

Moving the heat around: the impact of metamorphism on the distribution of crustal heat production

Thesis submitted in accordance with the requirements of the University of
Adelaide for an Honours Degree in Geology

Christopher Wilde Kemp

November 2014



THE UNIVERSITY
of ADELAIDE

MOVING THE HEAT AROUND: THE IMPACT OF METAMORPHISM ON THE DISTRIBUTION OF CRUSTAL HEAT PRODUCTION

RUNNING TITLE: METAMORPHIC IMPACT ON CRUSTAL HEAT PRODUCTION

ABSTRACT

Crustal differentiation has resulted in the concentration of heat producing elements (HPEs) in the upper crust due to partial melting processes. Recent studies into the mineral hosts of HPEs have shown that it may be possible to enrich a rock in HPEs via partial melting rather than depleting it. This paper details transects that were performed across metamorphic grade at Mt Stafford, the Reynolds Ranges and Broken Hill using portable Gamma Ray Spectrometer (GRS) devices. The paper found that there is a small, but significant rise in heat production with an increase in metamorphic grade from greenschist to granulite facies rocks exposed at the surface at those locations driven by thorium concentration. A definite non-linear trend pattern was also found in the distribution of heat production with increasing grade, predominantly at Mt Stafford. The methods and findings were compared to contemporary airborne radiometry scans and geochemical assay studies at Mt Stafford in order to compare the newer largely untested GRS method to these modern standards. Findings indicate that the HPE bearing rocks at these locations are enriched enough in HPEs that they can further self-enrich in open partial melting systems, increasing heat production and leading to structurally weaker crust.

KEYWORDS

Metamorphism, Crustal heat production, Radiogenic heat production, Distribution of heat production, Portable gamma ray spectrometry, Field sampling, Mt Stafford, Reynolds Ranges, Broken Hill.

TABLE OF CONTENTS

List of figures and tables	iii
1. Introduction	1
2. Geological Setting	4
2.1 Mt Stafford	4
2.2 Broken Hill	6
2.3 Reynolds Range	7
3. Methods	10
3.1 Portable gamma ray spectrometer measurements	10
3.2 Geochemistry	13
3.3 Elemental Mapping	14
4. Results	15
4.1 Airborne radiometry comparisons:	21
4.2 Geochemical assay comparisons:	24
4.3 Elemental maps	27
5. Discussion	28
5.1 Analytical Considerations	28
5.2 Further study	34
6. Conclusions	35
7. Acknowledgments	35
References	36
Appendix 1: GRS field sampling Methods	40
Appendix 2: Figures of elementary breakdown of heat producing elements by metamorphic grade (greenschist to granulite)	43
Appendix 3: GRS data.....	46
Mt Stafford Beds	46
Sundown Group	48
Pine Hill Formation	51
Appendix 4: XRF Geochemical Data.....	53
Mt Stafford Beds	53
Pine Hill Formation	54

LIST OF FIGURES AND TABLES

Figure 1: Locations of the field sites	4
Figure 2: Metamorphic isograds of the Mt Stafford Beds, from (White et al. 2003).	5
Figure 3: Metamorphic isograds in the Broken Hill area, including the Sundown group. From (Webb and Crooks 2005).	7
Figure 4: Metamorphic isograds of the Reynolds Range area, including the Pine Hill Formation. From (Hand and Buick 2001).	8
Table 1: Field photos of the nature of the outcrops across metamorphic grade at each of the three field locations. Scales: The GPS unit is about 10 cm long, the pens are around 15 cm long, the portable GRS device in the yellow case is around 30cm tall and the boot is around 13cm across. No locations at amphibolite grade were visited in the Reynolds Range	9
Figure 5: Portable GRS devices at a sample location at Mt Stafford	11
Figure 6: Locations of the sample sites at Mt Stafford along with their radiogenic heat production as determined by portable GRS. The raster overlay is RHP calculated from airborne radiometry was calculated from separate U, Th and K layers from Geoscience Australia. Both data sets used the formula from Rybach 1988 to calculate RHP (Rybach 1988). The zones are those defined in the paper by (White et al. 2003).	15
Figure 7: Normalized heat production determined via GRS measurements in each of the metamorphic grades (greenschist, lower and upper amphibolite and granulite) in the Mt Stafford beds.....	16
Figure 8: Heat production variation in the Mt Stafford beds, sorted by location of sample site in relation to known metamorphic grade. Each colour represents a separate transect. A trend line has been added to show the general pattern of the data.	16
Figure 9: Locations of the sample sites at Broken Hill along with their general radiogenic heat production. RHP from airborne radiometry was calculated from separate U, Th and K layers from Geoscience Australia. The metamorphic areas are those defined by the paper by Webb and Crooks (Webb and Crooks 2005).	17
Figure 10: Normalized heat production in each of the metamorphic grades (greenschist, lower and upper amphibolite and granulite) within the Sundown group, showing the distribution of radiogenic heat production at each grade.....	17
Figure 11: Heat production variation in the Sundown Group, sorted by location of sample site in relation to known metamorphic grade. Each colour represents a separate transect. A trend line has been added to show the general pattern of the data.	19
Figure 12: Locations of the sample sites within the Pine Hill Formation of the Reynolds Range along with their general radiogenic heat production (RHP). RHP from airborne radiometry was calculated from separate U, Th and K layers from Geoscience Australia. Both data sets used the method from (Rybach 1988) to calculate RHP. The metamorphic isograds are those defined in (Hand et al. 1995).	20
Figure 13: Normalized heat production within the Pine Hill Formation at the Reynolds Ranges.....	20
Figure 14: Heat production at the Reynolds Range, sorted by location of sample site in relation to known metamorphic grade. Each colour represents a separate transect.	21
Figure 15: Potassium, thorium and uranium trends at each of the three field locations, normalised for number of samples so that each of the four metamorphic facies takes up a quarter of the plot. Trend lines	

have been added to show the trend of each element with increasing metamorphic grade. These plots are individually separated in Appendix 2.23

Figure 16: Plot of geochemical data at Mt Stafford, sorted by metamorphic grade and divided into metamorphic facies, with each colour representing a metamorphic facie.25

Figure 17: Comparison of XRF determination of U-Th-K data versus GRS data, using 10 data points from the same 10 outcrops, sorted by metamorphic grades, from greenschist to granulite facies rocks. ...26

Figure 18: Normalized heat production within the Pine Hill Formation at the Reynolds Ranges from geochemical analysis.26

Table 1: The change in quantity of the HPE hosting minerals between greenschist samples and granulite samples from the element maps as a percentage (Greenschist quantity/granulite quantity, so ‘100% gain’ indicates a doubling in quantity and 50% loss a halving). Metamorphic peak temperature and pressures for each sample site have been included for comparative purposes.27

Table 3: Mt Stafford Beds GRS data, including sample locations using 53K UTM and individual breakdown of HPEs by sample site.47

Table 4: Sundown Group GRS data, including sample locations using 54K UTM and individual breakdown of HPEs by sample site.50

Table 5: Pine Hill Formation GRS data, including sample locations using 53K UTM and individual breakdown of HPEs by sample site52

Table 6: Mt Stafford Beds geochemical samples, including sample location and metamorphic grade.53

Table 7: Pine Hill Formation geochemical samples, including sample location and metamorphic grade.54