolution thermal data in a sedimentary basin. Pageoph, 133, 251-267

Jessop,A.M. 1992. Thermal imput from the basement of the Western Canada Sedimentary Basin. Bull.Can.Soc.Petrol.Geol. 40, 198-206

Jessop,A.M. and Judge,A.S. 1971. Five measurements of heat flow in southern Canada. Can.J.Eartth Sci., 8, 711-716

Jessop,A.M. and Judge,A.S. 1975. Temperature and heat flux measurements through permafrost as a geophysical tool. Assoc.Com.Geotech.Res., Technical Memorandum 114, 17-27

Jessop,A.M. and Judge,A.S. 1975. Temperature measurements in boreholes for the mining industry. In - Borehole Geophysics applied to metallic mineral prospecting, a review. Geol.Surv. Can. Paper 75-31, 55-65

Jessop,A.M. and Lewis,T.J. 1978. Heat flow and heat generation in the Superior Province of the Canadian Shield. Tectonophysics, 50, 55-77

Jessop,A.M. and Majorowicz,J.A. 1994. Fluid flow and heat transfer in sedimentary basins. In - Geofluids: Origin, Migration and Evolution of Fluids in Sedimentary Basins, Geol.Soc. Spec.Publ.78, 43-54

Jessop,A.M. and Vigrass,L.W. 1989. Geothermal measurements in a deep well at Regina, Saskatchewan. J.Volcan.Geothermal Res., 37, 151-166

Jessop,A.M., Allen,V.S. and eight others. 2005. The Canadian geothermal data compilation. Geological Survey of Canada, Open File 4887

Jessop,A.M., Hobart,M.A. and Sclater,J.G. 1976. The world heat flow data collection - 1975. Earth Physics Br., Geothermal Series 5, 125pp

Jessop,A.M., Lewis,T.J., Judge,A.S., and two others. 1984. Terrestrial heat flow in Canada. Tectonophysics, 103, 239-261

Jessop,A.M., Robertson,P.B. and Lewis,T.J. 1979. A brief summary of the thermal conductivity of crystalline rocks. Atomic Energy Can., Tech Rept. TR-12

Jessop,A.M., Souther,J.G., Lewis,T.J. and Judge,A.S. 1984. Geothermal measurements in northern British Columbia and southern Yukon Territory. Can.J.Earth Sci., 21, 599-608

Jessop.A.M., Lewis,T.J. and Drury,M.J. 1991. Terrestrial heat flow in Canada. In - Terrestrial heat flow and the lithosphere Structure, Ed. Cermak,V. and Rybach,L., Springer Verlag, 1-22

Jones,F.W. and Majorowicz,J.A. 1987. Regional trends in radiogenic heat generation in the Precambrian basement of the Western Canadian Basin. Geophys.Res.Lett., 14, 268-271

Jones,F.W. and Pascal,F. 1994. Numerical model calculations of the effects of grain size and orientations on the thermal conductivities of composites. Geothermics, 23, 365-371.

Jones,F.W. and Pascal,F. 1995. Numerical calculations of the thermal conductivities of composites - a 3-D model. Geophysics, 60, 1038-1050.

Jones,F.W. and Sydora,R.D. 1980. Numerical calculations of the perturbation of normal heat flow by topography and local conductivity structure. J.Volcan.Geoth.Res., 8, 285-295

Jones,F.W., Kushigbor,C., Lam,H.L., and two others. 1984. Estimates of terrestrial thermal gradients and heat flow variations with depth in the Hinton-Edson area of the Alberta Basin derived from petroleum bottom-hole temperature data. Geophys.Prospecting, 32 1111-1130

Jones,F.W., Majorowicz,J.A. and Embry,A.F. 1989. A heat flow profile across the Sverdrup Basin, Canadian Arctic Islands. Geophysics, 54, 171-180

Jones,F.W., Majorowicz,J.A. and Lam,H.L. 1985. The variation of heat flow density with depth in the Prairies Basin of western Canada. Tectonophysics, 121, 35-44

Jones,F.W., Majorowicz,J.A., Dietrich,J. and Jessop,A.M. 1990. Geothermal gradients and heat flow in the Beaufort-Mackenzie Basin, Arctic Canada. Pageoph, 134, 473-483

Jones,F.W., Majorowicz,J.A., Embry,A.F. and Jessop,A.M. 1990. Geothermal gradients and terrestrial heat flow along a south-north profile in the Sverdrup Basin, Canadian Arctic Archipelago. Geophysics, 55, 1105-1107

Jones,F.W., Majorowicz,J.A., Linville,A. and Osadetz,K.G. 1986. The relationship of hydrocarbon occurrences to geothermal gradients and time-temperature indices in mesozoic formations of southern Alberta. Bull.Can.Petrol.Geol., 34, 2, 226-239

Jones,F.W., Pascal,F. and Ertman,M.E. 1993. The thermal regime of a three-dimensional subducting lithospheric slab and its electromagnetic response: a numerical model. Tectonophysics, 222, 35-48

Jones,F.W., Rahman,M., Majorowicz,J.A. and Lam,H.L. 1983. A study of thermal properties of sedimentary rocks of western Canada. Earth Physics Br., Open File 83-7, 1079pp

Jones.F.W., Lam,H.L. and Yuen,D. 1982. A study of existing temperature data from Canadian sedimentary basins. Earth Physics Br., Open File 82-22, 107pp

Judge,A.S. 1971. Geothermal measurements in a sedimentary basin. Thesis, Ph.D., University of Western Ontario

Judge,A.S. 1973. The prediction of permafrost thickness. Can.Geotech.J., 10, 1-11

Judge,A.S. 1973. Deep temperature observations in the Canadian North. North American Contr. Second Int. Permafrost Conf., NAS/NRC, Washington, 35-41

Judge,A.S. 1973. Measurement of thermal conductivity of earth materials. Proc. Symp. Thermal Regime and Meas. in Permafrost, Tech Memo. 108, Assoc. Comm. Geotech. Res. NRC. 26-31

Judge,A.S. 1973. Ground temperature measurement using thermistors. Proc. Symp. Thermal Regime and Meas. in Permafrost, Tech Memo. 108, Assoc. Comm. Geotech. Res. NRC. 13-22

Judge,A.S. 1973. Selected bibliography of heat flow measurements and subsurface temperatures in the Canadian Arctic and Alaska. Proc. Symp. Thermal Regime and Meas. in Permafrost, Tech Memo. 108, Assoc. Comm. Geotech. Res. NRC. 54-59

Judge,A.S. 1974. Geothermal measurements in northern Canada. Proc. Symp. Geology of the Canadian Arctic GAC/CSPG. 301-312

Judge,A.S. 1975. Geothermal studies in the Mackenzie Valley by the Earth Physics Branch. Earth Physics Br., Geothermal Series 2, 12pp

Judge,A.S. and Bawden,W. 1987. Geothermal contours and geothermal gradients. In - Marine science atlas of the Beaufort Sea, geology and geophysics. Ed Pelletier,B.R. Geol.Survey Can. Misc.Rept.m, 40, 6-7

Judge,A.S. and Beck,A.E. 1967. An anomalous heat flow layer at London, Ontario. Earth,Planet.Sci.Lett., 3, 167-170

Judge,A.S. and Beck,A.E. 1973. Analysis of heat flow data - several boreholes in a sedimentary basin. Can.J.Earth Sci.,10, 1494-1507

Judge,A.S. and Jessop,A.M. 1978. Heat flow north of 60N. In - Arctic Geophysical Review, Ed.Sweeney, Publ.Earth Phys.Br., 45, 4, 25-33

Judge,A.S. and Majorowicz,J.A. 1992. Geothermal conditions for gas hydrate stability in the Beaufort-Mackenzie area: the global change aspect. Palaeogeog.Palaeoclim.Palaeoecol., 98, 251-263

Judge,A.S., Duguid,A., Taylor,A.E. and Allen,V. 1989. The automatic well temperature measuring system installed at Cape Allison C-47, offshore well, Arctic Islands of Canada. J.Can.Petrol.Tech., 28, 89-94

Judge,A.S., Hunter,J.A., Good,R.L., Cowan,J. and Robb,G. 1976. Thermistor cable installation in permafrost materials with a water-jet drilling method. Geol.Surv.Can., Paper 76-1A, 479-480

Judge,A.S., Smith,S.L. and Majorowicz,J.A. 1994. The current distribution and thermal stability of natural gas hydrates in the Canadian polar regions. Proc.Fourth Intl.Offshore and Polar Engng Cong., Osaka, Japan, 307-314

Judge,A.S., Taylor,A.E. and Burgess,M.M. 1979. Canadian geothermal data collection - northern wells 1977-78. Earth Physics Br., Geothermal Series 11, 187pp

Judge,A.S., Taylor,A.E. and Rutledge,L. 1979. A supplement to the Canadian geothermal data collection - northern wells 1977-78. Earth Physics Br., Open File 79-13, 64pp

Judge,A.S., Taylor,A.E., Burgess,M. and Allen,V.A. 1981. Canadian geothermal data collection - northern wells 1978-80. Earth Physics Br., Geothermal Series 12, 190pp

Kamp,G van der. 1982. Interactions between heat flow and groundwater flow - a review. Earth Physics Br., Open File 82-19, 87pp

Kamp,G.van der and Bachu,S. 1989. Use of dimensional analysis in the study of thermal effects of various hydrological regimes. In - Hydrological regimes and their subsurface effects. Ed. Beck,A.E., Garven,G, Stegena,L. Am.Geophys.Un., Geophys.Momogr. 47, 23-28

Keen,C.E. and Lewis,T.J. 1982. Radiogenic heat production in sediments from the continental margin of eastern North America - implications for hydrocarbon generation. Bull.Am.Ass.Petrol.Geol., 66, 1402-1407.

Kennedy,P.L. and Woodbury,A.D. 2000. Minimum relative entropy: theory and application to surface temperature reconstruction from borehole surface measurements. Geophys. Res. Lett., 27, 3081-3084

Lachenbruch,A.H. 1957. Thermal effects of the ocean on permafrost. Bull.Geol.Soc.Am., 68, 1515-1529

Lachenbruch,A.H. and Marshall,B.V. 1969. Heat flow in the Arctic. Arctic, 22, 300-311

Lam,H.L., Jones,F.W. and Majorowicz,J.A. 1985. A statistical analysis of bottom-hole temperature data in southern Alberta. Geophysics, 50, 677-684

Lam.H.L. and Jones,F.W. 1984. Geothermal gradients of Alberta in western Canada. Geothermics, 13, 181-192

Langseth,M.G., Hyndman,R.D., Becker,K., and two others. 1984. The hydrological regime of isolated sediment ponds in mid-oceanic ridges. Init.Rept.Deep Sea Drilling Proj., 78, 825-837

Law,L.K., Paterson,W.S.B. and Whitham,K. 1965. Heat flow determinations in the Canadian

Arctic Archipelago. Can.J.Earth Sci., 2, 59-71

Leblanc,Y., Pascoe,L.J. and Jones,F.W. 1981. The temperature stabilisation of a borehole. Geophysics, 46, 1301-1303

Leith,T.H. 1952. Heat flow at Kirkland Lake. Trans.Am.Geophys.Un., 33, 435-443

Lewis,J.F. and Hyndman,R.D. 1976. Oceanic heat flow measurements over the continental margins of eastern Canada. Can.J.Earth Sci., 13, 1031-1038

Lewis,J.F. and Jessop,A.M. 1981. Heat flow in the Garibaldi Volcanic Belt, a possible Canadian geothermal energy resource area. Can.J.Earth Sci., 18, 366-375

Lewis,T.J. 1969. Terrestrial heat flow at Eldorado, Saskatchewan. Can.J.Earth Sci., 6, 1191-1197

Lewis,T.J. 1974. Heat production measurement in rocks using a gamma ray spectrometer with a solid state detector. Can.J.Earth Sci.,11, 526-532

Lewis,T.J. 1975. A geothermal survey at Lake Dufault, Quebec. Thesis, Ph.D. Univ Western Ontario

Lewis,T.J. 1976. Heat generation in the Coast Range Complex and other areas of British Columbia. Can.J.Earth Sci., 13, 1634-1642

Lewis,T.J. 1983. Bottom water temperature variations as observed and recorded in the bottom sediments, Alice Arm and Douglas Channel, British Columbia. Proc. Workshop kitimat Marine environment, Ed. MacDonald,R.W., Can.Tech Rept. Hydrography, Ocean Sci., 18, 138-161

Lewis,T.J. 1984. Geothermal energy from Penticton Tertiary Outlier, British Columbia, an initial assessment. Can.J.Earth Sci., 21 181-188

Lewis,T.J. 1987. Heat flow and heat generation in the Churchill Province of the Canadian Shield, and their paleotectonic significance: discussion. Tectonophysics, 132, 343-347

Lewis,T.J. 1987. Measuring the thermal conductivity and heat generation of sedimentary units. In - Hydrology of sedimentary basins: application to exploration and exploitation. Proc Third Can/Am.Conf Hydrogeol., 140-142

Lewis,T.J. 1989. Canadian Cordillera geothermal data base. In - Geophysics of North America, Ed. Hittelman,a.m. et al ,Natl.Geophys. Data Centre, NOAA

Lewis,T.J. 1989. Heat flux profile across Lithoprobe transect B2. Trans.Am.Geophys.Un., EOS, 70, 1989

Lewis,T.J. 1991. Heat flux in the Canadian Cordillera. In - Neotectonics of North America, Ed. Slemmons, Engdahl, Zoback, and Blackwell, Geol.Soc.Am., Decade Map Volume 1, 445-456

Lewis,T.J. 1998. The effect of deforestation on ground surface temperatures. Glo., Planet. Change, 18, 1-13

Lewis,T.J. and Beck,A.E. 1977. Analysis of heat flow data - detailed observations in many holes in a small area. Tectonophysics, 41, 41-59

Lewis,T.J. and Bentkowski,W.H. 1988. Potassium, uranium, and thorium concentrations of crustal rocks: a data file. Geol.Surv.Can., Open File 1744, 9pp + tables

Lewis,T.J. and Bentkowski,W.H. 1991. Blocky sediments in Bute and Knight Inlets, British Columbia. Geol.Surv.Can, Paper 91-1A, 303-308

Lewis,T.J. and Skinner,W. 2003. Inferring climate change from underground temperatures: apparent climatic stability and apparent climatic warming. Earth Interactions, 7, 1-9

Lewis,T.J. and Souther,J.G. 1978. Meager Mountain, B.C. - a possible geothermal energy resource. Earth Physics Br., Geothermal Series 9, 17pp

Lewis,T.J. and Wang,K. 1992. Clues to past climate found down a borehole. Earth in Space, 5, 10-12

Lewis,T.J. and Wang,K. 1992. Geopthermal research related to past climate. Trans. Am. Geophys. Un., Eos, 73,265-269

Lewis,T.J. and Wang,K. 1992. Influence of terrain on bedrock temperatures. Palaeogeog. Palaeoclim. Palaeoecol., 98, 87-100

Lewis,T.J. and Wang,K. 1998. Geothermal evidence for deforestation induced warming: implications for the climatic impact of land development. Geophys.Res.Lett., 25, 535-538

Lewis,T.J. and Werner,L. 1982. Geotherma gradients on the west side of Okanagan Lake, B.C. Earth Physics Br., Open File 82-6.

Lewis,T.J. and Werner,L. 1982. Geothermal gradients on the west side of Okanagan Lake, B.C. Earth Physics Br., Open File 82-6, 58 pp

Lewis,T.J. and Woodsworth,G.H. 1981. Heat generation in the northern Hogem Batholith and nearby plutons of McConnell Creek map area, B.C. Geol.Surv.Can. Paper 81-1B,, 163-164

Lewis,T.J., Allen,V.A., Taylor,A.E. and Jessop,A.M. 1979. Temperature observations during drilling of two 400 m wells in the Coryell intrusives north of Grand Forks, British Columbia, 1978. Earth Physics Br., Open File 79-4, 24 pp

Lewis,T.J., Bennetts,H., Allen,V.S. and Chan,F. 1984. Uranium, thorium and Potassium concentrations and heat generated in samples of crustal rocks. Earth Physics Br., Open File 84-15, 163pp

Lewis,T.J., Bentkowski,W.H. and Hyndman,R.D. 1992. Crustal temperatures near the Southern Canadian Cordillera Transect. Can.J.Earth Sci., 29, 1197-1214

Lewis,T.J., Bentkowski,W.H. and Hyndman,R.D. 1993. Crustal reflectors, metamorphic reactions and crustal temperatures in the southern Canadian Cordillera. Tectonophysics, 225, 57-61

Lewis,T.J., Bentkowski,W.H. and Hyndman,R.D. 1993. Crustal temperatures near the Lithoprobe southern Canadian Cordilleran transect. Can.J.Earth Sci., 29, 57-61

Lewis,T.J., Bentkowski,W.H. and Wright,J.A. 1991. Thermal state of the Queen Charlotte Basin, British Columbia: warm. In - Evolution and hydrocarbon potential of the Queen Charlotte Basin, British Columbia. Ed.Woodsworth,G., Geol.Surv.Paper 90-10, 489-506

Lewis,T.J., Bentkowski,W.H., Bone,M. and Wright,J.A. 1989. Note on the thermal structure of Queen Charlotte Basin, British Columbia. Geol.Surv.Can., Paper 89-1H, 121-125

Lewis,T.J., Bentkowski,W.H., Bone,M., and two others. 1988. Geothermal studies in the Queen Charlotte Basin, British Columbia. Geol.Surv.Can. Paper88-1E, 247-249

Lewis,T.J., Bentkowski,W.H., Davis,E.E., and two others. 1988. Subduction of the Juan de Fuca Plate: thermal consequences. J.Geophys.Res., 93, 15207-15225

Lewis,T.J., Bentkowski,W.H., Davis,E.E., and two others. 1989. Thermal structure of the northern (Canadian) Cascades. Proc.Conf.Geol.Geophys.Tectonic setting of the Cascade Range. U.S.Geol.Surv. Open File 89-178, 104-121

Lewis,T.J., Hyndman,R.D. and Fluck,P. 2003. Heat flow, heat generation, and crustal temperature in the Northern Canadian Cordillera: thermal control of tectonics. J.Geophys.Res., 108, B6, 2316

Lewis,T.J., Jessop,A.M. and Judge,A.S. 1985. Heat flux measurements in southwestern British Columbia: the thermal consequences of plate tectonics. Can.J.Earth Sci., 22, 1262-1273

Lewis,T.J., Judge,A.S. and Souther,J.G. 1979. Possible geothermal sources in the Coast Plutonic Complex of southern British Columbia. Pageoph, 117, 172-179

Lewis,T.J., Lowe,C. and Hamilton,T.S. 1997. Continental signature of a ridge-trench-triple junction: Northern Vancouver Island. J.Geophys.Res., 102, 7767-7781

Lewis,T.J., Villinger,H. and Davis,E.E. 1993. Thermal conductivity measurement of rock fragments using a pulsed needle probe. Can.J.Earth Sci.,30, 480-485

Lewis,T.J., Wang,K. and Majorowicz,J.A. 1994. Regional differences in past climates: evidence from temperature logs in Canada. Proc.7th Intl.Symp. Observations of the continental crust through drilling, Santa Fe, 185-188

Lister,C.R.B., Sclater,J.G., Davis,E.E. and Villinger,H. 1990. Heat flow maintained in ocean basins of great age: investigations in the north-equatorial west Pacific. Geophys.J.Int., 102, 603-630

Louden,K.E. and Wright,J.A. 1989. Marine heat flow data: a new compilation of observations and brief review of its analysis. In - CRC handbook of seafloor heat flow, Ed. Wright,J.A., Louden,K.E., CRC Press, 3-67

Louden,K.E., Dadey,K.A. and Srivastava,S.P. 1989. Heat flow measurements at Hole 646A. In - Proceedings of the Ocean Drilling Program; Baffin Bay and Labrador Sea, Leg 105, 923-931

Louden,K.E., Leger,G. and Hamilton,N. 1990. Marine heat flow observations on the Canadian Arctic Continental Shelf and Slope. Mar.Geol., 93, 267-288

Louden,K.E., Sibuet,J.C. and Foucher,J.P. 1991. Variations in heat flow across the Goban Spur and Galicia Bank continental margins. J.Geophys.Res., 96, 16131-16150

Louden,K.E., Sibuet,J.C. and Harmegnies,F. 1997. Variations in heat flow across the ocean - continent transition in the Iberia abyssal plain. Eart Planet.Sci Lett., 151, 233-254.

Louden,K.E., Wallace,D.O. and Courtney,R.C. 1987. Heat flow and depth versus age for the Mesozoic northwest Atlantic Ocean: results from the Sohm Abyssal Plain and implications for the Bermuda Rise. Earth,Planet.Sci.Lett., 83, 109-122

Majorowicz,J.A. 1989. The controversy over the significance of hydrodynamic effect on heat flow in the Prairies Basin. In - Hydrological regimes and their subsurface effects. Ed. Beck,A.E., Garven,G, Stegena,L. Am.Geophys.Un., Geophys.Momogr. 47, 101-105

Majorowicz,J.A. 1993. Climate change inferred from analysis of borehole temperatures: first results from Alberta Basin, Canada. Pageoph, 140, 655-666

Majorowicz,J.A. 1996. Accelerating ground warming in the Canadian Prairie Provinces: is it a result of global warming?. Pageoph, 147, 1-24

Majorowicz,J.A. 1996. Anomalous heat flow regime in the western margin of the North American Craton, Canada. J.Geodynamics, 21, 123-140

Majorowicz,J.A. 1998. A constraint to the methane gas hydrate stability from the analysis of thermal data in the northern Canadian sedimentary basins - Arctic Archipelago case. Proc. 7th Intnl Conf. Permafrost, Yellowknife, Nwt, Canada, Nordicana, Univ. Laval, 703-709

Majorowicz,J.A. and Deitrich,J.R. 1989. Comparison of the geothermal and organic maturation gradients of the central and southwestern Beaufort-Mackenzie Basin, Yukon and Northwest Territories. Geol.Surv.Can., Paper 89-1G, Frontier Geoscience Program, 63-67

Majorowicz,J.A. and Dietrich,J.R. 1989. Comparison of the thermal and organic maturation gradients of the central and southwestern Beaufort-Mackenzie Basin, Yukon and Northwest Territories. In - Current Research, Geol Surv.Can.Paper 89-1G, 63-67

Majorowicz,J.A. and Embry,A. 1998. Present heat flow and paleogeothermal regime in the Canadian Arctic margin - analysis of industrial thermal data and coalification gradients. In - Heast flow and structure of the lithosphere, Ed: Cermak,V., Tectonophysics, 291, 141-159

Majorowicz,J.A. and Gough,D.I. 1994. A model of crustal conductive structure in the Canadian Cordillera. Geophys.J.Int., 117,301-312

Majorowicz,J.A. and Hannigan,P. 2000. Stability zone of natural gas hydrates in a permafrost-bearing region of the Beaufort-Mackenzie Basin: study of a feasible energy source. Natural Resour.Res.,9, 3-25

Majorowicz,J.A. and Hannigan,P. 2000. Natural gas hydrates in the offshore Beaufort-Mackenzie Basin - study of a feasible energy source ii. Natural Resour.Res.,9, 201-214

Majorowicz,J.A. and Jessop,A.M. 1981. Present heat flow and a preliminary geothermal history of the Central Prairies Basin, Canada. Geothermics, 10, 81-93

Majorowicz,J.A. and Jessop,A.M. 1981. Regional heat flow patterns in the Western Canadian Sedimentary Basin. Tectonophysics, 74, 209-238

Majorowicz,J.A. and Jessop,A.M. 1993. Relation between basement heat flow and thermal state of the sedimentary succession of the Alberta Plains. Bull.Can.Petr.Geol., 41, 358-368

Majorowicz,J.A. and Morrow,D.W. 1998. Subsurface temperature and heat flow - Yukon and Northwest territories. Geol.Surv.Can., Open File 3626, 6pp + figs.

Majorowicz,J.A. and Osadetz,K.G. 2001. Gas hydrate volume and distribution in Canada. Bull.Am.Assoc.Petrol.Geol., 85, 1211-1230

Majorowicz,J.A. and Safanda,J. 1998. Ground surface temperature history from inversion of underground temperatures - a case study of the Western Canadian Sedimentary Basin. Tectonophysics, 291, 287-298

Majorowicz,J.A. and Safanda,J. 2001. Composite surface temperature history from simultaneous inversion of borehole temperatures in Western Canadian Plains. In - Inference of climate change from geothermal data, Ed: Beltrami,H, Harris,R.N., Glob.Planet.Change, 29, 231-239

Majororwicz,J.A. and Safanda,J. 2005. Measured versus simulated transkents of temperature logs - a test of borehole climatology. J.Geophys. Eng., 2, 1-8

Majorowicz,J.A. and Skinner,W.R. 1997. Recent and pre-instrumental climatic conditions as reconstructed from temperatire logs in western and northern Canada. AMS trans., Global Change Symposium, Long Beach, California, Paper 15.1.

Majorowicz,J.A. and Skinner,W.R. 1997. Potential causes of differences between ground and surface air temperature warming across different ecozones in Alberta, Canada. Glob., Planet Change, 15, 79-91

Majorowicz,J.A. and Skinner,W.R. 1997. Anomalous ground warming vs surface air warming in the Canadian Prairie provinces. Climat.Change, 35, 485-500

Majorowicz,J.A. and Skinner,W.R. 2001. Reconstruction of the surface warming history of western interior canada from borehole temperature profiles and other climate information. Clim.Res., 16, 157-167

Majorowicz,J.A. and Smith,S.L. 1999. Review of ground temperatures in the Malik field area: a constraint to the methane hydrate stability. In - Sci results JAPEX/JNOC/GSC Malik 2L-38 Gas Hydrate REs. Well, Ed Dallimore et al, 45-56.

Majorowicz,J.A. and Smith,S.L. 1999. Review of ground temperatures in the Mallik field area: a constraint to the methane hydrate stability. In - Scientific results from JAPEX/JNOC/GSC Mallik 2L-38 gas hyfdrate well. Mackenzie Delta, Northwest Territories, Canada. Geol.Survey Can Bull.544, 45-56

Majorowicz,J.A., Cermak,V., Safanda,J. and four others. 2003. Heat flow models across the Trans-European Suture Zone in the area of the Polonaise 97 seismic experiment. Phy. Chem. Earth,

Majorowicz,J.A., Garven,G., Jessop,A.M. and Jessop,C. 1999. Present heat flow along a profile across the Western Canada Sedimentary Basin: the extent of hydrodynamic influence. In - Geothermics in basin analysis, Ed. Forster,A and Merriam,D.F. Kluwer/Plenum, 61-79

Majorowicz,J.A., Garven,G., Jessop,A.M. and Jessop,C.M. 1998. Present heat flow across the Western Canada Sedimentary Basin: the extent of hydrodynamic influence. In - Geothermics in Basin Analysis, Ed.Foerster,A. and Merriam,D.F., Plenum Press, New York.

Majorowicz,J.A., Gough,D.I. and Lewis,T.J. 1993. Correlation between the depth to the lower-crustal high conductive layer and heat flow in the Canadian Cordillera. Tectonophysics, 225, 49-56

Majorowicz,J.A., Gough,D.I. and Lewis,T.J. 1993. Electrical conductivity and temperature in the Canadian Cordilleran crust. Earth,Planet.Sci.Lett., 115,, 57-64

Majorowicz,J.A., Hannigan,P.K. and Osadetz,K.G. 2002. Study of the natural gas hydrate Trap Zone and the methane hydrate potential in the Sverdrup Basin, Canada. Natural Resour.Res., 11, 79-96

Majorowicz,J.A., Jessop,A.M. and Judge,A.S. 1996. Geothermal regime. In - Geological atlas of the Beaufort Mackenzie area, Ed J.Dixon, Geol.Surv.Can. Report 59, 33-37.

Majorowicz,J.A., Jones,F.W. and Ertman,M.E. 1989. Subsurface conductive and hydrological related thermal effects in the area of the crustal electrical conductors of the Williston Basin. In - Hydrological regimes and their subsurface effects. Ed. Beck,A.E., Garven,G, Stegena,L. Am.Geophys.Un., Geophys.Momogr. 47, 149-150

Majorowicz,J.A., Jones,F.W. and Ertman,M.E. 1989. Model of terrestrial thermal effects in the area of the crustal electrical conductors of the Williston Basin. Can.J.Explor.Geophys., 25, 45-49

Majorowicz,J.A., Jones,F.W. and Jessop,A.M. 1986. Geothermics of the Williston Basin in Canada in relation to hydrodynamics and hydrocarbon occurrences. Geophysics, 51, 3, 767-779

Majorowicz,J.A., Jones,F.W. and Jessop,A.M. 1988. Preliminary geothermics of the sedimentary basins in the Yukon and Northwest territories (60-70 degrees north) - estimates from petroleum bottom-hole temperature data. Bull.Can.Petrol.Geol., 36, 39-51

Majorowicz,J.A., Jones,F.W. and Osadetz,K.G. 1988. Heat flow environment of the electrical conducting anomalies in the Williston Basin, and occurrences of hydrocarbons. Bull.Can.Petrol.Geol., 36, 86-90

Majorowicz,J.A., Jones,F.W., Ertman,M.E., and two others. 1990. The relationship between thermal maturation gradients, geothermal gradients and estimates of thickness of the eroded foreland section, southern Alberta Plains, Canada. Marine Petro.Geol., 7, 138-152

Majorowicz,J.A., Jones,F.W., Lam,H.L. and Jessop,A.M. 1984. The variability of heat flow both regional and with depth in southern Alberta, Canada - effect of groundwater flow. Tectonophysics, 106, 1-29,

Majorowicz,J.A., Jones,F.W., Lam,H.L. and Jessop,A.M. 1985. Regional variations of heat flow differences with depth in Alberta, Canada. Geophys.J.R.Astr.Soc., 81, 479-487

Majorowicz,J.A., Jones,F.W., Lam,H.L. and Jessop,A.M. 1985. Terrestrial heat flow and geothermal gradients in relation to hydrodynamics in the Alberta Basin, Canada. J.Geodyn., 4, 265-283

Majorowicz,J.A., Jones,F.W., Macqueen,R.W. and Ertman,M.E. 1989. The bearing of heat flow data on the nature of fluid flow in the Keg River Barrier - Pine Point ore field region, Canada,. Econ.Geol., 84, 708-714

Majorowicz,J.A., Judge,A.S. and Jones F.W. 1990. Deep subpermafrost thermal regime in the Mackenzie Delta Basin, northern Canada, analysis from petroleum bottom hole temperature data. Geophysics, 55, 362-371

Majorowicz,J.A., Rahman,M., Jones,F.W. and MacMillan,N.J. 1985. The paleogeothermal and present thermal regimes of the Alberta Basin and their significance for petroleum occurrence. Bull.Can.Petrol.Geol., 33, 12-21

Majorowicz,J.A., Safanda,J. and Skinner,W. 2002. East to west retardation in the onset of the recent warming across Canada from inversion of temperature logs. J.Geophys.Res., 107,2227, doi:10.1029/2001JB000519

Majorowicz,J.A., Safanda,J., Harris,R.N. and Skinner,W.R. 1999. Large ground surface temperature changes of the last three centuries inferred from borehole temperatures in the southern Canadian Prairies, Saskatchewan. Glob.,Planet., 20, 227-241

Majorowicz,J.A., Safanda,J., Harris,R.N. and Skinner,W.R. 1999. Large ground surface temperature of the last three centuries inferred from boreholes temperatures in the southern Canadian Prairies, Saskatchewan. Glob. Planet. Change, 20, 227-241

Majorowicz,J.A., Safanda.J. and Skinner,W.R. 2002. East to west retardation in the onset of the recent warming across Canada inferred from inversions of temperature logs. J.Geophys.Res., 107, B10-, 2227-

Majorowicz,J.A., Skinner,W.R. and Safanda,J. 2004. Ground surface warming history in Northern Canada inferred from inversion of temperature logs ans comparison with other proxy climate reconstructions. Pure Appl.Geophys., 162, 109-128.

Majorowicz,J.A., Skinner,W.R. and Safanda,J. 2004. Large ground warming in the Canadian Arctic inferred from inversions of temperature logs. Earth,Planet.Sci.Lett., in press

Majorowicz,J.A., Skinner,W.R. and Safanda,J. 2004. Large ground warmong in the Canadian Arctic inferred from inversion of temperature logs. Earth Plan.Sci.Lett., 221, 15-25, doi:10.1016/S0012-821X(04)00106-2.

Mareschal,J.C. 1986. Comments on Models of an extending lithosphere and heat flow in the Basin and Range Province by A.H.Lachenbruch and J.H.Sass, and reply by A.H.Lachenbruch. J.Geophys.Res., 91, 7561-7569

Mareschal,J.C. 1991. Downward continuation of heat flow density data and thermal regime in eastern Canada. Tectonophysics, 194, 349-356

Mareschal,J.C. 1991. Determination of the past heat flow from subsidence data in intracontinental basins and passive margins. In - Terrestrial heat flow and the lithosphere Structure, Ed. Cermak,V. and Rybach,L., Springer Verlag, 70-85

Mareschal,J.C. and Jaupart,C. 2004. Variations of surface heat flow and lithospheric thermal structure beneath the North American craton. Earth,Planet.Sci.Lett., 223, 65-77

Mareschal,J.C. and Vasseur,G. 1992. Ground temperature history from two deep boreholes in central France. Palaeogeog.Palaeoclim.Palaeoecol., 98, 185-192

Mareschal,J.C., Hamdani,Y. and Jessup,D.M. 1989. Downward continuation of heat flow. Tectonophysics, 164, 129-137

Mareschal,J.C., Jaupart,C., Cheng,L.Z., and five others. 1999. Heat flow in the Trans-Hudson Orogen of the Canadian Shield: implications for Proterozoic continental growth. J.Geophys.Res., 104, 29007-29024

Mareschal,J.C., Jaupart,C., Gariepy,L.Z. and four others. 2000. Heat flow and deep thermal structure near the southeastern edge of the Canadian Shield. Can.J.Earth Sci., 37, 399-414

Mareschal,J.C., Nyblade,A., Perry,H.K.C., and two others. 2004. Heat flow and deep lithospheric thermal structure at Lac de Gras, Slave Province, Canada. Geophys. Res. Lett., 31, L12611

Mareschal,J.C., Pinet,C. et al. 1989. New heat flow density and radiogenic heat production data in the Canadian Shield and the Quebec Appalachians. Can.J.Earth Sc., 25, 845-852

Mareschal,J.C., Rolandone,F. and Bienfait,G. 1999. Heat flow variations in a deep borehole near Sept-Iles, Quebec, Canada: paleoclimatic interpretation and implications for regional heat flow estimates. Geophys.Res.Lett., 26, 2049-2052

Mathews,W.H. 1972. Geothermal data from the Granduc area, northern Coast Mountains of British Columbia. Can.J.Earth Sci., 9, 1333-1337

Misener,A.D. 1949. Temperature gradients in the Canadian Shield. Trans.Can.Inst.Min.Met., 52, 125-132

Misener,A.D. 1955. Heat flow and depth of permafrost at Resolute Bay, Cornwallis Island, N.W.T., Canada. Trans.Am.Geophys.Un., 36, 1055-1060

Misener,A.D. and Beck, A.E. 1960. The measurement of heat flow over land. In -Methods and Technoiques in Geophysics, Ed.Runcorn, Interscience, 11-61

Misener,A.D. and Thompson,L.G.D. 1950. Temperature gradients in Ontario and Quebec. Trans.Can.Inst.Min.Met., 53, 368-371

Misener,A.D., Bremner,P.C. and Hodgson,J.H. 1956. Heat flow measurements in permafrost at Resolute Bay, Northwest Territories. J.Roy.Astron.Soc.Can., 50, 14-24

Misener,A.D., Thompson,L.G.D. and Uffen,R.J. 1951. Terrestrial heat flow in Ontario and Quebec. Trans.Am.Geophys.Un., 32, 729-738

Mustonen,E.D. 1967. A micro-geothermal survey, Lake Dufault, Quebec. Thesis,M.Sc.,University of Western Ontario

Mwenifumbo,C.J., Bezys,R., Betcher,R. and Killeen,P.G. 1995. Borehole geophysical logs Manitoba (1992) (including logs from Grand Rapids and Winnipeg). Geol.Surv.Can., Open File 2734

Nagihara,S., Brooks,J.S. and three others. 2002. Application of marine heat flow data important in oil, gas exploration. Oil and gas J., 100,43-50

Nagihara,S., Sclater,J.G., Phillips,J.D. and six others. 1996. Heat flow in the western abyssal plain of the Gulf of Mexico: implications for thermal evolution of the old oceanic lithosphere. J.Geophys.Res., 101,2895-2913

Nielsen,S.B. 1987. Steady state heat flow in a random medium and the linear heat flow - heat production relationship. Geophys.Res.Lett., 14, 318-321

Nielsen,S.B. and Beck,A.E. 1989. Heat flow density values and paleoclimate determined from stochastic inversion of four temperature-depth profiles from the Superior Province of the Canadian Shield. Tectonophysics, 164, 345-359

Osadetz,K.G., Hannigan,P.K., Stasiuk,L.D. and six others. 1998. Williston Basin thermotectonics: variations in heat flow and hydrocarbon generation. In - Proc.Eighth Intl. Williston Basin Symp., Sask.Geol.Soc.,Spec.Publ.13, 147-165

Osadetz,K.G., Jones,F.W., Majorowicz,J.A. et al. 1992. Thermal history of the Cordilleran Foreland Basins in Western Canada: a review. In - Foreland basins and fold belts, Ed. Macqueen, R.W. and Leckie,D., AAPG Mem 55, 259-278

Osadetz,K.G., Kohn,B.P., Feinstein,S. and O'Sullivan,P.B. 2002. Thermal history of Canadian Williston Basin from apatite fission-track thermochronology - implications for petroleum systems and geodynamic history. Tectonophysics, 349, 221-249

Pascal,F. and Jones,F.W. 1994. Numerical calculations of the thermal conductivities of composites: a 2-D model. Geophys.J.Int., 118, 623,635

Paterson,W.S.B. and Law,L.K. 1966. Additional heat flow determinations in the area of Mould

Bay, Arctic Canada. Can.J.Earth Sci., 3, 237-246

Perry,C., Jaupart,C., Mareschal,J.C. and Bienfait,G. 2006. Crustal heat production in the Superior Province, Canadian Shield, and in North America inferred from heat flow. J.Geophys.Res., 111, B04401.

Pinet,C., Jaupart,C., Mareschal,J.C., Gariepy,C., Bienfait,G. 1991. Heat flow and structure of the lithosphere in the eastern Canadian Shield. J.Geophys.Res., 96, 19941-19963

Powell,W.G., Chapman,D.S., Balling,N. and Beck,A.E. 1988. Continental heat flow density. In - Handbook of terrestrial heat-flow density determination, Ed.Haenel,R., Rybach,L., Stegena,L., Kluwer Acas Publ., 167-222

Pribnow,D.F.C., Davis,E.E. and Fisher,A.T. 2000. Borehole heat flow along the eastern flank of the Juan ed Fuca Ridge, including the effects of anisotropy and temperature dependence of sediment thermal conductivity. J.Geophys.Res., 105, 13449-13456.

Przybylak,R., Majorowicz,J.A. and seven others. 2005. Temperature changes in Poland from the 16th to the 20th centuries. Intl.J.Climatology, 25, 773-791

Pye,G.D. 1971. Heat flow measurements in Baffin Bay and the Labrador Sea. Thesis, M.Sc., Dalhousie University

Pye,G.D. and Hyndman,R.D. 1972. Heat-flow measurements in Baffin Bay and the Labrador Sea. J.Geophys.Res., 77, 938-944

Ranalli,G. 1991. Regional variations in lithosphere rheology from heat flow observations. In - Terrestrial heat flow and the lithosphere Structure, Ed. Cermak,V. and Rybach,L., Springer Verlag, 1-22

Rankin,D.S. 1974. Heat flow - heat production studies in Nova Scotia. Thesis, Ph.D., Dalhousie University, 188pp

Rankin,D.S. and Hyndman,R.D. 1971. Shallow water heat flow measurements in Bras d'Or Lake, Nova Scotia. Can.J.Earth Sci., 8, 96-101

Rao,R.U.M. and Jessop,A.M. 1975. A comparison of the thermal characters of shields. Can.J.Earth Sci., 12, 347-360

Ravenhurst,C.E., Willett,S., Dinelick,R.A. and Beaumont,C. 1994. Apatite fission track thermochronometry from central Alberta: implications for the thermal history of the western Canada Sedimentary Basin. J.Geophys.Res., 99, 20023-20041.

Reader,J.F. and Fairbank, B.D. 1983. Heat flow in the vicinity of the Meager Volcanic Complex, southwestern British Columbia. Trans.Geothermal REsoour.Coun., 7, 535-539

Rehault,J.P., Tisseau,C., Brunet,M.F. and Louden,K.E. 1990. Subsidence analysis on Sardinian marine and central Tyrrhenian Basin: thermal modelling and heat flow control: deep structure implications. J.Geodyn., 12, 269-310

Reiter,M.A. 1982. Extrapolated equilibrium bottom-hole temperatures for offshore petroleum drill tests in Atlantic Canada. Earth Physics Br., Open File 82-17, 11pp

Reiter,M.A. and Jessop,A.M. 1985. Estimates of terrestrial heat flow in offshore eastern Canada. Can.J.Earth Sci., 22, 1503-1517

Reiter,M.A. and Jessop,A.M. 1986. Estimates of terrestrial heat flow in offshore eastern Canada: reply. Can.J.Earth Sci.,, 23, 2085-2086

Rolandone,F., Jaupart,C., Mareschal,J.C. and four others. 2002. Surface heat flow, crustal temperatures nd matle heat flow in the Proterozoic Trans-Hudson Orogen, Canadian Shield. J.Geophys.Res., 107, 2341.

Rolandone,F., Mareschal,J.C. Jaupart,C. and three others. 2003. Heat flow in the western Superior Province of the Canadian Shield. Geophys Res.Lett., 30, 1637

Rona,P.A., Daveis,E.E. and Ludwig,R.J. 1998. Thermal properties of tag hydrothermal precipitates, Mid-Atlantic Ridge, and comparison with Middle Valley, Juan de Fuca Ridge. In - PRoc.Ocean Dr.Prog.,Sci.Results, 158, Ed Herzig et al. 329-335

Russell,J.K., Dipple,G.M. and Kopylova,M.G. 2001. Heat production and heat flow in the mantle lithosphere, Slave Craton, Canada. Phys.Earth Planet Interiors, 123, 27-44

Safanda,J., Szewczyk,J. and Majorowicz,J.A. 2003. Geothermal evidence of verylow glacial temperatures on a rim of the Fennoscandian ice sheet. In press

Sass,J.H. 1964. Evaluation of in-situ methods of measurement of thermal conductivity of rocks. Thesis, M.Sc., Univ.Western Ontario

Sass,J.H., Killeen,P.G. and Mustonen.E.D. 1968. Heat flow and surface radioactivity in the Quirke Lake Syncline near Elliot Lake, Ontario, Canada. Can.J.Earth Sci., 5, 1417-1428

Sass,J.H., Lachenbruch,A.H. and Jessop,A.M. 1971. Uniform heat flow in a deep hole in the Canadian Shield and its paleoclimatic implications. J.Geophys.Res., 76, 8586-8596

Saull,V.A., Clark,T.H., Doig,R.P. and Butler,R.B. 1962. Terrestrial heat flow in the St.Lawrence Lowland of Quebec. Can.Min.Met.Bull.,65,63-66

Schneider,R.V. and Roy,R.F. 1987. Investigations and interpretations of the vertical distribution of U, Th, and K: South Africa and Canada. Geophys.Res.Lett., 14,4 264-267

Shen,P.Y. and Beck,A.E. 1981. Determination of surface temperature history from borehole temperature gradients. J.Geophys.Res., 88, 7385-7493

Shen,P.Y. and Beck,A.E. 1981. Least squares inversion of borehole temperature measurements in functional space. J.Geophys.Res., 96, 19965-19979

Shen,P.Y. and Beck,A.E. 1983. Determination of surface temperature history from borehole temperature gradients. J.Geophys.Res., 88, 7385-7493.

Shen,P.Y. and Beck,A.E. 1992. Paleoclimatic change and heat flow density inferred from temperature data in the Superior Province on the Canadian Shield. Palaeogeog. Palaeoclim. Palaeoecol., 98, 143-165

Shen,P.Y., Pollack,H.N. and Huang,S. 1996. Inference of ground surface temperature history from borehole temperature data: a comparison of two inverse methods. Glob. Planet. Change, 14, 49-57.

Shen,P.Y., Wang,K. and Beck,A.E. 1990. Two-dimensional inverse modeling of crustal thermal regime with application to east European geotraverses. J.Geophys.Res.,95,19903-19925

Shen,P.Y., Wang,K. and Beck,A.E. 1991. Crustal thermal models along East European geotraverses: inverse solutions. Tectonophysics, 194, 363-385

Shen,P.Y., Wang,K., Beltrami,H. and Mareschal,J.C. 1992. A comparative study of inverse methods for estimating climatic history from borehole temperature data. Palaeogeog. Palaeoclim. Palaeoecol., 98, 113-127

Skinner,W.R. and Majorowicz,J.A. 1999. Regional climatic warming and associated Twentieth Century land cover changes in north-western North America. Climate Research, 12, 39-52

Smith,L., Forster,C. and Woodbury,A. 1989. Numerical simulation techniques and modeling advectively-disturbed thermal regimes. In - Hydrological regimes and their subsurface effects. Ed. Beck,A.E., Garven,G, Stegena,L. Am.Geophys.Un., Geophys.Momogr. 47, 1-5

Sweeney,J.F., Coles,R.L., Delaurier,J.M., abd others. 1978. Arctic geophysical review - a summary. Publ. Earth Physics Br., 45, 4, 101-108

Tatlor,A.E., Burgess,M., Judge,A.S., and Allen,V.S. 1982. Canadian Geothermal Data Collection - northern wells 1981. Earth Physics Br., Geothermal Series 13, 153 pp.

Taylor,A.E. 1978. Temperatures and heat flow in a system of cylindrical symmetry including a phase boundary. Earth Physics Br., Geothermal Series 7, 95pp

Taylor,A.E. 1988. A constraint to the Wisconsin glacial history, Canadian Arctic Archipelago. J.Quaternary Sci., 3, 15-18.

Taylor,A.E. 1991. Holocene paleoenvironmental reconstruction from deep ground temperatures: a comparison with paleoclimate derived from the 18O record in an ice core from the Agassiz Ice Cap, Canadian Arctic Archipelag. J.Gaciology, 37, 209-219.

Taylor,A.E. 1991. Marine transgression, shoreline emergence: evidence in seabed and terrestrial ground temperatures of changing relative sea levels, Arctic Canada. J.Geophys.Res., 96, 6893-6909

Taylor,A.E. and Allen,V.S. 1987. Shallow sediment temperature perturbations and sediment thermal conductivities. Can.J.Earth Sci., 24, 2223-2234

Taylor,A.E. and Judge,A.S. 1974. Canadian geothermal data collection - northern wells, 1955 to 1974. Earth Physics Br., Geothermal Series 1, 171 pp

Taylor,A.E. and Judge,A.S. 1975. Canadian geothermal data collection - northern wells, 1974. Earth Physics Br., Geothermal Series 3, 127pp

Taylor,A.E. and Judge,A.S. 1976. Canadian geothermal data collection - northern wells, 1975. Earth Physics Br., Geothermal Series 6, 142pp

Taylor,A.E. and Judge,A.S. 1977. Canadian geothermal data collection - northern wells, 1976-77.-. Earth Physics Br., Geothermal Series 10,

Taylor,A.E. and Judge,A.S. 1979. Permafrost studies in northern Quebec. Geogr.Phyr.Quat., 33, 245-251

Taylor,A.E. and Judge,A.S. 1980. Geothermal measurements and glacial surface temperature histories, northern Quebec, Canada. Am.Geophys.Un., Spring Mtg.Prog., 92

Taylor,A.E., Dallimore,S.R., Hyndman,R.D. and Wright,F. . Comparing the sensitivity of terrestrial and marine gas hydrtes to climate warming at the end of the last ice age.

Taylor,A.E., Judge,A.S. and Allen,V.S. 1986. Terrestrial heat flow from project Cesar, Alpha Ridge, Arctic Canada. J.Geodyn., 6, 137-176

Taylor,A.E., Judge,A.S. and Allen,V.S. 1989. Recovery off precise offshore permafrost temperatures from a deep geotechnical hole, Canadian Beaufort Sea. Geol.Surv.Can. Paper 89-1D, 119-123

Taylor,A.E., Judge,A.S. and Allen,V.S. 1989. The automatic well temperature measuring system installed at Cape Allison C-47, offshore well, Arctic Islands of Canada. Part 2 - data retrieval and analysis of the thermal regime. J.Can.Petrol.Tech., 28, 95-101

Thompson,J.E. 1948. The main ore zone at Kirkland Lake - geothermal gradient. Ont.Dept.Mines 57th Annual Rept.

Thompson,P.H., Judge,A.S. and Lewis,T.J. 1995. Thermal parameters in rock units of the Winter Lake - Lac de Gras area, central Slave Probince, Northwest Territories - implications for diamond genesis. Geol.Surv.Can. paper 95-1E, 125-135

Thompson,P.H., Judge,A.S. and Lewis,T.J. 1996. Thermal evolution of the lithosphere in the central Slave Province: inlications for diamond genesis. Geol.Surv.Can. Open File 3228, 151-160

Villinger,H. and Davis,E.E. 1987. A new reduction algorithm for marine heat flow measurements. J.Geophys.Res., 92, 12846-12856

Wang,K. 1992. Groundwater flow and geotemperature pattern. Encycl.Earth Syst.Science, 2, 441-453

Wang,K. and Beck,A.E. 1987. Heat flow measurement in lacustrine or oceanic sediments without recording bottom temperature variations. J.Geophys.Res., 92, 12837-12845

Wang,K. and Beck.A.E. 1989. An inverse approach to heat flow study in hydrologically active areas. Geophys.Res.Int., 98, 69-84

Wang,K. and Davis,E.E. 1992. Thermal effects of marine sedimentation in hydrothermally active areas. Geophys.J.Int., 110, 70-78

Wang,K. and Lewis,T.J. 1992. Geothermal evidence from Canada for a cold period before recent climatic warming. Science, 256, 1003-1005

Wang,K., Hyndman,R.D. and Davis,E.E. 1993. Thermal effects of sediment thickening and fluid expulsion in accretionary prisms: model and parameter analysis. J.Geophys.Res., 98, 9975-9984

Wang,K., Lewis,T.J. and Jessop,A.M. 1992. Climatic changes in central and eastern Canada inferred from deepborehole temperature data. Palaeogeog.Palaeoclim.Palaeoecol., 98, 129-141

Wang,K., Lewis,T.J., Belton,D.S., and Shen,P.Y. 1994. Differences in recent ground surface warming in eastern and western Canada: evidence from borehole temperatures. Geophys.Res.Lett., 21, 2689-2692

Wang,K., Shen,P. and Beck,A.E. 1989. A solution to the inverse problem of coupled hydrological and thermal regimes. In - Hydrological regimes and their subsurface effects. Ed. Beck,A.E., Garven,G, Stegena,L. Am.Geophys.Un., Geophys.Momogr. 47, 7-21

Wankiewicz,A. 1979. Temperature measurements under arctic streams. Pros.Symp.on Permafrost Geophysics, Tech.Memo.124, Ass.Com.Nat.Res.Coun.Can., Geotech.Res., 191-206

Weaver,J.G. 1967. Geothermal temperature measurements using oscillators. Thesis, M.Sc., Univ.Toronto

Woodroffe,D.A. 1984. Acquisition and testing of an integrated system to instrument an offshore well for the purpose of recording wellbore temperature. Earth Physics Br., Open File 84-25, 117pp

Wright,J.A. 1965. In-situ measurement of thermal conductivity of rocks. Thesis, M.Sc., Univ.of Toronto, 67pp+append

Wright,J.A. 1968. Geothermal investigations using in-situ techniques. Thesis, Ph.D., Univ.Toronto, 109pp

Wright,J.A. 1988. A microprocessor-based marine heat flow probe with solid-state data storage. In - CRC handbook of seafloor heat flow, Ed.Wright, and Louden, CRC Press, 121-134

Wright,J.A. and Garland,G.D. 1968. In-situ measurement of thermal conductivity in the presence of transverse anisotropy. J.Geophys.Res.,73, 5477-5484

Wright,J.A. and Louden,K.E. (Eds). 1988. CRC Handbook of seafloor heat flow. CRC Press., 323pp

Wright,J.A., Jessop,A.M., Judge,A.S. and Lewis,T.J. 1980. Geothermal measurements in Newfoundland. Can.J.Earth Sci., 17, 1370-1376

Yorath,C.J. and Hyndman,R.D. 1983. Subsidence and thermal history of Queen Charlotte Basin. Can.J.Earth Sci., 20, 135-159

Young,S. and Judge,A.S. 1985. A ground temperature data collection for northern Canada. Proc. McGill workshop on climate and thermal regimes in northern Canada,16pp

THE GEOTHERMAL ENERGY PROGRAM

APPENDICES

APPENDIX ONE: EXPENDITURES OF THE PROGRAM

Expenditures under the Geothermal Energy Research and Development Program of 1976 to 1986 are here divided into four general categories: Earth science, Feasibility studies, Engineering studies, and overheads. These may include a variety of projects as follows:

Earth science -	field surveys, data assembly, analysis
Engineering -	engineering studies, projects, and general studies of applications.
Feasibility -	site-specific studies of feasibility of geothermal development
Drilling -	all drilling, in all parts of Canada
Overheads -	divisional overheads, DSS charges, travel, operating, capital, personnel costs other than for the one PY, and cuts imposed after the beginning of the year.

Expenditures, broken down into these categories and expressed in k$, are shown in Table 6.

Table 6

Summary of total expenditures

Year	Earth Science	Engng Studies	Feasblty Studies	Drilling	Overh'ds and cuts	Total
1976/77	100	0	0	0	0	100
1977/78	183	0	0	60	37	280
1978/79	74	0	200	708	21	1003
1979/80	64	130	151	0	15	360
1980/81	144	17	38	131	30	360
1981/82	268	163	0	115	69	615
1982/83	388	117	0	170	52	727
1983/84	550	107	57	164	145	1023
1984/85	437	72	196	331	182	1218
1985/86	176	30	75	0	116	397
Total	2384	636	777	1619	667	6083

Table 6 does not include expenditures before the start of the Geothermal Energy Program, such as drilling at Meager Creek and the first Sproule report, or expenditures after the termination of the program. It also does not include expenditures managed by the "Conservation and Renewable Officers", which are unknown but are believed to have contributed in a very small way to research.

These figures are taken from progress reports, which give anticipated costs for contracts, but do not always give the exact figures after the contracting process. Totals are correct, but the breakdowns between types of expenditure are approximate. Figures do not include the cost of salaries for the personnel involved in managing the Program, letting contracts, conducting drilling supervision and field tests, and preparing summary documentation. These activities are estimated to have occupied about 25 person-years during the ten years of the Program. These figures do not include any amounts spent under the Federal-Provincial Agreements on Energy (CREDA). 1978/79 includes special allocation of k$655 for the drilling of the Regina well

Major projects are identified in Table 7 in the year in which they occurred. Where no figures are given records of the costs have not been found. Smaller projects are not individually identified, but the totals under the four headings above are given in Table 6. All costs are expressed in k$.

For Table 7 please see the next page.

Table 7
Major Expenditures in each year

1973-74		
	Drilling at Meager Creek	
1974-75		
1975-76		
	First Sproule Contract	
1976-77		
	Second Sproule contract (29),	Total 100
1977-78		
	Drilling in Garibaldi V.B. (57), Meager Creek (92), Feasibility at Regina (60),	Total 280
1978-79		
	Drilling in Coryell (53), Drilling at Regina (655) Share at Meager (200)	Total 1003
1979-80		
	MT in Garibaldi V.B. (45), Pump tests at Regina (111) Feasibility at Meager Cr. (40), Regina fracturing (130)	Total 360
1980-81		
	Drilling at Cayley (75), Drilling in Okanagan (56), Net-rock data collection (57), Studies at Meager (38), Rock fracturing (17)	Total 360
1981-82		
	Shallow drilling interior B.C. (115), SNC contract (100) Development of LSES (63)	Total 615
1982-83		
	Shallow drilling in Garibaldi V.B. (70), Drilling at Cayley (100) E-scan at Cayley (60), MT at Anahim V.B, (46)Acres study (70)	Total 727
1983-84		
	Drilling at Meager (100), Aquifer mapping study (70), Shallow drilling in Anahim V.B. (64), Prairies analysis (58), Drilling at Charlottetown (57), Utilisation in Atlantic region (40), Legal and institutional (60)	Total 1023
1984-85		
	Various drilling (331), Various sediment analysis (166), Various E and M methods (105), Feasibility at Moose Jaw (40), Feasibility at Edson (90), Mine air heating (33), Fouling and corrosion (25)	Total 1218
1985-86		
	Sedimentary analysis (73), Feasibility at Springhill (40), Water production (35), Heat pump study (30)	Total 397

APPENDIX TWO: FEDERAL PARTICIPANTS

Overall coordination of the Geothermal Energy Program was assigned to A.M Jessop (EPB), initially with assistance from J.G.Souther (GSC) and T.J.Lewis (EPB). After an initial period of evolving responsibilities, a pattern emerged by which the division was as follows.

J.G.Souther - geothermal resources in volcanic belts of the cordillera, geological mapping, inventory and geothermometry of hot springs, cooperation with BCH at Meager Mountain;

T.J.Lewis - geothermal resources of the cordillera outside the volcanic belts, thermal anomalies of the crust, hot dry rock potential, small sedimentary basins of the cordillera;

A.M.Jessop - geothermal resources of sedimentary basins, thermal regime within the sediments, cooperation with the University of Regina in their geothermal project and Program coordination.

To these were added, as the Program developed:

M.J.Drury (EPB) - geothermal resources of the Atlantic region, hot dry rock potential of Appalachian granites, thermal regime of sedimentary basins;

B.S.Larkin (NRC) - engineering requirements for geothermal development in Canada, economic factors, geothermal systems, demonstration projects.

These five people provided the management and operation of the Geothermal Program. Late in the life of the Program a formal Program Committee was set up, with J.Legg (OERD) as chairman. This provided an improved contact with OERD, but otherwise continued to do what the five principals had been doing for themselves in a less formal manner throughout the life of the Program.

During the course of the Program the participants in the part on sedimentary basins met in an informal manner at irregular interval. These meetings went under the name of the “Sedimentary Panel on Geothermal Energy” (SPONGE).

Names and addresses of federal participants, as of 2007, where known or still employed by EMR

Wanda Bentkowski
Resigned from Pacific Geoscience Centre.
Sidney, British Columbia.

Malcolm J.Drury
Office of Energy Research and Development
Natural Resources Canada,
580 Booth Street,
Ottawa, Ontario, K1A 0E8.

Alan M.Jessop
Retired from Institute of Sedimentary and Petroleum Geology
333 Silver Ridge Crescent NW
Calgary, Alberta, T3B 3T6.

Brian Larkin
Retired from National Research Council.
Ottawa, Ontario

John Legg
Retired from Office of Energy Research and Development
580 Booth Street,
Ottawa, Ontario

Trevor J.Lewis
Retired from Pacific Geoscience Centre
Sidney, British Columbia.

J.G.Souther
Retired from Geological Survey of Canada,
Vancouver, British Columbia.

APPENDIX THREE: INDUSTRIAL PARTICIPANTS

The following names and addresses were valid during the time of the Geothermal Energy Program. Their present status is unknown.

Acres International Ltd.,
845 Cambie Street,
Vancouver, B.C., V6B 2P4.
Attn. R. J. Cousins.

John A. Leslie and Associates Ltd.,
P. O. Box 193,
248 Bedford Highway,
Bedford, N.S., B4A 2X2.
Attn. J. A. Leslie.

Nevin, Sadlier-Brown, Goodbrand, Ltd.,
500 - 342 Water Street,
Vancouver, B.C., V6B 1B6.
Attn. T. Sadlier-Brown.

Noval Technologies Ltd.,
Pontac House, Historic Properties,
1869 Upper Water Street,
Halifax, N.S., B3J 1S9.
Attn. G. P. Isenor

SNC Engineering and Project Management Services Inc.

Sproule Associates Ltd.
140 4th Avenue S.W., Box 181,
Calgary, Alberta, T2P 3N3.
Attn. M. Wayne Sargent.

Underwood McLellan Ltd.,
17007 107th Avenue,
Edmonton, Alberta, T5S 1G3.
Attn. A. F. Scheybeler.

Fairbank Engineering Ltd.,
1201 - 675 W. Hastings Street,
Vancouver, B.C., V6B 1N2.
Attn. B. D. Fairbank.

John M. Booth Engineering Ltd.,
5604 Morris Street,
Halifax, N.S., B3J 1C2.
Attn. J. M. Booth.

Premier Geophysics Inc.,
1184 Forge Walk,
Vancouver, B.C., V6H 3P9.
Attn. G. A. Shore.

APPENDIX FOUR: UNIVERSITY PARTICIPANTS

University of Alberta
Prof. F. W. Jones,
Retired from Dept. of Physics,

University of British Columbia
Prof. M. Ghomshei

University of Regina
Prof. L. W. Vigrass,
Retired from Dept. of Geology,

University of Saskatchewan

University of Toronto
Prof. J.C.Roegiers