

ResearchOnline@JCU

This file is part of the following reference:

Hoadley, Elizabeth (2003) *Evolution of the Sybella Batholith: Petrographic, geochemical and structural development of an A-type intrusive complex, Northwest Queensland* PhD thesis, James Cook University.

Access to this file is available from:

<http://eprints.jcu.edu.au/1346>

The author has certified to JCU that they have made a reasonable effort to gain permission and acknowledge the owner of any third party copyright material included in this document. If you believe that this is not the case, please contact ResearchOnline@jcu.edu.au and quote <http://eprints.jcu.edu.au/1346>

Evolution of the Sybella Batholith:
Petrographic, geochemical and structural
development of an A-type intrusive complex,
Northwest Queensland

Thesis submitted by
Elizabeth Hoadley BSc (Hon) JCU
in September 2003

For the degree of Doctor of Philosophy
in the School of Earth Sciences
James Cook University

STATEMENT OF ACCESS

I, the undersigned author of this thesis, understand that James Cook University of North Queensland will make it available for use within the University Library and, by microfilm or other means, allow access to users in other approved libraries. All users consulting this thesis will have to sign the following statement:

In consulting this thesis, I agree not to copy or closely paraphrase it in whole or in part without the written consent of the author; and to make proper public written acknowledgment for any assistance which I have obtained from it.

Beyond this, I do not wish to place any restrictions on the access to this thesis.

Elizabeth Hoadley

September 2003

STATEMENT OF SOURCES

DECLARATION

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any other university or institution of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and list of references given.

Elizabeth Hoadley

September 2003

ABSTRACT

The Sybella Batholith is an A-type composite granitoid complex that was emplaced as a series of distinct phases. The first phase began with the intrusion of tholeiitic doleritic (Mosses Tank Dolerite, 45-55 wt% SiO₂) and dioritic hybrid magmas (Mafic Hybrid Complex, 58.2 - 65 wt % SiO₂). The second phase involved intrusion of a minor suite of rapakivi hybrid (63-69 wt % SiO₂). Subsequent phases included the volumetrically largest part of the batholith, the high-K, Fe-enriched K-feldspar megacrystic syenogranites (known as 'Main Phase', approximately 70 wt % SiO₂), associated porphyritic and aplitic dykes, and a phase of microgranites (75-77 wt % SiO₂). Intruded during an extensional phase during the development of the Mount Isa Basin, the Sybella Batholith is ideal for the assessment of petrogenetic processes (including magma mixing and mingling) that gave rise to a composite batholith, and also the effect of syn- to post-magmatic deformation during emplacement (~1670 Ma) and subsequent metamorphism and deformation during the Isan Orogeny (1590-1500 Ma).

Mixing and mingling were significant processes in the evolution of the batholith. In the mafic rocks in both the Easter Egg and Guns Knob regions, hybridization was found to have taken place to some extent at a deeper level before the magmas were emplaced as distinct intrusions to form the Mafic Hybrid Complex. Within the Mafic Hybrid Complex there is a lack of mafic rocks that show no contamination with felsic magmas. Minor hybridization also occurred locally at emplacement level. The Main Phase granite, although relatively homogeneous, displays features indicative of hybridization at depth (rapakivi textures) and of interaction with the Mafic Hybrid Complex at emplacement level with true hybrid rocks at the contacts. In the northern Kitty Plains region, fractionation was probably the dominant process in the evolution of the mafic rocks of the Mosses Tank Dolerite (MTD), with hybridization limited to the contacts with intruded sheets of microgranite. Along the eastern margin of the pluton, large areas of MTD were brecciated by the intruding microgranite as rheological contrast between felsic and mafic magmas inhibited voluminous mixing. However, behaviour of the dolerite transitional between solid and liquid was observed along many of the intrusive contacts and within magmatic shear zones (dated at ~1673 Ma) with partially solidified mafic enclaves being mechanically broken-up during high strain forming schlieren and hybrids.

Few methods for determining the intensive parameters (T, P, fO_2 , fH_2O) of granitic magmas are applicable to rapakivi A-type magmas, the main difficulty being that the granites consists of disequilibrium mineral assemblages (different generations and order of mafic/silicic minerals etc) and the high Fe-content of minerals. However, calculated temperatures of 850-900°C at approximately 4 kbars for the Main Phase granite are similar to other A-type granites. The absence of source rock restites is also indicative of high magma temperatures. The composition of minerals in the Main Phase granite is indicative of relatively low fO_2 for granites; however it was still higher than the initially low fO_2 in the Mafic Hybrid Complex. Oxidation of the mafic magmas during mixing resulted in abundant magnetite and other mineralogical changes. The occurrence of large biotite flakes ± late amphibole in the mafic units, and the apparent late crystallization of mafic minerals in the granites indicates H₂O undersaturated magmas. The low water fugacities and high-temperature of the melts enabled the magmas to intrude into the upper crust at relatively shallow depths.

The Main Phase of the Sybella Batholith contains 64.32 ppm Nd and 11.40 ppm Sm, and has a ϵNd of -3.86 . A T_2 model source age of 2419 Ma was calculated using the emplacement age of ~ 1670 Ma. The Nd and Sm contents of the main phase hybrids have a positive correlation with the SiO_2 , which is not consistent with fractionation (fractionation of amphibole would partition Nd and Sm from the melt), but rather mixing between the mafic and felsic end member magmas. No mafic end member was analysed; however a mafic enclave from within the Main Phase granite (with similar geochemical properties to the dolerites) had the lowest ϵNd of -6.15 and a T_2 model source age of 2587 Ma. The older model source age for the mafic rocks indicates that the melt from the mantle source region (dolerite) was probably contaminated with radiogenically older crustal material (Archaen crust). This is also consistent with the intrusion's enriched LREE, K and Rb contents. The microgranite contains 41.46 ppm Nd and 6.96 ppm Sm, has a ϵNd of -2.24 and a T_2 model source age of 2300 Ma. These values are outside the range determined for the Main Phase granites and are likely to represent a different source. The Mosses Tank Dolerite has a ϵNd of -2.27 and a T_2 model source age of 2303 Ma suggesting the dolerite was also contaminated with radiogenically older crustal material.

The shallow origin of A-type granites is a result of tectonic extension that is associated with crustal thinning and mantle upwelling possibly in a back-arc setting (Giles *et al.* 2002). Fluid absent partial melting of metaluminous protoliths (metamorphosed igneous rocks in the lower crust) heated by underplated or intraplated mafic magma produced the potassic incompatible and radiogenic element-rich high-temperature character of the Sybella Batholith. However, in the Sybella Batholith, the mafic rocks are iron-enriched resulting from fractionation of minerals at depth rather than direct emplacement from the mantle.

The Sybella Batholith was emplaced into strongly deformed country rocks of mafic and felsic gneisses and amphibolites of the May Downs Gneiss and Eastern Creek Volcanics of the Haslingden Group, Cover Sequence 2. At the time of the emplacement of the Sybella Batholith, the Mount Isa Inlier experienced large magnitude extension (O'Dea *et al.* 1997) and a suite of sedimentary basins developed in areas of extension (i.e Cover Sequence 3). In the Sybella Batholith, three stages of development for the fabric were determined: (1) magmatic flow; (2) submagmatic/high-temperature solid-state flow; (3) moderate-high temperature solid-state flow, marked by plastic deformation with temperature above 600°C . Deformation was heterogeneous with the first and second processes dominant within the northern regions at Kitty Plain and Guns Knob and occurring locally within the Easter Egg region. The second and third processes predominate within the Easter Egg Region. The third process may have related to either deformation during emplacement or overprinting regional metamorphism and deformation during the Isan Orogeny. The later deformation has also obscured earlier primary magmatic features or high-temperature fabrics by recrystallization and reactivation.

ACKNOWLEDGEMENTS

I would like to thank all those people who have had such valuable input into this project:

Firstly, my supervisor, Dr Mike Rubenach, for his encouragement and enthusiasm for the project;

Dr Andrew Allibone, for reviewing the final draft as it was greatly appreciated and needed;

The staff at MIMEX, Mount Isa, for funding and support during field work;

My fellow PhD students who helped distract, encourage and support me during a very eventful time at JCU;

And last, but by no means least, my family, friends, and husband Tony God bless you for being with me.

During a PhD, you learn a lot from people,
about people and most of all,
about yourself.

- TABLE OF CONTENTS -

Statement of access	ii
Statement of sources	iii
Abstract	iv
Acknowledgements	vi
Table of Contents	vii
List of Appendices	x
List of Figures and Tables	xi

CHAPTER 1 INTRODUCTION AND REGIONAL GEOLOGY

1.1	INTRODUCTION	1-1
1.2	AIMS	1-6
1.3	APPROACH	1-6
1.4	REGIONAL GEOLOGY OF THE MOUNT ISA INLIER	1-7
1.4.1	Regional Structural Framework	1-9
1.4.2	Sybella Batholith, Western Fold Belt, Mount Isa Inlier	1-11

CHAPTER 2 SYBELLA BATHOLITH INTRUSIVE PHASES

2.1	INTRODUCTION	2-1
2.2	BROAD SCALE RELATIONSHIPS AND GEOPHYSICS	2-5
2.3	COUNTRY ROCKS	2-11
2.3.1	May Downs Gneiss	2-11
2.3.2	Eastern Creek Volcanics	2-13
2.3.3	Metasomatic rocks of the Sybella Batholith	2-16
2.4	SYBELLA BATHOLITH INTRUSIVES	2-18
2.4.1	Mafic Intrusive Suite	2-18
	<i>Mosses Tank Dolerite</i>	2-18
	<i>Mafic Hybrid Complex</i>	2-19
2.4.2	Main Phase Potassic Granitoid Suite	2-22
	<i>Rapakivi Granitoids</i>	2-23
	<i>“Main Phase” Megacrystic Syenogranite</i>	2-25

	<i>Porphyritic and aplitic Syenogranite</i>	2-29
2.4.3	Microgranite Suite	2-31
	<i>Microgranite</i>	2-31
	<i>Enclave-rich Microgranite and Hybrids</i>	2-32
2.5	DISCUSSION	2-36
2.5.1	<i>Mixing During Emplacement</i>	2-39
2.5.2	<i>Mixing at Depth Prior to Emplacement</i>	2-40
CHAPTER 3 PETROGRAPHY AND MINERALOGY		
3.1	INTRODUCTION	3-1
3.2	PETROGRAPHY	3-2
3.2.1	Mafic Intrusive Suite	3-2
	<i>Mosses Tank Dolerites</i>	3-11
	<i>Mafic Hybrid Complex</i>	3-13
	<i>Mafic Enclaves</i>	3-20
3.2.2	Main Phase Potassic Granitoid Suite	3-20
	<i>“Main phase” megacrystic syenogranite</i>	3-20
	<i>Porphyritic and aplitic syenogranite</i>	3-23
3.2.3	Microgranite Suite	3-25
3.2.4	Mafic – Felsic Hybrids	3-25
3.3	DISCUSSION OF MINERALOGY AND TEXTURES	3-35
3.3.1	Mafic mineral compositions	3-35
3.3.2	Textural and compositional evidence for mixing	3-37
	<i>Quartz Ocelli</i>	3-37
	<i>K-feldspar megacrysts</i>	3-37
	<i>Rapakivi textures</i>	3-38
	<i>Plagioclase phenocrysts</i>	3-39
	<i>Intergrown Plagioclase-K-feldspar xenocrysts</i>	3-40
	<i>Acicular apatite</i>	3-41
3.3.3	Other textures	3-41
3.4	ESTIMATES OF INTENSIVE VARIABLES	3-42
3.4.1	Pressure	3-42
3.4.2	Temperature	3-46

3.4.3	Oxygen Fugacity	3-49
3.4.4	Water Fugacity	3-52
3.5	SUMMARY	3-54

CHAPTER 4 GEOCHEMISTRY

4.1	INTRODUCTION	4-1
4.2	COMPOSITIONAL DISTINCTIONS AMONG INTRUSIVE UNITS	4-2
4.2.1	Mafic rocks	4-9
4.2.2	Main Phase Potassic Rocks	4-11
4.2.3	Microgranites	4-12
4.2.4	Granite-Dolerite Hybrids	4-12
	<i>Rapakivi granitoid hybrids</i>	4-12
	<i>Microgranite hybrids</i>	4-15
4.2.5	Country Rocks	4-15
4.3	MAGMA MIXING MODELS	4-18
4.4	ISOTOPE GEOCHEMISTRY	4-24
4.4.1	The Rb-Sr System	4-25
4.4.2	Pb Isotopes	4-25
4.4.3	Sm-Nd Results	4-26
4.5	GEOCHEMICAL INTERPRETATION	4-31
4.6	DISCUSSION	4-35

CHAPTER 5 DEFORMATION AND EMPLACEMENT STRUCTURES

5.1	INTRODUCTION	5-1
5.2	STRUCTURES FORMED PRIOR TO BATHOLITH EMPLACEMENT	5-5
5.3	STRUCTURES FORMED DURING BATHOLITH EMPLACEMENT	5-15
5.3.1	Main Phase Granite Suite	5-16
	<i>Guns' Knob Region</i>	5-16
	<i>Easter Egg Region</i>	5-22
	<i>Rapakivi Granitoids</i>	5-25
	<i>Porphyritic to Aplitic Main Phase granite</i>	5-28
5.3.2	Kitty Plains Microgranite	5-30

5.4	STRUCTURES FORMED AFTER BATHOLITH EMPLACEMENT (ISAN OROGENY)	5-33
	<i>Guns Knob Region</i>	5-34
	<i>Easter Egg Region</i>	5-35
	<i>Kitty Plain Region</i>	5-37
5.5	DISCUSSION	5-37
	5.5.1 Macroscopic relationships	5-44
5.6	SUMMARY	5-46

CHAPTER 6 SYNTHESIS: GRANITE GENESIS, EVOLUTION AND EMPLACEMENT

6.1	INTRODUCTION	6-1
6.2	MELT SOURCE AND GENERATION	6-1
6.3	MAGMATIC EVOLUTION	6-3
6.4	PLUTON EMPLACEMENT	6-4
6.5	POST-EMPLACEMENT EVENTS	6-5

REFERENCES

- APPENDICES -

<i>I</i>	Slaughter Yard Creek Drill hole log
<i>II</i>	Modal Analysis of Batholith intrusives
<i>III</i>	Electron Microprobe analysis
<i>IV</i>	Geochemical Sample Locations and Descriptions
<i>V</i>	Geochemical analysis (this study)
<i>VI</i>	Additional geochemical analysis: Sisois (2001), Coleborn (1999), Gunter (1986)
<i>VII</i>	CIPW normative mineralogy
<i>VIII</i>	Isotope Analysis and equations
<i>IX</i>	JCU Catalogue Numbers

- LIST OF FIGURES -

Figure		Page
1-1	Simplified geological map of the Igneous units Mount Isa Inlier	1-2
1-2	Simplified geological map of the northern portion of the Sybella Batholith	1-5
1-3	Schematic relationships of structural events and stratigraphic units west Mt Isa	1-8
2-1	Geological map of northeastern Sybella Batholith	2-2
2-2	Lithological log and magnetic signature of Slaughter Yard drill hole MIMEX SYC1	2-3
2-3	Radiometric image of northern Sybella Batholith	2-7
2-4	Aeromagnetic image of northern Sybella Batholith	2-8
2-5	Detailed aeromagnetic image of northeastern Sybella Batholith	2-9
2-6	Compiled geological map from geophysical data and regional mapping	2-10
2-7	Field photo- Country rocks, May Downs Gneiss and Mafic Gneisses	2-14
2-8	Field photo- Country rocks, granite intruding Mafic Gneisses and calcisilicate	2-15
2-9	Field photo- Metasomatic alteration within and around Sybella Batholith	2-17
2-10	Field photo- Mosses Tank Dolerite intrusions	2-20
2-11	Field photo- Mafic Hybrid Complex intrusions	2-21
2-12	Field photo- Rapakivi Granitoid	2-24
2-13	Field photo- Main phase granite	2-27
2-14	Field photo- Enclaves and xenoliths in main phase granite	2-28
2-15	Field photo- Porphyritic and aplitic late stage intrusive granites	2-30
2-16	Detailed map Kitty Plain	2-33
2-17	Field photo- Kitty Plain granite and hybrids	2-34
2-18	Field photo- Microgranite and Mosses Tank Dolerite interaction	2-35
2-19	Schematic diagrams of intrusive relationships in the Sybella Batholith	2-38
2-20	Schematic diagrams of mixing processes	2-41
3-1	Modal Mineralogy and Classification of Sybella Batholith Intrusives	3-3
3-2	Mineral Compositional data for the of Sybella Batholith Intrusives	3-5
3-3	Mafic Mineral compositions- amphibole composition	3-6
3-4	Mafic Mineral compositions- biotite composition	3-7
3-5	Mafic Mineral compositions- pyroxene composition	3-8
3-6	Plagioclase compositions	3-9
3-7	K-feldspar composition	3-10
3-8	Mosses Tank Dolerite photomicrographs	3-12
3-9	Mosses Tank Dolerite photomicrographs	3-15
3-10	Mafic Hybrid Complex photomicrographs	3-16

3-11	Photomicrographs of textures indicating hybridization	3-17
3-12	Photomicrographs of textures indicating hybridization	3-18
3-13	Photomicrographs of radial and acicular mineral growth in enclaves and hybrids	3-19
3-14	Photomicrograph of main phase granite	3-21
3-15	Photomicrographs of main phase granite	3-22
3-16	Photomicrographs of porphyritic granite textures	3-24
3-17	Photomicrographs of Kitty Plains microgranite	3-26
3-18	Photomicrographs of plagioclase phenocrysts in hybrids	3-29
3-19	Photomicrographs and backscatter microprobe images of composition zoning in plagioclase phenocryst (zone of inclusions define core and rim)	3-30
3-20	Photomicrographs and backscatter microprobe images of composition zoning in plagioclase phenocryst (inclusion rich core and rim)	3-31
3-21	Photomicrographs of rapakivi texture on K-feldspar phenocrysts	3-32
3-22	Photomicrographs and backscatter microprobe images of K-feldspar-plagioclase phenocryst intergrowth	3-33
3-23	Photomicrographs of mixing textures in hybrid units	3-34
3-24	Zircon and apatite saturation, and hornblende plagioclase geothermometry	3-48
3-25	Oxygen fugacity based on Fe content of amphibole and phase diagrams	3-51
3-26	Source depth and water content estimation	3-53
4-1	Major Element Harker Diagrams	4-5
4-2	Trace Element Harker Diagrams	4-6
4-3	Trace element and major element variation diagrams	4-7
4-4	Tectonic discrimination diagrams	4-8
4-5	REE and multi-element normalized spider diagrams – mafic units	4-10
4-6	REE and multi-element normalized spider diagrams – granitic units	4-13
4-7	REE and multi-element normalized spider diagrams – main phase hybrid units	4-14
4-8	REE and multi-element normalized spider diagrams – microgranite hybrid units	4-16
4-9	REE and multi-element normalized spider diagrams – country rocks	4-17
4-10	Variation of major and trace elements of selected granites, hybrids and dolerites	4-20
4-11	Ratio-ratio diagrams and companion plots	4-23
4-12	Sr isotope and element variation diagrams	4-28
4-13	Pb isotope and element variation diagrams	4-29
4-14	Nd isotope and element variation diagrams	4-30
4-15	Schematic evolution of Sybella Batholith	4-39
5-1	Arzi type diagram of the transition from magmatic to solid-state deformation	5-4
5-2	Structural trends and geology of northeastern Sybella Batholith	5-6

5-3	Structural trends of Easter Egg region	5-7
5-4	Structural trends of Guns Knob region	5-8
5-5	Structural trends of Kitty plain region	5-9
5-6	Structural trends of detailed map area of Kitty Plains region	5-10
5-7	Microstructures of Country rocks - ECV and MDG	5-13
5-8	Microstructures of Country rocks -mafic gneisses	5-14
5-9	Stereonet diagrams Guns Knob region (GKR)	5-17
5-10	Hand specimen of magmatic aligned K-feldspars in main phase granite (GKR)	5-19
5-11	Outcrop photo of xenoliths within GKR	5-20
5-12	Microstructures of main phase granite GKR	5-21
5-13	Stereonet diagrams Easter Egg region	5-23
5-14	Stereonet diagrams of subarea 4 Easter Egg Region	5-23
5-15	Field photos of magmatic and solidstate deformation in Sybella Event MPG	5-26
5-16	Microstructures Easter Egg region Main Phase granite	5-27
5-17	Microstructures Easter Egg region rapakivi granitoids and porphyritic granite	5-29
5-18	Stereonet diagrams Kitty Plain	5-31
5-19	Microstructures Kitty Plain magmatic foliation in granite and hybrids and dolerite	5-32
5-20	Field photos of overprinting Isan Orogeny deformation	5-38
5-21	Microstructures of overprinting deformation Guns Knob region	5-39
5-22	Microstructures of overprinting deformation Easter Egg region	5-40
5-23	Microstructures of overprinting deformation Kitty Plains region	5-41

- LIST OF TABLES -

2-1	Geophysical characteristics of Northern Sybella Batholith	2-6
3-1	Summary of Mineral compositions Sybella Batholith	3-4
3-2	Average amphibole compositions and geothermometry calculations	3-43
3-3	Al-in hornblende Geobarometry calculations	3-44
4-1	Whole rock major, trace and REE Geochemistry of Sybella Batholith	4-3-4
4-2	Pearson's Mixing Correlation Main Phase granites and hybrids	4-21
4-3	Pearson's Mixing Correlation microgranite and hybrids	4-22
4-4	Isotope data	4-27
5-1	Correlation of deformation in western fold belt	5-3