

STUDIES IN THE GEOMETRY OF FOLDING
AND ITS
MECHANICAL INTERPRETATION

by

CHRISTOPHER McAULAY POWELL, B. Sc. (Hons).
(University of Queensland)

A thesis submitted in partial fulfilment of the
requirements for the degree of

Doctor of Philosophy

UNIVERSITY OF TASMANIA

HOBART

July 1967

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university and to the best of my knowledge and belief contains no copy or paraphrase of material previously published or written by another person except where due reference is made in the text of the thesis.

C. M^cA. Powell

CHRISTOPHER McA. POWELL

University of Tasmania

Hobart

July 1967

ABSTRACT

Analysis of thickness variation of folded layers in terms of apparent flattening indicates the relative "viscosities" of the layers, and hence modes of deformation. Orthogonal-thickness ratios, which are unique for each percentage of flattening, are convenient indicators of the equivalent flattening of an initially concentric profile. Axial-thickness ratios, intrinsically more sensitive, are less useful because there is a spread of values for each percentage of flattening.

Measurements of fold profiles from diverse sedimentary, diagenetic and low-grade metamorphic environments show that the higher the temperature and pressure at which the rocks were deformed the smaller the range of fold style. At Port Moresby, Papua, progressive syntaphral sliding has folded Eocene cherts and less competent argillite in a complex polyclinal style. Individual layers, then groups of layers up to one metre thick, and finally slip sheets tens of metres thick slid towards the west-southwest.

Structural analysis of linear and planar fold elements in diagenetic or low-grade metamorphic environments in Tasmania leads to the conclusion that cleavage developed contemporaneously in both sandstone and slate as a planar feature. The cleavage

in the slate is penetrative to the scale of detrital grains, but non-penetrative in the sandstone where pelitic ribbons anastomose through the rock enclosing non-cleaved lenses of normal greywacke fabric. The most satisfactory hypothesis to account for the observed mesoscopic configurations is that the cleavage formed during deformation as pelitic deposits in channels along which excessive water was forced out of the rock at very high pore pressures.

The ratio between pore pressure and confining pressure is a significant parameter determining fold style. Heterogeneities necessary for concentric folding are effective where the pore pressure is relatively low, and the fold style is similar where the pore pressure approaches the pressure on the grain fabric. Pore-pressure ratios are most readily varied in superficial deposits, and many different fold styles occur in the intrastratal contortions in the terrestrial, Pleistocene, proglacial deposits in Tasmania, and in the intraformational slumps of the Pleistocene Lisan Formation in Israel. Irregular "flow" folds in the contact aureoles of two intrusive bodies in Tasmania grade outwards into more regular, concentric and disjunctive folds. Both the folding and the variation in fold style may have been caused by water pressures approaching the lithostatic load in the intrusions, and decreasing outwards.

CONTENTS

	<i>Page pages prec.</i>
ABSTRACT	
LIST OF ILLUSTRATIONS	i
INTRODUCTION	vii
CHAPTER 1 THICKNESS MEASUREMENTS	1
1. INTRODUCTION	1
2. RELATIONSHIP OF FOLD PARAMETERS IN IDEAL PROFILES	4
(a) VARIATION OF AXIAL THICKNESS, $T\alpha$, WITH RESPECT TO α , THE ANGLE BETWEEN THE NORMAL TO THE LAYER AND THE AXIAL PLANE, IN CONCENTRIC FOLDS	4
(b) TYPES OF FLATTENING	5
(c) RECOGNITION OF DIFFERENTIAL FLATTENING	7
(d) RECOGNITION OF NONUNIFORM FLATTENING	8
(e) NON-AXIAL-PLANE FLATTENING	8
(f) EFFECTS OF FLATTENING ON A CONCENTRIC PROFILE	9
(g) DIFFICULTIES IN THE MEASUREMENT OF ORTHOGONAL THICKNESS IN FLATTENED CONCENTRIC FOLDS	11
(h) EFFECT OF THE R-RATIO ON THE AXIAL-RATIO PLOT FOR FLATTENED CONCENTRIC FOLDS	13
(i) USE OF AXIAL-RATIO PLOTS FOR FLATTENED CONCENTRIC FOLDS	14
(j) DIFFICULTIES IN LOCATING THE CENTRE OF CURVATURE IN FLATTENED CONCENTRIC PROFILES	15
(k) EFFECTS OF SIMPLE AND PURE SHEAR OF A CONCENTRIC PROFILE	16

	Page
3. STRUCTURE	
(a) GENERALIZED SECTION	39
(b) FLAP FOLDS	40
(c) SMALL-SCALE GLIDES	46
(d) SLIP SHEETS AND SLIP ZONES	46
(e) BROAD SYNCLINES AND TIGHT ANTICLINES	48
(f) ZONE OF GENERAL INVOLUTION	48
(g) RECUMBENT FOLDS	49
(h) FAULTING	49
4. ORIGIN OF THE FOLDING	50
(a) THE LACK OF CLEAVAGE	50
(b) THE LACK OF ANY METAMORPHISM	51
(c) THE SEQUENCE OF OVERFOLDING	51
(d) GEOMETRY OF THE FOLDING	52
(e) ORIENTATION OF AXIAL SURFACES	52
5. CONCLUSIONS	53
 CHAPTER 3	
TECTONIC DIAGENETIC FOLDS AT SULPHUR CREEK, NORTHERN COAST OF TASMANIA	54
1. INTRODUCTION	54
2. STRUCTURAL DESCRIPTIONS	56
(a) GENERAL DESCRIPTION	56
(b) DISJUNCTIVE FOLD IN AREA A	58
(c) AREA B	60
(d) AREA C	64

	Page
(e) AREA D	74
(f) AREA E	76
(g) INDIVIDUAL FOLD DESCRIPTIONS	78
3. DESCRIPTION OF CLEAVAGE	98
(a) GENERAL STATEMENT	98
(b) MESOSCOPIC DESCRIPTION	99
(c) THIN-SECTION DESCRIPTION	102
(d) CONCLUSIONS	103
4. ORIGIN OF CLEAVAGE	104
(a) GENERAL STATEMENT	104
(b) DETAILED CONSIDERATIONS	106
5. REFRACTION OF CLEAVAGE	114
(a) GENERAL DESCRIPTION	114
(b) ORIGIN	115
(c) CONCLUSIONS	119
6. THE NATURE OF THE P1 DEFORMATION AT SULPHUR CREEK	119
(a) THE EARLY DIAGENETIC PHASE	120
(b) THE EARLY P1 PHASE	120
(c) THE CLEAVAGE FORMATION	121
(d) THE LATE P1 PHASE	122
CHAPTER 4 FOLDING IN INTERBEDDED SANDSTONES AND SLATES AT TULLOCHGORUM, NORTHEASTERN TASMANIA	123

	Page
1. INTRODUCTION	123
2. STRUCTURAL DESCRIPTIONS	125
(a) ANTICLINE 1 AND SYNCLINE 1	125
(b) ANTICLINE 2	127
(c) SYNCLINE 2	128
(d) ANTICLINE 3	129
(e) SYNCLINE 3	130
(f) SYNCLINE 4	132
(g) FOLDED SLATE-CLEAVAGE	133
(h) JOINTING	137
3. FLATTENING	138
4. CLEAVAGE	142
(a) GENERAL DESCRIPTION	142
(b) THIN-SECTION DESCRIPTION	144
(c) ORIGIN OF CLEAVAGE	147
5. HISTORY OF STRUCTURAL EVOLUTION	161
(a) SEDIMENTARY AND EARLY DIAGENETIC STAGE	161
(b) EARLY FOLDING STAGE	161
(c) CLEAVAGE FORMATION	162
(d) LATE FOLDING STAGE	163

	Page
CHAPTER 5 INTRAFORMATIONAL STRUCTURES IN THE PLEISTOCENE GLACIAL MORaine AT GORMANSTON, WEST COAST OF TASMANIA	164
1. INTRODUCTION	164
2. STRUCTURAL DESCRIPTIONS	167
(a) GENERAL DESCRIPTION	167
(b) COMPACTION STRUCTURES	168
(c) DIAPIRIC FOLDS	170
(d) CONVOLUTE FOLDS	174
(e) MISCELLANEOUS STRUCTURES	177
3. INTERPRETATION	183
(a) ORIGIN OF THE CONTORTIONS	183
(b) CONCLUSIONS	186
CHAPTER 6 EARLY-DIAGENETIC, INTRAFORMATIONAL FOLDING IN THE PLEISTOCENE LISAN FORMATION, ISRAEL	187
1. INTRODUCTION	187
2. PETROLOGY	188
3. STRUCTURAL DESCRIPTIONS	190
4. ORIGIN OF THE INTRASTRATAL CONTORTIONS	196
5. CONCLUSIONS	200
CHAPTER 7 FOLDING IN THE CONTACT AUREOLE OF A QUARTZ-DIORITE DYKE, NORTHEASTERN TASMANIA	201
1. INTRODUCTION	201

	Page
2. STRUCTURE	202
(a) GENERAL	202
(b) FOLDING	203
3. PETROGRAPHY	206
(a) QUARTZ DIORITE	206
(b) HORNFELS	207
(c) GRANODIORITIC VEINS	210
(d) HORNFELS CONTACT ZONE	210
(e) ZONED PLAGIOCLASE CRYSTALS	211
4. STRUCTURAL INTERPRETATION	213
(a) INTRUSIVE NATURE OF THE QUARTZ DIORITE	213
(b) ORIGIN OF THE QUARTZ-DIORITE LOBES	213
(c) ORIGIN OF THE FOLDING	215
(d) NATURE OF THE QUARTZ DIORITE DURING INTRUSION	216
(e) INTERPRETATION OF THE HISTORY OF INTRUSION	222
CHAPTER 8 FOLDING IN A HORNFELS ADJACENT TO A DOLERITE CONTACT, REMARKABLE CAVE, S. E. TASMANIA	225
1. INTRODUCTION	225
2. PETROGRAPHY	226
3. FOLDING	230
(a) GENERAL STATEMENT	230
(b) DETAILED DESCRIPTIONS	232

	Page
4. INTERPRETATION	237
CHAPTER 9 MISCELLANEOUS FOLDS	240
1. A SMALL-SCALE INTRAFORMATIONAL FOLD FROM ARM RIVER, NORTHERN TASMANIA	240
(a) INTRODUCTION	240
(b) STRUCTURAL DESCRIPTIONS	241
(c) INTERPRETATION	248
(d) CONCLUSION	252
2. FOLDS IN THE MARTINSBURG SLATE, PENNSYLVANIA	252
3. PECUMBENT, ZIG-ZAG FOLDS IN THE FRANCISCAN CHERTS, CALIFORNIA	256
CHAPTER 10 VARIATION IN FOLD STYLE	261
1. INTRODUCTION	261
2. GEOMETRICAL ANALYSIS OF FOLDS	262
(a) THE BEHAVIOUR OF GEOLOGIC MATERIALS IN DIFFERENT ENVIRONMENTS	262
(b) VARIATION OF STYLE IN A SINGLE FOLD	264
(c) VARIATION OF STYLE IN DIFFERENT ENVIRONMENTS	266
3. MECHANICAL ANALYSIS OF FOLDS	267
(a) GENERAL STATEMENT	267
(b) SCALE IN MECHANICAL INTERPRETATIONS	269
(c) THE ROLE OF LAYERING IN DEFORMATION	269
(d) POSSIBLE MECHANICAL CAUSES OF VARIATION IN FOLD STYLE	270

	Page
REFERENCES	274
APPENDIX I DEFINITION OF TERMS	14 pages
APPENDIX 2 THE TERMS <i>SEDIMENTARY</i> AND <i>TECTONIC</i> AS APPLIED TO ROCK STRUCTURES	7 pages
APPENDIX 3 CRITIQUE OF SOME ASPECTS OF MODERN STRUCTURAL ANALYSIS	11 pages