REGIONAL TRENDS IN RADIOGENIC HEAT GENERATION IN THE PRECAMBRIAN BASEMENT OF THE WESTERN CANADIAN BASIN

F. W. Jones[1] and J. A. Majorowicz[2]

[1] Institute of Earth and Planetary Physics

[2] Department of Physics, University of Alberta

Abstract. Radiogenic heat generation values for 381 basement samples from 229 sites in the western Canadian basin exhibit a lognormal frequency distribution. The mean value $\langle A \rangle$ = 2.06 (S.D. = 1.22) μWm^{-3} is larger than the radiogenic heat generation values reported for the shield in the Superior (ca. 1.2 μWm^{-3}, Jessop and Lewis, 1978) and Churchill (ca. 0.7 μWm^{-3}, Drury, 1985) provinces. When equal Log A contour intervals are used to map the basement heat generation, three large zones of relatively high heat generation are found. One coincides with the Peace River Arch basement structure and one with the Athabasca axis (Darnley, 1981). There is no apparent indication of increased heat flow through the Paleozoic formations associated with these two zones. The third zone, in southwestern Saskatchewan, coincides with a high heat flow zone in the Swift Current area. The lack of correlation between heat flow and heat generation in Alberta may be due to the disturbance to the heat flow in the Paleozoic formations by water motion, or may indicate that the heat is from uranium, thorium and potassium isotope enrichment near the basement surface rather than enrichment throughout the entire upper crust.

Introduction

The work of Burwash and Cumming (1976) has provided the data on uranium and thorium concentrations for 182 samples from the Precambrian basement of the Churchill province in Alberta and Saskatchewan, and the Superior province in eastern Saskatchewan and Manitoba. The measurements were made by the delayed neutron activation method. These data, and information on average ratios of K/U were used by Majorowicz and Jessop (1981) to estimate basement radiogenic heat generation. They found that there was no clear correlation between estimated heat flow through the sediments and heat generation in the basement. This observation was used by Majorowicz and Jessop (1981) as an argument to support the hypothesis that most of the crustal and mantle heat which flows into the sediments is redistributed by fluid motion through the permeable strata. Beach (1985) used the Burwash and Cumming (1976) data and additional unpublished information on potassium isotope concentrations provided by Prof. R. Burwash to determine basement heat generation in a zone through central Alberta. From comparison of heat flow and heat generation values in the central part of the basin between fluid recharge and discharge zones in Alberta and heat flow and heat genera-

tion data from the Churchill province in the shield, Beach et al., (1987) suggested that the high heat flow in central Alberta (71 mWm^{-2}±12 mWm^{-2}, n = 24 data), which is approximately 30 mWm^{-2} higher than in the shield (44±7, n = 8 for the Churchill [Drury, 1985], and 40±8, n = 11 for the Superior [Jessop and Lewis, 1978]) might be due to higher basement heat generation under the approximately 500 million year old sedimentary cover in the basin.

From their work, Burwash and Cumming (1976) observed that the Churchill province beneath the sedimentary cover is enriched in U and Th isotopes relative to the shield in terms of regional averages. They also found that maximum concentrations can be spatially related to features which lie within the southwestward extension of the Churchill province.

Heat Generation Data and Preliminary Interpretation

The frequency distributions of U and Th concentrations found by Burwash and Cumming (1976) show extreme positive skewness and therefore lognormal scales of U and Th concentration frequency distributions were used by Burwash (1979). However, the histograms did not conform exactly to a Gaussian shape, and more than one population was obvious in the total sample. In addition to the 182 core samples analyzed by Burwash and Cumming (1976), 199 basement samples from 47 wells in the Peace River Arch area have been recovered from core material. Heat generation has been estimated for these latter samples on the basis of U and Th concentrations determined by the delayed neutron activation method and from assumed K/U ratios for the analyzed area. The amount of radioelement K(%) was not measured and so had to be estimated from measurements in the same area by Burwash (see Beach, 1985). The mean estimated K/U value for the Peace River Arch area is 1.8 x 10^4 with S.D. = 1.7 x 10^4, and is close to the 'average' crustal value of 1 x 10^4 (Heier and Rogers, 1963). The average K% is 3.76% with S.D. = 1.69%. The estimated error in A (due to the lack of K% determinations for the 47 wells in the Peace River Arch area and assumed K values) is ±0.3 μWm^{-3} and the mean value of A for the area is 4.3 μWm^{-3} (S.D. = 4.0 μWm^{-3}).

A histogram of the log of the radiogenic heat generation for the 229 sample locations in which the average values of multiple samples from single locations are used as representative of those locations, is shown in Figure 1. This figure has a slight negative skew, but the shape of the histogram is near a Gaussian curve and there is no evidence of more than one population in the total sample. The extreme positive skew in U and Th frequency distributions shown by Burwash and Cumming (1976) is similar to the heat generation distributions determined more recently
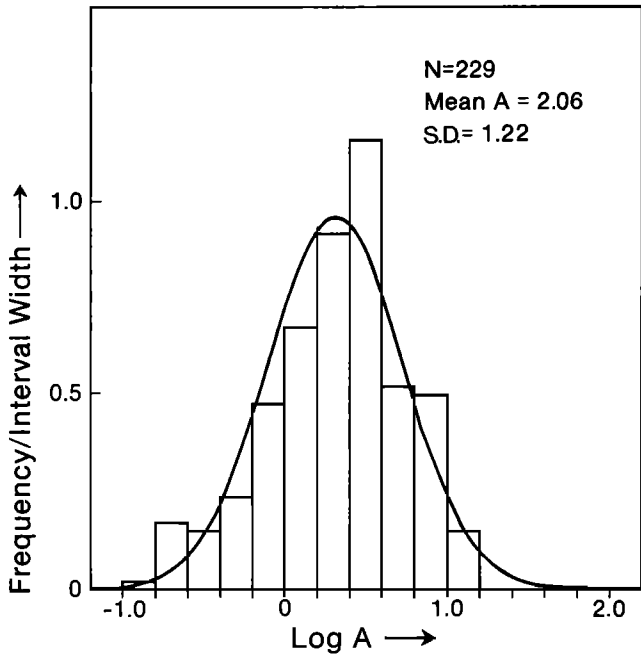
Fig. 1. Histogram of log A (A = heat generation in μWm^{-3}) for Precambrian basement rocks in the Western Canadian Sedimentary Basin. A normal (Gaussian) distribution for the data is superimposed.

by Majorowicz and Jessop (1981) and Beach et al., (1987). It is likely that the extreme high values represent local enrichments of radiogenic heat generating elements and so their correlation with regional heat flow patterns is unlikely.

In order to obtain a more regional represent-ation of the radiogenic heat generation distribu-tion, a contour map of heat generation was plot-ted in which equal log A contour intervals of 0.2 were used (Figure 2). Three zones of high heat generation are indicated from this map. One zone coincides with the Peace River Arch where a good data suite is available for contouring. The second is a zone referred to as the Athabasca axis which lies northeast of Edmonton (see Darnley [1981]), and the third coincides with high U-Th concentrations in southwestern Saskatchewan (see Burwash and Cumming [1976] for details). The high heat generation zones shown here by mapping log A by equal contour intervals are much broader and less linear than the feat-ures on the surface maps of U and Th concentra-tions (Burwash and Cumming, 1976) and heat gen-eration (Beach et al., 1987). For example, it is found that high heat generation coincides with the whole Peace River Arch structure. The high heat generation zone north of Edmonton in north central Alberta also appears to be less linear than the U-enriched zone which is based on only three data points with high U concentrations shown on the smoothed trend surface by Burwash and Cumming (1976).
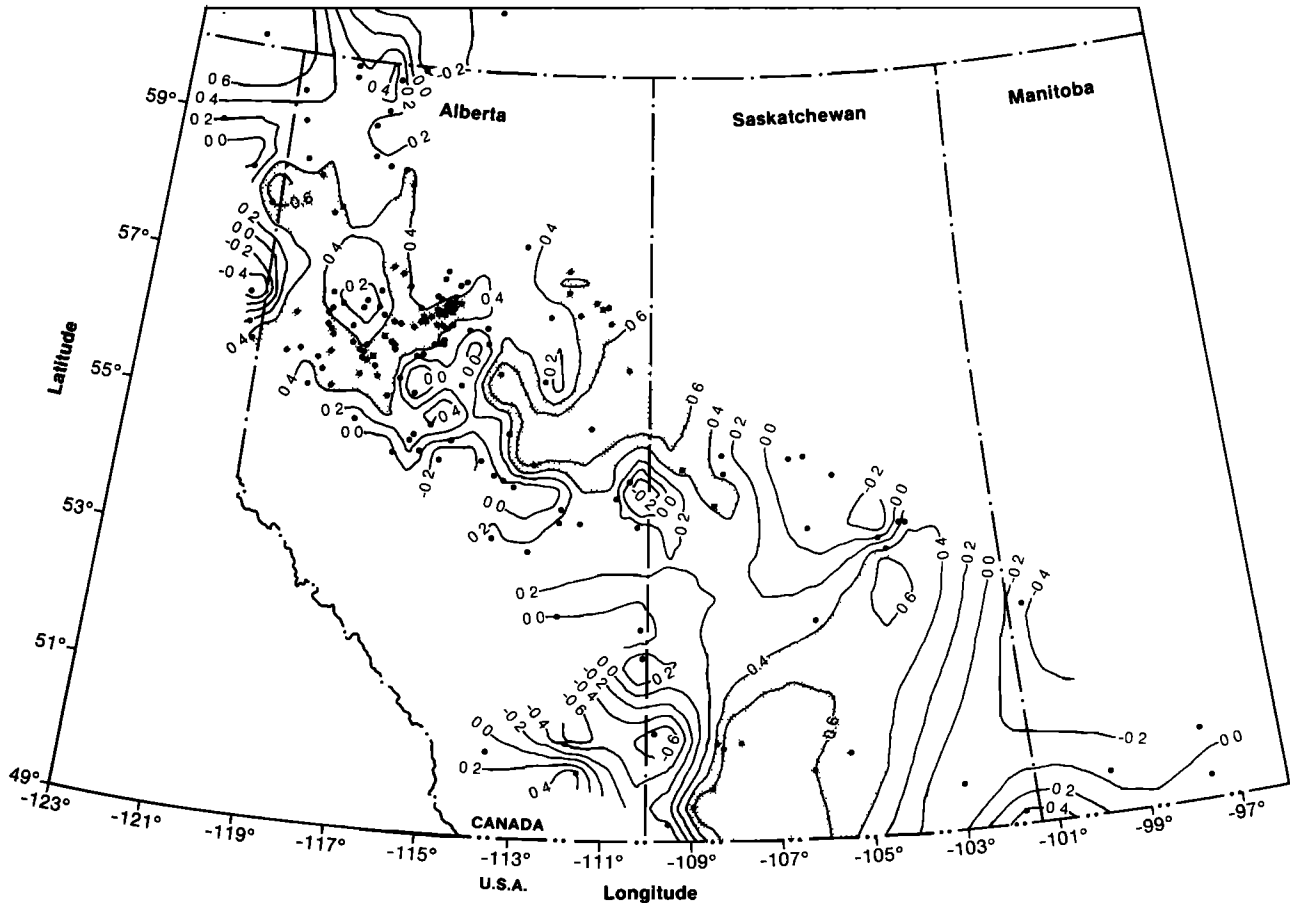

Fig. 2. Contour map of log A (A = heat generation in μWm^{-3}) for Precambrian basement rocks in the Western Canadian Sedimentary Basin. The contours are drawn every log A = 0.2. High heat generation zones where log A>4 are shaded. The locations of wells from which samples have been measured are indicated by dots.
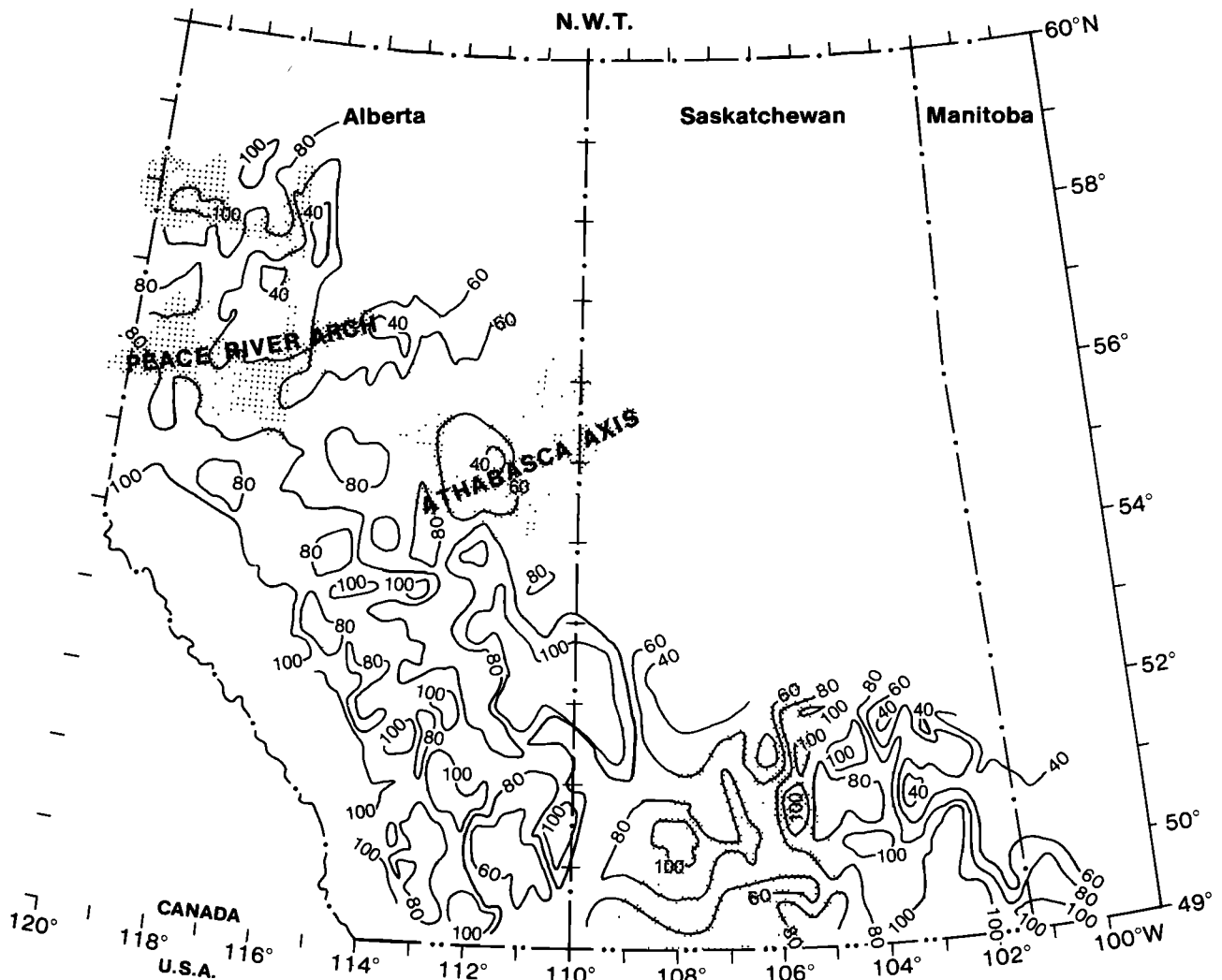
Fig. 3. The high heat generation zones from Figure 3 superimposed on the contour map of heat flow through the Paleozoic sediments (from Jones and Majorowicz, 1985). The heat flow estimates were based on temperature and conductivity data for Paleozoic sedimentary strata in 3 x 3 township/range areas (a township/range as defined by the Dominion Land Survey System is approximately 9.6 x 9.6 km).

Discussion

The average heat flow in the Canadian basin is higher than in the shield (Majorowicz and Jessop, 1981, Jones and Majorowicz, 1985, Beach et. al., 1987). This may be related to higher average basement radiogenic heat generation in the basin when compared with the shield (see Beach et al., 1987). However, there is little evidence of a correlation between the heat flow patterns from Majorowicz and Jessop (1981) and Jones and Majorowicz (1985) and the heat generation pattern shown in Figure 2.

However, there is clear evidence that the heat flow, especially through the Mesozoic sediments in the upper part of the section, closely correlates with the hydraulic potentiometric surface which is related to the large change of topographic elevation from the Rocky Mountain Foothills northwestward toward the low elevation shield (Majorowicz and Jessop, 1981; Majorowicz et al., 1986). There is less evidence that the heat flow in the deeper Paleozoic strata is related to changes in hydraulic head (Jones and Majorowicz, 1985). However, the regions of

higher heat flow in the Paleozoic (Figure 3) do not correlate with the high radiogenic heat generation areas in central Alberta. The region of high heat generation through the Peace River area in western Alberta at about 56°N exhibits lower heat flow through the Paleozoic strata than areas to the north and south. Similarly, the high heat generation area in eastern Alberta is a region of relatively low heat flow. High heat flow zones that show some correlation with elevated radiogenic heat generation are observed in southwestern Saskatchewan and northwestern Alberta (see Figure 3).

Conclusions

Areas of relatively high basement heat generation of radiogenic origin exist in the Western Canadian Basin. The higher average heat generation of the basement under the sediments than in the exposed shield may be responsible for the higher average heat flow in the basin area compared with the shield. However, there is no hard evidence that large regional zones of high basement heat generation are accompanied by high heat

flow through the sedimentary column above. This
may be because the higher heat generation may
result from radiogenic isotope enrichment in only
the upper part of the basement and not throughout
the entire upper crust. However, water motion
through the sediments plays an important role in
redistribution of heat in the basin, and so the
question as to what causes the lack of correla-
tion between sedimentary heat flow and basement
heat generation cannot be answered at present.

Acknowledgements

References

Beach, R.D.W., Sedimentary heat flow in ΔQ=0
    region of Alberta, MSc. Thesis, Department of
    Physics, University of Alberta, Edmonton, 1985
    128 pp.
Beach, R.D.W., Jones, F.W. and Majorowicz, J.A.,
    Heat flow and heat generation estimates for
    the Churchill basement of the Western Canadian
    basin in Alberta, Canada, Geothermics, 16 No.
    1. (in press), 1987.
Burwash, R.A. and Cumming, G.L., Uranium and
    thorium in the Precambrian basement in western
    Canada, 1. Abundance and distribution, Can. J.
    Earth Sci., 13, 284-293, 1976.
Burwash, R.A., Uranium and thorium in the Pre-
    cambrian basement of western Canada, II.
    Petrologic and tectonic controls, Can. J.
    Earth Sci., 16, 472-483, 1979.

Darnley, A.G., The relationship between uranium
    distribution and some major crustal features
    in Canada, Mineralogical Magazine, 44, 425-
    436, 1981.
Drury, M.J., Heat flow and heat generation in the
    Churchill Province of the Canadian Shield, and
    their paleotectonic significance,
    Tectonophysics, 115, 25-44, 1985.
Heier, K.S. and Rogers, J.J.W., Radiometric
    determination of thorium, uranium and
    potassium in basalts and in two magentic dif-
    ferentiation series, Geochemica and
    Cosmochemica Acta, 27, 137-154, 1963.
Jessop, A.M. and Lewis, T.J., Heat flow and heat
    generation in the Superior Province of the
    Canadian Shield, Tectonophysics, 50, 55-77,
    1978.
Jones, F.W. and Majorowicz, J.A., Some aspects of
    the thermal regime and hydrodynamics of the
    Western Canadian sedimentary basin, Proceed-
    ings, Fluid Flow in Sedimentary Basins and
    Aquifers, Joint Meeting of Petroleum and
    Hydrogeology Groups, Geological Society of
    London, June 12-13, 1985, (in press).
Majorowicz, J.A. and Jessop, A.M., Regional heat
    flow patterns in the Western Canadian Sedi-
    mentary Basin, Tectonophysics, 74, 209-238,
    1981.
Majorowicz, J.A., Jones, F.W. and Jessop, A.M.,
    Geothermics of the Williston Basin in Canada
    in relation to hydrodynamics and hydrocarbon
    occurrences, Geophysics, 51, 767-779, 1986.

F.W. Jones and J.A. Majorowicz, Institute of
Earth and Planetary Physics and Department of
Physics, University of Alberta, Edmonton,
Alberta, Canada T6G 2J1